Final Feasibility Study

Lower Fox River and Green Bay, Wisconsin
Remedial Investigation and Feasibility Study

Prepared for:

Wisconsin Dept. of Natural Resources

Prepared by: The RETEC Group, Inc.

December 2002

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EXECUTIVE SUMMARY
FEASIBILITY STUDY

Lower Fox River and Green Bay

The Feasibility Study (FS) developed and evaluated a range of remedial alternatives for the Lower Fox River and Green Bay (Figure 1) to manage the risk associated with the presence of industrial contaminants discharged to the river. This RI/FS report is consistent with the findings of the National Academy of Sciences Research Council Report entitled *A Risk Management Strategy for PCB-Contaminated Sediments* (NAS, 2001).

Each alternative was compared to nine evaluation criteria including: 1) risk reduction, 2) overall protectiveness of human health and the environment, 3) implementability, 4) short-term effectiveness associated with the remedy action, 5) permanence, 6) reduction in toxicity, mobility and volume, 7) cost, 8) regulatory acceptance, and 9) community acceptance.

The area of concern includes the Lower Fox River extending 63 km (39 mi) from Lake Winnebago to the mouth of Green Bay, and includes the entire 4,150 km^2 (1,600 mi^2) of the bay. Remedial alternatives were developed for the four reaches of the Lower Fox River including: Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (same as Green Bay Zone 1); as well as the four zones of Green Bay: Zone 2, Zone 3A, Zone 3B, and Zone 4.

The purpose of the FS is to support the selection of a remedy that will eliminate, reduce and/or control short-term and long-term risks. The evaluation in the FS used data developed in the Remedial Investigation (RI), Risk Assessment (RA), and Model Documentation reports to support the screening of alternatives. This screening of alternatives followed EPA's Superfund Guidance document for conducting RI/FS studies under CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980).

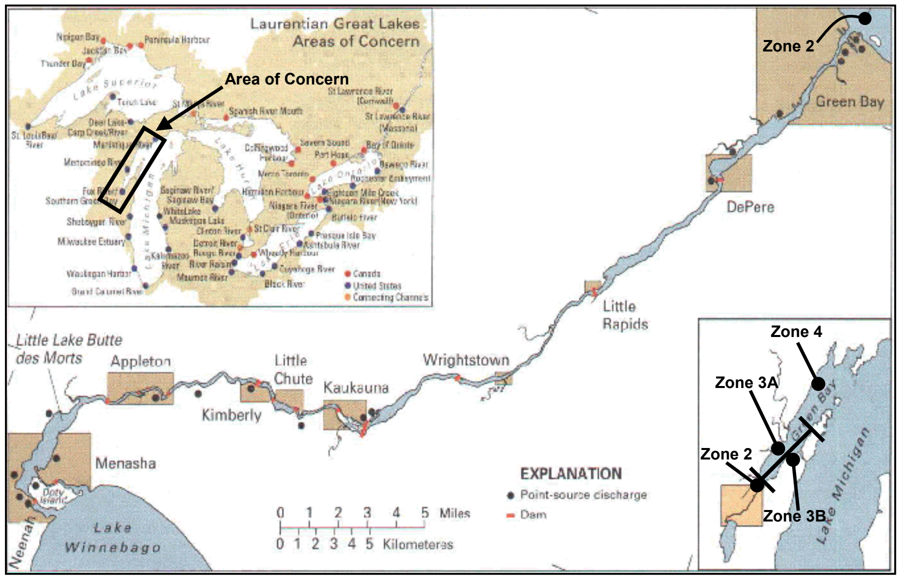

Figure 1 (Fitzgerald & Steuer, 1996)

Site History and PCB Discharges

Between 1954 and 1971, paper mills in the Lower Fox River valley manufactured and recycled carbonless copy paper that contained polychlorinated biphenyls (PCBs), resulting in the release of an estimated 300,000 kg (600,000 pounds) of PCBs to the river. The highest PCB concentrations detected in site sediments were 223 mg/kg in the Little Lake Butte des Morts Reach and 710 mg/kg in the De Pere to Green Bay Reach. WDNR issued PCB consumption advisories in 1976 and 1983 for fish and waterfowl, respectively. The State of Michigan also issued consumption advisories for Green Bay fish in

1977. These advisories are still in effect today.

PCB Distribution, Volume, and Transport

The Remedial Investigation identified the sources of PCBs, the estimated mass, and volume of PCBs in bedded sediments. The RI also estimated the sediment and PCB mass transport rates. Between 65 and 175 kg of PCBs are transported downstream annually from each reach, and 280 kg of PCBs move into Green Bay annually. A significant portion of the PCB loading that occurs in Green Bay is derived from the Lower Fox River. This transport of PCBs also extends to Lake Michigan.

PCBs discharged into the river, in large part today, remain in the bedded sediments of the river and bay. For sediments containing more than 50 μg/kg PCBs, approximately 28,600 kg (63,050 pounds) of PCBs remain in the Lower Fox River (Figure 2) compared to approximately 68,200 kg (150,300 pounds) of PCBs in Green Bay (Figure 3). As stated in the RI report, the PCBs are contained within about 11.8 million cy of sediment in the river. In Green Bay, the PCBs are dispersed in a much greater volume of sediment, approximately 610 million cy.

Risks to Human and Ecological Receptors

The chemicals of concern (COCs) from the Baseline Risk Assessment (RA) included polychlorinated biphenyls (PCBs) (total and selected congeners), mercury, and DDE as the primary compounds of risk to human health and the environment, with PCBs presenting the highest risk. The exposure pathway presenting the greatest level of risk to both human health and ecological receptors is through fish consumption (other than direct risk to benthic invertebrates). Receptors at risk include recreational anglers, high-intake fish consumers, benthic invertebrates, fish, birds, and riverine mammals. PCBs contribute more than 70 percent of the cancer risks found from the consumption of fish and waterfowl.

The risk assessment also derived sediment quality thresholds (SQTs) that were linked to estimated magnitudes of risk to valued receptors. SQTs were developed for over 100 pathways and receptors and arrayed to show the magnitude and protectiveness of potential risks. SQTs themselves are not cleanup criteria, but were used to evaluate levels of PCB risk and help develop FS action levels.

Remedial Action Objectives

The FS reviewed multiple community, state, federal, and private documents to identify common expectations for the Fox River and Green Bay. From this review, five remedial action objectives were formulated. These objectives lay the foundation for remedial expectations for the FS and provide a metrics to measure long-term success. These objectives include:

1. Achieve surface water quality criteria, to the extent practicable;
2. Protect humans who consume aquatic organisms (i.e., remove consumption advisories);
3. Protect ecological receptors (i.e., healthy invertebrate, bird, fish, mammal populations);
4. Reduce transport of PCBs from the river into Green Bay and Lake Michigan; and

5. Minimize contaminant releases during remediation.

These objectives can be further defined into measurable metrics for evaluating long-term remedial success. These measurable expectations were defined by WDNR and EPA as the ability for recreational anglers to consume fish within 10 years following completion of a remedy and 30 years for high-intake fish consumers for human health (RAO 2).

Ecological expectations were defined by WDNR and EPA as the ability to achieve safe ecological thresholds for piscivorous birds and mammals. Although not a specific metric, the FS used 30 years following remedy completion (RAO 3). These expectations assumed several years of active remediation followed by 30 years of recovery, after which the endpoints are measured and compared to protective fish tissue levels.

Other metrics used to measure remedial success include the time to achieve state surface water criteria (RAO 1) and the time for PCB loading rates from the Lower Fox River into Green Bay to equal the combined loading estimates from other tributaries into Green Bay (10 kg/yr PCBs) (RAO 4). For relative comparison between different remedies and action levels, the FS used 30 years following remedy completion to achieve these goals.

Array of Remedial Action Levels

The FS evaluated remedial alternatives, risks, duration, and costs relative to a series of potential sediment cleanup values. These values, termed "remedial action levels," were 125, 250, 500, 1,000, and 5,000 ppb PCBs. For all action levels, it was assumed that different levels of residual risk would remain after remediation. Natural processes would be relied upon to further decrease COC sediment concentrations to protective levels.

Remedial Alternatives

Over 100 technologies were screened during the feasibility study. The remedial alternatives retained for detailed analysis included:

A. No action;

B. Monitored natural recovery (MNR);

C. Dredge and off-site disposal;

D. Dredge and on-site disposal (CDF);

E. Dredge and thermal treatment;

F. *In-situ* containment (capping); and

G. Dredge to confined aquatic disposal (CAD) site.

The alternatives were considered for each of the four river reaches and Green Bay zones (Table 1). All of the active remedies are designed to be completed in 10 years, in combination with natural recovery after remedy completion, with the degree of recovery dependent on the action level selected. Each of these remedial options categories is discussed below. However, final selection of a remedy will be governed by site-specific conditions and expectations.

Monitored Natural Recovery. Natural recovery refers to the processes by which COCs decline over time by biodegradation, dilution, or transport mechanisms. Institutional controls will remain in place to restrict site use until the system has recovered to protective thresholds. Natural recovery of sediments primarily occurs through three processes: burial; mixing and transport; or dechlorination/ biodegradation. The FS determined that all three of these processes occur in the Lower Fox River system, but the success of these processes is continually influenced by ongoing physical processes resulting in limited overall effectiveness in many areas. To evaluate a natural recovery option, it was assumed that the current systems of dams on the river would remain in perpetuity. A long-term monitoring program would be implemented to ensure that sediment, water, and fish tissue PCBs would decline over time.

Table 1 Summary of Evaluated Remedial Alternatives by Reach and Zone

Alternative Description		Lower Fox River Reaches				Green Bay Zones			
		Little Lake Butte des Morts	Appleton to Little Rapids	Little Rapids to De Pere	De Pere to Green Bay	Zone 2	Zone 3A	Zone 3B	Zone 4
A	No Action	✔	✔	✔	✔	✔	✔	✔	✔
B	Monitored Natural Recovery	✔	✔	✔	✔	✔	✔	✔	✔
C	Dredge and Off-Site Disposal	✔	✔	✔	✔	✔	✔		
D	Dredge to CDF	✔		✔	✔	✔	✔	✔	
E	Dredge and Thermal Treat	✔	✔	✔	✔				
F	Cap	✔		✔	✔				
G	Dredge to CAD					✔	✔	✔	

Removal (Dredging). Removal involves excavation of site sediments using mechanical or hydraulic dredging techniques. Dredging is a common practice for managing impacted sediments but would require careful consideration of: dewatering methods, disposal options, physical obstructions, site access, staging areas, community disturbance, and potential release of contaminants to the environment during implementation. Removal of impacted sediments is a permanent solution and does not require long-term maintenance or access restrictions.

Treatment. The FS also evaluated treatment and non-treatment options. Retained treatment options included thermal, technologies such as desorption and vitrification, where the resulting product would have the potential for beneficial reuse.

Disposal. Disposal of dredged material can managed in three ways: permanent placement in upland, nearshore, and in-water facilities. It is generally expensive and requires intensive dewatering techniques to adequately prepare sediments for long-term disposal. Several on-site and off-site disposal options were retained in the FS including: nearshore fills, free-standing confined disposal facilities (CDFs), submerged aquatic disposal sites (CADs), and upland landfills where impacted sediments are placed in containment structures designed to isolate and contain contaminants over the long-term.

Containment (Capping). Containment involves the physical isolation and immobilization of chemicals in sediments. Capping is a common method for containing impacted sediments in-place. It would require long-term restrictions on site access and land use rights, in addition to long-term monitoring and maintenance to ensure integrity of the capping structure. The capping alternative would require careful consideration of site conditions, navigational channels, river currents, vessel propeller wash, water depths, and ice scour as well as other factors that may limit the installation and subsequent permanence of cap placement.

Comparative Analysis

Each alternative was compared to the nine evaluation criteria defined above for each river reach and Green Bay zone. Risk reduction and overall protectiveness are discussed below. Implementablity and effectiveness were determined as feasible for each retained alternative based on availability, previous experience, and performance-based results. Reduction of toxicity, mobility, and volume is related to cost. Both are dependent on the action level selected. Thermal treatment is the only alternative that permanently reduces PCB volume and mass. Relative costs are discussed below, and community acceptance of the retained alternatives will be evaluated during public comment periods and outreach programs.

Risk Reduction

The ability of the seven remedial alternatives to achieve the FS expectations were quantified by relative risk reduction over time using hydrodynamic and bioaccumulation models over a projected 100-year time frame. These models predicted the number of years required to reach protective thresholds for human health and the environment (e.g., number of years required to remove fish consumption advisories). The projected number of years required to consistently meet protective water quality, human health, ecological health, and PCB transport thresholds following remediation (the RAOs) were compared to different action levels and costs for each alternative. Results are presented on Figures 2 and 3. A comparative analysis of action levels that meet protective levels between the different river reaches is presented on Figures 4 and 5.

Water Quality. The state surface water quality criteria for protection of human health are not met for any combination of remedial scenario and action level in the river. Only the wildlife criteria (0.12 ng/L) is met in 16 years after remediation for the 125 ppb action level, increasing to 69 years for the 1,000 ppb action level.

Human Health. As shown on Figures 4 and 5, in order to remove recreational fish consumption advisories within 10 years following remediation (WDNR's expectation), remedies implemented to the 1,000 ppb PCB action level for surface sediments would be required for most of the river reaches. Action levels ranging from 250 ppb to 1,000 ppb would be required to remove high-intake consumer advisories within 30 years following remediation depending upon the specific reach of the river. For Green Bay, none of the remedies are projected to achieve the protective human health values. These model projections account for dynamic physical properties of the system including water velocity, water depth, currents, flooding, natural deposition, scour events, and storm events.

Ecological Health. To meet the protective ecological thresholds in the expected 30-year time frame following remedy completion, an estimated minimum action level of 1,000 ppb would be required in the Little Lake Butte de Morts and Appleton to Little Rapids reaches. A minimum action level of 250 ppb would be required in the Little Rapids to De Pere and De Pere to Green Bay reaches. The No Action alternative (passive remediation) would require greater than 100 years to meet protective ecological thresholds in the Lower Fox River (Figure 4). In Green Bay, none of the remedies will meet protective ecological thresholds in 100 years based on projected fish tissue concentrations, regardless of the action taken in the Lower Fox River (Figure 5).

PCB Transport. One of the long-term goals of the project is to reduce the transport and load of PCBs to Green Bay, and subsequent movement to Lake Michigan. The total annual average loading rates of PCBs to Green Bay from all tributaries combined (without the Fox River) is currently 10 kg/year PCBs. The Fox River fate and transport models were used to predict the number of years required to reduce the PCB loads from the Fox River into Green Bay over time after remedy completion. At the expected 30-year time frame following remedy completion, the projected loading rates from the Fox River were compared to the loading rates of all other Green Bay tributaries combined. These levels could be considered “background” levels.

Remedies to at least the 5,000 ppb action level would be required in the De Pere to Green Bay Reach to meet projected expectations. PCB load expectations for these two action levels would require 24 years to meet tributary levels. At the 1,000 ppb action level, the target level is achieved in 4 years following remediation. The model predications for PCB loading rates from the mouth of the Fox River (De Pere to Green Bay Reach) takes into consideration the cumulative PCB loads from the upper reaches; therefore, only the last reach was evaluated in the FS.

It is important to note there is uncertainty associated with these projected estimations of risk reduction and duration to meet protective thresholds. The model projections were calibrated over a finite time interval and projected out to 100 years based on the trends observed during the short calibration period. The projected risk reductions/durations cannot predict the actual number of years to reach protective thresholds with considerable precision. However, the strength of these models is the relative risk reduction estimates for comparing between different action levels and remedial alternatives. More information on the models may be found in the Lower Fox River and Green Bay Model Documentation Report.

FS Costs

Total remediation costs were estimated for each remediation alternative and each PCB action level (±30 percent), as presented on Figures 2 and 3. In the Lower Fox River, the costs for active remediation (Alternatives C through F) range from approximately $38,300,000 to $769,100,000 per river reach (Table 2). In Green Bay, the costs for active remediation (Alternatives C, D, and G) range from approximately $11,000,000 to $1,155,100,000 (Table 3). Costs include land acquisition, mobilization, permits, facility construction, dredging and dewatering, disposal, materials, labor oversight, public outreach, site restoration efforts, operation and maintenance costs, in addition to long-term monitoring efforts for 30 years following remediation.

The cost for passive remediation, or monitored natural recovery (Alternative B), is approximately $9,900,000 per reach/zone over a 30-year period. MNR costs include maintenance of institutional controls along with sediment, surface water, bird and fish tissue sampling, and invertebrate sampling events conducted every 5 years for 30 years. Costs are calculated as net present worth costs.

The largest variability in costs are observed between different action levels. Remediation costs are directly proportional to sediment volumes; therefore, as the action level decreases (becomes more protective), the sediment volume requiring removal increases and the cost increases. For example, the cost to place an *in-situ* sand cap (Alternative F) in the Little Lake Butte des Morts Reach will cost approximately $145,200,000 at the 125 ppb action level but only $66,200,000 at the 5,000 ppb action level.

When comparing costs between different alternatives in the Lower Fox River, the active remedy costs are 3 to 78 times higher than the passive remedy costs. Among the active remedies, the Dredge and Treat Alternative is the least-cost remedy (ranging from a 3-fold to 40-fold increase over the MNR Alternative). The Capping Alternative and Dredge to CDF Alternative are generally the medium-cost remedies (ranging from a 4-fold to 60-fold increase over the MNR Alternative). The Dredge and Off-site Disposal Alternative is the highest-cost remedy (ranging from a 4-fold to 78-fold increase over the MNR Alternative). In Green Bay, the active remedy costs are similar when compared within a single action level.

Further Information

Remedy selection for the Lower Fox River and Green Bay will be based on the information contained within the RI, RA and FS, as well as numerous opportunities for input by the public and interested parties. For further information regarding the Lower Fox River RI, FS, RA, or MDR documents, please contact:

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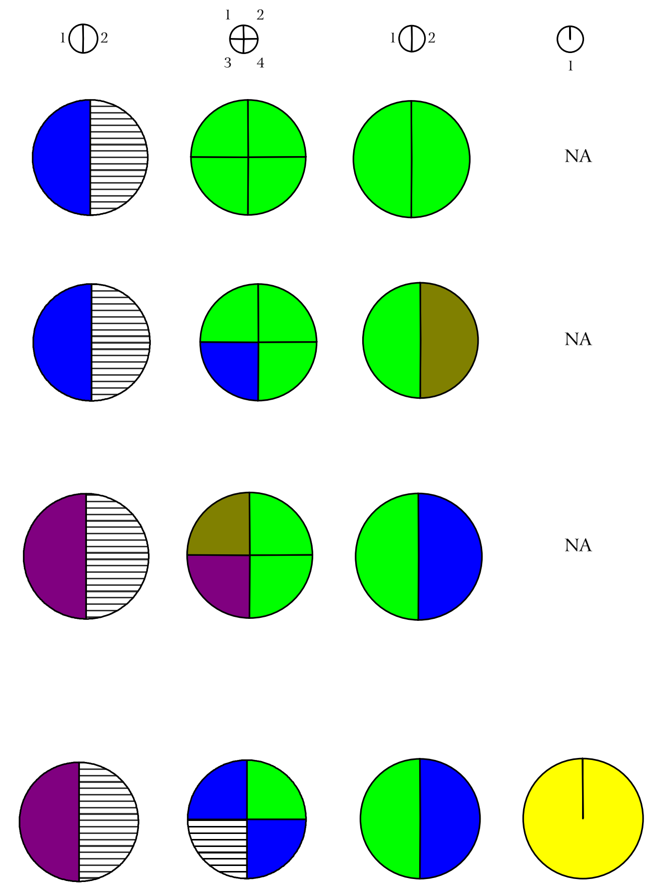
Figure 2 Lower Fox River Summary of Remedial Action Levels and Projects Risk Reduction by Reach

Lower Fox River Reaches	Remediation Alternative	PCB Action Level (ppb) 125	250	500	1,000	5,000
Little Lake Butte des Morts	Impacted Volume (cy)	1,689,173	1,322,818	1,023,621	784,192	281,689
	PCB Mass (kg)	1,838	1,814	1,782	1,715	1,329
	Remedial Cost (in 1,000s $)					
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900
	C1: Dredge, Off-site Disp. (Pass. Dewater)	$231,500	$185,600	$147,800	$116,700	$48,500
	C2: Dredge, Off-site Disp. (Mech. Dewater)	$126,200	$102,500	$82,800	$66,200	$28,300
	D: Dredge to CDF, Off-site TSCA Disp.	$116,000	$110,300	$105,100	$68,000	$54,500
	E: Dredge and Thermal Treatment	$117,200	$96,000	$78,500	$63,600	$29,300
	F: Cap and Dredge to CDF	$145,200	$138,600	$99,300	$90,500	$66,200
Appleton to Little Rapids	Impacted Volume (cy)	182,450	80,611	56,998	46,178	20,148
	PCB Mass (kg)	106	99	95	92	67
	Remedial Cost (in 1,000s $)					
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900
	C: Dredge, Off-site Disp.	$38,300	$25,000	$21,700	$20,100	$16,500
	E: Dredge and Thermal Treatment	$26,200	$19,700	$17,900	$17,100	$15,200
Little Rapids to De Pere	Impacted Volume (cy)	1,483,156	1,171,585	776,791	586,788	186,348
	PCB Mass (kg)	1,210	1,192	1,157	1,111	798
	Remedial Cost (in 1,000s $)					
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900
	C1: Dredge to NR 500 Facility (Pass. Dewater)	$224,200	$180,700	$124,200	$95,100	$38,100
	C2A: Dredge to Comb. Dewater/Disp. Facility	$72,300	$63,200	$51,400	$43,900	$32,400
	C2B: Dredge to Sep. Dewater/Disp. Facilities	$179,800	$152,800	$118,300	$99,900	$65,300
	C3: Dredge to NR 500 Facility (Mech. Dewater)	$161,700	$130,800	$90,300	$69,100	$28,400
	D: Dredge to CDF, Off-site TSCA Disp.	$72,300	$66,800	$58,400	$52,500	$44,400
	E: Dredge and Thermal Treatment	$142,700	$123,800	$99,500	$86,200	$61,900
	F: Cap and Dredge to CDF	$143,700	$114,300	$87,800	$62,900	$34,700
De Pere to Green Bay	Impacted Volume (cy)	6,868,500	6,449,065	6,169,458	5,879,529	4,517,391
	TSCA Volume (cy)	240,778	240,778	240,778	240,778	240,778
	PCB Mass (kg)	26,620	26,581	26,528	26,433	24,950
	Remedial Cost (in 1,000s $)					
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900
	C1: Dredge to NR 500 Facility (Pass. Dewater)	$769,100	$723,100	$692,300	$660,600	$511,100
	C2A: Dredge to Comb. Dewater/Disp. Facility	$196,000	$186,900	$180,400	$173,500	$138,700
	C2B: Dredge to Sep. Dewater/Disp. Facilities	$564,500	$534,100	$513,500	$491,800	$388,000
	C3: Dredge to NR 500 Facility (Mech. Dewater)	$595,200	$561,000	$537,800	$513,500	$397,200
	D: Dredge to CDF, Off-site TSCA Disp.	$611,800	$566,400	$536,200	$505,100	$360,700
	E: Dredge and Thermal Treatment	$404,500	$384,000	$370,000	$355,100	$283,300
	F: Cap and Dredge to CDF	$432,600	$403,900	$381,900	$357,100	$234,400

Maximum Action Level that Meets Risk Reduction Criteria Related to Project RAOs



Notes:

Threshold criteria used to evaluate risk reduction:

RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.
RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.
RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.
RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.
NA - Not applicable.

Action Level (ppb) that Consistently Meets Criteria after 10 or 30 Years of Recovery after Remediation Completion

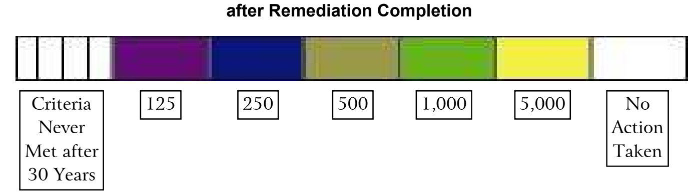
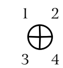
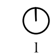
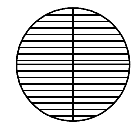
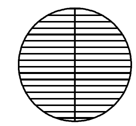
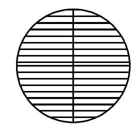
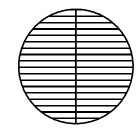
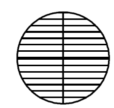
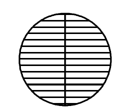
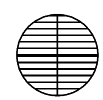
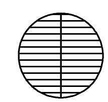


Figure 3 Green Bay Summary of Remedial Action Levels and Projected Risk Reduction by Zone

Green Bay Zone	Remediation Alternative	Action Level (ppb)					Maximum Action Level that Meets Risk Reduction Criteria Related to Project RAOs			
		125	250	500	1,000	5,000	RAO 1 SWQ	RAO 2 HH	RAO 3 Eco	RAO 4 Transport
										
Green Bay Zone 2	Impacted Volume (cy)	NE	NE	29,748,004	29,322,254	4,070,170				
	PCB Mass (kg)	NE	NE	29,896	29,768	6,113				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	NA	NA	$9,900	$9,900	$9,900	NE			NA
	C: Dredge, Off-site Disp.	NA	NA	NA	NA	$507,200				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$824,700	$814,100	$166,500				
	G: Dredge to CAD	NA	NA	$707,400	$697,800	$124,000				
Green Bay Zone 3A	Impacted Volume (cy)	NE	NE	16,328,102	14,410	NE				
	PCB Mass (kg)	NE	NE	2,156	2	NE				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	NA	NA	$9,900	$9,900	NA	NE			NA
	C: Dredge, Off-site Disp.	NA	NA	NA	$11,000	NA				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$474,300	NA	NA				
	G: Dredge to CAD	NA	NA	$389,100	NA	NA				
Green Bay Zone 3B	Impacted Volume (cy)	NE	NE	43,625,096	NE	NE				
	PCB Mass (kg)	NE	NE	4,818	NE	NE				
	Remedial Cost (in 1,000s $)						NE			NA
	A/B: No Action	NA	NA	$9,900	NA	NA				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$1,155,100	NA	NA				
	G: Dredge to CAD	NA	NA	$1,010,900	NA	NA				
Green Bay Zone 4	Impacted Volume (cy)	NE	NE	0	NE	NE				
	PCB Mass (kg)	NE	NE	0	NE	NE				
	Remedial Cost (in 1,000s $)						NE			NA
	A/B: No Action	NA	NA	$9,900	NA	NA				

Notes:

Threshold criteria used to evaluate risk reduction:

RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.
RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.
RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.
RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.
NA - Not applicable.
NE - Not evaluated.

Action Level (ppb) that Consistently Meets Criteria after 10 or 30 Years of Recovery after Remediation Completion

Figure 4 Comparison of Human Health Protectiveness - All Reaches

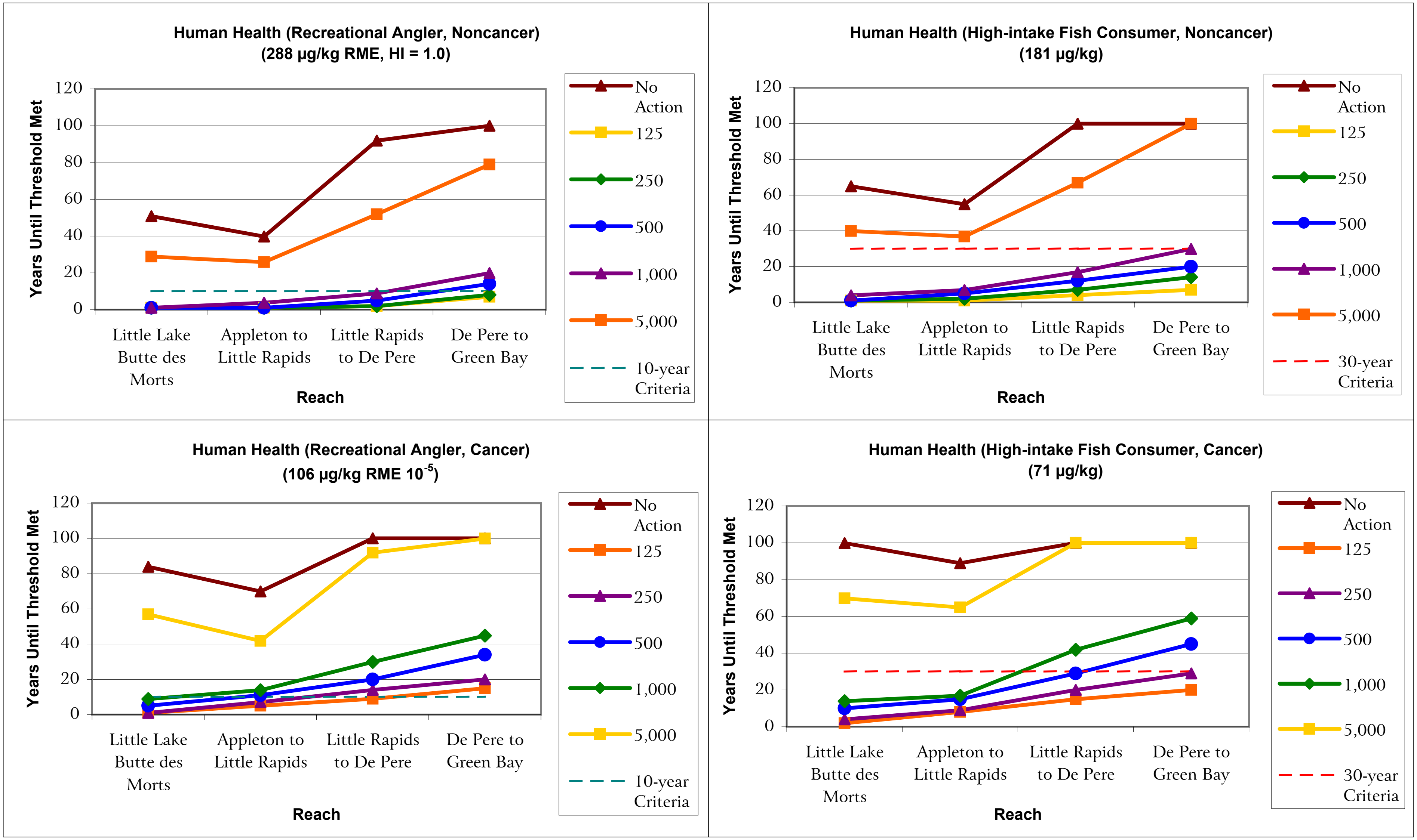
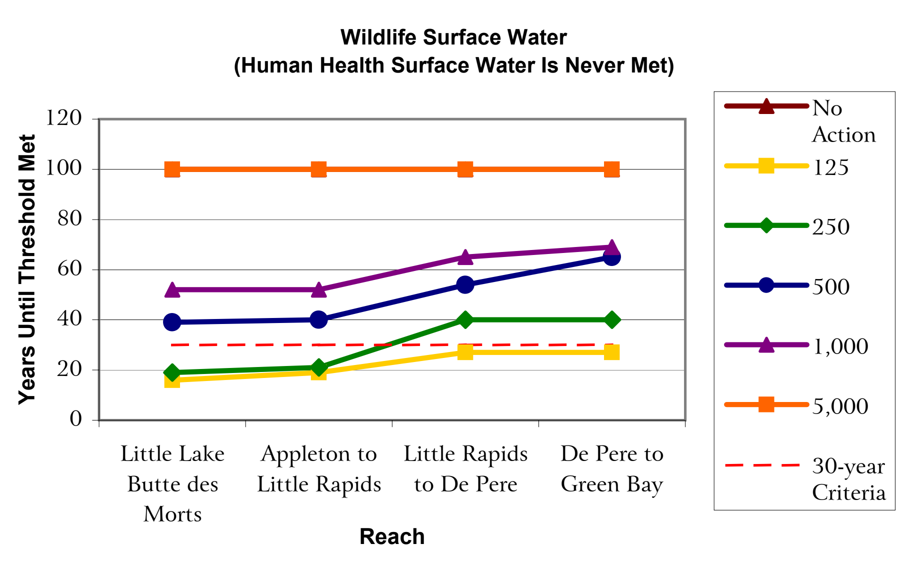
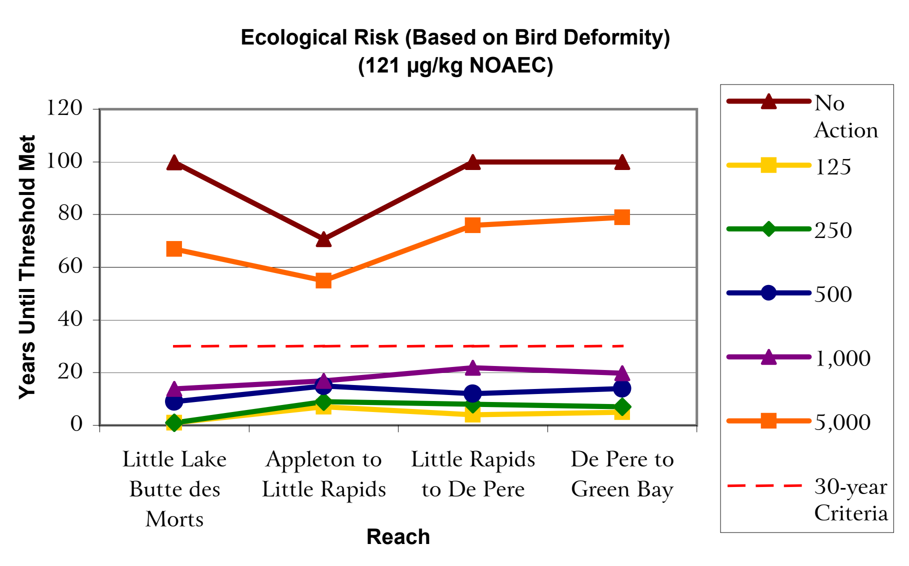
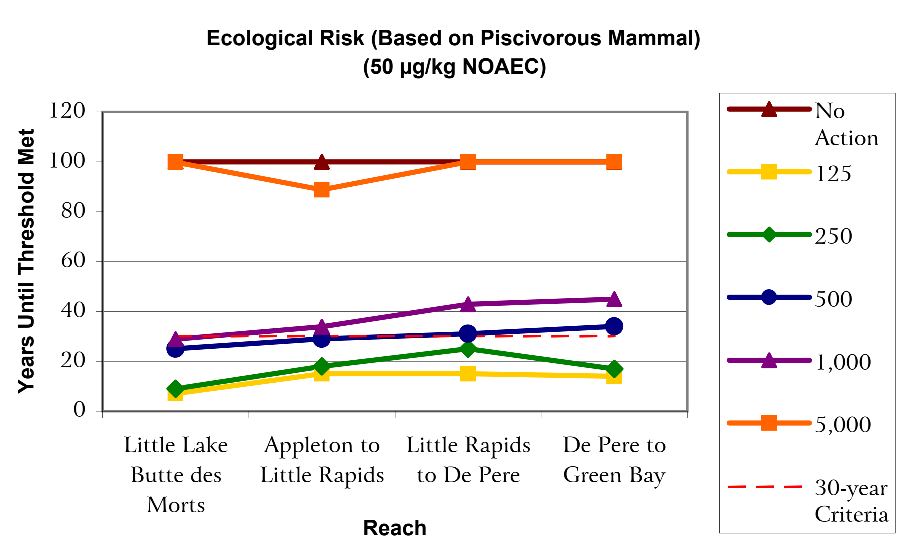


Figure 5 Comparison of Protection - All Reaches







RAO 4 not evaluated in Fox River reaches.

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List of Appendices

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List of Acronyms

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
2,3,7,8-TCDF	2,3,7,8-tetrachlorodibenzo-*p*-furan
˚C	degrees centigrade
˚F	degrees Fahrenheit
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
AOC	Area of Concern
APEG	potassium polyethylene glycol
ARAR	Applicable or Relevant and Appropriate Requirement
ARCS	Assessment and Remediation of Contaminated Sediments
ASRA	Alternative-specific Risk Assessment
ATP	anaerobic thermal processor
AVM	acoustic velocity meter
BBL	Blasland, Bouck, and Lee
BCD	base catalyzed decomposition
Be-7	beryllium-7
BLRA	Baseline Human Health and Ecological Risk Assessment
BOD	SMU 56/57 Basis of Design Report
CAD	confined aquatic disposal
CAMP	Comprehensive Analysis of Mitigation Pathways
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund Statute)
cf	cubic feet
CFR	Code of Federal Regulations
cfs	cubic feet per second
CH	highly plastic clay
cm	centimeter
cm/s	centimeters per second
cm/yr	centimeters per year
COC	chemical of concern
COPC	chemical of potential concern
Cs-137	cesium 137
CTE	central tendency exposure
CTF	confined treatment facility
CWA	Clean Water Act
cy	cubic yard
cy/hr	cubic yards per hour
DAMOS	Disposal Area Monitoring System

List of Acronyms

DDD	4,4'-dichlorodiphenyl dichloroethane (includes isomers o,p'-DDD and p,p'-DDD)
DDE	4,4'-dichlorodiphenyl dichloroethylene (includes isomers o,p'-DDE and p,p'-DDE)
DDT	4,4'-dichlorodiphenyl trichloroethylene (includes isomers o,p'-DDT and p,p'-DDT)
DGPS	differential global positioning system
DM	data management
DO	dissolved oxygen
DOD	United States Department of Defense
DOER	Dredging Operations and Environmental Research Program
DRE	destruction removal efficiency
EPA	United States Environmental Protection Agency
ESRI	Environmental Systems Research Institute
EWI	EWI Engineering Associated, Inc.
FEMA	Federal Emergency Management Agency
FRDB	Fox River Database
FRFood	Lower Fox River Food Web Model
FRG	Fox River Group
FRM	Fox River Model
FS	Feasibility Study
ft	foot or feet
ft^2	square feet
ft^3	cubic feet
ft/ft	feet per foot
ft/s	feet per second
g	gram
g/cc	grams per cubic centimeter
GAC	granular activated carbon
GAS	Graef, Anhalt, Schloemer and Associates, Inc.
GBFood	Green Bay Food Web Model
GBHYDRO	Green Bay Hydrodynamics Model
GBMBS	Green Bay Mass Balance Study
GBSED	Green Bay Sediment Transport Model
GBTOX	Green Bay Toxics Model
GBTOXe	Enhanced Green Bay Toxics Model
g/cm^3	grams per cubic centimeter
GLNPO	Great Lakes National Program Office (EPA)
GLSFA	Great Lakes Sport Fish Advisory Task Force

List of Acronyms

GLWQI	Great Lakes Water Quality Initiative
GM	General Motors
gpm	gallons per minute
GRA	general response action
HAZMAT	hazardous materials
HDPE	high-density polyethylene
HI	hazard index
HQ	hazard quotient
HTTD	high-temperature thermal desorption
IDA	inter-deposit area
IGLD	International Great Lakes Datum
IJC	International Joint Commission
K_d	log soil/water partition coefficient
kg	kilogram
kg/yr	kilograms per year
km	kilometer
km^2	square kilometer
K_{oc}	organic carbon partitioning coefficient
K_{ow}	octanol water partitioning coefficient
L	liter
LCL	Lower Confidence Limit
LFR	Lower Fox River
LLBdM	Little Lake Butte des Morts
LOAEC	Lowest Observed Adverse Effect Concentration
LTA	long-term average
LTMP	Long-term Monitoring Plan
m	meter
m^2	square meter
m^3	cubic meter
m/s	meters per second
m^3/s	cubic meters per second
mg/cm^2	milligrams per square centimeter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MH	high-compressibility silt
mi^2	square mile
m/km	meters per kilometer
MNR	monitored natural recovery
Mpa	mega Pascal

List of Acronyms

MSL	mean sea level
MT	metric tons
MT/yr	metric tons per year
NAAQS	National Primary and Secondary Ambient Air Quality Standards
NAS	National Academy of Sciences
NCP	National Contingency Plan
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
ng/kg	nanograms per kilogram
ng/L	nanograms per liter
NGVD29	National Geodetic Vertical Datum 1929
NOAA	National Oceanic and Atmospheric Administration
NOAEC	No Observed Adverse Effect Concentration
NPDES	National Pollutant Discharge Elimination System
NR	Natural Recovery
NRC	National Research Council
NRDA	Natural Resources Damage Estimate
O&M	operation and maintenance
OBAI	Ogden-Beeman and Associates
OSHA	Occupational Safety and Health Administration
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD	dibenzo-*p*-dioxin
PCH	planar chlorinated hydrocarbon
PCP	pentachlorophenol
POTW	publicly-owned treatment works
PPE	personal protective equipment
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRP	potentially responsible party
psi	pounds per square inch
PSNS	Puget Sound Naval Shipyard
$Q_{7,10}$	7-day average low stream flow with a 10-year frequency
RA	Risk Assessment
RAO	Remedial Action Objective
RBFC	risk-based fish concentration
RCRA	Resource Conservation and Recovery Act
RETEC	Remediation Technologies, Inc.
RI	Remedial Investigation

List of Acronyms

RI/FS	Remedial Investigation and Feasibility Study
RME	reasonable maximum exposure
ROD	Record of Decision
rpm	revolutions per minute
SCS	Soil Conservation Service
SEDTEC	Sediment Technologies CD-ROM by Environment Canada
SFV	stream flow velocity
SITE	Superfund Innovative Technology Evaluation
SLRA	Screening Level Risk Assessment
SMU	Sediment Management Unit
SQT	sediment quality threshold
SRD	sediment remediation demonstration
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWAC	surface-weighted average concentration
TBC	information “to be considered”
TEL	threshold effect concentration
TEQ	toxic equivalency factor
TMDL	total maximum daily loads
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TSS	total suspended solids
TWA	time-weighted average
UCL	Upper Confidence Limit
UFR	Upper Fox River
UFR/LFR	Upper Fox River/Lower Fox River Sediment Transport Model
UP	Michigan’s Upper Peninsula
U.S.	United States of America
USACE	United States Army Corps of Engineers
U.S.C.	United States Code
U.S.C.A.	United States Code, Amended
USCS	Unified Soil Classification System
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UV	ultraviolet
VOC	volatile organic compound
v/v	volume per volume
WAC	Wisconsin Administrative Code
WASP4	Water Quality Analysis Simulation Program Version 4

List of Acronyms

WDNR	Wisconsin Department of Natural Resources
wLFR	whole Lower Fox River
wLFRM	Whole Lower Fox River Fate and Transport Model
WPDES	Wisconsin Pollutant Discharge Elimination System
WQC	water quality criteria
WSEV	Window Subsampling Empirical Variance
w/w	weight per weight
WY	water year
yr	year

1 Introduction

This Feasibility Study Report (FS) develops and evaluates a range of remedial alternatives for contaminated sediments in the Lower Fox River and Green Bay (Wisconsin). The FS Report was prepared by The RETEC Group, Inc. (formerly known as ThermoRetec Consulting Corporation [ThermoRetec]), on behalf of the Wisconsin Department of Natural Resources (WDNR). WDNR directed the project and received both funding and technical assistance from the United States Environmental Protection Agency (EPA) Region 5.

The FS completes the remedial investigation and feasibility study (RI/FS) program for the Lower Fox River and Green Bay Superfund site in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP). Preparation of the FS conformed to procedures outlined in the EPA guidance document: *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA RI/FS Guidance) (EPA, 1988). This RI/FS report is consistent with the findings of the National Academy of Sciences National Research Council report entitled *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC, 2001).

This FS develops remedial alternatives exclusively for the cleanup of contaminated sediments in the Lower Fox River and Green Bay for the long-term protection of human health and the environment. The following major components of the RI/FS program supported preparation of the FS:

- **Data Management (DM).** DM involved the development of a usable database produced through the identification, acquisition, review (validation), catalog, classification and archive of known available data sources (electronic and hard copy) pertinent to the Lower Fox River/Green Bay Risk Assessment (RA) and RI/FS. Usable data includes water, sediment, and fish tissue chemistry data. DM procedures and results are provided in the *Data Management Summary Report* prepared by EcoChem, Inc. under subcontract to ThermoRetec (EcoChem, 2000).

- **Remedial Investigation (RI).** The RI provided a compilation, review, and organization of physical, chemical and biological characteristics of the Lower Fox River and Green Bay. These characteristics provide the framework for a site conceptual model describing the magnitude and extent of chemicals of concern (COCs) in both sediment and water, and in the valued biological resources within the Lower Fox River and Green

Bay. Relevant physical and chemical characteristics of the Lower Fox River and Green Bay such as geology, surface water hydrology, sedimentation, chemical distribution, and fish/bird habitats are presented in the *Remedial Investigation for the Lower Fox River* (RI Report) (RETEC, 2002a). A summary of the RI is presented in Section 2 of this FS Report.

- **Risk Assessment (RA).** The RA involved the identification of COCs and risk-based sediment cleanup goals based upon realistic assessments of potential risks to ecological and human receptors. The RA provides an assessment of risks to human health and the environment that will support selection of a remedy to eliminate, reduce, or control those risks. The RA is presented in two documents: *Screening Level Human Health and Ecological Risk Assessment* (SLRA) (RETEC, 1998) and *Baseline Human Health and Ecological Risk Assessment* (BLRA) (RETEC, 2002b). A summary of the RA is presented in Section 3 of this FS Report.

- **Model Documentation Report (MDR).** The MDR compiled the fate and transport and bioaccumulation models used to estimate and forecast the movement of contaminated PCB sediment in the Lower Fox River and Green Bay. This report provides a "concise" compilation of the models used in the RI/FS including the Whole Lower Fox River Fate and Transport Model (wLFRM) developed by WDNR, the Lower Fox River Food Web Model (FRFood) developed by ThermoRetec, the Enhanced Green Bay Toxics Model (GBTOXe) developed by HydroQual, and the Green Bay Food Web Model (GBFood) developed by QEA. These models were used to predict long-term risk reduction in surface water and fish tissue levels over time after remedy completion.

1.1 Site Description

The project study area includes the Lower Fox River and Green Bay aquatic systems. The Lower Fox River is located in northeastern Wisconsin within the eastern ridges and lowlands of the state. The Lower Fox River is defined as the 39-mile portion of the Fox River, beginning at the outlet of Lake Winnebago and terminating at the mouth of the river into Green Bay, Lake Michigan (Figure 1-1). The river flows north and drains approximately 6,330 square miles, making it a primary tributary to Green Bay and a part of the Great Lakes system. Green Bay is a freshwater system approximately 120 miles long which drains into Lake Michigan (Figure 1-2), and is located on the state border between Wisconsin and Michigan along a northeast- to southwest-trending axis.

Historic discharges from municipal, industrial, and agricultural sources in the Lower Fox River region have degraded sediment and water quality and adversely impacted the ecology of the river and bay. The SLRA identified a list of chemicals of potential concern (COPCs) which included: polychlorinated biphenyls (PCBs) (total and Aroclors), dioxins/furans, 4,4'-dichlorodiphenyl trichloroethylene (DDT) and its metabolites, dieldrin, and several metals (arsenic, lead, and mercury). The BLRA concluded that the chemicals of concern (PCBs, mercury, DDE) represented the potential risks to human health and ecological receptors.

PCBs in the Lower Fox River pose the major potential threat to human health and ecological receptors due to their tendency to sorb to sediments, persist in the environment, and bioaccumulate in aquatic organisms. Contaminated sediments acting as "sinks" for PCBs and other contaminants are also subject to physical and chemical processes that affect the overlying water column and adjoining water bodies in natural (uncontrolled) environments. For example, PCBs from sediment in the Lower Fox River are discharged into Green Bay at the mouth of the river through sediment transport and PCB dissolution in the water column. The RA and RI should be referred to for a complete description of human and ecological impacts as well as the fate and transport of PCBs and other COCs, respectively.

1.2 Feasibility Study Process

The FS develops and evaluates a range of remedial alternatives for the Lower Fox River and Green Bay. This analysis provides the basis for selection of an appropriate cleanup remedy that meets site-specific remedial action objectives. While this is a state-lead (WDNR) effort, the overall assessment follows the procedures and paradigms developed as part of CERCLA and the NCP. The primary steps of the FS process include:

- Establishment of remedial action objectives (RAOs),
- Identification and screening of general response actions (GRAs) and remedial technologies that address the GRAs, and
- Development and detailed analysis of remedial alternatives.

Figure 1-3 illustrates how each section of this FS Report relates to fundamental steps of the FS process. By following EPA RI/FS guidance, a list of potential remedial alternatives for the Lower Fox River and Green Bay was developed and evaluated. The remedial alternatives provide the basis for the development of a Record of Decision (ROD). The following subsections describe the organization and contents of this FS Report.

1.2.1 Summary of the Remedial Investigation - Section 2

Section 2 summarizes the RI Report in terms of the hydrological, physical, chemical, and biological characteristics of the river. The summary describes the following elements of the river system that are pertinent to the FS process:

- **Environmental Setting:** a chronology of major developments and regulatory actions in the Lower Fox River region that have impacted the quality of the river and the river/bay ecosystem;
- **Physical Characteristics:** a detailed description of the four reaches comprising the Lower Fox River and the four zones of Green Bay;
- **Soft Sediment Thickness:** a summary of soft sediment thicknesses and distribution in the Lower Fox River and Green Bay;
- **Nature and Extent of Contaminants of Concern:** a summary of sediment chemical concentrations and vertical distributions across the four reaches and four zones;
- **Fate and Transport:** a generalized description of the processes by which chemical compounds are transported from their source(s) to potential human and environmental receptors; and
- **Time Trends:** a description of statistical changes in PCB concentrations in sediments, birds, and fish in both the river and bay over time.

1.2.2 Summary of the Baseline Human Health and Ecological Risk Assessment - Section 3

Section 3 summarizes the assessment of potential risks to ecological and human receptors that live, feed, and recreate in the Lower Fox River and Green Bay. Results of the risk assessment provide the basis for setting risk-based sediment cleanup goals and determining an appropriate remedial alternative that will eliminate, reduce, or control those risks. The summary describes the following elements of the RA that are pertinent to the FS process:

- **Overview of the Risk Assessment:** a description of potential risks associated with the Lower Fox River and the primary components (i.e., COPCs, sediment quality thresholds [SQTs], etc.) that are identified as part of the process;

- **Human Health Risk Assessment:** a brief discussion of the general methodology used for assessing potential risks posed to human health, including a summary of the results;

- **Ecological Risk Assessment:** a description of the general methodology used for assessing potential risks posed to ecological receptors, including a summary of the results; and

- **Sediment Quality Thresholds:** a summary of the assumptions and methods used to develop an array of SQTs with varying degrees of protectiveness to human health and the environment.

Sections 2 and 3 precede Sections 4 through 10 in this FS Report since they were integral to the direction of the FS process described in the following subsections.

1.2.3 Development of Remedial Action Objectives and General Response Actions - Section 4

The first step in the FS process involves establishing RAOs by integrating data from three key sources: site characteristics, human health and ecological risk, and applicable or relevant and appropriate requirements (ARARs).

Section 4 presents the RAOs and discusses the basis for establishing the RAOs for the Lower Fox River and Green Bay. This section also lists the ARARs and information that is "to be considered" (TBC) that constitute the regulatory/ guidance body for the project.

The GRAs selected to address the RAOs were developed from eight primary remediation strategy categories:

- No Action,
- Institutional Controls,
- Monitored Natural Recovery,
- Containment,
- Removal,
- *In-situ* Treatment,
- *Ex-situ* Treatment, and
- Disposal.

These GRAs were used to identify and screen appropriate action levels in Section 5 and remedial technologies in Section 6.

1.2.4 Development of PCB Action Levels for the Lower Fox River and Green Bay - Section 5

Prior to the development of remedial alternatives, the extent (volumes and areas) of contaminated sediments are identified, to which the GRAs apply. This task was accomplished by identifying areas of contaminated sediment based on analytical data and modeling. Action levels were used to define volumes and potential areas for remediation. These action levels, coupled with monitored natural recovery processes, will be used to determine the relative time frame expected for attainment of the project RAOs and residual SQT concentrations.

Section 5 identifies volumes and areas of impacted sediment and defines the extent of contaminated sediments to be addressed in the remedial alternatives.

1.2.5 Identification and Screening of Technologies - Section 6

A master list of remedial technology types and process options applicable to remediation of the Lower Fox River and Green Bay sediments was compiled for each GRA. An initial screening was performed to determine which technology types and process options were technically practicable and implementable. A second and final screening was performed to evaluate the various process options representing technology types that were retained from the initial screening. These were evaluated based on effectiveness, cost, and administrative (i.e., permitting issues, equipment availability, etc.) implementability.

Section 6 presents a description of the screening process and results of the screening. Additional criteria and other considerations that influence the development and analysis of remedial alternatives for the Lower Fox River and Green Bay are also presented in Section 6.

1.2.6 Reach-specific Remedial Alternatives - Section 7

Technology types and process options that were retained after completion of the screening were combined to develop remedial alternatives for each of the four river reaches and four Green Bay zones. A range of alternatives was developed as follows:

- No action as a baseline to which other remedial options are compared.

- Monitored natural recovery in which sediments will attenuate over time without active remediation. Provide institutional controls until remedial action objectives are met.

- Contain the COCs in place to reduce and/or eliminate exposure to human and ecological receptors.

- Remove and treat contaminated sediments to reduce the risk of human and ecological exposure to COCs.

- Remove and contain contaminated sediments within an on-site or off-site disposal facility to reduce risk to human and ecological receptors and minimize long-term management.

Section 7 presents potential remedial alternatives for the four river reaches and four zones of Green Bay. Section 7 also provides a discussion of the basis for development of the remedial alternatives, considerations for implementation of the different process options incorporated into each remedial alternative, and costs associated with implementation of each remedial alternative.

1.2.7 Alternative-specific Risk Assessment - Section 8

The reach-specific remedial alternatives are further evaluated in terms of risk reduction and residual risks. This evaluation identifies residual ecological or human health risks based on estimates of the effective reduction of the concentrations of COCs in the Lower Fox River and Green Bay attributable to a selected alternative.

Section 8 presents the alternative-specific risk assessment. This evaluation is intended to support a risk-based remedial alternative selection for the Lower Fox River and Green Bay. An alternative-specific risk assessment provides further comparative data on each remedial alternative that can be used as an additional decision-making tool in the ROD.

1.2.8 Detailed Analysis of Remedial Alternatives - Section 9

Each of the remedial alternatives was evaluated using criteria specified in the EPA RI/FS guidance. The criteria are divided into three categories as follows:

- Threshold Criteria
  - Overall Protection of Human Health
  - Compliance with ARARs

- Balancing Criteria
  - Long-term Effectiveness and Permanence
  - Reduction of Toxicity, Mobility, and Volume Through Treatment
  - Short-term Effectiveness

    - Implementability
    - Cost

- Regulatory/Community Criteria
    - State Acceptance
    - Community Acceptance

The regulatory/community criteria are typically addressed in the ROD and will be considered in the FS process during review by WDNR. WDNR will hold public meetings during the public comment period and will solicit comments on the contents of the RI and FS reports.

Section 9 presents a detailed analysis of each remedial alternative developed for the four reaches and four zones.

1.2.9 Comparative Analysis of Alternatives - Section 10

A comparative analysis focused on synthesizing the detailed analysis of Section 9 into a readily accessible decision-making tool will be performed in Section 10. This comparison is in contrast with the detailed analysis conducted in Section 9 in which each alternative is analyzed independently without a consideration of other alternatives. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another, so that the key tradeoffs the decision-maker must weigh can be identified. To accomplish this, numerical measures are used to evaluate how each alternative compares relative to all others with respect to addressing each of the following questions:

- What is the residual human health risk after implementation of an alternative?

- What is the residual ecological risk after implementation of an alternative?

- What is the level of disruption to local communities associated with the construction of each alternative?

- What is the administrative effort necessary to implement each alternative?

- What is the volume of contaminated sediment removed from the Lower Fox River and Green Bay?

- What is the cost of implementing each alternative?

- What is the incremental cost of reducing risk for each alternative?

Section 10 presents a synoptic comparison of the predicted performance of each of the reach-specific alternatives in relation to specific decision-making evaluation criteria.

1.2.10 References - Section 11

This section is a compilation of references cited in the FS. These references will be included in the administrative record for the project.

1.3 Application of NRC Findings and Recommendations

Based on national and growing concern regarding the long-term management of PCB-contaminated sediments, the National Academy of Sciences (NAS) was mandated by the United States Congress, via the National Research Council (NRC), to address the complexities and risks associated with managing PCB-contaminated sediments. The NRC was tasked with reviewing the availability, effectiveness, cost, and effects of technologies used for the remediation of sediments containing PCBs. The results of their findings were published in a document titled *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC, 2001). Based on their review of PCB effects at several sites nationally, the NRC concluded that PCBs in sediment pose a chronic risk to human health and the environment, and that these risks must be managed. The NRC recommended that remedies should be site-specific and risk-based, and that no one remedy (dredging, capping, or monitored natural recovery) is applicable or preferred for all sites.

The recommendations of the NRC were adapted by the United States Environmental Protection Agency (EPA) in a document titled *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA, 2002). EPA used the guiding principals defined by the NRC to develop a set of 11 risk management principles for application at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) sediment sites. The EPA guidance principles specify use of scientific, risk-based, site-specific remedy decisions using an iterative decision process, as appropriate, which evaluates the short-term and long-term risks of all potential cleanup alternatives. These principles are consistent with the nine remedy selection criteria defined in the National Contingency Plan (NCP) (40 CFR Part 300.430) and application of these principles does not affect existing statutory and regulatory requirements. A comparison of the NRC-developed and the EPA sediment management principals is given in the white paper titled *Applicability of the NRC Recommendations and EPA's 11 Management Principles* in the Responsiveness Summary.

The Lower Fox River and Green Bay RI/FS followed the guidance set forth by both the EPA and the NRC. These included:

- Using EPA risk assessment frameworks (EPA, 1989b for human health risk; 1997 and 1998b for ecological risk) that were based on the framework developed by NRC in 1983 which recommended a tiered and iterative approach;

- Using an extensive body of site-specific scientific information and data to bound the problem;

- Defining the problem in a site-specific manner through review of all existing scientific information in a preliminary assessment;

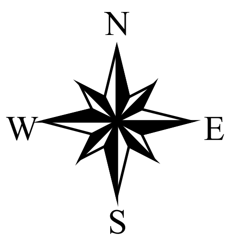
- Calibrating and defining the uncertainty of models that were used in the assessment; and by

- Structuring the documents so that a range of site-specific risks to human health and the environment were delineated, and articulating RAOs around which to structure potential remedial alternatives.

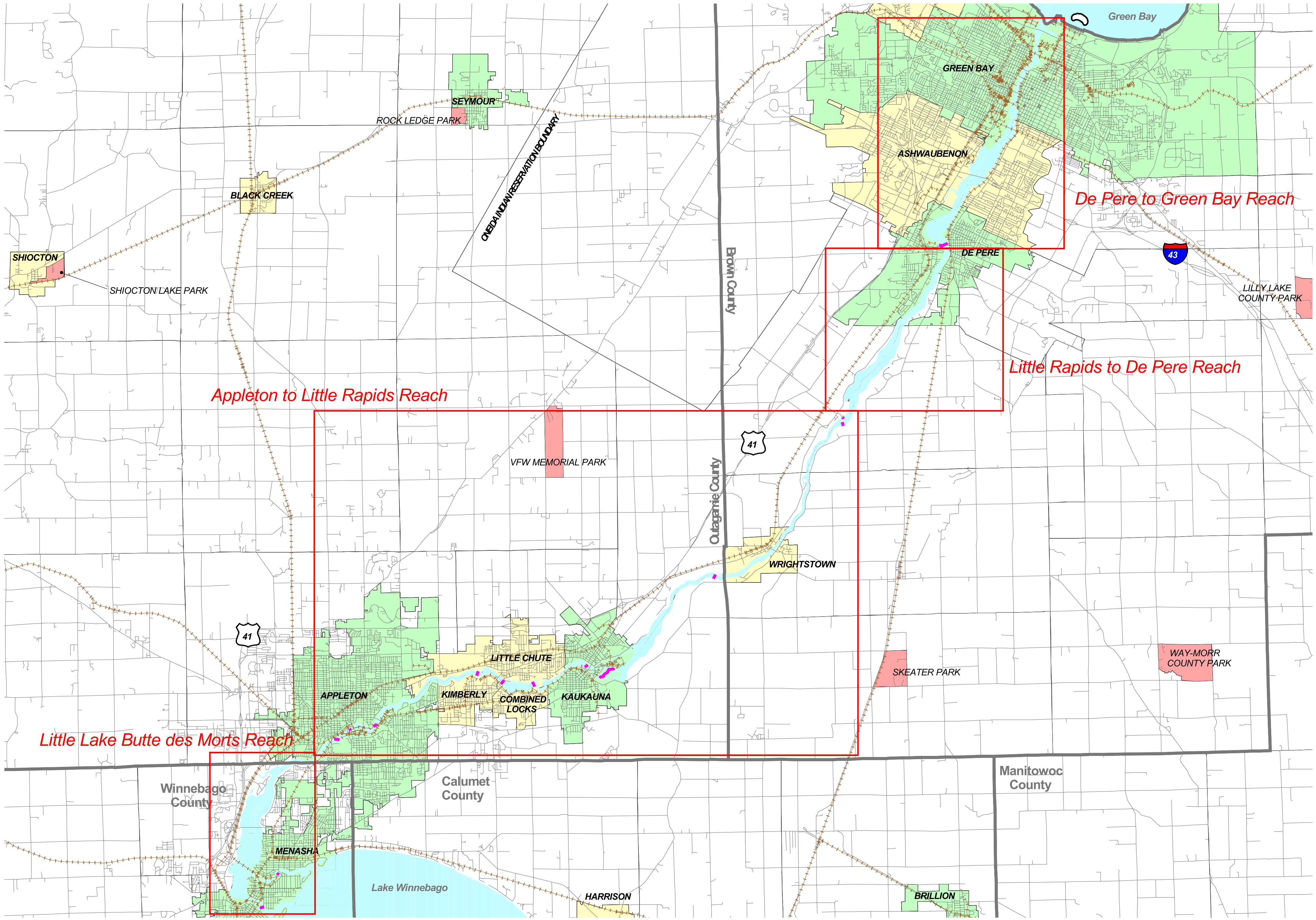
EPA's 11 risk management principles also are covered by the above bullet, as well as through public involvement; development of sophisticated fate, transport, and bioaccumulation models; early involvement of trustee groups; and implementation of three demonstration projects to test potential remedial technologies. These are discussed throughout the FS.

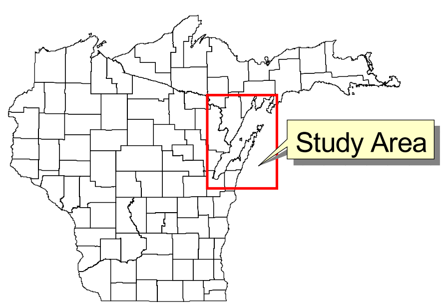
1.4 Section 1 Figures

Figures for Section 1 follow this page and include:



County Boundaries
Dam Locations
Railroads
Roads
Wisconsin State Parks
Water
Civil Divisions
City
Township
Village
Reach Boundary





3 0 3 6 Kilometers

3 0 3 6 Miles

NOTE:
Basemap generated in ArcView GIS, Version 3.2, 1998,
and from TIGER Census data, 1995.

ThermoRetec
Smart Solutions. Positive Outcomes.

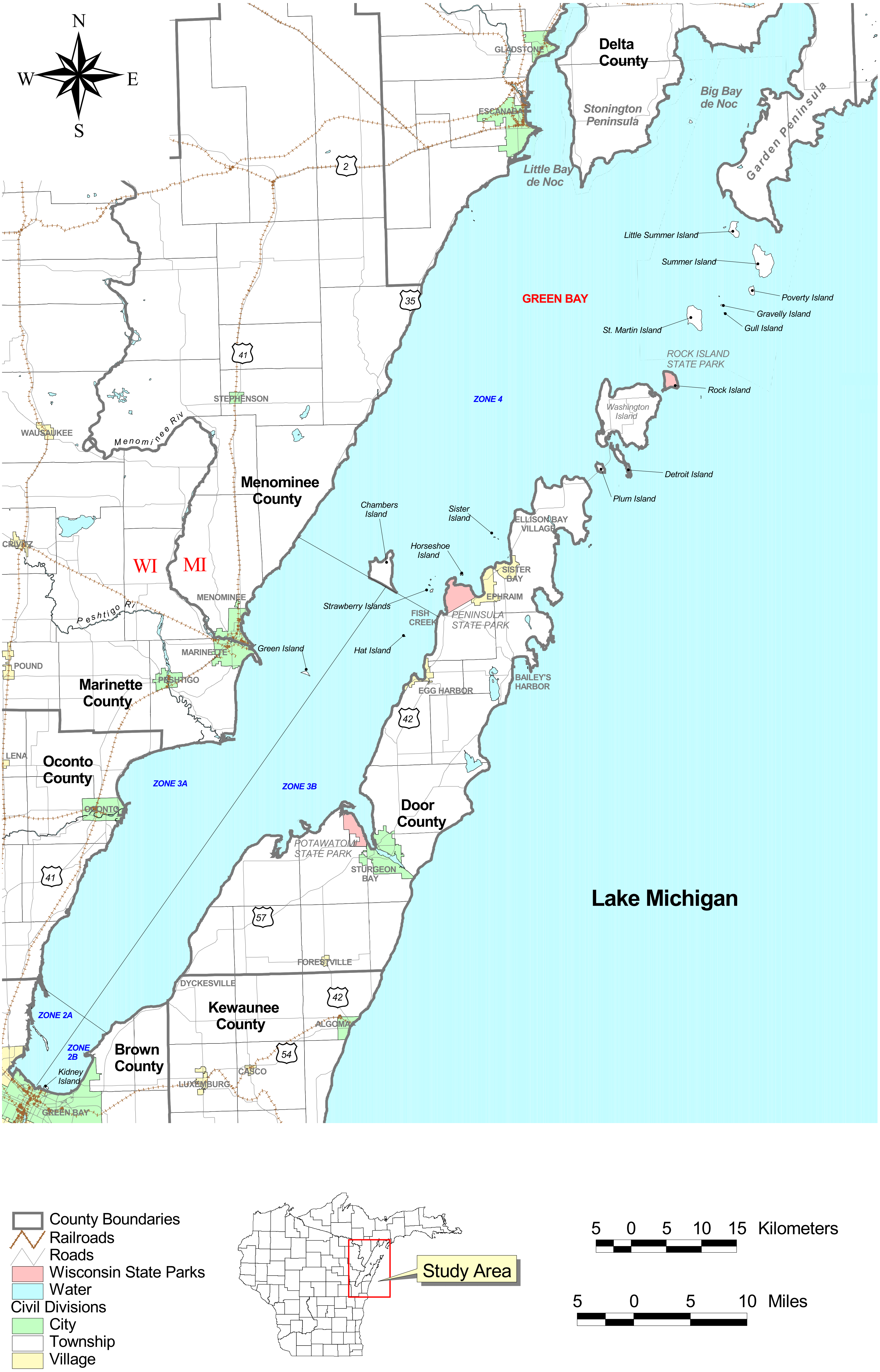
Natural Resource Technology

Lower Fox River & Green Bay Feasibility Study

Lower Fox River Study Area

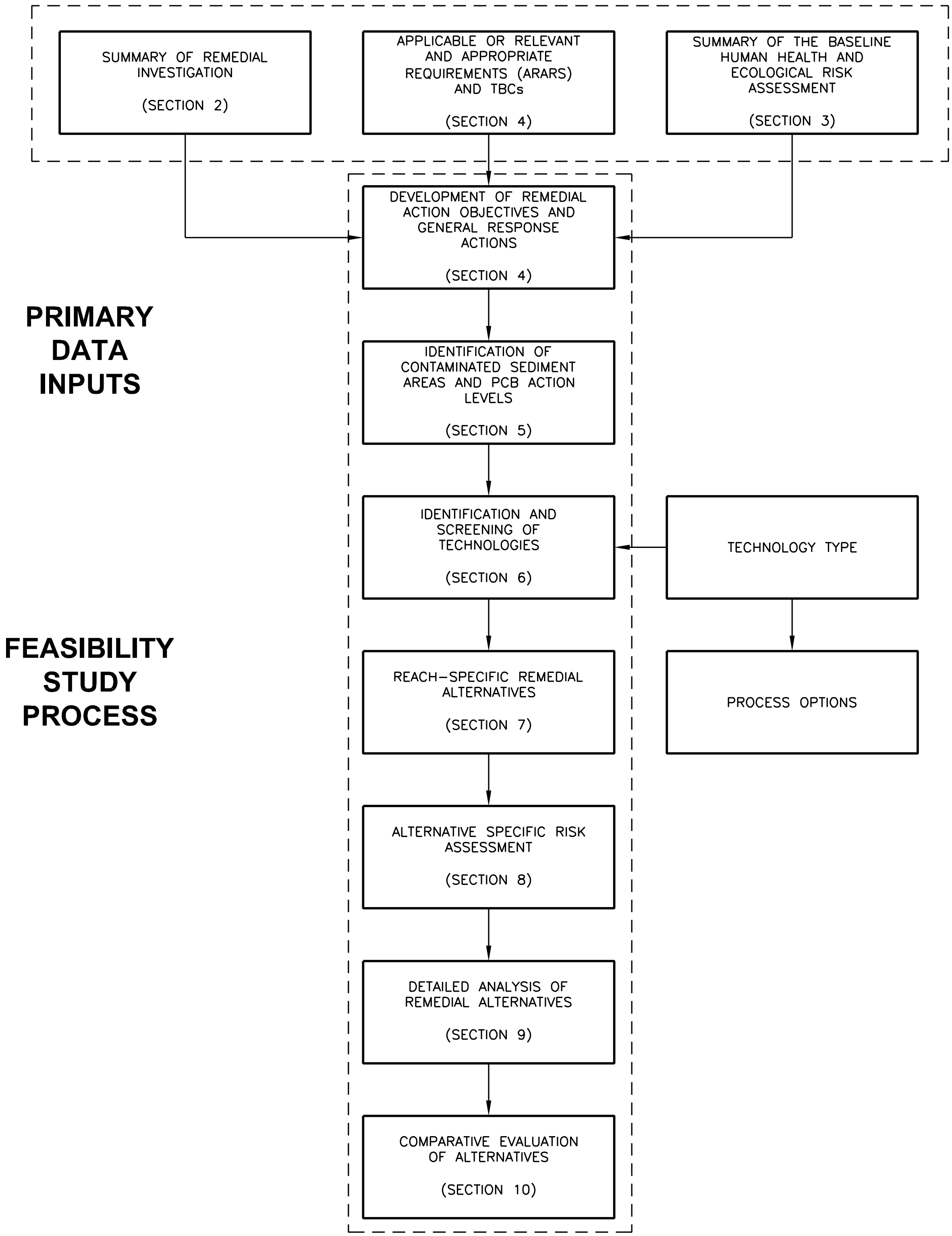
FIGURE 1-1

REF NO: FS-14414-535-1-1
CREATED BY: SCJ
PRINT DATE: 3/9/01
APPROVED: AGF



NOTE:
Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Green Bay Study Area	REF NO: FS-14414-535-1-2
				CREATED BY: SCJ
				PRINT DATE: 3/9/01
			FIGURE 1-2	APPROVED: AGF



ThermoRetec

LOWER FOX RIVER AND GREEN BAY FEASIBILITY STUDY WISCN-14414-535			OVERVIEW OF FEASIBILITY STUDY PROCESS
DATE: 01/16/01	DRWN: N.S.	FILE: 14414s017	FIGURE 1-3

2 Remedial Investigation Summary

This section summarizes information from the Remedial Investigation (RI) Report for the Lower Fox River and Green Bay that is relevant to the feasibility study. Specifically, this summary of the RI Report will:

- Define the historical setting, including sources of chemicals of concern in the Lower Fox River;
- Describe the physical characteristics of the Lower Fox River and Green Bay along areas of impacted sediment deposits;
- Estimate the occurrence, volume, and mass of sediments containing identified chemical compounds, particularly polychlorinated biphenyls (PCBs);
- Discuss the fate and transport of contaminants within the Lower Fox River and Green Bay; and
- Present the results of an analysis of time trends within the Lower Fox River for changing sediment and fish tissue concentrations.

References and data sources pertaining to information presented in the RI summary can be found in the *Lower Fox River and Green Bay Remedial Investigation Report* (RETEC, 2002a).

2.1 Environmental Setting and Background

2.1.1 Lower Fox River Setting

The Lower Fox River flows northeast approximately 63 kilometers (km) (39 miles) from Lake Winnebago to Green Bay, Wisconsin (Figure 1-1). The Lower Fox River is the primary tributary to lower Green Bay, draining approximately 16,395 square kilometers (km^2) (6,330 square miles [mi^2]) with a mean discharge of 122 cubic meters (m^3) per second (4,300 cubic feet per second [cfs]). The change in river elevation between Lake Winnebago and Green Bay is approximately 51 meters (168 feet).

Reach Designations

To facilitate modeling activities and identification of specific points along the river, the Lower Fox River was divided into the following four separate reaches in sequential order going downstream:

- Little Lake Butte des Morts (LLBdM),
- Appleton to Little Rapids,
- Little Rapids to De Pere, and
- De Pere to Green Bay (also Green Bay Zone 1).

These four reaches were based on similar water depths, current velocities, contaminant concentrations and distribution, and dam/lock structures (Figures 2-1 through 2-4). These reach designations were used during the RI to streamline the evaluation and reporting of sediment, water, and biological tissue data. Specific sediment deposits were identified in the first three reaches (Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere). These deposits were labeled A through HH and POG. Deposits were originally designated based on physical attributes, then later the chemical nature and extent of each deposit was determined. The De Pere to Green Bay Reach was divided into 96 Sediment Management Units (SMUs) to support the modeling efforts of the 1989 Green Bay Mass Balance Study. Table 2-1 summarizes the 35 sediment deposits (labeled A through HH) upstream of the De Pere dam and 96 Sediment Management Units (SMUs 20 through 115) downstream of the De Pere dam.

2.1.2 Green Bay

Green Bay is a narrow, elongated bay, approximately 190 km (119 miles) in length and an average of 37 km (23 miles) in width (Figure 1-2). The bay is bounded by the city of Green Bay at the south end and by both Big and Little Bays de Noc, in Michigan's Upper Peninsula (UP), on the north end. Wisconsin's Door Peninsula separates the majority of Green Bay from Lake Michigan. Urban areas located along the west shore of Green Bay include the cities of Marinette, Peshtigo, and Oconto, Wisconsin, and Escanaba and Menominee, Michigan. The city of Sturgeon Bay, Wisconsin, is located on the east shore of Green Bay.

The Green Bay watershed drains approximately 40,000 km^2 (15,625 mi^2) or about one-third of the Lake Michigan drainage basin. Two-thirds of the Green Bay drainage is in Wisconsin and one-third is in Michigan. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments. Other significant tributaries located along the west and north sides of the bay include Duck Creek and the following rivers: Suamico, Pensaukee, Oconto, Peshtigo, Menominee, Cedar, Ford, Escanaba, Tacoosh, Rapid, Whitefish, Sturgeon, and Fishdam.

Zone Designations

The Green Bay Mass Balance Study (GBMBS) (EPA, 1989a) divided the bay into four morphometric zones based on physical/chemical/biological characteristics observed in the bay: identified as zones 1, 2, 3, and 4 (Figure 1-2). Observations included eutrophication, chemical contaminants, foraging areas, habitat gradients, and distribution of fish populations. Green Bay Zone 1 is the same as the De Pere to Green Bay Reach of the Lower Fox River. Zones 2 and 3 are further divided into A and B segments by a center line extending out from the mouth of the Lower Fox River to Chambers Island. Zones 2A and 3A are located on the west side of this line while zones 2B and 3B are located on the east side of this line. Table 2-2 summarizes the physical characteristics of the Green Bay zones.

2.1.3 Site History

The Lower Fox River and Green Bay regions have long been important transportation corridors within the state of Wisconsin. Abundant and reliable food, as well as other natural resources in the area, have fostered development since prior to the arrival of Europeans to the region. By the early 1800s, timber, agriculture, fishing and fur trading, and other commercial activities were either well established or beginning to be developed, due to the availability of local resources. During the 1820s and 1830s, Green Bay was a key entrance into the American west and large-scale migration to the area and development occurred (Burridge, 1997). In 1839–40, representatives of the U.S. federal government (the Topographical Engineers office) recommended the construction of a series of dams, locks, canals, and other improvements in order to make the Lower Fox River navigable between Green Bay and Lake Winnebago. Channelization of the Lower Fox River began as part of this effort, as did construction of the locks and dams at each of the river's rapids. Along with development came utilization, exploitation, and degradation of the local resources, including the water quality of the river and bay.

2.1.4 Current Land Use

Currently, the Green Bay and Lower Fox River areas support a population of approximately 595,000, about 10 percent of the state's population. The Lower Fox River valley, especially in the Appleton and Neenah-Menasha area, may still contain the largest concentration of pulp and paper industries in the world (20 mills in approximately 37 miles). The paper industry remains active within the valley and plays a vital role in the local and state economy. Other industries important to the region include metal working, printing, food and beverages, textiles, leather goods, wood products, and chemicals. In addition to heavy industrial land use, the region also supports a mixture of agricultural, residential, light industrial, conservation, and wetland areas.

Regional land use along the Lower Fox River is identified on maps prepared by planning commissions in both the Fox Cities and Brown County. Land use details on these maps provide a general description of development in the river vicinity.

The approximated general land use percentages for areas within about 0.25 mile of the bank of the Lower Fox River are summarized below.

Land Use [1]	Fox River Cities [2] (1996)	Brown County (1990)	Entire River
Residential	32.9%	25.5%	29.2%
Industrial/Commercial	26.2%	25.3%	25.8%
Woodlands	14.6%	17.9%	16.2%
Parks	11.6%	6.8%	9.3%
Agricultural	0.5%	11.4%	5.8%
Public [3]	7.2%	1.3%	4.3%
Wetlands	5.1%	1.6%	3.4%
Vacant	1.9%	10.2%	6.0%

Notes:

1. Percentages are approximate and are intended to provide a general indication of land use along the Lower Fox River.
2. The Fox Cities includes all communities between Neenah/Menasha and Kaukauna.
3. Public land includes school properties.

The majority of the Lower Fox River is accessible to the public, including individual landowners along the banks. About 25 percent of the river shoreline area is considered wildlife habitat (agriculture, woodland, wetland). The wildlife habitat is largely located between Kaukauna and De Pere in both the Appleton to Little Rapids and Little Rapids to De Pere reaches.

Land use in the vicinity of Green Bay was collected from available county records for Brown, Door, Kewaunee, Oconto, and Marinette counties in Wisconsin and for Delta and Menominee counties in Michigan. A summary of the land use in the counties bordering Green Bay is presented in Table 2-3. The counties located along Green Bay are largely undeveloped. Brown County, Wisconsin is the only county where more than 5 percent of the total land is used for residential or industrial/commercial purposes. Also, between 65 and 85 percent of all land in these counties is classified as either agricultural or forested, reflecting the overall rural nature of this area. Wetlands comprise 3 to 20 percent of the land in the counties. The largest wetland areas are located in Brown, Oconto, and Marinette counties, all located along the western side of Green Bay. Door County, located on the eastern side of the bay, has less than 3.3 percent wetlands.

2.2 Physical Characteristics

Knowledge of the physical characteristics of a site provide the foundation for developing a site conceptual model and understanding the distribution and transport of contaminants throughout the river/bay system. Physical characteristics briefly described in this section for the Lower Fox River and Green Bay include: regional geology, sediment grain size, river and bay bathymetry, surface water hydrology, and sediment bulk density. In addition, a brief history of dredging activities is provided. The RI Report contains considerably more detail for each of these subjects.

2.2.1 Geologic Characteristics

Presented here is a brief summary of geology in the Lower Fox River and Green Bay basins. The RI contains considerably more detail pertaining to the bedrock formations, glacial stratigraphy, and native material underlying the recent soft sediment deposits.

Regional Geologic Setting

The Lower Fox River and Green Bay basins lie in the ridges and lowlands province of eastern Wisconsin and western Michigan. The eastern ridges and lowlands generally trend north-south across Wisconsin from northeastern Illinois to the Michigan shores of Lake Superior. The bedrock does not entirely control surface geomorphology, as the glacial advances and retreats planed off the bedrock highs and filled in bedrock valleys with till and outwash deposits.

The Lower Fox River valley and Green Bay is underlain by a bedrock sequence of Precambrian granite overlain by Paleozoic sandstones, dolomite, and shale. The surface of the bedrock units slope east, approximately 5.7 to 7.6 meters per kilometer (m/km) (30 to 40 feet per mile), toward and beneath Lake Michigan. This regional dip has resulted in the Silurian Niagara Escarpment, east of and parallel to the Lower Fox River lowlands, and erosion of the Ordovician Maquoketa shale in the western part of the study area.

Due to the erosion of the Silurian dolomite and Ordovician shale bedrock units, the uppermost bedrock in the Lower Fox River valley and along the western side of Green Bay (from the city of Green Bay to Little Bay de Noc) are Ordovician age limestone/dolomite units. Additionally, bedrock units of the western shore of Green Bay are comprised of the Galena and Platteville formations. Within Michigan, these units are referred to as the Trenton and Black River Formation and they are contemporaneous with the Galena and Platteville units.

Glacial Geology and Regional Soils

Unconsolidated Quaternary glacial deposits cover the bedrock units and consist of silty clay to clay loam tills with associated sand and gravel outwash and lacustrine units. In the Lower Fox River valley, the glacial deposits range in thickness from approximately 15 meters (50 feet) over much of the area to over

61 meters (200 feet) in the area around Wrightstown (Attig *et al.*, 1988). On the Door and Garden peninsulas, these deposits are generally less than 3 meters (10 feet) thick, and are thinner along the shores of the bay.

Soils and river sediments in the region are predominantly silt and clay units with varying amounts of sand and gravel due to the glacial events that occurred in region. The glacial deposits also affect the surficial soils in the vicinity of the Lower Fox River, many of which are described as silty clay loam, silty clay, and clay. In the northern portion of Green Bay, especially along the west side of the bay, outwash and glacial lake plains (typically dominated by sands) developed and ultimately affected soil formation, while on the Door and Garden peninsulas, clay till deposits are predominant. Superimposed on the glacial deposits are modern fluvial and alluvial sediments associated with slopewash, river, and floodplain deposits (Krohelski and Brown, 1986).

2.2.2 Sediment Grain Size

The Lower Fox River sediment grain size distribution reflects the mixture of sand, silt, and clay comprising the native silty clay glacial till deposits of the area. Sand and silt are the dominant grain sizes in Lower Fox River sediments, typically accounting for 75 to 90 percent of the particle sizes present.

In Little Lake Butte des Morts, the Appleton to Little Rapids Reach, and the De Pere to Green Bay Reach, silt comprises about 40 percent of the sediments encountered, while the sand content ranges between 41 and 46 percent. However, in the Little Rapids to De Pere Reach, where extensive sediment accumulations have been observed at Deposit EE, the silt content is 54 percent while sand comprises only about 23 percent of the sediments. These results confirm that the De Pere dam is a significant trap for finer-grained sediments on the Lower Fox River.

Sediments within Green Bay have a higher percentage of sand than those in the river. Sand content in Zone 2 (2A/2B) ranges between about 52 and 93 percent, with an average of 73 percent. In Zone 3A, along the west side of Green Bay, sand content is greater than 97 percent, while the sand content in Zone 3B generally ranges between 60 and 80 percent. The results for Zone 3B reflect the influx of sediments from the Lower Fox River, with a slightly higher silt/clay content in this area than in the other three areas of Green Bay. In Zone 4, the sand content averages 96 percent, which is similar to Zone 3A. Overall, the average sand content of the bay is 78 percent.

Atterberg Limits data collected during the 1993 and 1998 sampling activities characterized the sediments by high liquid and plastic limits. Under the Unified

Soil Classification System (USCS), the majority of the sediments were classified as high-compressibility silts (MH) while a small percentage were classified as highly plastic clays (CH).

2.2.3 Lower Fox River Bathymetry

The Lower Fox River is relatively narrow, generally less than 305 meters (1,000 feet) wide over much of its length, and ranges up to approximately 6.1 meters (20 feet) deep in some areas. Where the river widens significantly, water depths generally decrease to less than 3 meters (10 feet) and in the case of Little Lake Butte des Morts, water depths range between 0.61 and 1.53 meters (2 and 5 feet) except in the main channel. In general, however, the main channel of the river ranges from approximately 1.8 to 6.1 meters (6 to 20 feet) deep. Bathymetry information from the NOAA recreational charts (NOAA, 1992) is included on Figures 2-5 through 2-8.

The Little Lake Butte des Morts Reach is approximately 10 km (6 miles) in length and the water depth is generally less than 1.8 meters (6 feet). The main flow channel, which starts near the edge of sediment Deposit C, is approximately 2.4 meters (8 feet) deep on the south end and increases to approximately 5.8 meters (19 feet) near the outflow of the lake. Water depths outside the main channel and along the banks of the river are generally less than 1.8 meters (6 feet) deep (NOAA, 1992).

The Appleton to Little Rapids Reach is the longest reach of the river, extending approximately 32 km (20 miles). This reach meanders more than any other reach and is comprised of a series of large contiguous pools. Water depths in the main channel range between 1.8 and 3 meters (6 and 10 feet). Water depths in other areas of the reach vary from as little as 0.3 meter (1 foot) just downstream of Kaukauna to as great as 16 feet near the Rapide Croche dam. Between the Rapide Croche and Little Rapids dams, the river is generally narrow and main channel water depths are usually between 1.4 and 3.7 meters (8 and 12 feet).

The Little Rapids to De Pere Reach is approximately 10 km (6 miles) in length and the channel is relatively straight. The width is greatest at the upstream end and decreases downstream. The main channel depth is usually greater than 2.7 meters (9 feet) and increases to 5.5 meters (18 feet) approaching the De Pere dam. Along the banks of the river the water depths are generally less than 1.8 meters (6 feet).

Water depths in the De Pere to Green Bay Reach range between 1.8 and 7.3 meters (6 and 24 feet) in the main channel. This reach is approximately 11.3 km (7 miles) long and the lower 4.8 km (3 miles) of the reach are dredged by the U.S.

Army Corps of Engineers (USACE) in order to maintain a navigation channel. Prior to 1982, the navigation channel was maintained from the mouth of the river to the De Pere dam, but since 1982 this upper portion of the channel has been maintained to a depth of 1.8 meters (6 feet). Between De Pere and the Fort James-West turning basin (formerly Fort Howard), the depth of water is generally less than 1.8 meters (6 feet) outside of the navigation channel. Downstream of the Fort James-West turning basin, the river narrows so that the navigation channel almost encompasses the entire width of the river. The authorized navigation channel depth in this reach is 24 feet deep.

2.2.4 Lower Fox River Surface Water Hydrology

The slope of the bedrock and the pre-glacial bedrock valleys control drainage in the Lower Fox River valley. The Lower Fox River lies along the axis of a former bedrock valley which was filled with glacial and proglacial lake sediments. The Lower Fox River and its tributaries have flowed over and cut through these relatively flat glacial lake plain sediments.

Surface Water Flow Controls - Neenah-Menasha (Lake Winnebago)

Lake Winnebago is a highly controlled waterway with specific water level targets, depending on the season of the year. These controls influence flow in the Lower Fox River. The USACE oversees the Lake Winnebago flow controls and set specific water level targets to provide water usage for hydro power and navigation while preserving or enhancing fish, wildlife, wetland habitat, and water quality in the Lower Fox River and the Lake Winnebago pool. The local water level datum for Lake Winnebago is the Oshkosh datum.

Lake Winnebago seasonal water level targets have a range of less than 107 cm (3.5 feet) between the low (5.5 cm or 0.18 feet Oshkosh) and high (105 cm or 3.45 feet Oshkosh) water levels allowed under the plan. The water level targets are based on seasonal water level objectives. The regulation periods and objectives are briefly described below (USACE, 1998a).

Winter Drawdown. Following formation of solid ice cover in the Lake Winnebago pool, the water level is slowly lowered to the winter drawdown level of 21 cm (0.68 foot) Oshkosh. This drawdown level provides storage needed to contain spring runoff. Typically, drawdown commences at a rate designed to achieve a target level by about March 1.

Once the target drawdown level has been achieved, the stage is held constant until ice cover in the Lake Winnebago pool breaks up and starts moving out, which usually occurs in late March to early April. Following breakup of the ice, the Lake Winnebago pool is refilled. The target navigation stage, 91 cm (3.0 feet)

Oshkosh, is to be achieved by the beginning of May, typically the start of the navigation season.

Summer Navigation. During the navigation season (May to mid-October), the Lake Winnebago water level is held as close as possible to the target stage. However, since the year's lowest inflows occur during this time, it is not always possible to maintain the target level throughout the navigation season. When the navigation season ends, the water level in Lake Winnebago is decreased to approximately 61 to 76 cm (2.0 to 2.5 feet) Oshkosh by December 1. The only outflow constraint is to observe a maximum safe discharge of about 510 cubic meters per second (m^3/s) (18,000 cfs), while allowing only gradual changes in stage to minimize impacts on wildlife.

Lower Fox River Navigational Controls

There are 17 locks (Fox locks) and 12 dams located on the Lower Fox River between Lake Winnebago and the De Pere dam (Table 2-4). The Fox locks are an important aspect of navigation on the Lower Fox River. The Neenah and Menasha dams control flow out of Lake Winnebago, while the other 10 dams located between Little Lake Butte des Morts and De Pere control flow in the lower portion of the river. These dams control water levels and flow volumes throughout the river to provide a continued source of power for the hydroelectric plants associated with the dams and allow for navigation.

In 1984, the navigation portion of the Lower Fox River project was placed in "caretaker status" by the USACE. Under this status, the USACE performs minimal maintenance, and only three of the 17 navigation locks are in operational condition: the De Pere, Little Rapids, and Menasha locks. With the exception of the Rapide Croche lock (which is permanently closed to restrict the movement of sea lampreys), all the other locks would require maintenance and renovation before operational status can be restored.

The State of Wisconsin and the USACE signed a memorandum of agreement in September 2000 for the transfer of the Fox River locks from federal to state control. This agreement does not actually transfer the control or property yet, but it rather establishes the framework for the transfer to occur in the future. A number of general provisions of the agreement include the following:

- The Rapide Croche lock will be maintained as a sea lamprey barrier;
- The federal government will provide funding for the repair and rehabilitation of the land, locks, and appurtenant features prior to transfer;

- The locks and dams will be inspected to evaluate which features require immediate attention; and

- The State of Wisconsin will be responsible for the operation, maintenance, repair, replacement, and rehabilitation of the locks and appurtenant features after the transfer is complete.

Lower Fox River Surface Elevation

The Lower Fox River decreases about 48.2 meters (158 feet) between the Menasha dam and De Pere dam and approximately 51.5 meters (169 feet) between the Menasha dam and the mouth of the river. The overall gradient for the Lower Fox River is 51.5 meters (169 feet) over 63 km (39 miles) or 8.2×10^{-4} feet per foot (ft/ft). The river profile is shown on Figure 2-10.

Three areas exist where the water level elevation decline approaches or exceeds 9.1 meters (30 feet) between dams occurs largely within the Appleton to Little Rapids Reach, specifically in river stretches between the Appleton Upper and Appleton Lower dams, and between the Little Chute dam to the Rapide Croche dam. The gradients for each of these river sections is approximately an order of magnitude higher than the gradients for the remaining sections of the river. These three sections of the river contain limited soft sediment deposits because of increased flow velocities.

Measured and Estimated Stream Flow Velocities

Average stream flow velocity in each reach of the river has been estimated using discharge measurements collected from USGS gauges along the river (Table 2-5). These estimates were completed using the river cross-sections determined for the GBMBS modeling efforts (WDNR, 1995). Stream flow velocity is an important factor in evaluating areas where net sediment deposition is likely to occur. The overall Lower Fox River velocity average is just under 0.14 meters per second (m/s).

The average stream flow velocity in the Little Lake Butte des Morts Reach is just over 0.15 m/s (0.5 feet per second [ft/s]) and ranges from 0.08 to 0.35 m/s (0.26 to 1.15 ft/s). However, in Little Lake Butte des Morts proper, the average stream flow velocity is 0.13 m/s (0.42 ft/s) and ranges from 0.08 to 0.20 m/s (0.26 to 0.65 ft/s).

The average stream flow velocity in the Appleton to Little Rapids Reach is 0.24 m/s (0.78 ft/s), approximately 65 percent higher than the Little Lake Butte des Morts Reach and almost double the velocity found in Little Lake Butte des Morts proper. This reach had the greatest estimated stream flow velocities, ranging from 0.15 to 0.37 m/s (0.48 to 1.23 ft/s).

In the Little Rapids to De Pere Reach, the average stream flow velocity is 0.12 m/s (0.40 ft/s); this is approximately half of the average velocity for the Appleton to Little Rapids Reach. Flow velocities in this reach range from 0.11 to 0.13 m/s (0.37 to 0.42 ft/s), which is the smallest variation in flow velocities noted in any reach.

The De Pere to Green Bay Reach has an average stream flow velocity of 0.08 m/s (0.25 ft/s); this is the lowest found in the entire river. Due to these overall low stream flow velocities, it is not surprising that the largest volume of deposited sediment is located in this reach (Section 2.3).

Low Flow and Flood Frequencies

The flow of the Lower Fox River has been monitored by as many as six stream gauging stations operated by the United States Geological Survey (USGS). The historical river discharge information from the Rapide Croche dam station (#04084500) is presented on Table 2-6. This gauging station recorded stream flow and discharge between October 1917 and September 1997. The water year (WY) extends from October 1 through September 30 of the following year.

The Rapide Croche results show that daily discharge volumes ranged from a low of 4 m^3/s (138 cfs) to a maximum of 680 m^3/s (24,000 cfs). According to the monthly results, following winter snowmelt and the generally heavy spring rains, April has the highest discharge volumes, while the late summer months of August and September generally have the lowest flows. These results are similar to the other Lower Fox River gauges. In addition, the results indicate that only 4 months, March through June, have average daily discharge volumes exceeding the annual average of 122 m^3/s (4,300 cfs). Based on the 7-day average low stream flow with a 10-year frequency ($Q_{7,10}$), the low-flow value is 26.9 m^3/s (950 cfs).

A similar flood frequency evaluation at the Rapide Croche gauging station was completed by USGS (Krug *et al.*, 1992). The results indicated that the 10-year flood discharge is 544 m^3/s (19,200 cfs) while the 100-year flood flow is over 685 m^3/s (24,200 cfs). These volumes are five to six times greater than the average discharge of 122 m^3/s (4,300 cfs).

The Federal Emergency Management Agency (FEMA) mapped the 100-year flood elevation at the mouth of the Lower Fox River at 178.31 meters (585 feet) IGLD 1985 (FEMA, 1984). This is approximately 1.82 meters (6 feet) higher than the long-term average elevation of 176.485 meters (579.02 feet) IGLD 1985.

However, FEMA (1984) did not indicate what the flow rate was for this 100-year flood event (National Flood Insurance Program, 1984).

2.2.5 Green Bay Bathymetry

The bathymetry in Green Bay is controlled by its geologic history. Based on the eastern dip of the bedrock units along its lengthwise axis and the glacial scouring of the basin, the bay gently slopes to mid-bay moving from west to east. Eastward of this mid-bay, the bottom is a relatively flat sediment plain that rises abruptly near the east shore. Within this framework, the bathymetry for each Green Bay zone has unique characteristics. The bathymetry for the De Pere to Green Bay Reach (Zone 1) has been described above. The bathymetry of Zone 2 is more complicated than the bathymetry of either Zone 3 or Zone 4, due to the numerous shallow areas located within Zone 2. Zones 3 and 4 generally represent a large, relatively deep body of water which only have areas with depths less than 9 meters (30 feet) located along the shoreline (Figure 2-9).

The bathymetry of Zone 2 is generally shallow, with all water depths less than 8 meters (26.5 feet). From the mouth of the Lower Fox River to a line connecting Long Tail Point/Point Sable (the Lower Green Bay AOC), water depths range from 0.3 to 3.4 meters (1 to 11 feet), excluding the navigation channel (Figure 2-9). Water depths at the very southern end of Green Bay are extremely shallow and generally less than 1.5 meters (5 feet). The navigation channel lies almost entirely within Zone 2. The navigation channel extends approximately 18.8 km (11.7 miles), from the mouth of the Lower Fox River to a line from Dyckesville (on the east shore). The depth of the navigation channel is maintained between 6.25 and 7.16 meters (20.5 and 23.5 feet), while water depths in Zone 2 are generally less than 3.7 meters (12 feet) over much of this area.

There are a number of spits, shoals, and other shallows located in Green Bay that are prominent physical features of the bathymetry. Many of the shoals/shallows are associated with the tributaries, predominantly located along the west side of the bay. In Zone 2, these shallow areas are expressed as the island chains and points extending from the west shore out into the bay. Long Tail Point is located just south of the Suamico River mouth while Little Tail Point is located just south the Little Suamico River (Figure 2-9).

The depth of water in Zone 3 is generally greater than 10 meters (30 feet). Water depths in Zone 3 range from about 12.5 meters (41 feet) at the boundary between Zones 2 and 3 to 33.5 meters (110 feet) just west of Chambers Island, near the boundary between zones 3 and 4. The deepest part of Zone 3 is located just southeast of Green Island where water depths of 34.4 meters (113 feet) have been measured.

Large portions of Zone 4, from Chambers Island to just south of Big and Little Bays de Noc, have water depths exceeding 9.1 meters (30 feet). However, in the vicinity of Big and Little Bays de Noc, the water depths decrease and shallow areas with water depths less than 9.1 meters (30 feet) are predominant. Similar to Zone 3, the depth gradient on the east side of the bay is up to one order of magnitude greater than the gradient on the west side of the bay. The deepest point in the bay is 53 meters (176 feet) deep, located about 6.4 km (4 miles) west of Washington Island.

Green Bay-Lake Michigan Passages

The four main passages connecting Green Bay with Lake Michigan are: 1) Porte des Morts Passage; 2) Rock Island Passage; 3) St. Martin Island Passage; and 4) Poverty Island Passage. The Porte des Morts Passage is approximately 2.3 km (1.4 miles) wide and water depths in the passage range as deep as 39.3 meters (129 feet). The Rock Island Passage is approximately 3.9 km (2.4 miles) wide and water depths range as deep as 46.6 meters (153 feet). The passage is narrow due to the presence of the St. Martin Island Shoal, which extends south of St. Martin Island. The St. Martin Island Passage is located between St. Martin Island and a number of small islands and shallows, including Gull, Little Gull, and Gravelly islands, as well as the Gravelly Island Shoals (Gull/Gravelly Island complex). This passage is only approximately 2 km (1.2 miles) wide and water depths range as high as 36.3 meters (119 feet). Finally, Poverty Island Passage is located between the Gull/Gravelly Island complex and Poverty Island. This passage is approximately 3.4 km (2.1 miles) wide and water depths range up to 26.5 meters (87 feet). No significant waterway passage is located north of Poverty Island.

2.2.6 Green Bay Surface Water Hydrology

Green Bay Water Level Elevations

Green Bay water level elevations are controlled by and related to the water level in the Lake Michigan-Huron basin. These two lakes are connected through the Straits of Mackinac and are treated as a single lake basin. Water levels within the Great Lakes are measured according to the International Great Lakes Datum (IGLD 1985) which has its zero reference elevation point located at Rimouski, Quebec, Canada.

The overall annual long-term average (LTA) elevation for the Lake Michigan-Huron basin is 176.49 meters (579.02 feet) IGLD 1985 (USACE, 1996). The monthly LTA elevation ranges from a low of 176.34 meters (578.54 feet) IGLD 1985 in February to a high of 176.64 meters (579.53 feet) IGLD 1985 in July (USACE, 1998b). Historically, the lowest and highest monthly water elevation levels were recorded in March 1964 and October 1986, and the basin has an overall range of approximately 1.92 meters (6.3 feet).

Water levels within the Great Lakes are currently dropping. Between March 1999 and February 2000, only 68 percent of the normal annual precipitation fell in the Lake Michigan-Huron basin. In addition, snowmelt runoff is responsible for about 40 percent of the annual water supply into the Great Lakes. In March 2000, the snow-water equivalent was less than 10 cm (4 inches) throughout Michigan and Wisconsin. In addition to less snowfall, the warmer winters of 1998, 1999, and 2000 have reduced ice cover over the lakes and increased evaporation. Combined, these factors have contributed to lake levels which are approaching the record low for the Lake Michigan-Huron basin (USACE, 2000b).

Green Bay Water Circulation, Currents, and Mixing Patterns

Green Bay has complex water currents and circulation patterns. However, there is an overall general counterclockwise movement of water in the bay. Water from Lake Michigan moves into the bay and south along the west shore. Water from the Fox River is generally transported north along the east shore of the bay, carrying suspended sediment as well as contaminants in dissolved and particulate phases. In addition, the inner bay and outer bay each have their own general counterclockwise currents (or gyres), which are affected by the presence of spits and shoals on the west side of the bay.

HydroQual, Inc. completed modeling analysis of current patterns in Green Bay using 1989/90 GBMBS data. A 3-dimensional circulation model calculated the monthly mean surface and bottom circulation patterns for August 1989. Based on modeling results, it was estimated that monthly average residual currents exceeding 5.0 cm/s were common in most of the bay during August 1989 (Blumberg *et al.*, 2000).

Water circulation in Green Bay is controlled by a number of different factors: 1) surface water elevation changes induced by wind and barometric pressure; 2) wind speed and direction; 3) river discharge; 4) upwelling of the thermocline in Lake Michigan; 5) thermal and density gradients between the bay and Lake Michigan; 6) ice cover and; and 7) the Coriolis effect.

Long-term averaging of Green Bay currents reveals steady, residual circulation patterns responsible for the net mass transport of suspended solids. The monthly averaging of currents shows a relatively consistent circulation pattern, with the magnitude of the currents varying from month to month. Figures 2-12 and 2-13 show the formation of several gyres in the bay, resulting in a complex residual circulation pattern in Green Bay. This circulation pattern affects mixing, flushing, and mass transport.

The formation of so many small-scale gyres, in both the inner and outer bays, causes localized entrapment of water masses and associated constituents. Due to the localized gyres, the flushing time for Green Bay is estimated to be on the order of 1,000 days. Estimated flushing times for the inner portion of Green Bay are much lower than for the entire bay. The areas within 10 and 25 km of the mouth of the Lower Fox River flush in about 25 and 100 days, respectively (Mortimer, 1978).

Lower Fox River Discharge into Green Bay

The USGS acoustic velocity meter (AVM) located at the mouth of the Lower Fox River records the river discharge into Green Bay. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments (WDNR, 1999a; Smith *et al.*, 1988). The average discharge is 122 m^3/s (4,300 cfs). However, water levels in the bay cyclically rise higher than levels in the river and flow is reversed, affecting the De Pere to Green Bay Reach of the river. This reversal in flow is due to wind-induced increases in water levels (seiche effect) and a small lunar tide. A seiche is produced when northeast winds push water to the south end of the bay. Water levels in this end of the bay can increase as much as 0.9 meter (3 feet), although the fluctuation often ranges between 0.15 and 0.3 meter (0.5 and 1 foot). The seiche occurs daily and, as evidenced by the AVM data, results in reversed stream flows in the lower reach of the river. The flow reversal can be significant, with recorded velocities exceeding 92 m^3/s (3,250 cfs) on a daily basis and even greater flow reversal recorded for individual storm events. The seiche also produces a counterclockwise flow in Green Bay, which facilitates mixing of the river and bay water nutrient loads.

Lower Fox River Plume Studies

Water entering Green Bay from the Lower Fox River is typically warmer and more sediment-laden than the rest of the bay water, thus allowing the Lower Fox River plume to be tracked within the bay. Studies conducted since the late 1960s of the Lower Fox River plume show that river water moves up the east shore of the bay. The plume has been observed and detected up to 40 km (25 miles) from the mouth of the river (Gottlieb *et al.*, 1990).

The Lower Fox River plume was also discernible in the water column by higher chloride and higher conductivity measurements. A plume with higher chloride and conductivity concentrations extended from the river mouth along the east shore of the bay for a distance of approximately 42 km (26 miles), which is consistent with other observations. A plume of lower-conductivity water was also detected along the western shore of the inner bay and was ascertained to be outer bay or Lake Michigan water moving south along the western shore.

The plume studies show that Long Tail Point, which begins about 6 km (3.7 miles) north of the river mouth on the western side of the bay, forms a mixing barrier in the southernmost portion of Green Bay. This barrier allows Lower Fox River water to move farther up the bay before becoming thoroughly mixed with other water. The August 1989 surface and bottom water currents (Figures 2-11 and 2-12) indicate that northward flow occurs immediately adjacent to the east shore of the bay, from the mouth of the river to about the location of Little Sturgeon Bay. North of Little Sturgeon Bay, the flow patterns become much more varied and complicated (Lathrop *et al.*, 1990).

Inner Bay/Outer Bay Mixing Studies

Chambers Island is the boundary between inner and outer Green Bay. Flow around Chambers Island is an important aspect of circulation in Green Bay. Previous studies have found that net flow is from the inner to outer bay and that most of the flow from the inner to outer bay occurs along the eastern side of Chambers Island.

Currents. Water flow around Chambers Island is more complex than a simple counterclockwise motion. During the summer months, the colder, deeper water tends to flow south into the inner bay on the west of Chambers Island, and the shallow, warmer water layer flows north out of the inner bay on both the west and east sides. These results are shown on Figures 2-11 and 2-12. During the summer, surface currents are stronger east of the Oconto River, with two clockwise gyres between the Oconto and Menominee Rivers. These gyres merge along the northern shore, downstream of the Peshtigo River and the combined surface currents are then directed northeast towards Washington Island (Blumberg *et al.*, 2000). Around Chambers Island, surface currents are clockwise northwest of the island and counterclockwise southeast of the island (Figure 2-12). In addition, the formation of many small-scale gyres causes localized entrapment of water masses and their constituents, implying that the mass crossing the Chambers Island transect is not directly transported to the mouth of Green Bay and into Lake Michigan (Miller and Saylor, 1993).

During the winter, water tends to flow north out of the inner bay on the east side of the island and the eastern half of the western passage. These flow patterns result in a lesser, separate counterclockwise flow pattern in both the inner and outer bay.

Water Exchange. Water exchange between the inner and outer bays has a net outward flow of approximately 130 m^3/s (4,591 cfs). Current velocities were greatest east of Chambers Island, sometimes ranging as high as 0.35 m/s (1.1 ft/s). West of Chambers Island, the velocities typically range from 0.12 to 0.24 m/s (0.4 to 0.8 ft/s). Current velocities in the inner bay typically range up to 0.12 m/s (0.4 ft/s) (Miller and Saylor, 1993).

Sediment Transport. Approximately 17,500 metric tons (MT) (19,290 tons) of sediment were transported from the inner bay to the outer bay, generally along the east side of Chambers Island, between May and October 1989. Approximately 19,900 MT (21,940 tons) of sediment were transported from the outer bay to the inner bay along the west side of Chambers Island (Hawley and Niester, 1993). Therefore, there was a net increase of approximately 2,400 MT (2,650 tons) of sediment transported into the inner bay. However, as bay sediments are often subjected to a repeating cycling of suspension-transport-deposition, movement of sediment between the inner and outer bays may occur a number of times before sediment is ultimately transported further north into the bay and Lake Michigan.

Green Bay/Lake Michigan Mixing Studies

The exchange of water between Green Bay and Lake Michigan is highly variable and complex. The four main channels connecting Green Bay and Lake Michigan are: Poverty Passage, Porte des Morts Passage, Rock Island Passage, and St. Martin Island Passage, and are described in the Green Bay bathymetry section.

Large volumes of water consistently move between the bay and the lake through the Porte des Morts and Rock Island passages. Currents measured in the passages connecting Green Bay with Lake Michigan typically ranged from 0.12 to 0.30 m/s (0.4 to 1.0 ft/s). The estimated flow into the bay is approximately 3,300 m^3/s (116,540 cfs or 871,000 gallons per second). In 1992, the estimated water volume exchange between the bay and the lake was about 3,500 m^3/s (123,600 cfs).

Warm water leaves the bay in the upper portion of the water column while cold water enters the bay in the lower part of the water column (Figures 2-11 and 2-12). August 1989 modeling results suggest that warm surface water (epilimnetic) flow from Green Bay to Lake Michigan was about 3,000 m^3/s (105,940 cfs), while cold bottom water (hypolimnetic) flow to the bay was about 2,870 m^3/s (101,350 cfs). This resulted in a net outflow of about 130 m^3/s (4,590 cfs) from the bay. These results indicate that the exchange of water between Green Bay and Lake Michigan is much greater than any other source of water into or out of the bay (Miller and Saylor, 1985; Blumberg *et al.*, 2000).

The estimated precipitation input to the bay is 105 m^3/s, tributary input is 336 m^3/s, and evaporation loss is 87 m^3/s. These values are all at least an order of magnitude less than the estimated exchange between Green Bay and Lake Michigan.

2.2.7 Green Bay and Lower Fox River Ice Cover

The Port of Green Bay is closed to shipping from January 1 through March 31 due to ice cover (Haen, 2000). Although the port is officially closed for this 3-month period, ice cover in the bay is usually present from early to mid-December through mid- to late April (Gottlieb *et al.*, 1990).

Ice cover in Green Bay initially occurs over the shallowest water areas of the inner bay as well as both Bays de Noc. Ice typically begins forming loose, open pack-ice floes in these areas in early to mid-December, as temperatures usually range from -10 to -4 degrees centigrade (˚C) (14 to 24 degrees Fahrenheit [˚F]). During December, the ice slowly consolidates from loose pack to a solid ice sheet covering the shallowest areas and slowly expanding. During January, which has the coldest average temperatures, ice cover within the bay usually ranges from 95 to 100 percent. Depending upon seasonal conditions, open-water areas usually form in the outer bay in late January and February. This occurs first in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay (due to the counterclockwise currents) because Lake Michigan water is generally about 1 to 2 ˚C warmer than water within Green Bay. Additionally, water from the Green Bay tributaries is generally the coldest water within the bay, due to the fact that the formation of frazil ice within the river can cool water temperatures below 0 ˚C (32 ˚F).

Frazil ice is composed of small ice crystals that form in turbulent water. Due to the water movement, the ice crystals flow within the water and act to super-cool the water to temperatures below 0 ˚C (32 ˚F). The ice does not solidify until the water movement slows or until the water comes in contact with solid objects that slow the current velocity. Therefore, frazil ice can cause difficulties with intake structures and pier/dock structures located along the rivers or bay, where it is present. Additionally, as the water flows from the rivers into the bay, current velocities decrease and ice forms rapidly.

Ice thickness in the Lower Fox River averages 12 to 24 inches thick from year to year and may occasionally measure greater than 36 inches thick (Paulson, 2000; Boronow, 2000). Many areas of the lower reaches and near dams/drops remain open with flowing water year-round. The pools above the dams usually freeze over solid (Boronow, 2000). Flowing water and temperature influence ice thickness from year to year in addition to snowfall, rainfall, and snowpack conditions.

In either late January or February, open-water areas usually form in the outer bay, especially in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay. This occurs because Lake Michigan water is generally about 1 to 2 °C warmer than water within Green Bay and it reflects the influences of the generally counterclockwise currents.

2.2.8 Total Organic Carbon

Total organic carbon (TOC) affects the bioavailability and toxicity of some substances and influences the composition and abundance of benthic communities. Some chemicals (particularly low-solubility organic compounds) strongly adsorb onto organic coatings over the surfaces of inorganic particles. As a result, sediment with high TOC content tends to accumulate higher concentrations of organic compounds than sediment with lower TOC content. TOC was analyzed in over 1,600 sediment samples from the Lower Fox River, Green Bay, and select tributaries to assist in the interpretation of the sediment organics data. TOC concentrations in sediments are extremely variable.

Average TOC value in Lake Winnebago is 7.8 percent (78,000 milligrams per kilogram [mg/kg]), suggesting that significant background TOC levels are present within the system. Moving downstream, the TOC average in each reach shows a general decline. The river-wide TOC average is 4.91 percent. The average TOC concentrations in Green Bay range from 0.14 to 2.33 percent. In comparison, the Lake Michigan TOC average is 0.35 percent.

2.2.9 Other Physical Parameters

Percent solid results indicate that solids generally comprise approximately 40 percent of the sediment samples analyzed. The average values for all three of the reaches upstream of the De Pere dam range from 37 to 42 percent. However, individual values have a much greater range; between 18.1 and 88.2 percent. The results indicate that the nature of the material changes significantly throughout each river reach and individual deposits may require additional characterization prior to implementation of selected remedial alternatives. The average result in Green Bay is 44 percent; similar to the river. However, in Green Bay Zone 4, the average solid result is approximately 70 percent, indicating that sediments in this portion of the bay are much more likely to consist of coarse-grained sands rather than fine-grained silt/clay.

The average dry bulk density results range from 0.31 to 1.18 grams per cubic centimeter (g/cm^3). The average results for each reach range between 0.51 and

0.66 g/cm^3, while the river-wide average is 0.55 g/cm^3. These results are lower than the average dry bulk density for soils of 1.3 to 1.35 g/cm^3.

Wet bulk density and specific gravity results are available for only a few deposits/SMUs. Wet bulk density results give an indication of how much the mass of the material will change once sediments are removed from the river (e.g., during remedial efforts). The wet bulk density results ranged from 1.15 to 1.23 g/cm^3 with an average of 1.17 g/cm^3. The moisture content was also calculated as part of the bulk density determinations and the water content (mass) generally comprises approximately 50 to 75 percent of the sediment sample mass. Specific gravity results ranged from 2.32 to 2.59, with an average value of 2.46.

2.2.10 River and Bay Sediment Dredging

Due to the expansive areas of sediments that have accumulated downstream of the De Pere dam and out into the southern end of Green Bay, the USACE periodically dredges the navigation channel. The original navigation channel extends from Lake Winnebago out into Green Bay approximately 18.8 km (11.7 miles). However, the USACE currently only dredges and maintains the navigation channel in Green Bay and as far upstream as the Fort James turning basin, which is located approximately 5.5 km (3.4 miles) upstream of the mouth of the river. The remaining portions of the navigation channel, along with the lock and dam system, have been placed in a caretaker status.

The only dredging records available for the Lower Fox River (above the De Pere dam) since 1957 indicate that approximately 9,900 m^3 (12,950 cubic yards [cy]) were dredged from the Menasha Channel and Neenah Harbor in 1965 and 1968, respectively.

USACE records below the De Pere dam and for Green Bay indicate that over 12.1 million m^3 (15.9 million cy) have been dredged from the navigation channel since 1957. According to the dredging records, on average, approximately 282,350 m^3 (369,300 cy) of sediment are removed from the channel annually. Between 1957 and 1965, approximately 2.8 million m^3 (3.7 million cy) of sediment were disposed of at open-water locations. The primary open-water sediment disposal areas were located in the vicinity of the former Cat Island Chain and on the north side of the shoal extending from Point Au Sable to Frying Pan Island (Figure 2-9). The Bay Port CDF was opened in 1965 and has served as the primary disposal facility for navigation channel sediments. Almost 7.3 million m^3 (9.4 million cy) have been placed in the Bay Port CDF and, according to Dean Haen (Haen, 2000), the facility still has capacity for another 1.5 million m^3 (2 million cy) of sediment. The Kidney (Renard) Island CDF opened in 1979 and received over 2 million m^3 (2.7 million cy) of sediment. The last year this CDF received sediments was 1996. Since its closure, the CDF has a navigation channel depth of 20.5 to 23.5 feet.

2.3 Soft Sediment Thickness

The soft sediment thickness of river sediments is generally from 1 to 2 meters thick (3 to 6.5 feet) while some of the larger deposits can range up to 3.28 meters (10.76 feet) thickness (Table 2-1). The thickest deposits are located in the De Pere to Green Bay Reach, with sediment thickness ranging up to 5.8 meters (19 feet) near the turning basin (Montgomery-Watson, 1998).

2.3.1 Calculation of Thickness

During the early portion of the 1989/1990 sampling efforts, sediment thickness was measured to a maximum depth of 1.06 meters (3.5 feet). Greater sediment thicknesses were subsequently noted in some deposits from later studies and these results are included in the database. The maximum depths from which PCB samples were collected in each deposit/SMU group, as well as in each bay zone, are listed in Table 2-7. If these depths were greater than 1.06 meters (3.5 feet), then the maximum sediment thickness of these deposits was changed to match the PCB sampling depth. In some areas, no sediment thickness data was collected because either: 1) PCBs were not detected in these areas, or 2) results of poling data showed no soft sediment was present. Sediment thickness contours were primarily dependent on Option 1.

2.3.2 Mapping the Occurrence of Sediment

Interpolated grids were developed for the presence or absence of sediment in the Lower Fox River and Green Bay. Sediment occurrence grids, also called sediment thickness contour maps, for the Lower Fox River were developed from field measurement of sediment thickness (Figures 2-5 through 2-8). The occurrence of sediment was interpolated separately for all nine depth layers on the Lower Fox River. If the thickness at a sampling location was less than half the layer thickness, then the area was designated as not containing sediment. Using this approach, sediment was also absent in deeper layers because the sample depth did not extend to the modeled depth (e.g., if a sample was collected from 0 to 50 cm, then the interpolation results indicate that there is no sediment in the 50- to 100-cm layer).

For Green Bay, the occurrence-of-sediment grid was developed from the GBMBS using a 5,000-meter (16,400-foot) by 5,000-meter (16,400-foot) grid. Based on sampling results, each grid cell was determined to be either soft sediments or glacial till (no soft sediments present). Grid cells that were not sampled were assigned to either the soft sediment or glacial till categories based on professional judgement, which included consideration of adjacent cells where sampling occurred and the depositional environment. For instance, areas near the mouth of the Lower Fox River that were not sampled were considered to contain soft sediment, as this is a depositional zone for sediments from the river. The 5,000-meter (16,400-foot) grid was translated into a 100-meter (328-foot) grid to match the sediment interpolation grids and allow a direct overlaying of the different grids.

2.4 Nature and Extent of Chemicals of Concern

The Screening Level Risk Assessment (SLRA) identified chemicals of potential concern (COPCs) in the Lower Fox River and Green Bay which included: PCBs, dioxins/furans, DDT (and its metabolites), dieldrin, arsenic, lead, and mercury (RETEC, 1998). The Baseline Risk Assessment (BLRA) concluded that the chemicals of concern (COCs) were PCBs, mercury, and DDE (RETEC, 2002b). The COCs represent potential risks to human and ecological receptors as described in Section 3. Although PCBs are the primary focus of the FS, all three compounds (PCBs, mercury, DDE) are carried forward in the FS.

2.4.1 Historical Sources of Chemicals of Concern in the Lower Fox River

Polychlorinated Biphenyls (PCBs)

From the early 1950s through early 1970s, the manufacture of carbonless copy paper used a PCB emulsion. In 1954, Fox River valley paper mills began manufacturing carbonless copy paper and PCBs were released to the environment through manufacture, de-inking, and recycling of carbonless paper. Aroclor 1242 was the PCB mixture used in the manufacture of carbonless copy paper and approximately 45 million pounds of this emulsion were reportedly used in the Lower Fox River valley between about 1954 and 1971. The use of PCBs was unregulated and their potential health effects were unknown during this time period.

The use of PCBs in carbonless paper manufacturing ceased in 1971. WDNR (1999a) estimated that approximately 313,600 kg (691,370 pounds) of PCBs were released to the environment during this time, although the discharge estimates range from 126,450 to 399,450 kg (278,775 to 880,640 pounds) based on the percentages of PCBs lost during production or recycling of carbonless copy paper. Further, WDNR (1999a) estimated that 98 percent of the total PCBs released into the Lower Fox River had occurred by the end of 1971. In addition, WDNR (1999a) indicated that five facilities, including the Appleton Papers-Coating Mill, P. H. Glatfelter Company and associated Arrowhead Landfill, Fort James-Green Bay West Mill (formerly Fort Howard), Wisconsin Tissue, and Appleton Papers-Locks Mill, contributed over 99 percent of the total

PCBs discharged to the river. A portion of these PCBs settled into river sediments.

The companies discussed above have been named as potentially responsible parties (PRPs) under the CERCLA statute. Fort James Corporation, P. H. Glatfelter, Riverside Paper Company, U.S. Paper Mills Corporation, and Wisconsin Paper Mills, Inc. were identified as PRPs by the U.S. Fish and Wildlife Service in 1994, and NCR Corporation and Appleton Papers, Inc. in 1996. This group calls itself the Fox River Group (FRG).

Point source discharges of the COPCs have decreased significantly since implementation of the Clean Water Act and other environmental regulations in the early 1970s. As a result, input of PCBs into the Lower Fox River from regulated discharges is essentially eliminated. However, residual sources for PCBs and other detected compounds remain in the river sediments, which continue to affect water quality, fish, wildlife, and potentially humans. PCBs have also been detected in many fish and bird species in the Lower Fox River and Green Bay. Due to the continued elevated levels of PCBs present within the Lower Fox River and Green Bay, WDNR issued consumption advisories in 1977 and 1987 for fish and waterfowl, respectively; Michigan issued fish consumption advisories for Green Bay in 1977. Most of these advisories are still in place.

Sediments are the most significant source of PCBs entering the water column and over 95 percent of the PCB load into Green Bay is derived from the Lower Fox River. PCBs from sediment deposits are discharged into Green Bay at the mouth of the Lower Fox River through sediment transport and PCB dissolution in the water column. Up to 280 kg (620 pounds) of PCBs were transported from the Lower Fox River into Green Bay during a 1-year period in 1989–1990. Approximately 122 kg (270 pounds) of PCBs are transported from Green Bay to Lake Michigan annually. Based on the data included in the Fox River database, the estimated mass of PCBs in sediments of the Lower Fox River and Green Bay is approximately 100,000 kg (220,000 pounds).

Mercury and DDE

Sediments from upstream of the Kaukauna dam to Green Bay contain elevated mercury concentrations. Elevated mercury levels in Lower Fox River sediments are attributed to mercuric slimicides (phenyl mercuric acetate) used in paper manufacturing. This practice was discontinued in 1971. Studies completed in the 1990s indicate that mercury concentrations remain elevated more than 20 years after mercury use was discontinued (WDNR, 1996).

Few identifiable point sources exist for the other compounds of potential concern in the Lower Fox River. The pesticides DDT and dieldrin once had widespread use in agriculture, but there is no point source associated with these compounds. However, DDE in sediments below the De Pere dam and Green Bay are of risk to fish and birds. Similarly, the metals lead and arsenic, even now, have widespread uses and are not associated with any specific point sources.

2.4.2 PCB Distribution in Sediments

This section discusses: 1) data interpolation methods for determining PCB spatial distributions, 2) occurrence of sediment, 3) PCB sediment volume and mass distribution, and 4) riverbed maps showing the occurrence of PCBs in the sediments of the Lower Fox River and Green Bay. These bed maps were prepared from surface and subsurface sediment profile data contained within the Fox River database (FRDB) and originating at specific points along the river and in the bay. Specific details of the bed mapping procedure may be found in the Remedial Investigation Report (RETEC, 2002a). The distribution of PCBs in sediments within each river reach and zone of Green Bay are illustrated on Plates 2-1 through 2-5.

Data Interpolation for the Lower Fox River

In order to view the spatial distribution of PCBs across the study area, a methodology was developed to predict, or interpolate, sediment concentrations between known data collection points. An interpolation grid was necessary to resolve discrepancies between samples with different detection limits, depth intervals, and sample collection and compositing methods from numerous studies conducted over a 10-year period. From the interpolated PCB concentration points, a map of the overall concentrations as sediment isopleths was produced. The methodology for mapping property distributions was developed jointly by WDNR and the Fox River Group. Sediment bed properties and bed mapping are further discussed in the RI Report.

The interpolations for the Lower Fox River are based on the results included in the FRDB as of March 1, 2000, consisting of about 900 sample results and locations in the Lower Fox River from nine studies conducted between 1989 and 1999. The 1999 data set included post-dredge sampling data from the Deposit N sediment removal demonstration project.

Data for the Lower Fox River were first screened to remove older data that were geographically too close to locations with newer data. Sediment data for the Lower Fox River has been collected in various studies since 1989. In order to use the most recent data available, the data were assigned to three different time periods: 1989 through 1992, 1993 through 1995, and 1996 through 1998. All of the data from the period 1996 through 1998 were used in the interpolation. A relationship was developed between similar ranges of PCB concentrations and the distances between data points in each range. From this analysis, a distance of less than 133 meters (436 feet) was determined to indicate that an older sample location was too close to a newer sample location. In this case, the older data were not used in the interpolations. This analysis was conducted first on the 1993 through 1996 data set to create a new data set for the 1993 through 1998 period. The analysis was then repeated using the 1989 through 1992 data set. In this way, the entire data set from 1989 through 1998 was used, but older data were superceded by newer data.

The interpolation used the revised 1989 through 1998 data set. The entire area of the Lower Fox River was superimposed with a square grid containing cells 10 meters by 10 meters. The screened data were used to interpolate the parameter value at each grid point.

Interpolations used the inverse distance method, whereby grid point values were more strongly affected by the sampling location(s) closest to the grid point. The inverse distance method gives more weight to closer points by using an inverse distance to the fifth power, meaning that points farther away have significantly less effect on the interpolated value at a point. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes 32 times more to the interpolation than does the second point.

In addition to inverse weighting, a maximum set distance was selected for which data points may influence grid point results. Erroneous interpolations can occur if data are extrapolated over excessive distances. To prevent this condition, grid point values were computed using data within a certain distance or radius of the grid point location. Data points located further from the grid point than the established radius were not used in the interpolation. If there were no data points within the interpolation radius of a grid point, then no value was interpolated for that grid point.

The interpolation radius for computing sediment thickness was set at 100 meters. For all other parameters, the interpolation radius varied among the river reaches. In the Little Lake Butte des Morts Reach, complete coverage of the river required that a radius of 400 meters (1,312 feet). For the Appleton to Little Rapids Reach, the river is more narrow and linear. For this reach, the interpolation radius was computed as one-third of the average river width, or 79 meters (259 feet), to minimize the influence of separate deposits on the interpolation. The Little Rapids to De Pere and De Pere to Green Bay reaches used an interpolation radius of 1,000 meters (3,280 feet), as specified in Technical Memorandum 2e and Technical Memorandum 2e Addendum (WDNR, 1999b, 2001).

Data interpolations for the Fox River were conducted for nine different layers of sediment depth: 0 to 10, 10 to 30, 30 to 50, 50 to 100, 100 to 150, 150 to 200, 200 to 250, 250 to 300, and greater than 350 cm. These sediment depths were selected based on previous and current modeling efforts as well as being defined by WDNR (1999b).

Data Interpolation for Green Bay

Interpolation of sediment data from Green Bay followed the same methods as used in the Lower Fox River. The data set for the Green Bay interpolations included approximately 240 sample results and locations from 3 studies conducted between 1989 and 1998.

For the interpolation, Green Bay was divided into a square grid with 100 meters between points. The same inverse distance approach was used on both the Lower Fox River and Green Bay, but the analysis on Green Bay used the distance squared rather than distance raised to the fifth power. Therefore, interpolated results in Green Bay were more affected by data points farther way from the grid point than in the Lower Fox River interpolation. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes four times more to the interpolation than does the second point.

The maximum interpolation radius for Green Bay was set at 8,000 meters (26,250 feet). This means that data points more than 8,000 meters (26,250 feet) from a grid point were not used in the interpolation for that grid point. Conversely, grid points more than 8,000 meters (26,250 feet) from any data point have no interpolated value, and this is evidenced by the lack of data in some areas of the bay, particularly along the west shore of Zone 3A and in Zone 4.

Green Bay data were integrated for four different layers of sediment depth: 0 to 2, 2 to 10, 10 to 30, and greater than 30 cm. In addition to these four sediment layers, a composite sediment layer was developed for a thickness of 0 to 10 cm. This layer was computed as a thickness-weighted average of the 0- to 2- and 2- to 10-cm layers. The 0- to 10-cm composite layer was developed for use in the RA and food web modeling. The other two layers were selected to coincide with layering developed for the river.

Occurrence of Sediment

The occurrence-of-sediment grids were used to edit the PCB concentration grids. This was necessary because the PCB interpolation could not identify areas where sediment was absent. Without an overlay of sediment thickness, PCB concentrations could be interpolated into areas that do not contain sediment. By using the occurrence-of-sediment grids, the PCB interpolation was restricted to those areas where sediments are present.

PCB Sediment Volume and Mass Distribution

The interpolated grids provided a means of computing the volume of contaminated sediment and the mass of PCB in the Lower Fox River and Green Bay (Tables 2-1 and 2-2). Each grid point represents a grid cell with an area 10 meters (33 feet) by 10 meters (33 feet) in the Lower Fox River and an area 100 meters (330 feet) by 100 meters (330 feet) in Green Bay. The sediment volume at each grid cell in a layer was computed as the area of grid cell multiplied by the layer thickness. The volume within a layer above some PCB concentration was estimated by summing the number of grid points above the PCB concentration and multiplying by the area of a grid cell and the thickness of the layer. The grid points were also counted within a river reach, deposit/SMU area, or Green Bay zone to determine the volume of contaminated sediment within an area of the river or bay. The estimated volume of sediments with PCBs will be discussed for each reach or zone below.

Mass calculations were computed in a manner similar to the volume calculation. The mass was computed by multiplying the sediment volume by the bulk density and the PCB concentration at a grid cell. Summing the mass over the grid cells within a reach, deposit/SMU, or zone yielded the mass of PCB within that area of the river or bay. The estimated mass of PCBs will be discussed for each reach or zone below.

PCB Bed Maps

Maps showing the distribution of PCBs in sediment were constructed directly from the interpolated grids using GIS ArcView and Spatial Analyst. The methods used to produce these maps were the same as those outlined in Technical Memorandum 2e, the Addendum to Technical Memorandum 2e, and Technical Memorandum 2f (WDNR, 1999b, 2001, 2000b, respectively). The interpolated grid was displayed and color contoured into different ranges based on PCB concentration. Areas where sediment is absent were not included in the color contouring. Similarly, areas outside the interpolation radius were not included in the color contouring. The concentration intervals selected for the bed maps were based upon a combination of observed concentration ranges, cleanup level evaluations, the 50 ppb PCB detection limit, variability of data collection, and criteria for bed mapping. The total PCB concentration ranges and mapping intervals used for the Lower Fox River and Green Bay (in micrograms per kilogram [μg/kg]) are:

- 0 to 50,
- 50 to 125,
- 125 to 250,
- 250 to 500,
- 500 to 1,000,
- 1,000 to 5,000,
- 5,000 to 10,000,
- 10,000 to 50,000,
- Greater than 50,000 (Lower Fox River), and
- Greater than 5,000 (Green Bay).

Sediment bed maps for total PCBs are shown on Plates 2-1 through 2-5, and are discussed below.

2.4.3 Extent of PCB Chemical Impacts

Approximately 96,800 kg (213,400 pounds) of PCB in the Lower Fox River and Green Bay system are distributed in about 474 million m^3 (620 million cy). Review of the PCB mass and contaminated sediment volume herein considers sediments which contain more than 50 μg/kg PCB. The results are summarized below and indicate that the De Pere to Green Bay Reach and Green Bay Zone 2, combined, contain almost 60 percent of the total PCB mass in the system in less than 10 percent of the total contaminated sediment volume. The PCB mass and volume of contaminated sediment for each river reach and bay zone are listed in Table 2-7.

As shown in Table 2-7, over 96 percent of the total PCB mass within the Lower Fox River and Green Bay is located between the De Pere dam and the northern boundary of Zone 3, which is bounded by Chambers Island. The magnitude and extent of PCB-impacted sediments for each river reach and zone of Green Bay are summarized below.

Little Lake Butte des Morts Reach

The nine sediment deposits in this reach (deposits A through H and POG) contain about 1,540 kg (3,395 pounds) of PCBs in about 1.35 million m^3 (1.77 million cy) of sediment with concentrations greater than 50 μg/kg PCB (Plate 2-1). These deposits cover about 314 hectares (775 acres) and thicknesses range up to approximately 1.9 meters (6.2 feet) thick. The highest detected total PCB concentration in sediment was 222,722 μg/kg (average 15,043 μg/kg). Upstream deposits A, B, and POG have the highest PCB mass to volume ratios in this reach. These three deposits contain 952 kg (2,100 pounds) of the PCBs in about 252,000 m^3 (329,600 cy) of sediment. About 910 kg (2,000 pounds) of the PCBs in these three deposits is present in the upper 100 cm (3.28 feet) of sediment. Deposits A/B, E, and POG contain over 1,400 kg (3,086 pounds) of PCBs, or about 91 percent of the PCBs present in this reach. About 53 percent of the mass in the deposits listed above are present in the upper 30 cm (1 foot) of sediment.

Appleton to Little Rapids Reach

Sediment accumulation in the Appleton to Little Rapids Reach is more localized compared with the other three reaches. The 22 sediment deposits in this reach (deposits I through DD) contain about 94 kg (207 pounds) of PCBs in about 184,790 m^3 (241,700 cy) of sediment, with concentrations greater than 50 μg/kg PCBs (Plate 2-2). These deposits cover approximately 153 hectares (378 acres) and generally occur in areas of slower stream flow velocities (e.g., where the river widens, in the vicinity of dams/locks, eddy pools along the banks, etc.). Sediment thicknesses range up to approximately 100 cm (3.23 feet) thick. The highest detected total PCB concentration in sediment was 77,444 μg/kg (average 6,406 μg/kg). Only deposits W, X, and DD have a volume exceeding 30,000 m^3 (39,240 cy) of sediment and these are located where the river widens and/or upstream of a dam. The average sediment volume in each of the remaining 19 deposits in this reach is about 3,780 m^3 (4,944 cy). Approximately 32 kg (71 pounds) of PCBs remain in deposits N and O following completion of the 1999 sediment remediation demonstration project, and no future attempt to remove this mass is currently under consideration. The total surface area of this reach is approximately 7,000,000 m^2 while deposits with measurable PCBs are only 870,000 m^2 (12.6 percent). In general, surface sediment PCB concentrations are less than 1,000 μg/kg in this section.

Little Rapids to De Pere Reach

Sediment accumulation in this reach extends over a long distance and large area. The four sediment deposits in this reach (deposits EE through HH) contain 980 kg (2,160 pounds) of PCBs in approximately 1.71 million m^3 (2.24 million cy) of sediment with concentrations greater than 50 μg/kg PCB (Plate 2-3). The four deposits in this reach are essentially a single sediment unit covering about 266 hectares (657 acres). Sediment thicknesses range up to 2.3 meters (7.5 feet) thick in select areas, especially near the De Pere dam. The highest detected total PCB concentration in sediment was 54,000 μg/kg (average 6,292 μg/kg). Concentrations exceeding 5,000 μg/kg exist at the southernmost limit to Deposit EE, and at the northernmost part of the reach behind the De Pere dam. Almost all of the PCBs are contained in the upper 100 cm (3.28 feet) of sediments, with 535 kg (1,180 pounds) contained in the upper 0 to 30 cm (0 to 1 foot).

De Pere to Green Bay Reach (Green Bay Zone 1)

This reach contains the largest volume and areal extent of impacted sediments in the Lower Fox River (Plate 2-4). Ninety-one (91) percent of the PCB mass for the entire river is present in this reach. The 96 SMUs in this reach contain 25,984 kg (57,285 pounds) of PCBs in over 5.5 million m^3 (7.2 million cy) of sediments with concentrations greater than 50 μg/kg PCB (Plate 2-4). Almost the entire sediment bottom contains soft sediment covering about 524 hectares (1,295 acres) and ranging in thickness up to 4 meters (13 feet). The highest detected total PCB concentration in sediment was 710,000 μg/kg (average 21,722 μg/kg) before the completion of SMU 56/57 demonstration project.

Approximately 636 kg (1,400 pounds) of PCB and 31,000 m^3 (40,550 cy) of sediment were removed from SMUs 56–61 during the SMU 56/57 sediment remediation demonstration project. Further, removal of additional sediment and PCBs from SMU 56/57 started in August 2000, but the final mass and volume estimates are not expected to be known until early 2001. Excluding SMUs 56–61, six SMU groups (SMUs 20–25, 32–37, 38–43, 62–67, 78–73, and 80–85) contain almost 11,000 kg (24,250 pounds) of PCBs, or about 37 percent of the total mass in the Lower Fox River. These SMU groups also exhibit the highest PCB concentrations or greatest PCB mass to sediment volume ratios in the river.

The mass of PCBs increases significantly with depth. Approximately 16,150 kg (35,530 pounds) of PCBs, or about 55 percent of the total PCB mass in the Lower Fox River, occurs in the upper 100 cm (3.28 feet) of sediment. Approximately 10,600 kg (23,370 pounds) of PCBs (36 percent of the PCBs in the river) are buried below 100 cm (3.28 feet).

PCBs are fairly evenly distributed in the surface sediments within this reach. Of the 5,210,000 m^2 of sediment surface within this reach, 4,500,000 m^2 (87 percent) have PCB concentrations greater than 1,000 μg/kg.

Green Bay Zone 2

This zone contains approximately 32,000 kg (70,550 pounds) of PCBs in 39.5 million m^3 (51.6 million cy) of sediment with concentrations greater than 50 μg/kg (Plate 2-5). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The PCB distribution reflects the influence of Green Bay current patterns, as higher concentrations are located along the east side of the bay. Sediments in Zone 2A cover about 5,930 hectares (14,650 acres) and have an average thickness of about 0.34 meter (1.1 feet). In Zone 2B, the sediments cover about 5,150 hectares (12,725 acres) and have an average thickness of about 0.38 meter (1.25 feet). The highest total PCB concentration in sediment was 17,000 μg/kg (average 324 μg/kg).

Considering only sediments with more than 1,000 μg/kg PCBs reduces the mass and volume estimates to 27,470 kg (60,430 pounds) and 17.8 million m^3 (23.3 million cy). This represents slightly more than 45 percent of the PCBs, but less than 3 percent of the estimated volume of impacted sediment in the bay.

Approximately 14,500 kg (31,900 pounds) of PCBs are contained in about 29.8 million m^3 (39 million cy) of sediment in the upper 30 cm (1 foot). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The distribution shows the influence of Green Bay current patterns, as higher PCB concentrations are located along the east side of the bay.

Green Bay Zone 3

This zone contains approximate 35,240 kg (77,700 pounds) of PCBs in approximately 397 million m^3 (519 million cy) of sediment with concentrations greater than 50 μg/kg (Plate 2-5). PCB distribution results show that sediments with the highest concentrations have accumulated along the east shore of Green Bay, extending from Dyckesville to Egg Harbor, reflecting the influence of Green Bay current patterns. Sediments in Zone 3A cover about 85,890 hectares (212,240 acres) and have an average thickness of just 0.21 meter (0.7 foot). In Zone 3B, the sediments cover about 69,340 hectares (171,340 acres) and have an average thickness of about 0.31 meter (1 foot). The highest detected total PCB concentration in sediment was 1,320 μg/kg (average 448 μg/kg) in Zone 3B.

Considering sediments with more than 1,000 μg/kg PCBs reduces the mass and volume estimates to 1.65 kg (3.64 pounds) and 8,800 m^3 (11,510 cy), respectively. This represents less than 0.003 percent of both the PCB mass and sediment volumes in the bay.

Considering the upper 30 cm (1 foot) of sediments, approximately 30,000 kg (66,000 pounds) of PCBs are contained within about 355.9 million m^3 (465.5 million cy). However, as indicated above, a large majority of this mass is located in sediments with concentrations below 1,000 μg/kg PCBs. Surface sediment PCB concentrations are generally higher in the southern part of the zone (greater than 500 μg/kg), and lower (less than 125 μg/kg) just below Chambers Island.

Green Bay Zone 4

The estimated PCB mass and sediment volume results indicate that Zone 4 is relatively unaffected by PCBs compared to zones 2 and 3. However, fewer soft sediment locations were noted and sampled in this zone than in either zones 2 or 3 during 1989 and 1990 sampling activities. Zone 4 contains less than 925 kg (2,040 pounds) of PCBs, or only about 1 percent of the total mass in the system. Total PCB concentrations detected in sediment within Zone 4 are all less than 500 μg/kg (average 54 μg/kg).

Findings regarding the presence and distribution of other COPCs identified in the Screening Level Risk Assessment are fully described in the Lower Fox River and Green Bay RI Report (RETEC, 2002a).

2.4.4 Extent of Other COPC Impacts

Major findings regarding the distribution of other chemical parameters in sediments include:

- Mercury was used in a number of pulp and paper production activities to reduce slime. The SLRA identified mercury concentrations exceeding 0.15 mg/kg as a potential concern. Mercury concentrations in Lake Winnebago sediments averaged 0.14 mg/kg while average concentrations in each reach of the Lower Fox River ranged from 1.26 to 2.42 mg/kg. The elevated mercury concentrations are widespread in the Lower Fox River sediments and are not associated with any specific deposit or point source discharge.

- Mercury concentrations in Green Bay are much lower than levels in the river. The average concentration is Zone 2 was 0.593 mg/kg, but averages in zones 3 and 4 range only up to 0.19 mg/kg, which is just above the Lake Winnebago background concentration.

- The spatial distribution of dioxin/furan compounds cannot be evaluated because only 22 samples were collected from deposits D/E/POG, deposits EE/HH, and SMUs 56/57. Concentrations of 2,3,7,8-TCDD/TCDF detected in sediments ranged from 0.23 to 170 nanograms/kilogram (ng/kg) (parts per trillion [ppt]).

- Sixteen (16) chlorinated pesticides, generally associated with agricultural non-point source activities, were detected in river sediments at concentrations up to 67 μg/kg. Additional non-point pesticide sources may include atmospheric deposition and stormwater runoff from pesticides used at parks, golf courses, and other institutional facilities; however, these sources are likely to be small compared with agricultural activities. Only seven compounds, DDT, DDD, DDE, endrin aldehyde, endrin ketone, gamma-BHC (lindane), and heptachlor, were detected in more than four sediment samples. Distribution of these compounds was generally sporadic. Only DDT and dieldrin were identified by the SLRA as being chemicals of potential concern. The SLRA identified DDT (total) concentrations above 1.6 μg/kg as a potential concern. DDT was detected at 10 widely-distributed locations within the Lower Fox River above this concentration. There is no established concentration of concern for dieldrin, which was detected in only one sample from Little Lake Butte des Morts, suggesting that dieldrin distribution is very limited. Neither DDT nor dieldrin were detected within Green Bay.

- Lead is a naturally-occurring element in soil and sediment. Background lead concentrations in Lake Winnebago sediments averaged 35 mg/kg while average concentrations in each reach of the Lower Fox River ranged from 75.6 to 167.8 mg/kg. The SLRA identified lead concentrations above 47 mg/kg as a potential concern. While some deposits detected lead concentrations as high as 1,400 mg/kg, lead occurrence is widespread in the Lower Fox River sediments and cannot be related to any specific point source discharge. In Green Bay, the average lead concentration ranged from 1.5 to 29.9 mg/kg, which is lower than the Lake Winnebago background concentration.

- Arsenic is also naturally occurring in soil and sediment. Background arsenic concentrations in Lake Winnebago sediments averaged 5.33 mg/kg. The SLRA identified arsenic concentrations above 8.2 mg/kg as a potential concern. An elevated arsenic concentration was detected in only one location (SMU 38) at 385 mg/kg. Excluding this arsenic detection, average concentrations in both the river and the bay were below the Lake Winnebago background concentration of 8.2 mg/kg.

- SVOCs, which result from both point and non-point sources in urban and rural areas, were detected throughout the Lower Fox River at concentrations exceeding the background levels observed in Lake Winnebago. The SVOCs detected at higher concentrations included PAHs and also occurred in widespread areas of the river. Total PAH concentrations below 4,000 μg/kg typically do not warrant further assessment. Total PAH concentrations along the Lower Fox River ranged non-detectable to 60,000 μg/kg. A number of locations from Little Lake Butte des Morts to the mouth of the river exceeded 4,000 μg/kg with the highest values frequently observed downstream of more urbanized areas. None of the sediments samples collected within Green Bay Zone 2 exceeded 4,000 μg/kg, and PAHs were not detected in zones 3 or 4.

2.5 Chemical Fate and Transport

Chemical fate and transport in the Lower Fox River and Green Bay is largely a function of suspension, deposition, and redeposition of the chemicals of concern that are bound to sediment particles. The organic compounds of potential concern, including PCBs and pesticides, exhibit strong affinities for organic material in the sediments. The suspension and transport of these compounds absorbed onto the sediments is largely controlled by moving water in the Lower Fox River and Green Bay. Greater volumes of sediments become suspended and are transported during high-flow events (such as storms and spring snowmelt). The Lower Fox River has an average discharge of 122 m^3/s (9,605 cfs) 10 percent of the time. Previous investigators have estimated that these high-flow events transport more than 50 to 60 percent of the PCB mass which moves over the De Pere dam and into Green Bay.

Other modes of contaminant transport such as volatilization, atmospheric deposition, and point source discharges are negligible when compared to the river transport. Figures 2-13 and 2-14 each present a conceptual model of PCB fate and transport in the Lower Fox River and Green Bay system by TSS load and PCB mass, respectively. Total suspended solids (TSS) loads are from the Fox River into Green Bay and are summarized on Table 2-8.

2.5.1 Lower Fox River Sediment Deposition

Sediment deposition and resuspension processes are primarily a function of particle size and water velocity. Transport of sediments occurs as particles are suspended in the water or moved along the base of the river as bed load. The system is dynamic and areas of sediment accumulation may become erosional areas, or vice versa, based on changes in water velocity (e.g., storm events), river bathymetry (e.g., shoreline erosion) and other factors.

TSS data have been evaluated to estimate the movement of sediment through the system. Distinct deposits of accumulated sediment occur throughout the Lower Fox River in areas of low stream flow velocity. These areas are generally in the vicinity of the locks, dams, shoreline coves and back eddies, or in areas where the river widens. However, estimates of net deposition or net erosion only reflect an average accumulation or loss over time for an entire reach and do not explain finer-scale deposition/erosion events occurring within a reach. Net deposition does not imply a purely depositional environment and vice versa.

Over 75,000 MT (82,700 tons) of TSS enters Little Lake Butte des Morts from Lake Winnebago annually. However, the TSS load at the Appleton gauging station is lower than this figure by approximately 8,000 MT (8,800 tons). Based on the net loss of TSS load, the slow water velocity, shallow bathymetry, and extensive sediment deposits, the Little Lake Butte des Morts Reach is subject to sediment accumulation.

The Appleton to Little Rapids Reach experiences a net loss of sediment. Between Appleton and Kaukauna, the river shows a marginal increase of approximately 2,500 MT (2,750 tons) in the TSS load. However, between Kaukauna and Little Rapids, the river experiences a net erosion as the TSS load doubles from approximately 70,000 MT (77,000 tons) to approximately 142,000 MT (154,000 tons) (Figure 2-13). The lack of soft sediment between Rapide Croche dam and Little Rapids suggest that resuspended sediments are likely transported to Little Rapids (Deposit DD) or further downstream. Based on the net increase of TSS load, the fast stream velocities (as high as 0.3 m/s), the narrow river sections, and the lack of many sediment deposits, the Appleton to Little Rapids Reach is subject to a net loss of sediment.

The TSS load within the Little Rapids to De Pere Reach declines by about 61,500 MT (68,000 tons), a 43 percent decrease from upstream inputs. Deposit EE, the largest sediment deposit upstream of the De Pere dam, extends approximately 8.5 km (5.3 miles) upstream of the dam. Based on the significant net decrease of TSS load, the large number of sediment deposits, and the slow stream flow velocities (average of 0.12 m/s), the Little Rapids to De Pere Reach experiences net sediment deposition and accumulation.

In the De Pere to Green Bay Reach, TSS loads coming over the De Pere dam range between approximately 80,000 and about 100,000 MT (90,000 and 110,000 tons) annually. At the river mouth, the TSS load was only 20,000 MT (22,000 tons), indicating that the TSS load declined by approximately 75 to 80 percent. The average stream flow velocity in this reach was less than 0.08 m/s, which is the lowest value for any of the four river reaches. Results of the Green Bay Mass Balance Study show that at a typical discharge rate of 105 m^3/s (3,700 cfs), approximately 272 MT (300 tons) per day of TSS flows over the De Pere dam; however, only approximately 54 MT (60 tons) per day are discharged at the mouth. Based on the significant net decrease of TSS load, the large number of thick sediment deposits, and the slow stream flow velocities, the De Pere to Green Bay Reach experiences net sediment deposition.

For storm events with flows around 280 m^3/s (9,900 cfs), the TSS load over the De Pere dam increases to 1,800 MT (2,000 tons) per day, while storm events with flows of 430 m^3/s (15,250 cfs) have a TSS load of about 7,100 MT (7,850 tons) per day. Quadrupling the stream flow rate in the river results in an approximately 26 times greater TSS load.

2.5.2 Green Bay Sediment Deposition

Estimated annual sediment accumulation in Green Bay varies from about 20,000 MT to about 150,000 MT (22,050 to 165,350 tons). The USGS estimated the average annual sediment load from the Fox River into Green Bay is approximately 82,500 MT (90,940 tons) to 136,000 MT (150,000 tons). Recent 1998 data suggests that about 153,000 MT (168,800 tons) of sediment were discharged into the bay during 1998.

Sediment is not deposited uniformly across the bottom of the bay. Water current patterns determine the distribution of sediments, and ultimately, that of PCBs and other chemical compounds in Green Bay. The primary depositional zone in Green Bay extends along the east shore of the bay for a distance of approximately 25 km (15.5 miles) north of the Lower Fox River mouth.

Approximately 17,500 MT of sediment is transported from the inner bay to the outer bay along the east side of Chambers Island. However, about 19,000 MT of sediment is transported from the outer bay to the inner bay along the west side of the island, following dominant circulation patterns (Figures 2-11 and 2-12). Therefore, there is a net sediment gain in the inner bay of approximately 2,400 MT. Approximately 10 to 33 percent of the inner bay tributary sediment load (the majority of which is from the Lower Fox River) is transported to the outer bay.

Sediments that have been deposited can be re-entrained and transported. A number of different studies and models have evaluated sediment resuspension, and it has been shown that most sediment transport within the bay occurs during large storms. A large volume of sediment was transported from the inner bay to the outer bay as a result of a September 1989 storm. Erosion of shore and nearshore sediments was found to be directly related to the magnitude, direction, and duration of winds within the bay, which effected currents and wave action. Within the bay, sediment deposits are located in areas where the stress ratios were less than about five to nine, in comparison with the Lower Fox River ratios of three to five. Sediments within the bay settle in a far less turbulent environment than those of the Lower Fox River; therefore, the uppermost layer of sediment was found to have consolidated in 7 to 14 days, rather than less than 3 hours. Moderate to strong winds, which are the single most important factor for bay sediment resuspension, occur on average every 7 days on the Great Lakes.

2.5.3 PCB Transport

Review of sediment transport through the river reaches and bay zones was evaluated to assess where PCB transport is occurring with all movement. The conceptual models show the PCB mass/volume contained with each reach/zone (greater than 50 μg/kg PCB) and how much PCBs are transported from one reach/zone into the next annuli (Figures 2-13 and 2-14).

Fox River

Approximately 1,540 kg of PCBs are present within the Little Lake Butte des Morts Reach. The sediments of the lake have long acted as a continuing source of PCBs to the river/bay system. WDNR (1995) estimates are that less than 1 kg per year is annually transported from Lake Winnebago into Little Lake Butte des Morts (Figure 2-14). Approximately 40 kg of PCBs are resuspended and transported from Little Lake Butte des Morts to the Appleton to Little Rapids Reach, even though Little Lake Butte des Morts is a net depositional area.

The Appleton to Little Rapids Reach exhibits increased stream flow velocities compared with the rest of the river. Stream flow velocity in this reach averages about 0.283 m/s, which is more than twice the entire river average of 0.137 m/s. Only about 94 kg of PCBs are located within sediments in this reach. These data show that little of the sediment or PCBs are deposited permanently within this reach.

Within the Little Rapids to De Pere Reach, the De Pere dam acts as a sediment trap. Approximately 64 kg per year of PCBs enter the reach and 77 kg per year are transported over the De Pere dam. Although net sediment deposition occurs in this reach (Figure 2-13), dissolution of PCBs from sediment into the water column becomes more important than does actual transport of sediment to which PCB is sorbed. Stream flow velocities downstream of the Little Rapids dam decrease to approximately 0.122 m/s, which is below the river average of 0.137 m/s.

The De Pere to Green Bay Reach has the greatest PCB mass and volume of sediment within the Lower Fox River (over 25,900 kg of PCB). Over 90 percent of the PCB mass and 60 percent of the PCB-impacted sediment present in the Lower Fox River are located within this reach. The average stream flow velocity in this reach is approximately 0.077 m/s, well below the river average of 0.137 m/s. This low river velocity accounts for the high volumes of sediments deposited within this reach. Although approximately 80,000 MT TSS flows over the De Pere dam, only about 20,000 MT TSS (about 25 percent) is transported passed the river mouth and into the bay. On a mass and volume basis, this reach has the most significant sediment load in the river. Sediments in this reach act as the major continuing source of PCBs into Green Bay.

Green Bay and Lake Michigan

Based on river water sample results, approximately 220 to 280 kg (484 pounds) of PCBs were transported from the Lower Fox River into Green Bay annually in 1989/90 and 1994/95. These results suggested that roughly one percent of the PCB mass within the river is discharged into the bay annually. However, recent 1998 data suggest that the PCB load into Green Bay may be decreasing and only about 125 kg of PCBs were discharged from the river into the bay based on the 1998 data, which is just over 0.4 percent of the river mass. The average estimates of the PCB mass entering Green Bay from the Lower Fox River annually range between 125 and 220 kg per year. Based on peak flow conditions within the river, the highest estimated PCB load into Green Bay is about 550 kg per year. Approximately 120 kg of PCBs are transported from Green Bay into Lake Michigan annually (Figure 2-14). However, the results of these studies suggest that the PCB mass located between the De Pere dam (in the Lower Fox River) and Chambers Island (in Green Bay) is so large that, at these low rates of loss, a large mass of PCBs will remain in these sediments far into the future.

Other PCB Pathways

In addition to PCB input to the river and bay from contaminated sediments, other PCB sources and sinks exist. Approximately 3 to 5 kg of PCBs are introduced into the river from other discharge locations where PCBs remain in effluent lines or from continued carbonless paper recycling. Due to the ubiquitous and resilient nature of PCBs, low concentrations of PCBs have been detected at discharge locations that continue to contribute PCBs to the system. Estimates of atmospheric deposition of PCBs into Green Bay range from 2 to 35 kg annually. Based on a 1987 and 1988 USGS PCB mass-loading study of major tributaries into Green Bay, more than 90 percent of the PCB load into Green Bay was attributable to the Lower Fox River. The other Green Bay tributaries contributed only about 10 kg annually to the bay (Figure 2-14).

In addition to accumulation of PCBs in river and bay sediments, PCBs do exit the system through volatilization (Figure 2-14). A number of studies have indicated that PCB volatilization from the water exceeds atmospheric deposition. PCB losses through volatilization to the atmosphere ranges between 0 and 5 kg/yr for the Lower Fox River, whereas volatilization losses in Green Bay range between 130 and 500 kg annually. The surface area for Green Bay is a significant volatilization pathway.

2.6 Time Trends of Contaminants in Sediment and Fish

A time trends analysis was conducted on sediments and fish tissue within the Lower Fox River and Zone 2 of Green Bay in order to assess whether statistically significant changes in PCB concentrations were occurring. For the purposes of the BLRA, it was important to understand if apparent or implied decreases in PCB concentrations in sediments and fish tissue were real, and if so, determine if the rate of change could be estimated. A brief description of the methods and results is given below. The detailed analysis may be found as Appendix B of the Remedial Investigation Report (RETEC, 2002a).

2.6.1 Sediment Methods

For sediments, the overall approach was to first review the data for usability, then explore relevant groupings of the data both horizontally and vertically to conduct regression-type analyses for increases or decreases in PCB concentrations over time. All data used in these analyses were from the Fox River database.

Exploratory analysis demonstrated that PCB concentrations varied across locations in the river. To adequately conduct the analysis of time trends, it was necessary to undertake a separate evaluation of the spatial layout; a horizontal evaluation within the river bed and a vertical evaluation with each depth stratum. The deposit designations used in the RI/FS (e.g., A, POG, EE, or SMU 26, shown on Figures 2-1 through 2-4) were found to be unsuited to defining spatially-cohesive subsets, many samples had no deposit designation and some deposit designations spanned stretches of a river reach too long to allow adequate assessment and control of spatial structure. Based upon analysis of the spatial layout, 23 distinct geographic "deposit groups" were determined, forming data subsets with spatial structures far more amenable to statistical analysis. These were given designations that reflected the general deposit designations in the RI/FS, with the added benefit that these groups designated non-overlapping spatial sets. The statistical groups analyzed are shown on Figures 2-15 through 2-17.

Depth strata within each deposit group were consistent with the RI/FS: 0 to 10 cm (0 to 4 inches), 10 to 30 cm (0.33 to 1 foot), 30 to 50 cm (1 to 1.6 feet), 50 to 100 cm (1.6 to 3.3 feet), and 100+ cm (3.3+ feet). Sample groups defined by a specific deposit and depth stratum were analyzed separately for the time trends. Depth strata within some deposits were excluded due to either inadequate sample size or lack of time variation. After averaging samples from a common sediment core within a particular stratum, 1,618 observations in 46 combinations of deposit and depth were included in the sediment time trends analysis. PCBs were analyzed as the logarithm of PCB concentration (in μg/kg) due to the approximately lognormal distribution of these values.

Spatial correlation among observations was determined using semivariograms, a common technique in geostatistics. In order to avoid overstating statistical significance of time trends in the presence of spatially-correlated observations, the Window Subsampling Empirical Variance (WSEV) (Heagerty and Lumley, 2000) estimation method was used. WSEV is analogous to averaging observations within cells of a grid, where the grid size is specified such that sample subsets falling into different cells of the grid are approximately independent of each other. The WSEV method yields a proper estimate of variance that can be used to calculate statistical significance.

The WSEV method for handling spatial dependence was used in conjunction with a standard method for estimating time trends; regression analysis. Regression models for log PCB concentration versus time, depth, and linear and quadratic spatial coordinates were fitted using the method of maximum likelihood, which readily incorporates the observations below detection limit without imputation of a value such as half the detection limit. Throughout the analysis, significance levels of $p < 0.05$ from regression analysis or from any other analysis were designated as "statistically significant."

2.6.2 Fish Methods

Like sediments, the approach for examining time trends in fish tissue PCB concentrations was to first review the data, then explore relevant groupings of the data on which to conduct regression-type analyses. In addition to the four reaches of the Lower Fox River, fish time trends were examined in Green Bay Zone 2. This was undertaken to determine whether PCB exposure in Zone 1 and Zone 2 were identical (i.e., represent a single exposure unit), or if there were distinct trends in these two zones for the target fish species. Fish tissue data from those two zones were explored first to ascertain whether they represented a single or separate exposure units (i.e., have different time trends for PCBs). This was conducted to determine whether the data should be combined for a single analysis, or to conduct separate time trends analyses for the two zones.

All data used in these analyses were from the Fox River database. A total of 1,677 fish samples were available for analysis, divided into three main sample types: fillet without skin, fillet with skin, and whole body. Inadequate sample size presented the greatest obstacle to analysis. There were several cases where there were substantial data, but there was inadequate spread in the years between collections. It should be noted that within the Little Rapids to De Pere Reach, there were no fish groups with both sufficient sample size and time spread. There were over a hundred combinations of reach, species, and sample type with at least one observation, but only 19 of these had sufficient numbers of samples and a sufficient time spread for analysis of time trends. Carp and walleye provided the largest number of observations of any species. These 19 combinations represent 867 samples—over half of all samples of whole body, fillet with skin, and fillet without skin. In addition to the 19 combinations, there were 4 analyses which could statistically combine samples from the fillet and whole body categories (within a single reach and single species) to come up with a single time trend estimate.

Data on PCBs in fish were analyzed as the logarithm of PCB concentration in micrograms per kilogram. The percent lipid content of samples was significantly associated with PCB concentration in most species and sample types, and was thus used as a normalization term in all analyses.[1]

Regression models for PCB concentrations versus time were fitted using the logarithm of percent lipid content and time as independent variables. A linear spline function was included in some time trends analyses to accommodate different rates of change in PCB concentrations during earlier versus later periods. The maximum likelihood method was used to accommodate observations below detection limit. A test for changing trends was also carried out.

The difference in fish PCB concentrations between Green Bay Zone 1 (De Pere to Green Bay Reach) and Green Bay Zone 2 was analyzed using both cross-sectional data (five analyses) and time trends data (three analyses), again controlling for percent lipid content of samples in regression models. All regression models for the fish analysis were fitted using the maximum likelihood method to accommodate the small fraction of observations below the detection limit.

2.6.3 Time Trend Results

Results of the sediment time trends are presented in Table 2-10, and are represented graphically on Figures 2-15 through 2-17. Seventy percent of all calculated slopes (32 out of 46) were negative. However, only 13 out of the 46 slopes were statistically significant, such that a hypothesis of no change in PCB

[1] Note that fish concentrations of PCBs were not normalized by dividing by lipid content of samples. Thus, the concentrations are expressed as log micrograms of PCBs per kilogram of tissue rather than per kilogram of lipid.

concentration over time could be rejected. Of those, 10 were negative,[2] and within that subset eight were in the 0- to 10-cm (0- to 4-inch) segment.

Conducting a meta-analysis on the surface sediment data showed a negative trend in all reaches except Appleton to Little Rapids. A meta-analysis of time trends in surface sediments yielded an average rate of decrease in PCB concentration per year of -18 percent in Little Lake Butte des Morts, +0.6 percent in the Appleton Reach, -10 percent in the Little Rapids Reach, and -15 percent in the De Pere Reach. These trends were statistically significant except for the Appleton Reach.

While those data suggest an overall decline in PCBs in the Lower Fox River, a more careful analysis of the subsurface data suggest that these declines are restricted to the upper 0 to 10 cm (4 inches). While 32 out of the 46 analyses were negative, there is a strong trend toward fewer and weaker negative slopes at increasing depth. Table 2-10 and Figures 2-15 through 2-17 show in general that the subsurface deposits do not significantly decline in sediment PCB concentrations. For Little Lake Butte des Morts, the figures suggest that there is a generally increasing trend in subsurface PCBs, and an indeterminate mixture of trends that is not distinguishable from zero in the Appleton and De Pere reaches. For Little Rapids to De Pere, there are consistently negative trends in the 10- to 30-cm (0.33- to 1-foot) strata, but in the lower strata, the data are consistent with either zero trend (30 to 50 cm [1 to 1.6 feet]), or an increasing trend (50 to 100 cm [1.6 to 3.3 feet]).

These results suggest that over time, the surface sediment concentrations of PCBs have been steadily decreasing. However, numerically this was difficult to define, and depended upon the specific deposits or sediment management units. PCB concentrations in sediment suggest declines, but a large fraction of analyses provided little useful trend information. A large fraction of sediment analyses yielded imprecise or inconclusive trends such that positive, negative, or zero trends are consistent with the data.

Like sediment PCB concentrations, fish tissue PCB concentrations showed a significant but slow rate of change throughout the lower Fox River and lower Green Bay (Table 2-11). Initial exploration of the data demonstrated that there were statistically significant declines in tissue PCB concentrations in all species in all reaches. More detailed analyses were then conducted to determine if there had been a constant linear rate of decline, or if significant changes in the rate of decline, or "breakpoints," could be identified. Among fish time trends analyzed,

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[2] A negative slope indicates decreasing PCB concentrations; a positive slope indicates increasing PCB concentrations over time.

9 out of 19 combinations of reach, species, and sample type showed a statistically significant change in slope during earlier and later periods. In all of the reaches of the river, and in Zone 2, there were steep declines in fish tissue PCB concentrations from the 1970s, but with significant breakpoints in declines beginning around 1980. After the breakpoint, depending upon the fish species, the additional apparent declines were either not significantly different from zero, or were relatively low (5 to 7 percent annually). However, for two species there were increases in PCB concentrations after the breakpoint; walleye in Little lake Butte des Morts and carp in Green Bay Zone 1.

Most slopes were negative, and all statistically significant slopes were negative. Over the period of analyzed data, percentage rates of decrease were usually between -5 and -10 percent per year (compounded). Percent lipid content of tissue was significantly related to PCB concentration in 16 out of the 19 analyses. Specific trends in sediment and fish by reach are discussed below.

Little Lake Butte des Morts

Time trend results for sediments in Little Lake Butte des Morts are presented in Table 2-10 and on Figures 2-15 through 2-17. With the exception of two strata at 10 to 30 cm (0.33 to 1 foot) in two separate deposit groups, slopes are negative (9 out of 11 analyses). However, statistically significant negative slopes (decreasing PCB concentration over time) was found only in surface sediments (0 to 10 cm [0 to 4 inches]) of four deposit groups (AB, D, F, GH). The estimated rates of decrease ranged from 8 to 24 percent per year, with wide confidence intervals for these rates of change; a rate of decrease of as little as 1 to 5 percent and as much as 15 to 43 percent per year. While the slopes were negative, there were no significant trends at deposits C or POG. In fact, for POG the estimated annual slope was -18.6 percent per year, but the upper and lower confidence bound on the estimate ranged from -43.3 to +16.9 percent per year.

When pooled across all deposits, there was an estimated significant ($p < 0.001$) average annual decrease of -15 percent of surface concentrations within the period supported by the data. It is important to note that on a reach basis, the 95 percent confidence intervals around the estimated average were 22 percent, up to 8 percent annual rate of decrease.

The only statistically significant increasing trend of PCB concentrations occurs at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D, where the rate of increase is 108 percent per year. The confidence interval for the significantly increasing slope at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D indicates a rate as low as 59 percent and as high as 171 percent per year. The Time Trends Analysis Report noted that this must represent a temporary positive trend because a projection of the PCB concentration even at the minimum of 59 percent per year would yield an absurd 10,000-fold increase in PCB concentration after 20 years.

Caution needs to be used in the interpretation of the estimated average decrease within this reach. As noted previously, there were wide confidence intervals around all estimates for the sediment deposit groups. While the mass-weighted time trend for surface sediments indicated a significant decrease, the fact that the estimate did not include Deposit E, the largest depositional area within the reach, must be considered. There were insufficient data to conduct the analysis for Deposit E, and thus the sediment time trend is somewhat skewed by the lack of inclusion here.

For the fish examined in this reach, an early rapid decline was observed until around 1987, followed by either a slower decline or a flattening without further decline, depending upon the species (Table 2-11). Within this reach, time trends were conducted on carp and walleye (skin-on fillet and whole body), and northern pike and perch (skin-on fillet). For carp, the breakpoints identified for the skin-on fillet and whole body were 1979 and 1987, respectively. Walleye data fillet and whole body data show that the breakpoint occurs between 1987 and 1990. The fillet data suggests no change in concentration after the breakpoint, while the whole body data showed a sharp rate of increase (22 percent per year). However, the latter analysis, when tested, was not significantly different from zero. For northern pike skin-on fillets, the analysis showed no breakpoint, but a constant rate of decline of 12 percent per year. By contrast, yellow perch skin-on fillets declined sharply until 1981, and have since remained at constant levels. A meta-analysis conducted on all fish data combined yields a statistically significant, but slow rate of decline of 4.9 percent (range 2.1 to 7.5 percent decrease) per year.

Appleton to Little Rapids

For this reach, there were only sufficient data to evaluate Deposit Group IMOR, Deposit N (pre-demonstration dredging), and Deposit Group VCC. For these three groupings, surface sediments at IMOR showed an estimated annual increase of 9.9 percent, while the other two showed decreases in total PCB concentrations (Table 2-10). While Deposit N surface sediments were found to be significant, there were non-significant increases observed in the subsurface sediments. Again, confidence limits around the estimated mean for all deposits was wide. Meta-analysis for the reach showed a non-significant increase of 0.6 percent per year.

For fish in this reach, the only tissue type with sufficient numbers and time spread of data were walleye skin-on fillet. Analysis of those data showed a relatively constant rate of decline of 10 percent (range 5.6 to 17.9 percent decrease) per year (Table 2-11).

Little Rapids to De Pere

Time trends in sediments for this reach have a majority of negative slopes; but two of only three significant slopes were negative and occur in the 0- to 10-cm (0- to 4-inch) and 10- to 30-cm (0.33- to 1-foot) depth strata. One large, positive, statistically significant slope occurs at the 30- to 50-cm (1- to 1.6-foot) depth (Table 2-10, Figure 2-16).

The surface sediment (0 to 10 cm [0 to 4 inches]) in the Lower EE Deposit Group has a significantly negative slope (p = 0.04), implying a rate of decrease of 15 percent per year with a 95 percent confidence interval of 2 to 26 percent rate of decrease per year. In the same deposit group, the deeper 30- to 50-cm (1- to 1.6-foot) stratum shows a significantly positive slope, indicating a rate of increase of 23 percent per year and a 95 percent confidence interval of 4 to 46 percent per year. In Deposit Group FF, the 10- to 30-cm (0.33- to 1-foot) layer has a significantly negative slope with a rate of PCB concentration decrease of 20 percent per year with a 95 percent confidence interval of 1 to 35 percent. Again, while the estimates speak to significant decreasing or increasing PCB concentrations over time in these strata and deposit group combinations, the analysis showed wide confidence intervals. For surface sediments, the annual change ranged from an increase of 19.1 percent per year to a decrease of 33 percent per year.

Although only one surface sediment has a statistically significant decline, the mass-based meta-analysis found an overall statistically significant combination of declining PCB concentrations in the reach, with a slope of -0.046 per year ($p = 0.01$), implying a 10 percent per year rate of decrease (95 percent confidence interval: -17 to -2 percent). While some uncertainty may persist in the individual surface deposits, the PCB mass in the surface of this reach appears to be generally declining as of the mass estimation date, 1989 through 1990.

As noted previously, there were not sufficient fish tissue data for analysis of time trends.

De Pere to Green Bay (Zone 1)

The time trends analysis for surface sediments in this reach showed primarily negative slopes (Table 2-10). Statistically significant negative slopes were found in only three combinations of deposit group and depth. SMU Group 2649 showed a significantly negative slope ($p < 0.001$) in the surface deposit (0 to 10 cm [0 to 4 inches]), with a rate of decrease of 13 percent per year (95 percent confidence interval of 8 to 17 percent decrease per year). SMU Group 5067, 0 to 10 cm (0 to 4 inches), also has a significantly negative slope (p = 0.01) implying an annual rate of decrease of 21 percent (95 percent confidence interval of 5 to 33 percent). In the same SMU group (5067), at a greater depth of 50 to 100 cm (1.6 to 3.3 feet), a significant ($p = 0.003$) and large positive slope with a rate of increase of 133 percent per year (95 percent confidence interval of 56 to 250 percent) was observed.

It is important to note that an exceptionally high value of PCB concentration in SMU Group 5067 was excluded from the analysis. Sample A3_0-4 had a concentration of 99,000 ppb, whereas all other samples in the 0- to 10-cm (0- to 4-inch) stratum in this deposit ranged from 400 to 7,800 ppb. In a statistical sense, the sample is an "outlier," but that does not imply error in the value of 99,000.

For fish, Green Bay Zone 1 and Zone 2 PCB exposures were found to be significantly different (Table 2-11). This difference was determined using two methods: 1) cross-sectional analyses, which compared fish PCB concentrations within a single year (e.g., 1989 data only) between the zones; and 2) estimating the significant differences between time trend slopes calculated separately for the two zones. Four out of five cross-sectional analyses showed statistically significant differences, either in the relationship of lipid content and PCB concentration or in the mean PCB concentration, while controlling for lipid content. All three time trend analyses comparing the two zones showed significantly different trends in the two reaches. Thus, the time trends in the two zones were handled separately.

For Zone 1, there appears to be a significant but slow rate of decline for most fish species tested with no breakpoint identified. The exception to this pattern were carp, which showed a breakpoint in 1995, and steep significant increases in PCB concentrations of 22 percent per year. Other fish tested within the reach included gizzard shad, northern pike, walleye (fillet and whole body), white bass, and white sucker. With the exception noted for carp, all species showed a rate of decline in PCB concentrations of between 5 and 10 percent annually. Combining all data showed that there is an average rate of decline of 7 percent per year.

Green Bay Zone 2

Zone 2 shows decreasing trends with no significant breakpoints in most species tested, including carp. Significant decreases of between 4 and 15 percent annually were found in alewife, carp, and yellow perch. The exception to this was gizzard shad, which showed a significant increasing trend of 6 percent PCBs in tissues per year (Table 2-11).

2.6.4 Conclusion

The objective of the time trends analysis was to determine if PCB concentrations in the Lower Fox River were decreasing over time. For PCB concentrations in surface sediment, the data suggest an overall decline. PCB concentrations in surface sediments in the Lower Fox River are generally decreasing over time, but apparent detectable loss is limited to the top 10 cm (4 inches) of sediment. The apparent declines observed in surface sediments is consistent with the continued observed transport of PCBs from the river to Green Bay, as discussed in Section 2.5. The rate of change in surface sediments is both reach- and deposit-specific. The change averages an annual decrease of 15 percent, but ranges from an increase of 17 percent to a decrease of 43 percent (Table 2-12). A large fraction of analyses provided little useful information for projecting future trends because of the lack of statistical significance and the wide confidence limits observed. This is especially true for sediments below the top 10 cm (4 inches); changes in the sediment PCB concentrations cannot be distinguished from zero, or no change.

PCB concentrations in fish are also generally decreasing over the analysis period. The changes in PCBs in the sediments are reflected in the significant but slow declines in fish tissue concentrations of between 5 and 7 percent annually. Exceptions to the general overall decline were noted with walleye in Little Lake Butte des Morts, carp in Green Bay Zone 1, and gizzard shad in Zone 2 where significant increases in PCB concentrations were observed. In all reaches, a breakpoint was observed in the fish tissue declines. The presence of an earlier slowing of rates of decrease in fish, along with a more recent phenomenon of changing trends in some species and sample types, suggests that fish time trends are changeable. Since PCBs in fish are derived from PCBs in sediment, the sediment rates of change may also be changeable.

It is important to note that the trends discussed are limited to the period of time for which data existed. These analyses are not suitable for projecting trends; the data do not provide the assurance of a future steady or rapid decline in PCB concentrations. Even though there are a number of negative time trends that suggest PCB declines, future projections of PCB concentrations in sediments and fish are highly uncertain. Over the period of data collection, surface sediments and fish species have, on the average, declined in PCB concentrations. Yet the presence of increases in PCB concentrations in deeper sediments, and of breakpoints and other non-linear phenomena in fish PCB time trends (on the log scale), suggest that the river, its sediment, and its species may be experiencing an arrest or reversal of such a decline. The analyzed data do not assure continued PCB decreases over time.

The time trends analysis dealt strictly with the testing of changes in PCB concentrations over time, and not with the mechanisms that could control changes in sediment and tissue loads. As discussed in Section 2.5, studies have shown that PCBs are being transported out of the Lower Fox River into Green

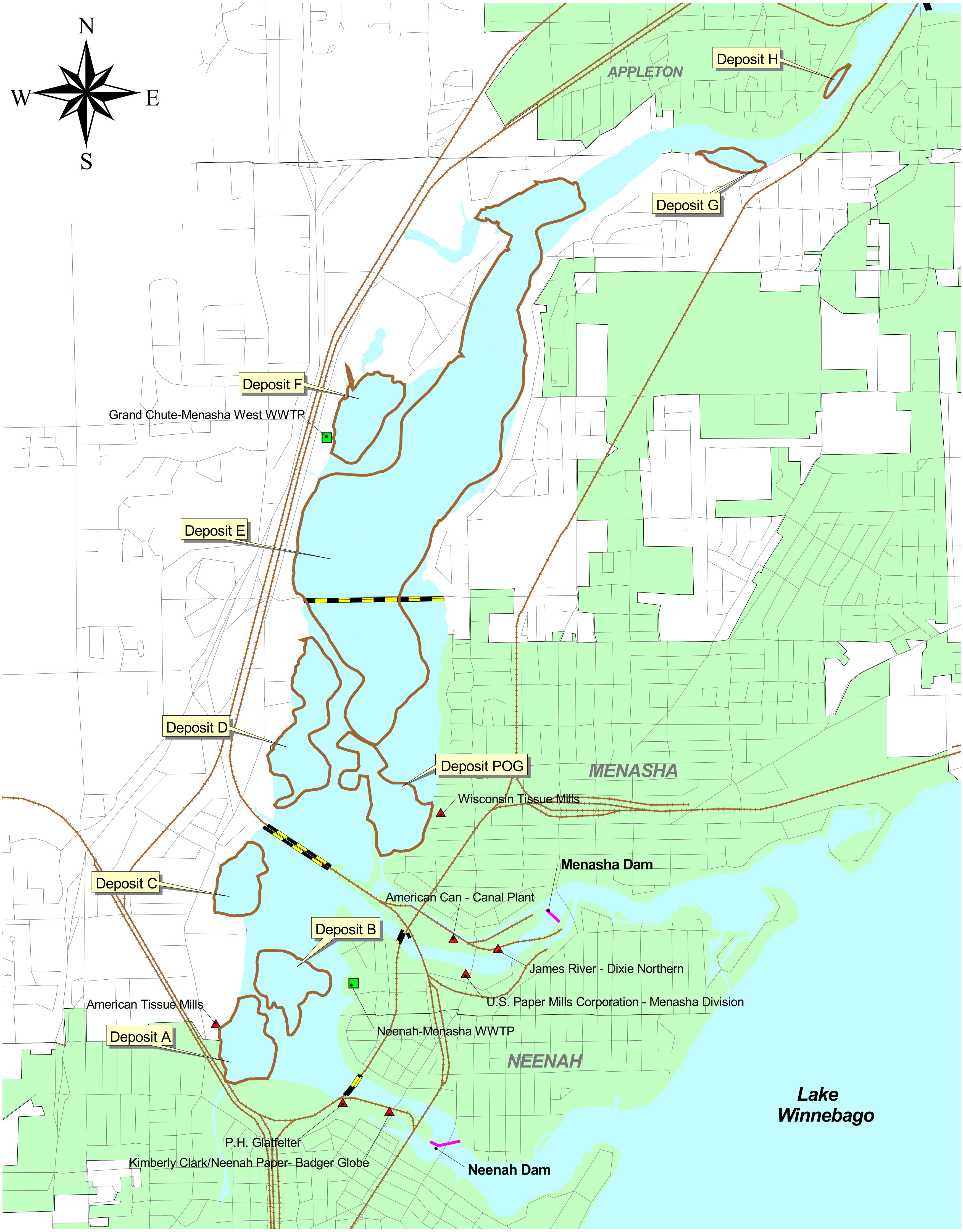
Bay, while PCBs in Green Bay migrate into Lake Michigan. Therefore, PCB dispersal is one factor in the observed PCB declines. In addition, some of the variability observed in the data may be accounted for by changes in river profile, burial, scour by flood or ice, and propeller wash in the lower reaches of the river. As the analysis focused solely on the existing data, these potential mechanisms could not be adequately controlled or accounted for.

The conclusions of a general decrease in PCB burdens in sediments and fish of the Lower Fox River and in Zone 1 of Green Bay are consistent with findings by other researchers in the Great Lakes. Deceases in PCB concentrations have been observed in Lake Michigan (Offenberg and Baker, 2000; DeVault *et al.*, 1996; Lamon *et al.*, 1998), Lake Ontario (DeVault *et al.*, 1996; Gobas *et al.*, 1995) and Lake Superior (Smith, 2000). The yearly rate of decline for PCBs in biota and sediment of Lake Superior has been estimated at 5 to 10 percent per year (Smith, 2000), which is generally consistent with the trends observed in the Lower Fox River (Table 2-12). However, several other researchers have also noted breakpoints, or constant levels of PCBs beginning in the mid- to late 1980s. Lake trout and smelt are reported to have been relatively constant in Lake Ontario since 1985 (Gobas *et al.*, 1995). PCB body burdens in Lake Erie walleye were shown to be declining between the periods of 1977 and 1982, but after that period remained constant through 1990 (DeVault *et al.*, 1996). Time tends analysis for salmonids in Lake Michigan showed generally decreasing tissue concentrations, but upper-bound forecast estimates for lake trout and chinook indicated that there would be a steady, or slightly increasing annual average PCB concentration. These findings are consistent with the time trends analysis for the Lower Fox River, and suggest that there may continue to be slow, gradual declines, or steady-state concentrations for many years to come.

Given the potential for disturbance and redistribution of sediments, which has been observed in the past due to scouring, there is a high degree of uncertainty in projecting future PCB concentrations in sediments and fish. Given this, coupled with similar observations for sediments and fish on other Great Lakes systems, there is too much uncertainty to apply the information to human health or ecological risk analysis. The current Fox River data shows wide confidence limits on slopes. Some important game fish such as walleye or carp, as well as forage fish (gizzard shad) show increasing PCB levels.

2.7 Section 2 Figures, Tables, and Plates

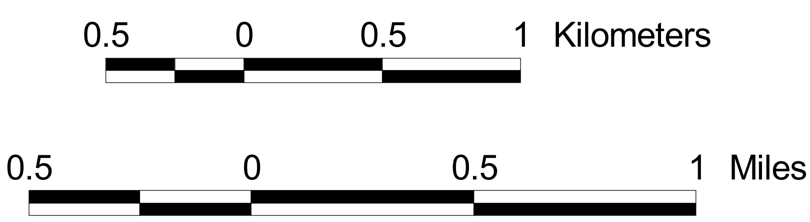
Figures, tables, and plates for Section 2 follow page 2-50 and include:

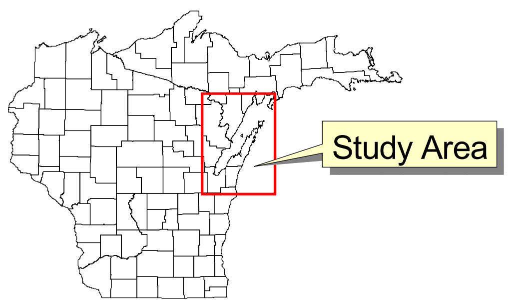


Point Source Locations
- Industrial
- Municipal
- Dam Locations
- Railroads
- Roads

Structures
- Locks
- Bridges
- Deposits
- County Boundaries
- Water

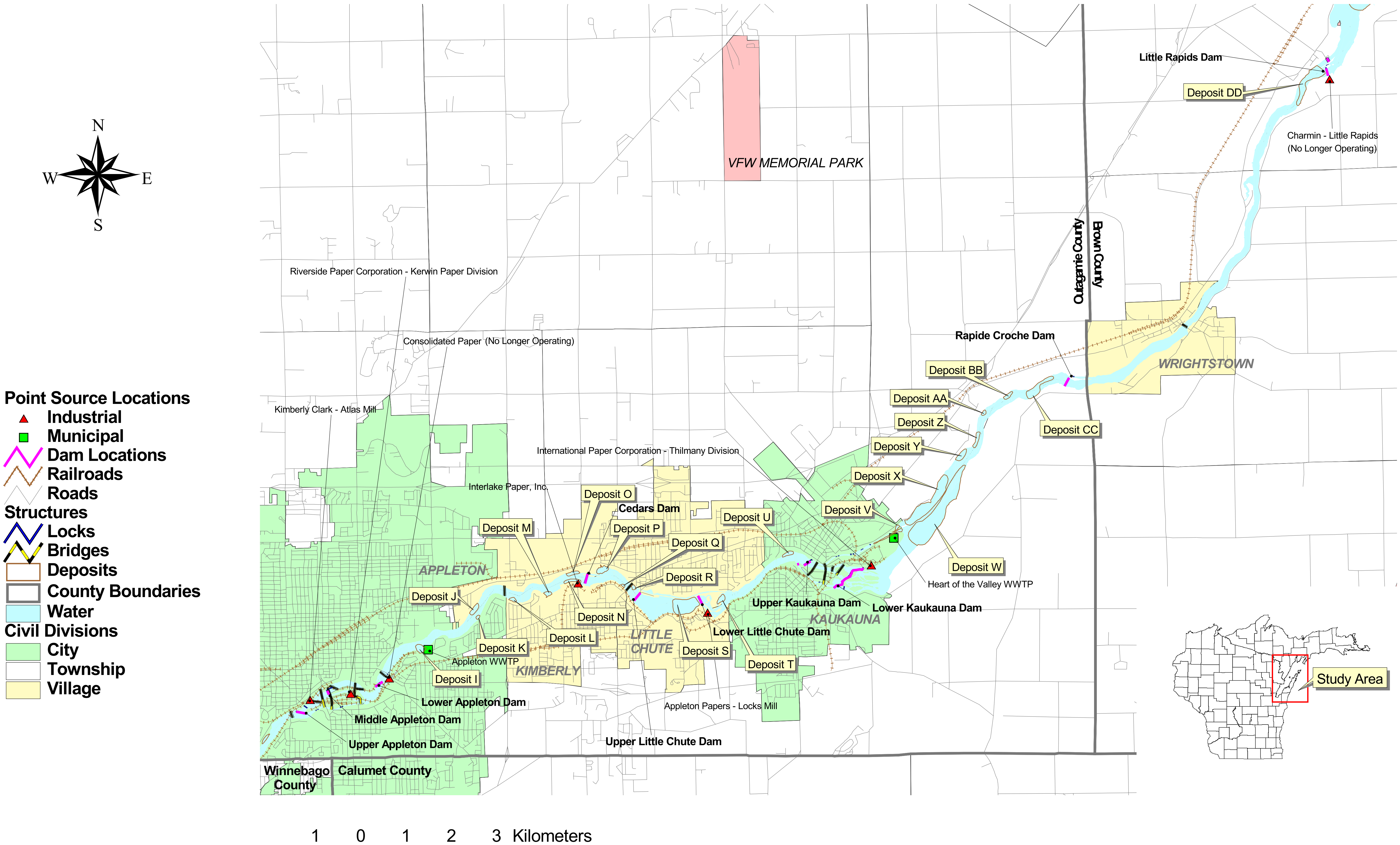
Civil Divisions
- City
- Township
- Village





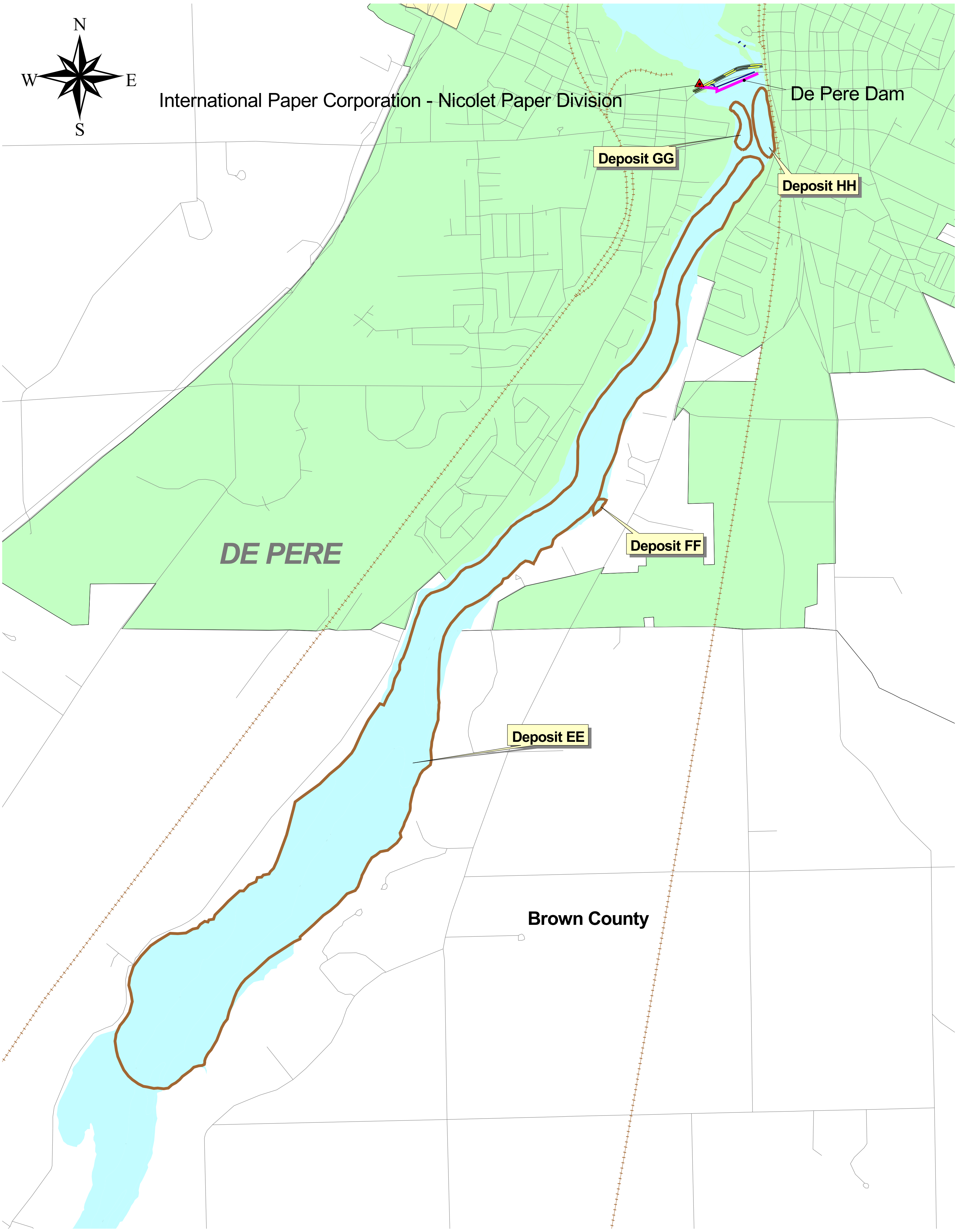
NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Little Lake Butte des Morts Reach	REF NO: FS-14414-535-2-1
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 2-1	APPROVED: AGF



NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

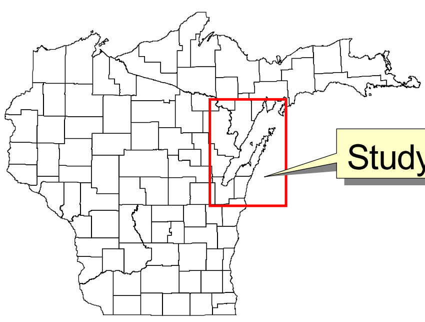
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Appleton to Little Rapids Reach	REF NO: FS-14414-535-2-2
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 2-2	APPROVED: AGF

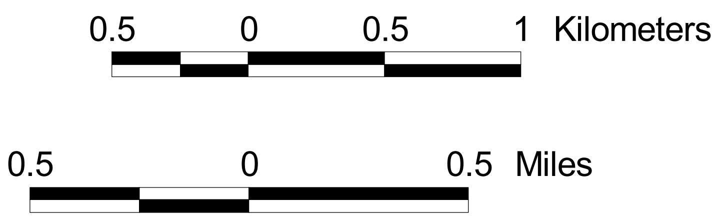


Point Source Locations
- Industrial
- Municipal
- Dam Locations
- Railroads
- Roads

Structures
- Locks
- Bridges
- Deposits
- County Boundaries
- Water

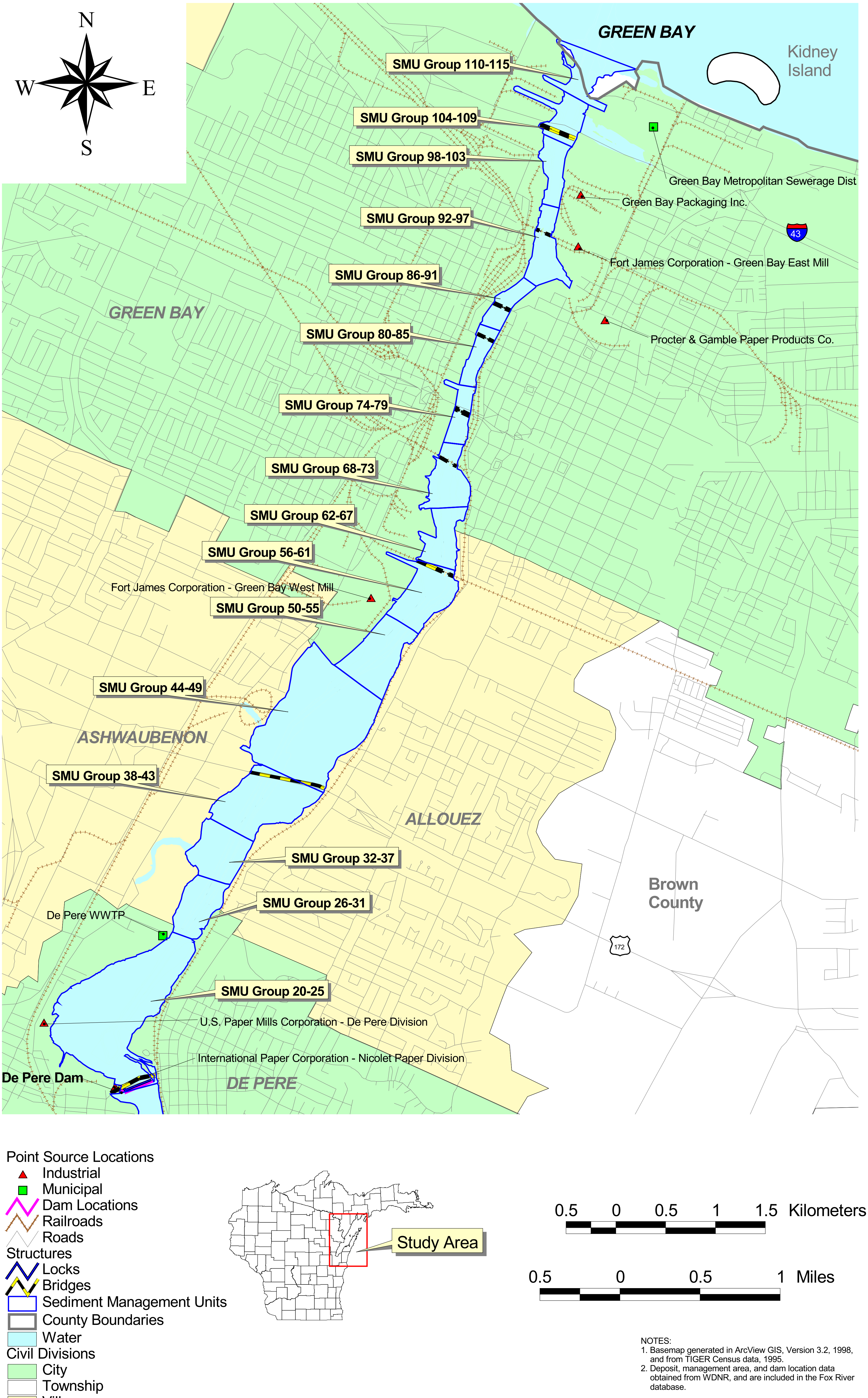
Civil Divisions
- City
- Township
- Village





NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Little Rapids to De Pere Reach	REF NO: FS-14414-535-2-3
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 2-3	APPROVED: AGF



ThermoRetec Smart Solutions. Positive Outcomes.

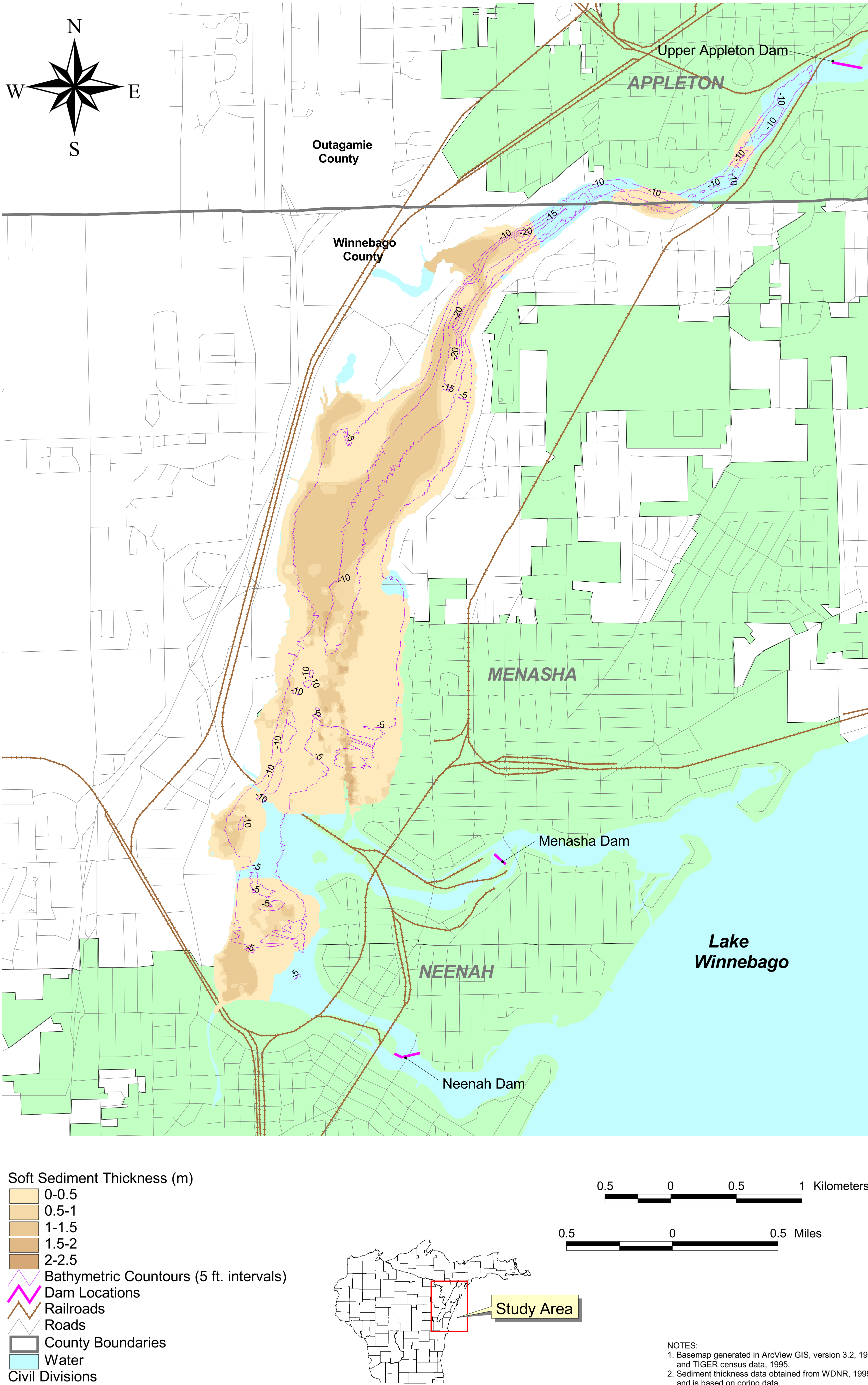
Natural Resource Technology

Lower Fox River & Green Bay Feasibility Study

De Pere to Green Bay Reach

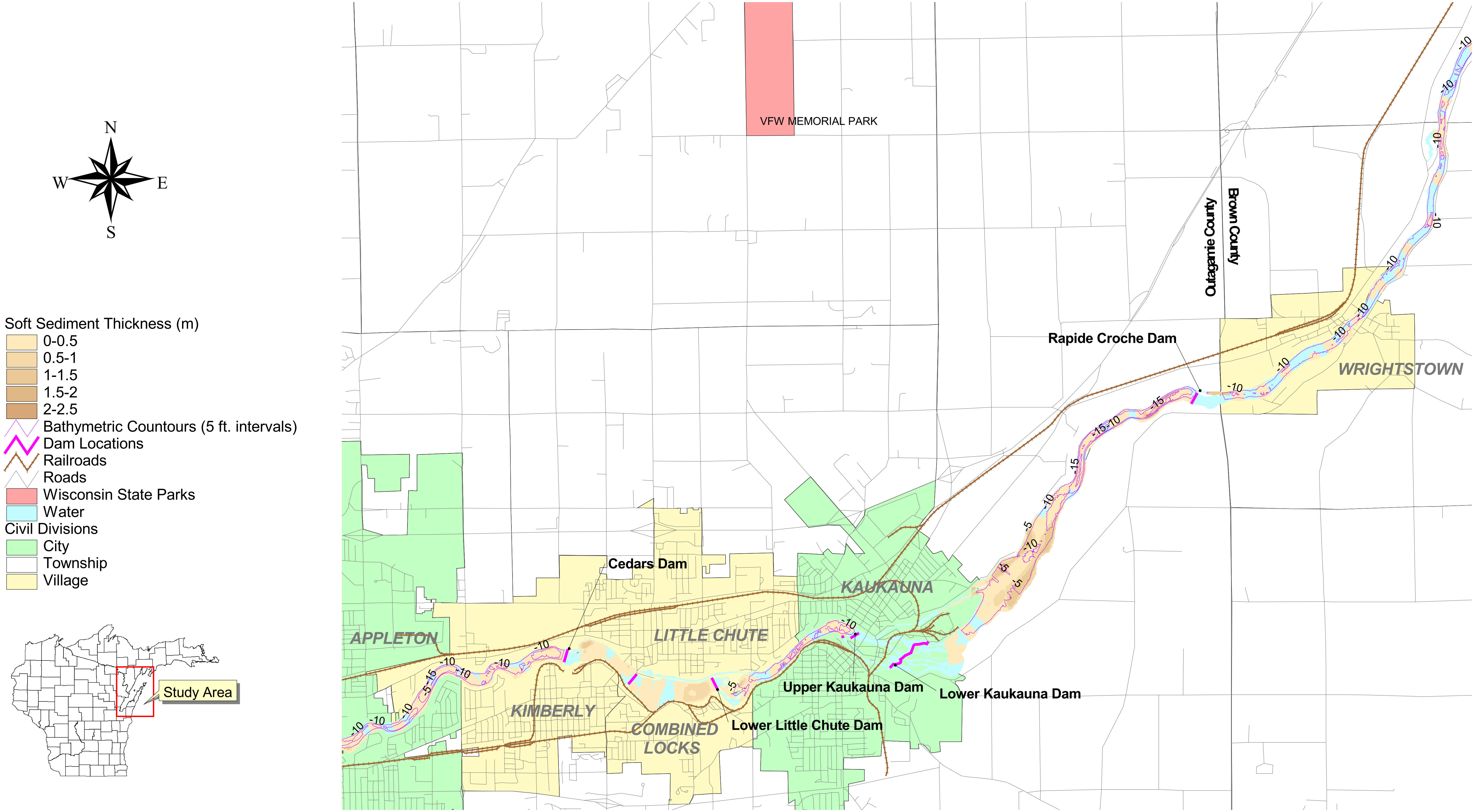
FIGURE 2-4

REF NO:	FS-14414-535-2-4
CREATED BY:	SCJ
PRINT DATE:	3/7/01
APPROVED:	AGF



NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Soft Sediment Thickness (m) and Bathymetry (ft): Little Lake Butte des Morts	REF NO: FS-14414-535-2-5
				CREATED BY: SCJ
				PRINT DATE: 3/9/01
			FIGURE 2-5	APPROVED: AGF

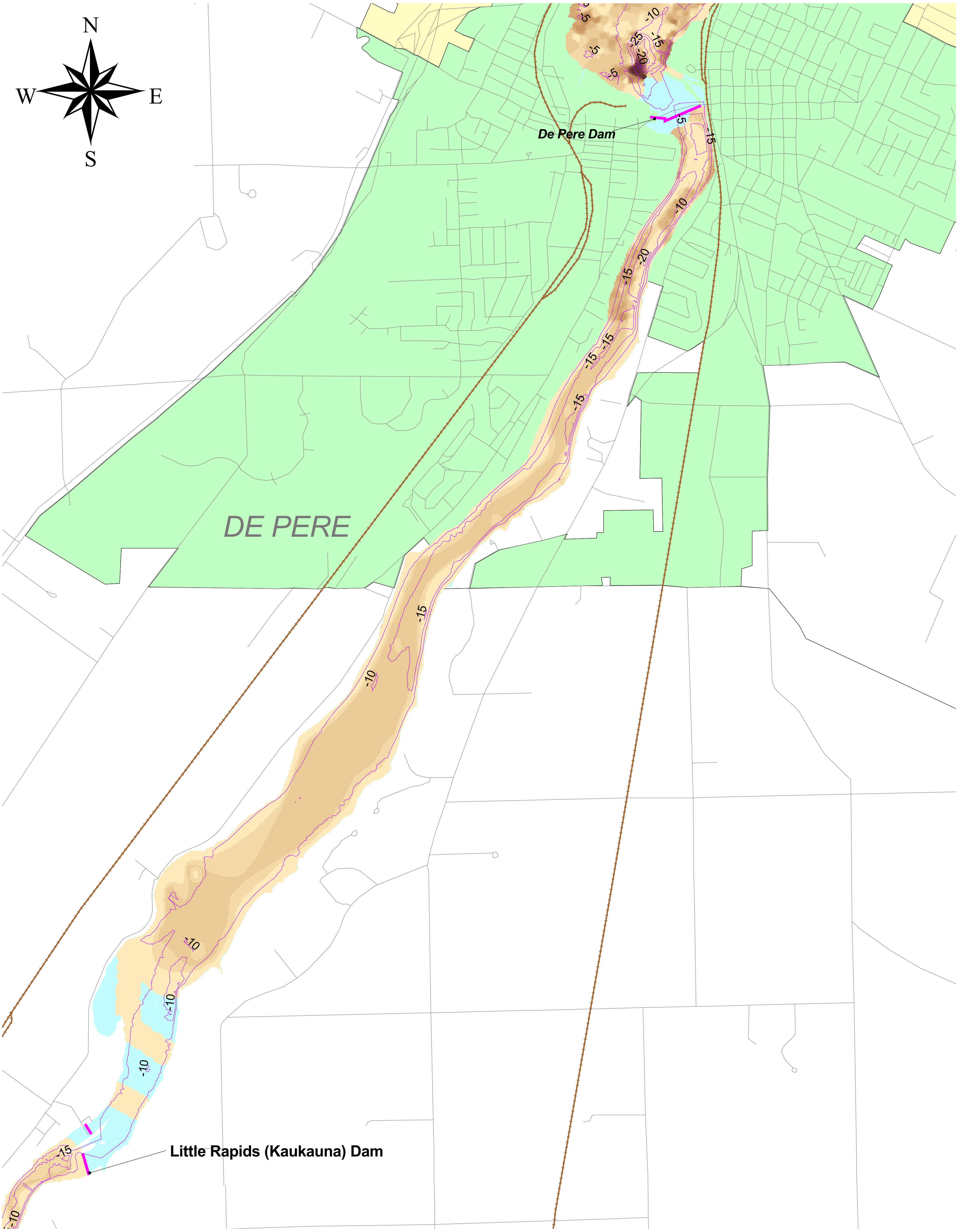


NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

1 0 1 2 Kilometers

1 0 1 2 Miles

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Soft Sediment Thickness (m) and Bathymetry (ft): Appleton to Little Rapids	REF NO: FS-14414-535-2-6 CREATED BY: SCJ PRINT DATE: 3/9/01 APPROVED: AGF
			FIGURE 2-6	

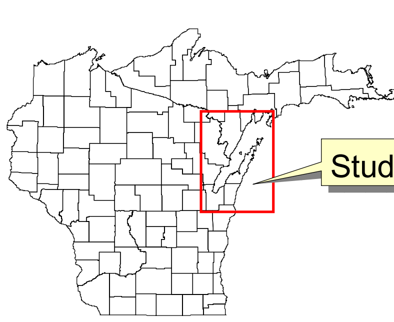


Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- Bathymetric Countours (5 ft. intervals)
- Dam Locations
- Railroads
- Roads
- County Boundaries
- Water

Civil Divisions
- City
- Township
- Village

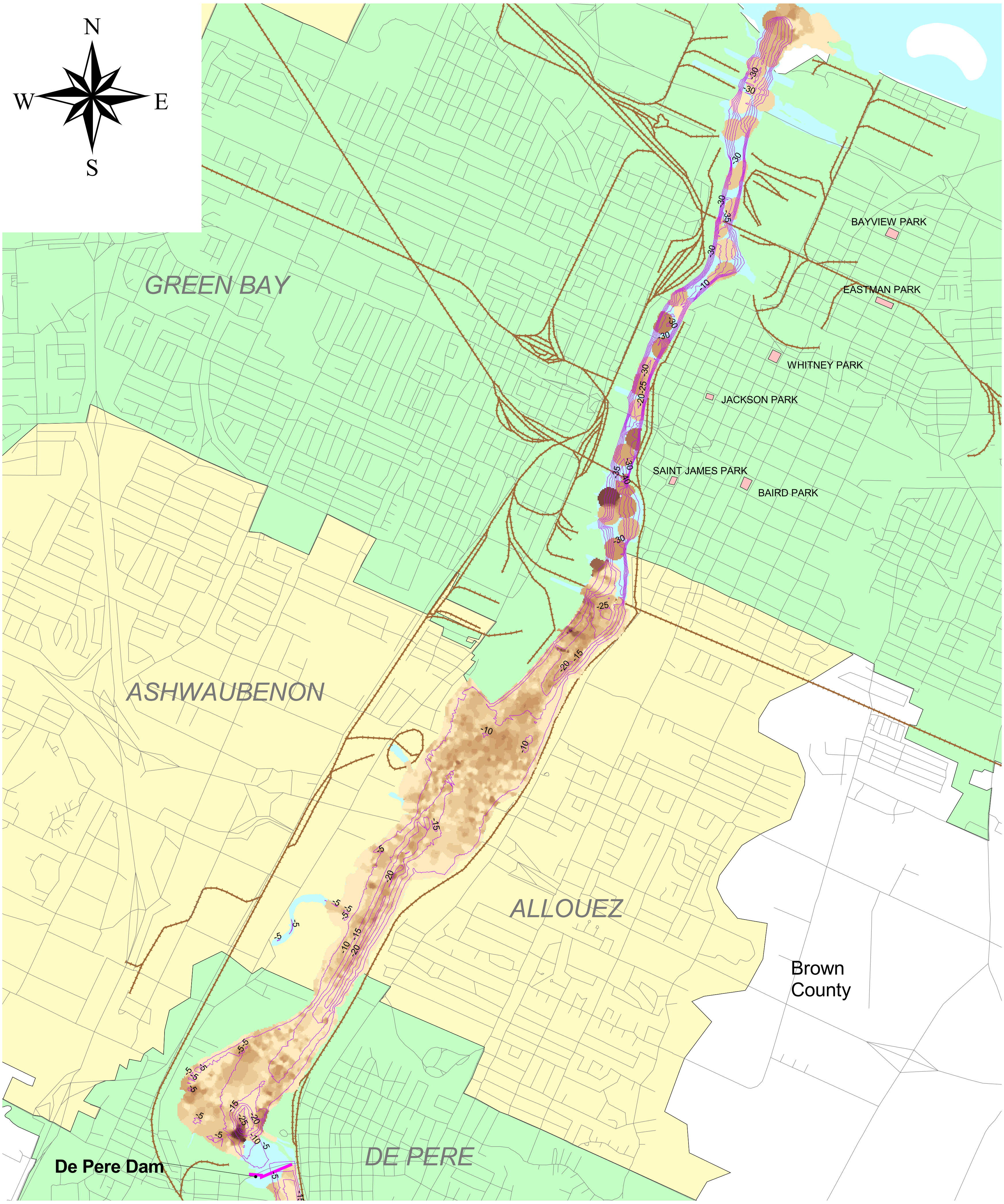
1 0 1 Kilometers

0.5 0 0.5 1 Miles



NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Soft Sediment Thickness (m) and Bathymetry (ft): Little Rapids to De Pere	REF NO: FS-14414-535-2-7
				CREATED BY: SCJ
				PRINT DATE: 3/9/01
			FIGURE 2-7	APPROVED: AGF

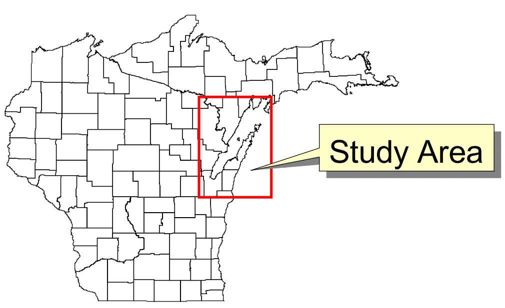


Soft Sediment Thickness (m)

- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- 2.5-3
- 3-3.5
- 3.5-4
- 4-4.5
- 4.5-5
- 5-5.5
- 5.5-6
- Bathymetric Countours (5 ft. intervals)
- Dam Locations
- Railroads
- Roads
- County Boundaries
- Wisconsin State Parks
- Water

Civil Divisions

- City
- Township
- Village

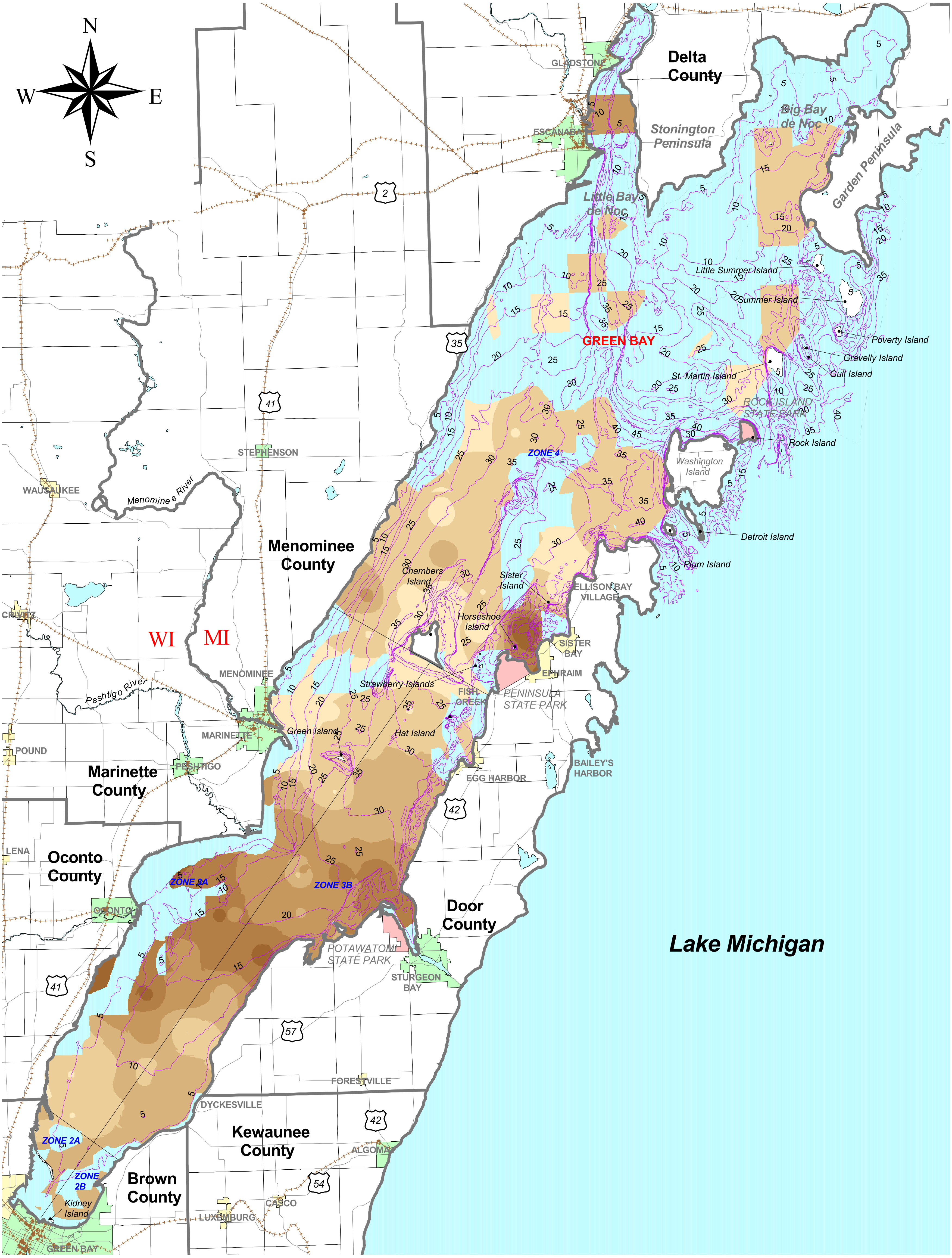


0.5 0 0.5 1 1.5 Miles

0.9 0 0.9 1.8 Kilometers

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Soft Sediment Thickness (m) and Bathymetry (ft): De Pere to Green Bay	REF NO: FS-14414-535-2-8
				CREATED BY: SCJ
				PRINT DATE: 3/9/01
			FIGURE 2-8	APPROVED: AGF



Soft Sediment Thickness (cm)

- 0 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- Bathymetric Contours (5 m intervals)
- Railroads
- Roads
- County Boundaries
- Wisconsin State Parks
- Water

Civil Divisions

- City
- Township
- Village

Study Area

5 0 5 10 15 Kilometers

5 0 5 10 15 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

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Natural Resource Technology

Lower Fox River & Green Bay Feasibility Study

Soft Sediment Thickness (cm) and Bathymetry (m): Green Bay

FIGURE 2-9

REF NO:	FS-14414-535-2-9
CREATED BY:	SCJ
PRINT DATE:	3/12/01
APPROVED:	AGF

Figure 2-10 Lower Fox River Elevation Profile

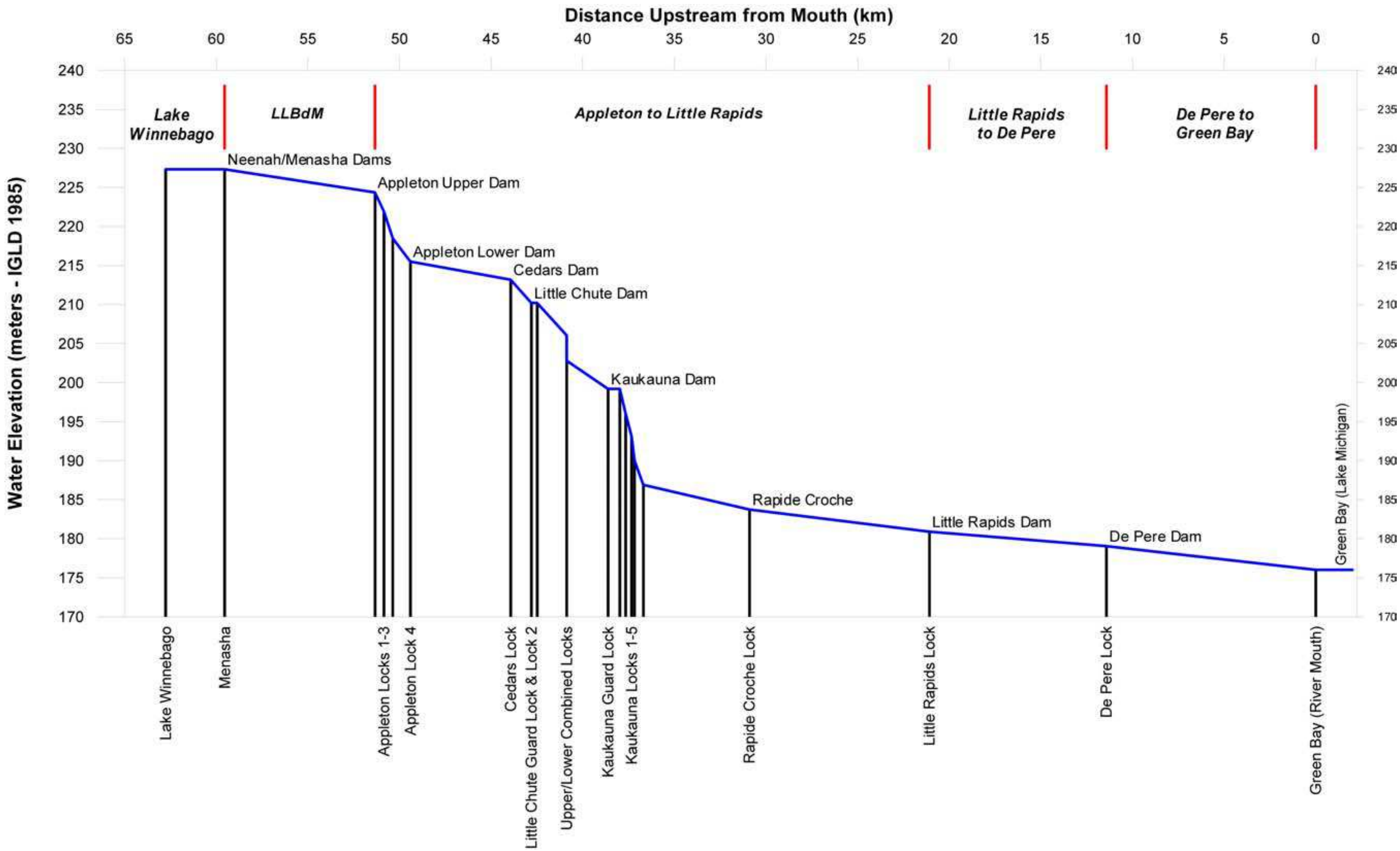


Figure 2-11 Green Bay Monthly Mean Bottom Circulation—July 1989

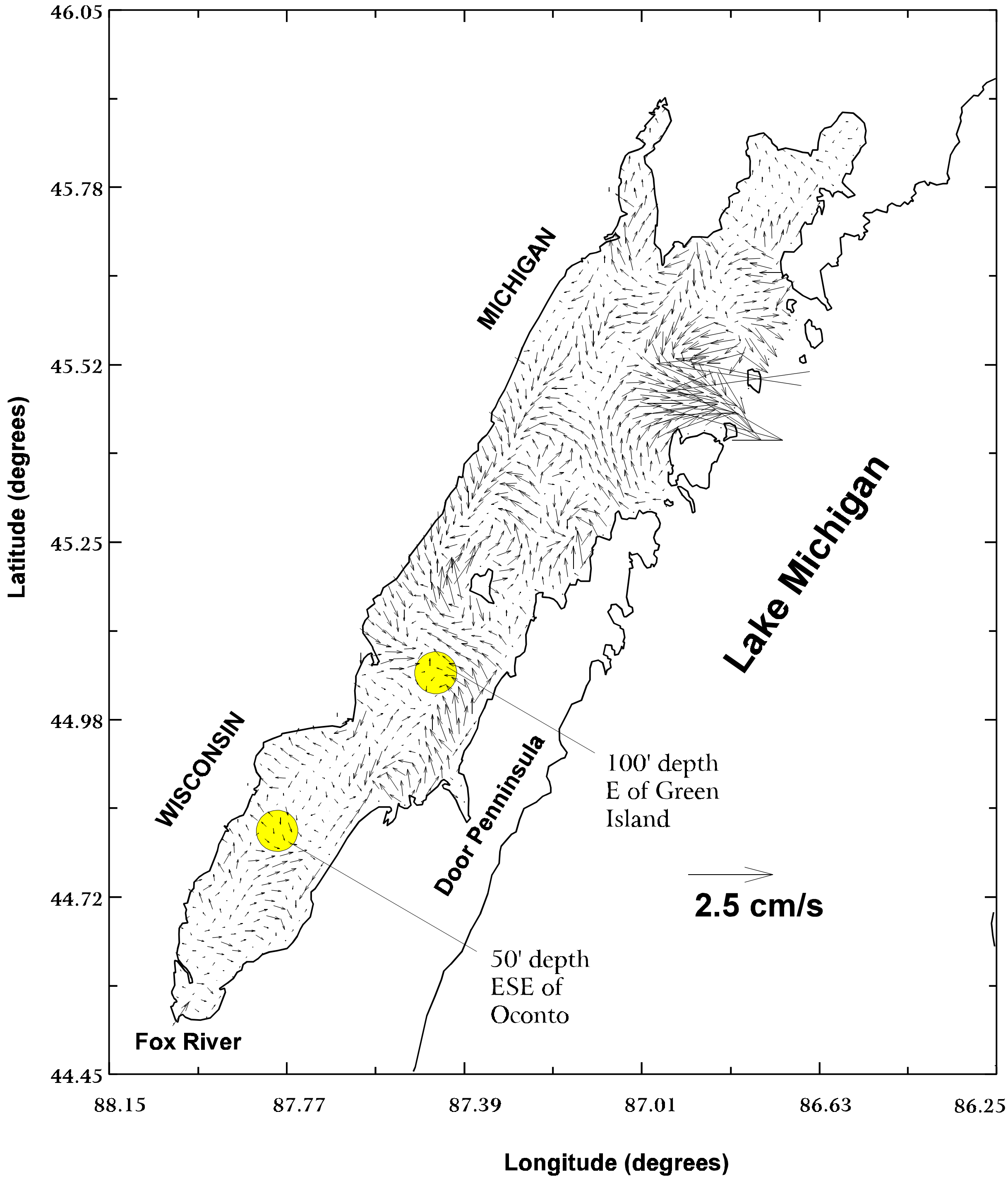


Figure 2-12 Green Bay Monthly Mean Bottom Circulation—August 1989

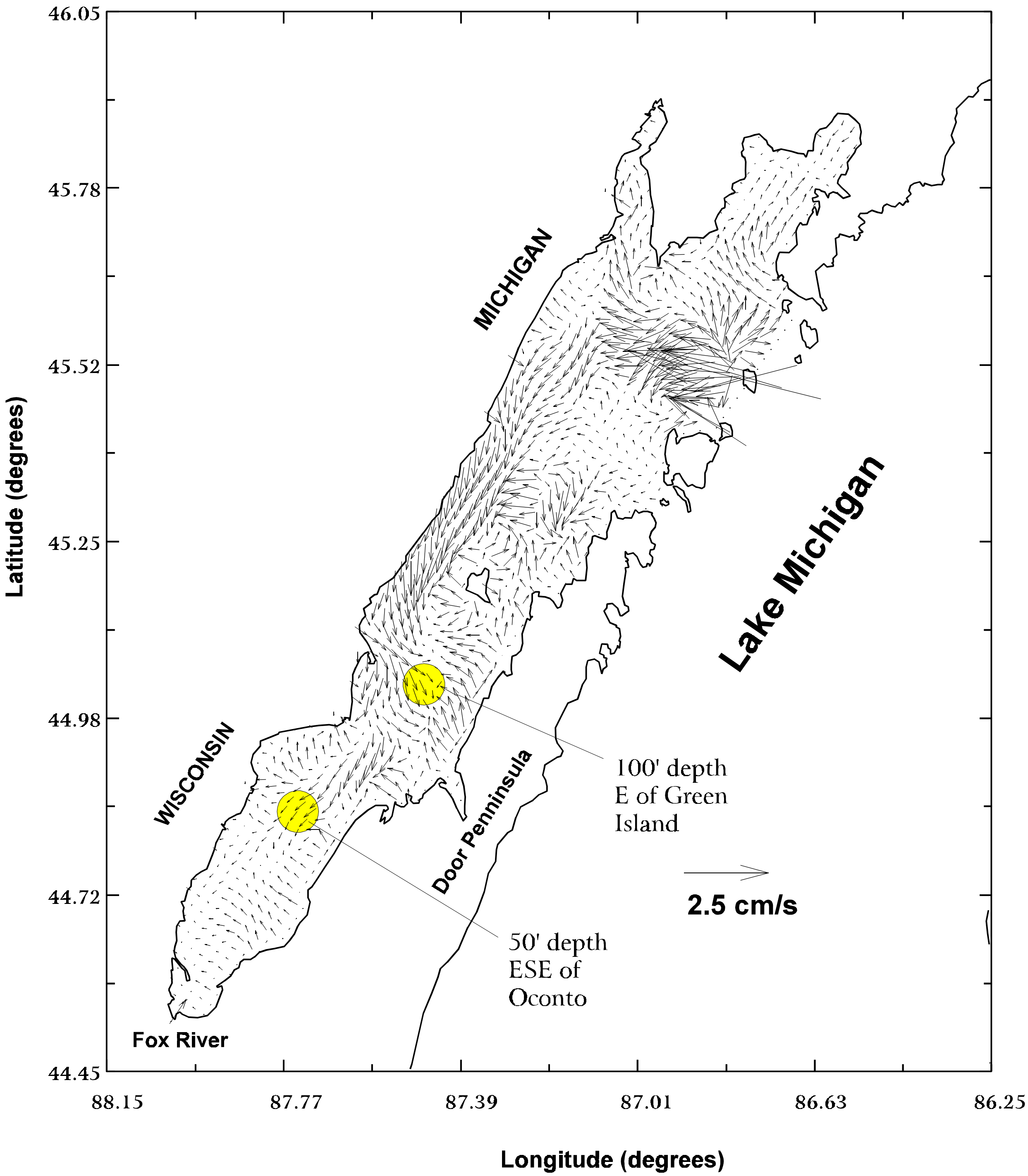
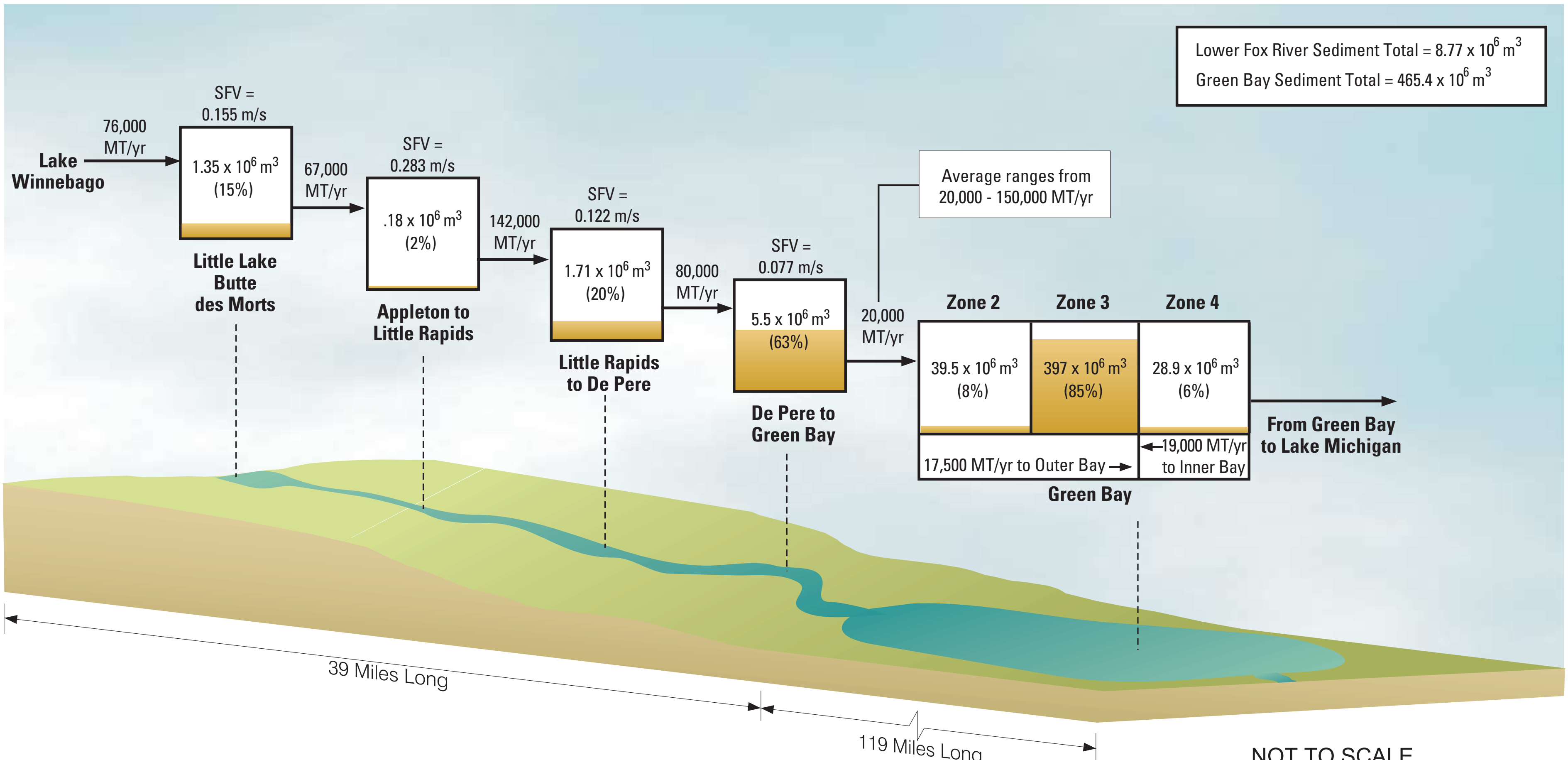


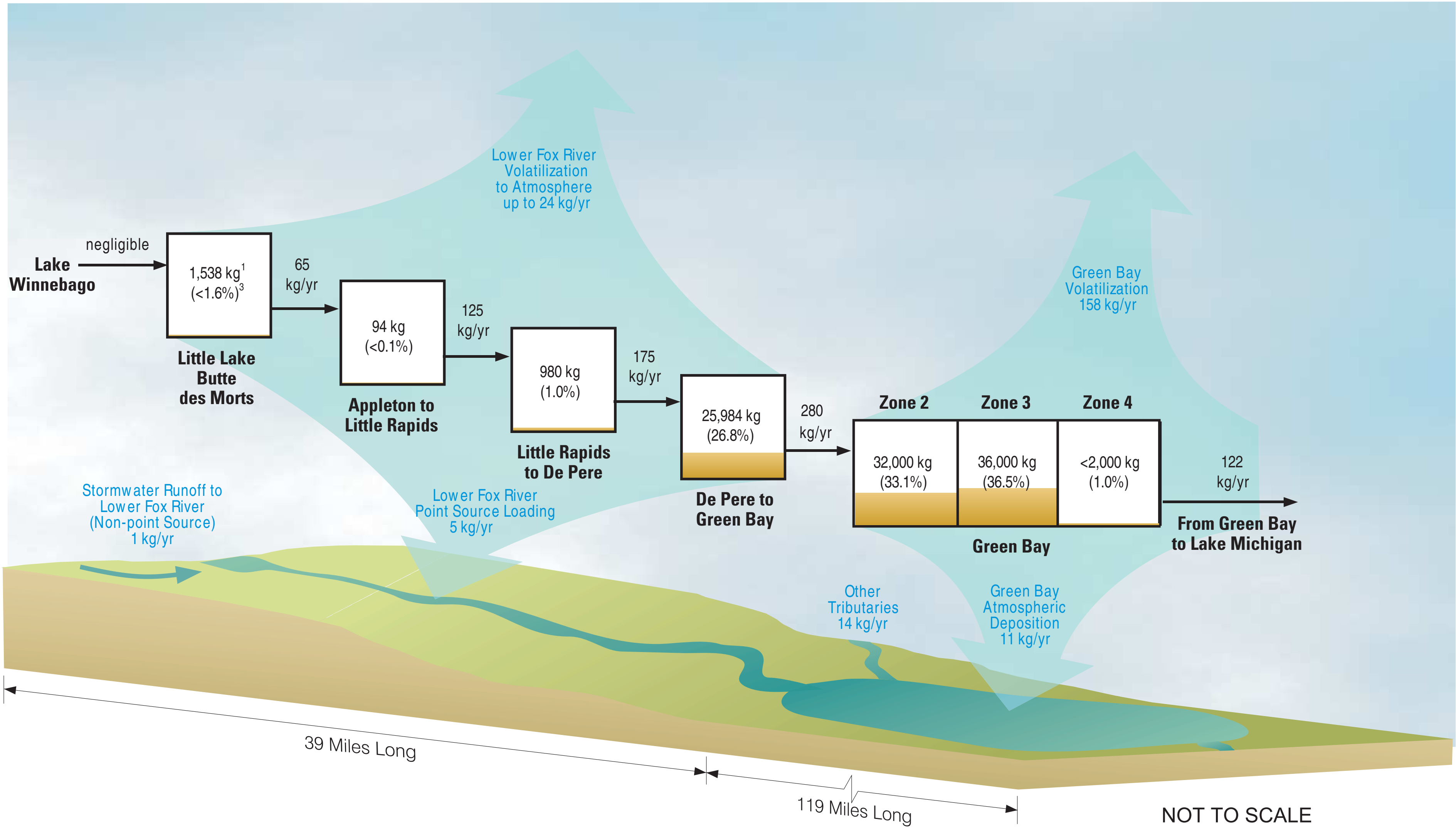
Figure 2-13 Estimated Annual Sediment Transport Rates and Stream Flow Velocities



Notes: 1. Sediment volumes contain PCB concentrations > 50 µg/kg PCBs.
2. MT/yr = metric ton per year.
3. Data source for discharge rates is Steuer *et al.*, 1995.
4. Percentages correspond to fraction of total sediment volumes residing in each river reach or bay zone. Volume estimates obtained from RI Tables 5-13, 5-14 and 5-15 (ThermoRetec, 2001a).
5. SFV = Stream Flow Velocity.
6. The average Stream Flow Velocity for the entire Lower Fox River is 0.137 m/s.
7. 1 x $10^6 m^3$ = one million cubic meters of sediment

F:\PROJECTS\DOCS\4414\DOC\FS\DRAFT\FIGURES\SEC2\SEC2FIGS.PDF

Figure 2-14 Lower Fox River and Green Bay System Estimated PCB Mass and Major PCB Flux Pathways



Notes: 1. PCB mass in sediments with PCB concentrations of 50 µg/kg or more.
2. Flux rates are average estimated loading rates per year.
3. Percentages correspond to fraction of total PCB mass in project area residing in each reach or zone. PCB mass estimates obtained from Tables 5-13, 5-14 and 5-15 in the Remedial Investigation.
4. Estimate of PCB loads from WDNR 1995 and www.epa.gov/med/images/gbmassbal.gif

Figure 2-15 Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm

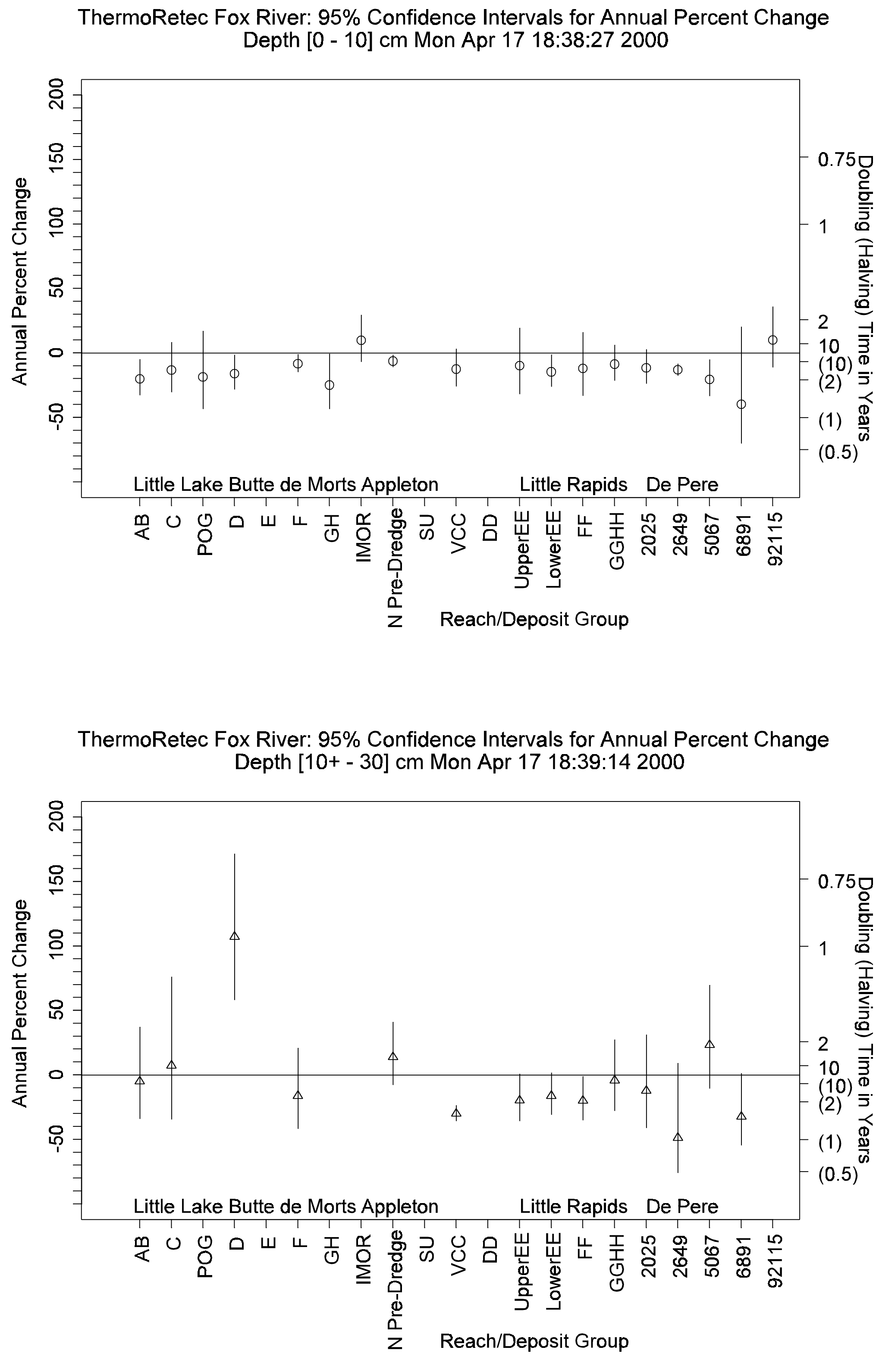
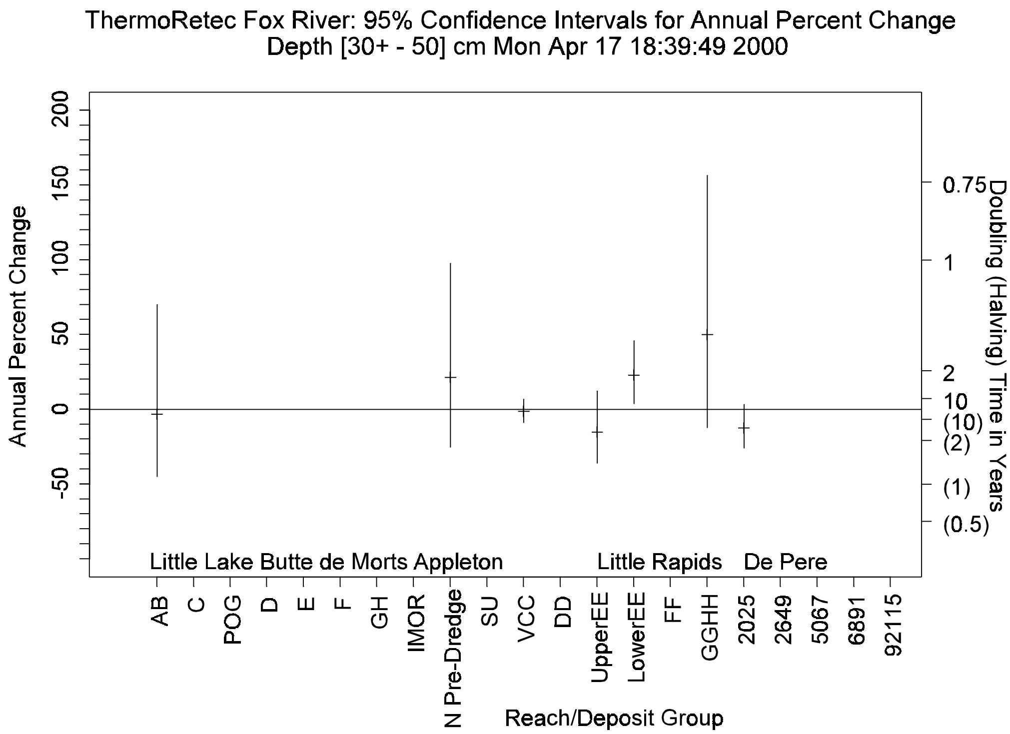


Figure 2-16 Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm



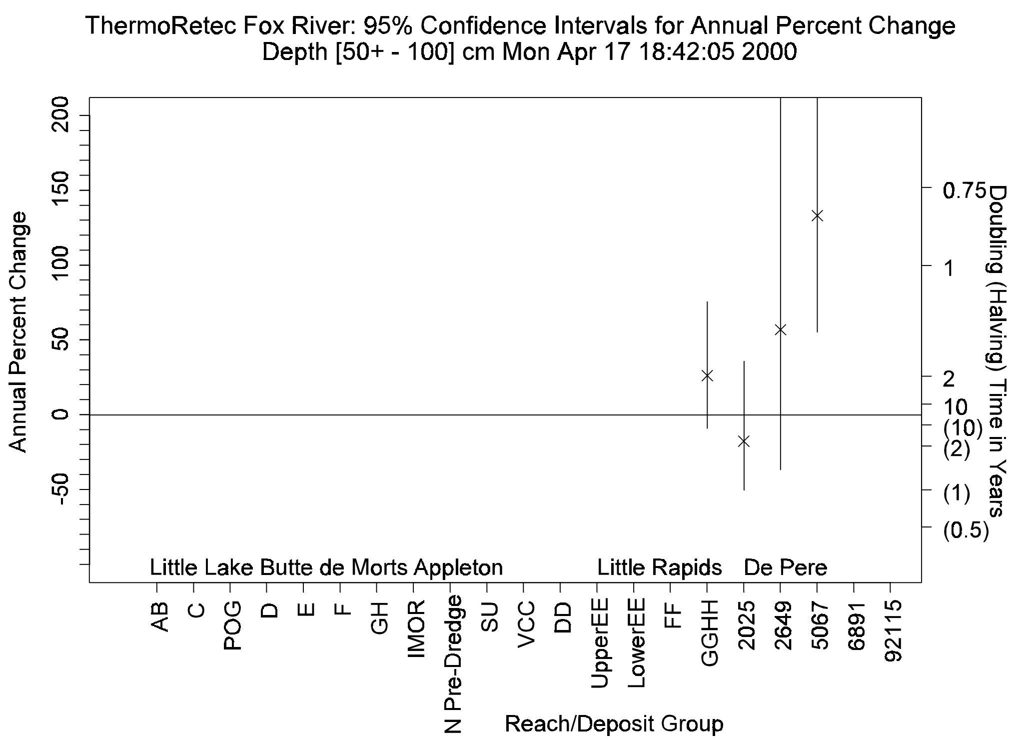


Figure 2-17 Time Trends of PCBs in Sediments for Depths over 100 cm

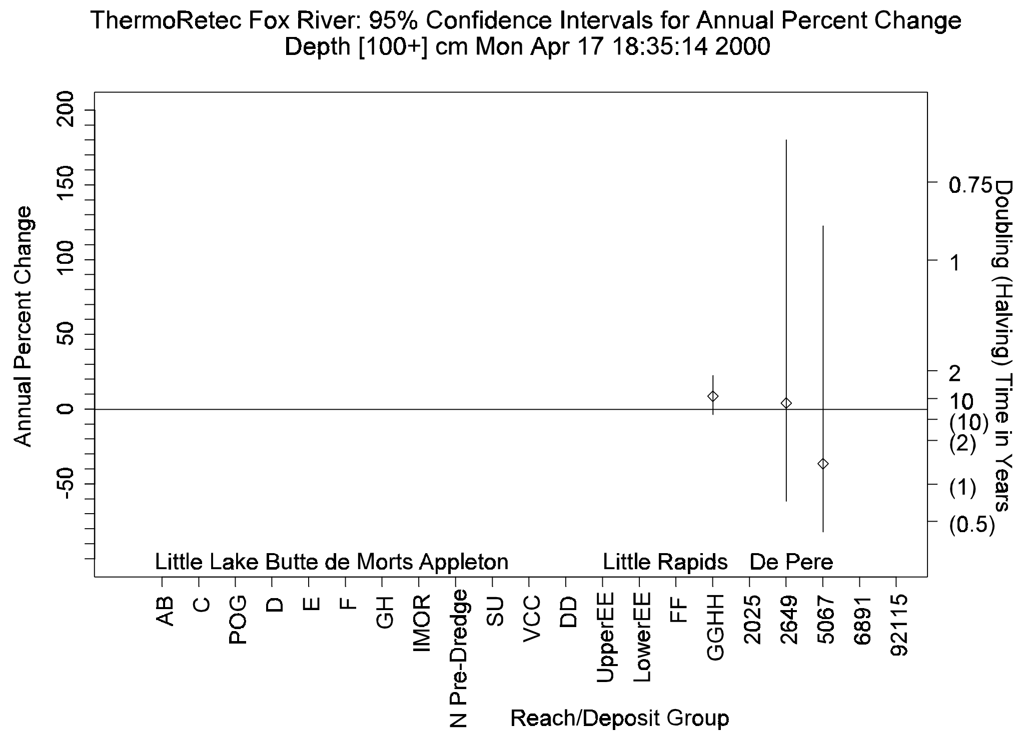


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Table 2-1 Physical Characteristics of the Lower Fox River

Deposit or SMU Group	Total PCB Mass [1] (kg)	Areal Extent				Hydraulic Parameters		Grain Size (all Depths) [5]				Percent Moisture	Average Dry Bulk Density (g/cc)	Specific Gravity
		Surface Area [1] (hectares)	Average Thickness (m) [2]	Maximum PCB Sample Depth (m) [2]	Volume [1] (m^3)	Average Flow [3] (m/s)	100-year Peak [4] (m/s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)			
Little Lake Butte des Morts Reach														
Reach Total	**1,847.4**	**313.5**	**0.39**	**1.89**	**1,533,205**	**0.16**	**0.82**	**0.6**	**45.7**	**39.0**	**14.7**	**64**	**0.61**	**2.51**
A	237.4	15.3	0.71	1.80	107,730	0.19	1.07	0.0	37.5	45.2	17.3	—	0.59	NA
B	410.9	14.7	0.28	0.43	41,740	0.15	0.85	0.0	64.7	25.1	10.1	—	1.00	NA
C	38.9	12.4	0.48	0.91	59,230	0.09	0.50	0.0	26.1	53.8	20.1	—	0.42	2.59
D	82.6	25.2	0.26	1.22	66,710	0.08	0.44	0.3	43.8	44.1	11.9	—	0.62	NA
E	452.8	202.5	0.43	1.74	869,910	0.08	0.45	0.3	27.7	50.2	21.8	—	0.53	2.43
F	10.9	16.9	0.57	1.83	95,920	0.10	0.55	0.0	27.1	50.8	22.1	—	0.31	NA
G	0.7	4.1	0.20	0.30	8,380	0.35	1.10	0.0	55.7	31.0	13.3	—	0.68	NA
H	0.7	1.1	0.06	0.38	690	0.35	1.95	0.0	67.7	20.3	12.0	—	0.91	NA
POG	303.5	21.3	0.48	1.89	103,030	0.09	0.50	2.2	57.4	34.4	6.0	—	0.40	NA
IDAs [6]	309.0	NA	NA	0.15	179,865	NA	NA	3.2	49.3	35.6	12.0	—	NA	NA
Appleton to Little Rapids Reach														
Reach Total	**108.5**	**153.1**	**0.13**	**1.83**	**197,015**	**0.22**	**1.22**	**0.0**	**40.5**	**40.3**	**19.2**	**55**	**0.71**	**2.44**
I	0.2	3.0	0.12	0.54	3,570	0.30	1.67	0.0	35.0	45.3	19.8	—	0.81	NA
J	0.1	2.5	0.06	0.42	1,630	0.30	1.67	0.0	15.0	65.7	19.3	—	0.65	NA
K	0.1	0.5	0.09	0.21	480	0.30	1.67	0.0	62.7	22.3	15.0	—	0.77	NA
L	0.1	1.1	0.05	0.30	570	0.21	1.17	0.0	45.3	34.0	20.8	—	1.02	NA
M	0.2	1.3	0.12	0.36	1,650	0.21	1.17	0.0	7.3	63.3	29.3	—	0.46	NA
N	29.6	2.3	0.22	0.89	4,880	0.21	1.17	0.5	41.1	46.9	11.6	—	—	NA
O	2.0	1.9	0.13	0.35	2,430	0.21	1.17	0.0	39.4	43.6	17.0	—	0.57	NA
P	5.3	3.1	0.41	0.94	12,800	0.21	1.17	0.0	36.0	49.6	14.4	—	0.67	NA
Q	0.2	0.4	0.05	0.55	210	0.21	1.17	0.0	49.0	39.7	11.3	—	0.49	NA
R	0.0	0.8	0.13	0.13	990	0.21	1.17	0.0	12.0	56.0	32.0	—	0.99	NA
S	0.1	16.6	0.08	0.34	12,550	0.23	1.26	0.0	46.5	36.0	17.5	—	0.54	NA
T	11.3	2.1	0.40	0.52	8,360	0.21	1.18	0.0	87.7	7.3	5.0	—	0.46	NA
U	0.2	1.7	0.03	0.26	600	0.21	1.18	0.0	51.8	35.8	12.5	—	0.76	NA
V	0.0	2.4	0.00	0.63	60	0.15	0.82	0.0	32.2	52.0	15.8	—	0.41	NA
W	6.8	56.4	0.09	1.52	53,490	0.16	0.87	0.0	50.1	32.5	17.4	—	0.66	2.34
X	2.5	25.6	0.12	1.83	30,820	0.16	0.87	0.0	33.2	52.8	14.0	—	0.52	2.54
Y	0.3	3.2	0.04	0.34	1,330	0.17	0.93	0.0	45.0	39.7	15.3	—	0.67	NA
Z	0.4	2.4	0.18	0.83	4,280	0.17	0.93	0.0	34.7	42.7	22.7	—	0.76	NA
AA	0.0	0.8	0.05	0.35	390	0.27	1.49	0.0	54.7	20.7	24.7	—	1.18	NA
BB	0.1	1.6	0.05	0.39	780	0.27	1.49	0.0	47.7	33.0	19.3	—	0.93	NA
CC	0.7	8.5	0.17	0.43	14,300	0.27	1.49	0.0	31.3	26.0	42.7	—	0.92	NA
DD	33.5	14.9	0.19	0.53	28,620	0.19	1.04	0.0	32.6	42.1	25.3	—	0.65	NA
IDAs [6]	14.8	NA	NA	0.10	12,225	NA	NA	NA	NA	NA	NA	—	NA	NA

Table 2-1 Physical Characteristics of the Lower Fox River (Continued)

Deposit or SMU Group	Total PCB Mass[1] (kg)	Areal Extent: Surface Area[1] (hectares)	Areal Extent: Average Thickness (m)[2]	Areal Extent: Maximum PCB Sample Depth (m)[2]	Areal Extent: Volume[1] (m^3)	Hydraulic Parameters: Average Flow[3] (m/s)	Hydraulic Parameters: 100-year Peak[4] (m/s)	Grain Size (all Depths)[5]: Gravel (%)	Grain Size: Sand (%)	Grain Size: Silt (%)	Grain Size: Clay (%)	Percent Moisture	Average Dry Bulk Density (g/cc)	Specific Gravity
Little Rapids to De Pere Reach														
Reach Total	**1,245.5**	**266.2**	**0.55**	**2.30**	**1,932,690**	**0.12**	**0.68**	**1.6**	**25.1**	**48.1**	**25.2**	**64**	**0.56**	**2.47**
EE	828.4	258.8	0.64	2.30	1,660,390	0.12	0.68	0.5	26.8	49.7	23.0	—	0.50	2.47
FF	0.1	0.5	0.14	0.46	700	0.12	0.68	0.0	27.2	51.6	21.1	—	0.72	NA
GG	81.0	2.4	0.76	2.30	18,320	0.12	0.68	1.2	18.0	57.6	23.1	—	0.48	NA
HH	70.2	4.5	0.66	2.30	29,550	0.12	0.68	2.8	21.7	57.1	18.4	—	0.53	NA
IDAs[6]	265.8	NA	NA	1.83	223,730	NA	NA	3.7	31.9	24.3	40.1	—	NA	NA
De Pere to Green Bay Reach														
Reach Total	**25,983.8**	**523.6**	**1.06**	**3.96**	**5,518,180**	**0.08**	**0.44**	**0.0**	**42.5**	**40.6**	**16.9**	**51**	**0.57**	**2.36**
20 to 25	5,557.3	113.4	0.93	2.13	1,054,580	0.07	0.39	0.0	42.3	42.5	15.2	—	0.60	2.32
26 to 31	761.2	22.0	0.75	2.13	166,230	0.11	0.61	0.0	50.8	34.5	14.7	—	NA	NA
32 to 37	1,172.9	26.8	0.87	2.74	233,230	0.10	0.53	0.0	31.8	49.9	18.3	—	0.34	NA
38 to 43	1,149.5	46.5	0.87	2.74	402,360	0.08	0.43	0.0	34.5	47.4	18.1	—	0.50	NA
44 to 49	5,211.2	107.2	1.29	3.35	1,379,690	0.07	0.37	0.0	37.8	44.6	17.6	—	0.59	2.40
50 to 55	1,829.7	32.9	1.23	1.52	405,280	0.08	0.47	0.0	40.5	44.2	15.3	—	0.55	NA
56 to 61	5,174.7	29.7	1.54	3.96	457,490	0.06	0.36	0.0	32.1	51.9	16.0	—	0.65	NA
62 to 67	861.3	18.2	1.05	2.13	190,570	0.07	0.37	0.0	29.8	51.7	18.6	—	NA	NA
68 to 73	1,858.2	21.6	1.56	2.74	337,250	0.06	0.37	0.5	34.8	41.6	23.1	—	0.39	NA
74 to 79	430.2	11.8	1.20	1.52	141,950	0.07	0.38	0.0	34.8	42.2	23.0	—	0.71	NA
80 to 85	385.3	10.6	1.55	2.13	164,650	0.09	0.49	0.0	45.4	36.8	17.8	—	NA	NA
86 to 91	253.1	11.3	0.92	2.13	103,400	0.08	0.45	0.0	45.5	37.6	17.0	—	0.78	NA
92 to 97	254.8	19.8	0.60	0.91	118,500	NA	NA	0.0	60.3	27.9	11.8	—	0.62	NA
98 to 103	94.3	14.0	0.59	0.91	82,200	NA	NA	0.0	73.2	17.8	9.0	—	NA	NA
104 to 109	151.1	17.0	0.44	0.30	74,550	NA	NA	0.0	41.7	40.5	17.8	—	0.63	NA
110 to 115	839.0	20.8	1.52	1.52	206,250	NA	NA	0.0	44.2	38.9	16.9	—	0.50	NA
Entire River Values[7]	**29,185**	**1,256**	**0.53**	**3.96**	**9,181,090**	**0.15**	**0.79**	**0.6**	**38.4**	**42.0**	**19.0**	**59**	**0.61**	**2.45**

Notes:

1. Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.
2. The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval.
3. The average flow for the river is 122 m^3/s.
4. The 100-year peak stream flow is 680 m^3/s.
5. Grain size results are averaged for all samples collected, regardless of depth. Gravel content is difference of 100 and sum of sand/silt/clay content.
6. IDAs are inter-deposit areas in each reach.
7. Physical characteristics generated from data in the Fox River Database (except flow) and may vary from PCB mass and volume estimates generated in later sections for remediation.
8. NA - Parameter value or average value is not available.
9. "—" - Percent moisture value averaged for reach.

Table 2-2 Physical Characteristics of Green Bay

Deposit or Zone	Total PCB Mass[1] (kg)	Areal Extent: Surface Area[1] (hectares)	Areal Extent: Average Thickness (m)[2]	Areal Extent: Maximum PCB Sample Depth (m)[2]	Areal Extent: Volume[1] (m^3)	Hydraulic Parameters: Average Flow[3] (m/s)	Hydraulic Parameters: 100-year Peak[4] (m/s)	Grain Size (all Depths): Gravel (%)	Grain Size (all Depths): Sand (%)	Grain Size (all Depths): Silt (%)	Grain Size (all Depths): Clay (%)	Percent Moisture	Average Bulk Density (g/cc)	Specific Gravity
Bay Totals	**67,556**	**421,288**	**0.25**	**0.91**	**465,396,800**	**0.05**	**unknown**	**0.4**	**82.7**	**11.4**	**5.6**	**NA**	**NA**	**NA**
2A	14,118	5,931	0.34	0.91	20,033,600	0.05	unknown	0.1	73.3	18.0	8.6	NA	NA	NA
2B	17,273	5,150	0.38	0.91	19,458,000	0.05	unknown					NA	NA	NA
3A	18,537	85,891	0.21	0.30	181,301,800	0.05	unknown	0.0	98.4	0.8	0.9	NA	NA	NA
3B	16,703	69,339	0.31	0.62	215,681,400	0.05	unknown	0.1	62.7	24.9	12.4	NA	NA	NA
4	925	254,977	0.01	0.30	28,922,000	0.05	unknown	1.4	96.3	1.9	0.5	NA	NA	NA

Note:

1 Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.

2 The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval

3 The average flow for the bay is based on HydroQual Modeling Efforts (Blumberg *et al.* , 2000).

4 The 100-year peak stream flow is unknown within Green Bay.

5 NA - Parameter value or average value is not available.

Table 2-3 Land Use Classification for Counties Bordering Green Bay

Land Use Class	Wisconsin Counties										Michigan Counties				Total Land Usage [6]	
	Brown [1]		Door [2]		Kewaunee [3]		Oconto [4]		Marinette [5]		Menominee		Delta			
	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares
Residential	7.8%	10,687	4.0%	5,092	1.9%	172	3.1%	1,904	0.4%	1,483	1.0%	2,726	1.2%	3,661	1.9%	24,984
Ind./Com.	9.3%	12,742	0.9%	1,146	3.3%	297	0.7%	426			0.7%	1,908	0.9%	2,746	1.5%	19,882
Agriculture	58.6%	80,275	49.3%	62,758	69.1%	6,187	37.3%	23,307	12.2%	45,227	14.4%	39,251	8.7%	26,543	22.1%	283,547
Forested			34.1%	43,409	21.7%	1,947	51.6%	32,210	53.1%	196,849	71.9%	195,954	76.2%	232,419	55.0%	705,816
Open	6.7%	9,180	3.3%	4,201	0.4%	38	5.5%	3,454	8.6%	31,881	4.4%	11,993	3.9%	11,899	5.2%	66,477
Vacant			0.1%	127			0.0%	22	0.6%	2,187	0.01%	27	0.01%	31	0.4%	5,443
Public	7.8%	10,687	6.5%	8,274	0.1%	7	0.6%	358	0.01%	37	0.1%	273	0.01%	31	1.5%	19,666
Wetlands	9.8%	13,427	0.6%	764	3.3%	295	0.1%	40	23.0%	85,264	6.8%	18,535	8.3%	25,323	11.2%	143,648
Water	0.01%	14	1.2%	1,528	0.1%	7	1.1%	686	2.1%	7,785	0.7%	1,908	0.8%	2,441	1.1%	14,368
Total:	**100.0%**	**137,011**	**100.0%**	**127,298**	**100.0%**	**8,951**	**100.0%**	**62,408**	**100.00%**	**370,714**	**100.0%**	**272,574**	**100.00%**	**305,091**	**100.0%**	**1,283,831**

Notes:

Ind./Com. is Industrial/Commercial. This category also includes lands designated for transportation/utility use.

Open land is non-forested land not currently under cultivation.

[1] For Brown County, there was no distinction between forested, open, and vacant land use.

[2] For Door County, wetlands, beaches, marshes, grasslands, and meadows are combined and equal about 0.6% of land designated as wetlands.

[3] For Kewaunee County, only land use in the Town of Red River was available. This is the area which borders Green Bay and in which Dyckesville is located. Also, open and vacant land are not distinguished.

[4] Land use information only available for the eastern one-quarter of Oconto County. Total area of Oconto County is 263,442 hectares (650,976 acres).

[5] There was no distinction of urban land use between residential and industrial/commercial or Marinette County.

[6] Combined classifications were divided equally when calculating total land usage values.

Table 2-4 Lower Fox River Gradient and Lock/Dam Information

Lock	Lock Water Elevation (meters IGLD*)	Lock Water Elevation (feet IGLD*)	Dam	Dam Water Elevation (meters IGLD*)	Dam Water Elevation (feet IGLD*)	Miles Upstream	Gradient**
Lake Winnebago	227.11	745.10		227.11	745.10	39.0	—
Menasha	227.11	745.10	Menasha Dam	227.09	745.03	37.0	6.6E-06
Appleton Lock 1	224.15	735.40	Appleton Upper Dam	224.15	735.40	31.9	3.6E-04
Appleton Lock 2	221.19	725.70				31.6	
Appleton Lock 3	218.27	716.10				31.3	
Appleton Lock 4	215.28	706.30	Appleton Lower Dam	215.27	706.25	30.7	4.6E-03
Cedars Lock	212.96	698.70	Cedars Dam	212.95	698.66	27.3	4.2E-04
Little Chute Guard Lock	209.98	688.90	Little Chute Dam	209.97	688.88	26.6	2.6E-03
Little Chute Lock 2	209.98	688.90				26.4	
Upper Combined Lock	205.83	675.30				25.4	
Lower Combined Lock	202.60	664.70				25.4	
Kaukauna Guard Lock	198.97	652.80	Kaukauna Dam	198.96	652.76	24.0	2.6E-03
Kaukauna Lock 1	198.97	652.80				23.6	
Kaukauna Lock 2	195.83	642.50				23.4	
Kaukauna Lock 3	192.91	632.90				23.2	
Kaukauna Lock 4	189.80	622.70				23.1	
Kaukauna Lock 5	186.69	612.50				22.8	
Rapide Croche Lock	183.52	602.10	Rapide Croche	183.52	602.10	19.2	2.0E-03
Little Kaukauna (Little Rapids) Lock	180.69	592.80	Little Kaukauna (Little Rapids) Dam	180.69	592.80	13.1	2.9E-04
De Pere Lock	178.83	586.70	De Pere Dam	178.81	586.66	7.1	1.9E-04
Green Bay (River Mouth)	175.81	576.80	Green Bay (River Mouth)	175.81	576.80	0.0	2.6E-04
Entire River:		—	—		—	—	**8.2E-04**

Notes:

Information obtained from the USACE and from the NOAA Recreational Atlas 14916 (1992).

* IGLD - International Great Lakes Datum, 1955.

** Gradient values from upstream dam to this dam.

Table 2-5 Lower Fox River Stream Velocity Estimates

Model Segments	Deposits Within Lower # Segment	Cross-sectional Area (ft^2)	Cross-sectional Area (m^2)	Flow Velocity (m/s)									
				Average Flow (4,300 cfs)	@ Average Flow (122 m^3/s)	10-year Peak (19,200 cfs)	@ 10-year Peak (544 m^3/s)	10-year Low (950 cfs)	@ 10-year Low (27 m^3/s)	100-year Peak (24,000 cfs)	@ 100-year Peak (680 m^3/s)	100-year Low (140 cfs)	@ 100-year Low (4 m^3/s)
Little Lake Butte des Morts Reach													
2/3	A	6,832.6	634.8	0.63	0.192	2.81	0.857	0.14	0.042	3.51	1.071	0.02	0.006
3/4	B	8,640.3	802.7	0.50	0.152	2.22	0.677	0.11	0.034	2.78	0.847	0.02	0.005
4/6	C, POG	14,762.7	1,371.5	0.29	0.089	1.30	0.396	0.06	0.020	1.63	0.496	0.01	0.003
6/7	D, E	16,678.0	1,549.4	0.26	0.079	1.15	0.351	0.06	0.017	1.44	0.439	0.01	0.003
7/8	D, E	16,097.0	1,495.5	0.27	0.081	1.19	0.364	0.06	0.018	1.49	0.454	0.01	0.003
8/9	E, F	13,191.8	1,225.6	0.33	0.099	1.46	0.444	0.07	0.022	1.82	0.555	0.01	0.003
9/10	E	6,638.9	616.8	0.65	0.197	2.89	0.881	0.14	0.044	3.62	1.102	0.02	0.006
10/11	G, H	3,755.2	348.9	1.15	0.349	5.11	1.558	0.25	0.077	6.39	1.948	0.04	0.011
Reach Average				**0.51**	**0.155**	**2.27**	**0.691**	**0.11**	**0.034**	**2.83**	**0.864**	**0.02**	**0.005**
Appleton to Little Rapids Reach													
11/12	I, J, K	4,368.6	405.9	0.98	0.300	4.40	1.340	0.22	0.066	5.49	1.675	0.03	0.010
12/14	L through R	6,230.0	578.8	0.69	0.210	3.08	0.939	0.15	0.046	3.85	1.174	0.02	0.007
14/15	S	5,788.9	537.8	0.74	0.226	3.32	1.011	0.16	0.050	4.15	1.264	0.02	0.007
15/16	T, U	6,219.3	577.8	0.69	0.211	3.09	0.941	0.15	0.047	3.86	1.176	0.02	0.007
16/17	V, W, X	8,952.3	831.7	0.48	0.146	2.14	0.654	0.11	0.032	2.68	0.817	0.02	0.005
17/18	W, X, Y, Z	7,865.6	730.7	0.55	0.167	2.44	0.744	0.12	0.037	3.05	0.930	0.02	0.005
18/19	AA, BB, CC	4,917.3	456.8	0.87	0.267	3.90	1.190	0.19	0.059	4.88	1.488	0.03	0.009
19/20	—	3,497.0	324.9	1.23	0.375	5.49	1.673	0.27	0.083	6.86	2.092	0.04	0.012
20/21	—	4,573.0	424.8	0.94	0.287	4.20	1.280	0.21	0.063	5.25	1.600	0.03	0.009
21/22	DD	7,026.3	652.8	0.61	0.187	2.73	0.833	0.14	0.041	3.42	1.041	0.02	0.006
Reach Average				**0.78**	**0.238**	**3.48**	**1.060**	**0.17**	**0.052**	**4.35**	**1.326**	**0.03**	**0.008**
Little Rapids to De Pere Reach													
22/23	EE	10,200.5	947.7	0.42	0.128	1.88	0.574	0.09	0.028	2.35	0.717	0.01	0.004
23/24	EE	11,642.3	1,081.6	0.37	0.113	1.65	0.503	0.08	0.025	2.06	0.628	0.01	0.004
24/25	EE	10,942.9	1,016.6	0.39	0.120	1.75	0.535	0.09	0.026	2.19	0.668	0.01	0.004
25/26	EE	10,609.4	985.6	0.41	0.124	1.81	0.552	0.09	0.027	2.26	0.690	0.01	0.004
26/27	EE through HH	10,641.6	988.6	0.40	0.123	1.80	0.550	0.09	0.027	2.26	0.687	0.01	0.004
Reach Average				**0.40**	**0.122**	**1.78**	**0.543**	**0.09**	**0.027**	**2.22**	**0.678**	**0.01**	**0.004**
De Pere to Green Bay Reach													
28/29	SMU 20–25	18,593.3	1,727.4	0.23	0.070	1.03	0.315	0.05	0.016	1.29	0.393	0.01	0.002
29/30	SMU 25–31	12,083.5	1,122.6	0.36	0.108	1.59	0.484	0.08	0.024	1.99	0.605	0.01	0.004
30/31	SMU 32–37	13,751.3	1,277.5	0.31	0.095	1.40	0.426	0.07	0.021	1.75	0.532	0.01	0.003
31/32	SMU 38–43	16,947.0	1,574.4	0.25	0.077	1.13	0.345	0.06	0.017	1.42	0.432	0.01	0.003
32/33	SMU 44–49	20,002.8	1,858.3	0.21	0.066	0.96	0.293	0.05	0.014	1.20	0.366	0.01	0.002
33/34	SMU 50–55	15,698.8	1,458.5	0.27	0.083	1.22	0.373	0.06	0.018	1.53	0.466	0.01	0.003
34/35	SMU 56–61	20,519.3	1,906.3	0.21	0.064	0.94	0.285	0.05	0.014	1.17	0.357	0.01	0.002
35/36	SMU 62–67	20,056.6	1,863.3	0.21	0.065	0.96	0.292	0.05	0.014	1.20	0.365	0.01	0.002
36/37	SMU 68–73	20,551.6	1,909.3	0.21	0.064	0.93	0.285	0.05	0.014	1.17	0.356	0.01	0.002
37/38	SMU 73–79	19,389.5	1,801.3	0.22	0.068	0.99	0.302	0.05	0.015	1.24	0.377	0.01	0.002
38/39	SMU 80–85	14,891.8	1,383.5	0.29	0.088	1.29	0.393	0.06	0.019	1.61	0.491	0.01	0.003
39/40	SMU 86–91	16,387	1,522	0.26	0.080	1.17	0.357	0.06	0.018	1.46	0.446	0.01	0.003
Reach Average				**0.25**	**0.077**	**1.13**	**0.346**	**0.06**	**0.017**	**1.42**	**0.432**	**0.01**	**0.003**
Entire River Averages				**0.45**	**0.137**	**2.01**	**0.612**	**0.10**	**0.030**	**2.51**	**0.766**	**0.01**	**0.004**

Notes:

[1] The average, peak, and low flow velocities listed are from USGS records for the Rapide Croche gauging station, #04084500.

[2] Cross-sectional areas obtained from Velleux & Endicott, 1994 and WDNR, 1995.

Table 2-6 Lower Fox River Discharge Results: Rapide Croche Gauging Station

Summary of Flow Conditions for Water Years 1918 to 1997	Discharge (m^3/s)	Discharge (cfs)	Date	
Daily Average	122	4,314	—	
Highest Daily Mean	680	24,000	April 18, 1952	
Lowest Daily Mean	4	138	August 2, 1936	
Monthly Mean Maximum	206	7,286	April	
Monthly Mean Minimum	74	2,609	August	
	Monthly Discharge Results			
Month	**Average (m^3/s)**	**Average (cfs)**	**Minimum (m^3/s)**	**Maximum (m^3/s)**
January	116	4,082	31	269
February	117	4,126	30	340
March	146	5,156	25	603
April	206	7,286	22	680
May	171	6,048	23	669
June	137	4,821	17	603
July	96	3,372	18	530
August	74	2,609	4	419
September	81	2,872	8	510
October	94	3,315	6	516
November	116	4,084	15	445
December	115	4,043	32	363

Note:

A water year runs from October 1 through September 30.

Table 2-7 Lower Fox River and Green Bay Maximum PCB Sampling Depth

Location	PCB Mass and Percent in System*	Contaminated Sediment Volume and Percent in System*
Little Lake Butte des Morts Reach	1,540 kg (1.6%)	1.35 million m^3 (0.29%)
Appleton to Little Rapids Reach	94 kg (0.1%)	0.18 million m^3 (0.04%)
Little Rapids to De Pere Reach	980 kg (1.0%)	1.71 million m^3 (0.36%)
De Pere to Green Bay Reach	25,984 kg (26.8%)	5.52 million m^3 (1.16%)
Green Bay Zone 2	32,013 kg (33.1%)	39.5 million m^3 (8.33%)
Green Bay Zone 3	35,243 kg (36.4%)	397 million m^3 (83.72%)
Green Bay Zone 4	925 kg (1.0%)	28.9 million m^3 (6.10%)
Total	**96,784 kg**	**474.16 million m^3**

Note:

* Includes sediments containing PCB concentrations greater than 50 μg/kg.

Table 2-8 Lower Fox River Mouth Gauging Station Results (1989–1997)

Summary of Flow Conditions	Discharge m^3/s (cfs)	Date (or month)
Daily Average: WY 1989–1997	149 (5,262)	—
Highest Daily Mean: WY 1989–1997	957 (33,800)	June 23, 1990
Lowest Daily Mean: WY 1989–1997	-92 (-3,250)	November 4, 1990
Monthly Mean Maximum: WY 1989–1997	210 (7,420)	April
Monthly Mean Minimum: WY 1989–1997	103 (3,635)	September
Monthly Mean Maximum: WY 1997	244 (8,620)	April
Monthly Mean Minimum: WY 1997	56 (1,980)	September
Daily Maximum: WY 1997	419 (14,800)	March 28, 1997
Daily Minimum: WY 1997	-15 (-530)	May 28, 1997

Table 2-9 Total Suspended Solid (TSS) Loads from the Lower Fox River into Green Bay

Sampling Point	River Discharge (m^3/s)	River Discharge (cfs)	Total Suspended Solids (TSS) (mg/L)	(MT/year)	(Ton/year)
Mean Values from WDNR, 1995					
Lower Fox River Reaches					
Menasha gauge*	140	4,938	7.7	33,968	37,365
Neenah gauge*	80	2,809	17	42,661	46,927
Appleton gauge	93	3,279	23	67,375	74,113
Kaukauna gauge*	85	3,009	26	69,892	76,881
Little Rapids gauge**	87	3,058	52	142,060	156,266
De Pere gauge	85	3,003	30	80,484	88,532
Mean Values from Gailani et al., 1991					
De Pere to Green Bay Reach					
De Pere dam	105	3,700	30	99,164	109,081
River mouth	105	3,700	6	19,833	21,816

Sampling Point	River Discharge m^3/s	River Discharge cfs	Total Suspended Solids mg/L	Total Suspended Solids MT/year
De Pere dam	105	3,706.50	30	99,338
	280	9,884.00	75	662,256
	432	15,249.60	190	2,588,475
River mouth	105	3,706.50	6	19,868
	280	9,884.00	57	503,315
	432	15,249.60	130	1,771,062

Notes:

* The stream flow result for this station is actually the flow at the Appleton station

** The stream flow result for this station is actually the flow at the De Pere station

MT - metric tons.

Table 2-10 Results of Sediment Time Trends Analysis on the Lower Fox River

Deposit Group	Depth Range (cm)	Log_{10} (PCB) Time Trend Slope Estimate	WSEV Standard Error	WSEV *p*-Value	Estimated Annual Compound Percent Increase (Decrease) in PCB Level	Estimated Annual Compound Percent Increase (Decrease) in PCB Level 95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Little Lake Butte des Morts Reach							
AB	0–10	-0.0970	0.0348	0.0131	-20.0252	-32.5184	-5.2190
	10–30	-0.0213	0.0647	0.7535	-4.7785	-33.8607	37.0914
	30–50	-0.0144	0.1113	0.8995	-3.2580	-44.9528	70.0179
C	0–10	-0.0612	0.0342	0.1481	-13.1527	-30.2218	8.0920
	10–30	0.0317	0.0770	0.7018	7.5669	-34.2398	75.9520
POG	0–10	-0.0893	0.0567	0.1900	-18.5943	-43.3347	16.9478
D	0–10	-0.0755	0.0317	0.0307	-15.9649	-28.0617	-1.8339
	10–30	0.3168	0.0454	0.0009	107.3860	58.5121	171.3292
F	0–10	-0.0373	0.0136	0.0252	-8.2308	-14.6158	-1.3684
	10–30	-0.0760	0.0749	0.3246	-16.0577	-41.6741	20.8094
GH	0–10	-0.1244	0.0541	0.0443	-24.9124	-43.1170	-0.8818
Appleton to Little Rapids Reach							
IMOR	0–10	0.0412	0.0255	0.1810	9.9476	-6.5658	29.3796
N Pre-dredge	0–10	-0.0281	0.0065	0.0233	-6.2555	-10.6450	-1.6504
	10–30	0.0572	0.0440	0.2061	14.0840	-7.4773	40.6698
	30–50	0.0846	0.0932	0.3877	21.5002	-25.2171	97.4021
VCC	0–10	-0.0582	0.0275	0.0878	-12.5329	-25.6543	2.9044
	10–30	-0.1537	0.0164	0.0000	-29.8115	-35.4198	-23.7163
	30–50	-0.0060	0.0151	0.6984	-1.3741	-8.7096	6.5507
Little Rapids to De Pere Reach							
Upper EE	0–10	-0.0447	0.0435	0.3618	-9.7861	-31.6823	19.1279
	10–30	-0.0944	0.0429	0.0554	-19.5286	-35.6413	0.6181
	30–50	-0.0712	0.0536	0.2173	-15.1118	-35.8039	12.2499
Lower EE	0–10	-0.0682	0.0193	0.0387	-14.5308	-25.8145	-1.5310
	10–30	-0.0759	0.0390	0.0695	-16.0283	-30.5817	1.5761
	30–50	0.0900	0.0330	0.0213	23.0209	3.8593	45.7177
FF	0–10	-0.0549	0.0557	0.3400	-11.8664	-32.9367	15.8238
	10–30	-0.0962	0.0390	0.0389	-19.8690	-34.8569	-1.4327
GGHH	0–10	-0.0394	0.0231	0.1643	-8.6641	-21.2286	5.9045
	10–30	-0.0182	0.0596	0.7631	-4.0982	-27.7264	27.2546
	30–50	0.1762	0.1008	0.1188	50.0238	-12.1753	156.2737
	50–100	0.1012	0.0700	0.1586	26.2311	-9.1644	75.4191
	100+	0.0365	0.0249	0.1587	8.7556	-3.5026	22.5710
De Pere to Green Bay Reach							
SMU Group 20–25	0–10	-0.0528	0.0231	0.0838	-11.4462	-23.5795	2.6135
	10–30	-0.0556	0.0750	0.4796	-12.0176	-40.9140	31.0108
	30–50	-0.0580	0.0322	0.1016	-12.4973	-25.8079	3.2014
	50–100	-0.0847	0.1058	0.4306	-17.7243	-50.1718	35.8538
26–49	0–10	-0.0608	0.0109	0.0000	-13.0594	-17.4071	-8.4827
	10–30	-0.2882	0.1440	0.0764	-48.5003	-75.6756	9.0355
	50–100	0.1957	0.1419	0.2399	56.9258	-36.6450	288.6939
	100+	0.0177	0.1548	0.9146	4.1538	-61.2934	180.2628
50–67	0–10	-0.0998	0.0345	0.0136	-20.5271	-33.1743	-5.4864
	10–30	0.0912	0.0649	0.1800	23.3725	-10.2622	69.6138
	50–100	0.3677	0.0684	0.0030	133.1723	55.5425	249.5468
	100+	-0.1963	0.2223	0.4112	-36.3596	-81.8094	122.6480
68–91	0–10	-0.2208	0.0944	0.1013	-39.8569	-69.8854	20.1142
	10–30	-0.1685	0.0765	0.0550	-32.1613	-54.4475	1.0282
92–115	0–10	0.0413	0.0426	0.3493	9.9747	-10.9075	35.7515

Table 2-11 Results of Fish Time Trends Analysis on the Lower Fox River

Species	Type	Sample Size	Year of Breakpoint	Percent Change per Year	95% Confidence Interval		*p*-Value
					LCL	UCL	
Little Lake Butte des Morts							
Carp	fillet on skin	55	1979	-6.15	-10.9	-1.1	0.0177
Carp	whole fish	40	1987	0.71	-12.3	15.6	0.9172
Northern Pike	fillet on skin	19		-11.83	-16.7	-6.7	0.0003
Walleye	fillet on skin	63	1990	3.44	-7.8	16.0	0.5576
Walleye	whole fish	18	1987	21.47	-3.5	52.9	0.0874
Yellow Perch	fillet on skin	34	1981	0.73	-5.0	6.8	0.8025
Combined				**-4.86**			**0.0055**
Appleton to Little Rapids							
Walleye	fillet on skin	30		-9.97	-15.7	-3.9	0.0028
De Pere to Green Bay (Zone 1)							
Carp	whole fish	90	1995	21.76	2.2	45.0	0.0277
Gizzard Shad	whole fish	19		-5.07	-7.2	-2.9	0.0002
Northern Pike	fillet on skin	40		-9.95	-13.0	-6.8	<0.0001
Walleye	fillet on skin	120		-7.19	-8.7	-5.6	<0.0001
Walleye	whole fish	58		-8.11	-10.4	-5.8	<0.0001
White Bass	fillet on skin	58		-4.72	-7.5	-1.8	<0.0001
White Sucker	fillet on skin	44		-7.90	-10.3	-5.5	<0.0001
Combined				**-6.89**			**<0.0001**
Green Bay Zone 2							
Alewife	whole fish	44		-3.96	-7.8	0.0	0.0497
Carp	fillet on skin	28		-5.06	-11.8	2.2	0.1557
Carp	whole fish	57	1983	-15.54	-19.5	-11.4	<0.0001
Gizzard Shad	whole fish	32		5.91	1.2	10.8	0.0144
Yellow Perch	fillet on skin	19		-10.75	-16.8	-4.2	0.0038
Combined				**-5.11**			**<0.0001**

Table 2-12 Mass-weighted Combined Time Trend for 0 to 10 cm Depth by Reach

Deposit Group	Log_{10}(PCB) Time Trend Slope Estimate	WSEV Standard Error	PCB Mass (kg)	*p*-value	Annual Percent Change in PCB Concen-tration	Percent Change 95% Lower-bound	Percent Change 95% Upper-bound
Little Lake Butte des Morts							
AB	-0.09705	0.034798	71.7				
C	-0.06124	0.03423	25.4				
POG	-0.08935	0.056669	113.5				
D	-0.07554	0.031669	32.1				
F	-0.0373	0.013582	142.5				
GH	-0.12443	0.054119	15.7				
Reach, Combined	**-0.07071**	**0.01831**	**400.9**	**0.0001*** **	**-15.0**	**-21.8**	**-7.7**
Appleton							
IMOR	0.041186	0.025457	13.7				
N Pre-dredge	-0.02805	0.006544	6.9				
VCC	-0.05816	0.02746	5.2				
Reach, Combined	**-0.0025**	**0.01469**	**25.9**	**0.9**	**0.6**	**-5.9**	**7.5**
Little Rapids							
Upper EE	-0.04473	0.043487	85.0				
Lower EE	-0.06819	0.019322	25.4				
FF	-0.05486	0.055669	36.7				
GGHH	-0.03936	0.023149	131.6				
Reach, Combined	**-0.04567**	**0.018764**	**278.7**	**0.01***	**-10.0**	**-17.3**	**-2.0**
De Pere							
SMU Group 2025	-0.05279	0.02305	225.6				
SMU Group 2649	-0.06078	0.010894	356.8				
SMU Group 5067	-0.09978	0.034549	92.4				
SMU Group 6891	-0.22081	0.094396	72.1				
SMU Group 92115	0.041293	0.042639	37.1				
Reach, Combined	**-0.07296**	**0.012829**	**784.0**	**<0.0001*** **	**-15.5**	**-20.2**	**-10.4**

Notes:

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

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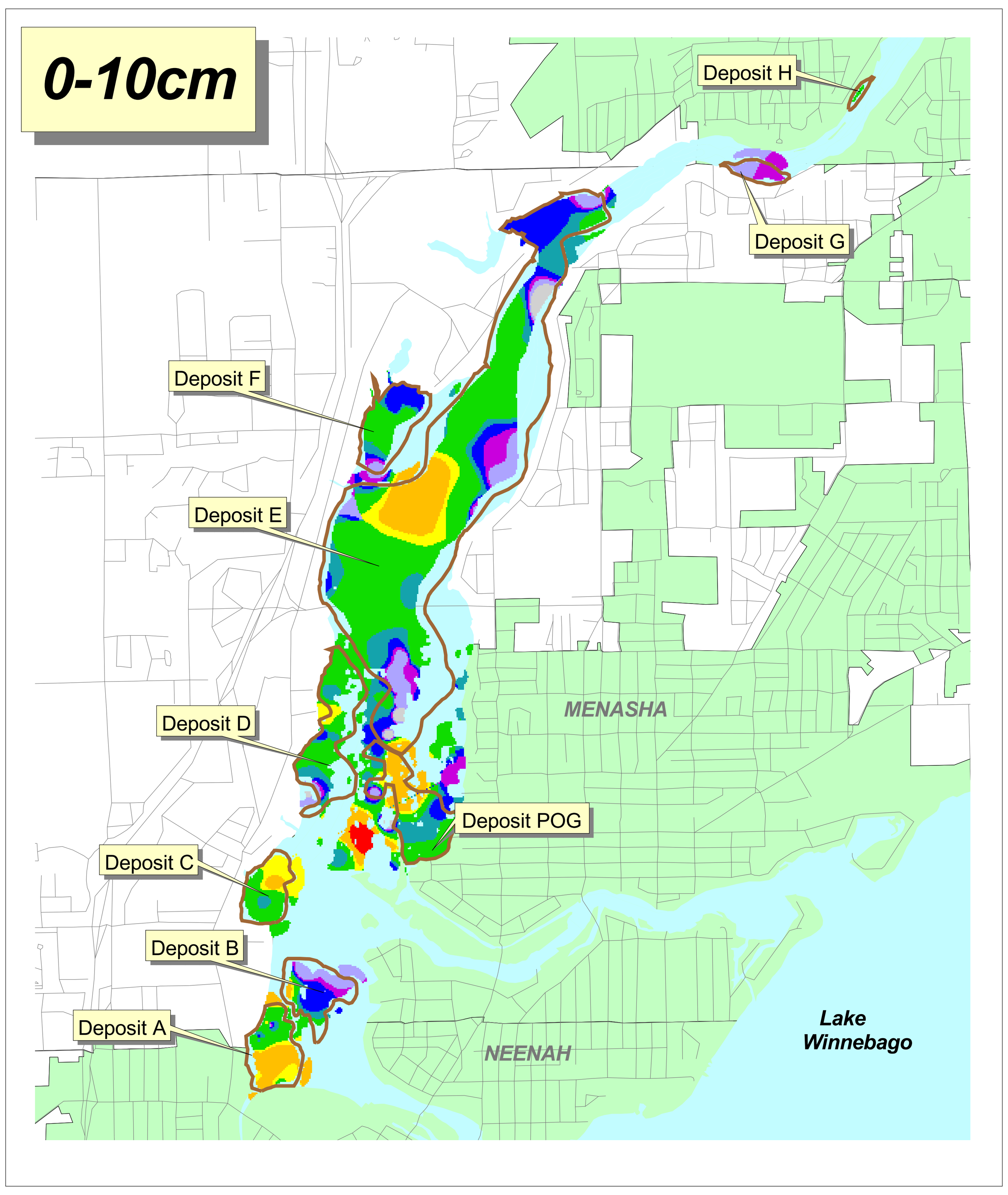
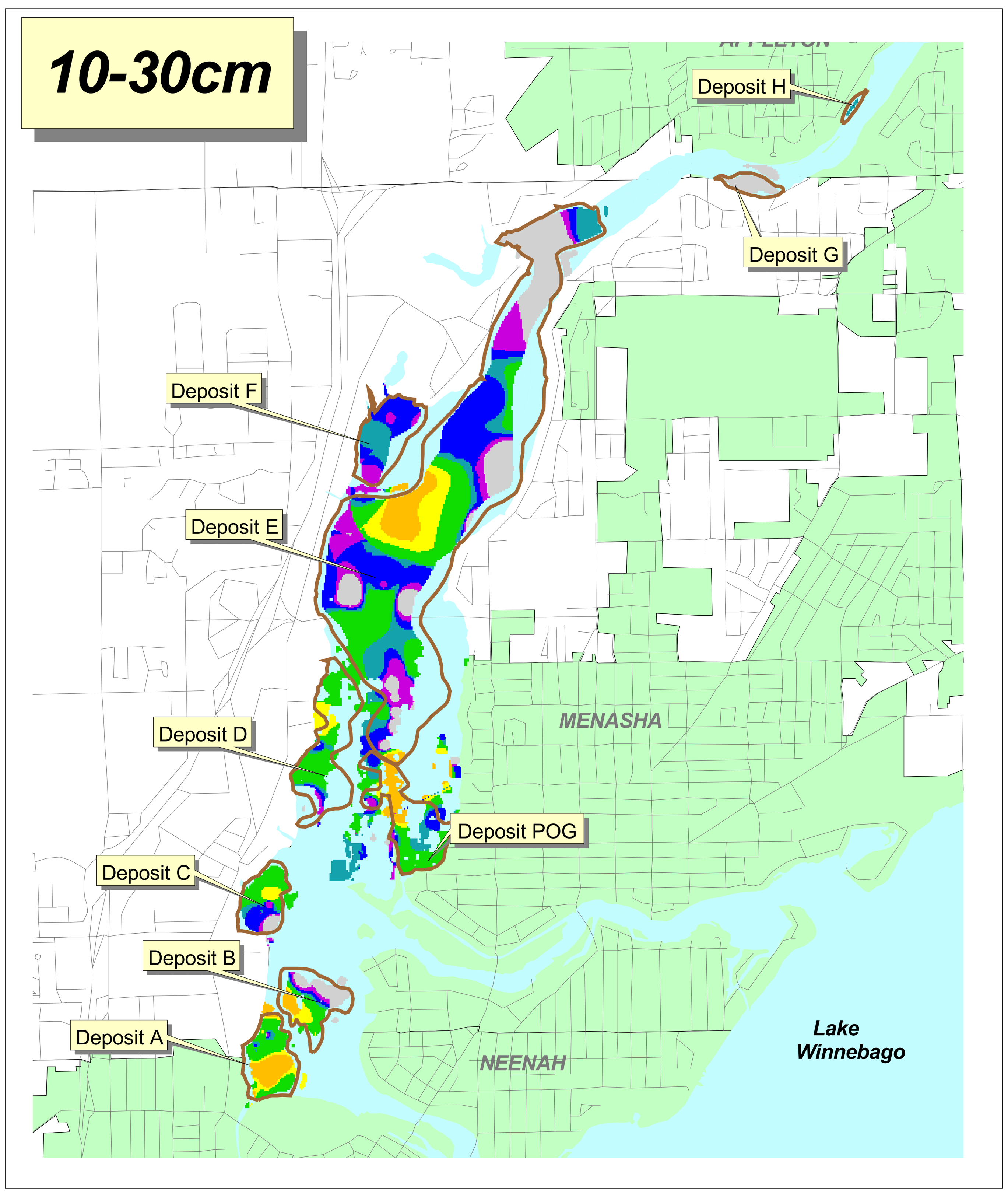
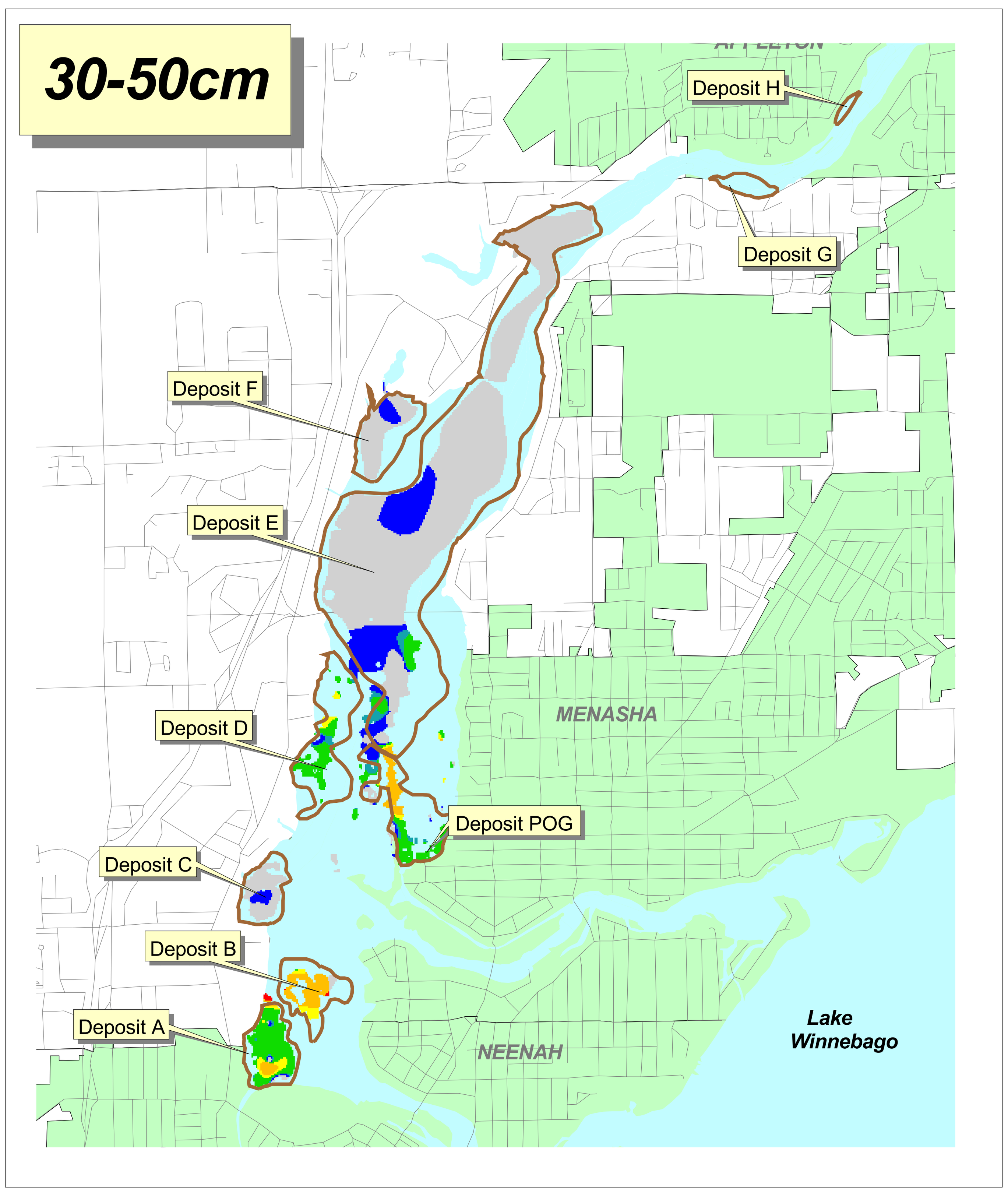
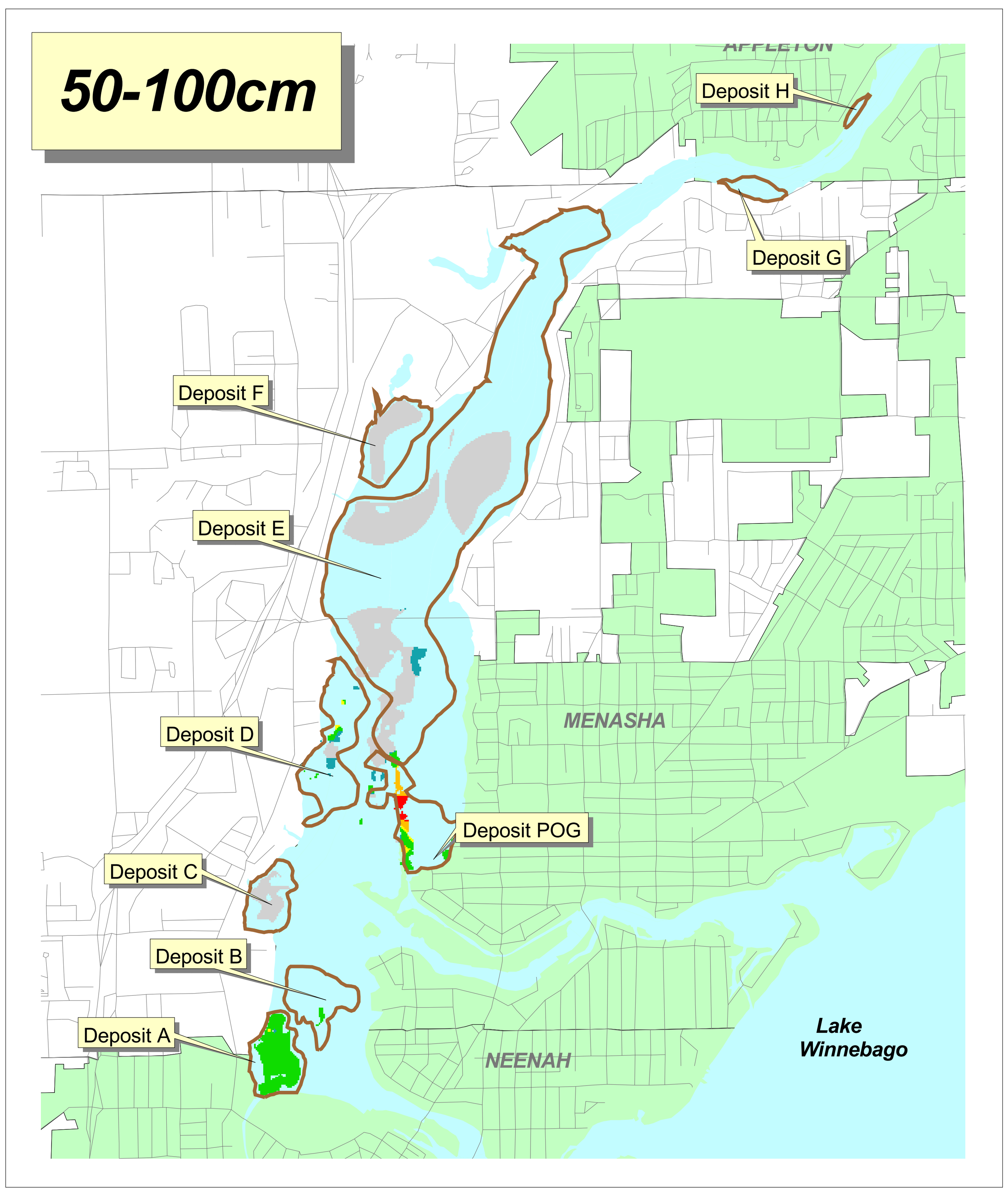
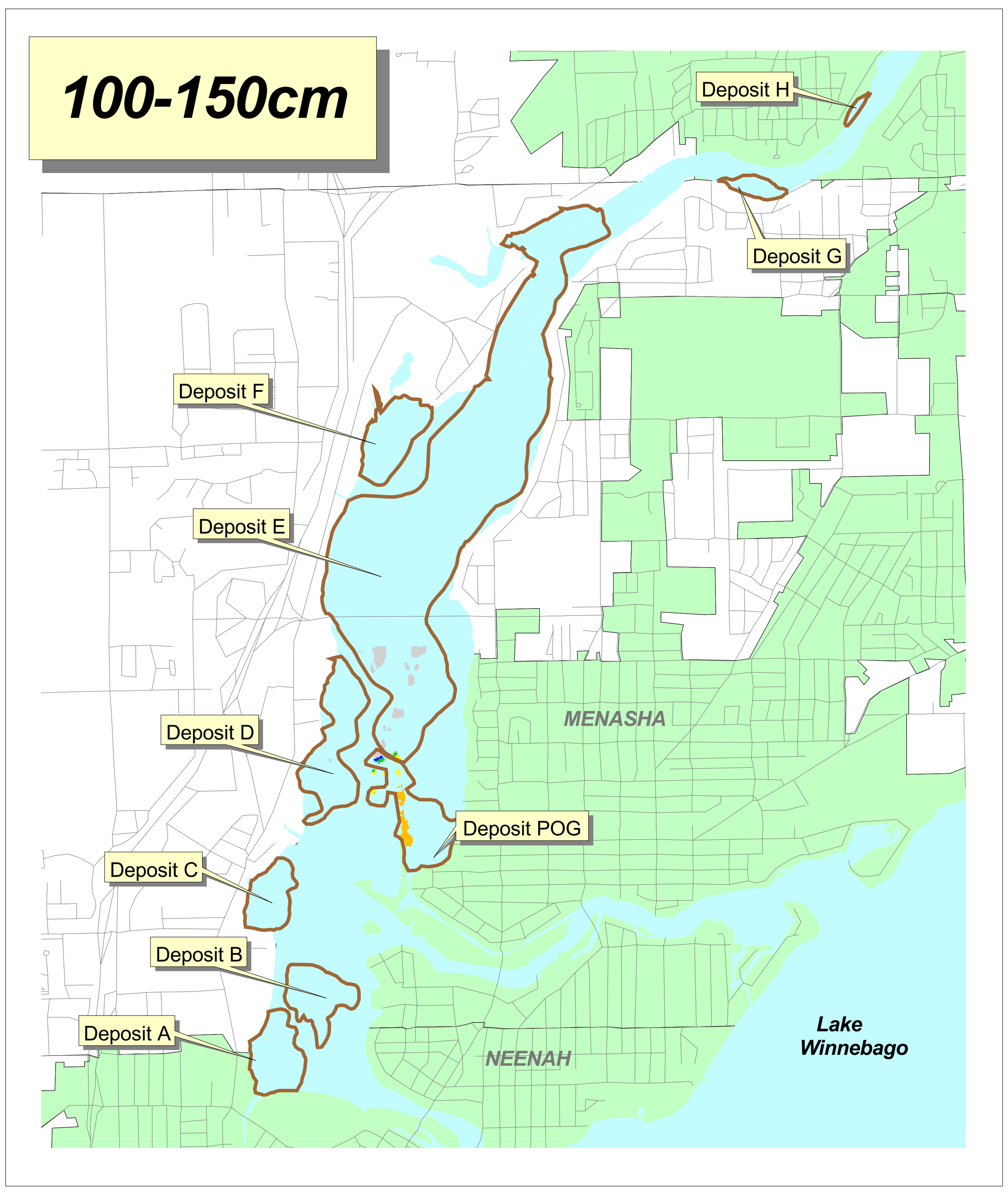








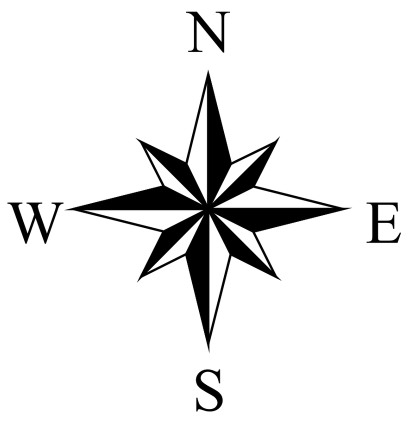


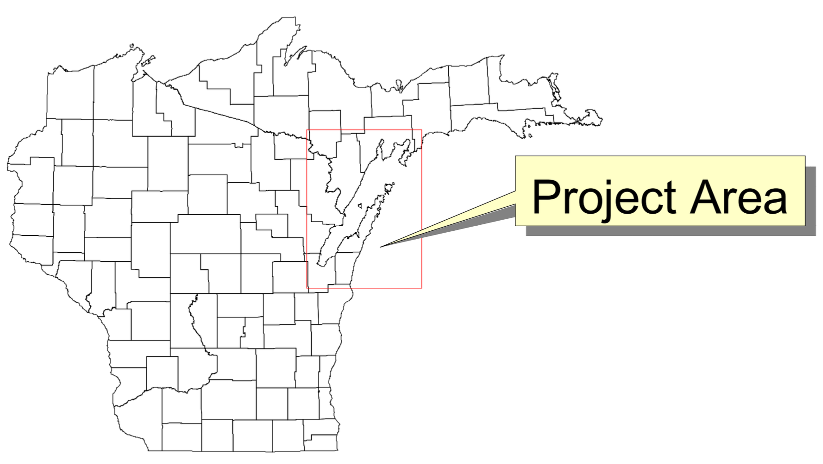
PCB Sediment Concentrations (ug/kg)

- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000
- Deposits
- Roads
- Water

Civil Divisions

- City
- Township
- Village



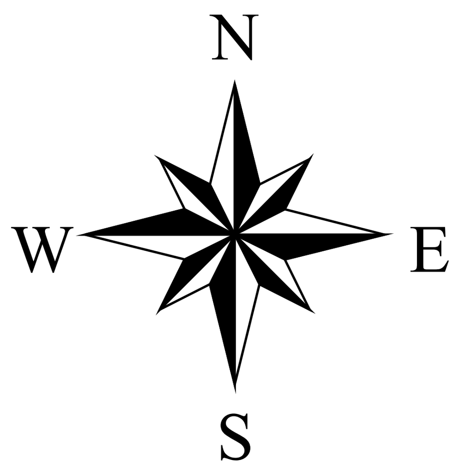


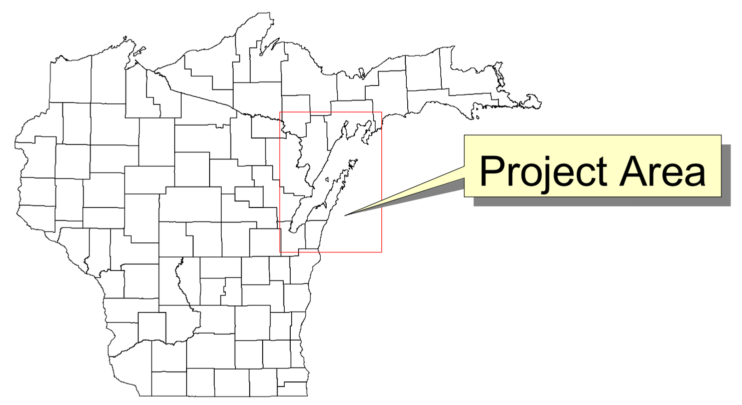
1 0 1 2 3 Kilometers

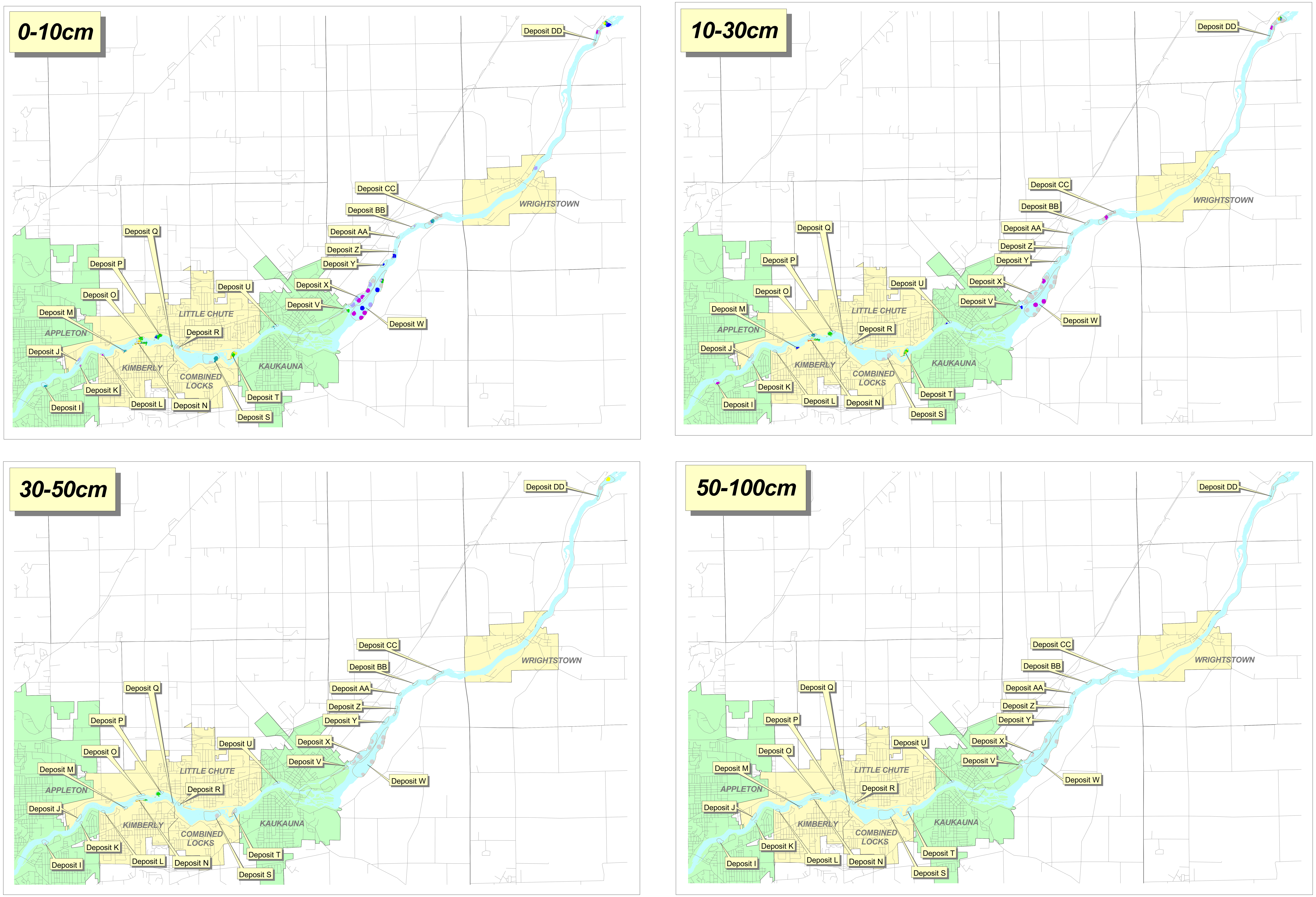
1 0 1 2 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Interpolated PCB Distribution in Sediments: Little Lake Butte des Morts Reach	DRAWING NO: FS-14414-535-2-1
				PRINT DATE: 3/8/01
				CREATED BY: SCJ
			PLATE 2-1	APPROVED: AGF







PCB Sediment Concentrations (ug/kg)
- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000
- Deposits
- Roads
- Water

Civil Divisions
- City
- Township
- Village

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998, and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. Deposit N has been removed, but is still shown for reference.
5. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

2 0 2 4 6 Kilometers

2 0 2 4 Miles

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Lower Fox River & Green Bay Feasibility Study

Interpolated PCB Distribution in Sediments: Appleton to Little Rapids Reach

PLATE 2-2

DRAWING NO:	FS-14414-535-2-2
PRINT DATE:	3/8/01
CREATED BY:	SCJ
APPROVED:	AGF

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

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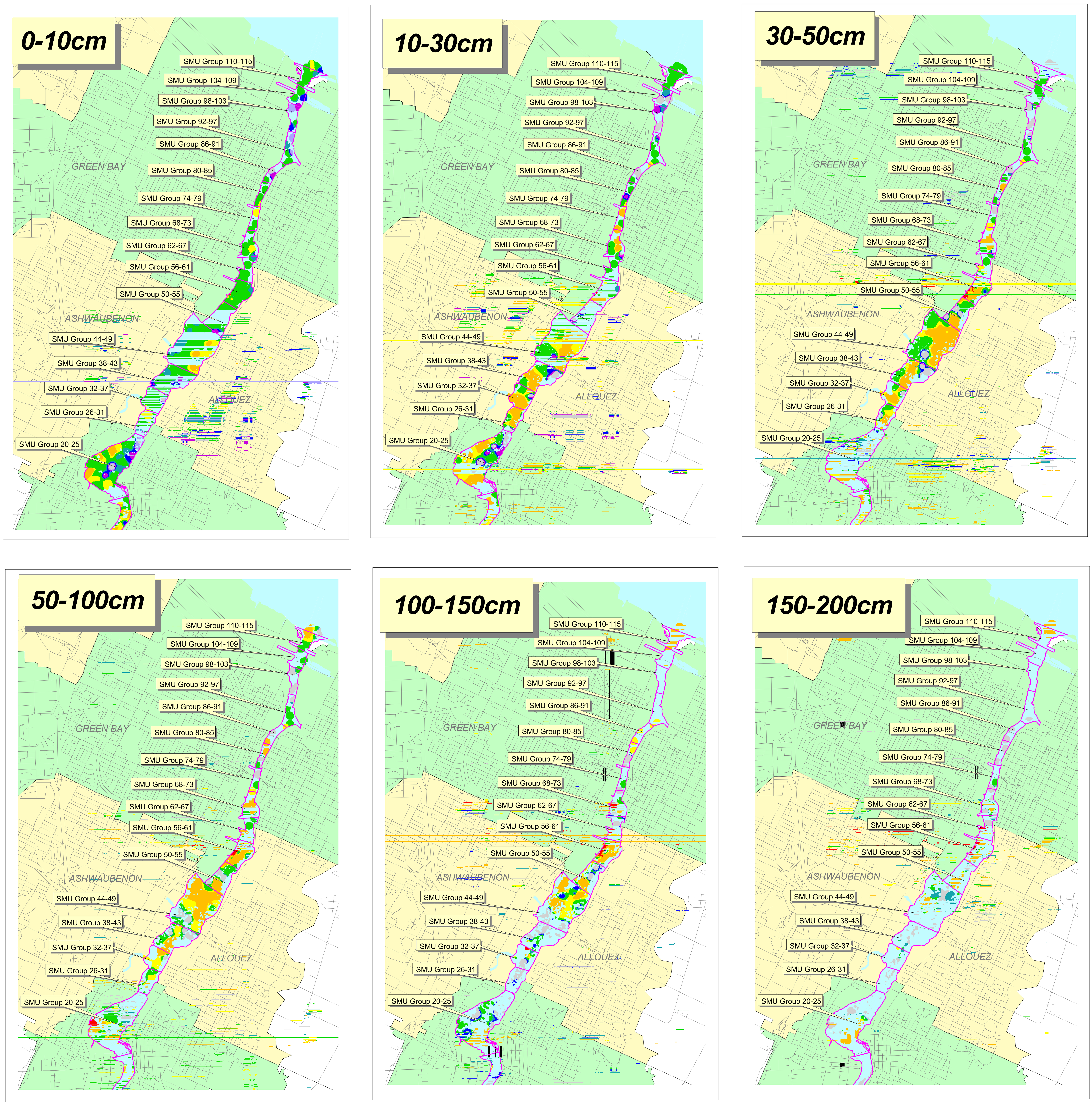
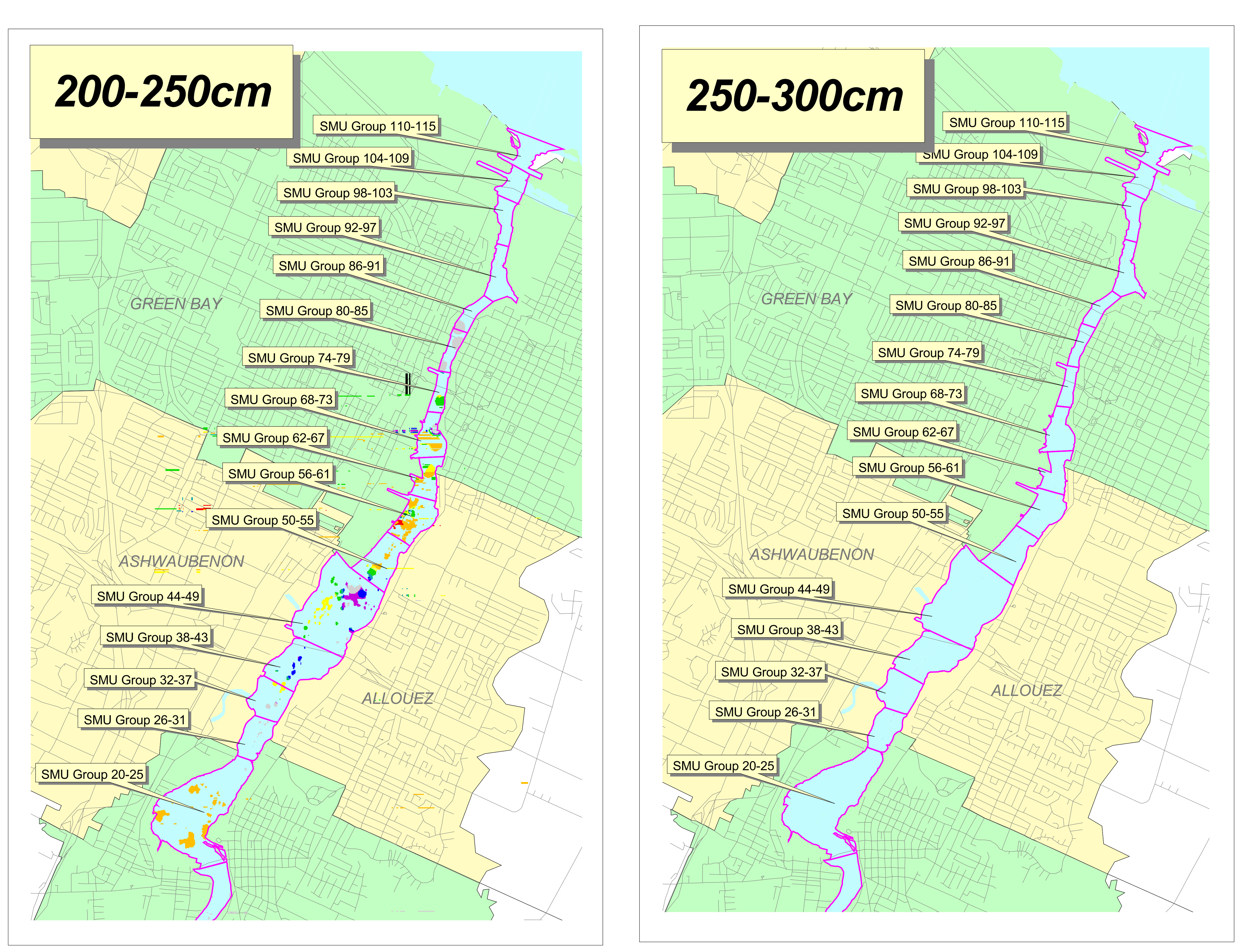
Lower Fox River & Green Bay Feasibility Study

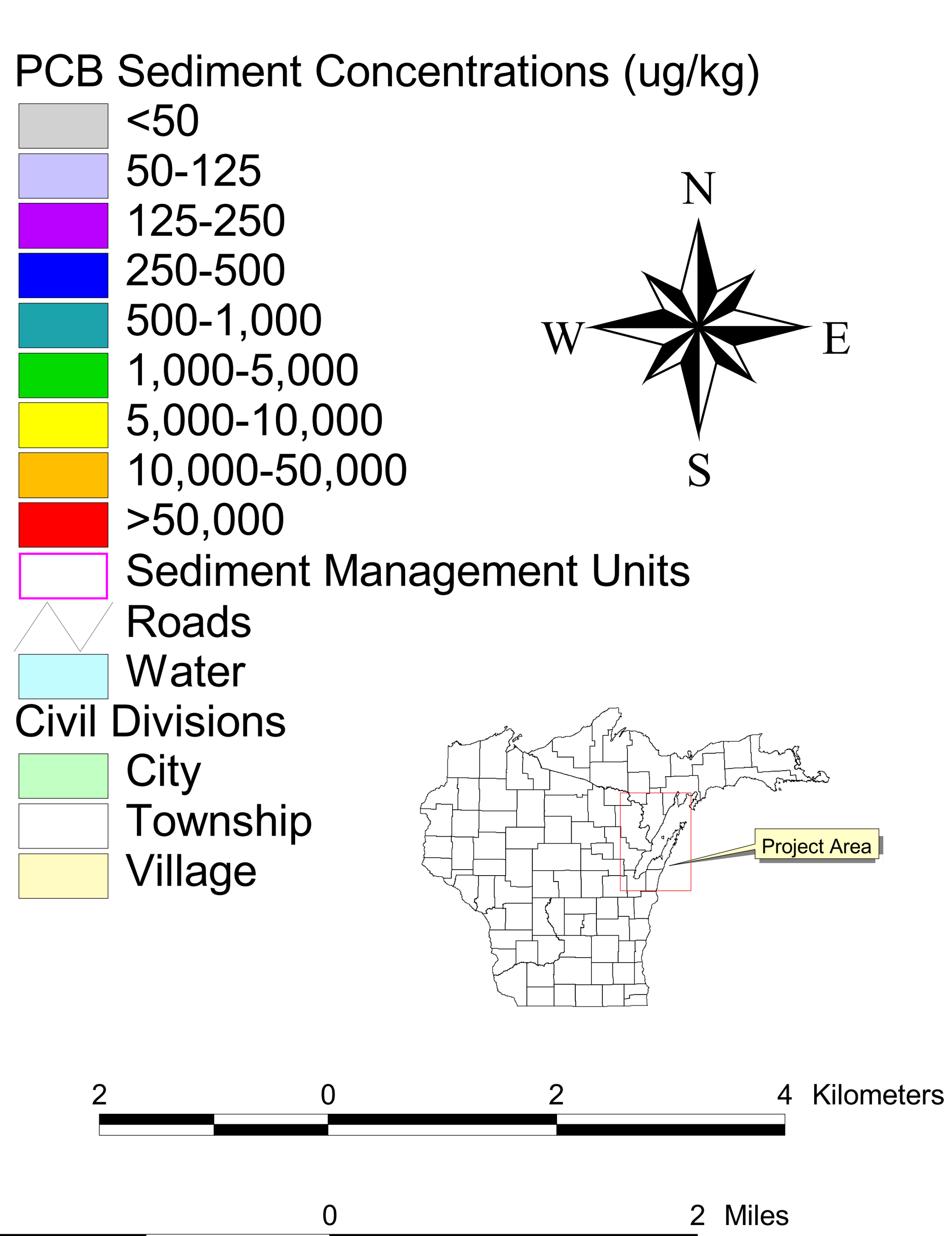
Interpolated PCB Distribution in Sediments: Little Rapids to De Pere Reach

PLATE 2-3

DRAWING NO: FS-14414-535-2-3
PRINT DATE: 3/8/01
CREATED BY: SCJ
APPROVED: AGF







NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

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Lower Fox River & Green Bay Feasibility Study

Interpolated PCB Distribution in Sediments: De Pere to Green Bay Reach

PLATE 2-4

DRAWING NO: FS-14414-535-2-4
PRINT DATE: 3/8/01
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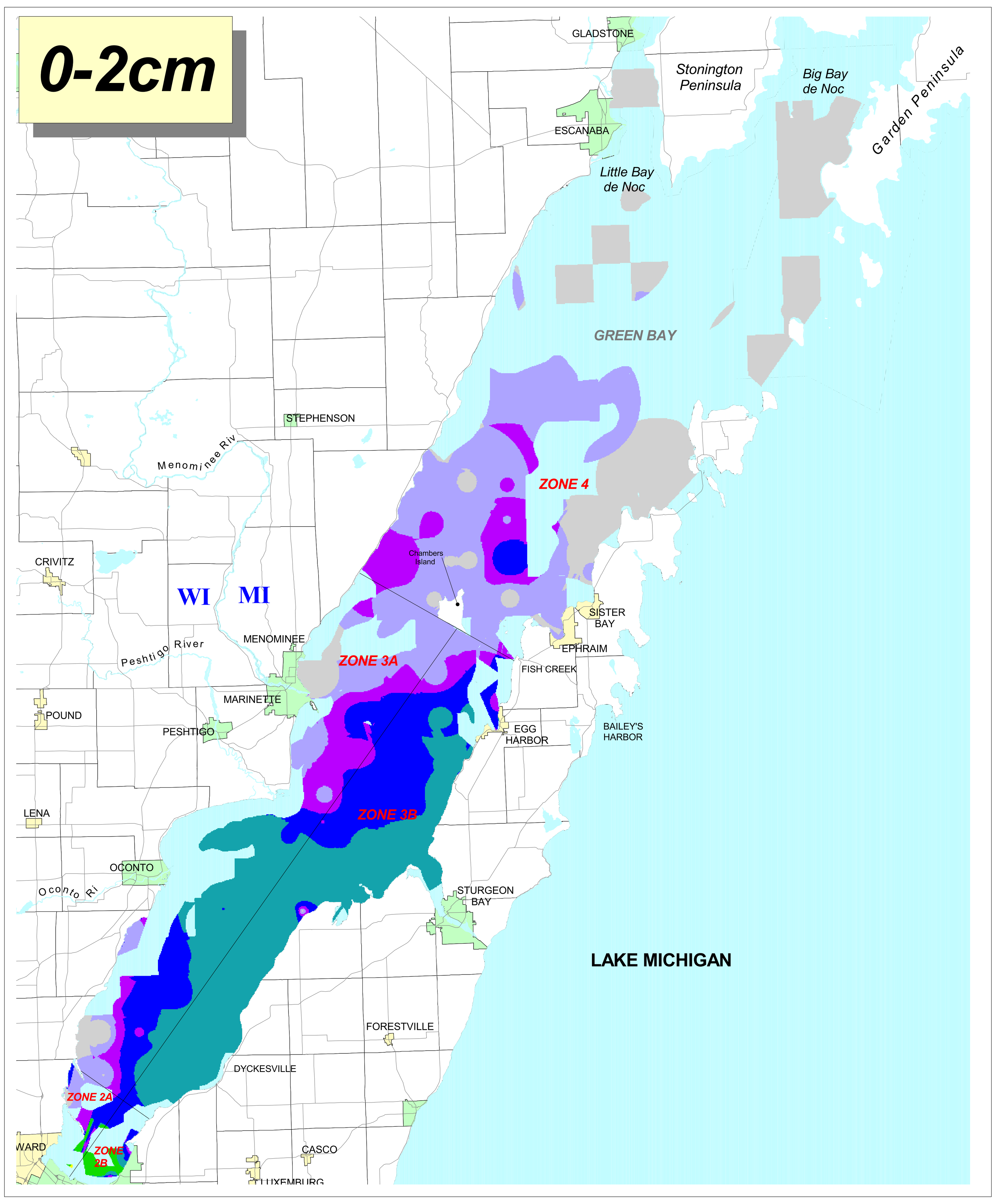
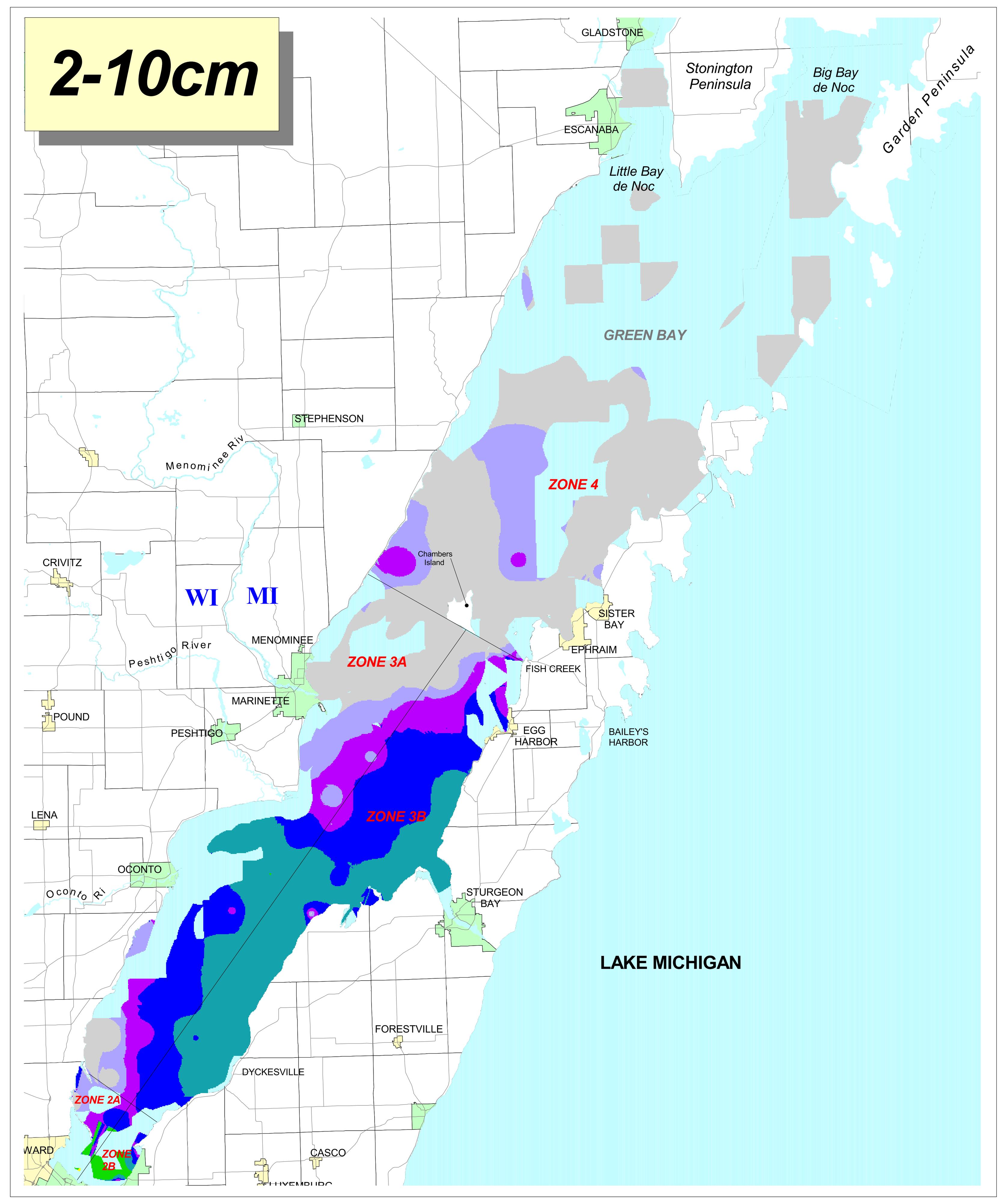
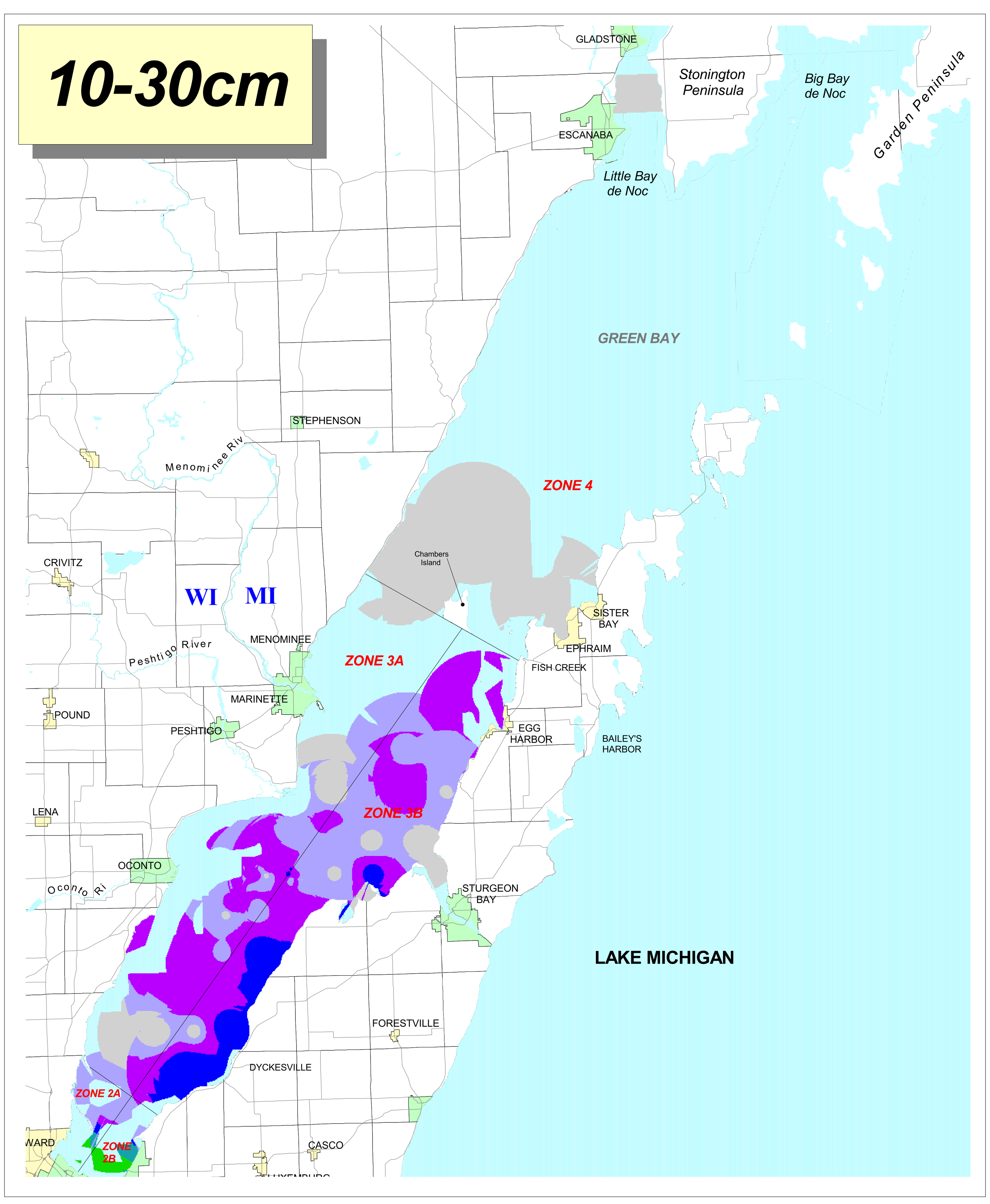
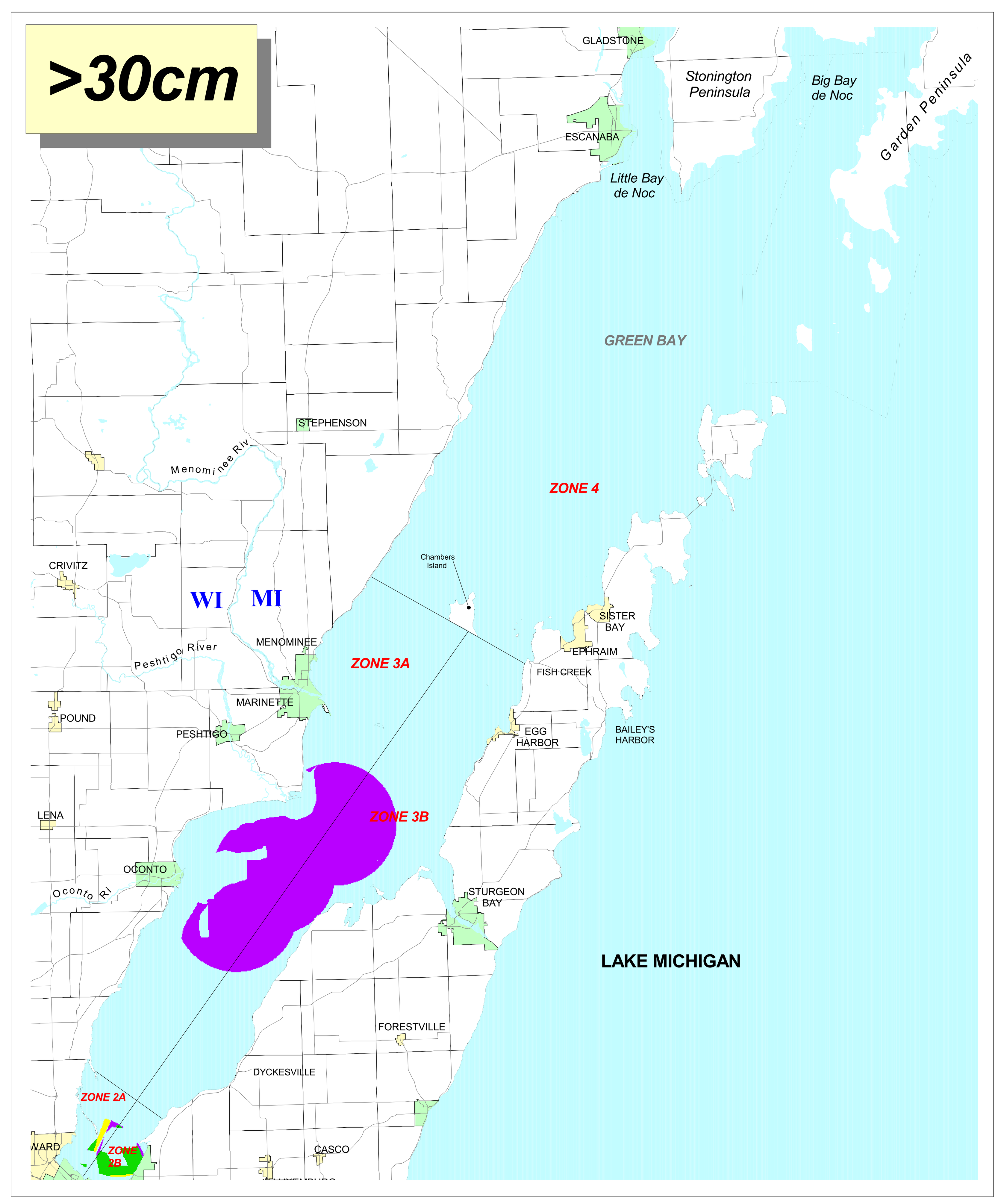
APPROVED: AGF







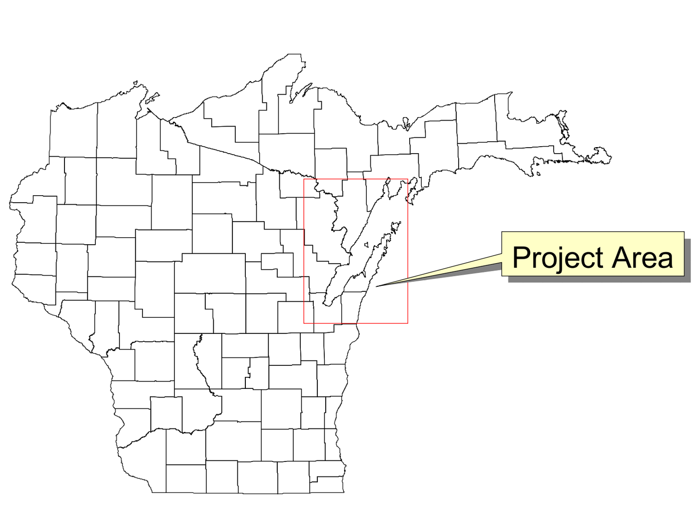


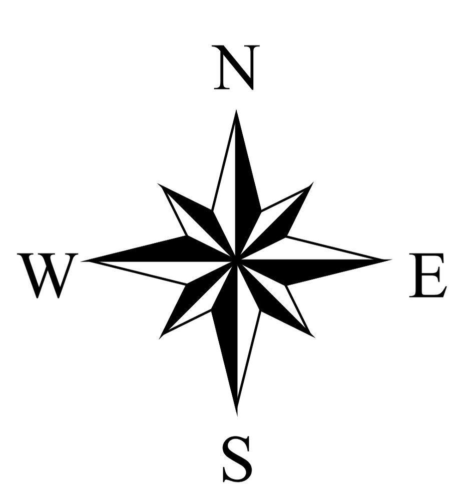
PCB Sediment Concentrations (ug/kg)

- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- >5,000
- Roads
- Water

Civil Divisions

- City
- Township
- Village





20 0 20 40 Kilometers

20 0 20 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 30 cm depths.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

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				PRINT DATE: 3/8/01
				CREATED BY: SCJ
			PLATE 2-5	APPROVED: AGF

3 Summary of the Baseline Human Health and Ecological Risk Assessment

As a follow-up to the Screening Level Risk Assessment (SLRA) which identified chemicals of potential concern (COPCs), a Baseline Human Health and Ecological Risk Assessment (BLRA) for the Lower Fox River and Green Bay (RETEC, 2002b) has been prepared as a companion document to the RI and FS. This BLRA was undertaken to provide an assessment of risks to human health and the environment that will support the selection of a remedy to eliminate, reduce, or control those risks. Specific goals of the BLRA for the Lower Fox River and Green Bay were to:

- Examine how the COPCs carried forward from the SLRA (RETEC, 1998) move from the sediment and water into humans and ecological receptors within the Lower Fox River and Green Bay.
- Quantify the current (or baseline) human health and ecological risk associated with the COPCs.
- Distinguish those COPCs which pose the greatest potential for risk from those that pose negligible risks to human health and the environment.
- Determine which exposure pathways lead to the greatest risks.
- Determine which COPCs are carried forward in the FS as COCs.
- Support the selection of a remedy to eliminate, reduce, or control identified risks by calculating sediment quality thresholds (SQTs).

The COPCs carried forward from the SLRA included polychlorinated biphenyls (PCBs) (total and selected congeners), dioxins/furans (2,3,7,8-TCDD and 2,3,7,8-TCDF), DDT and its metabolites DDE and DDD, dieldrin, and three metals (arsenic, lead, and mercury). For both assessments, risk was characterized for the four reaches of the Lower Fox River, including Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (Green Bay Zone 1) as well as the zones of the bay: Zone 2, Zone 3A, Zone 3B, and Zone 4. Therefore, risks between each of these reaches and zones could be compared.

Details of the human health risk assessment and the ecological risk assessment are provided in Sections 3.1 and 3.2, respectively. General conclusions of both assessments were that:

- Fish consumption is the exposure pathway that represents the greatest level of risk for receptors (other than direct risk to benthic invertebrates).

- The primary COC is total PCBs. Other COCs carried forward for remedial evaluation and long-term monitoring are mercury and DDE.

- In general, areas with the greatest risk are Green Bay zones 1 and 2, although for human health, estimated risk did not differ greatly between the river reaches and bay zones.

SQTs were estimated for PCBs with the assumption that a remedial action targeting PCBs would also capture the other COCs. The SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level. The SQTs and risk associated with SQTs are further evaluated and discussed in Section 8 of this FS. Safe concentrations in fish for human and ecological receptors were determined for:

- Human and ecological receptors (e.g., fish-eating humans, fish, piscivorous birds, and piscivorous mammals);

- Appropriate human health risk levels (10^{-5} for cancer risk in humans and a hazard index (HI) of 1.0 for noncancer risk based on fish consumption), and both the no observed adverse effect concentrations (NOAECs) and lowest observed adverse effect concentrations (LOAECs) for ecological receptors; and

- Two different assumptions regarding fish consumption rates for humans: subsistence fishing and sport fishing.

Once the "safe" PCB fish tissue concentrations were determined, corresponding sediment concentrations that would need to exist in the river or bay were calculated. This was accomplished using a bioenergetic food web model—the FRFood Model. PCB SQTs are the output of the model and are further discussed in Section 3.3. The development and validation of the mathematical model used to define SQTs is described in the BLRA (Section 7) and the FRFood Model Documentation Memorandum (RETEC, 2002c).

The SQTs themselves do not provide specific cleanup goals, but rather provide the resources managers (Wisconsin and federal agencies) an array of risk-based thresholds from which to select remedial action levels for evaluation in the FS. The final selection of the remedial action levels carried forward in the FS is a policy decision left to the response agencies. A summary of the results of the BLRA are presented in the two sections below. In addition, the SQTs are presented in Section 3.3.

3.1 Human Health Risk Assessment

Using the results of the SLRA as its starting point, the human health risk assessment for the Lower Fox River and Green Bay calculated cancer risks and noncancer hazard indices for the following receptors:

- Recreational anglers,
- High-intake fish consumers,
- Hunters,
- Drinking water users,
- Local residents,
- Recreational water users (swimmers and waders), and
- Marine construction workers.

For the human health risk assessment, two evaluations were performed, a baseline risk assessment and a focused risk assessment. For the baseline risk assessment, all data for a specific medium for each COPC were used to evaluate exposures and risks. The highest cancer risks and noncancer hazard indices were calculated for recreational anglers and high-intake fish consumers due primarily to consumption of fish containing PCBs. For the focused risk assessment, which examined only exposure to PCBs in fish by recreational anglers and high-intake fish consumers, and only fish tissue data from 1989 and after were used.

In a follow-up, focused assessment, potential risks to recreational anglers and high-intake fish consumers were examined in more detail. Using fish concentration data from 1990 on (and walleye data from 1989 in Green Bay), the cancer risks were as high as 9.8×10^{-4} for recreational anglers and 1.4×10^{-3} for high-intake fish consumers. These risks are 100 times greater than the 10^{-5} cancer risk level commonly used in Wisconsin according to administrative rules such as Chapter NR 105 Wisconsin Administrative Code for the protection of human health based on fish consumption (Chapter 105 specifies a 10^{-5} risk level for fish consumption). These risks are 1,000 times greater than the 10^{-6} cancer risk level, which is the point at which risk management decisions may be made under Superfund. The highest cancer risks for recreational anglers and high-intake fish consumers are more than 20 times greater than background risks calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay).

The hazard indices were as high as 36.9 for the recreational angler and 52.0 for the high-intake fish consumer; far in exceedance of the value of 1.0 established to protect people from long-term adverse noncancer health effects. The noncancer health effects associated with exposure to PCBs include reproductive effects (e.g., conception failure in highly exposed women), developmental effects (e.g., neurological impairment in highly exposed infants and children), and immune system suppression (e.g., increased incidence of infectious disease in highly exposed infants). The highest noncancer hazard indices for recreational anglers and high-intake fish consumers are more than 20 times greater than background hazard indices calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay).

To provide perspective on the number of individuals who are potentially exposed in the state of Wisconsin, there are on the order of 136,000 registered recreational anglers, and about 5,000 high-intake fish consumers, based on fish licenses and a variety of surveys, respectively. The high-intake fish consumers can include low-income minority anglers, Native American anglers, Hmong/Laotian anglers, and anyone else who consumes an amount of fish consistent with the assumptions used to define a "high-intake fish consumer."

Cancer risks and hazard indices were calculated by river reach and Green Bay zone. However, there was relatively little difference between the highest risk in any reach or zone, which occurred in the Green Bay Zone 3A, and the lowest risk in any reach or zone, which occurred in the Little Rapids to De Pere Reach. The risk in Green Bay Zone 3A is 2.3 times greater than the risk in the Little Rapids to De Pere Reach.

The cancer risks and hazard indices were examined in detail in four species: carp, perch, walleye, and white bass. Carp generally had the highest concentrations of PCBs in each reach or zone where data were available and so exhibited the highest cancer risks and hazard indices. The lowest concentrations of PCBs occurred for perch, walleye, or white bass, depending on the river reach or Green Bay zone. The cancer risks and hazard indices for these three species are comparable.

The only other receptors with cancer risks exceeding 10^{-6} were the hunters and drinking water users. Cancer risks for the marine construction worker slightly exceed the 1×10^{-6} level in the Little Lake Butte des Morts Reach. The risks to the hunter were as high as 8.3×10^{-5}, but were at least 10 times lower than the risks to the anglers. The risk to the hunter was due to ingestion of PCBs in waterfowl. The risk to drinking water users exceeded 10^{-6} only in the De Pere to Green Bay Reach. This exceedance was due to arsenic in surface water, and the arsenic value was from one detected value in a total of four samples. A more systematic sampling of this water for arsenic might show this single detected value to be anomalous. Additionally, the water in this reach is not currently used as a source of drinking water, and there are no plans to use it as such in the foreseeable future (this reach of the Lower Fox River is not classified for use as a source of drinking water). The cancer risks to drinking water users in all other reaches of the Lower Fox River and zones of Green Bay were below the 10^{-6} level, as were the cancer risks for the local residents and recreational water users (swimmers and waders).

The only other receptors with hazard indices exceeding 1.0 were the hunter, drinking water user, and local resident. The highest HI for these receptors was 3.8, only slightly above 1.0. These hazard indices are more than 10 times lower than the highest hazard indices for the high-intake fish consumers and about 10 times lower than the highest hazard indices for the recreational angler. The hazard indices were below 1.0 for the recreational water users and marine construction workers in all reaches of the Lower Fox River and zones of Green Bay.

In conclusion, recreational anglers and high-intake fish consumers are at greatest risk for contracting cancer or experiencing noncancer health effects. A summary of these risks is presented on Figures 3-1 and 3-2. The highest cancer risks are more than 20 times greater than background risks calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay). The primary reason for these elevated risks and hazard indices is ingestion of fish containing PCBs.

3.2 Ecological Risk Assessment

As part of the ecological BLRA exposure assessment, assessment endpoints selected for risk evaluation were:

- **Aquatic Invertebrates:** Insects and other invertebrates that live in the water and are important prey items for fish and other insects.

- **Benthic Invertebrates:** Insects and other invertebrates that live in or on the sediment that are important in recycling nutrients and a principal part of fish diets.

- **Benthic Fish:** Fish, such as carp and catfish, that live on and forage in the sediments and are in turn eaten by other fish, birds, mammals, and people.

- **Pelagic Fish:** Fish, such as walleye and yellow perch, that live in the water column, and eat other fish or insects that live in the water or on the sediments. These fish may be in turn eaten by other fish, birds, mammals, and people.

- **Insectivorous Birds:** Birds, such as swallows, that eat insects that hatch from the sediment.

- **Piscivorous Birds:** Birds, such as cormorants or terns, that principally eat fish from the Lower Fox River or Green Bay.

- **Carnivorous Birds:** Birds, such as eagles, that will eat a variety of prey, including fish or small mammals.

- **Piscivorous Mammals:** Mammals, such as mink, that eat fish as an important part of their diet.

Risk was characterized for these assessment endpoints principally based on the calculation of hazard quotients (HQs). HQs are the ratios of measured COPC concentrations in media (water, sediment, tissue) as compared to safe COPC concentrations in these media. HQs that are greater than 1.0 imply that risk may be present. Where available, both NOAEC and LOAEC HQs were calculated. Effects evaluated were reproductive dysfunction, death at birth, or deformities in the surviving offspring. When NOAEC HQs exceeded 1.0, but LOAEC HQs were less than 1.0, then it was concluded that there was potential risk. When both the NOAEC and LOAEC HQs exceeded 1.0, it was assumed that risk was present.

Besides HQs, other factors that were considered in determining risk to assessment endpoints were: field studies, habitat, and population levels. Together, each of the components of the evaluation provided a weight of evidence for the presence or absence of risk.

Risks were evaluated by river reach and bay zone, and are summarized below and on Figures 3-1 through 3-3.

3.2.1 Little Lake Butte des Morts Reach

In summary, the results taken in total suggest that only measured or estimated concentrations of total PCBs are at sufficient levels to cause, risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks from total PCBs are indicated for water column invertebrates, benthic and pelagic fish, insectivorous and piscivorous birds. Measured or estimated concentrations of mercury are found to be at sufficient concentrations to cause or potentially cause risk to water column and benthic invertebrates, and piscivorous birds. Concentrations of 2,3,7,8-TCDD, DDD, and DDT are only sufficient to be of risk to benthic invertebrates. Sediment concentrations of elevated PCBs are widespread and persistent throughout the reach. Concentrations of arsenic, dieldrin, and all o,p'- isomers of DDT and its metabolites are not found to pose risk to any assessment endpoint. While all assessment endpoints are potentially at risk or are at risk based upon HQs from total PCBs, it was concluded on the weight of evidence that only benthic invertebrates, carnivorous birds, and piscivorous mammals are at risk to elevated levels of PCBs.

3.2.2 Appleton to Little Rapids Reach

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for all other receptors except insectivorous birds, for which there are no data. Measured or estimated concentrations of mercury were found to be at sufficient concentrations to cause or potentially cause risk to benthic invertebrates, piscivorous birds, and carnivorous birds. Concentrations of lead are only of risk to benthic invertebrates. Concentrations of all chlorinated pesticides (dieldrin, o,p'-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE, p,p'-DDT) are not found to pose risk to any assessment endpoint. Surface sediment concentrations of elevated PCBs indicate reach-wide effects, but are likely limited to specific deposits. Carnivorous birds may have potential risks from PCB exposure, but there do not appear to be any apparent impairments to successful reproduction. Piscivorous mammals are estimated to be at risk to PCBs in this reach.

3.2.3 Little Rapids to De Pere Reach

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for benthic and pelagic fish, and piscivorous birds. There are no data to evaluate insectivorous birds. Measured or estimated concentrations of mercury are found to be at sufficient concentrations to cause, or potentially cause, risk to aquatic invertebrates, benthic invertebrates, pelagic fish, piscivorous birds, and carnivorous birds. Concentrations of arsenic, dieldrin, all o,p'- isomers of DDT and its metabolites, and p,p'-DDD are not sufficient to pose risk to any assessment endpoint. While all fish and birds are potentially at risk from mercury and total PCBs, only water column and benthic invertebrates and piscivorous mammals are assumed to be at risk, based on elevated HQs.

There are persistent risks to benthic infaunal communities in sediments from exposure to lead, mercury, 2,3,7,8-TCDD, total PCBs, p,p'-DDE, and p,p'-DDT. Surface sediment concentrations of elevated PCBs are fairly uniformly distributed throughout the reach, and thus it is inferred that invertebrate communities are at risk throughout the entire reach. Apparent population level impacts of COCs on reproduction and survival for benthic and pelagic fish are not indicated, although sublethal effects may occur. Carnivorous birds may have sublethal risks from PCB exposure, and because of their status are considered to be at risk. Piscivorous mammals are estimated to be at risk to PCBs in this reach.

3.2.4 De Pere to Green Bay Reach (Green Bay Zone 1)

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risk to benthic invertebrates and piscivorous mammals. Total PCBs are at sufficient levels to potentially cause risk to aquatic invertebrates and insectivorous birds. Concentrations of dieldrin, all o,p'- isomers of DDT and its metabolites, and p,p'-DDT are not sufficient to pose risk to any of the evaluated assessment endpoints. Measured concentrations of mercury were found to be at sufficient concentrations to cause or potentially cause risk to benthic invertebrates. Risks to fish and birds are discussed in the risk summary for Green Bay Zone 2.

3.2.5 Green Bay Zone 2

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risks to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for benthic and pelagial fish, and piscivorous birds. Measured or estimated concentrations of mercury are at sufficient concentrations to cause or potentially cause risk to aquatic invertebrates, benthic invertebrates, pelagial fish, piscivorous birds, and carnivorous birds. Measured or estimated concentrations of DDE are at sufficient concentrations to cause, or potentially cause, risk to benthic fish, pelagic fish, insectivorous birds, piscivorous birds, and carnivorous birds.

Benthic and pelagial fish populations appear to be relatively robust throughout lower Green Bay, as evidenced by maintenance of self-reproducing populations of benthic fish and the reintroduction of self-sustaining walleye populations. However, the weight of evidence suggests that while population level impacts do not appear to be occurring, individuals may remain at risk to sublethal effects such as liver tumors.

Insectivorous bird field evaluations showed no discernable effects on nesting behavior, clutch size, hatching success, or deformity.

Chemical levels of organochlorines in piscivorous birds remain sufficiently high to pose risks for at least reproductive impairment and deformities. While the historical levels of PCBs and DDE clearly impacted these birds at the individual and population level, some species (e.g., double-crested cormorants) within the bay have experienced substantial population increases. However, persistence of abnormal development within the area indicates that some level of risk remains for all piscivorous bird species.

Elevated mercury and organochlorine levels in prey continue to pose risk to survival and reproduction of carnivorous birds in zones 1 and 2 of Green Bay. The reproductive rates of nesting bald eagles in these zones appear depressed relative to both inland areas as well as other areas within the Fox River and Green Bay.

Based upon the estimated dietary intakes, PCBs are estimated to be sufficient to cause survival or reproductive impairment to piscivorous mammals.

3.2.6 Green Bay Zone 3A

In summary, the results taken in total suggest that concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, benthic fish, pelagic fish, piscivorous birds, carnivorous birds, and piscivorous mammals. There were no data to evaluate insectivorous birds. Mercury concentrations are potentially causing risk to piscivorous birds. Concentrations of dieldrin are a potential risk for carnivorous birds and piscivorous mammals. Concentrations of arsenic, lead, and all o,p'- and p,p'- isomers of DDT and its metabolites were not found to pose risk to any assessment endpoint.

3.2.7 Green Bay Zone 3B

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, pelagial fish, piscivorous birds, carnivorous birds, and piscivorous mammals. There are no data to evaluate insectivorous birds. Mercury concentrations are causing or potentially causing risk to benthic invertebrates, pelagial fish, piscivorous birds, and carnivorous birds. DDE concentrations are causing, or potentially causing, risk to pelagial fish, piscivorous birds, and carnivorous birds. Dieldrin concentrations are potentially causing risk to piscivorous mammals. Arsenic and lead concentrations are only of risk to benthic invertebrates.

3.2.8 Green Bay Zone 4

In summary, these results taken in total suggest that concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, pelagial fish, piscivorous birds, carnivorous birds, and piscivorous mammals. Concentrations of DDE (measured in tissue) are causing or potentially causing risk to pelagial fish and carnivorous birds. Concentrations of mercury are causing or potentially causing risk to piscivorous and carnivorous birds.

3.2.9 Ecological Risk Summary for PCBs Mercury, and DDE

Overall, PCBs, mercury, and DDE were the COPCs that most frequently exceeded risk thresholds for all receptors (human and ecological) evaluated and, therefore these three compounds are considered COCs and carried forward in the FS. This section presents selected representative reasonable maximum exposure (RME) HQs developed from the BLRA for PCBs, mercury, and DDE, although, as indicated above, calculated HQs were only one part of the weight of evidence evaluated in the estimation of risk. These risks are summarized in Table 3-1.

HQs exceeding 1.0 for PCBs in the river and bay are presented on Figure 3-4 and Figure 3-5, respectively. For sediment, total PCB HQs in all areas exceeded 1.0. Sediment PCB HQs were greatest in Little Lake Butte des Morts Reach and lowest in Green Bay Zone 4, and generally, sediment HQs in intermediate areas indicated decreasing HQs while moving downstream from the river into the bay. Alternatively, in both benthic and pelagic fish, total PCB HQs increased moving downstream in the river. Total PCB HQs for benthic fish were highest in Green Bay zones 1 and 2, and for pelagic fish they were highest in Green Bay Zone 3B. No benthic fish data were available, however, for Green Bay zones 3B and 4.

Carnivorous and piscivorous bird data were limited to select areas in Green Bay, but did suggest that adverse reproductive risk is occurring. Therefore, because of this potential risk and the limited data, exposure concentrations for areas with no data were estimated through modeling. HQs for piscivorous and carnivorous birds based on exposure modeling suggest that, for both bird types, reproductive risk is greatest for Green Bay zones 1 and 2, followed by Green Bay Zone 3B. No data were available for piscivorous mammals and, therefore, exposure was estimated through modeling dietary intake as was done for piscivorous and carnivorous birds. Similar to the reproductive risk found for birds, the calculated HQs for piscivorous mammals suggest that reproductive risk is greatest for Green Bay zones 1 and 2, followed by Green Bay Zone 3B.

HQs exceeding 1.0 for mercury in all areas evaluated are presented on Figure 3-3. As indicated on this figure, mercury concentrations in sediment are higher in the river than the bay, and the highest sediment concentrations in the river are found in the Little Rapids to De Pere Reach. Mercury HQs for fish only exceeded 1.0 in three areas: Little Rapids to De Pere Reach, Green Bay zones 1 and 2, and Green Bay Zone 3B. Fish concentrations were highest in the Little Rapids to De Pere Reach. Based on exposure modeling, piscivorous bird HQs were highest in Green Bay zones 1 and 2, and all other areas had HQs of similar magnitude. For carnivorous birds, exposure modeling indicated that HQs are highest in Green Bay Zone 3B, followed by Green Bay Zone 4.

HQs exceeding 1.0 for DDT and metabolites in all areas evaluated are presented on Figure 3-6. DDT (in the form of DDE) HQs are highest in the Little Rapids to De Pere reach, and HQs for DDT or its metabolites exceed 1.0 in surface sediment in all other areas evaluated except for Green Bay zones 3A, 3B, and 4. All HQs that exceeded 1.0 for tissues were concentrations of DDE, and all of these HQs were less than 10. DDE HQs for fish only exceeded 1.0 in three areas: Green Bay zones 1 and 2, Green Bay Zone 3B, and Green Bay Zone 4. DDE HQs in piscivorous birds exceeded 1.0 in Green Bay zones 1, 2, and 3B based on both measured and estimated tissue DDE concentrations; and HQs in carnivorous birds exceeded 1.0 in Green Bay zones 1, 2, and 4 based on exposure modeling. Estimated HQs for piscivorous mammals did not exceed 1.0.

3.3 Sediment Quality Thresholds

For both human health and ecological risk, the BLRA concludes that the greatest potential risk is from the PCBs that are found in the sediments of the Lower Fox River and Green Bay. For human health, the greatest risk comes from individuals who consume fish caught in the Lower Fox River and Green Bay. For the ecological receptors, the greatest risks were from total PCBs in the surface sediment, as well as PCBs in birds and mammals that rely principally on fish for food. Reducing total PCBs in fish by reducing the levels of total PCBs in the sediments was determined to be the most important means of reducing risks in the Lower Fox River and Green Bay.

The Fox River Bioaccumulation Model (FRFood Model) is a series of mathematical equations that describes a food web and the transfer of bioaccumulating contaminants within that food web. The model includes uptake routes from sediment and water to benthic infauna and ultimately fish, and the model was constructed so that it could be used to either predict fish tissue concentrations from a given sediment concentration, or to predict sediment concentrations from a given fish tissue concentration. The model was validated by running the model "forward;" that is, fish tissue concentrations were predicted from existing sediment concentrations and then compared to measured fish tissue concentrations. When the predicted concentrations were compared to the actual measured concentrations of total PCBs in fish collected in the Lower Fox River and Green Bay, the results were highly comparable. Calibration of the FRFood Model indicated that all predicted fish tissue concentrations were within one-half order of magnitude of observed concentrations of total PCBs, except for yellow perch in the Little Lake Butte des Morts Reach. However, within this reach data were only available for one fish. As a result, the risk analysis carried forward in later sections of the FS focused primarily on walleye and carp, and not on yellow perch.

Human health and ecological SQTs were derived based on conditions present in the De Pere to Green Bay Reach (Green Bay Zone 1) (e.g., sediment organic carbon levels, organism lipid concentrations). As a risk management decision, it is assumed that SQTs derived for Green Bay Zone 1 will be applied to the whole Lower Fox River and Green Bay even if reach-specific or zone-specific water-to-sediment ratios may differ in part because the greatest human health and ecological risks are found in Green Bay Zone 1. Because of the uncertainty associated with the sediment-to-water ratio, SQTs may differ by an order of magnitude. For example, walleye NOAEC SQTs based on a sediment-to-water ratio of 10^{-5} are 8 times less than SQTs based on a sediment-to-water ratio of 10^{-6} and 25 times less than SQTs based on a sediment-to-water ratio of 10^{-7}. These derived SQTs are detailed below.

3.3.1 Human Health SQTs

To determine SQTs for the protection of human health, sediment concentrations associated with a variety of risk-based fish concentrations (RBFCs) were determined. The RBFCs were calculated for recreational anglers and high-intake fish consumers for reasonable maximum exposure (RME) and central tendency exposure (CTE) scenarios. For recreational anglers, the amount of fish consumed was determined from two studies of Michigan anglers, while for high-intake fish consumers, the amount of fish consumed was determined from a study of low-income minority anglers and a study of Hmong anglers. RBFCs were calculated for a cancer risk level of 10^{-5} and a noncancer HI of 1.0 for each receptor. The RBFCs were translated into SQTs using the FRFood Model. These SQTs are presented in Table 3-2.

SQTs for a cancer risk level 10^{-6} are 10 times less than the SQTs for the cancer risk level 10^{-5}, and the SQTs for a cancer risk level of 10^{-4} are 10 times greater than the SQTs for the cancer risk level of 10^{-5}. SQTs for the cancer risk level of 10^{-5} ranged from 11 to 677 μg/kg. Noncancer SQTs ranged from 28 to 1,128 μg/kg. For SQTs based on cancer and noncancer effects, the minimum SQTs were based on consumption of carp by the high-intake fish consumer under a RME scenario and the maximum SQTs were based on consumption of yellow perch by the recreational angler under a CTE scenario.

3.3.2 Ecological SQTs

SQTs calculated for the De Pere to Green Bay Reach (Green Bay Zone 1) are shown in Table 3-3. These SQTs are based upon levels of total PCBs in fish that either cause risk to the fish themselves, or to birds or mink eating the fish, or total PCB concentrations in the sediment that cause risk to benthic invertebrates. The SQTs for no observed adverse effects (NOAEC) to walleye is 176 μg/kg and for carp is 363 μg/kg. The only calculated SQTs that were lower than these were the SQT for benthic invertebrates and the SQTs for piscivorous mammals (mink). The benthic invertebrates threshold effect concentration (TEL) is a sediment PCB concentration of 31.6 μg/kg. The NOAEC SQT for mink is 24. The highest derived SQT is 5,231 μg/kg and this concentration was derived based on the LOAEC potential for deformity in common terns. SQTs based on NOAECs were up to 10 times lower than SQTs based on LOAECs.

3.4 Section 3 Figures and Tables

Figures and tables for Section 3 follow page 3-14 and include:

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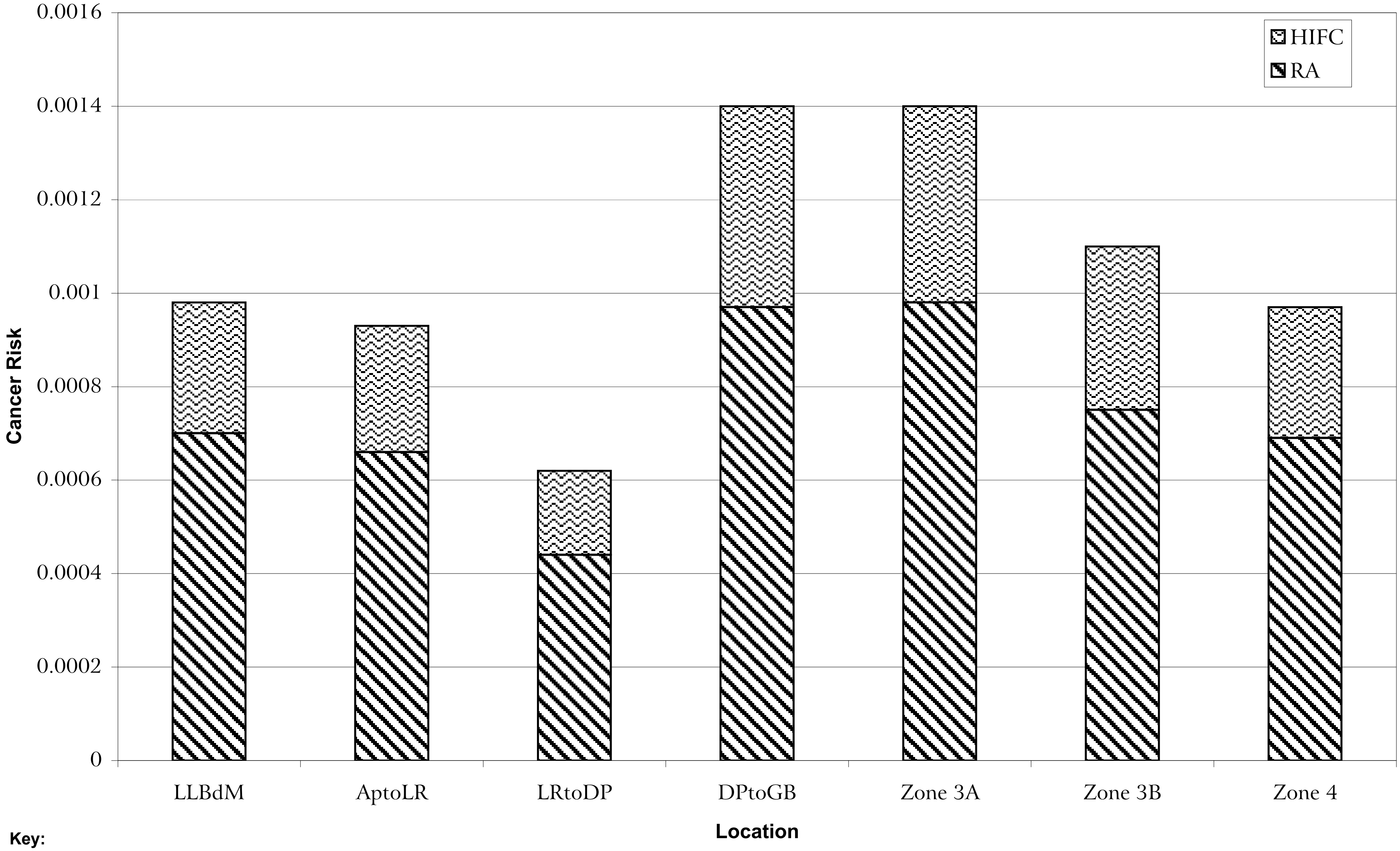
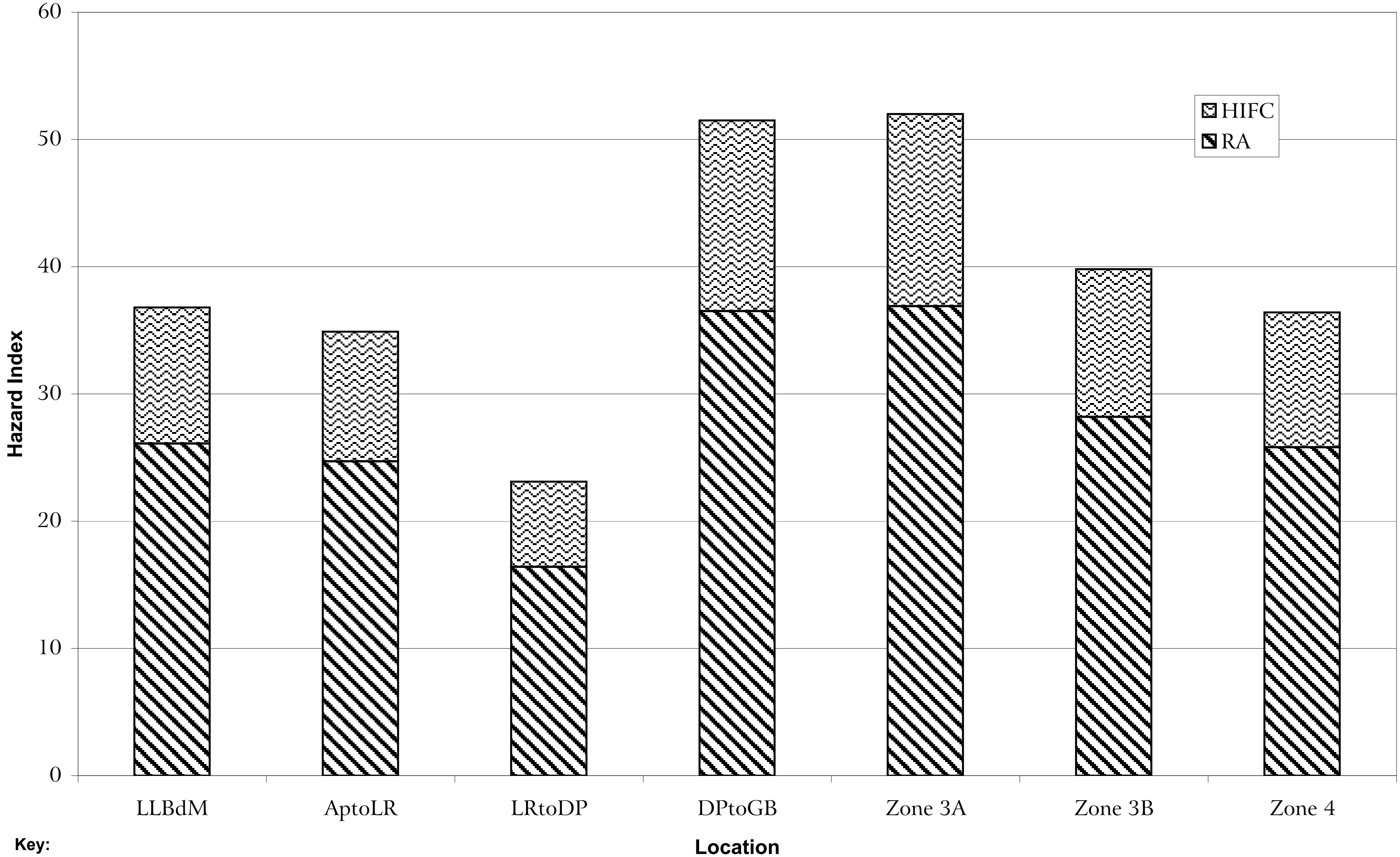
Figure 3-1 Maximum Cancer Risks for Recreational Anglers and High-intake Fish Consumers



Key:

RA - Recreational Angler
HIFC - High Intake Fish Consumer
LLBdM - Little Lake Butte des Morts
AptoLR - Appleton to Little Rapids
LRtoDP - Little Rapids to De Pere
DPtoGB - De Pere to Green Bay
Zone 3A - Zone 3A of Green Bay
Zone 3B - Zone 3B of Green Bay
Zone 4 - Zone 4 of Green Bay

Figure 3-2 Maximum Hazard Indices for Recreational Anglers and High-intake Fish Consumers



Key:

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HIFC - High Intake Fish Consumer
LLBdM - Little Lake Butte des Morts
AptoLR - Appleton to Little Rapids
LRtoDP - Little Rapids to De Pere
DPtoGB - De Pere to Green Bay
Zone 3A - Zone 3A of Green Bay
Zone 3B - Zone 3B of Green Bay
Zone 4 - Zone 4 of Green Bay

Figure 3-3 Selected Mercury HQs that Exceed 1.0

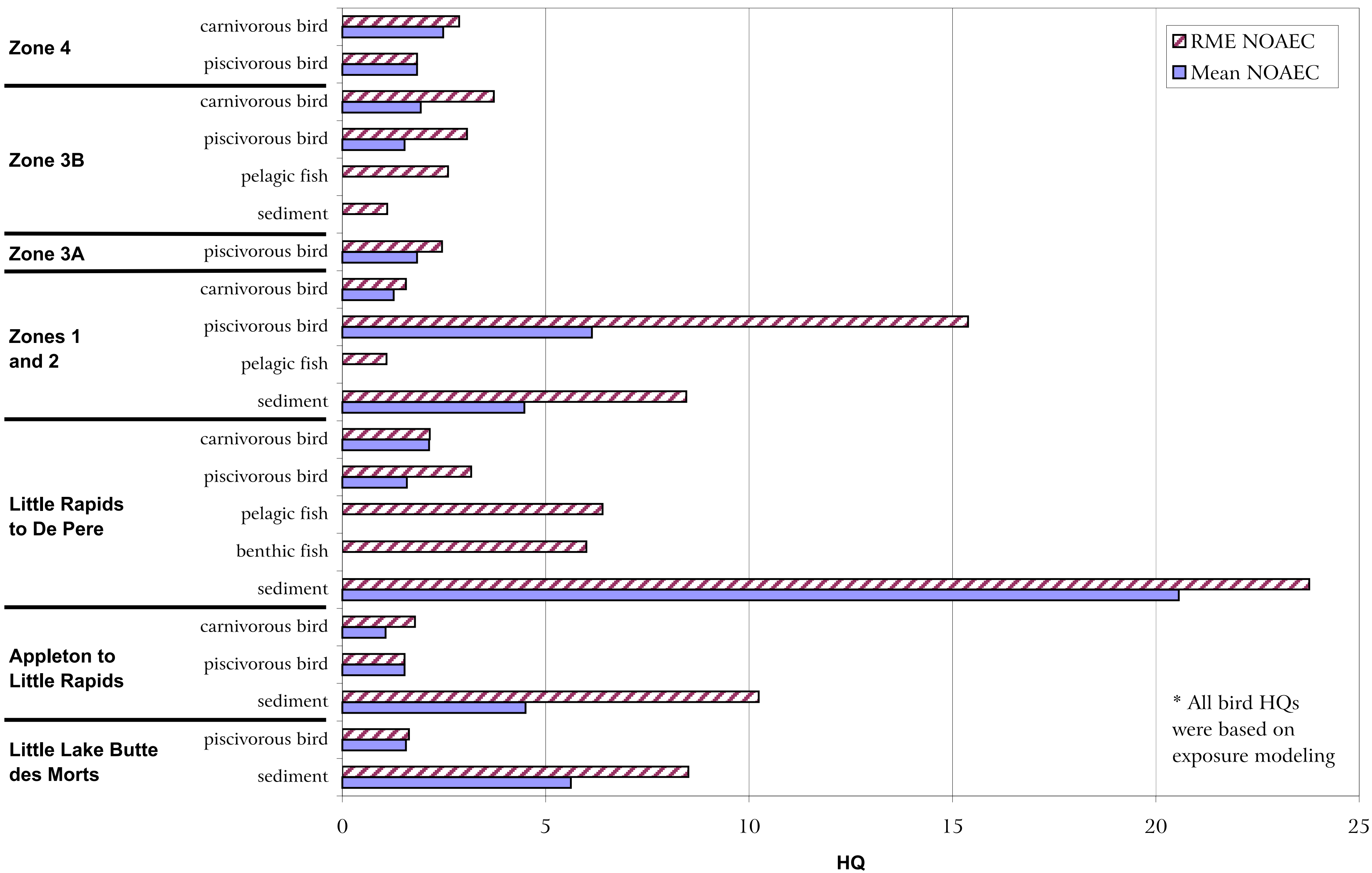

Figure 3-4 Selected PCB HQs that Exceed 1.0 for Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere Reaches

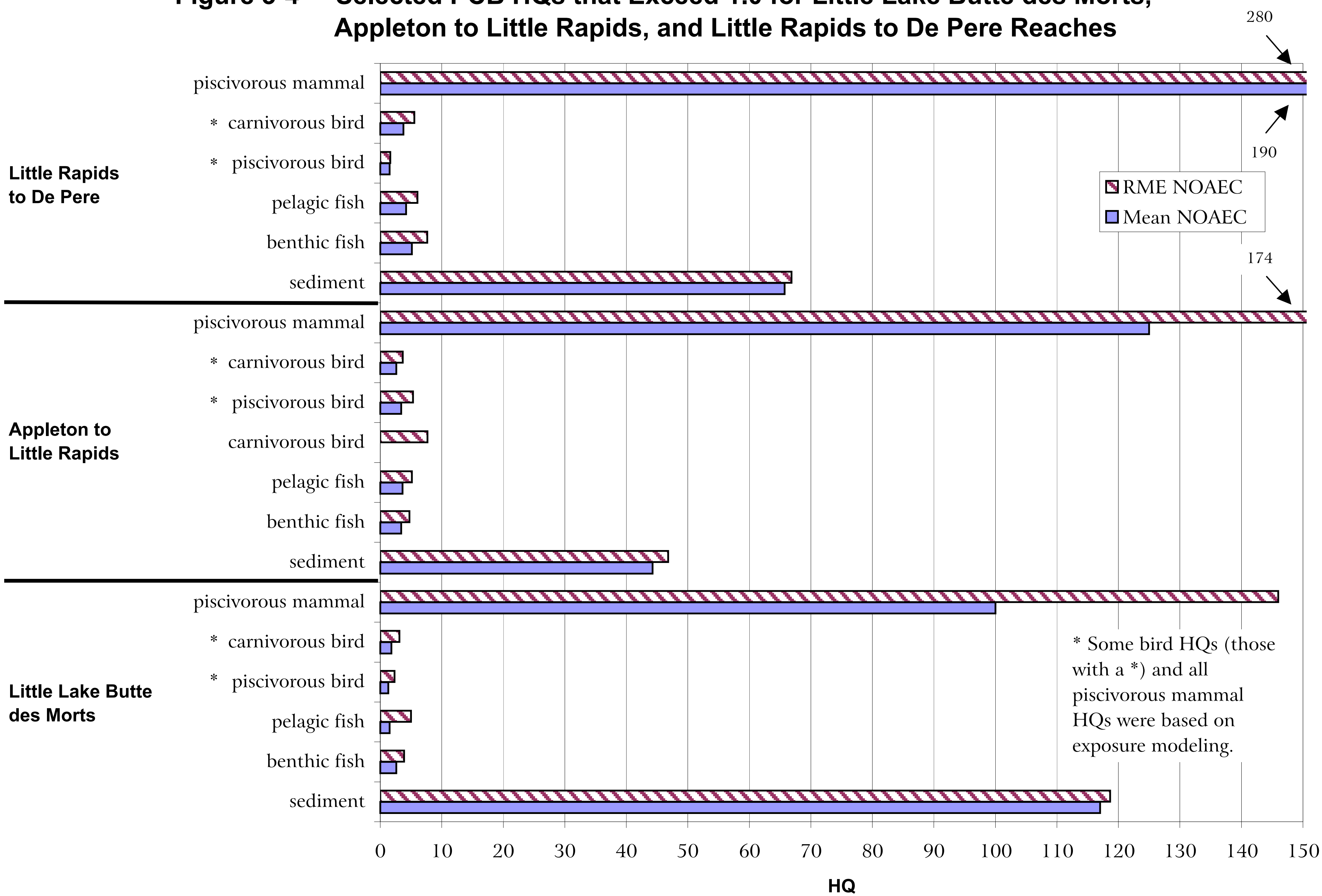

Figure 3-5 Selected PCB HQs that Exceed 1.0 for Green Bay Zones 1, 2, 3A, 3B, and 4

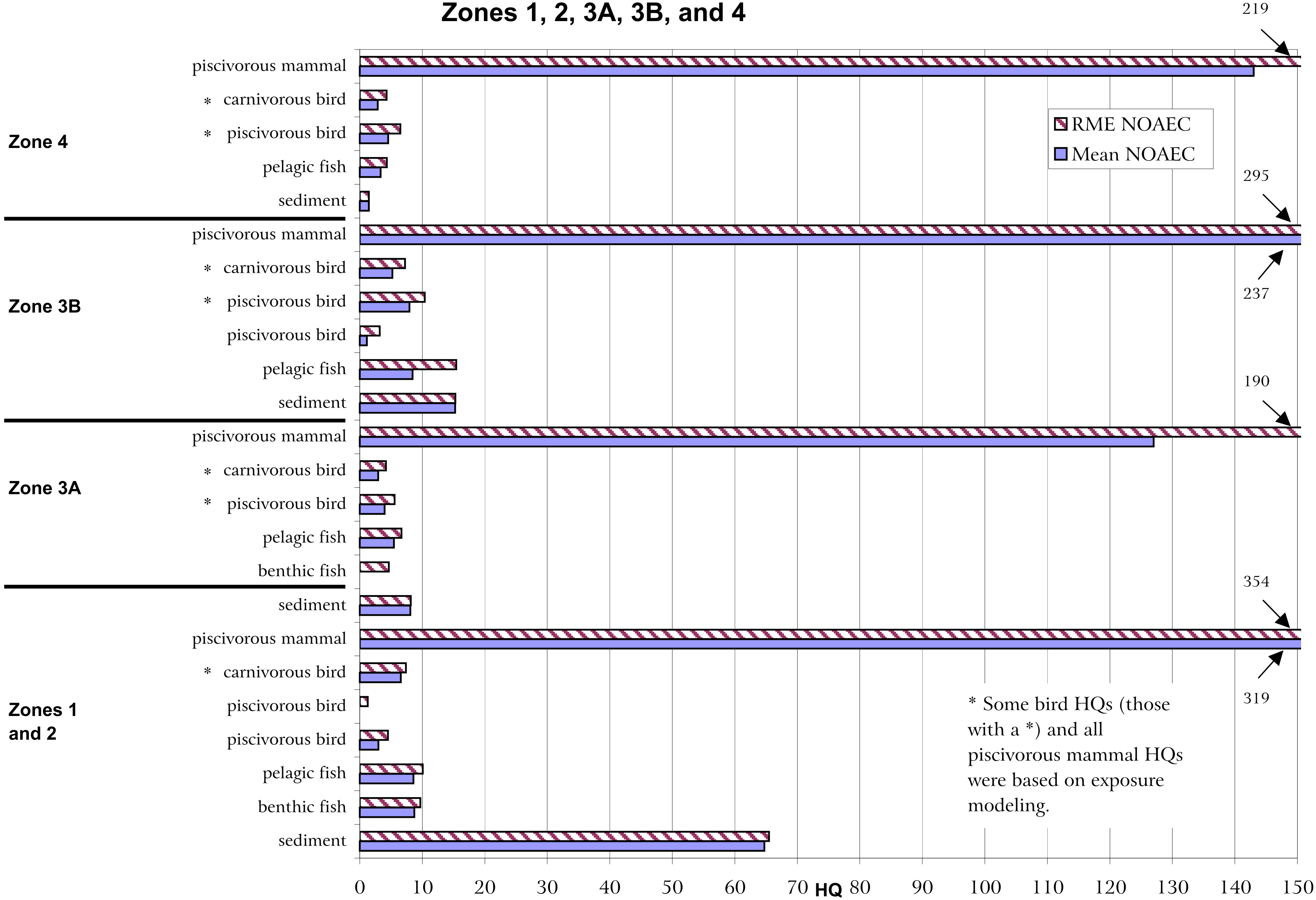

Figure 3-6 Selected DDT or Metabolite HQs that Exceed 1.0

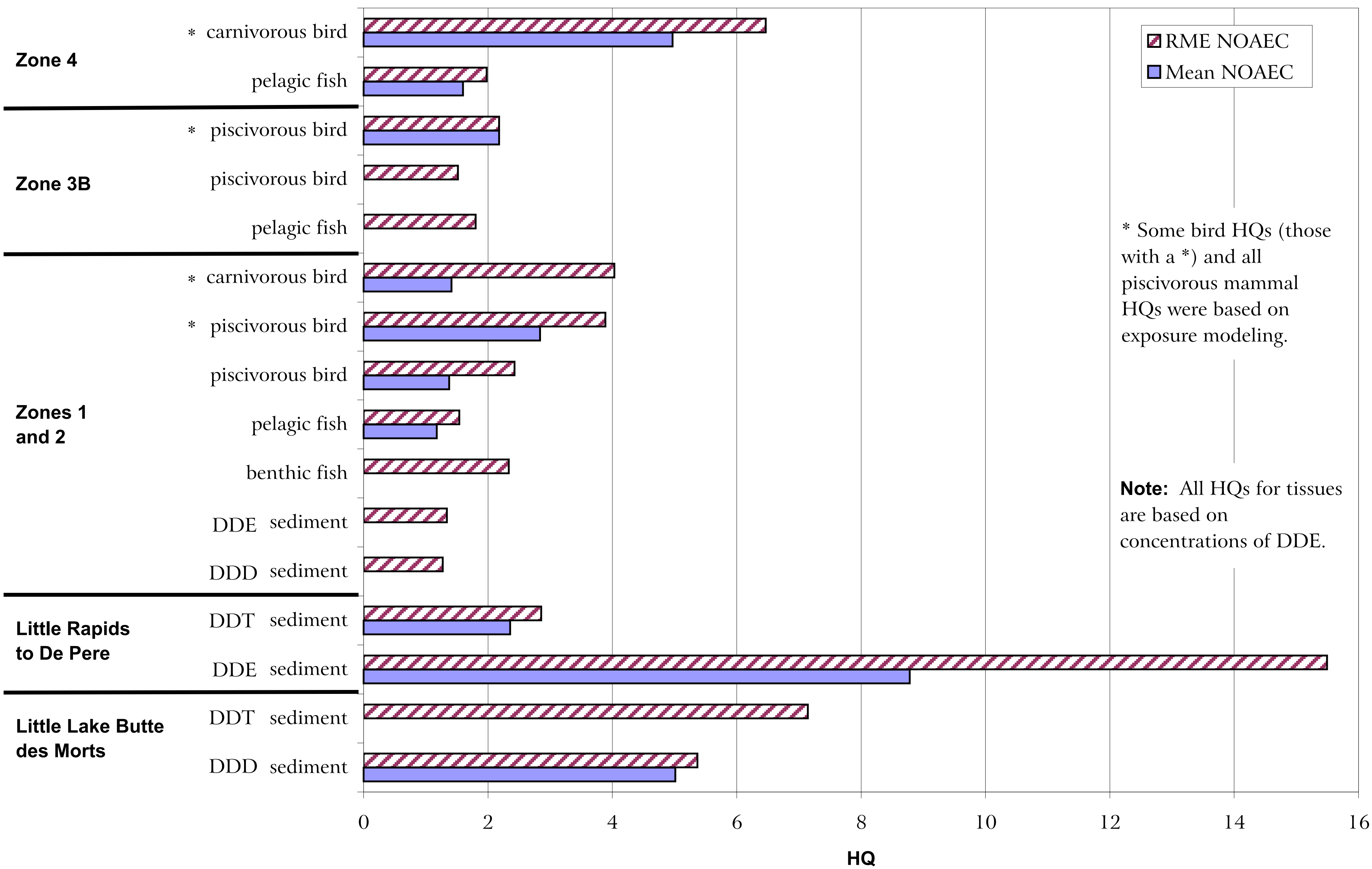

Table 3-1 Ecological Risk Summary Table

Location	Water Column Invertebrates	Benthic Invertebrates	Benthic Fish	Pelagial Fish	Insectivorous Bird	Piscivorous Bird	Carnivorous Bird	Piscivorous Mammal
Little Lake Butte des Morts	● *Mercury* ○ *PCBs*	● *Lead; Mercury; 2,3,7,8-TCDD; PCBs; DDD; DDT*	○ *PCBs*	○ *PCBs*	○ *PCBs*	○ *Mercury; PCBs*	○ *PCBs*	● *PCBs*
Appleton to Little Rapids	○ *PCBs*	● *Lead; Mercury; PCBs*	○ *PCBs*	○ *PCBs*	NA	○ *Mercury; PCBs*	● *PCBs* ○ *Mercury*	● *PCBs*
Little Rapids to De Pere	● *Mercury*	● *Lead; Mercury; 2,3,7,8-TCDD; PCBs; DDE; DDT*	○ *Mercury; PCBs*	○ *Mercury; PCBs*	NA	○ *Mercury; PCBs*	○ *Mercury; PCBs*	● *PCBs*
Green Bay Zone 1	○ *PCBs*	● *Arsenic; Lead; Mercury; PCBs; DDD; DDE*	○ *PCBs; DDE*	○ *Mercury; PCBs; DDE*	○ *PCBs*	○ *Mercury; PCBs; Dieldrin; DDE*	○ *Mercury; PCBs; DDE*	● *PCBs*
Green Bay Zone 2	● *Mercury*	● *Mercury; PCBs*			○ *PCBs; DDE*			
Green Bay Zone 3A		● *PCBs*	○ *PCBs*	○ *PCBs*	NA	○ *Mercury; PCBs*	● *PCBs* ○ *Dieldrin*	● *PCBs* ○ *Dieldrin*
Green Bay Zone 3B		● *Arsenic; Lead; Mercury; PCBs*		● *PCBs* ○ *Mercury; DDE*	NA	● *PCBs* ○ *Mercury; Dieldrin; DDE*	○ *Mercury; PCBs; DDE*	● *PCBs* ○ *Dieldrin*
Green Bay Zone 4		● *PCBs*	NA	○ *PCBs; DDE*	NA	○ *Mercury; PCBs*	○ *Mercury; PCBs; DDE*	● *PCBs*

Note:

NA - No data available.

Risk Conclusions Based on Hazard Quotients:

(blank box) - No risk.

● - Risk.

○ - Potential Risk.

Risk Conclusions Based on Weight of Evidence:

(yellow) - Site-specific receptor data suggest that there is no risk.

(blue-green) - Because of the federal listing of the bald eagle as threatened, it is concluded that potential risk is actual risk.

Table 3-2 Sediment Quality Thresholds Estimated for Human Health Effects at a 10^{-5} Cancer Risk and a Noncancer Hazard Index of 1.0

	Fish Parameters	Sediment Quality Thresholds			
	Fillet-to-Whole Fish Ratio	Recreational Anglers: Avgerage of Michigan Studies (West *et al.* , 1989; West *et al.* , 1993)		High-intake Fish Consumers: Average of Low-income Minority Anglers and Hmong Anglers (West *et al.* , 1993 and Hutchison and Kraft, 1994)	
		RME µg/kg	CTE µg/kg	RME µg/kg	CTE µg/kg
*Sediment Quality Thresholds for Risk of 10^{-5} **					
Carp	0.53	***16***	***180***	***11***	***57***
Walleye	0.17	***21***	***143***	***14***	***75***
Yellow Perch	0.17	***105***	***677***	***68***	***356***
Sediment Quality Thresholds for HI of 1.0					
Carp	0.53	***44***	***180***	***28***	***90***
Walleye	0.17	***58***	***238***	***37***	***119***
Yellow Perch	0.17	***276***	***1,128***	***175***	***564***

Notes:

* SQTs for cancer risks of 10^{-4} and 10^{-6} are an order of magnitude higher and lower, respectively.
RME indicates reasonable maximum exposure and CTE indicates central tendency exposure.
Sediment quality thresholds are bolded and in italics.

Table 3-3 Sediment Quality Thresholds Estimated for Ecological Effects

Species	Effect	Whole Fish Concentration (µg/kg ww)	Estimated SQT (µg/kg)
Benthic Invertebrates	Threshold Effect Concentration (TEL)	—	31.6
Walleye	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	176 1,759
Carp	NOAEC - fry growth and mortality LOAEC - fry growth and mortality	760 7,600	363 3,633
Common Tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,508 4,055 427 4,269	3,073 4,969 523 5,231
Forster's Tern	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	2,399 3,879 408 4,083	2,940 4,753 500 5,003
Double-crested Cormorant	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	814 1,317 139 1,386	997 1,614 170 1,698
Bald Eagle	NOAEC - hatching success LOAEC - hatching success NOAEC - deformity LOAEC - deformity	709 1,147 121 1,207	339 548 58 577
Mink	NOAEC - reproduction and kit survival LOAEC - reproduction and kit survival	50 500	24 239

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4 Development of Remedial Action Objectives and General Response Actions

This section defines several key cleanup concepts common to all feasibility studies prepared in accordance with CERCLA rules and guidance:

- Remedial action objectives,
- Applicable or relevant and appropriate requirements (ARARs) and information that is "to be considered" (TBC) in the development of remedial alternatives, and
- General response actions (GRAs).

Collectively, these concepts set the stage for developing effective and protective remedial alternatives for cleaning up the Lower Fox River and Green Bay.

RAOs are general cleanup objectives designed to protect human health and the environment. RAOs for the Lower Fox River and Green Bay address the threats site contaminants pose to human and ecological receptors. Risks to biological receptors were characterized and estimated in the BLRA (Section 3).

ARARs and TBCs constitute the body of existing statutes, regulations, ordinances, guidance, and published reports pertaining to any and all aspects of a potential cleanup action in the Lower Fox River and Green Bay. This information typically influences the development of remedial alternatives insofar as the establishment of numeric cleanup levels, permitting, siting, disposal, operating parameters, health and safety, and monitoring. The remedial alternatives developed in Section 7 must, to the extent practicable, meet the requirements of ARARs and address the findings of TBCs.

Lastly, this section presents GRAs for the Lower Fox River and Green Bay. GRAs are broad categories of actions such as treatment, containment, disposal, or combinations of the various categories designed to satisfy one or more of the RAOs. The remedial alternatives developed in Section 7 of this report are a synthesis of the applicable remedial technologies identified in Section 6 and the GRAs presented here.

4.1 Media and Chemicals of Concern

Defining the media and chemicals of concern (COCs) in the Lower Fox River and Green Bay is a necessary prerequisite to developing site-specific RAOs and GRAs. RAOs often state what media (e.g., surface water, soil, sediments) must be targeted for cleanup in order to protect human health and the environment. GRAs are also specific to the media and COCs insofar as the physical actions (e.g., removal, disposal) and treatment processes that should be considered. Finally, ARARs and TBC information are generally specified based on media and COCs. For example, identifying surface water as a medium of concern triggers consideration of state and federal clean water regulations.

4.1.1 Media of Concern

The RI identified surface water and sediments as the media of concern in the Lower Fox River and Green Bay. Contamination to these media pose risks to human health and ecological receptors. The BLRA (Section 3) determined that the sediments have the greatest impact on improving surface water quality, and thus on reducing risks to humans and wildlife. GRAs presented later in this section describe general cleanup options for COCs contained in sediments only. Cleanup of surface water and reductions in fish tissue COC concentrations will occur naturally once the source of contamination to surface water (i.e., impacted sediments) is removed, treated, or contained.

The vast majority of the mass of COCs is sorbed to sediment particles and is transported through the Fox River and Green Bay in suspended solids. Thus, water quality improvements of the two water bodies must focus on the reservoir of COCs contained in the sediment deposits.

4.1.2 Chemicals of Concern

Investigations of sediment and water quality coupled with information on former process operations along the Lower Fox River identified over 300 potential contaminants in the Lower Fox River (WDNR, 1993). *The Lower Green Bay Remedial Action Plan 1993 Update for the Lower Green Bay and Fox River Area of Concern* (WDNR, 1993) and the *Screening Level Risk Assessment* (RETEC, 1998) narrowed this list to eight COPCs for evaluation in the Baseline Risk Assessment (RETEC, 2002b) as follows:

- **COPCs**
  - PCBs (total and/or Aroclor 1242, PCB coplanar congeners),
  - Dioxins (2,3,7,8-TCDD),
  - Furans (2,3,7,8-TCDF),
  - DDT and metabolites (DDE and DDD),
  - Dieldrin,

  - Arsenic,
  - Lead, and
  - Mercury.

A detailed examination of these eight organic and inorganic constituents in the BLRA (Section 3) determined that PCBs pose the greatest human and ecological health risks in both surface water and sediments of the Lower Fox River and Green Bay. Mercury is the single inorganic constituent that presents significant risks. The BLRA also determined that DDE is a concern in sediments and that the risks from this constituent are confined to Green Bay. The COCs identified in the BLRA (RETEC, 2002b) and carried forward in the FS evaluation include:

- **COCs**
  - PCBs (total and coplanar congener),
  - Mercury, and
  - DDE.

However, PCBs are the dominant contributor to risks at the site as a whole. The remedial alternatives developed in this FS focus on the cleanup of sediments containing PCBs at levels considered a threat to human and ecological receptors.

4.2 Remedial Action Objectives for Lower Fox River and Green Bay

Protection of human health and the environment in the Lower Fox River and Green Bay can be achieved through fulfillment of the five RAOs discussed below and summarized in Table 4-1.

4.2.1 Surface Water Quality

RAO 1: Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.

RAO 1 addresses the impacts contaminated sediments in the Lower Fox River and Green Bay have on surface water quality. The primary focus of this FS is on management of sediments. The principal measure of management and/or cleanup success is achieving protective levels of COCs in fish tissue (see Sections 4.2.2 and 4.2.3) as determined in the BLRA. For this reason, water quality criteria are TBCs for all COCs in this FS. However, WDNR recognizes the importance of meeting, to the extent physically practicable, project ARARs and surface water quality TBCs for all COCs. The standards and criteria associated with ARARs and TBCs are discussed in Section 4.3.1. For relative comparison purposes between different remedial alternatives in this FS, expected surface water quality in 30 years following remedy completion is compared to Wisconsin state surface water quality for protection of human and wildlife health.

4.2.2 Human Health Risks

RAO 2: Protect humans who consume fish from exposure to COCs that exceed protective levels.

The BLRA determined that human exposure to PCBs through ingestion of fish is the exposure pathway leading to the greatest potential for adverse human health effects. Reducing levels and/or exposures of COCs in sediments is the most important means of reducing levels in fish residing in the Lower Fox River and Green Bay. The BLRA also identified ingestion of resident waterfowl by hunters as a significant exposure pathway. However, the health effects associated with this exposure pathway are less than those associated with ingestion of fish. Meeting the RAO for anglers will also protect hunters.

Several key thresholds were carried forward in the FS for relative comparison between alternatives. These thresholds were selected by both WDNR and EPA as important risk evaluation criteria that relate to the human health RAOs for the project:

- Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, HI is 1.0 (noncancer) (288 μg/kg);

- Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, 10^{-5} cancer risk (106 μg/kg);

- Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish RME, HI is 1.0 (noncancer) (181 μg/kg); and

- Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish, RME, 10^{-5} cancer risk (71 μg/kg).

  Because many of the recreational angler thresholds are met within 30 years following cleanup without implementation of an active remedy, the high-intake fish consumer threshold was added to the comparative analysis.

WDNR and EPA have established a remedy expectation that recreational anglers will be able to safely consume fish within 10 years following remedy completion, and high-intake fish consumers will be able to safely eat fish within 30 years following remedy completion.

4.2.3 Ecological Risks

RAO 3: Protect ecological receptors from exposure to COCs above protective levels.

The BLRA established exposure pathways and risks to multiple ecological receptors. At greatest risk from exposure to COCs (primarily PCBs) are:

- The insects and other organisms that live in the sediments and form the base of the food chain;
- Fish; and
- Birds and mammals that rely principally on fish for food.

The BLRA also concluded that reducing levels of COCs or exposures in surface sediments is the most important means of reducing risks to wildlife in the Lower Fox River and Green Bay. WDNR and EPA have established a remedy expectation that safe ecological thresholds will be consistently met within 30 years following remedy completion.

Several key thresholds were carried forward in the FS for relative comparison between alternatives. These thresholds were selected by both WDNR and EPA as important risk evaluation criteria that relate to the ecological health RAOs for the project:

- Achieve protective levels in 30 years following cleanup based on carnivorous bird deformity - NOAEC based on carp, whole fish (121 μg/kg);
- Achieve protective levels in 30 years following cleanup based on protection of piscivorous mammals (mink) - NOAEC based on carp, whole fish (50 μg/kg); and
- Achieve surface water quality for the protection of wildlife (0.12 ng/L) in 30 years following cleanup.

4.2.4 Transport of Contaminants to Lake Michigan

RAO 4: Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.

Contaminant transport from the Lower Fox River to Green Bay and greater Lake Michigan is detrimental to environmental quality in these aquatic systems. Dissolved-phase COCs are transported downstream and along prevailing currents in the water column. Similarly, the movement of COCs adsorbed to resuspended sediments is a concern, particularly during high-flow periods. This RAO is designed to improve environmental conditions in the Lower Fox River and Green Bay as well as in Lake Michigan. The performance evaluation of remedial actions must consider the long-term transport of residual COCs and the potential such transport has to cause adverse human and ecological health effects. For relative comparison purposes between different remedial alternatives in this FS, the PCB loading rates onto Green Bay at the mouth of the Lower Fox River are compared to the combined loading rates of other Green Bay tributaries following remedy completion in the Lower Fox River.

4.2.5 Contaminant Releases During Remediation

RAO 5: Minimize the downstream movement of PCBs during implementation of the remedy.

This RAO focuses attention on the short-term effectiveness of remedial alternatives. Contaminant releases may occur through various mechanisms, such as volatilization or sediment resuspension (i.e., during dredging). Achieving the goals of this RAO may require incorporation of measures to control contaminant releases during remediation.

4.3 Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Information

Section 121(d) of CERCLA stipulates that remedial actions instituted under the Superfund program comply with ARARs. Consideration must also be given to relevant information that, while not legally binding, is collectively referred to as TBC information. ARARs are promulgated cleanup standards and other environmental protection requirements, criteria, or limitations contained within local, state, and federal laws and regulations. TBCs may or may not be promulgated standards and not legally enforceable. Nevertheless, TBCs may contribute to the development and implementation of effective and protective remedial alternatives.

The identification of ARARs and TBCs depends on the media, COCs, site-specific characteristics, and the technologies employed during remediation. ARARs and TBCs that may contribute to defining remedial alternatives for the Lower Fox

River are provided in Tables 4-2 and 4-3 and are grouped into chemical-specific, location-specific, and action-specific categories.

4.3.1 Chemical-specific ARARs and TBCs

Chemical-specific ARARs define concentration limits for environmental media. These requirements may be used to set cleanup levels for COCs in sediment and water. For example, the Federal Clean Water Act establishes concentration limits in surface water that are considered protective of human and aquatic life. The principal chemical-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **Toxic Substances Control Act (TSCA).** TSCA is both a chemical and action ARAR that establishes federal requirements for handling, storage and disposal of materials containing PCBs in excess of 50 ppm.

- **Federal Clean Water Act.** Ambient water quality criteria developed under the Clean Water Act are non-enforceable guidelines that identify protective concentrations of various chemical constituents for surface waters. As non-enforceable guidelines, the ambient water quality criteria are TBCs for the site.

- **State of Wisconsin Water Quality Standards - WAC NR 100 Series.** Wisconsin Administrative Code (WAC) Sections NR 102 through 105 establishes surface water quality standards for the state. The standards are used in making water management decisions and in the control of municipal, business, land development, and agricultural discharges. The WAC NR 140 establishes groundwater quality standards for the state. These standards are used for managing upland disposal facilities. These standards are ARARs for water quality criteria that must be achieved following sediment remediation work in the Lower Fox River and Green Bay. Water quality ARARs related to point discharges are covered under action-specific ARARs.

With respect to establishing sediment cleanup levels, WDNR's sediment guidance (WDNR, 1996) states that state water quality standards are goals to be considered in the development and evaluation of sediment cleanup actions. They are not to be used to develop sediment cleanup values. Although the WDNR's water quality criteria (WQC) are legally promulgated standards, they are not legally enforceable since WDNR does not have a promulgated method for establishing sediment cleanup standards derived from WQC. Protective sediment COC concentrations for the Lower Fox River and Green Bay were developed in the BLRA as discussed in Section 3. This approach is supported by EPA's 1996

Superfund PCB cleanup guidance (EPA, 1996a) which allows for the calculation and use of risk-based sediment cleanup levels as opposed to levels calculated based on equilibrium partitioning between sediments and the overlying water column. Thus, the water quality standards are TBCs for sediment remediation in the Lower Fox River and Green Bay.

4.3.2 Location-specific ARARs

Location-specific ARARs place constraints or define requirements for remedial activities that occur in environmentally sensitive areas (e.g., wetlands, floodplains). Location-specific ARARs are used to manage the disposal of sediment-derived wastes in the State of Wisconsin and out-of-state landfills (i.e., preservation of historical sites, navigational constraints). In addition, this category of ARARs defines the siting and permitting requirements for new treatment and disposal facilities (e.g., landfills). The principal location-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **Wisconsin Statutes Chapter 289.** Prohibits the construction of landfill facilities in floodplains or in open-water areas except by special state permits or legislative authority. Also manages the landfill siting and approval process for upland disposal.

- **Wisconsin Statutes Chapter 30.** Regulates work performed in navigable waters and harbors.

4.3.3 Action-specific ARARs

Action-specific ARARs govern the design, performance, or operational aspects of contaminated materials management. For example, action-specific ARARs are used to establish safe concentration levels for discharge of materials during implementation of a remedial action. The National Pollution Discharge Elimination System (NPDES) defines concentration limits on water discharged to surface water from industrial facilities and operations. Discharge limitations would likely apply to sediment cleanups involving the dredging and subsequent discharge of dredge water to surface water. The principal action-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **State of Wisconsin WAC NR 500 through 520.** These regulations are ARARs that establish standards for collection, handling, transport, storage, and disposal of solid wastes, respectively. These disposal standards apply for both new and existing landfills. Under Wisconsin law, dredged material is considered a solid waste.

- **State of Wisconsin WAC NR 600.** These regulations are ARARs that establish standards for handling and management of hazardous wastes. These disposal standards apply for both new and existing hazardous waste landfills. The NR 600 series would also include hazardous waste management using high-temperature thermal desorption (HTTD) and incinerator units.

- **State of Wisconsin WAC NR 500 and Wisconsin Statute 289.43.** These regulations contain exemptions for the management of solid and low-hazard wastes.

- **State of Wisconsin WAC NR 400.** These regulations are ARARs that establish air quality standards for removal and disposal of hazardous waste. They also set allowable chemical concentration levels for removal and disposal of contaminated sediments. Treatment of sediments by HTTD units would be managed as incinerators under this series by air quality, if TSCA-level materials are treated.

- **State of Wisconsin WAC NR 200 (WPDES program).** These regulations establish water quality effluent limits for discharges during sediment remediation activities. The dewatering ponds/lagoons used for temporary dewatering of dredged material would likely be managed as a wastewater lagoon under the WAC NR 200 series. The WAC NR 213 regulation specifically addresses the requirements for lining of industrial lagoons and design of storage structures regarding effluent limits.

- **Wisconsin Statutes Chapter 30.** This section of the Wisconsin Statutes contains provisions to minimize adverse effects on navigable waterways. The statute specifically bans open-water disposal of dredged material on the beds of navigable waters unless a permit is granted by WDNR pursuant to the statute or the state legislature specifically authorizes an open-water disposal project. It does not, however, prohibit construction of a nearshore confined disposal facility (CDF) and disposal of dredged sediments (less than 50 ppm PCBs) into a newly constructed CDF.

- **Wisconsin Statutes Chapter 289 (Low-hazard Waste Exemption).** This section of the Wisconsin Statutes addresses the permitting and siting requirements for construction of new upland landfills and disposal of solid waste along a river. Under this statute, WDNR has the authority to waive setback requirements for siting disposal facilities.

The low-hazard exemption statute could be used for non-TSCA dredged material disposal sites if no impact to the surrounding environment can be justified.

- **Section 10 - Rivers and Harbors Act.** This federal statute contains provisions for minimizing adverse effects from dredge and fill work conducted within navigable waterways of the United States.

- **Section 404 - Clean Water Act.** This ARAR requires approval from the USACE for discharges of dredge or fill materials into waters of the United States.

- **Federal Clean Water Act.** Surface water quality standards under Section 304 of the Clean Water Act are ARARs for point discharges to the river. Discharges occurring as a part of sediment remediation must comply with this ARAR.

4.3.4 To Be Considered Information

TBCs can be grouped into chemical-, location-, or action-specific categories. Important laws, regulations, and guidance that are TBCs for the cleanup of sediments in the Lower Fox River and Green Bay are as follows:

- **State of Wisconsin Surface Water Quality Standards.** The state water quality standards are TBCs for evaluating the effectiveness of sediment remedial alternatives. One of the RAOs for site cleanup is meeting these standards to the extent practicable.

- **Federal Safe Drinking Water Act.** As with water quality standards, drinking water standards are TBCs for sediment cleanup in the Lower Fox River and Green Bay. RAO 1 requires that remedial alternatives meet drinking water standards to the extent practical. These standards are not used to develop sediment cleanup levels.

- **Great Lakes Water Quality Agreement.** This agreement calls for the identification of "Areas of Concern" and the establishment of remedial goals for impacted ports, harbors, and river mouths in the Great Lakes area.

- **Section 303(d) - Clean Water Act.** This portion of the Clean Water Act requires states to formulate and submit to EPA lists of "impaired waterways" that may be subject to watershed planning with respect to total maximum daily loads (TMDL) of various water quality parameters. In December 1996, WDNR submitted its first list of impaired waterways to EPA, which included the Fox River because of the presence of PCBs.

- **Sediment Remediation Implementation Guidance.** Part of the 1995 Strategic Directions Report prepared by WDNR addresses how sediment remediation work should be approached in the State of Wisconsin. The guidance calls for using a risk management process to appraise environmental impacts and assess the technical feasibility and costs of sediment remediation, and states that water quality standards are goals for evaluating sediment impacts to the aquatic environment and for evaluating the performance of various remedial options.

- **Great Lakes Water Quality Initiative.** This initiative sets forth guidance to states bordering the Great Lakes regarding wastewater discharge programs. For remedial actions involving discharges, any lowering of water quality should be minimized to the extent practicable. These concepts are embodied in WAC NR 102 through 106.

4.3.5 Numeric Surface Water and Drinking Water TBCs

Table 4-4 lists drinking water and surface water quality standards and criteria for the eight COPCs identified in the SLRA. PCBs, DDE, and mercury are the primary COCs that pose a risk to human health and the environment with respect to impairment of water quality. These values are goals (RAO 1) for ambient water quality following sediment cleanup and ARARs with respect to limiting point discharges during remediation.

4.4 Development of General Response Actions (GRAs)

The RAOs, in conjunction with results of the RI and BLRA, establish the basis for identifying general response actions to clean up the Lower Fox River and Green Bay. GRAs are broad categories of actions such as treatment, containment, disposal, or combinations of the various categories. Specific categories of GRAs identified for contamination in the Lower Fox River and Green Bay sediments are as follows:

- No Action,
- Institutional Controls,
- Monitored Natural Recovery,
- Containment,
- Removal,

- *In-situ* Treatment,
- *Ex-situ* Treatment, and
- Disposal.

4.4.1 Description of GRAs

No Action

Consideration of a "No Action" response is required by the National Contingency Plan (NCP). No action serves as a baseline against which the performance of other remedial alternatives can be compared. This response assumes no active remedial measures are implemented.

Institutional Controls

Institutional controls are legal or administrative measures designed to restrict site access or limit site use. The measures reduce exposure to COCs by precluding activities that could lead to exposure. Dredging moratoriums and fish consumption advisories are relevant examples of institutional controls.

Monitored Natural Recovery

Natural recovery refers to the processes by which concentrations of COCs in impacted media decline over time by natural processes such as biodegradation, burial, or dilution. While both mercury and PCBs are persistent in the sediment environment, reductions in the concentrations of these constituents over time will occur as a result of these natural processes. However, the time frame required to achieve sufficient reductions in bioavailable concentrations must be calculated and it must be determined whether the time frame is reasonable and acceptable. As discussed in the next section of this report (Section 5), the assumption of natural recovery is central to the development of a range of sediment cleanup action levels that can be used to evaluate varying cleanup time frames for the proposed alternatives.

Containment

Containment involves the physical isolation and immobilization of contaminants in sediment. Capping is a common method used in lakes, bays, marine, and riverine environments for containing impacted sediments. No sediment treatment occurs other than by natural processes under the cap surface. Assuming effective cap placement, the bioavailability and mobility of contaminants present in the sediments would be immediately limited.

Removal

Sediment removal by dredging or excavation is another common practice for managing contaminated sediments. Following removal, the material is usually relocated to a treatment or disposal facility. Dredging often requires consideration of other unit processes such as:

- In-water controls to minimize contaminant resuspension during removal,
- Dewatering to reduce sediment moisture content,
- Treatment of dredge water before discharge, and
- Disposal and/or treatment of dredged material.

In-situ Treatment

In-situ treatment involves chemical or biological methods for reducing contaminant concentrations or bioavailability without first removing the sediment.

Ex-situ Treatment

Ex-situ treatment involves the application of treatment technologies to transform, destroy or immobilize COCs following removal of the contaminated sediments. Thermal destruction is one of the more common treatment technologies for PCBs and other chlorinated organics. Metals are commonly treated with cement or other stabilizing materials.

Disposal

Disposal is the permanent placement of material into an appropriate structure or facility. It is often a significant component of alternatives involving removal of sediments (capacity and cost). Disposal or possible beneficial reuse considerations involve the contaminated media and/or residues from pretreatment and treatment operations.

4.4.2 Summary of GRAs and Expectations

Several of the individual GRAs described above likely would not be implemented alone. Rather, they would be implemented in conjunction with other actions. Final selection and design of GRAs will depend on the technological ability to meet the project expectations described in Table 4-5. These expectations are used in this FS to compare the relative risk reduction, costs, and number of years to reach protective thresholds between different alternatives and action levels. Project expectations are a comparative tool and actual implementation of expectations for management of risks will be determined during the design phase. With respect to sediment remediation, the response actions (or combinations) carried forward in this FS are as follows:

- No action,
- Monitored natural recovery and institutional controls,
- Containment (capping),
- Removal and disposal, and
- Removal and *ex-situ* treatment.

Depending on the level of treatment, ARARs, and the physical composition of sediment, treated material may be beneficially used as fill, precluding disposal in a landfill.

In Section 6 of this FS Report, remedial action technologies are identified and screened for each of the aforementioned response actions. In addition, process options within each technology type are identified and screened. The technology types and process options retained after screening are utilized in the development of remedial alternatives (Section 7) for the Lower Fox River and Green Bay.

4.5 Section 4 Tables

Tables for Section 4 follow this page and include:

Table 4-1 Remedial Action Objectives for the Lower Fox River and Green Bay

Number	Definition
1	*Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.*
2	*Protect humans who consume fish from exposure to COCs that exceed protective levels.*
3	*Protect ecological receptors from exposure to COCs above protective levels.* This RAO considers: • Adverse effects to the diversity and reproductive viability of aquatic organisms (fish and insects) in the Lower Fox River and Green Bay, • Adverse effects to fish, • Adverse effects to insect-eating birds through ingestion of fish, and • Adverse effects to fish-eating mammals through ingestion of fish.
4	*Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.*
5	*Minimize the downstream movement of PCBs during implementation of the remedy.*

Table 4-2 Potential Federal ARARs and TBCs for the Lower Fox River and Green Bay

Program	Requirements	Citation	Description	Application	Comment
Clean Water Act		33 U.S.C.A. Sec. 1251–1387			
	Ambient Water Quality Criteria	CWA Section 304 Quality Criteria for Water, EPA, 1986	Establishes non-enforceable guidelines for States to set water quality standards for surface water. Criteria based on protection of aquatic life and human health.	Chemical	Applicable only if concentrations of surface water above sediments exceed these criteria; otherwise becomes a cross-media check.
	Water Quality Standards	CWA Section 303 40 CFR 131	Requires states to develop water quality standards based on federal guidelines.	Chemical Action	Applicable only if concentrations of surface water above sediments exceed these criteria; otherwise becomes a cross-media check.
	National Pollutant Discharge Elimination System	CWA Section 401	Requires compliance with permit limitations for discharge to navigable waters, including water quality effluent limits, water quality standards, national performance standards, and toxic and pretreatment effluent standards.	Action	NPDES program is administered by the state. (see Wisconsin NPDES Permit Regulations.) Applicable for actions involving discharges of liquid effluent to surface water.
	Effluent Standards - Technology- Based Discharge Requirements	CWA Section 301(b)	Requires all direct discharges to be treated with best control technology prior to discharge.	Action	Applicable if surface water is channeled directly to a surface water body via a ditch, culvert, storm sewer, or other means; or treated water is discharged.
	Dredge and Fill Requirements	CWA Section 404 (Inland Testing Manual)	Regulates discharge of dredged or fill material to U.S. waters, including wetlands. Testing manual establishes procedures for determining the potential for contaminant-related impacts associated with discharge of dredged material in inland waters.	Action	Applicable for consideration of any practicable alternatives and may require protection of environmental values of the site.
	Proposed Sediment Quality Criteria	CWA Section 304 Sediment Quality Criteria, EPA, 1991	Establishes sediment quality standards that will not unacceptably affect benthic organisms.	Chemical	Potentially applicable once promulgated.
	Great Lakes Critical Program Act of 1990 - Assessment and Remediation of Contaminated Sediments (ARCS) Program	CWA Section 118 (c)(7) 40 CFR Part 132 (Appendix E)	Provide environmental managers at AOCs and elsewhere with the tools and information necessary for making informed cost-effective, and environmentally sound decisions in addressing a local contaminated sediment problem.	Location	To be considered in addressing existing and possible pollutant problems in the Great Lakes and their tributaries.

Table 4-2 Potential Federal ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

Program	Requirements	Citation	Description	Application	Comment
Resource Conservation and Recovery Act		42 U.S.C.A. 6901–6992k			
	General Requirements	40 CFR Parts 172 and 173	Establishes standards for transporting PCB waste.	Action	Applicable in evaluating transportation and handling of PCB-dredged material.
	Definition of Hazardous Waste	40 CFR 261	Defines threshold levels and criteria to determine whether material is hazardous waste.	Chemical Action	Applicable in evaluating which wastes would be classified hazardous. These regulations do not set cleanup standards, but would apply during various remedial actions.
	Water Resources Development Act				
	Toxic Substances Control Act (TSCA)	40 CFR Parts 750 and 761	Establishes requirements for handling, storage, and disposal of PCB-containing materials in excess of 50 ppm.	Chemical Action	Applicable to alternatives that address PCB-containing materials in excess of 50 ppm
		40 CFR Part 761	Establishes performance standards for disposal technologies (i.e., incinerators, capping).	Action	Air emissions from incineration cannot exceed 0.001 gram of PCBs per kilogram of PCBs treated.
	Occupational Safety and Health Administration (OSHA)	29 CFR Parts 1910.120, 1910.132, 1910.134, 1910.138	Establishes 8-hour time-weighted average concentrations for protection of worker breathing zones, PPE requirements, medical monitoring requirements, respiratory protection requirements, HAZMAT training requirements.	Action	Applicable for workers near areas of contamination
Clean Air Act		42 U.S.C. 7401–7642			
	National Primary and Secondary Ambient Air Quality Standards (NAAQS)	40 CFR Part 50	Establishes ambient air quality standards for protection of public health.	Chemical Action	Applicable in evaluating air impacts prior to or during remediation
	National Emissions Standards for Hazardous Air Pollutants (NESHAP)	40 CFR Part 61	Establishes emission standards for sources emitting benzene, arsenic, asbestos, beryllium, mercury, radionuclides, and vinyl chloride.	Chemical Action	Applicable in evaluating emission standards on treatment technologies.
International Joint Commission (IJC)		IJC, 1992	Protection of fish tissue	Location	To be Considered
Land Disposal of PCB Sediments		Valdas Adamkus 1/24/95 EPA Memorandum to WDNR	Outlines requirements for disposal of PCB sediments greater than 50 mg/kg within Wisconsin NR 500-licensed landfills.	Action	Applicable in evaluating disposal options of sediments. This requirement is being renegotiated as of December 2000.

Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay

Program	Requirements	Citation	Description	Application	Comment
Wisconsin State Environmental Protection Administrative Code					
General		*WAC NR 100 Series*			
	Water Quality Standards for Wisconsin Surface Waters	WAC NR 102–105	Establishes definition of water use and criteria for protection of public health and enjoyment and protection and propagation of fish, shellfish, and wildlife.	Chemical	Applicable only if concentrations of surface water above sediments exceed these criteria. They are TBCs.
	Groundwater Quality	WAC NR 140	Establishes groundwater quality standards for substances detected or having reasonable probability of entering groundwater resources.	Chemical	Applicable for removal, transport, and disposal of contaminated sediments (impacts to groundwater).
	Management of PCBs and Products Containing PCBs	WAC NR 157	Establishes procedures for the storage, collection, transportation, processing, and final disposal of PCBs and materials containing PCBs at any level. It refers to NR 500 and 600 series.	Action	Applicable for removal, transport, and disposal of contaminated sediments.
	Plans and Specifications Review of Projects and Operations	WAC NR 108	WDNR approval of any reviewable project, general operation and control of specific water/wastewater system.	Action	Applicable for community water systems, sewage systems, and industrial wastewater facilities.
WPDES		*WAC NR 200 Series*			
	Wisconsin Pollutant Discharge Elimination System	WAC NR 200	Technology-based effluent limits (NR 220–297). Requires compliance with permit limitations for discharge to navigable waters, including water quality effluent limits, water quality standards, national performance standards, and toxic and pretreatment effluent standards.	Action	Applicable action-specific ARAR for remedial alternatives involving discharges.
	Water Quality Antidegradation	WAC NR 207	Establish implementation procedures for the antidegradation policy in s. NR 102.05(1)(a).	Action	Applicable to proposed new or increased discharges.
	Water Quality Antidegradation: Waste Load Allocated, Water Quality-related Effluent Standards and Limitations	WAC NR 212–220	Establishes permit limitations for effluent discharges.	Action	Applicable for remedial alternatives involving effluent discharges.
	Lining of Industrial Lagoons and Design of Storage Structures	WAC NR 213	Requires compliance with permit limitations for discharge to navigable waters from industrial treatment systems.	Action	Potentially applicable for waste management of temporary sediment dewatering and treatment systems.

Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

Program	Requirements	Citation	Description	Application	Comment
Water Regulation		*WAC NR 300 Series*			
	Wisconsin's General Permit Program for Certain Water Regulatory Permits	WAC NR 322	Establishes minimum design standards and specifications for projects permitted under a general permit.	Action	Potentially applicable for implementation of a given remedial alternative.
	Dredging Contract Fees	WAC NR 346	Establishes procedures applicable to the removal of material from the beds of natural lakes and outlying waters for which a contract is required between the state and person desiring to remove bed material.	Action	Potentially applicable for removal, transport, and disposal of sediments.
	Sediment Sampling and Analysis, Monitoring Protocol, and Disposal Criteria for Dredging Projects	WAC NR 347	Establishes procedures and protocols for sediment sampling and analysis, disposal criteria, and monitoring requirements for dredging projects regulated by the State of Wisconsin.	Action	Potentially applicable for removal, transport, and disposal of sediments.
Air Pollution Control		*WAC NR 400 Series*			
	Wisconsin State Air Pollutant Control Regulations	WAC NR 400–499	Establishes concentration levels, by chemical, for new sources. Manages construction and operation permits.	Action	Applicable action-specific ARAR for removal and disposal of mercury- and PCB-contaminated sediments.
Solid Waste Management		*WAC NR 500 Series*			
	Solid Waste Management	WAC NR 500–520	Provides definitions, submittal requirements, exemptions and other general information relating to solid waste facilities which are subject to regulations under s. 2789.01(35) Stats. Applicable for off-site siting processes. Applicable to new and existing facilities.	Action	Applicable for implementation of a given remedial alternative.
	Beneficial Reuse Solid Waste Exemption	WAC NR 500.08	Establishes criteria for possible beneficial use of solid wastes after treatment. Applies for on-site reuse options only.	Location Action	Applicable for disposal of treated sediments meeting disposal criteria.
Hazardous Waste Management		*WAC NR 600 Series*			
	Hazardous Waste Management	WAC NR 600–685	Provides definitions, general permit application information, incorporation by reference citations and general information concerning the hazardous waste management program. Establishes procedures for handling, storage, and disposal of hazardous wastes.	Action	Applicable for removal, transport, and disposal of contaminated sediments. Applicable to treatment units, regulated as incinerators.
	Identification and Listing of Hazardous Waste	WAC NR 605	Establishes criteria for identifying the characteristics of hazardous waste to determine if the waste is subject to regulation.	Action	Applicable for removal, transport, and disposal of contaminated sediments.

Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

Program	Requirements	Citation	Description	Application	Comment
	Investigation and Remediation of Environmental	*WAC NR 700 Series*	Management of contaminated soil.		
	Investigation and Remediation of Environmental Contamination	WAC NR 700	Establishes standards and procedures that allow for site-specific flexibility, pertaining to the identification, investigation, and remediation of sites and facilities which are subject to regulation under s. 144.442, 144.76, or 144.77, Stats.	Action	Applicable for implementation of a given remedial alternative.
	Notification of the Discharge of Hazardous Substances	WAC NR 706	Notification procedures and responsibilities by discharger of hazardous substances including containment, cleanup, disposal, and restoration.	Action	Applicable for removal, transport, and disposal of contaminated sediments.
	Soil Cleanup Standards	WAC NR 720	Allows for the calculation of site-specific risk-based cleanup standards based on the intended reuse of the property. Generally applied to unsaturated material or soils.	Chemical	Likely managed under NR 500. Potentially applicable if dewatered sediment is considered soil after treatment.
	Standards for Selecting Remedial Actions	WAC NR 722	Establishes standards for selection of remedial actions. Generally applied to soil cleanup programs.	Chemical	Potentially applicable, but likely managed under NR 500.
Dredge and Fill Requirements		WDNR 1985, 1990	Report of the Technical Subcommittee on Determination of Dredge Material Suitability of In-Water Disposal.	Location Action	To be considered for alternatives involving in-water disposal, such as confined aquatic disposal (CAD).
Lower Green Bay Remedial Action Plan		WDNR, 1993	Mercury limits.	Chemical	To be considered.
Local Permits (building, zoning, other)			Construction in floodplain or wetland and miscellaneous construction activities.	Location	To be considered for implementation of a given remedial alternative.
Great Lakes Water Quality Initiative (GLI)		WAC 102 and 106 EPA 1995	Sets forth guidance for any remedial action in states bordering the Great Lakes. In general, minimize any lowering of water quality to the extent practicable.	Action	To be considered with regard to remedial alternatives involving wastewater discharge.

Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

Program	Requirements	Citation	Description	Application	Comment
Wisconsin State Environmental Protection Statutes					
	Sediment Remediation Implementation Guidance	Strategic Directions Report, WDNR 1995	Addresses the sediment remediation approach recommended by WDNR for sediment remediation projects.	Action	To be considered in risk management, technological feasibility and cost.
	Landfill Siting and Approval Process	Wis. Stats. Ch. 289	State statute for solid waste facilities. Addresses the upland disposal of solid waste along with in-river disposal options. Landfill facilities are prohibited from shoreland and floodplain zone areas except by permits issued from WDNR.	Location	Applicable for implementation of any given remedial alternative disposal option.
	Low-hazard Solid Waste Exemption	Wis. Stats. Ch. 289.43	Solid waste law that allows issuance of exemption from siting requirements in NR 500–520. Dredged material may be considered "exempt" after treatment if "new" product is created.	Action	Potentially applicable if *ex-situ* treatment option is selected.
	Permit in Navigable Waters	Wis. Stats. Ch. 30	State statute for navigable waters, harbors, and navigation. Substantive provisions that address minimizing adverse effects on navigable waterways resulting from work performed.	Location	Applicable for work performed in navigable waterways.
	EPA TSCA Approval Letter for Land Disposal of PCB Sediments	January 24, 1995 (from Valdas Adamkus)	EPA 5-year approval letter allows WDNR to waive disposal requirements in NR 500 landfills and allow disposal of TSCA-level sediments (>50 ppm).	Action	Applicable in evaluating disposal options of sediments. The requirement is being renegotiated with EPA as of December 2000.

Note:

Wisconsin State Administrative Code can be found at website: http://www.legis.state.wi.us/rsb/code/. Table 4-3 last updated from website on December 10, 2000.

Table 4-4 Surface Water Quality Criteria

Chemical of Potential Concern	Clean Water Act [1]				Safe Drinking Water Act [2] Standards		Wisconsin Surface Water Quality [3]	Wisconsin Surface Water (warm water forage, limited forage, and warm water sport fish communities) [3]	
	Freshwater CMC [4] (μg/L)	Freshwater CCC [5] (μg/L)	Human Health for Consumption of Water and Organism (μg/L)	Human Health for Consumption of Organism Only (μg/L)	MCLG (μg/L)	MCL (μg/L)	Wildlife Criteria [3] (μg/L)	Human Threshold Criteria [8] (μg/L)	Human Cancer Criteria [8] (μg/L)
Total PCBs	NL	0.014	0.00017 [A]	0.00017 [A]	0	0.5	0.00012	—	0.00001
4,4'-DDT	1.1	0.111	0.00059 [A]	0.00059 [A]	—	—	—	0.003	0.00022
4,4'-DDE	—	—	0.00059 [A]	0.00059 [A]	—	—	—	—	—
4,4'-DDD	—	—	0.00083 [A]	0.00084 [A]	—	—	—	—	—
Dioxin (2,3,7,8-TCDD)	—	—	0.000000013 [A]	0.000000014 [A]	0	3.00E-05	3.00E-09	1.10E-07	1.40E-08
Furan (2,3,7,8-TCDF)	—	—	—	—	—	—	—	—	—
Dieldrin	0.24	0.056	0.00014 [A]	0.00014 [A]	NL	NL	—	0.00059	9.10E-06
Arsenic	340	150	0.018 [A]	0.14 [A]	NL	50	—	—	50
Lead	65	2.5	[B]	[B]	0	TT	—	140	—
Mercury	1.4	0.77	0.050	0.051	2	2	0.00013	0.0015	—

Notes:

"—" - The chemical of concern was not listed.
NL - No criterion listed for the chemical of concern.
TT - Treatment technique, action level 15 μg/L.
[1] National Recommended Water Quality Criteria - Correction. EPA Office of Water, April 1999. EPA 822-Z-99-01.
[2] Drinking Water Regulations and Health Advisories. EPA Office of Water, October 1996. EPA 822-B-96-002.
[3] Wisconsin Department of Natural Resources, Chapter NR 105, Surface Water Quality and Secondary Values for Toxic Substances.
[4] Criteria Maximum Concentration.
[5] Criterion Continuous Concentration.
[6] Maximum Contaminant Level Goal. A nonenforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.
[7] Maximum Contaminant Level. Maximum permissible level of a contaminant in water which is delivered to any user of a public water system.
[8] Criteria for non-public water supply (μg/L).
[A] Criterion based on carcinogenicity of 10^{-6} risk.
[B] EPA has not calculated human health criterion for this contaminant. However, permit authorities should address this contaminant in NPDES permit actions using the state's existing narrative criteria for toxics.

Table 4-5 Remediation Goals and Project Expectations

Remedial Action Objective	Valued Endpoint Goal	Remediation Goal	Primary Exposure Pathway	Strategic End Goal and Expectation	Monitoring Metrics
FS Section 4		*FS Section 5*	*BLRA Section 3*	*Long-term Monitoring Plan (Appendix C)*	
Achieve Surface Water Quality	We can eat fish and swim in the water.	Reduce exposure pathway in surface sediments by reducing concentrations in surface water.	Respiration in water, dermal contact	Surface water is ≤ to levels in upstream areas. Water quality meets state and federal criteria.	• Concentrations in surface water
Protect Human Health	We can all eat fish and birds.	Minimize exposure pathway in surface sediments by reducing concentrations in fish.	Direct ingestion of fish and waterfowl with COCs	Lift consumption advisories in 10 years for recreational anglers and 30 years for high-intake fish consumers following remedy completion.	• Concentrations in fish tissue • Concentrations in waterfowl tissue
Protect Ecological Receptors	Habitats and populations are healthy and diverse in 30 years.	Minimize exposure pathway by reducing or isolating concentrations in surface sediments.	Direct contact with sediment and surface water; ingestion of sediment, water, and fish	Fish tissue levels meet protective thresholds in 30 years following remedy completion.	• Concentrations in fish, bird, and invertebrate tissue • Mink habitat assessment • Bird population and deformity assessment
Reduce PCB Transport from Lower Fox River to Green Bay and to Lake Michigan	Protect downstream habitats and water quality.	Reduce or contain contaminant mass that may mobilize during regular storm events.	Dermal contact or ingestion of fish	Surface water and sediment levels are ≤ to upstream areas. Loading estimates to Green Bay are reduced to tributary levels.	• Surface sediment levels • Bathymetry • Flow rates and mass balance
Minimize Releases During Active Remediation	Protect downstream habitats.	Contain contaminant mass during remedy implementation through monitoring and physical barriers.	Ingestion of sediment, water, and prey.	<5% of PCBs are transported downstream during remediation.	• Concentration in surface water • Concentration in sediment

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5 Development of PCB Action Levels for the Lower Fox River and Green Bay

This section of the FS puts forward a rational basis for developing remedial action levels from the array of sediment quality thresholds (SQTs) developed earlier in Section 4. An SQT is a risk-based PCB threshold in sediments derived to be protective of specific human health pathways and ecological receptors (fish, avian, or mammal). An action level is a specific PCB cleanup goal carried forward in the FS that considers the level of risk reduction estimated from the SQT thresholds and the variety of PCB concentrations present at the site. Both SQTs and remedial action levels were derived with the assumption that a remedial action targeting PCBs would also capture the other COCs. This section evaluates a series of PCB action levels that brackets the array of SQTs. These action levels result in different volumes/masses of sediment removed, and different levels of risk reduction (Figures 5-1 and 5-2). Unless the most stringent SQT is set as the cleanup goal for the Lower Fox River and Green Bay (correlating to the 125 ppb PCB action level), then some level of risk will remain at the site after remediation. The levels of remaining risk will be discussed and evaluated in Sections 8 and 10 of this FS.

Residual risk in sediments may be quantified in terms of COC concentrations at discrete locations or surface-weighted average concentrations (SWAC) in surface sediments. Cleanup to a higher concentration (absolute concentration or SWAC) may be protective in the long term. The dynamics of the Lower Fox River and Green Bay aquatic systems promote the slow decline of surface sediment concentrations by natural processes (e.g., sedimentation). Thus, actions to remove and isolate or treat sediment to higher levels may be acceptable if natural processes can be relied upon to return sediment COC concentrations to protective levels in a reasonable time frame.

This section presents a rationale for adopting specific PCB action levels central to the evaluation of remedial alternatives that involve sediment removal (dredging) or isolation (capping). As discussed in Section 4, these are often the most important active general response actions to consider for sediment cleanup. Indeed, the alternatives developed and evaluated in Section 7 that involve active remediation arise principally from these two response actions. Valuations are therefore presented for the following key parameters:

- Sediment volume removed or isolated under an active management alternative,
- Mass of PCB removed or isolated in sediments, and
- Residual surface-weighted average concentrations (SWAC) following sediment removal.

Results of the volume, mass, and SWAC calculations are presented for each river reach and for each zone of Green Bay.

5.1 Rationale

Action levels are COC concentrations in surface sediments designed to meet project expectations and RAOs. These action levels represent safe thresholds in surface sediment that are protective of both human and ecological receptors. However, action levels that precipitate an active removal or containment action may include or exceed cleanup levels established by chemical-specific ARARs or risk assessment to satisfy project RAOs. In these cases, action levels depend on natural processes capable of further reducing risks in the long term (e.g., sedimentation, degradation, dispersion). Therefore, an evaluation of alternatives at action levels above SQTs necessarily requires a predictive capability. For this site, four fate and transport, and exposure models will be used to determine whether or to what extent cleanup to an action level is capable of meeting RAOs within a reasonable time frame. These computer models include:

- Whole Lower Fox River (wLFR) Sediment Fate and Transport Model,
- Lower Fox River Food Web Model (FRFood),
- Green Bay Toxicity (GBTOXe) Fate and Transport Model, and
- Green Bay Food Web Model (GBFood).

These fate, transport, and exposure models for the Lower Fox River and Green Bay predict the distribution of COCs (in this case PCBs) as a function of time in both sediment and the water column. The evaluation of alternatives (Section 8) compares the relative benefits of short-term risk reduction (immediate attainment of protective concentrations) and longer term natural attainment of protective concentrations following removal or capping to a higher action level.

5.1.1 Array of SQTs

The Final Baseline Human Health and Ecological Risk Assessment (RETEC, 2002b) developed SQTs that provide receptor-specific protective PCB concentrations (Section 3). These SQTs were based upon bioaccumulation modeling from tissue concentrations of PCBs in fish that placed human or ecological receptors at risk. The SQTs, and some of the critical receptors they were intended to protect for both the Lower Fox River and Green Bay, are shown on Figures 5-1 and 5-2 for human health and ecological health, respectively. For the purposes of this FS, SQTs are expressed in μg/kg units. SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level. SQTs are used to evaluate harmful levels of chemicals that must be addressed, what levels of those chemicals can be safely left behind, and which remedial option offers the best risk reduction. From the array of PCB-SQTs for specific human health and ecological receptors, the response agencies can evaluate risk reduction and select cleanup standards, or remedial action levels for the Lower Fox River and Green Bay, at the conclusion of the feasibility study. Limits on the application of SQTs for predicting future risk are discussed in Section 3.

5.1.2 Array of Action Levels

The action levels selected for evaluation (125, 250, 500, 1,000, 5,000, and 10,000 parts per billion [ppb] PCBs) bracket the risk-based SQTs for human and ecological receptors discussed in Section 3 (see Figures 5-1 and 5-2). Action levels carried forward in the FS were selected based on several considerations:

- Select an array of action levels that bracket the human health and ecological SQT values;
- Select lowest action level where residual SWAC is protective of approximately 90 percent of human/ecological receptors (Section 3);
- Select highest action level (minimal protection) where residual SWAC is protective of approximately 10 percent of human/ecological receptors (Section 3);
- Consider the implementability of concentration levels based on precedent set on other sediment remediation projects (i.e., dredging, capping, natural recovery) (Appendices B and C); and
- Select an array of action levels that bracket a commonly implemented action level of 1 ppm PCBs. The array includes multiples of the 1 ppm action level including 10×, 5×, 0.5×, 0.25×, and 0.125×.

For the purposes of this FS, action levels are expressed in ppb units. Action levels are remediation cleanup criteria for sediments that define the size of the dredge prism requiring removal.

The analysis presented here partitions the sediment volumes and associated PCB mass distribution between those that exceed a given action level and those that are below the same action level. Further, the analysis estimates the SWAC for the PCB residual following hypothetical removal of material exceeding the action level. Trends in the relationships between the three parameters (volume, mass, SWAC) can be used to subjectively determine which specific action levels to retain for fate and transport modeling. Ultimately, output from the Fox River and Green Bay models determines how much time is required for fish tissue concentration to reach acceptable levels (Section 8). The relationship between action level and restoration time (i.e., time to reach acceptable fish tissue concentrations) is central to the comparative evaluation of alternatives in Section 10.

5.2 Procedures for Estimating Sediment Volume, Mass and SWAC

As part of the Remedial Investigation (RETEC, 2002a), interpolated concentrations of sediment properties through the entire areal and volumetric extent of the Lower Fox River and Green Bay were developed based on data from the Fox River Database (FRDB). The interpolation profiles sediment bed properties (PCB concentration, PCB mass, dry bulk density, and sediment thickness) across the four reaches of the Lower Fox River and the three zones of Green Bay. ArcView GIS software with Spatial Analyst uses the data profiles to compute where sediment quality exceeds the action level and therefore what sediment requires remedial action (removal or isolation). Further, the same software enables calculation of a post-removal or post-isolation SWAC profile. The specific methods for interpolation were summarized in Section 2.4.2 of the FS.

The volume and mass computations use the same basic method of analysis. The interpolated sediment profile was analyzed from bottom to top to determine locations that exceed the action level. Any material that exceeded the action level, or was located above a depth that exceeds the action level, was included in the volume and mass calculation. Locations within layers that do not contain sediment or sediment that is less than half the model layer thickness (i.e., station thickness is only 10 cm in a 30-cm-thick layer) are not included in the volume and mass analyses. Locations that exist outside of the defined "deposits" known as "interdeposit areas" that exceed the selected action level were also included in the PCB mass and volume estimates requiring removal. The specific step-wise procedure for these calculations is provided in Table 5-1.

A similar approach computes the SWAC for material remaining at the surface following hypothetical removal. For undredged areas, the new surface concentration at a location is the same as the concentration in the interpolated surface concentration. In dredged areas, the new surface concentration is taken as the concentration in the layer below the dredged layer. If the bottommost layer is removed, then the new surface concentration is assumed equal to the action level. Areas that do not contain sediment or where sediment thickness is less than half the model layer thickness are assumed to have a PCB concentration of 50 μg/kg. The SWAC was computed for each river reach by summing the new surface concentration over the entire reach and then dividing by the area of the reach. The step-by-step procedure for the SWAC calculations is provided in Table 5-2. For the purposes of this FS, SWAC values are expressed in μg/kg units.

5.3 Lower Fox River Results

Results of the action level analysis for sediment volumes, associated mass of PCBs, and SWACs are presented in the accompanying tables and figures. Table 5-3 shows the estimated volume and mass values by identified deposits within each reach. As expected from the RI data, the majority of contaminated sediment volume and PCB mass resides in the De Pere to Green Bay Reach. The Appleton to Little Rapids Reach contains the least sediment volume and PCB mass. Table 5-4 presents the calculated SWAC values exposed at the surface after dredging for each reach.

Figure 5-3 presents sediment volume as a function of action level. The percentage values embedded in the graphs represent the percent differences between bracketing volume estimates. For example, there is a 56 percent difference between the calculated sediment volumes at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach. Figure 5-3 demonstrates the sensitivity of sediment volume to action level across most of the Lower Fox River. With the exception of the De Pere to Green Bay Reach (below 1,000 ppb action level), sediment volumes decline appreciably as a function of action level. This strong dependency of volume to action level bears directly on remedial costs, particularly for cleanup alternatives that involve dredging.

Figure 5-4 relates PCB mass removed to action level. The embedded percentage values, in this case, are the percentages of PCB mass removed relative to the total present at the lowest action level (i.e., 125 ppb). The assumption here is that the PCB mass at 125 ppb is a reasonable estimate of the total mass present that could pose a risk. Figure 5-4 shows that, for the most part, PCB mass is considerably less sensitive to action level than sediment volume at the lower end of the range (e.g., less than 1,000 ppb). Thus, for example, one can remove 96 percent of the PCB mass in the Little Rapids to De Pere Reach at the 500 ppb action level with just 55 percent of the sediment volume (i.e., relative to the estimated volume at the 125 ppb action level).

Figure 5-5 presents the mass and volume calculations in a single graph for each reach. This figure perhaps best illustrates how efficiently the PCB mass and/or sediment volume can be removed or isolated at a selected action level.

Figure 5-6 shows the relationship between SWAC and action level for the four reaches. SWAC is less sensitive to action level in the Appleton to Little Rapids Reach because of the low levels of PCBs found in this section of the river. In the remaining three reaches, SWAC is considerably more sensitive to action level. Note in Figure 5-6 that the 1,000 ppb action level yields a residual SWAC reasonably close (within a factor of 2) to the lowest cleanup action levels (i.e., 125 and 250 ppb) proposed for the FS. The cleanup action level of 5,000 ppb yields a residual SWAC value that is three to four times higher than 250 ppb (the lower action level). Conversely, it should be noted that there is little difference in the residual SWACs between 125 and 250 ppb action levels. These results suggest that 5,000 ppb is a reasonable upper limit action level for evaluating cleanup alternatives considering the time required to reach protective levels (the SQT of 250 μg/kg) by natural processes following sediment removal or containment actions.

5.4 Green Bay Results

Table 5-5 presents sediment volume, PCB mass and SWAC values for Green Bay at action levels of 125, 250, 500, 1,000 and 5,000 ppb. Figure 5-7 presents sediment volume as a function of action level for each zone. Sediment volume is very sensitive to action level, particularly in zones 2A, 3A, and 3B. The lowest two action levels correspond with extraordinarily large sediment volumes (greater than 100,000,000 cubic meters [m^3]) most of which reside in zones 3A and 3B. Even at the 1,000 ppb action level, where the impacts are limited to zones 2A and 2B, the calculated sediment volume is in excess of 20,000,000 m^3.

PCB mass is not very sensitive to action level in zones 2A and 2B (Figure 5-8). Approximately 90 percent of the total mass of PCBs in zones 2A and 2B (i.e., at concentrations equal to or greater than 125 μg/kg) can be removed at the 1,000 ppb action level. Further from the mouth of the river (zones 3 and 4) the majority of the mass occurs at concentrations of 250 μg/kg or less. Figure 5-9 further illustrates these trends by directly relating sediment volume to PCB mass.

Figure 5-10 presents SWAC as a function of action level. SWAC is most sensitive to action level in zones 2A and 2B, where the most significant sediment impacts reside. The SWAC in Zone 3A is slightly above the 250 μg/kg benchmark at the highest action level, while in Zone 3B the maximum SWAC is a little more than twice as high. The SWAC in Zone 4 is less than one-half the SQT of 250 μg/kg, regardless of action level.

5.5 Selection of Action Levels for Evaluation of Remedial Alternatives

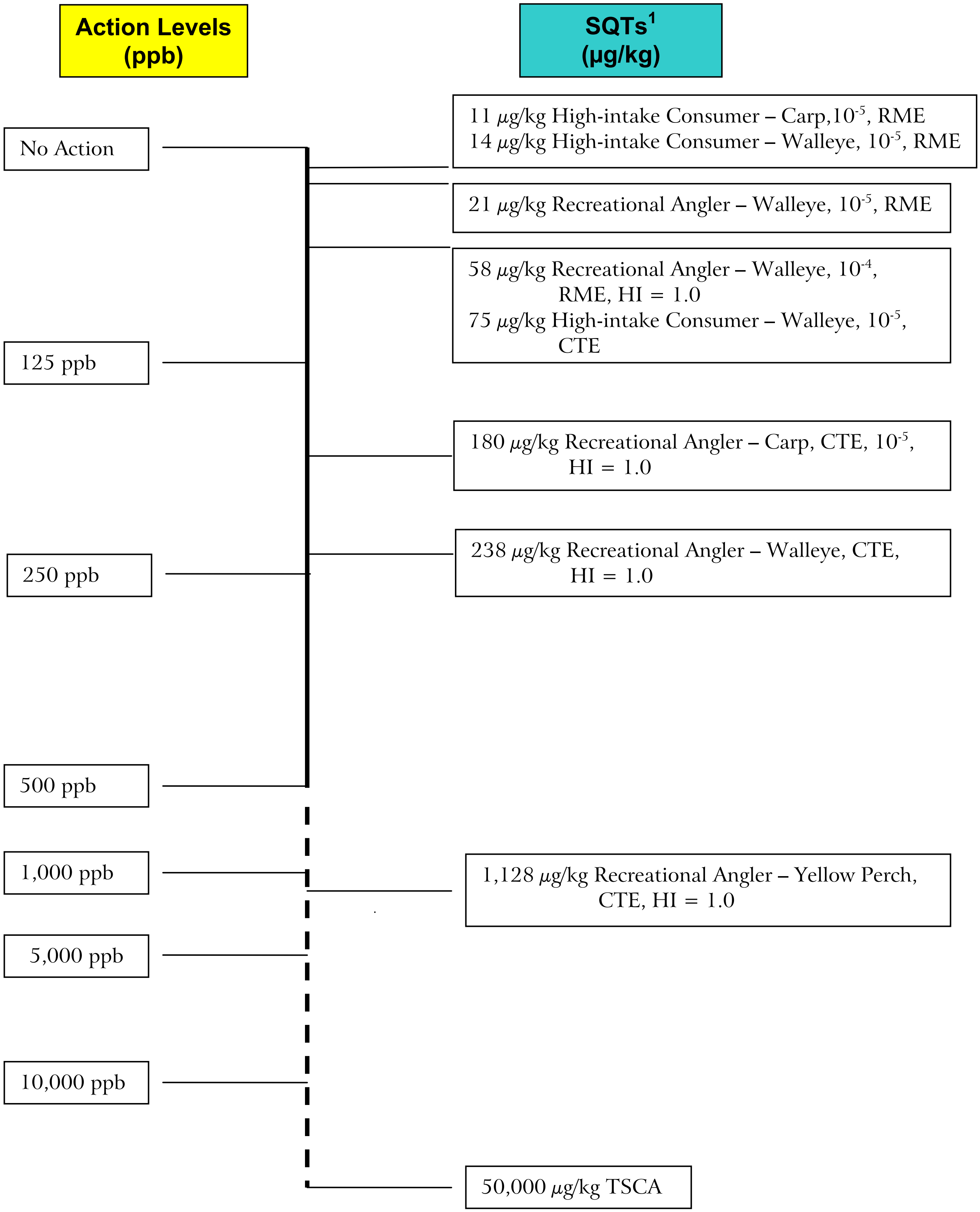
Remedial alternatives for the Lower Fox River that involve containment (capping) or removal (dredging) will be developed for action levels of 125, 250, 500, 1,000, and 5,000 ppb. For Green Bay, containment and removal alternatives will be developed for action levels of 500, 1,000, and 5,000 ppb. The 10,000 ppb action level was eventually dropped from the Lower Fox River evaluation because the bulk of PCB-impacted sediments were addressed at the 5,000 ppb level, and the 10,000 ppb level was not considered adequately protective of valued receptors to warrant further consideration. The 10,000 ppb action level was dropped from the Green Bay evaluation since the maximum detected concentration in Green Bay was below 10,000 μg/kg. The lowest two action levels were dropped from the Green Bay analysis simply based on the massive volume of sediment requiring removal and disposal. Finding a disposal site with adequate capacity would be technically and administratively challenging and improbable. The corresponding estimates of affected area, sediment volume, PCB mass, and SWAC are central to the development and evaluation of remedial alternatives in subsequent sections of this document (Sections 7, 8, and 9). Following are several key aspects of the cleanup alternatives that are strongly influenced by action level:

- Facility and equipment sizing,
- Siting requirements,
- The duration of active cleanup operations,
- Duration of monitoring and maintenance programs,
- Time to reach protective concentrations through natural processes, and
- Costs.

5.6 Section 5 Figures and Tables

Figures and tables for Section 5 follow page 5-8 and include:

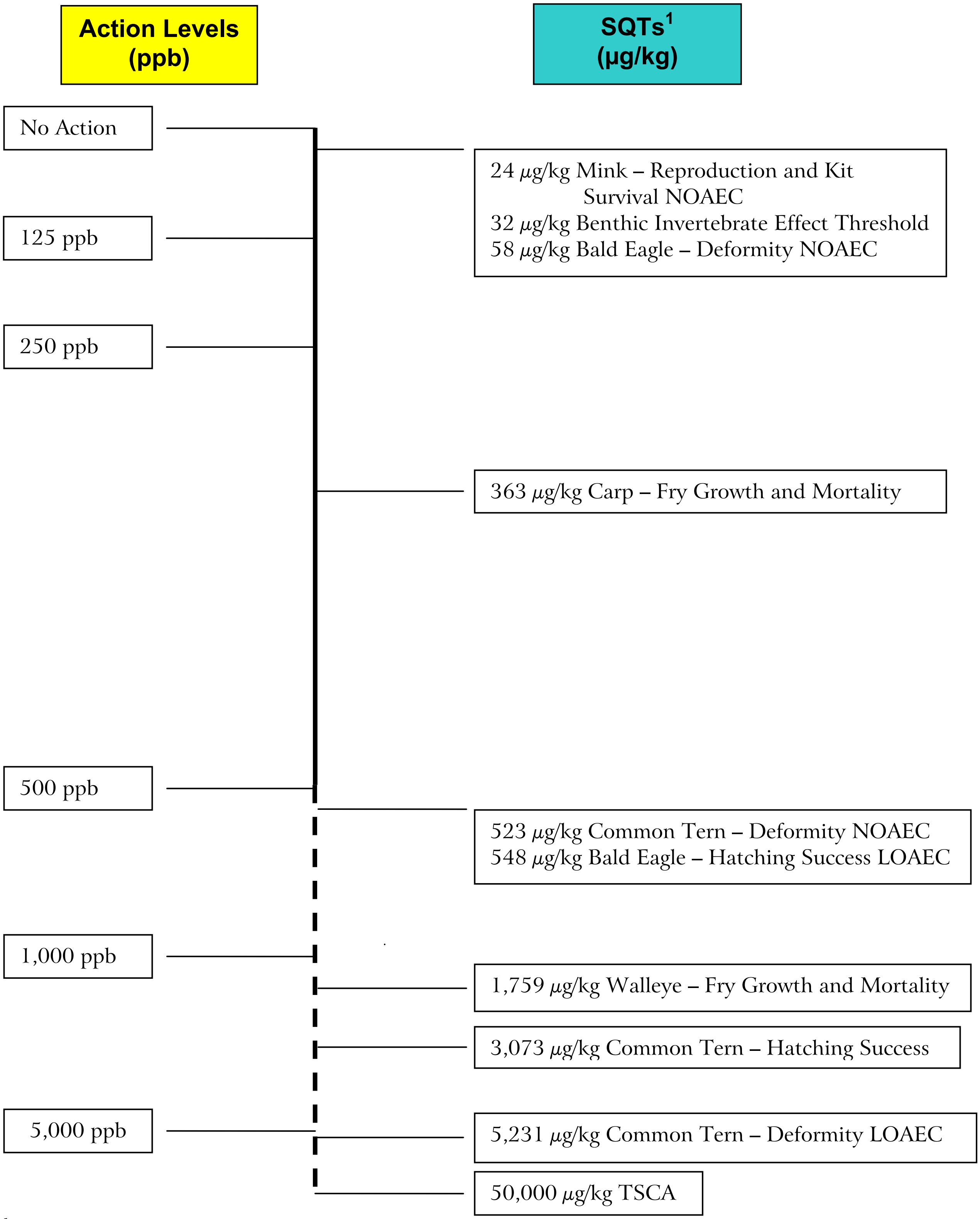
Figure 5-1 Action Levels and Sediment Quality Thresholds for Human Health



[1] With the exception of the 50,000 µg/kg TSCA number, all values are sediment quality thresholds developed in the *Baseline Human Health and Ecological Risk Assessment* (RETEC, 2002b).

10^{-5} – Risk of one additional cancer in 100,000 people.
CTE – Central Tendency Exposure
HI – Hazard Index
RME – Reasonable Maximum Exposure

Figure 5-2 Action Levels and Sediment Quality Thresholds for Ecological Health



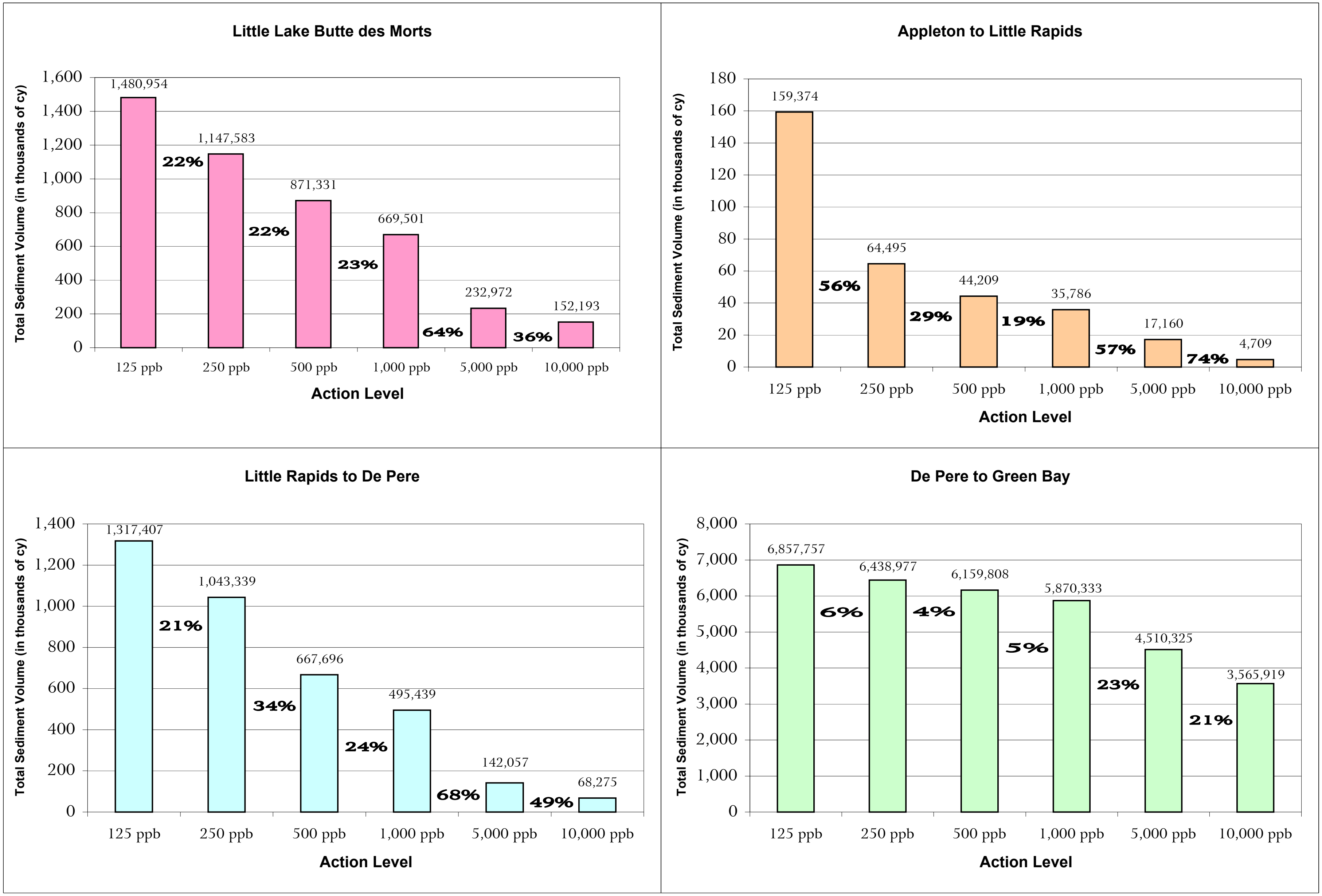
[1] With the exception of the 50,000 µg/kg TSCA number, all values are sediment quality thresholds developed in the *Baseline Human Health and Ecological Risk Assessment* (RETEC, 2002b).

Effect Threshold – A TEL based on *Hyallela azteca* 28-day toxicity test (ARCS, 1996, as cited in RA).

LOAEC – Lowest Observable Adverse Effect Concentration

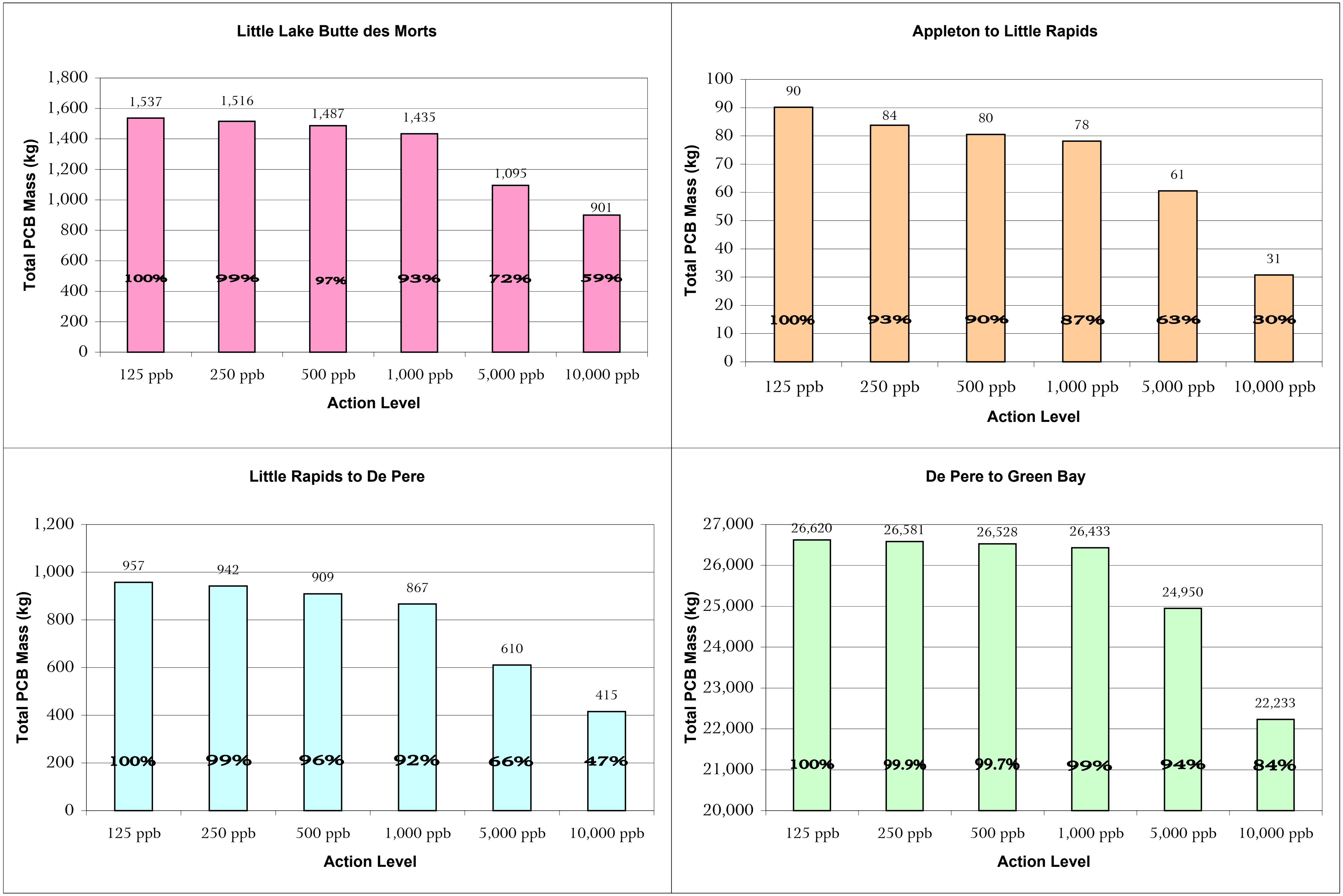
NOAEC – No Observable Adverse Effect Concentration

Figure 5-3 Total Sediment Volume versus Action Level by Reach in the Lower Fox River



Note: The embedded percentage values are the percent differences between the bracketing volumes. For example, there is a 56 percent difference in the sediment volumes removed at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach.

Figure 5-4 Total PCB Mass versus Action Level by Reach in the Lower Fox River



Note: Embedded percentages represent the percent of PCB mass theoretically removed at each action level relative to the total estimated mass at 125 ppb.

Figure 5-5 Total PCB Mass versus Sediment Volume by Reach in the Lower Fox River

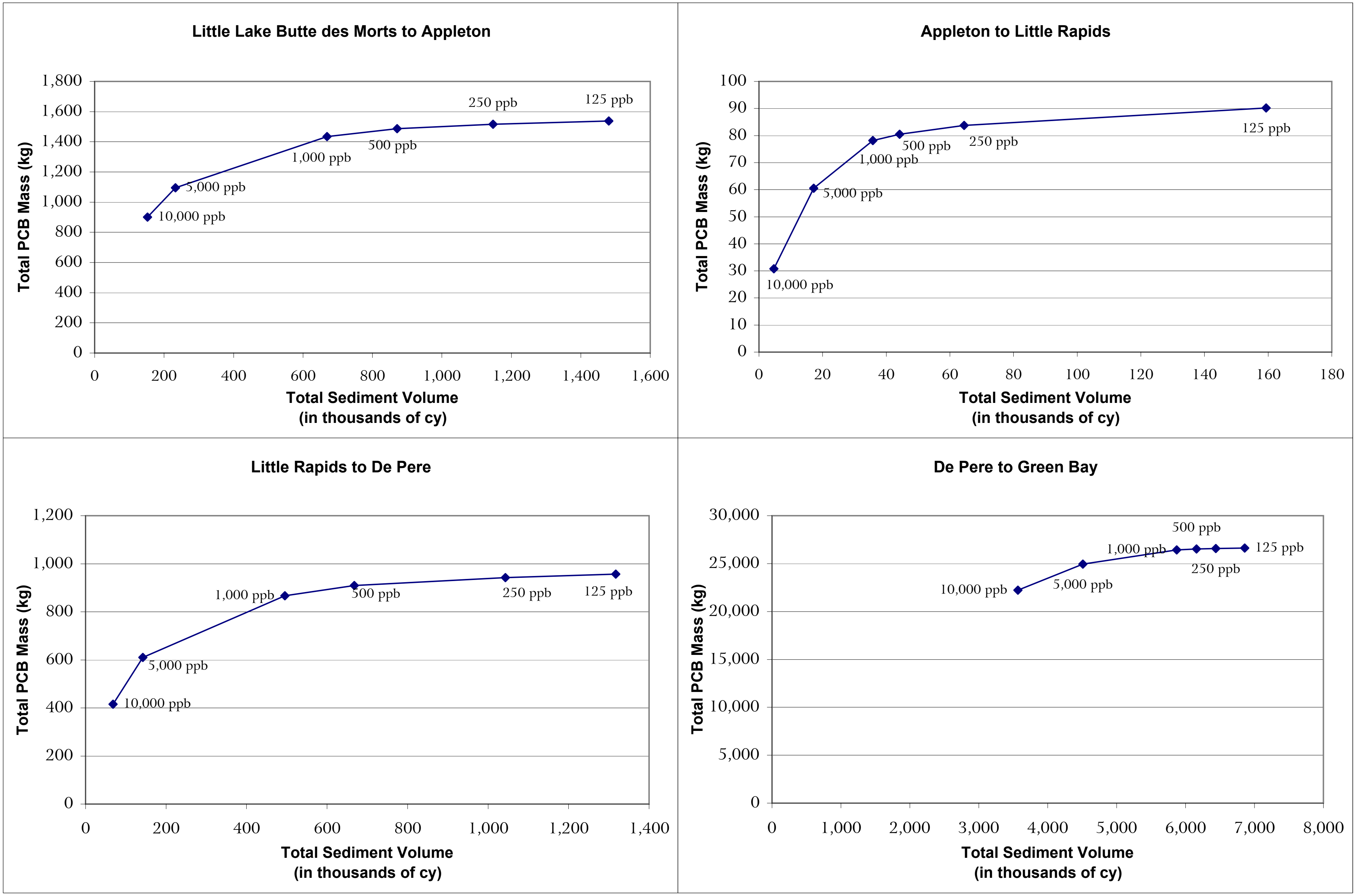
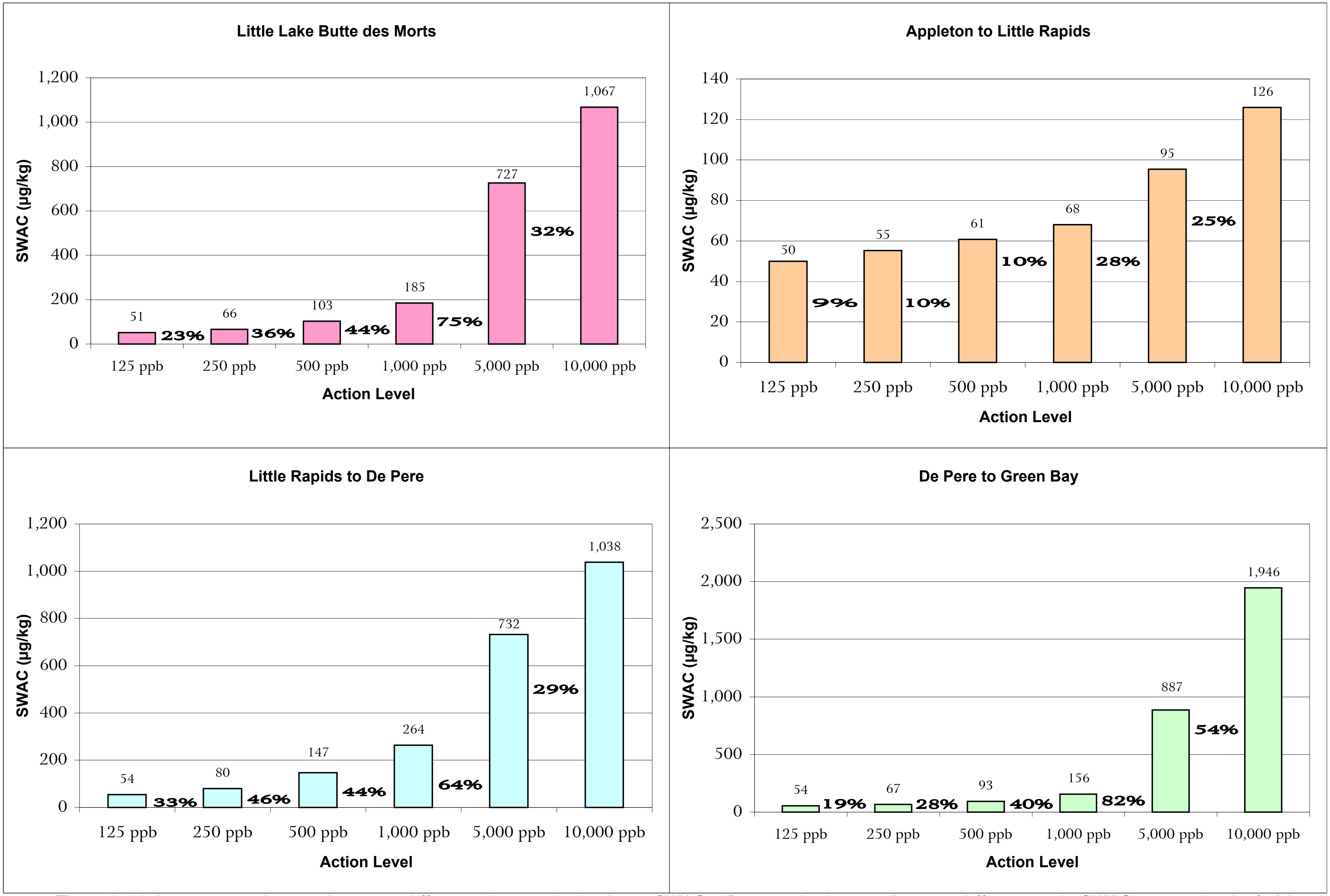
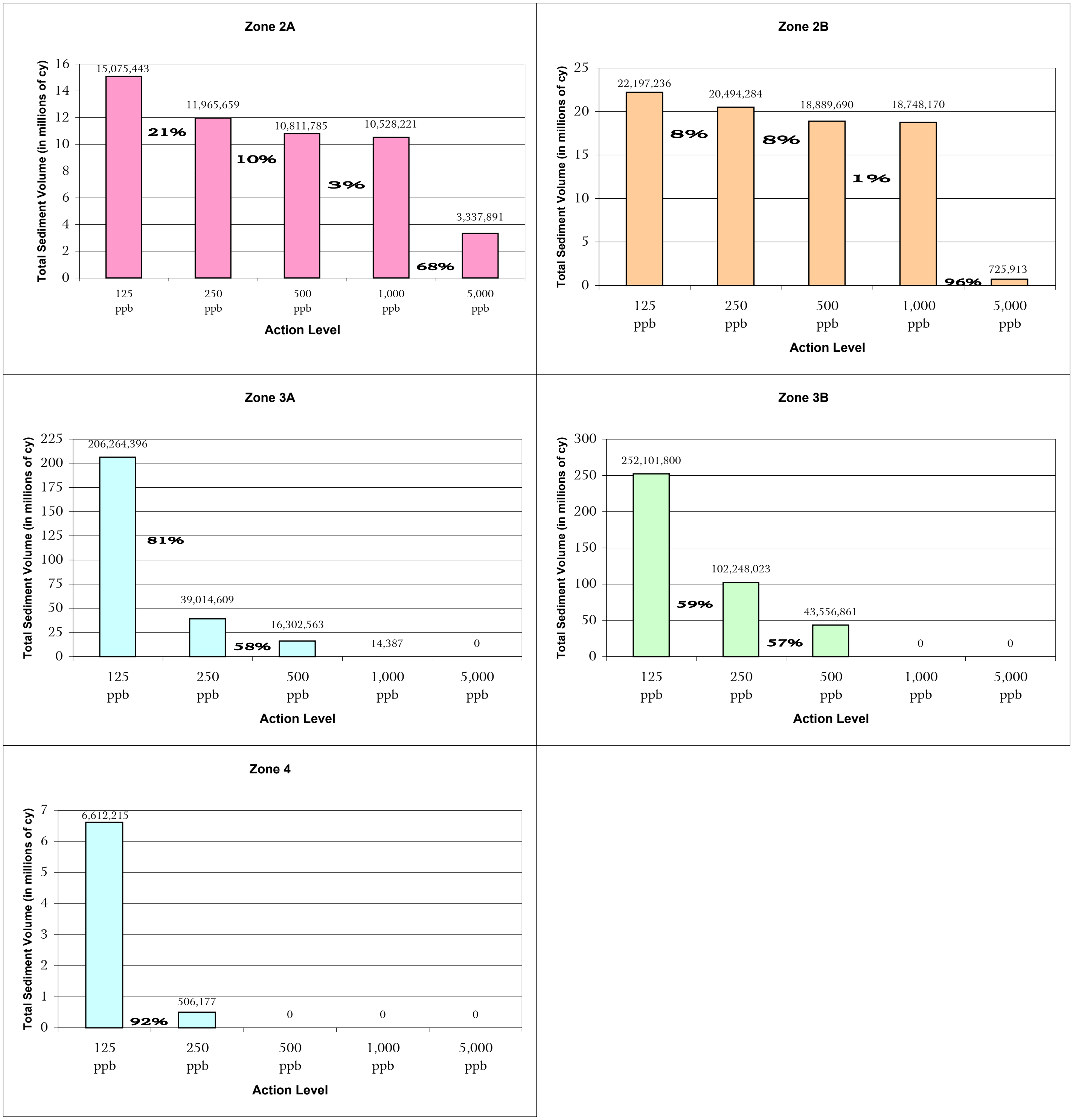


Figure 5-6 Residual SWAC versus Action Level by Reach in the Lower Fox River



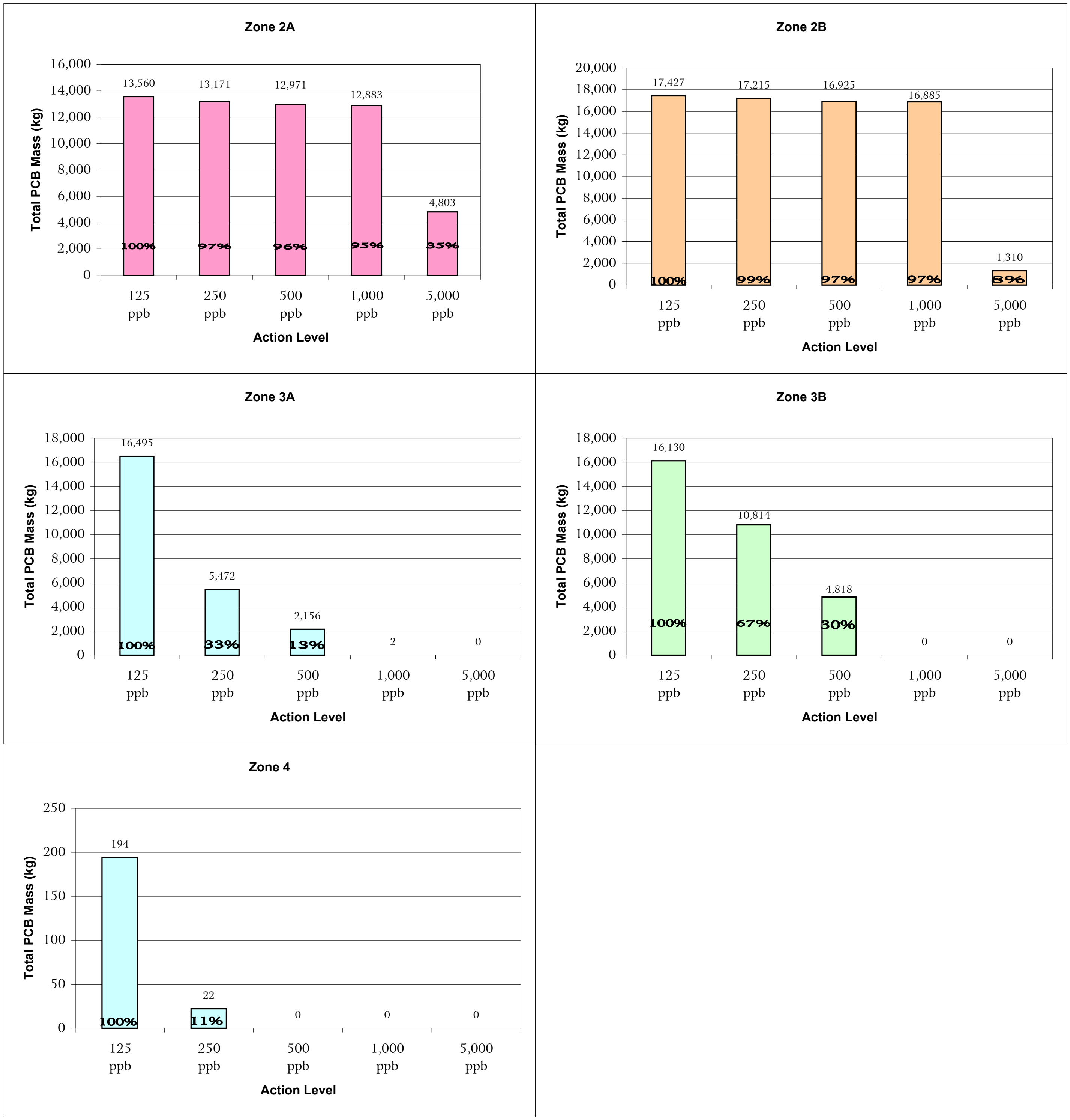
Note: The embedded percentage values are the percent differences between the bracketing SWACs. For example, there is a 9 percent difference in the SWAC at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach.

Figure 5-7 Total Sediment Volume versus Action Level by Zone in Green Bay



Note: The embedded percentage values are the percent differences between the bracketing volumes. For example, there is a 59 percent difference in the sediment volumes removed at action levels of 125 and 250 ppb in the Zone 3B.

Figure 5-8 Total PCB Mass versus Action Level by Zone in Green Bay



Note: Embedded percentages represent the percent of PCB mass theoretically removed at each action level relative to the total estimated mass at 125 ppb.

Figure 5-9 Total PCB Mass versus Sediment Volume by Zone in Green Bay

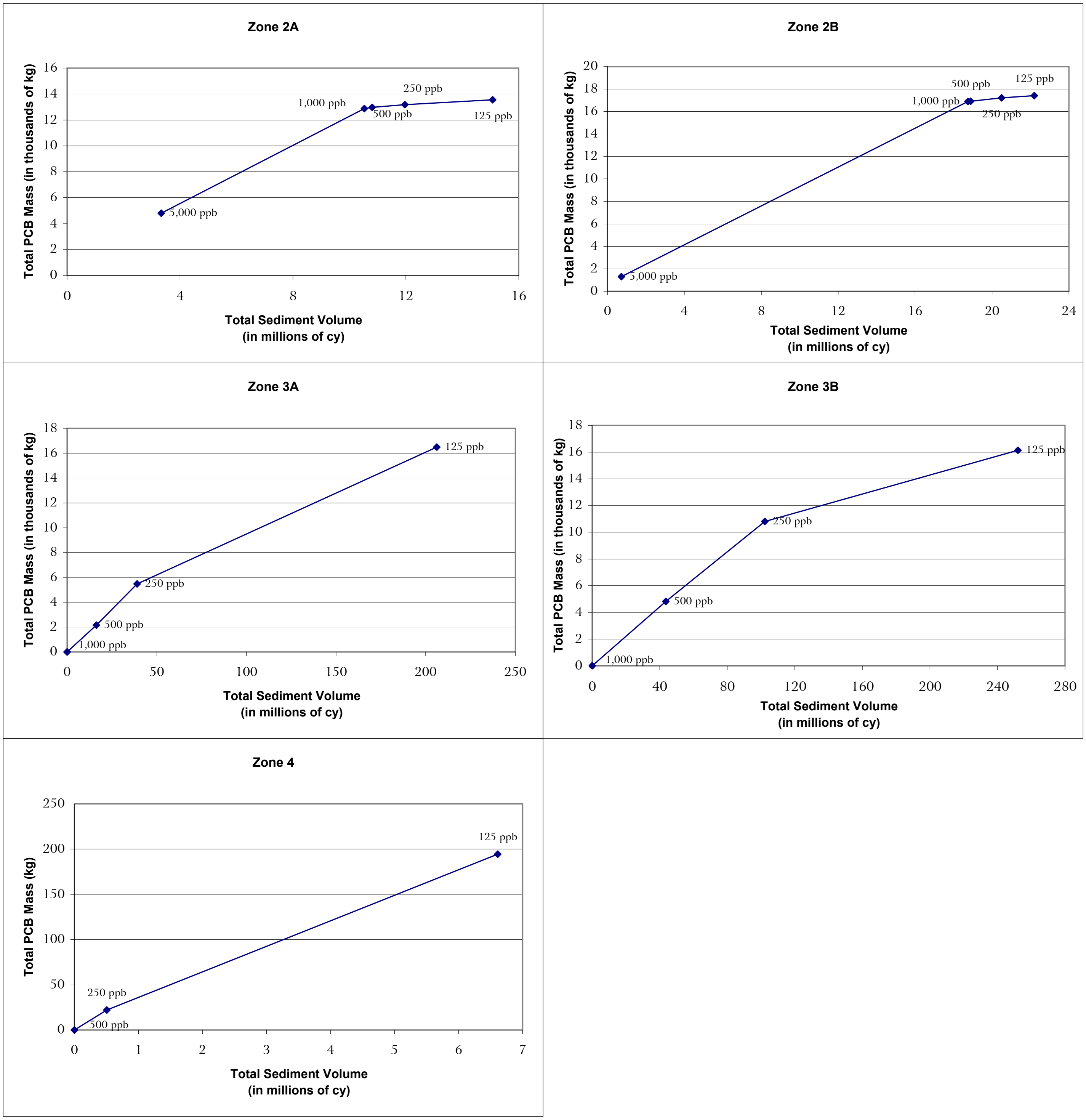
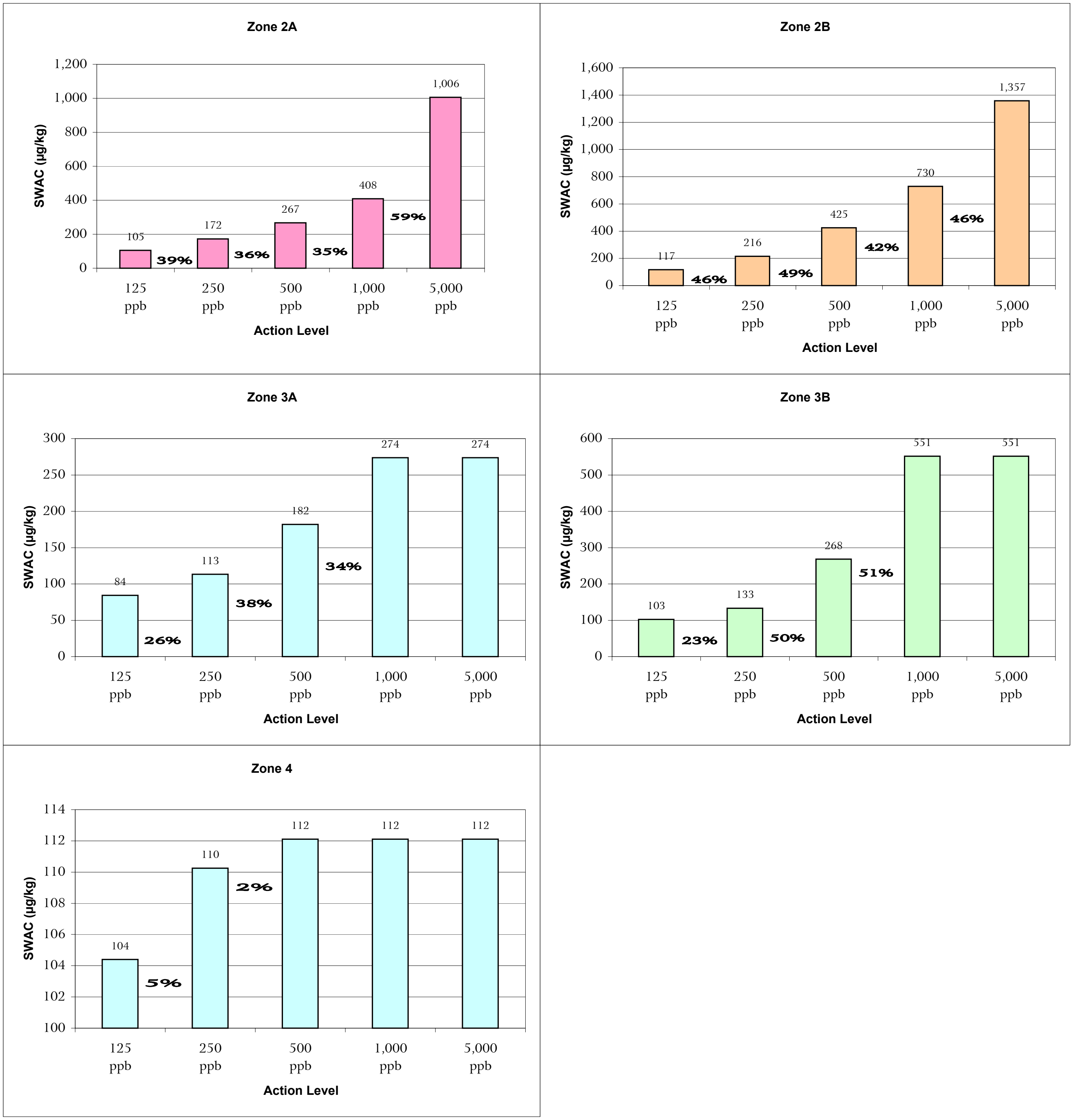


Figure 5-10 SWAC versus Action Level by Zone in Green Bay



Note: The embedded percentage values are the percent differences between the bracketing SWACs. For example, there is a 39 percent difference in the SWAC at action levels of 125 and 250 ppb in the Zone 2A.

Table 5-1 Procedure for Computing PCB Mass Removed by Dredging Sediments above Selected Action Levels

Step	Description	Action
1	Open Mask Grids: 0 for areas with sediment and 1 for areas without sediment.	Loads nine sediment mask grids.
2	Open PCB interpolated concentration grids: PCB concentration unless outside river footprint or not interpolated based on interpolation criteria.	Loads nine concentration grids.
3	Starting at bottom layer, identify areas with sediment above action level from bottom up. This will include clean sediments over deeper sediments exceeding an action level.	Generates grid for each layer with 0 if not dredged and 1 if dredged. Areas with no sediment or no interpolated concentration are set at 0.
4	Load PCB mass grids: Produced by WDNR from concentration and bulk density.	Loads nine grids of PCB mass by layer.
5	Multiply dredge grid for each layer by mass grid for each layer.	Generates grid for dredged mass in each layer.
6	Sum over all layers.	Generates single-layer grid of total volume dredged at each cell location.
7	Save mass results to statistics tables. Results are saved by deposit, by model segment, and by reach. Statistics generated include number of cells, area, minimum, maximum, range, mean, standard deviation, and sum for each category, such as for each river reach.	Generates three output tables for each action level.
8	Save mass grid from Step 5.	Grid of mass dredged for displaying dredge footprint for each action level.

Note:

Procedure uses interpolated PCB concentration grids, PCB mass grids and grids of presence or absence of sediment (mask grids). PCB concentration, PCB mass, and mask grids prepared by WDNR.

Table 5-2 Procedure for Computing SWAC for Selected Action

Step	Description	Action
1	Open Mask Grids: 0 for areas with sediment and 1 for areas without sediment.	Loads nine sediment mask grids.
2	Open PCB interpolated concentration grids: PCB concentration unless outside river footprint or not interpolated based on interpolation criteria.	Loads nine concentration grids.
3	Starting at bottom layer, identify areas with sediment above action level from bottom up. This will include clean sediments dredged to remove deeper areas exceeding an action level.	Generates grid for each layer with 0 if not dredged and 1 if dredged. Areas with no sediment or no interpolated concentration are set at 0.
4	Multiply dredge grid for each layer by thickness of layer and area of cell.	Generates grid for each layer of the volume dredged at each cell location.
5	Sum over all layers.	Generates single-layer grid of total volume dredged at each cell location.
6	Save volume results to statistics tables. Results are saved by deposit, by model segment, and by reach. Statistics generated include number of cells, area, minimum, maximum, range, mean, standard deviation, and sum for each category, such as for each river reach.	Generates three output tables for each action level.
7	Save volume grid from Step 5.	Grid of volume dredged for displaying dredge footprint for each action level.

Note:

SWAC is calculated from interpolated PCB concentration grids and grids of presence or absence of sediment (mask grids). PCB concentration and mask grids prepared by WDNR.

Table 5-3 PCB Mass and Sediment Volume by Action Level—Lower Fox River

River Reach / Deposit	Sediment Volume Based on Action Levels (cy)[1]						PCB Mass Based on Action Levels (kg)[1]						
	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	10,000 ppb	Total[2]	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	10,000 ppb
Little Lake Butte des Morts													
A	140,801	140,539	140,487	139,964	30,841	20,744	238	238	237	237	237	135	112
B	49,951	44,784	43,856	42,835	38,035	30,423	411	411	410	410	409	396	353
C	78,098	75,691	30,174	25,989	7,468	1,256	39	39	39	36	35	20	3
D	87,136	85,305	78,215	69,858	9,718	0	83	83	83	81	78	22	0
E	862,973	568,972	433,089	276,318	83,500	44,719	453	450	432	415	373	243	165
F	123,287	101,196	23,726	8,593	0	0	11	11	10	4	3	0	0
G	3,662	0	0	0	0	0	0.7	0.3	0	0	0	0	0
H	902	902	902	301	0	0	0.7	0.7	0.7	0.7	0.4	0	0
POG	134,143	130,193	120,881	105,643	63,409	55,052	305	305	304	303	299	279	267
Interdeposit Areas							309	276					
Reach Total:	**1,480,954**	**1,147,583**	**871,331**	**669,501**	**232,972**	**152,193**	**1,850**	**1,813**	**1,516**	**1,487**	**1,435**	**1,095**	**901**
Appleton to Little Rapids													
I	2,668	889	889	0	0	0	0.2	0.4	0.3	0.3	0	0	0
J	0	0	0	0	0	0	0.1	0	0	0	0	0	0
K	209	209	0	0	0	0	0.1	<0.1	<0.1	0	0	0	0
L	249	249	0	0	0	0	0.1	<0.1	<0.1	0	0	0	0
M	1,844	1,844	615	0	0	0	0.2	0.3	0.3	0.1	0	0	0
N	6,383	6,383	6,370	6,108	3,165	2,158	30	30	30	30	30	22	19
O	3,100	3,021	2,943	1,059	0	0	2	2	2	2	0.9	0	0
P	16,742	16,742	10,045	10,045	0	0	5.3	5	5	4	4	0	0
Q	275	275	249	196	0	0	0.2	0.2	0.2	0.2	0.2	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0
S	2,721	2,721	2,721	0	0	0	0.1	0	0	0	0	0	0
T	6,330	6,330	6,330	6,330	3,048	0	11.3	11	11	11	11	7	0
U	785	785	262	0	0	0	0.2	0.2	0.2	0.1	0	0	0
V	78	78	26	26	0	0	0	<0.1	<0.1	<0.1	<0.1	0	0
W	42,862	6,592	1,256	981	0	0	6.8	5	2	0.5	0.5	0	0
X	41,305	2,080	0	0	0	0	2.5	2	0.2	0	0	0	0
Y	562	562	0	0	0	0	0.3	0.1	0.1	0	0	0	0
Z	955	955	0	0	0	0	0.4	0.2	0.2	0	0	0	0
AA	0	0	0	0	0	0	0	0	0	0	0	0	0
BB	340	0	0	0	0	0	0.1	0	0	0	0	0	0
CC	4,460	1,583	1,465	0	0	0	0.7	0.6	0.5	0.4	0	0	0
DD	27,506	13,197	11,039	11,039	10,948	2,551	34	33	32	31	31	31	12
Interdeposit Areas							15	45					
Reach Total:	**159,374**	**64,495**	**44,209**	**35,786**	**17,160**	**4,709**	**110**	**135**	**84**	**80**	**78**	**61**	**31**

Table 5-3 PCB Mass and Sediment Volume—Lower Fox River (Continued)

River Reach	Deposit	Sediment Volume Based on Action Levels (cy) [1]						PCB Mass Based on Action Levels (kg) [1]						
		125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	10,000 ppb	Total [2]	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	10,000 ppb
Little Rapids to De Pere														
	EE	1,254,456	984,246	609,401	440,675	112,745	47,217	828	806	791	758	716	492	312
	FF	471	471	0	0	0	0	0.1	<0.1	<0.1	0	0	0	0
	GG	23,962	23,308	22,981	22,850	16,232	14,374	81	81	81	81	81	72	69
	HH	38,519	35,315	35,315	31,914	13,080	6,684	70.2	70	70	70	70	45	35
	Interdeposit Areas							266	244					
	Reach Total:	**1,317,407**	**1,043,339**	**667,696**	**495,439**	**142,057**	**68,275**	**1,245**	**1,201**	**942**	**909**	**867**	**610**	**415**
De Pere to Green Bay														
	Group 20 to 25	1,295,316	1,213,046	1,157,275	1,081,270	802,716	679,088		5,558	5,551	5,541	5,515	5,225	4,903
	Group 26 to 31	198,246	169,432	163,651	157,673	107,841	64,142		761	758	757	754	649	478
	Group 32 to 37	289,175	281,353	257,156	250,970	202,798	116,238		1,174	1,173	1,167	1,165	1,099	720
	Group 38 to 43	458,973	420,519	379,240	346,555	227,060	162,591		1,148	1,145	1,136	1,125	987	788
	Group 44 to 49	1,753,007	1,704,116	1,632,781	1,538,713	1,169,897	887,288		5,213	5,209	5,197	5,170	4,833	4,065
	Group 50 to 55	512,651	492,535	477,114	456,266	325,758	260,295		1,831	1,829	1,826	1,819	1,667	1,494
	Group 56 to 61	636,305	633,755	630,289	621,813	577,657	533,879		5,812	5,812	5,811	5,808	5,767	5,681
	Group 62 to 67	249,125	246,052	240,323	231,050	163,494	109,475		862	861	861	859	799	711
	Group 68 to 73	420,689	389,900	375,565	363,676	291,869	265,527		1,858	1,855	1,853	1,850	1,770	1,690
	Group 74 to 79	153,723	140,945	134,941	129,644	123,693	101,942		429	427	426	425	416	338
	Group 80 to 85	184,029	123,719	98,463	91,923	62,782	39,893		384	380	374	372	327	241
	Group 86 to 91	133,123	93,610	91,099	89,464	85,932	24,197		253	249	249	248	245	98
	Group 92 to 97	145,980	130,782	126,178	121,038	46,890	0		255	253	251	248	137	0
	Group 98 to 103	67,307	40,821	38,859	34,151	24,720	24,720		93	90	89	87	79	79
	Group 104 to 109	90,340	89,791	89,791	89,438	38,061	38,061		150	150	150	150	116	116
	Group 110 to 115	269,765	268,601	267,084	266,691	259,157	258,582		840	840	839	839	833	832
	Reach Total:	**6,857,757**	**6,438,977**	**6,159,808**	**5,870,333**	**4,510,325**	**3,565,919**	**26,620**	**26,620**	**26,581**	**26,528**	**26,433**	**24,950**	**22,233**

Notes:

[1] Estimated mass or volume of sediment to be removed or isolated at a specific action level.

[2] Total PCB mass presented above were generated from a GIS map query of the Lower Fox River model layers. The mass contained in each model layer was summed to provide the total mass. Values may differ slightly from those listed in the Fox River Database (FRDB), in Section 2 of the FS, and in the RI Report (generated from the FRDB). Values may differ slightly from those listed in Section 7 of the FS Report since Section 7 includes overburden volumes and PCB mass required for removal. Use the Section 7 volumes and masses for remediation estimates.

Table 5-4 SWAC Based on Action Levels—Lower Fox River

River Reach	Residual SWAC (ppb) Based on Action Levels					
	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	10,000 ppb
Little Lake Butte des Morts	51	66	103	185	727	1,067
Appleton to Little Rapids	50	55	61	68	95	126
Little Rapids to De Pere	54	80	147	264	732	1,038
De Pere to Green Bay	54	67	93	156	887	1,946

Note:

Estimated residual surface-weighted average concentration (SWAC) of PCBs in surface sediment after removal.

Table 5-5 PCB Mass, Volume and SWAC—Green Bay

Bay Zone	Volume Based on Action Levels (cy)					PCB Mass Based on Action Levels (kg)					SWAC Based on Action Levels (ppb)				
	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb	125 ppb	250 ppb	500 ppb	1,000 ppb	5,000 ppb
Zone 2A	15,075,443	11,965,659	10,811,785	10,528,221	3,337,891	13,560	13,171	12,971	12,883	4,803	105	172	267	408	1,006
Zone 2B	22,197,236	20,494,284	18,889,690	18,748,170	725,913	17,427	17,215	16,925	16,885	1,310	117	216	425	730	1,357
Zone 2	37,272,680	32,459,943	29,701,474	29,276,390	4,063,804	30,986	30,386	29,895	29,768	6,113	222	388	692	1,138	2,363
Zone 3A	206,264,396	39,014,609	16,302,563	14,387	0	16,495	5,472	2,156	2	0	84	113	182	274	274
Zone 3B	252,101,800	102,248,023	43,556,861	0	0	16,130	10,814	4,818	0	0	103	133	268	551	551
Zone 4	6,612,215	506,177	0	0	0	194	22	0	0	0	104	110	112	112	112

Notes:

[1] Estimated mass or volume of sediment to be removed or isolated at a specific action level.

[2] Estimated residual SWAC concentration in surface sediments after removal.

6 Identification and Screening of Technologies

The purpose of this section is to identify and screen remedial action technology types and process options that are potentially applicable for management of contaminated sediments in the Lower Fox River and Green Bay. The screening process was conducted in accordance with the EPA RI/FS Guidance (EPA, 1988). First, a list of potentially applicable technologies is prepared based on the general response actions (GRAs) anticipated for site cleanup (identified in Section 4) and on available information on various technologies and processes that either exist or are under development. Next, the list is refined by evaluating each technology for implementability, effectiveness, and relative cost. Technologies are either retained for use in developing remedial alternatives (Section 7) or are dropped from further consideration. The following provides an overview of the review process:

- The initial step involves assembling a comprehensive list of technology types and specific process options applicable to the general response actions developed in Section 4.4 that could be potentially used to manage Lower Fox River and Green Bay sediments (Section 6.1).

- Secondly, criteria are presented to screen the potential technologies based upon their implementability, effectiveness, and relative costs (Section 6.2).

- The results of the technology screening and a brief description of the primary factors that influenced the retention/elimination screening decisions are discussed. The section culminates in a list of retained process options (Section 6.3).

- A detailed description of each of the retained process options that will be carried forward into the detailed reach-specific analysis in Section 7 is provided (Section 6.4). The site-specific factors that will influence implementability or effectiveness (i.e., operational constraints) are also identified here, and will be applied in Section 7.

- Ancillary technologies (i.e., transportation of dredged sediments) that are required to implement specific management options for the Lower Fox River and Green Bay, but do not necessarily require screening, are presented (Section 6.5).

- Additional information on water quality, including protection of the water column during dredging and requirements for discharge of water from sediment handling activities, are presented (Section 6.6).

The literature sources and databases utilized to compile and evaluate a broad list of potentially applicable technology types and process options are provided in Table 6-1. In addition to these sources, available site data, and specific criteria applicable to the process options were used in the screening process.

6.1 Identification of Technologies

The first step in the FS process involves the identification of GRAs, remedial action technology types (e.g., dredging, chemical treatment, capping), and remedial action process options (e.g., horizontal auger dredge, electrochemical oxidation, sand cap). Descriptions of GRAs, technology types, and process options include:

- **General Response Actions.** These are selected to address the extent of contamination and the potential for migration of COCs for a given medium. GRAs are described in broad terms in order to encompass all possible remedial actions for achieving the remedial action objectives. By identifying appropriate response actions which apply to contaminated sediments, the list of technologies to be reviewed can be substantially reduced. The GRAs for sediment cleanup in the Lower Fox River and Green Bay are:
  - No Action,
  - Institutional Controls,
  - Monitored Natural Recovery,
  - Containment,
  - Removal,
  - *In-situ* Treatment,
  - *Ex-situ* Treatment, and
  - Disposal.

- **Technology Types.** These are general categories that describe a means for achieving the GRAs (e.g., capping, dredging, dry excavation, or chemical treatment). For example, removal is a GRA that can be achieved by excavation or dredging, while treatment is a GRA that can be achieved using biological or chemical technologies.

- **Process Options.** These are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on an understanding of the characteristics of the medium and technologies that are available to address the medium.

The GRAs describe, in broad terms, remedial actions theoretically capable of achieving the RAOs described in Section 4. The technologies are grouped according to the GRAs discussed in Section 4. One or more technologies and technology process options may be considered within each GRA category. Literature sources used to develop the list of potentially applicable technologies are listed in Table 6-1. A summary of the technologies and process options reviewed and retained within each GRA are listed in Table 6-2. Shaded technologies were retained for further consideration in the development of remedial alternatives for the Lower Fox River and Green Bay.

This section also presents and evaluates several ancillary technologies that, while necessary to the overall implementation of a cleanup program, are secondary to the primary functions embodied by the GRAs. For example, sediment dewatering, water treatment, suspended solids controls during dredging, and monitoring are all discussed in this section as technologies ancillary to the primary GRAs.

The list of technologies evaluated in this section is comprehensive and is supported by numerous published articles, guidance, and technology databases developed over the years for sediment remediation (Table 6-1). Many of the cited publications address technologies and cleanup approaches specific to the Lower Fox River and Green Bay or very similar sites. Finally, site-specific data from the recently completed Site N and 56/57 dredging projects on the Lower Fox River aided the evaluation and selection of dredging, sediment dewatering, and water treatment technologies. A detailed description of the technologies and process options screened in this section are listed in Table 6-3.

6.2 Screening of Technologies

The technologies listed in Table 6-2 are screened in this section of the FS to determine which are appropriate for development of sediment remedial alternatives. The screening methodology used is consistent with that presented in the EPA RI/FS Guidance (EPA, 1988). The following subsections describe the process and screening criteria used for the identified technologies.

6.2.1 Screening Criteria

The criteria used to evaluate each process option were implementability, effectiveness, and relative cost. These criteria are discussed below.

Implementability

Technical implementability refers to the technical feasibility of implementing a particular technology. Technologies that are not applicable to site characteristics or the contaminants of concern (COCs) are eliminated from further consideration. Administrative implementability considers permitting and the availability of necessary services and equipment to implement a particular technology.

Effectiveness

Determining the effectiveness of a technology involves consideration of whether the technology can contain, reduce, or eliminate the COCs and generally achieve the RAOs set forth in Section 4. Effectiveness is evaluated relative to the other technologies identified in the screening. Consideration must also be given to the many aspects of remediation that contribute to a technology's overall effectiveness including:

- How well the technology will handle the estimated areas or volumes of contaminated sediment to be remediated;
- If the RAOs will be met through implementation of the technology;
- How efficiently does the technology reduce or eliminate the COC;
- To what scale (lab-, pilot-, full-) the technology has been tested;
- Timeliness of implementation and availability; and
- How effective is the process option in protecting human health and the environment during the implementation phase of remediation.

The effectiveness evaluation focuses on PCBs as the primary COC. Metals are also considered in the screening of certain process options for treatment.

Cost

Technologies were evaluated with respect to relative capital and operations and maintenance (O&M) costs. Detailed cost estimates of remedial alternatives are provided in Section 7 of this FS Report. Costs used for this phase of the screening process are defined in terms of high, moderate, and low, rather than a specific dollar amount and are determined on the basis of engineering judgement. The cost of each process option is relative to other process options of the same technology type. Technologies are retained or eliminated based, to a lesser degree, on cost during this phase of the screening (Table 6-4).

6.2.2 Screening Process

As specified in the EPA RI/FS Guidance (EPA, 1988), a two-step screening process was used to evaluate each process option listed in Table 6-2, with the exception of technology types or process options associated with the no action GRA. The no action GRA is retained as required by NCP for use as a baseline comparison against other technologies.

In the first step, referred to as the initial screening, process options determined to be technically implementable were retained for further evaluation. Technologies that have no applicability to the COCs, are not ready for full-scale operations, or are otherwise unworkable in the context of sediment remediation were eliminated from further discussion.

In the second step, the final screening of technologies considers effectiveness and cost. In some cases where several technologies are considered similar in approach and performance, a single representative technology is retained for further evaluation. Technologies retained through the screening steps receive extensive coverage in the following subsections. During the detailed analysis of alternatives (Chapter 9 of the FS), technologies evaluated during the screening process and retained are further refined, as appropriate. Technologies and alternatives will be analyzed in detail with respect to short-term impacts associated with implementation, long-term protection of remedy, compliance with ARARs and TBCs, and reduction of toxicity, mobility, and volume of COCs.

6.3 Results of Technology Screening

The technologies screened and retained for further consideration in the development of remedial alternatives (Section 7) are shaded in Table 6-2. The following discussion briefly describes the results in advance of the detailed screening that consumes the remainder of this section.

6.3.1 No Action

No action was retained, as required by the NCP, for comparing the merits of taking no remedial action whatsoever with other technology-based remedial alternatives (Table 6-4). With a no action alternative, natural restoration is the only means by which sediment quality can improve over time. However, implementation requires no planning, decision making, maintenance, or monitoring. No action does not meet RAOs for the Lower Fox River and Green Bay.

6.3.2 Institutional Controls

Institutional controls are administrative actions (e.g., fish consumption advisories, access restrictions, dredging moratoriums) designed to prevent exposure of humans and wildlife to contaminants. Institutional controls are generally effective at limiting human exposure, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing (Table 6-4). In general, institutional controls have no effect on ecological receptors. Nevertheless, institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (EPA, 1999a).

6.3.3 Monitored Natural Recovery

Monitored natural recovery (MNR) refers to the beneficial effects of natural processes that reduce surface sediment concentrations of PCBs. These processes include biodegradation, diffusion, dilution, sorption, volatilization, chemical and biochemical stabilization of contaminants, and burial by natural deposition of cleaner sediments. The primary mechanisms for MNR in the Lower Fox River and Green Bay are desorption and dispersion in the water column (i.e., as a dissolved constituent), burial, and sediment resuspension and transport. Biodegradation is a negligible contributor to the lowering of PCB concentrations and is not a factor for mercury (see Appendix F).

MNR can be an effective alternative under the appropriate conditions. However, for the Lower Fox River it may have limited utility for the Fox River and Green Bay to be protective in a reasonable time frame because of: 1) limitations of natural dechlorination, 2) slow time trend decrease in PCB concentrations in fish and sediment, and 3) substantial fluctuations in sediment bed elevations precluding long-term burial by cleaner sediment. For example, areas of net scour and deposition have measured up to 36 cm of short-term change (annually) and 100 cm of long-term change (several years) in bed elevations (WDNR, 1999c).

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). While MNR alone may not be protective of human health and the environment in heavily impacted areas, natural processes are central to evaluating the long-term performance of technology-based remedial alternatives covering the full range of cleanup action levels.

6.3.4 Containment

Various approaches to capping contaminated sediments *in situ* were evaluated (Table 6-4). Capping isolates contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new unimpacted substrate for recolonization by benthic organisms. Capping is considered effective at isolating low-solubility and highly sorbed contaminants like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs should minimize the potential for sediment resuspension under normal and extreme (storm) conditions. Cap placement as a remedial alternative assumes source control and minimal potential for recontamination from upstream sources via sediment transport.

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay where navigation would not be impeded. The technology is retained for use in developing remedial alternatives in Section 7. Of the various process options, conventional sand cap, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Thin-layer and enhanced caps are not appropriate for use at the site based on the time frame selected to meet the project RAOs. This is further explained in Section 6.4.4.

6.3.5 Removal

Both hydraulic and mechanical options were retained as removal options (Table 6-4). Despite recent claims that dredging is not an effective remedial alternative for PCB-impacted sediments, dredging is one of the most common remedial alternatives currently used throughout the world. There are supporting data that show that it can effectively reduce total concentrations and contaminant mass. A detailed review of local, national, and international dredging projects (summarized in Section 6.4.2 and in Appendix B) concluded that environmental dredging can feasibly remove contaminated sediments, with many projects showing reductions in surface sediment concentrations. With careful planning, application in appropriate environments, and use of engineering controls, dredging can be an effective tool to remove contaminated sediments. Hydraulic or mechanical dredging can be accomplished with minimal contaminant resuspension and transport during operations. However, removal options require water quality monitoring during and after activities and management of materials following removal.

6.3.6 *In-situ* Treatment

In-situ treatment of sediments refers to processes that fix, transform, or destroy COCs while leaving the sediments in place (i.e., without first removing the sediment). No *in-situ* technologies were retained for consideration in the development of remedial alternatives (Table 6-5). *In-situ* treatment technologies for PCBs have neither been sufficiently developed nor demonstrated in field applications.

6.3.7 *Ex-situ* Treatment

Ex-situ treatment refers to technologies that fix, transform, or destroy COCs after first removing sediment from the river or lake bottom. Three *ex-situ* treatment process options, all thermal technologies, were retained (Table 6-5). The elimination of other *ex-situ* treatment options was primarily based on media-specific characteristics (i.e., high water content of sediments), contaminant composition, and the lack of full-scale demonstrations. The retained options are incineration, high-temperature thermal desorption (HTTD) and vitrification.

6.3.8 Disposal

Disposal technologies are necessarily coupled with a removal action. Both on-site and off-site disposal technologies were retained for development of remedial alternatives (Table 6-6). The retained on-site disposal options are the level-bottom cap and confined disposal facility (CDF). These technologies involve the relocation and consolidation of dredged sediments in an engineered in-water or nearshore disposal facility. After dewatering and treatment, solids residuals may be taken to an appropriate off-site disposal facility depending upon concentration and management decisions.

6.3.9 Ancillary Technologies

Ancillary technologies and processes are essential elements of many remedial alternatives, mostly related to waste management and monitoring. Ancillaries are not subject to the same screening evaluation as remedial alternatives; however, they are discussed in this section as important considerations during selection of remedial process options (Table 6-7). Ancillary technologies and processes described in this section include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

Sediment dewatering is a requirement for most disposal and treatment processes. Both passive and mechanical dewatering will be considered in the development of remedial alternatives. Passive dewatering (also referred to as gravity dewatering) involves the gravity separation of water and solids in a sedimentation basin. Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, and plate-and-frame filter presses to remove moisture from the sediments. Treatment of wastewater generated during sediment dewatering may be required to meet water quality requirements before discharge back to the river or bay. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal.

Water quality impacts from sediment resuspension during dredging are an issue when planning a sediment removal operation. Operational controls involving modified construction practices, specialized equipment, and containment systems are effective in controlling sediment resuspension and off-site losses.

6.3.10 Monitoring

Although monitoring is not part of the technology screening process, monitoring is a key component of sediment remediation to verify project progress and success. For contaminated sediment projects, monitoring can be grouped into five categories: 1) baseline monitoring; 2) short-term monitoring during implementation; 3) verification monitoring immediately following an action; 4) operation and maintenance (O&M) monitoring of disposal sites; and 5) long-term performance monitoring to determine whether RAOs are attained. All five types of monitoring have been included in the FS costs and scope. A proposed model long-term monitoring plan has been developed to determine post-implementation effectiveness of a remedy (Appendix C).

6.4 Description and Selection of Retained Process Options

This section provides a detailed description of each of the retained process options and a review of pertinent selection criteria that influenced the screening process. The information presented in the following sections also provides the basis for development of the remedial alternatives in Section 7.

6.4.1 No Action

The GRA of no action was retained as required by the NCP for use as a baseline comparison against other technologies. The “no action” alternative requires no human intervention for cleanup. For the no action alternative, natural restoration is the only means of addressing the contaminated sediments in the Lower Fox River and Green Bay. Natural restoration may involve one or more processes that effectively reduce contaminant toxicity, mobility, or volume. These processes include biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants. The no action alternative is unlikely to meet the RAOs, and under this alternative verification of RAOs will not be required. Selection of this process option assumes that no decision-making requirements are involved, nor is a long-term operation and maintenance plan required.

6.4.2 Institutional Controls

Institutional controls are administrative actions designed to prevent activities that could expose humans and wildlife to contaminants. The primary controls envisioned for the Lower Fox River and Green Bay are:

- Fish consumption advisories and restrictions,
- Access and use restrictions, and
- Dredging moratoriums.

Consumption advisories warn the general public of risks posed by the consumption of fish caught in affected waters. Access restrictions such as fencing or boating restrictions control human access to contaminated areas. Boating restrictions would likely include "no access" or "no anchoring" restrictions. However, enforcement of these restrictions may be difficult. Dredging moratoriums preclude sediment disturbance or removal in contaminated areas, thereby reducing short-term direct contact and sediment resuspension risks. All of these controls are potentially applicable for use in remedial alternatives.

Implementability

Implementation of institutional controls for the Lower Fox River and Green Bay requires the cooperation of the implementing agencies, local Indian tribes, and public acceptance. Enforcement of these restrictions and public acceptance may be difficult to achieve. Restrictions would also apply to local Indian tribes.

Effectiveness

Institutional controls are effective at limiting human exposures, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing. Sediment resuspension and transport from the Lower Fox River to Green Bay continues under natural conditions.

Costs

Costs for institutional controls are primarily legal and administrative. In general, institutional controls are a low-cost approach to managing the risks posed by contaminated media in comparison with technology-based cleanup options that involve containment, removal, treatment, or disposal.

Screening Decision

Institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (Section 7). The management of some remedial systems (e.g., caps, CADs) and management of any residual risk after cleanup to a specified action level above protective concentrations (SQTs) will likely require implementation of institutional controls for a period of time, until the monitored natural recovery goals and project RAOs are achieved. Institutional controls are retained as part of the monitored natural recovery alternative (Table 6-4).

6.4.3 Monitored Natural Recovery

Natural recovery refers to the effects of natural processes that lower PCB surface sediment concentrations in the Lower Fox River and Green Bay. Natural recovery involves one or more processes that effectively reduce or isolate contaminant toxicity, mobility, or volume. These processes include physical processes (sediment deposition, mixing and burial, volatilization, diffusion, dilution and transport, and/or dispersion), chemical stabilization (sorption, redox), and biological processes (biodegradation and biotransformation). Monitoring of these processes to determine their effectiveness is commonly referred to as monitored natural recovery (MNR).

Of these potential mechanisms, natural recovery of contaminated sediments primarily occurs through four processes:

1. Loss of contaminants through bacterial biodegradation.

2. Loss of contaminants through diffusion into overlying water. Diffusion and/or volatilization into the atmosphere occur as partitioning mechanisms, especially for PCB congeners with low chlorine content as they tend to be more volatile and also more soluble in water.

3. Burial of contaminated sediments through natural deposition of clean sediments.

4. Mixing of cleaner surface sediments with contaminated deeper sediments by burrowing organisms, ship scour, propeller wash, and natural water currents (i.e., dilution), or downstream dispersion/transport of impacted sediments.

As part of the FS effort, the potential for natural recovery of sediment and fish tissue quality in the Lower Fox River and Green Bay systems was assessed through three lines of inquiry related to the pathways described above. First, available research on the natural biodegradation of PCBs in aquatic systems was summarized to determine whether this mechanism can be expected to significantly influence PCB concentrations over time (located in Appendix F). Second, sediment transport and burial mechanisms were evaluated using fate and transport models, sediment core profiles, and actual changes in sediment bed elevations over time (WDNR, 1999c) (located in the Model Documentation Report). Third, existing sediment and fish tissue PCB concentration data were statistically compared in an analysis of trends over the period of time represented in the FRDB. These statistical changes in PCB-impacted sediment and fish tissue concentrations over time are discussed in the Lower Fox River Time Trends Analysis by The Mountain-Whisper-Light Statistical Consulting (located in Appendix B of the RI Report) (Mountain-Whisper-Light and RETEC, 2002). These three lines of evidence for MNR are discussed below.

Natural Dechlorination. Biodegradation of PCBs can occur by bacterial-mediated removal of chlorine atoms from the PCB biphenyl ring (dechlorination, generally anaerobic) or by breaking open the carbon rings of PCBs with low chlorine content through oxidation (aerobic degradation) (Abramowicz, 1990). The most potent PCB congeners are planar and coplanar molecules with non-ortho or mono-ortho substituted PCBs, which chemically resemble and behave like 2,3,7,8-substituted dibenzo-*p*-dioxins (PCDDs). Collectively, these compounds are referred to as planar chlorinated hydrocarbons (PCHs). However, their potencies are structure-dependent (position of the chlorine atoms) and may vary by many orders of magnitude (Walker and Peterson, 1991; Fischer *et al.*, 1998). Conceptually, the dechlorination process given sufficient time, could be considered a viable mechanism to achieve natural recovery. However, the degree of chlorine removal (magnitude) and the rate of chlorine removal (time) are germane to evaluating dechlorination and MNR as a potential remedial alternative.

Most studies of PCB-contaminated sites demonstrate that a threshold PCB concentration must exist before anaerobic dechlorination can occur (discussed in Appendix F). The threshold PCB concentration level is site-specific. At different sites, thresholds have been shown to range between 10 and 50 mg/kg. Dechlorination does occur under anaerobic conditions in nature, but only minor (10 percent or lower) reductions in total PCB concentrations are ever achieved. Little or no reductions from natural anaerobic biodegradation occurs at PCB levels below 30 ppm PCBs. Aerobic degradation of the lower chlorinated PCB congeners has been documented in controlled laboratory studies, but is poorly documented under field conditions. Aerobic degradation is not effective for highly chlorinated PCB congeners.

In the Lower Fox River, natural degradation processes have been observed (McLaughlin, 1994). The threshold concentration PCB concentration level for dechlorinating activity in the Lower Fox River is approximately 30 mg/kg (McLaughlin, 1994). For sediment deposits in the Lower Fox River with average concentrations greater than 30 mg/kg, a 10 percent reduction in PCB mass was estimated due to anaerobic processes (McLaughlin, 1994). No PCB reductions due to anaerobic process for sediments with average PCB concentrations less than 30 mg/kg can be accounted for in the Lower Fox River sediments. No aerobic PCB degradation has been documented in the Lower Fox River or Green Bay (Appendix F).

The observed degradations were attributed mostly to desorptive losses to the water column taking place during sediment transport downstream, rather than aerobic biodegradation (McLaughlin, 1994). Some anaerobic dechlorination has occurred in many deposits along with physical/chemical weathering. The differences in congener distribution between the Lower Fox River and Green Bay sediments have been attributed to chemical and physical processes such as diffusion, solubilization, and resuspension, rather than biological processes such as aerobic degradation or anaerobic dechlorination.

Thus, natural biodegradation can not be relied upon to substantively reduce PCB concentrations over time. The dechlorination of PCBs by anaerobic bacteria is not synonymous with detoxification, as congeners having more carcinogenic activity can be formed through dechlorination (Brown and Wagner, 1990). While PCB dechlorination could contribute to an overall MNR alternative for the Fox River or Green Bay, the actual mass reductions or rates cannot be reliably quantified.

Sediment Transport and Burial. Resuspension, transport, and burial of PCB-contaminated sediments are recurring mechanisms that are well documented in the Lower Fox River and Green Bay (WDNR, 1995, 1999a, 1999b, 1999c; Baird and Associates, 2000a; LimnoTech, 1999; BBL, 1999; Velleux *et al.*, 1995). Common methods for estimating the influence and extent of these processes in an aquatic environment include: estimating sedimentation rates through field-collected data, monitoring changes in bed elevations over time, monitoring surface sediment chemistry over time, monitoring surface water quality and sediment loads, and applying fate and transport models to predict sediment transport.

These mechanisms can support the natural recovery process by burial of PCB-contaminated sediments by deposition of cleaner sediments. Alternatively, PCBs in sediments can be resuspended and transported from the river into the bay, and from the bay into Lake Michigan. Burial and transport are functions of the hydraulic conditions in the system, and are reflected as scour or deposition zone. Sediment scour and deposition patterns were evaluated using primarily three lines of evidence including: 1) geochronological sediment dating from radioisotope core data (WDNR, 1995; BBL, 1999), 2) estimated scour depths from episodic storm events and model projections (Baird and Associates, 2000a), and 3) long-term changes in observed bed elevations (WDNR, 1999c). These parameters serve as important input variables to the complex fate and transport and bioaccumulation models used for the Lower Fox River (wLFRM) and Green Bay (GBTOX).

Radioisotope Vertical Profiling. Sediment fluxes and resuspension of sediments are important parameters regarding material transport and the potential for natural recovery processes over time. Gross sedimentation rate (net + resuspension) is determined by the flux of settling particulate material which settles through the water column and is deposited on the river bottom (often measured by sediment traps). Net sedimentation flux is determined by the amount of material that remains on the river bottom and is subsequently buried over time (measured by radiological dating of sediment cores). The difference between the gross and net sedimentation rates provides information on the rate at which bottom sediments are resuspended to the overlying water column by physical processes such as ice scour, water currents, or propeller wash from passing vessels where bottom sediments may be subject to transport downstream (advection) or resettling.

Changes in deposition or scour patterns within a deposit or reach are recorded in the sediment profile and can be quantified by measuring changes in levels of atmospherically-deposited radioactive isotopes (i.e., cesium-137 [Cs-137] or lead-210) known as fallout, over time. Anthropogenic inputs of Cs-137 into aquatic systems began in 1950 from atmospheric testing and radioactive releases of nuclear weapons. Peak cesium activity is generally dated at year 1963 with a second sub-peak at year 1959 (Robbins and Edgington, 1975). Cs-137 input levels declined after 1963 following the test ban between the United States and U.S.S.R. Cs-137 profiles (concentration, depth) provide a means of determining the age of a sediment layer. By examining the depth and shape of Cs-137 sediment peaks and correlating theses profiles to the source and time of Cs-137 releases to a system, the profiles can be used to determine if the sediments are being deposited and buried, or scoured and redeposited. Stable depositional zones have stratified cesium levels with discrete horizons preserved in the sediment core. Deposits that are continually disturbed and redeposited, are represented by relatively homogenous cesium levels (no observable peaks) that indicate physical vertical mixing or bioturbation is occurring. Post-depositional redistribution by physical mixing or biological processes can also account for the appearance of Cs137 at greater depths in the core than would be predicted from the inferred sedimentation rate alone (Robbins and Edgington, 1975).

Cs-137 profiles were collected as part of the 1989–1990 Green Bay Mass Balance Study to determine long-term depositional rates (Velleux and Endicott, 1994). In most of the collected cores, the measured cesium levels were consistent with the high resuspension and sediment scour events predicted in the Fox River transport models (WDNR, 1995, 2000b). Of the 24 cores collected upstream of the De Pere dam in 1989/1990, only four cores showed little evidence of sediment diffusion or mixing in the upper layers. Fifteen of the 24 cores were considered inadequate for chronology measurements because of excessive disturbance in the profile. Apparent depths of disturbance ranged from 4 cm down to 40 cm below mudline surface. Geochronological sediment cores were also collected in 1998 as part of the NRDA assessment. The long-term net sedimentation rates were calculated from two usable cores: 1.06 centimeters per year [cm/yr] above the De Pere dam and 1.11 cm/yr below the De Pere dam (BBL, 1999). These rates are consistent with the long-term sedimentation rates of 0.3 to 0.5 cm/yr estimated by USGS based on Cs-137 profiles (as reported in Fitzgerald *et al.*, 2001). The remaining cores were difficult to interpret with evidence of sudden increases in Cs-137 concentrations in surface sediments. These anomalies observed in the profiles are consistent with the 1989/1990 data and likely indicate disturbance events.

The dating method developed for the Great Lakes (Robbins and Edgington, 1975) assumed that the major source of cesium input is via direct deposition from the atmosphere and that watershed inputs of cesium are small. While this condition may be true for the Great Lakes, it is not necessarily true for the Lower Fox River. The radioactive decay process occurs at the same rate regardless of whether a particle with Cs-137 enters river sediments immediately after atmospheric fallout or whether the particle is deposited further upstream in the watershed and takes 20 years to reach the river sediments. As a result, Cs-137 can be a poor tool to "date" sediments because of its long half-life (30 years). However, Cs-137 is a useful tool for showing the vertical extent of sediment disturbance (i.e., resuspension) in the Lower Fox River and Green Bay (ranging from 4 to 40 cm below the sediment-water interface).

Beryllium-7 (Be-7) profiles were used as a tracer to determine short-term (monthly) deposition rates and to refine the predictions of sediment resuspension on a finer scale. Be-7 is produced by cosmic ray spallation of nitrogen and oxygen in the atmosphere and decays rapidly with a half-life of 53 days. In aqueous environments, beryllium strongly sorbs to suspended particles in much the same way as other isotopes and PCBs, and quickly settles to the river bottom. Be-7 was studied in two locations of the Lower Fox River during the summer and fall of 1988 (Fitzgerald *et al.*, 2001). Sediment cores were co-located with sediment trap, Cs-137 profile, and PCB profile data. Be-7 was present in the upper 6 cm, with minimal activity below 6 cm. The profiles predict quiescent periods of low deposition followed by episodic deposition/scour events. The estimated scour depth can be at least 6 cm based on these profiles. The short-term deposition rates recorded at these stations ranged from 0 to 65 cm/yr on a yearly basis (linearly projected from discrete sampling events). These rates are one to two orders of magnitude higher than the long-term predictions by Cs-137 methods. The ratio between the short-term and long-term sedimentation rates represents a measure of the non-steady-state sediment movement into or out of a river deposit over time. This ratio varies from minus 16 cm (erosional episode) to greater than 130 cm (depositional episode) and indicates the contribution of minor resuspension events to mass transport downstream and redeposition over time in these highly dynamic systems.

Sediment Deposition and Scour Models. As described in the Model Evaluation Work Plan (WDNR, 1997), the hydrodynamics and sediment transport of the river were examined as part of a series of technical reports located in the Model Documentation Report (WDNR *et al.*, 2001). Hydrodynamic models of the Lower Fox River were developed as part of Technical Memorandum 5c (HydroQual, 2000) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine the structure of river currents. This information was used to estimate shear stresses in the wLFRM. Sediment transport models of the Lower Fox River were also developed as part of Technical Memorandum 5d (Baird and Associates, 2000b) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine aspects of sediment transport. This information was used to help estimate the magnitude and temporal dynamics of settling and resuspension velocities in the wLFRM.

Key findings of the technical memoranda related to sediment deposition and scour are discussed below and state that for any given resuspension event, the particle resuspension flux can be described as a function of the shear stress at the sediment-water interface, which can in turn be approximated as a function of flow. It is generally accepted that flow velocities increase with increasing surface water discharges; and that as flow rates increase, the scour depth and quantity of suspended solids in the water column increase. During a simulated high 100-year flow event of 24,000 cfs (685 m^3/s, surface shear stress of 4 to 24 dynes per square centimeter) below the De Pere dam, the predicted bed elevation change varied from 1 to 5 cm depth in the Lower Fox River (Baird and Associates, 2000a). Differences in flow rates at more regular intervals (i.e., 2- and 5-year intervals) are relatively small because the multiple dams and reservoirs throughout the river tend to smooth out the peak flow events.

An additional dimension of the deposition/scour analysis is the spatial scale of the hydrodynamic models applied to the Lower Fox River and Green Bay. All of the models applied to the Fox River are fairly coarse-scale evaluations of average changes in bed elevation over large areas of the riverbed (50 acres). The extrapolation of these coarse-scale model results are likely underpredictive with respect to bed sediment mixing and off-site transport. Finer-scale bed changes within a given model unit that occur from smaller-scale bedform dynamics will not be resolved by the model and will therefore under-predict localized scour and contaminant redistribution. Although these modeled events predict a maximum erosion depth (i.e., elevation loss) per event, the technical memoranda summarize that higher erosional events may occur, shear stresses are likely higher than predicted, and that the models cannot predict the range and magnitude of bed elevation changes observed in USGS monitoring data (discussed below).

Bed Elevation Changes. The magnitude of bed elevation changes measured in the De Pere to Green Bay Reach of the Lower Fox River (WDNR, 1999c) were significantly higher than the model-predicted scour depths during short-term storm events. The elevation change for short-term cycles (sub-annual) in the De Pere to Green Bay Reach ranged between 28 and 36 cm for both losses and gains. The elevation change measured over many years (a 25-year period) ranged between a 45-cm increase (net deposition) and 100-cm decrease (net scour). A maximum point change in bed elevation of 200 cm has been observed over a 7-year period (WDNR, 1999c). Flow events and their ability to erode bottom sediments are dependent not only upon the measured stream flow velocities, but also upon the cross-sectional depth of water, lake levels, operation of dams during flood conditions, and wind conditions that produce seiche events near the mouth of the Fox River.

In summary, monitored natural recovery may be appropriate in quiescent areas with net sediment deposition and little erosion potential. In these areas, sediment burial with non-impacted sediments may be possible. Based on radioisotope profiles (Fitzgerald *et al.*, 2001), short-term episodic storm events can expect scouring up to 6-cm depths and greater. In river channel areas with increased stream flow velocities and shear stresses encountered during moderate storm events (a 100-year storm event is not required) resuspension and downstream transport of surface sediment is likely. Additionally, long-term trends in observed bed elevation changes show that significant resuspension and redeposition (up to 100 and 45 cm, respectively) can occur over a period of many years (observed for 25 years) with little spatial or temporal continuity. Finally, these observed trends are based upon the existing hydraulic conditions that are in large part governed by the system of dams on the river. Any MNR alternative considered for a river reach would implicitly require maintenance of the dams, or explicitly require consideration of the effects of dam removal.

Time Trends Analysis. PCB concentrations in sediments and fish tissue can be reliable measures of changing conditions since PCBs tend to persist in sediments and bioaccumulate in fish and other animals for long periods of time. The time trends analysis summarized in Section 2.6 presented evidence that concentrations of PCBs in fish tissue and surface sediments have generally declined following the elimination of PCB point source discharges. Statistically significant breakpoints in the decline for most of the fish species examined suggest that the decline has slowed down or, in some cases, that tissue concentrations of PCBs have actually increased.

Data on PCBs in surface sediment samples suggest that PCB concentrations have generally declined over time. Trends in concentrations of PCBs in subsurface sediments are mixed; some deposits show declining trends, while others show trends either close to zero or not significantly different from zero, and yet others show increasing trends. The time trends appear to be quite changeable and confidence intervals for rates are quite wide so that it is not possible to project PCB concentrations into the future for fish or sediment with much confidence.

The time trends analysis was a purely statistical exercise that offered no insight into the mechanism(s) responsible for declining sediment PCB concentrations. The primary attenuating mechanisms for PCBs in the Lower Fox River and Green Bay are sediment resuspension and transport, followed to a lesser degree by desorption and dispersion in the water column (Section 2.5). Biodegradation, resulting from the actions of naturally occurring aerobic and anaerobic microorganisms in the sediments, is believed to be a minor contributor to changes in PCB concentrations.

In summary, much of the Lower Fox River system undergoes both erosional and depositional events, with areas of net deposition, creating areas known as "sediment deposits." However, in net depositional areas where settling exceeds erosion, erosion can still occur. Locating areas of long-term net sediment deposition that are not susceptible to erosional scour events need to be addressed prior to implementing a monitored natural recovery alternative. Transport modeling and bathymetry results indicated that significant erosion is confined to mostly the deeper, mid-channel river sediments (during periods of high flow), while the nearshore sediments are not eroded (Velleux *et al.*, 1995). Both the Be-7 and the Cs-137 data suggest that there are some areas within the Lower Fox River that may be net depositional (i.e., over long periods gross deposition exceeds gross erosion), but that on the aggregate, most deposits are subject to scour and resuspension.

Implementability

EPA has issued guidance for implementing MNR cleanup remedies at sites involving soil or groundwater contamination (EPA, 1999b). No specific guidance is available for implementing MNR remedies at sediment sites. However, EPA expects that similar natural attenuation considerations for upland sites also apply to sediments (EPA, 1998a).

MNR is an implementable remedy from a technical standpoint, as the means are available for monitoring environmental quality and modeling the rate of natural restoration. In high-energy environments, sediment scour and transport is likely to dominate sediment recovery processes, while in low-energy environments, bioturbation is likely to dominate contaminant movement in the upper layer of sediments. Physical processes such as net burial and isolation of impacted sediments is also likely to dominate the recovery process in low-energy environments. An MNR remedy would require long-term monitoring of Lower Fox River and Green Bay fish tissue, water quality, and sediment quality. This data could be used in conjunction with fate and transport models to determine the rate and extent of natural restoration actually occurring.

Effectiveness

MNR alone would likely be insufficient to meet project RAOs in the short- or long-term in many portions of the river and bay. Natural recovery may be sufficient in localized nearshore quiescent areas with only minor contamination and accumulating sediments. In areas of the river and bay with higher levels of contaminants and higher potential for scour events, MNR may become an integral component of an active remedy involving some degree of containment or removal. For example, MNR may be effective at reducing residual COC concentrations to acceptable levels over an extended period once the more contaminated sediments are removed. Monitored natural recovery may be an appropriate remedial alternative when:

- Large volumes of contaminated sediment have marginal levels of contamination;
- The area is a low-energy, depositional environment;
- Dredging for navigational needs are not required;
- Site restrictions and institutional controls are acceptable;
- Review of existing data suggest that the system is naturally attenuating and will continue to do so within an acceptable time frame; and
- The cost for an active remedy disproportionately outweighs the risk reduction benefit.

Monitored natural recovery has been selected as the primary remedial alternative at two sediment sites in the United States: 1) James River in Hopewell, Virginia; and 2) the Sangamo Weston/Twelve Mile Creek/Lake Hartwell Superfund site in South Carolina (described in Appendix B). At the Sangamo Weston site, for example, the selected remedy focused on extensive source control of PCB-impacted sediments in Twelve Mile Creek, and monitoring the recovery of sediment and biota in the quiescent, depositional waters of Lake Hartwell over time. Annual monitoring since 1994 has shown measurable decreases in surface sediment concentrations of PCBs. Burial by clean sediment is thought to be the dominant recovery process with measurable contributions from periodic releases by upstream dams. Sediment accumulation rates in Lake Hartwell, estimated from 10 samples collected during 2000 by radioisotope profiling methods, ranged from 0.66 to 19 cm/year. The sediment cores also showed that the PCB congener composition became increasingly dominated by lower chlorinated congeners with sediment depth and corresponding age, resulting in a relative accumulation of ortho-chlorinated congeners and losses of meta- and para-chlorinated congeners. This preliminary evaluation suggests that partial dechlorination in deeper sediments and dissolution/volatilization in surface sediments may also be contributing to the PCB degradation mechanisms at the site. It is possible that a concentration of ortho-substituted congeners at a given site represents the lower limit to the extent of dechlorination achievable at that site (http://www.clu-in.org/Products/NEWSLTRS/TTREND/tt0301.htm). Other case studies regarding the observed extent of biological degradation processes are described in Appendix F.

Costs

MNR is a generally a low-cost technology because no active sediment remediation occurs that involves containment, removal, or treatment. However, monitoring costs may be significant, extending into the millions of dollars, depending on the term and magnitude of the monitoring program.

Long-term monitoring costs vary widely depending upon the project expectations, media of concern, and residual risks. For the purposes of this FS, sampling costs for sediment, water, bird, fish, and invertebrate tissue are approximately $600,000 per sampling year (every fifth year), with a total present worth monitoring cost of $11.8 million over 40 years for each reach/zone (Appendix C). The *Long-term Monitoring Plan* (LTMP) located in Appendix C will likely be refined and finalized after the remedy has been selected. Elements of the LTMP may differ between locations with residual risk with areas meeting the most protective SQT criteria.

Screening Decision

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). As discussed above, MNR alone is unlikely to be an effective remedial approach in heavily-impacted areas of the site because of the anticipated time required to reach the project RAOs. In these areas where PCB concentrations exceed the apparent dechlorination threshold of 30 mg/kg described above, dechlorination of the PCB molecule is not a viable process. However, MNR alone may be a viable remedial alternative in areas where the PCB concentrations are moderate, impacted sediments are widely dispersed, and the inventory of PCB mass is relatively low due to historical natural dispersion or burial activities. Natural recovery processes are also critical components to the evaluation of cleanup alternatives over a range of cleanup action levels as described in Section 5.

6.4.4 Containment

In-situ capping is the containment and isolation of contaminated sediments by the placement of clean materials over the existing substrate. This alternative does not require removal of sediment; clean sediments are placed over old sediments as a barrier, isolating contaminants within the substrate. Capping of subaqueous contaminated sediments has become an accepted engineering option for managing dredged materials of *in-situ* remediation (NRC, 1997; EPA, 1991, 1994a; Palermo *et al.*, 1998). There are multiple references that discuss physical considerations, design, and monitoring requirements for capping. The following references were used in this FS Report to assess the applicability of containment technologies:

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Design Requirements for Capping* (Palermo, 1991);

- *Guidance for In Situ Subaqueous Capping of Contaminated Sediments* (Palermo *et al.*, 1998);

- *Placement Techniques for Capping Contaminated Sediments* (Palermo, 1994);

- *Washington State Department of Ecology 1990 Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);

- *Equipment and Placement Techniques for Capping* (USACE, 1991);

- *Monitoring Considerations for Capping* (USACE, 1992);

- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeeman, *et al.*, 1992); and

- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt, 1993a).

The last two references describe capping design and structural considerations for capping in a riverine environment in the Great Lakes.

Description of Containment Process Options

Caps may be grouped into three general categories: conventional sand, armored, and composite. Conventional capping includes sand and clay caps. Other miscellaneous capping techniques include thin-layer capping and enhanced capping.

Conventional Capping. Conventional caps involve the placement of sand or other suitable cover material (i.e., clay) over the top of contaminated sediments. Material selection and cap thickness are determined based on consideration of contaminant properties and local hydraulic conditions. Sandy soils and sediments are typically preferred as cap materials over fine-grained materials. The latter are more difficult to place evenly, cause a great deal of turbidity during placement, and are more erosive. A cap thickness of 30 to 50 cm is considered sufficient to chemically isolate PCBs and metals (Palermo, 1994).

Capping operations can disturb and displace loose fine-grained bottom sediment, resulting in resuspension losses and mixing of contaminants into the clean capping layer. Physical characteristics, such as solids content, plasticity, shear strength, consolidation, and grain size distribution affect the displacement of sediment. The sediment characteristics will often form the basis for determining the suitability of capping materials and placement options (Palermo, 1991).

A variety of methods are available for constructing conventional caps in riverine environments:

- Hydraulic pipeline delivery of a sand slurry through a floating spreader box or submerged diffuser;

- Physical dispersion of barged capping materials by dozing, clamming, or washing of material that settles through the water column;

- Distribution by controlled discharge from hopper barges;

- Mechanically-fed tremie to the river bottom; and

- High-pressure spraying of a hydraulic sediment-water slurry across the water surface.

The method used to place the cap material must be capable of achieving even placement of material over the target area while limiting the resuspension and loss of contaminated sediment into the water column or the emerging cap layer. Even placement and limited resuspension of contaminated sediment are generally achieved when the capping materials are dispersed and allowed to settle through the water column. The dumping of large, dense masses of capping material (e.g., pushing sands off a barge) or methods that lead to density-driven hydraulic flow should be avoided.

A summary of conventional capping projects in North America is provided in Appendix D.

Armored Capping. Armored caps are similar to conventional caps with the exception that the primary capping material (e.g., sand) is covered with stone or other suitable riprap (the armor) to add physical stability in erosive environments. Armored caps are commonly used in environments where high water velocities (i.e., flood flow, propeller wash) threaten the cap integrity. Examples of armored caps from Sheboygan Falls, Wisconsin and Manistique Harbor, Michigan are illustrated on Figure 6-1. However, the Manistique cap was never implemented and is solely based upon preliminary design drawings.

The conventional portion of the cap is placed using one of the previously described methods. Armoring materials (quarried rock or concrete riprap) are then barged to the site and placed using conventional equipment (excavators, cranes). Methods for determining the appropriate armor stone grade and thickness can be found in the *Assessment and Remediation of Contaminated Sediments (ARCS) Sediment Capping Study Final Report* (Maynord and Oswalt, 1993b).

Composite Capping. A composite cap generally involves placement of a geotextile or flexible membrane liner directly over the contaminated sediments. Permeable or impermeable liners may be considered, depending upon the migration potential of the chemical(s) of concern, and the potential for methane buildup under the liner in highly organic sediments. The liner is then armored with stone or riprap to ensure the physical integrity of the cap. Composite caps may also include a sand or activated carbon layer to capture any potential diffusive or advective migration of the underlying contaminants. For non-mobile contaminants, such as PCBs, the composite cap would likely only require a liner and armoring. A composite cap was placed at the Manistique River/Harbor site as a temporary containment measure (Figure 6-1).

Miscellaneous Capping Techniques. Additional capping approaches, besides those described above, have received attention in the capping literature including thin-layer capping, Aquiblock™, and Claymax™. Thin-layer capping involves the placement of a thin (1- to 3-inch) layer of clean sediments, that is subsequently mixed with the underlying contaminated sediments, to achieve acceptable COC concentrations and/or enhance the natural attenuation process. Mixing occurs naturally as a result of benthic organism activity (bioturbation). This approach is best suited to situations involving contaminants that naturally attenuate over time. However, PCBs do not naturally attenuate to any significant degree and, therefore, thin-layer capping would simply dilute surface sediment PCBs. Thin-layer capping would simply increase the volume of contaminated material albeit at reduced average concentrations. Aquiblock™ technology was used on the Ottawa River, Ohio as a pilot test, and Claymax™ technology was used on floodplain soils for Hudson River sediments.

Enhanced capping involves the incorporation of materials such as activated carbon, iron filings, imbiber beads, or other agents into the base capping material (e.g., sand) to enhance adsorption or *in-situ* chemical reaction. This approach is intended for circumstances in which contaminants are mobile and are expected to migrate through the cap as dissolved constituents in the pore water. These conditions do not exist at the site as PCBs are highly adsorbed to sediments and have a very low potential for migrating in sediment pore water.

Screening Criteria for Cap Selection

The criteria used for selection of a capping alternative are: presence of sediments with PCB concentrations of 50 ppm or greater (referred to as TSCA-level sediments, where the TSCA level is 50 ppm), site bathymetry, and current speed (median and 100-year flood). The latter two criteria are based upon general design guidance that caps should only be placed in a low-energy environment with little potential for erosion or disturbance of the cap (Palermo *et al.*, 1998).

- **Contaminant Concentration.** *Capping is not considered for sediments where total PCB concentrations exceed the 50 ppm TSCA level, unless the alternative involves removal of all TSCA-level material prior to capping.* Areas with sediment PCB concentrations exceeding the TSCA level of 50 ppm are unlikely to receive regulatory approval for capping. EPA has determined that capping of PCB-contaminated sediments is an action to contain and confine PCBs, though concentrations of 50 ppm or greater may not be approved by EPA (EPA Region 5 letter dated July 15, 1994, provided in Appendix E).

- **Site Bathymetry.** *The final constructed water depth shall be no less than 3 feet*. Site-specific water depth must be considered in selecting a cap as an option. To maintain physical integrity, the cap surface must be sufficiently below the water surface to minimize the potential for ice damage, ice flow scour, wind-induced currents or waves, and vessel draft. Commercial and recreational boating use of an area must also be considered to ensure both adequate draft clearance, as well as the potential damage from anchors or propeller wash. Since the maximum vessel draft, depth of ice scour, and propeller wash depth for recreational boats operating along the Fox River is approximately 2 feet, a minimum water depth of 3 feet should be maintained.

- **Currents.** *Capping is considered an alternative for a given river reach where the average current speed is less than 0.15 feet/second (ft/s), and the maximum (100-year flood) current speed is no greater than 0.7 ft/s.* Currents are important to consider because of their potential to cause scour and physical erosion of the cap. Consideration of currents should include both normal flow, flood events, and dramatic water fluctuation that may result from dam failure or dam drawdown. For a conventional sand cap, the site conditions should generally be non-dispersive in a relatively low-energy environment with low bottom current velocity. In addition, commercial boat-induced currents (propeller wash) should be considered. In the Lower Fox River, flood-flow velocities in the central river channels are expected to be the dominant potential erosional force within the Little Lake Butte des Morts Reach and the Little Rapids to De Pere Reach. Below the De Pere dam, navigation-induced water movement from the wake of a large boat or propeller wash should be considered in any potential capping scenario. Detailed evaluation methods for quantifying erosional potential are given in Palermo *et al.* (1998).

Additional guidance that is applied in this FS concerning the placement of a cap in the Lower Fox River includes the following:

- **Navigation Channels.** Capping is not selected as an alternative within the designated federal navigation channel below the De Pere dam, since periodic maintenance dredging may be required to support vessel draft of large commercial traffic (commercial vessels are limited to below the De Pere dam). While a constructed water depth of greater than 25 feet is sufficient clearance for most vessels, cap placement within the channel would require substantial armoring to protect against erosion by propeller wash, and would result in permanent deed restrictions prohibiting maintenance dredging and/or navigational improvements. In addition, any changes to the navigational channels would require congressional authorization to modify the federally-authorized depth of the navigation channel, assuming a cap placement would limit maintenance to the designated depth.

- **Bottom Sediment Characteristics.** As discussed earlier in this section, specific sediment characteristics will often form the basis for determining the suitability of capping materials and placement options.

- **Capping Materials.** For thin-layer capping, use of clean uniform granular materials (sands, fine gravels) enhances reliable application of the design layer thickness. Clumpy materials (cohesive silts/clays) and/or variable size gravels are more difficult to place evenly, and may only be placed by mechanical means.

- **Placement Method.** Both mechanical and hydraulic methods have been used for cap placement. Mechanical placement of capping material allows for greater placement accuracy while minimizing downstream turbidity. Restrictions to the mechanical application of capping material are related to the draft depths of the material barges, which are generally 8 to 10 feet. Hydraulic placement is not restricted by water depth, and has the advantage of minimizing the resuspension of contaminated sediment losses described above. Conversely, the placement activity itself will result in a temporary increase in downstream suspended solids due to the cap material.

- **Impact to Riverine Habitat and Future Use.** The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Creation of a cap will result in change of the site depth, which can significantly change the quality of the aquatic habitat. Conventional, armored, or composite caps result in significant change in substrate type, which can influence the functioning of the benthic community and food chain interactions.

- **Institutional Notifications/Monitoring.** All capping options result in permanent restrictions to future site use, as well as long-term monitoring and maintenance of the cap.

Implementability

Conventional sand caps and armored sand caps have been successfully placed over contaminated sediments in many in-water lakes (Soda Lake, Wyoming; Hamilton Harbour, Canada) and marine environments (Minamata Bay, Japan; New York Mud Dump; Eagle Harbor, Washington) (Palermo *et al.*, 1998). Other Puget Sound projects that have involved in-place capping of contaminated sediments included Simpson Tacoma Kraft (Commencement Bay), Denny Way (Elliott Bay), and Seattle Ferry Terminal (Elliott Bay). A few caps have been placed in riverine environments, but the number of projects is relatively few (Duwamish River, Washington) when compared to other systems. See Appendix D for a list of capping projects placed over contaminated sediments (metals, PAHs, PCBs). Average cap thickness has ranged from 1 to 5 feet thick and post-cap sediment cores show effective isolation of underlying material in most cases. Geosynthetic liner caps were used at the Minamata Bay, Japan, and Soer Fjord, Norway sites.

Placement of capping material can be accomplished by open-water surface discharge using a split-bottom hopper barge or subsurface discharge using a tremie pipe for more accurate placement. The site considerations listed above (i.e., bathymetry, surface water flow, substrate type) are all important design requirements for successful placement of a containment cap. Long-term chemical stability, erosion, and consolidation potentials should also be examined prior to placement.

In-situ sand capping may not be feasible if the bottom sediment is extremely soft where the sediment cannot support a cap, or if water flow conditions would impede accurate placement of sand material.

Effectiveness

Capping is meant to isolate contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new clean substrate for recolonization by benthic organisms. Capping is considered very effective for low-solubility and highly sorbed contaminants, like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs must preclude the potential for sediment resuspension under normal and extreme (storm) conditions.

The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Impacts include changes to the site depth, navigational and recreational uses, substrate type, and benthic community and food chain interactions. Creation of a cap will result in permanent restrictions and site access limitations in order to ensure adequate protection.

Conventional and armored caps may be effective for containing PCBs and mercury. Use of geotextiles (composite cap) may be an effective substitute for sand or clean sediment, but would likely require some form of armoring. Enhancing the cap medium with carbon or some other reactive agent is not necessary to prevent chemical migration of PCBs and mercury.

Capping Costs

Costs for capping are moderate with respect to more intensive approaches involving removal, treatment, or disposal. Total cap costs typically range from $30 to $50 per square meter ($300,000 to $500,000 per hectare), depending on cap construction and placement technique (EPA, 1994a).

Screening Decision

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay. The technology is retained for use in development of remedial alternatives in Section 7. Of the various process options, conventional, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Armored caps will be retained as the representative process option for in-place containment actions.

6.4.5 Removal

Removal refers to excavation or dredging of sediments. The discussion of removal process options herein integrates site knowledge, practical dredging experience, dredging sediment case studies, and demonstrated successful application under similar conditions found throughout the Lower Fox River. Wherever possible, Great Lakes practical experience was utilized to assess the applicability of a specific removal technology. Pilot demonstration dredging projects at Deposit N (in the Appleton to Little Rapids Reach) and SMU 56/57 (in the De Pere to Green Bay Reach) provide site-specific information on the implementability and effectiveness of dredging in the Lower Fox River.

The usefulness of dredging as a viable remedial technology is described, in depth, in the *Sediment Technologies Memorandum* located in Appendix B. This review paper provides a detailed review and summary of many large-scale environmental dredging projects. The major findings of this review and results from the two Lower Fox River demonstration projects (detailed in Appendix B) were used to assess the viability of dredging as a remedial technology. A few guidance documents also provided practical implementation information for sediment remediation projects in the Great Lakes region:

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a);

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Innovations in Dredging Technology: Equipment, Operations, and Management*, USACE DOER Program (McLellan and Hopman, 2000);

- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995); and

- *Guidance for Subaqueous Dredged Material Capping*, USACE (Palermo *et al.*, 1998).

Description of Removal Process Options

For the purposes of this FS, dredging is defined as the removal of sediment in the presence of overlying water (utilizing mechanical or hydraulic removal techniques). Wet excavation is defined as the in-water removal of sediment using typical earth moving equipment such as excavators and backhoes. Dry excavation is defined as the berming or rerouting of overlying water to create dewatered conditions accessible by upland earth moving equipment. Three categories of removal technologies are commonly considered for sediment removal in "wet" conditions with overlying water:

- Mechanical dredging,
- Excavators, and
- Hydraulic dredging.

All three of these technologies were retained for consideration during the development of remedial alternatives and are described in more detail below.

Mechanical Dredging. A mechanical dredge consists of a suspended or manipulated bucket that "bites" the sediment and raises it to the surface (Figure 6-2). The sediment is deposited on a haul barge, as illustrated on Figure 6-3, or other vessel for transport to disposal sites. A mechanical dredge and haul operation is currently used for routine maintenance dredging of the federal navigational channel in the Lower Fox River and Green Bay.

Under suitable conditions, mechanical dredges are capable of removing sediment at near *in-situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. A low water content is important if dewatering is required for ultimate sediment treatment or upland disposal.

Clamshell buckets (open and closed), dragline buckets, dipper dredges, and bucket ladder dredges are all examples of mechanical dredges. Dragline, dipper, and bucket ladder dredges are open-mouthed conveyances and are generally considered unsuitable where sediment resuspension must be minimized to limit the spread of sediment contaminants (EPA, 1994a). Consequently, dragline, dipper, and bucket ladder techniques are not considered further in this FS Report.

The clamshell bucket dredge, or grab-dredge, is widely used in the United States and throughout the world. It typically consists of a barge-mounted floating crane maneuvering a cable-suspended dredging bucket. The crane barge is held in place for stable accurate digging by deployable vertical spuds imbedded into the sediment. The operator lowers the clamshell bucket to the bottom, allowing it to sink into the sediment on contact. The bucket is closed, then lifted through the water column to the surface, swung to the side, and emptied into a waiting haul barge. When loaded, the haul barge is moved to shore where a second clamshell unloads the barge for re-handling and/or transport to treatment or disposal facilities. Clamshell dredges can work in depths over 100 feet, and using advanced positioning equipment (e.g., differential global positioning systems [DGPS]), dredging accuracy is on the order of ± 1 foot horizontally and ± 0.5 foot vertically. Clamshell buckets are designated by their digging capacity when full and range in size from less than 1 cy to more than 50 cy.

A conventional clamshell bucket may not be appropriate for removal of contaminated sediments from some areas of the Lower Fox River. Conventional buckets have a rounded cut that leaves a somewhat cratered sediment surface on the bottom. This irregular bottom surface results in the need to over-dredge to achieve a minimum depth of cut, and can also encourage dense resuspended sediment losses to settle in the craters. Furthermore, the conventional open clamshell bucket is prone to sediment losses over the top during retrieval. Recent innovations in bucket design have reduced the spill and sediment resuspension potential by enclosing the bucket top (Figure 6-2). Also, buckets can be fitted with tongue-in-groove rubber seals to limit sediment losses through the bottom and sides.

A recent alternative bucket demonstrated in several tests and prototype sediment remediation projects is the proprietary Cable Arm® bucket (Figure 6-2). This bucket offers the advantages of a large footprint, a level cut, the capability to remove even layers of sediment, and under careful operating conditions, reduce resuspension losses to the water column as shown on Figure 6-3. The Cable Arm®

bucket has been successfully demonstrated for contaminated sediment removal at a number of sites in the Great Lakes (Cleland, 1997; SEDTEC, 1997), and was used in a removal action in the summer of 1997 at a creosote-contaminated site in Thunder Bay, Ontario.

Production rates for clamshell dredging are highly project-specific. For navigation dredging, a 5-cy bucket might deliver more than 200 cubic yards per hour (cy/hr). This same bucket might only produce 20 to 30 cy/hr in controlled sediment remediation work so as to achieve a thorough removal, limit resuspension, minimize water content, comply with water quality constraints, and limit over-dredging. The presence of large debris requiring separation and re-handling will also slow dredging progress.

Excavators. This is a subset of mechanical dredges which includes barge-mounted backhoe and/or excavators, both of which have limited reach capability. Excavators can also be used for dry excavation where the overlying water is removed. Special closing buckets are available to reduce sediment losses and entrained water during excavation. Use of conventional excavating equipment is generally restricted to removal of contaminated sediment and debris in shallow water environments or dry excavations (areas that are bermed, then dewatered for access by land-based equipment). Dewatering of an area for dry dredging involves hydraulic isolation/removal of surface water using: 1) earthen dams, 2) sheet piling, or 3) rerouting the water body using dams. Although normally land-based, excavators can be positioned on floating equipment (e.g., spud-barge) for dredging in shallow environments.

A conventional excavator bucket is open at the top which may contribute to sediment resuspension and loss during dredging, although careful operation can minimize losses. Various improved excavating buckets have been developed which essentially enclose the dredged materials within the bucket prior to lifting through the water column. A special enclosed digging bucket was successfully used on the large excavator "Bonacavor" (C. F. Bean Corp.) for remediation of highly contaminated sediment in Slidell, Louisiana (NRC, 1997). Dredged material removed by backhoe exhibits much the same characteristics as for clamshell dredging, including near *in-situ* densities and limited free water.

Hydraulic Dredges. Hydraulic dredges remove and transport dredged materials as a pumped sediment-water slurry. The sediment is dislodged by mechanical agitation, cutterhead, augers, or by high-pressure water or air jets (Figure 6-4). In very soft sediment, it may be possible to remove surface sediment by straight suction and/or by forcing the intake into the sediment without dislodgement. The loosened slurry is essentially then "vacuumed" into the intake pipe by the dredge pump and transported over long distances through the dredge discharge pipeline. Figure 6-5 provides an illustration of a hydraulic dredge with a pipeline to an upland gravity dewatering cell, and Figure 6-6 shows a conceptual layout of a gravity dewatering cell.

Common hydraulic dredges include the conventional round cutterhead, horizontal auger cutterhead, open suction, dust pan, and hopper dredges. The conventional cutterhead and horizontal auger dredges are illustrated on Figure 6-4. Specialty hydraulic dredges are available that limit resuspension losses at the dredge head and increase the solids content of the dredged slurry. These latter include the auger-, cleanup-, and refresher-type dredges. Hydraulic dredges are rated by discharge pipe diameter, and those available in the Great Lakes range from smaller portable machines in the 6- to 16-inch category, to large 24- to 30-inch dredges. The most suitable and available hydraulic dredges for the Lower Fox River project are the open suction, cutterhead, and auger types. These are discussed below.

Suction dredges are open-ended hydraulic pipes that are limited to dredging soft, free-flowing, and unconsolidated material. As suction dredges are not equipped with any kind of cutting devices, they produce very little resuspension of solids during dredging. However, the presence of trash, logs, or other debris in the dredged material will clog the suction and greatly reduce the effectiveness of the dredge (Averett *et al.*, 1990).

The hydraulic pipeline cutterhead suction dredge is commonly used, with approximately 300 operating nationwide. The cutterhead is considered efficient and versatile (Averett *et al.*, 1990). It is similar to the open suction dredge, but is equipped with a rotating cutter surrounding the intake of the suction pipe. The combination of mechanical cutting action and hydraulic suction allows the dredge to work effectively in a wide range of sediment environments. Resuspension of sediments during cutterhead excavation is strongly dependent on operational parameters such as thickness of cut, rate of swing, and cutter rotation rate. Proper balance of operational parameters can result in suspended sediment concentrations as low as 10 mg/L in the vicinity of the cutterhead. More commonly, cutterheads produce suspended solids in the 50 to 150 mg/L range.

The horizontal auger dredge is a relatively small portable hydraulic dredge designed for projects where a small (50 to 120 cy/hr) discharge rate is desired. In contrast to a cutterhead, the auger dredge is equipped with horizontal cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger, where it is picked up by the suction. There are more than 500 horizontal auger dredges in operation. A specialized horizontal auger dredge has been used at the Manistique Harbor Superfund site.

The Toyo pump is a proprietary electrically-driven compact submerged pump assembly that is maneuvered into position using a derrick barge. This pump is capable of high solids production in uncohesive sediment and can be equipped with a rotating cutter or jet-ring to loosen sediment. This is a lower head pump that typically discharges through 6- to 12-inch-diameter pipes and may require a booster pump for long pipeline distances. Typically, slurry discharges are at a density of approximately one-third the *in-situ* density.

The Pneuma® pump is a proprietary pump developed in Italy that uses compressed air and vacuum system to dislodge sediments through a pipeline. It may be suspended from a crane or barge and generally operates like a cutterhead dredge. It was used at the Collingwood, Ontario demonstration dredging project (EPA, 1994a).

An important consideration in hydraulic dredging is the quantity of water needing treatment after dewatering from the dredge slurry. The greater the solids content of the dredge slurry, the better the relative removal efficiency and the less water needing treatment. Typical solids content (wet) for dredge slurry ranges between 5 and 8 percent w/w, but can be less than 5 percent. For the Lower Fox River demonstration projects, the average percent solids was 5 percent w/w with a maximum solids content of about 12 percent w/w. Factors influencing the solids content include dredge type, nature of sediment, condition of equipment, and operator skill and experience.

Screening Criteria for Dredging

Selection of appropriate dredging technologies and their potential effectiveness is dependent upon more than one variable. It is a formulaic effort considering multiple variables ranging from water depth to disposal sites. Significant operating parameters and constraints considered in selecting and applying the appropriate dredging equipment for the Lower Fox River and Green Bay include:

- **Operating Depths.** *Consider hydraulic dredging in areas with shallow water depths less than 8 feet.* Hydraulic dredging is selected for alternatives in areas where the depth of water is less than 8 feet. Small hydraulic dredges have been successfully utilized in river depths as shallow as 3 feet, whereas mechanical dredges are typically limited to minimum water depths of 8 to 10 feet, principally by the draw of the transport barges required to move the dredged materials to shore. Where water depths are greater than 8 feet, both hydraulic and mechanical dredging options are considered. The method carried forward in the FS depends upon sediment removal volumes (i.e., small hotspot removals of TSCA sediments), upland space capacity for dewatering, and disposal. In shallow areas, dry excavation may be considered.

- **Removal Efficiency.** Efficiency is the capability for removing the target contaminated sediment layer in a single (or minimum number of) pass(es) with the dredge equipment, while minimizing the quantity of over-dredged material to be treated and disposed. Where bedrock underlies contaminated sediments, removal by “over-dredging” to achieve low residual concentrations may be difficult or costly.

- **Contaminant Resuspension.** A major consideration is the capability for removing targeted sediments with minimum amount of sediment resuspension and loss during dredging.

- **Water Management.** Another selection criteria is practicality of managing large volumes of water associated with dredged material that will require collection and treatment prior to discharge of return flow to the river. This ranges from moderate amounts of free water and drainage arising from mechanically-dredged sediment to significant continuous volumes associated with return flow from a hydraulic dredge. Mechanical dredging and dry excavation produce smaller volumes of free water requiring treatment than hydraulic removal methods.

- **Equipment Availability.** Availability of dredging equipment is an important consideration. A number of floating clamshell dredges and small hydraulic dredges are available in the Great Lakes for use at the project site; however, the large quantity of PCB-impacted sediments located in the Lower Fox River and Green Bay may preclude equipment availability for long periods. Large construction backhoes and equipment barges are also available. However, many of the specialty dredges identified in the literature (e.g., pneumatic, refreshers, cleanup, matchbox dredges) are not available locally and/or would require fabrication of new dredging equipment and a period of operating experience.

- **Seasonal Restrictions.** *In-water work will occur within the months of April through October (an approximate 26-week time period).* A significant project constraint is the limited allowable work period for in-water construction activities. Freezing weather in winter will generally limit dredging to the months of April to October. In-water work near residential areas will be restricted to 10-hour work periods in order to minimize disturbance to the residents depending upon the nature of the work. For the purposes of the FS, all costs will be based on a 10-hour in-water work shift. The goal is to complete remediation activities within 10 years after initiation. The combination of sediment removal volume, sizing of pumps and equipment, dewatering facilities, and equipment type will influence the ability to meet the 10-year goal.

- **Work Sequencing.** Sediment removal will generally proceed from upstream to downstream in order to minimize the potential for recontamination of remediated downstream areas due to resuspension from upstream removal activities.

- **Access and Disposal.** Dredging can be limited by the ability to transport, dewater, and dispose of excavated material. A significant limiting constraint for dredging is the availability of on-land real estate for staging and support activities, as well as disposal options. The final destination of the excavated material will influence the type of dredging equipment selected. For example, if a nearshore CDF is considered, then hydraulic dredging and pumping directly into the CDF may be the best option.

- **The Lower Fox River Demonstration Projects.** Results of the Lower Fox River environmental dredging projects are essential considerations. The final selected remedy for a large-scale remediation effort will heavily depend upon the effectiveness of selected dredging equipment, containment systems, and dewatering operations of the pilot projects.

Implementability

Many regulatory and private interest groups are searching for answers to the same questions of how to cost-effectively manage contaminated sediments while ensuring protection of human health and the environment over the long term (Peterson *et al.*, 1999; Krantzberg *et al.*, 1999; Zarull *et al.*, 1999; SMWG, 1999; SPAC, 1997; Lower Fox River Group, 1998, 1999). Dredging is a common, well-developed technology that can be implemented in the Lower Fox River and Green Bay. Dredging is an effective technology utilized on numerous sites around the world for removing contaminated sediments.

Additionally, results of the Lower Fox River pilot projects demonstrate that dredging techniques can successfully remove a large mass of PCB-impacted sediments as well as achieve reductions in PCB sediment concentrations. Recent advances in dredge head construction and positioning technology enable accurate removal of sediment layers with minimum incidental over-dredging. However, concerns for sediment resuspension, surface recontamination, and downstream transport of impacted-sediments are commonly cited by dredging opponents as short-term limitations of the technology as a viable remedial alternative.

Results of the sediment technology review memo (Appendix B) indicate that dredging can be an implementable and effective method for managing contaminated sediments, provided that the technology is designed and managed appropriately for the site conditions. Expectations and project goals will also influence the perceived success of dredging projects along with a well-designed monitoring plan able to verify achievement of the intended goals. A few of the key concerns and findings are discussed below and detailed in Appendix B.

Sediment Resuspension. All removal technologies increase, to varying degrees, suspended solid concentrations in the surrounding waters. This resuspension may adversely impact localized water quality or result in spreading contaminated solids to clean sediment surfaces. Sediment resuspension can be managed by a combination of equipment selection and operational controls, including selection of an appropriate dredge type that best matches site conditions. Operator proficiency in placing and moving the dredge head, reduced dredging rates, and use of silt curtains can be important factors in limiting resuspension and spread of contaminated sediments. Field experience has shown that sediment resuspension by hydraulic dredges can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 revolutions per minute (rpm), a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

The cutterhead dredge was evaluated for removing contaminated sediment during the New Bedford Harbor Superfund Pilot Study. Compared to two other suction types, the cutterhead was superior for minimizing sediment resuspension (USACE, 1990). Round and horizontal auger cutterhead dredges was also used for removal of Deposit N and SMU 56/57 sediments, respectively.

Silt Curtains. Water quality impacts from sediment resuspension at the dredge may be reduced by conducting the dredging within a silt curtain, silt screen, or sheet pile enclosure in order to contain migration of the suspended solids/turbidity plume. A silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. A silt curtain can extend completely to the bottom with appropriate fringe weights and anchors.

Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates that a more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, a silt screen is constructed of permeable fabric designed to pass water, but not the fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Maintaining a stable geotextile silt curtain was difficult in soft sediments at the Lower Fox River SMU 56/57 project in 1999. Passing boat traffic disrupted the integrity of the silt curtain, requiring immediate repair during the demonstration project. In 2000, the SMU 56/57 project successfully used silt curtains with sheet pile anchors to provide stability for the dredge. An 80-mil HDPE containment barrier was used at the Lower Fox River Deposit N demonstration project and successfully maintained for the duration of the project.

Surface Recontamination. Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 19 projects had lower maximum post-dredge surface concentrations than maximum pre-dredge conditions. The average percent reduction in maximum detected surface concentration was 84 percent (percent reduction in area average was 97 percent). For a few projects, it is fair to mention that the maximum concentration measured in residual sediments were occasionally higher than the target criteria; however, the majority of subunits measured, on average, were below the chemical criteria.

Surface concentrations should not be the sole measure of dredging success and risk reduction. The percent of surface area coverage with elevated surface concentrations above protective levels would be a more accurate measure of residual risk. For example, the Deposit N project in Wisconsin and GM Foundry project located in New York, collected confirmation samples from the cracks and crevices between the bedrock or bedrock itself because of insufficient sediment volume remaining above the bedrock (in some areas). These values likely biased the "true condition" of residual contaminant distribution among surface sediments. Moreover, focus on short-term residual surface concentrations remaining after dredging may misrepresent site risks. Removal of contaminant mass would likely be reflected in lower bioavailable surface concentrations over the long term as natural processes including sediment deposition and scour events occur over time.

Contaminant Transport. The PCB mass balance study conducted during Deposit N dredging activities (Water Resources Institute, 2000), estimated that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river after treatment. The mass balance model and the river turbidity samples consistently measured TSS below background values during project operations and did not measure an overall increase in mass of particles in the water column during dredging (TSS) when compared to upstream inputs. However, an increased net load of 2.2 kg of PCBs was transported downstream during the active dredging period. The majority of PCB mass excavated from the site (112 pounds) was successfully removed and contained within the treatment process, allowing only 2 percent of the PCB mass to escape the containment system.

Results of the Deposit N mass balance study concluded that surface water quality measures of turbidity or TSS were not accurate measures of PCB mass loading and transport. The Fox River Remediation Advisory Team recommended conducting a mass balance study (deposit mass balance, river transport, and process mass balance) for reliably measuring the transport effect of dredging operations.

Effectiveness

Effectiveness is described in terms of short-term effectiveness (ability to meet performance criteria) and long-term effectiveness (ability to achieve risk reduction). This evaluation of dredging effectiveness summarizes the finding of the *Sediment Technologies Memorandum* located in Appendix B. It also includes a brief summary of dredging, dewatering, and monitoring performance of the two pilot demonstration projects conducted on the Lower Fox River at Deposit N and SMU 56/57.

Ability to Meet Short-term Target Goals. Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 17 projects met their stated short-term project goals. The target goals were stated as sediment excavation to a chemical concentration, mass, horizon, elevation, or depth compliance criteria. In general, verification criteria that relied on physical features were generally assumed to remove the entire impacted sediment deposit based on site investigations. The two projects that did not meet their stated target goals were GM Foundry (cleanup criteria of 1 ppm PCBs), and Lower Fox River SMU 56/57 (cleanup to an elevation). One project, Manistique (cleanup criteria of 10 ppm PCBs) Harbor, has not been completed yet and therefore, results are undetermined.

Both the GM Foundry and Manistique projects made repeated dredging attempts to remove residual sediments resting on bedrock; however, confirmation samples were higher than the target goals for the maximum concentration detected. For the case of SMU 56/57, the contractor demobilized from the site before reaching the target elevation, thereby exposing the middle of the sediment deposit. This deficit was not a limitation of the dredging equipment; the equipment was capable of reaching the target elevation and removing the entire vertical profile of PCB mass. New contractors returned to the SMU 56/57 site in August 2000 under a different contract to remove the remaining PCB mass (see Appendix B).

Ability to Achieve Long-term Remedial Objectives. Achievement of long-term objectives are often measured as improved habitat quality, lower fish tissue concentrations, rescinded consumption advisories, and restoration of a site to beneficial use (e.g., parks, public areas). Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), five projects met their stated long-term project objectives of protecting human health and the environment. Three of these projects (Bayou Bonfouca, Black River, and Minamata Bay) removed the fish consumption advisories listed for the project area within 7 years following remediation. The other two projects (Collingwood Harbour and Sitcum Waterway) were delisted from regulatory status. For Waukegan Harbor, the fish tissue concentrations in carp fillets showed a downward trend from pre-dredge conditions and the fish consumption advisories have been rescinded; however, the data are considered inconclusive because of small sample sizes. The fish tissue concentrations for most of the other projects showed preliminary decreasing trends, but additional sampling over time is required to determine trends. In many cases, the monitoring plans were not well defined nor implemented in order to distinguish site trends, nor has enough time elapsed since implementation to account for fish depuration rates.

Application to the Lower Fox River. The two Lower Fox River environmental dredging demonstration projects conducted at Deposit N and SMU 56/57 between 1998 and 2000 provided valuable feedback on the feasibility of dredging and dewatering sediments from the Lower Fox River. A summary of the field activities and performance/construction specifications for Deposit N and SMU 56/57 are summarized in Tables 6-8 and 6-9, respectively, and briefly described below. Detailed descriptions of the project design, implementation, monitoring activities, and lessons learned are presented as case studies in Appendix B.

The Lower Fox River Deposit N pilot demonstration project met the expected goals designed for the project. Due to the presence of a hard bedrock substrate located beneath the soft sediments, the target goal of the demonstration project was to remove contaminated sediment down to a design depth of 7.5 to 15 cm (3 to 6 inches) above bedrock. Approximately 5,475 m^3 (7,160 cy) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (Foth and Van Dyke, 2000). Overall, 82 percent of the PCB mass was removed from Deposit N and approximately 31 kg (68 pounds) of PCB remained in the sediments that were not accessible to dredging activities (Foth and Van Dyke, 2000).

The PCB mass balance study conducted during dredging activities (Water Resources Institute, 2000) estimated that the resulting press cake material contained 96 percent of the PCBs removed from the deposit and that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river. The mass balance model did not measure an overall increase in mass of particles transported downstream during dredging (TSS); however, the PCBs transported on the particles did increase (increased net load of 2.2 kg PCBs during the active dredging period). Currently, there are no further plans for additional work at Deposit N, now referred to as the former Deposit N.

The Lower Fox River SMU 56/57 pilot demonstration project removed approximately 81,000 cy of dredged material to the target elevations and met the expected goals designed for the project after returning to the site in 2000. Approximately 31,000 cy of dredged material was removed from SMU 56/57 in 1999, leaving a large portion of the contaminated material behind before equipment was demobilized for the winter. Under an EPA Administrative Order by Consent (AOC No. V-W-00-C-596), the Fort James Corporation continued sediment remediation activities at SMU 56/57 during the summer of 2000. Additional contaminated sediment (50,000 cy) was removed in 2000 from subunits that were previously disturbed (dredged) during the 1999 pilot project.

In 1999, the target goal of the SMU 56/57 project was to dredge to a design elevation of 565 feet (MSL, National Geodetic Vertical Datum 1929 [NGVD29]). Dredging to this design elevation was expected to remove sediments with PCB concentrations greater than 1 ppm. Confirmation sampling was compared to 1 ppm PCBs. However, the target elevation was not achieved in any of the subunits within the dredge prism. Due to the difficulties encountered during dredging and the onset of winter, the expected elevation was raised 2 to 3 feet in most areas. A final "cleanup pass" initially intended for all areas was only completed in 4 of the 59 subareas (WDNR, 2000a). In these areas, the final PCB concentrations in the newly exposed surface sediments showed a general decline compared with pre-dredging concentrations, and in some locations the final PCB concentrations were as low as 0.25 ppm. However, in other areas where no final pass was completed down to the targeted sediment elevations, the final PCB concentrations were higher (32 to 280 ppm) than baseline surface concentrations

(2 to 5 ppm). In 1999, the post-dredge average residual PCB concentration was 7.5 ppm (40% reduction from 11.7 ppm average).

Lessons learned during the 1999 removal effort were successfully applied to the 2000 removal effort. For instance, equipment difficulties and large debris was encountered during 1999 dredging which hindered progress and production rates. The auger cutterhead dredge produced a sediment slurry with 4.5 percent solids; much lower than the design specifications. The dredge needed shorter cables, better positioning, and more overlapping transects to remove residual sediment ridges. During early stages of the project, coal ships docking at the Fort James facility disturbed the silt curtain, ripping it from its moorings on at least one occasion. Also, the liner of one of the two settling ponds was damaged during October 1999, requiring discontinued use of that pond until the liner could be repaired. Dredging was suspended on December 15, 1999, due to ice on the river and icing of the wastewater treatment system. In 2000, equipment was mobilized to the site 1 month earlier to lengthen the available dredging window before the onset of winter conditions. Land-based excavation equipment conducted a pre-removal of large boulders and debris before mobilization of the hydraulic dredge. The percent solids of the sediment dredge slurry averaged 8.4 percent, almost double the percent solids obtained during 1999. In 2000, a different silt curtain system was used and the passive dewatering equalization basins were eliminated and slurry was pumped directly to holding tanks.

In 2000, the Lower Fox River SMU 56/57 dredging project removed approximately 50,000 cy of sediment to the target elevation of 565 feet MSL. Post-verification surface sediment samples ranged from non-detect to 9.5 ppm (average 2.2 ppm) after one cleanup pass (target goal was less than 10 ppm). A 6-inch cap was placed over areas where surface sediment was above 1 ppm PCBs (no cap necessary if sediment was less than 1 ppm). More cleanup passes were not conducted because the contractor prioritized placement of the cap prior to onset of winter conditions.

Dredging Costs

As summarized in the *Sediment Technologies Memorandum* (Appendix B), dredging costs range from $6 to $500 per cubic yard. Costs are dependent upon understanding site conditions, extent of containment and monitoring, removal volumes, project expectations, and appropriateness of selected technologies. Total project costs including project planning, dredging, treatment, disposal, redevelopment (in some cases), and long-term monitoring can range from $0.6 million to $50 million. More detailed dredging and disposal costs are described in Appendix B.

Screening Decision

Dredging is retained as a removal technology for development of sediment cleanup alternatives (Table 6-4). Dredging has been successfully implemented in the Lower Fox River and elsewhere in the Great Lakes system as a tool for sediment remediation. Hydraulic dredging technologies (round cutterhead and horizontal auger) and process equipment may be effective methods for removing contaminated sediments from the Lower Fox River when properly designed, communicated, and implemented. Mechanical and hydraulic dredges are primary process options likely to be used in sediment removal operations; however, dry excavation may also be retained for shallow areas. Depending on site characteristics, both could be used at different locations within a single reach of the Lower Fox River or section of Green Bay.

6.4.6 *In-situ* Treatment

In-situ treatment of sediments refers to chemical, physical, or biological techniques for reducing COC concentrations while leaving the impacted sediment mass in place. *In-situ* technologies are commonly employed for cleanup of contaminated soil and groundwater. No successful adaptations of these and other technologies to full-scale sediment cleanup involving PCBs have been reported in the literature. Table 6-3 presents the results of feasibility screening for several potential *in-situ* treatment technologies. None are feasible for implementation in the Lower Fox River and Green Bay (Table 6-5).

6.4.7 *Ex-situ* Treatment

Ex-situ treatment refers to the processing of dredged sediments to transform or destroy COCs. Table 6-5 screens *ex-situ* treatment technologies based on implementability and effectiveness.

Description of *Ex-situ* Treatment Process Options

Treatment processes may be classified as biological, chemical, physical, or thermal. *Ex-situ* thermal treatment includes three subcategories: incineration, high-temperature thermal desorption (HTTD), and vitrification. All of these treatment technologies were retained for consideration in the initial FS screening process; however, only thermal treatment was retained for the final screening.

Biological. Biological treatment methods involve amendments of nutrients, enzymes, oxygen, or other additives to enhance and encourage biological breakdown of contaminants. Inorganics (metals) and PCBs are not well suited to biological treatment techniques. There are no proven and effective biological techniques for treating PCBs full scale and no reports in the literature of PCB-contaminated sediments biotreated *ex situ*. A pilot-scale biological treatment study was conducted on PCB-impacted sediments from the Sheboygan River, Wisconsin and the Hudson River, New York, but neither the aerobic nor anaerobic treatment had a significant effect (BBL, 1995).

Chemical. Chemical treatment methods involve the addition of acids/solvents to extract contaminants or oxidizing agents to encourage conversion to less hazardous compounds. Chemical methods for treating contaminated sediments show little promise. Acid extraction is ineffective for treatment of PCB-contaminated sediments. Solvent extraction is specific to soluble organics (e.g., PCBs) and some organic-complexed metals. Other inorganics remain in the sediments requiring some other form of treatment or disposal. Further, additional treatment is required for the concentrated extract. The literature provides no reports of chemical technologies implemented full-scale for the treatment of sediments.

Physical. Physical separation or soil washing refers to the process of classifying sediment into fractions according to particle size or density. Separation may be accomplished by screening, gravity settling, flotation, or hydraulic classification using devices such as hydrocyclones (USACE-DOER, 2000a). Equipment for physical separation is widely available, and the concept has been demonstrated for sediments in both the United States and Europe (USACE-DOER, 2000a); however, physical treatment methods have limited application for removing PCBs from contaminated sediments. Physical separation involving removal of the larger sand and gravel fraction from finer-grained sediment may or may not reduce the residual contaminated sediment mass and/or volume.

Physical treatment can also refer to the solidification/stabilization of dredged material to reduce the mobility of constituents through the use of immobilization additives. Many additives commercially available can immobilize both organic and inorganic constituents. Solidification reagents often include: Type I Portland cement, pozzolan, cement kiln dust, lime kiln dust, lime fines, and other proprietary agents. As described in the *Basis of Design Report for the Lower Fox River SMU 56/57 Project* (Montgomery-Watson, 1998), bench-scale solidification studies using Portland cement and lime dust were tested on dredged material from the Lower Fox River; the lime performed better. In bench-scale studies conducted on PCB-impacted sediments from the Sheboygan River (BBL, 1995), the Portland cement additive provided desirable physical characteristics (i.e., compressive strength) and leachability characteristics.

Thermal. Thermal treatment technologies desorb and subsequently destroy organic compounds by combustion. Thermal process options may be grouped into the categories of incineration, thermal desorption, and vitrification. The former two options are widely practiced technologies for treatment of soil containing PCBs and other organics. Vitrification was developed initially for use in treating radioactive mixed wastes and is receiving attention as a cost-competitive thermal option for treating soils and sediments high in sand content. Regardless of the specific technology option, thermal treatment requires that sediments first be dewatered to reduce water content and therefore the amount of heating energy required.

Incineration. Incineration temperatures are typically between 1,400 and 2,200 degrees Fahrenheit (˚F) which is sufficient to volatilize and combust organic chemicals. A common incinerator design is the rotary kiln equipped with an afterburner, a solids quench (to reduce the temperature of the treated material), and an air pollution control system. Incinerator off-gases require treatment to remove particulates and neutralize and remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Incineration facilities are generally fixed-based. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. Incineration of PAH-contaminated sediment was successfully conducted at the Bayou Bonfouca Superfund site, Louisiana, at a unit cost of $154 per cubic yard. Residual incinerator ash was placed in an on-site landfill.

High-temperature Thermal Desorption. High-temperature thermal desorption (HTTD) is a full-scale technology in which temperatures in the range of 600 to 1,200 ˚F volatilize organic chemicals. HTTD desorption efficiencies for removing PCBs from sediment range between 90 and 99 percent. A carrier gas or vacuum system transports volatilized water and organics to a condenser or a gas treatment system. After sediment desorption in the HTTD unit, volatilized organics are destroyed in an afterburner operating at approximately 2,000 ˚F. This treatment technique has been used successfully at several other sites with PCB contamination. HTTD systems can be both fixed-based and transportable and typically use a rotary kiln. HTTD is a commonly used technology for soils and is readily adapted to sediments. Capacities on the order of 100 tons per hour are available in transportable models.

An anaerobic thermal processor (ATP) extraction system operated by Soil Tech successfully treated PCB-contaminated sediment from the Waukegan Harbor site in Illinois. The ATP system treated sediments with greater than 500 ppm PCBs with an average PCB removal efficiency of 99.98 percent (Appendix B). Air emissions met the 99.9999 percent destruction removal efficiency (DRE) stack emission requirement for final destruction of PCBs.

Vitrification. Vitrification is a process in which high temperatures (2,500 to 3,000 °F) are used to destroy organic chemicals by melting the contaminated soil and sediments into a glass aggregate product. Vitrification units can be operated to achieve 99.9999 percent destruction and removal efficiency requirement for PCBs and dioxin. Trace metals are trapped within the leach-resistant inert glass matrix. Various types of vitrification units exist that utilize different techniques to melt the sediments, including electricity and natural gas, and are discussed in detail below. The following references and project summaries were used in this FS Report to assess the applicability of vitrification technology:

- *Decontamination and Beneficial Reuse of Dredged Estuarine Sediment: The Westinghouse Plasma Vitrification Process* (McLaughlin *et al.*, 1999);
- *Glass Aggregate Feasibility Study - Phase I and II* (Minergy Corporation, 1999);
- *Final Report: Sediment Melter Demonstration Project* (Minergy Corporation, 2002a); and
- *Unit Cost Study for Commercial-Scale Sediment Melter Facility, Supplement to Glass Aggregate Feasibility Study* (Minergy Corporation, 2002b).

Plasma Vitrification Process. This process involves superheating air by passing it through electrodes of the plasma torch. Partially screened and dewatered sediment is injected into the plume of the torch and heated rapidly. After dredging, sediment must be dewatered to approximately 50 percent solids. Additional drying is required to further reduce moisture. Rotary steam-tube dryers or other indirectly heated drying systems are used for this purpose. The high temperature combusts and destroys all the organic contaminants and the mineral phase melts into a glass matrix. Fluxing agents such as calcium carbonate, aluminum oxide, and silica oxide are blended with the sediment, as needed, to obtain the desired molten glass viscosity. The molten glass is quickly quenched, resulting in a product suitable for a wide variety of applications.

Glass Furnace Technology. This process uses a state-of-the-art oxy-fuel-fired glass furnace to vitrify sediment into an inert glass aggregate product. Sediment is dewatered and partially dried before being fed into the glass furnace. The high temperature melts the sediments resulting in a homogenous glassy liquid. Additives such as calcium carbonate, aluminum oxide, and silica oxide are added to obtain the desired viscosity of molten glass. The molten glass is collected and cooled quickly in a water quench to form glass aggregate product. The final glass product has a wide range of industrial applications.

During the comment period of the 2001 draft of the Lower Fox River RI/FS, WDNR completed a project to evaluate the feasibility of a vitrification technology, based on standard glass furnace technology, to treat contaminated river sediment. The sediments treatment demonstration project was completed in 2001 under the EPA's Superfund Innovative Technology Evaluation (SITE) program. A summary of the sediment melter demonstration project with performance and construction specifications is summarized in Table 6-11. Detailed descriptions of the treatment process, process design and construction, observations, and cost estimates are provided in Appendix G.

Screening Criteria for *Ex-situ* Treatment Selection

This screening evaluation focuses on thermal technologies, as neither biological nor chemical/physical treatments are feasible for application in the Lower Fox River and Green Bay.

Implementability

Chemical and biological treatment technologies have not been implemented nor proven successful for PCB sediment remediation. Physical separation may be feasible for sediment dredged from the Lower Fox River, but this technology has not been included in the alternatives analysis. Incineration, HTTD, and vitrification are viable thermal technologies for treatment of PCBs in dredged sediment. Incineration and HTTD are well-developed technologies and are commonly used for treatment of PCB-contaminated soil. Vitrification has not been used full scale for treatment of contaminated sediments. However, based on the multi-phased feasibility study conducted by WDNR in 2001, this technology appears to be a viable option for application to sediments in the Lower Fox River.

Many sediment remediation projects in Europe require physical separation of the sand/silt fractions to minimize the sediment volumes requiring disposal, due to limited disposal options. Sediment removal costs and implementability depends upon the contaminant of concern, grain size distribution, and amount of debris in the substrate matrix. Sand reclamation costs for operation of a small plant that handles 150,000 to 200,000 m^3 annually costs \$35 per m^3 of sediment treated (McLellan and Hopman, 2000). A successful sand reclamation project was implemented at the Port of Rotterdam, Netherlands site (McLellan and Hopman, 2000). Hydrocyclones and "sand peelers" separate sand from the fine fraction and reuse the sand for industrial purposes and preserving disposal capacity at a 100 million m^3 nearshore fill. Sand reclamation may be considered during the design phase of the Lower Fox River/Green Bay project, but is not considered in this FS. However, physical treatment expressed as sediment dewatering is required to prepare the sediment solids for treatment and disposal and therefore, is not discussed separately.

Thermal processes must meet TSCA testing and air performance requirements specified in CFR 40 Part 761.70(b) if sediment PCB concentrations exceed 50 ppm. The glass furnace vitrification process evaluated for Lower Fox River sediments requires construction of a new melter facility. The plant size is dependent on the amount of dredged and dewatered sediment available for processing. The sediments feed rate through the melter is limited by the capacity of the facility and moisture content of the sediments. Dewatered sediments need to be mixed with drier materials to achieve optimum moisture content of 37 percent to prevent agglomeration and facilitate easy material handling. The dryer must further reduce the sediment moisture content to 10 percent prior to processing in the melter (Minergy Corporation, 2002a).

Effectiveness

Thermal desorption systems generally perform at lower destruction/removal efficiency than incineration systems. Thermal desorption removal efficiencies are generally in the neighborhood of 90 to 99 percent (Garbaciak and Miller, 1995). As stated earlier, biological and chemical treatment are likely to have little effect on site sediments. Physical treatment can effectively remove coarse-fractioned solids from dredged material and provide adequate physical characteristics needed for disposal.

River sediments processed during Phase III of the WDNR glass furnace demonstration project conducted in 2001 achieved a PCB destruction of greater than 99.99993 percent. The glass aggregate was subjected to both ASTM water leaching procedures and SPLP testing. The ASTM water leaching procedures and SPLP test did not detect any PCB congeners, SVOCs, or any of the eight heavy metals. Dioxins and furans were not generated during the sediment treatment process. The end product created by the treatment process was very consistent, producing a hard, dark granular material. The resulting glass aggregate has a wide range of industrial applications including roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan, and construction fill (Minergy Corporation, 2002a).

Treatment Costs

Exclusive of material preparation costs (e.g., dewatering), thermal treatment unit costs can range from $25 to $1,000 per ton (EPA, 1994a). Depending on the size of vitrification unit, unit costs range between $27 and $57 per ton (Minergy Corporation, 2002b). Detailed cost breakdowns and analysis are provided in the *Unit Cost Study for Commercial-Scale Sediment Melter Facility* provided in Appendix G.

Screening Decision

No biological or chemical treatment technologies are retained for development of remedial alternatives in Section 7. All three thermal technologies (incineration, vitrification, and HTTD) are implementable and effective for treatment of PCBs in sediments. Physical treatment is retained as a dewatering process option (ancillary technology).

6.4.8 Disposal Process Options

Disposal is the relocation and placement of removed sediments into a site, structure, or facility (e.g., landfill). Disposal is the most frequent endpoint for sediments in remediation projects that involve removal. PCB-contaminated sediment removed from the Lower Fox River can be disposed of at a number of upland disposal facilities, and depending upon the PCB concentration, in "in-water" contained aquatic disposal (CAD), or level-bottom caps.

Description of Disposal Process Options

Four general disposal options exist for the disposal of PCB-impacted sediments removed from the Lower Fox River. These are:

- Level-bottom cap;
- Confined aquatic disposal (CAD);
- Existing landfill (in- or out-of-state), construction of new, dedicated landfill; and
- Confined disposal facility (CDF).

Level-bottom Cap. Level-bottom capping involves the mounding of contaminated sediment in an area of a water body that has a relatively flat bottom. Capping material is then placed on top of the mounded sediments. The cap must be designed to prevent scour and erosion. Level-bottom caps have typically been constructed in large water bodies such as oceans or lakes. Applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods.

Confined Aquatic Disposal. Confined aquatic disposal (CAD) is similar to level-bottom capping, with the exception that the contaminated sediments have lateral sidewall containment from an engineered berm or as a result of excavating a depression at the disposal site (Figure 6-7). As with level-bottom capping, the cap must be designed to prevent scour, erosion, and bioturbation. CAD applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods. Thus, construction of a CAD facility is likely restricted to Green Bay.

The deposit site is prepared either by excavating a depression and using the excavated material for construction of a perimeter berm, or by importing material to construct a perimeter berm on the existing sediment surface. The contaminated sediment is deposited at the specified location and topped with clean sediments.

Existing or Proposed In-state Landfills. A landfill is an engineered facility that provides long-term isolation and disposal of waste material, thereby minimizing the potential for release of contaminants to the environment. Landfills are designed to prevent the release of contaminants to groundwater, control runoff to surface water, and limit dispersion into the air.

Landfills in Wisconsin must meet location, hydrogeologic evaluation, and groundwater performance standards (NR 500 WAC). Landfill design requirements in Wisconsin also include: 1) a cover system, 2) a liner system, 3) a leachate collection and treatment system, 4) a water monitoring system, and 5) a gas monitoring system. Landfills cannot accept wastes containing free liquids and sediments must first be dewatered or stabilized before disposal. A total of 13 existing landfills are located within a 40-mile radius of Green Bay, Wisconsin (Figure 6-8).

Construction of New, Dedicated Landfill. Contaminated sediment may also be placed within dedicated cells, or monofills, located within landfills. The monofill provides additional assurances that the contaminated sediment will not mix with other solid waste, and provides for more stable long-term control of the material.

Confined Disposal Facility. A confined disposal facility (CDF) is an engineered containment structure that provides for dewatering and permanent storage of dredged sediments. In essence, CDFs feature both solids separation and landfill capabilities (EPA, 1994a). Containment of contaminated sediments in CDFs is generally viewed as a cost-effective remedial option at Superfund sites (EPA, 1996b). Recent interest in CDFs for disposal of contaminated dredged sediment has led both the USACE and the EPA to develop detailed guidance documents for construction and management. These include:

- *Engineering and Design - Confined Disposal of Dredged Material* (USACE, 1987);

- *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);

- *Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience* (USACE-DOER, 2000b);

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (EPA, 1994a);

- *Verification of Procedures for Designing Dredged Material Containment Areas for Solids Retention* (Averett *et al.*, 1988); and

- *Comprehensive Analysis of Migration Pathways (CAMP): Contaminant Migration Pathways at Confined Dredged Material Disposal Facilities* (Brannon *et al.*, 1990).

A CDF may be constructed as an upland or floodplain site, as a nearshore site (one or more sides exposed to water), or as an in-water island containment area. For the purposes of this FS, only the in-water, nearshore and floodplain CDFs are considered. There are approximately 50 completed CDFs in the Great Lakes region. These facilities were constructed primarily for dredged material from navigation projects. Most of the CDFs are in-water lakefills that were constructed using stone retention dikes and simple water return systems. The remainder are upland facilities constructed with earthen dikes, or placed within existing or excavated depressions. Nearshore CDFs have been successfully completed at the Waukegan Harbor, Illinois and Sitcum Waterway, Washington sites for contaminated sediments (Appendix B).

There are two types of designs that are used in the construction of a CDF: solids retention and hydraulic isolation. Solids retention designs for CDFs physically isolate the sediment solids from the environment. Solids retention designs are used when the contaminants in the sediment are tightly bound to the retained solids and are not likely to leach and contaminate the surface or groundwater. Designs for these types of CDFs need only consider retention dikes or configurations such as geosynthetic liners placed between the inner wall of the retention dike and the dredged material. The design of in-water CDFs must consider a final construction height of at least 6 feet above the normal river level (the 100-year flood level) in order to maintain the surface above maximum expected flood height. External dike construction would need to consider the potential for flood- or ice-induced damage. Water treatment consists of settling out the particulates prior to discharge. An example of an in-water CDF is illustrated on Figures 6-9 and 6-10.

In contrast, hydraulic isolation designs isolate the solids and capture the associated water from the contaminated solids. Design of these facilities are similar to those for NR 500 WAC landfills and often employ extensive water recovery and treatment operations. For costing purposes in the FS, we have assumed a 6-foot berm level for all remediation areas, which is the approximate elevation gain increase in lower Green Bay for the 100-year flood event.

Regulatory Considerations

Open-water Disposal. Open-water disposal of contaminated sediments is banned in the waters of Wisconsin (Appendix C). The ban exists in Wisconsin Statutes Chapter 30.12(1)(a). There are, however, certain exceptions to the open-water disposal prohibition. The exceptions include: 1) legislative authorization, 2) lakebed grants, 3) bulkhead lines, and 4) leases. Obtaining any of these exceptions for disposal of dredged material into navigable water may be utilized for remediation of the Lower Fox River (Lynch, 1998), but each could require substantial time to obtain. To obtain an exemption, the activity must still meet the conditions and limitations of the state's responsibilities for protection of water quality and other related issues. This ban applies to level-bottom capping and construction of a CAD or CDF site. Thus, special approval by the state legislature addressing provisions of this ban would be required to implement open-water remedies. This option, by use of a lakebed grant, could be applied to a CDF where the title of a lakebed or bed of a waterway would be transferred from the state to a municipality.

Placement in an Upland Landfill. Dredged sediment is classified as solid waste in Wisconsin (Lynch, 1997, 1998). This determination has been made through statute and case law. Wisconsin Statute Chapter 289 and NR 500 through 520 of the WAC provide most of the regulatory framework for handling and disposing of solid waste, and therefore, dredged contaminated sediments. Additionally, in a January 24, 1995 agreement, the EPA gave WDNR the authority to manage the disposal of sediment contaminated with PCBs in concentrations of 50 ppm or greater in NR 500 WAC-approved landfills. Sediments containing PCBs of 50 ppm or greater may be disposed in an NR 500 WAC-approved landfill with EPA concurrence. A copy of the agreement (EPA, 1995b) is included in Appendix C. The agreement also allows WDNR to "select disposal facilities that comply with NR 500 through 520 WAC for the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater from sediment remediation projects conducted under the authority and supervision of the WDNR" (EPA, 1995b). Any landfill approved for disposal of contaminated sediment must meet the stringent state requirements for the design, operation, and maintenance of a Subtitle D landfill. In other words, TSCA approval issued from EPA Region 5 is only applicable to landfills that go through the landfill siting and licensing process.

WDNR has the authority to issue exemptions from regulation under Wisconsin Statutes Chapter 289, under some circumstances. The primary exemptions which cover dredged material exist in WAC NR 500.08(3) (Beneficial Reuse). The exemptions may not apply to sediment from the Lower Fox River and Green Bay (Lynch, 1998) because of the large volumes of sediment and the concentrations of PCBs within the sediments.

Other exemptions from solid waste regulations for dredged material are found in the Wisconsin Statutes Chapter 289.43(8), and related NR 500 WAC state codes. The exemption is known as the "Low Hazard Exemption." The Low Hazard Exemption allows exemptions from landfill siting roles and state statutes for either beneficial reuse or disposal. This exemption has been used in the past for nonhazardous dredged material (below TSCA levels *in situ*) generated from the Lower Fox River. The low-hazard waste grant of exemption is a possibility for at least some of the dredged material in the Lower Fox River, either for beneficial reuse or disposal.

New, Dedicated Upland Landfill. Construction of a new publically-owned, upland landfill dedicated to the disposal of sediments is a potential option. A dedicated and centrally-located facility would allow reasonable access from all areas of the river. The total capacity required may be up to 5,000,000 cy for the De Pere to Green Bay Reach. Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. It is important to note that the process of gaining approval for the location of a new landfill (the siting process, as detailed in Wisconsin Statutes Chapter 289) is lengthy and may take many months or years to complete (Huebner, 1996).

A new landfill dedicated to disposal of dredged material (and would not be used for municipal solid wastes) may be exempt from the free liquids and shear strength requirements of solid waste landfills. If the site is designed to accommodate the properties of dredged material (e.g., leachate collection system), then many of the physical requirements of the material may not apply.

Confined Disposal Facility. CDFs are disposal facilities located within a floodplain or a waterway and cannot be permitted through the landfill siting process. The mechanisms are available to permit this disposal option if there is a strong rationale to do so. One limitation to this option is the potential long period of time required to obtain the appropriate permits. Wisconsin has banned open-water disposal of dredged material on the bed of all navigable waters for more than 25 years.

In addition to the Wisconsin Statute Chapter 30 ban, NR 504 WAC provides for certain setback requirements when siting disposal facilities. Disposal facilities are required to be set back certain distances from water ways and floodplains. The WDNR has the authority to waive this requirement under Wisconsin Statute Chapter 289.

Floodplain and in-water CDFs can only be designed for nonhazardous solid waste and dredged material generated from non-TSCA-level sediments. In-water CDFs are unlikely to be permitted for sediment with PCB concentrations exceeding the TSCA limit of 50 ppm. As described previously for capping, EPA has not, to date, permitted any permanent in-water containment facilities.

CERCLA Exemptions. CERCLA exempts permitting requirements for "on-site" disposal facilities if the EPA is conducting the remediation, or has issued an order or signed a consent decree with the principal responsible parties (PRPs). The exemption does not apply if the State of Wisconsin conducts the work or issues the order or consent decree. For remediation of the Lower Fox River and Green Bay, WDNR's position is that disposal units adjacent to the river or in water could be considered "on-site." Additionally, WDNR does not believe that locational criteria ARARs for on-site disposal units could be exempted or waived even under an EPA-led CERCLA action (Lynch, 1998).

Screening Criteria for Disposal Selection

The criteria used for selection of a disposal alternative are primarily based on location, capacity, access, and long-term stability. Off-site disposal is considered potentially feasible for all river reach and bay alternatives requiring disposal. Final selection of disposal options will depend upon several criteria (EPA, 1994a):

- Location,
- Upland land use,
- Fill capacity,
- Length and quality of haul route,
- Site setting and design,
- Residential impacts,
- Multiple disposal locations,
- Regulatory considerations,
- Contaminant concentration, and
- Flood and erosion control.

Implementability

Level-bottom Cap. From a technical standpoint, a level-bottom cap is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion.

The effectiveness of level-bottom capping is similar to that of other capping approaches (Section 6.4.4). As long as the design criteria are met, a level-bottom cap contains the contaminated sediments and prevents exposure to humans and aquatic organisms.

Confined Aquatic Disposal. From a technical standpoint, a CAD is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion. The short-term impacts of contaminant loss to the water column during placement of the dredged sediments must be considered. Several placement equipment options along with use of engineering controls during placement can reduce losses. Results of empirical tests and computer modeling allows for prediction of contaminant losses during placement and aids in selection of the placement technique.

Monitoring and maintenance (if required) are essential components of a CAD project. Monitoring determines the extent to which CAD performance is matching design expectation in terms of preventing contaminant exposures.

Landfill. There are no technical obstacles related to the disposal of dredged sediments in landfills. With the exception of dewatering to an acceptable moisture content, sediment must merely meet the applicable acceptance criteria of the landfill.

If the dredge slurry is pumped directly to a disposal site located a few miles away from the dredge area (i.e., greater than 5 miles), then a detailed engineering design evaluation would be required to successfully pump the slurry large distances. Long slurry pipe runs are technically feasible as demonstrated in White Rock Lake, Dallas, Texas. A 20-mile-long steel, 24-inch-diameter dredge slurry pipe run extended from the dredge area in White Rock Lake through residential and commercial areas directly to a former sand and gravel quarry disposal site (Sosnin, 1998).

Confined Disposal Facility. CDFs are implementable from an engineering standpoint. As long as site conditions, placement constraints, and regulatory criteria are satisfied, construction and placement in a CDF is a reasonable disposal option for both the river and bay. A CDF could be technically designed to adequately isolate contaminated sediments over the long term.

Effectiveness

Disposal at a single location presents a long-term liability at a single facility. Disposal of the sediments at multiple locations may incrementally increase the overall long-term liability of the sediments. By disposing at numerous facilities, there is potential long-term liability associated with the waste disposed at each facility.

Level-bottom Caps. The most notable use of level-bottom capping techniques is the open-water multi-user New York Mud Dump Disposal Site operated through the Disposal Area Monitoring System (DAMOS) Program. This program uses level-bottom cap placement and containment technology to confine low- to moderately-contaminated sediments. This site is regularly monitored to ensure compliance within the confines of the program (USACE, 1995).

Confined Aquatic Disposal. The long-term effectiveness of a CAD is similar to that of other capping approaches (Section 6.4.4). The primary criteria for success is that the cap thickness required to isolate contaminated material from the environment be placed correctly and maintained. CAD experience demonstrates that proper site selection, design, and construction can eliminate resuspension due to bioturbation and erosion. Further chemical diffusion of contaminants through a properly designed cap is negligible and does not present a long-term risk to the environment.

Landfills. Table 6-10 lists municipal and non-municipal landfills located within the Lower Fox River valley and provides information about existing and proposed capacities. Information in the table was derived from WDNR records (WDNR, 1998). Approximately 14 existing and proposed municipal and non-municipal landfills exist within 40 miles of the Lower Fox River. Capacities for all the landfills were not available. Figure 6-8 shows the general location of these landfills.

Waste disposal capacity of landfills located within 40 miles of the river is in excess of 30 million cubic yards. Although several municipalities banned disposal of contaminated sediment in landfills in the past, most local governments have either removed the bans or are in the process of removing the bans, opening the way to additional landfill capacity in the Lower Fox River valley.

Disposal at out-of-state landfills may be an option if in-state disposal facilities have insufficient capacity or cannot be used for other reasons (e.g., permit restrictions). Other disposal locations may become available in the future. Adequate space will most likely exist in municipal and non-municipal landfills within 40 miles of the Lower Fox River to accept all sediments removed from the river, if this option is selected.

Preliminary engineering work has been completed for at least one landfill facility capable of accepting contaminated sediment from the Lower Fox River. The planned facility is located within 20 miles of the Lower Fox River in rural Brown County. The quantity of impacted sediment is compared to typical one-time solid waste disposal projects. The current capacity of landfills will determine the amount of sediment that can be disposed of at any landfill.

Confined Disposal Facility. As previously discussed, several CDFs have been constructed for disposal of contaminated sediments and considerable support is available in the literature for design and construction. Over 10 nearshore CDFs have been placed in Puget Sound (West Eagle Harbor, Washington; Sitcum/Milwaukee Waterway, Washington), the Great Lakes region (Calumet Harbor, Chicago; Waukegan Harbor, Illinois), and east coast (New Bedford Harbor, Massachusetts) combined (USACE-DOER, 2000b). Several isolated in-water cells have been placed in Europe and the United States.

Siting, acceptance by the public and regulatory communities, as well as permitting are central to the implementability of this disposal option. In-water CDFs would be limited to areas of the Lower Fox River that are relatively wide with general construction access. Likewise, floodplain CDFs would be limited to large near-river locations that could be permitted for landfill use. In-water CDFs would need to consider site access and potential losses of lake frontage to upland riparian landowners. Other potential uses of the Lower Fox River by upland owners, such as intake or permitted wastewater discharge pipes, and electrical or other cable crossing, must be considered in locating an in-water CDF.

Due to its size, large areas of Green Bay are suitable for siting a CDF.

Floodplain and in-water CDFs would need to meet the substantive requirements for landfills defined in NR 500 WAC. While PCBs alone might be considered particulate-bound contaminants and a simple solids retention design might be suitable, dredged sediments in the Lower Fox River and Green Bay will also contain quantities of other metals, pesticides, and semivolatile organic compounds (i.e., polyaromatic hydrocarbons) that may require some consideration of hydraulic control (i.e., collection of internal leachate; physical isolation).

Disposal of contaminated sediments in CDFs is an effective means of isolating COCs from the surrounding environment. As with other disposal options, CDFs prevent exposure of humans and aquatic organisms to the contaminants.

Migration of COCs out of a CDF over the long term is precluded through design features and the fact that the PCBs are strongly sorbed to the sediment particles.

Disposal Costs

Level-bottom capping and CAD sites are generally lower in cost than other engineered disposal options such as confined disposal facilities. Level-bottom capping is the lowest-cost disposal option for contaminated sediments as the material is merely deposited in a mound at a specific location and topped with clean sediments. Disposal costs for construction and filling of a CDF is expected to be comparable to landfill disposal (which includes transport). Landfill disposal costs typically range from $25 to $50 per ton exclusive of transportation. Disposal at out-of-state landfills would generally be more costly than disposal at existing local or regional in-state landfills or new dedicated landfills because of increased transportation costs.

Estimated costs to acquire and build the approximately 4 million-cubic-yard landfill currently planned in rural Brown County to accept contaminated sediment is $14 million plus a local siting fee of $5 per ton. Operating costs of the landfill were estimated at $500,000 per year for 10 years. Landfill closure was assumed to consist of a typical cap at $100,000 per acre. Post-closure O&M costs are estimated to be $30,000 per year for 40 years.

Screening Decision

Level-bottom capping and confined aquatic disposal are viable technologies for disposal of contaminated sediments in Green Bay as long as the statutory restrictions on open-water disposal can be accommodated. Dredged material located in an upland landfill could be subsequently removed for treatment, if desired, and would be more accessible for removal than in-water disposal options. CDFs are appropriate for consideration as a disposal option for dredged sediments of the Lower Fox River and Green Bay as long as the statutory restrictions for nearshore disposal can be accommodated. The disposal of contaminated sediments in landfills is considered an effective and implementable option for purposes of developing cleanup options for the Lower Fox River and Green Bay. However, under CERCLA, landfill disposal in addition to other disposal options mentioned above is not a preferred option primarily because the contaminated materials are merely relocated and the COCs are not destroyed.

6.5 Identification of Ancillary Technologies

Additional technologies and process options that are ancillary to the retained process options presented in Section 6.3 may be incorporated in the remedial alternatives. Incorporation of these technologies and process options is dependent on the process options chosen for a particular remedial alternative. For example, if removal and disposal in an off-site landfill is established as a remedial alternative, dewatering prior to transport of materials off site and subsequent treatment of the water generated in the process will take place.

Potential ancillary technologies and process options are not subject to the same screening process described in Section 6.2. However, they are presented here as considerations for the development of remedial alternatives provided in the following sections of this FS Report. A description of ancillary technologies that are a part of certain remedial alternatives are described in following subsections and include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

6.5.1 Dewatering

Dewatering involves the removal of water from dredged sediment to produce a material more amenable to handling with general construction equipment and that meets landfill disposal criteria (e.g., paint filter test and compaction specifications). Selection of an appropriate dewatering technology depends on the physical characteristics of the material being dredged, the dredging method, and the target moisture level of the dewatered material. Dewatering technologies can be grouped into the following three categories:

- Mechanical dewatering,
- Passive dewatering, and
- Solidification.

Description of Dewatering Process Options

After removal, the dredged solids typically have moisture contents that must be reduced for effective treatment. Mechanically-dredged sediments typically have a solids content of approximately 50 percent by weight. Hydraulically-dredged sediments are in a slurry with a solids content typically in the range of 6 to 10 percent, with a maximum range of 10 to 12 percent (EPA, 1994a). Dewatering these sediments requires management of the contaminated water, which has direct cost implications.

Mechanical Dewatering. Mechanical dewatering equipment physically forces water out of sediment. Four techniques are typically considered for dewatering dredged sediments: centrifugation, diaphragm filter presses, belt presses, and hydrocyclones.

Centrifugation uses centrifugal force to separate liquids from solids. Water and solids are separated based upon density differences. The use of a cloth filter or the addition of flocculent chemicals assists in the separation of fine particles. Typical production rates of a single centrifuge vary from 20 to 500 gallons per minute (gpm). Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, production rates vary from approximately 1 to 21 cy/hr. Centrifuges are suitable for areas along the Lower Fox River where larger dewatering systems (operations) are impractical. The process works well with oily sediments and can be used to thicken or dewater dredge slurries.

Hydrocyclones are continuously-operated devices that use centrifugal force to accelerate the settling rate of particles within water. Hydrocyclones are cone shaped. Slurries enter near the top and spin downward toward the point of the cone. The particles settle out through a drain in the bottom of the cone, while the effluent water exits through a pipe exiting the top of the cone. The production rate and minimum particle size separated are both dependent upon the diameter of the hydrocyclone. Generally, a wider hydrocyclone has a greater production rate, whereas narrower hydrocyclones are better at separating out smaller particles, albeit at lower throughput rates. The production rate of a single unit varies from 50 to 3,500 gpm, depending on equipment diameter. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 2 to 150 cy/hr. Two hydrocyclones were used during the Deposit N demonstration project to remove +200 sieve material after removal of gravel-sized stones and debris.

Diaphragm filter presses are filter presses with an inflatable diaphragm, which adds an additional force to the filter cake prior to removal of the dewatered sediments from the filter. Filter presses operate as a series of vertical filters that filter the sediments from the dredge slurry as the slurry is pumped past the filters. Once the filter's surface is covered by sediments, the flow of the slurry is stopped and the caked sediments are removed from the filter. Filter presses are available in portable units similar to the centrifuge units. Although very costly and labor intensive, production rates for a single unit vary from 1,200 to 6,000 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 50 to 250 cy/hr.

Belt presses use porous belts to compress sediments. Slurries are sandwiched between the belts, resulting in high-pressure compression and shear which promotes the separation. Flocculents are often used to assist the removal of water from the sediments. The overall dewatering process usually involves gravity-draining free water, low-pressure compression, and finally high-pressure compression. Belt presses can be fixed-based or transportable. They are commonly used in sludge management operations at municipal and industrial wastewater treatment plants throughout the Lower Fox River valley.

Belt press efficiencies are dependent upon belt speeds, tension, material composition, feed concentrations, and flocculent dosing. Typical production rates of a single unit vary from 40 to 100 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the typical production rate varies from approximately 2 to 4 cy/hr. A type of belt press, called the recessed chamber filter press, was used for dewatering hydraulically-dredged sediments from Deposit N. The press was used after a gravity-settling stage and polymer conditioning to enhance filter performance. The filter cake produced was sufficiently dewatered for transport and disposal off site.

Passive Dewatering. Passive dewatering refers to gravity settling of solids. Passive dewatering can occur on sediment barges, within CDFs, and in specially built lagoons or ponds. The process requires sufficient retention time to allow sediment particles to settle, after which the clarified water may be discharged (or treated and then discharged depending on composition and discharge limitations). Passive dewatering is used for mechanical dredging of the Green Bay navigation channel by the Green Bay Port Authority. Passive dewatering was considered feasible for the SMU 56/57 demonstration project (Montgomery-Watson, 1998).

On-barge dewatering is typically used in conjunction with mechanical dredging. Sediment is deposited inside the dredge-barge and water is allowed to drain by gravity. Typical dredge-barges are equipped with side drains which allow the water to flow from the barge into the water body. Dredge-barges may also be configured with a floor that slopes to a collection sump for collection and treatment of the water before discharge to the water body.

Dewatering in large upland ponds is typically used in conjunction with hydraulic dredging. The dredged sediments are pumped to the pond and allowed to settle. Clarified water is decanted and thickened sediment is removed once the pond fills to a level that reduces settling performance. The addition of baffles to the settling pond increases the effective holding time and separation. Figure 6-6 illustrates the layout of a 4-acre dewatering pond. This type of facility is currently used at Bayport to manage sediments dredged from the Green Bay navigation channel.

An in-river passive dewatering facility may also be considered in the design phase, particularly for the De Pere to Green Bay Reach or Little Lake Butte des Morts. An in-water facility could be constructed using sheet piling and likely requiring about 20 acres of river bottom. Dredge slurry would be pumped into a two-cell (or more) facility, dewatered, then dry excavated with earthmoving equipment. An underlying clay layer or bedrock would be a natural effective liner and would not entail additional construction costs or maintenance. An in-water facility would eliminate the need and cost of locating an upland area.

If temporary passive dewatering ponds are used, the performance requirements of Chapter NR 213 ("Lining of Industrial Lagoons and Design of Storage Structures") may apply. Alternatively, if WDNR decides to regulate passive dewatering ponds as a "solid waste processing facility," the requirements of the NR 500 series of rules may apply.

Solidification. Solidification involves mixing a chemical agent with dredged sediments to absorb moisture. Portland cement, pozzolan fly ash, fly ash/Portland cement mixtures, and lime kiln dust are common additives. The chemical agent and sediments may be mixed in a pug mill or in a contained area (e.g., a roll-off box or pit) using an excavator, depending upon sediment production rates and work space areas. Solidification is commonly used for sediments that have been partially dewatered by another means. Mechanically-dredged sediments can sometimes be solidified directly. Solidification is not a practical method for dewatering hydraulically-dredged sediments in the absence of thickening the solids by some other means, as the amount of chemical agent required becomes cost prohibitive. For the purposes of this FS, it was assumed that passively dewatered sediment would require solidification with 10 percent (w/w) lime, based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998).

Screening Criteria for Dewatering

The principal criteria used to screen dewatering methods are the type of removal options selected for a given river reach and available land for construction and operation of a passive dewatering facility.

- **Hydraulic Dredging.** *A passive dewatering facility is selected for all hydraulic dredging options where there are greater than 10 to 15 acres of land available for construction and operation of the settling ponds.* At least one alternative will include mechanical dewatering to provide a comparison in costs.

- **Mechanical Dredging.** Passive on-barge dewatering is selected for all mechanical dredging options.

Additional operating parameters and constraints which must be considered in selecting the appropriate dewatering technique for the Lower Fox River include:

- **Production Rate.** The selected dewatering technique should produce dewatered sediments at a rate equivalent to the sediment removal rate. This allows sediment to be removed by the dredges without concern for sediment storage prior to dewatering.

- **Effectiveness.** The selected dewatering technique must be capable of consistently meeting specific the requirements for disposal. This requirement is at least 50 percent solids without the addition of any solidification agents.

- **Dewatering Barge Availability.** Dredge-barges with onboard water collection sumps are not locally available. Such a barge may need to be constructed locally.

- **Siting.** Placing a dewatering pond a significant distance from the river may be impractical from a material handling standpoint. It may also be impractical to remove a large wooded area to install a dewatering pond.

- **Discharge Water Quality.** All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a publicly-owned treatment works (POTW) or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

Screening Evaluation for Dewatering

Implementability. All three dewatering technologies discussed above are implementable for cleanup of sediments in the Lower Fox River and Green Bay. Space availability for settling basins along the Lower Fox River and Green Bay will be a key implementability consideration in the development and evaluation of remedial alternatives (Section 7).

Dredge-barges with onboard water collection sumps are not locally available and therefore may need to be constructed locally.

In all cases, the dewatering operation must be sized so that the production rate is compatible with the sediment removal (dredging) rate.

Effectiveness. The water removal technologies discussed here are commonly practiced and effective methods for dewatering sediments. For treatment or disposal, dewatering must be capable of generating a material of at least 50 percent solids without the addition of any solidification agents.

All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a POTW or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

Dewatering Costs

Dewatering costs depend upon the size of the pond, time allowed to settle, physical properties of the material, and disposal requirements. For the Fox River project, passive dewatering costs are relatively low compared to moderately-priced mechanical dewatering options. However, the costs for dewatering are usually inversely proportional to disposal costs.

Screening Decision

In this FS, passive dewatering in settling basins is assumed for dewatering hydraulically-dredged sediments. This dewatering method requires adequate upland or nearshore space (e.g., greater than 10 to 15 acres) for construction and operation of the settling basins. Passive on-barge dewatering is assumed for mechanical dredging options. Solidification may be useful during some elements of sediment remediation in the Lower Fox River and Green Bay, but is not central to the development of remedial alternatives in Section 7.

For the purposes of this FS, it was assumed that passive dewatering would occur in bermed areas lined with asphalt pavement to allow access by heavy equipment. Due to space limitations and a desire to maximize the settling time, the design storage depth is 8 feet, thereby limiting the land needed to approximately 10 acres for the Little Lake Butte des Morts and Appleton to Little Rapids reaches and 15 acres for the Little Rapids to De Pere Reach. It was further assumed that the dewatered solids content would be 35 percent after dewatering for a period of 3 to 6 months based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998). In order for the dewatered sediment to be handled and disposed, it was assumed that solidification using 10 percent lime was also necessary.

6.5.2 Wastewater Treatment

Water from the dredged sediment dewatering operation must be treated to meet effluent water quality criteria for discharge to the receiving system. The receiving system may be a permitted discharge to the river or bay, a POTW, or an industrial wastewater facility. Water quality may be adversely impacted in and around dredging operations through resuspension and dispersion of contaminated sediments. Therefore, controls on suspended solids are an important consideration in the development of remedial alternatives involving sediment removal. These were discussed with respect to the effectiveness of dredging (Section 6.4.2). Water quality is also an issue in dewatering operations where produced water may require treatment to meet discharge standards.

Water Treatment

Mechanical Dredge Water Treatment. Free water derived from mechanical dredging is principally within the transfer barges, or at the consolidation (stockpile) facility. Dredged sediment transfer barges are left idle before off-loading to allow for collection of free water at the surface of the load by sediment self-consolidation. The free water can then be decanted and pumped ashore to a water treatment system, if necessary, before unloading the dredged material. An onshore water treatment system may consist of one or several Baker tanks for primary sedimentation of solids, coagulant-aided secondary flocculent settling of remaining suspended solids, and filtration (i.e., sand, mixed media, activated carbon), if needed, to meet water quality requirements.

Shoreside stockpile areas can be graded, bermed, and lined to contain and collect sediment drainage and rainfall runoff. Once sufficiently dewatered, stockpiled material may be treated on site, or loaded onto trucks or rail cars for transport to the treatment or disposal facility.

Water treatment may be required to meet water quality requirements for discharge back to the river. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal. The disposal cell could be designed with a compartment for quiescent settling with or without coagulant addition. Free water present at the surface of the haul barge would be pumped ashore to the disposal cell/water treatment system before off-loading in order to minimize tendency for washout/spillage during the off-load swing. More involved treatment, depending on discharge criteria, could involve the use of standard process options such as:

- Coagulation, flocculation, and settling;
- Filtration (i.e., sand, mixed media);

- Adsorption using granular activated carbon; and
- Ozone, UV/ozone, or UV/peroxide oxidation.

Alternatively, gravity-separated water could be directly discharged to a POTW. The discharge of water to a POTW depends on meeting certain discharge criteria as set by the municipality. In the past, WDNR has authorized a minimum dilution zone for dredge water return flow. For the purposes of this FS Report, it is assumed that acute water quality criteria must be met at the point of discharge and a mixing zone or zone of initial dilution is allowed to satisfy chronic criteria.

Hydraulic Dredge Water Treatment. Hydraulic dredging results in a large volume of sediment-water slurry to be managed. Flow rates in small dredges can range from as little as 900 gpm (80 cy/hr) for a 6-inch dredge, to more than 4,000 gpm (354 cy/hr) for a 14-inch dredge. Hydraulic dredging rates in contaminated sediment removal are frequently limited by the capacity and treatment rates of the water quality system.

Conventional separation of solids from the dredged slurry occurs by gravity sedimentation in a suitably-sized, quiescent retention pond. The return flow is decanted over a weir to skim the clarified water from the surface in order to meet water quality requirements before discharge.

Other means of solids removal for hydraulic dredging have been tested (EPA, 1994a; SEDTEC, 1997). In 1995 through 1996, approximately 100,000 cy of hydraulically-dredged contaminated sediment was dewatered by adding a coagulant aid to the slurry stream and routing the flow through a set of two clarifiers for thickening and then through belt presses for landfilling (Ohio River Dredge and Dock, Inc.). A proprietary process (Solomon Venture, Lakewood, Colorado) reports success in using a system of screens and grids to remove particles down to 1-micron size at dredge flows of 1,200 gpm. An emerging solids separation technology uses geomembrane tubes designed to pass water, but not selected sediment sizes. Sandy sediments have been pumped into such tubes for separation of solids. However, the membranes may be subject to blinding (plugging) for high concentrations of fine-grained materials.

Given the physical limitations on ponding cell sizes, it is likely that the hydraulic dredge used for the Lower Fox River in Little Lake Butte des Morts and between Little Rapids and De Pere would be limited to the small dredge sizes: 6 to 10 inches.

Ponding cells would be sized to at least provide the required hydraulic retention capacity. However, the minimum cell size would also need to be balanced with the sediment storage capacity required for deposition of the affected fractions of dredged materials. For Lower Fox River sediment removal, the requirement for cell storage capacity for sediment deposition would dominate the primary cell sizing. A properly designed coagulant-aided solids separation system would be expected to produce return flow effluent with less than 200 mg/L total suspended solids.

An alternative would be a constructed gravity thickener, or clarifier, in place of the above secondary settling cell. As the flocculated sediment settles toward the bottom of the clarifier, the thickened underflow would be collected and pumped to a mechanical filtration system (i.e., belt press) to produce a dewatered solids cake. The withdrawn water is cycled back to the clarifier inflow. Clarifier overflow water (i.e., the clarified dredge flow) is discharged back to the waterway, after meeting water quality requirements. Additional treatment of the effluent may be needed for water quality compliance, and might include sand, mixed media, and/or activated carbon filtration. If needed, such end-stage treatment will be expensive and may result in selecting an alternate dredging/disposal method.

An alternative to gravity sedimentation would be to import or construct a mechanical filtration system on site. Proprietary commercial installations have reported success in solids removal and dewatering the full slurry stream from a small hydraulic dredge (i.e., Solomon Liquids, Lakewood, Colorado; Global Dewatering, Edmonton, Canada.). Such systems can be utilized in tandem to increase overall flow capacity, if needed, for a project of this size (2,000 gpm). A typical system utilizes screens and centrifuges for solids removal, in some cases aided by chemical coagulants and short-term gravity separation. A properly designed and operated system would be expected to produce a return flow with less than 200 mg/L total suspended solids.

A multi-cell settling/treatment pond would allow addition of a coagulating agent to assist in secondary (final) sedimentation before discharge (USACE, 1987). The primary (first) cell would settle and retain the coarser-grained sediment within the first few hours of retention. The overlying suspended fine-grained supernatant would be discharged to the secondary settling cell after mixing with a chemical coagulant to aid in flocculent settling. Addition of the coagulating agent would be mixed by turbulence within the gravity flow discharge pipe(s) from the primary cell into the secondary cell, or a static mixing tank could be added between the cells if the gravity flow energy was not sufficient to result in proper mixing. Final design of the system would require additional testing to identify an optimum coagulant and concentration.

Other Wastewater Treatment Options

- **Off-site Commercial Treatment.** POTWs can be used for the treatment of effluent water from dredged sediments. This management option allows for the disposal of effluent waters. The discharge of water to a POTW is often dependent upon meeting certain discharge criteria as set by the municipality. This management method may be used in remedial alternatives where sediment dewatering is required.

- **Off-site Disposal of Hazardous Wastes.** Dredged material would be removed from dewatering cells as dewatered solids or filter cake by a rubber-tired front-end loader and loaded to screened refuse containers for transport to a treatment or disposal facility.

- **On-site Treatment of Organic Compound.** Carbon filtration and UV oxidation are commonly used management methods to remove organic compounds from effluent water. Treatment of organic compounds, depending upon concentrations, may be required to discharge effluent water to either a POTW or to the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

- **On-site Treatment of Suspended Solids and Metals.** Precipitation and froth tanks are commonly used management methods used to remove suspended solids and metals from effluent water. Treatment of suspended solids and metals, depending upon concentrations, may be required to discharge effluent water to either a POTW or the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

6.5.3 Residuals Management and Disposal

Residual management methods will be required for each remedial alternative. Residual management will vary depending upon the chosen remedial alternative. The following provides a description of each of the residual management methods including a summary of the applicability of these methods:

- **Off-site Disposal of Non-Hazardous Wastes.** Wastes such as personal protective equipment (PPE), filtration filters, and construction debris that is not characterized hazardous waste can be disposed of at a local municipal landfill. This management method will be used in all remedial alternatives. The quantity generated will depend upon the remedial alternative.

- **On-site Beneficial Use.** Dewatered and treated sediments may be suitable as soil/sediment construction fill or placed in newly-constructed CDFs as dikes or retaining walls. The feasibility of these disposal techniques depends upon the physical properties of the material, residual concentrations, local needs, and jurisdiction rulings.

No screening evaluation is necessary for residuals management and disposal process options.

6.5.4 Transportation

Transportation methods will be needed for any remedial alternative which involves removal of the contaminated sediments. The transportation methods included in each remedial alternative will be based upon the compatibility of that transportation method to the other process options. The following provides a description of each of the transportation methods including a summary of the compatibility of these methods:

- **Truck.** Transport of dewatered sediment over public roadways using dump trucks, roll-off boxes, or trailers. Includes associated loading facilities. This technology applies to transport for short distances, and will be used in remedial alternatives where dewatered sediment is transported to an in-state landfill.

- **Rail.** Transport of dewatered sediment by railroad using open gondolas. Includes associated loading facilities. This technology applies to transport over long distances (greater than 300 miles), and will be used in remedial alternatives where the dewatered sediment is transported to an out-of-state landfill.

- **Barge.** Transport of high-solids sediment through existing navigable waterways using barges. Includes associated unloading facilities on the river shoreline. This technology applies to transport on the river in segments between dams or locks, and will be used in remedial alternatives where sediment removal is conducted using a mechanical dredge.

- **Pipeline.** Transport of low-solids sediment through pipelines directly from dredge equipment to a receiving point on the river shoreline, or to an off-site location using conventional transport. This technology applies to transport on the river and can be conducted along a river segment, or over a dam. Pipeline transport will be used in remedial alternatives where sediment removal is conducted using a hydraulic dredge.

No screening evaluation is necessary for transportation.

6.5.5 Water Quality Management

All removal technologies may increase the suspended solid load of the overlying waters, but vary in their overall impact. Solids loss or resuspension may or may not be significant in terms of environmental impact on the water column. In general, environmental impact is related to the magnitude of losses. However, the impact of low losses from environmental dredging are likely to have minimal impact on the waterway (Appendix B). There are operational controls that can further reduce the impacts to water quality during dredging. For selection of the final removal technology(ies), these points must be considered for both environmental protectiveness and cost.

Dredge Operator

Water quality impacts can be controlled by the careful selection of dredging equipment as well as using specific operation and technical controls. These can include skilled operators working the dredging units at slower rates, careful placement of the dredging equipment, and use of sediment curtains or booms to control spread of suspended solids.

Field assessments have shown that sediment resuspension by hydraulic dredge can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 rpm, a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

Containment Barriers

Water quality impacts from sediment resuspension at the dredge can also be reduced by conducting the dredging within a silt curtain, silt screen, or sheet piling enclosure in order to contain migration of the suspended solids or turbidity plume. The silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. The silt curtain can extend completely to the bottom with appropriate fringe weights and anchors. Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, the silt screen is constructed of permeable fabric designed to pass water, but not fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Sheet piling may be selected when site conditions such as stray currents, high winds, changing water levels, excessive ship traffic and wave height, or drifting ice and debris preclude use of silt curtains/screens. Sheet piles are generally constructed of impermeable, interlocking steel plates that are driven below mudline into an underlying clay layer. If bedrock underlies the dredge prism, then piles can be connected to the bedrock using driving pins. Sheet piles can be expensive to install, difficult to remove without disturbing neighboring structures, and may be most practical in areas where "excessive" resuspension is expected.

6.6 Monitoring

Monitoring is a key control and assessment technology for sediment remediation. Numerous guidance documents confirm the necessity for monitoring to measure the effectiveness, stability, and integrity of source control measures, and to verify achievement of project RAOs (EPA, 1998a, 1994a; Krantzberg *et al.*, 1999). For contaminated sediment projects, monitoring can be grouped into five categories:

- Baseline monitoring,
- Short-term monitoring during implementation,
- Verification monitoring immediately following an action,
- Long-term operation and maintenance monitoring of storage sites, and
- Long-term performance monitoring to determine whether RAOs are attained.

6.6.1 Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing conditions before and after the cleanup action. The RI for the Lower Fox River and Green Bay presents a large body of data on the site. However, the database consists of information derived from numerous investigations that utilized varying methodologies. Further, the investigations cover a considerable time frame. Before implementing a specific cleanup action, baseline sampling and analysis of sediment and tissue samples will be required. The sampling design will be sufficiently rigorous to allow statistical comparison of conditions before, during, and following the cleanup action.

6.6.2 Implementation Monitoring

Short-term monitoring during remediation is used to evaluate whether the project is being implemented in accordance with specifications (i.e., performance of contractor, equipment, barriers, environmental controls). For removal or capping operations, short-term monitoring evaluates water quality near operations to determine whether contaminant resuspension and downgradient movement is being adequately controlled (e.g., with silt curtains). Water quality monitoring generally consists of surface water samples and frequent turbidity measurements. As demonstrated in the Deposit N pilot project, a PCB mass balance approach can be an effective method for tracking PCB mass management and loss through every phase. Bathymetric monitoring evaluates whether target sediments are being removed in dredging operations, or whether cap materials are being placed in the design location and at the design thickness. Bathymetry surveys are generally required during dredging operations to track removal progress and payment terms for contractors. Poling surveys are often used to ground-truth the bathymetry measurements. Other process monitoring may also be required depending on the remedial alternative. For example, sediment removal rates and slurry percent solids are important parameters to measure during hydraulic dredging operations.

6.6.3 Verification Monitoring

Verification monitoring evaluates post-removal surface and subsurface sediment conditions in dredging areas to confirm compliance with project specifications.

6.6.4 Operation and Maintenance Monitoring

Long-term maintenance monitoring of containment and/or disposal sites (i.e., nearshore fills, CAD sites, conventional *in-situ* caps) will be required to ensure adequate source control and continued stability of the structure. These O&M costs are included in the disposal (or containment) construction costs. The monitoring program will likely include surface and subsurface sediment and water quality monitoring, but the scope will be finalized during the remedial design phase.

6.6.5 Long-term Monitoring

Long-term monitoring evaluates sediment and tissue quality at the site for an extended period following the remedial action. In addition, disposal facilities are monitored for structural integrity and to ensure that the COCs continue to be contained. The scope of the former component of long-term monitoring (i.e., sediment and tissue sampling) is largely independent of the specific remedial action, although sampling locations and frequency can vary. The scope of the latter component depends on the location, type, and configuration of the disposal facility. A comprehensive *Long-term Monitoring Plan* for sediment and tissue quality for the Lower Fox River and Green Bay is detailed in Appendix C. Facility-specific monitoring is discussed in the context of remedial alternatives developed in Section 7.

No screening evaluation is necessary for monitoring options.

6.7 Section 6 Figures and Tables

Figures and tables for Section 6 follow page 6-74 and include:

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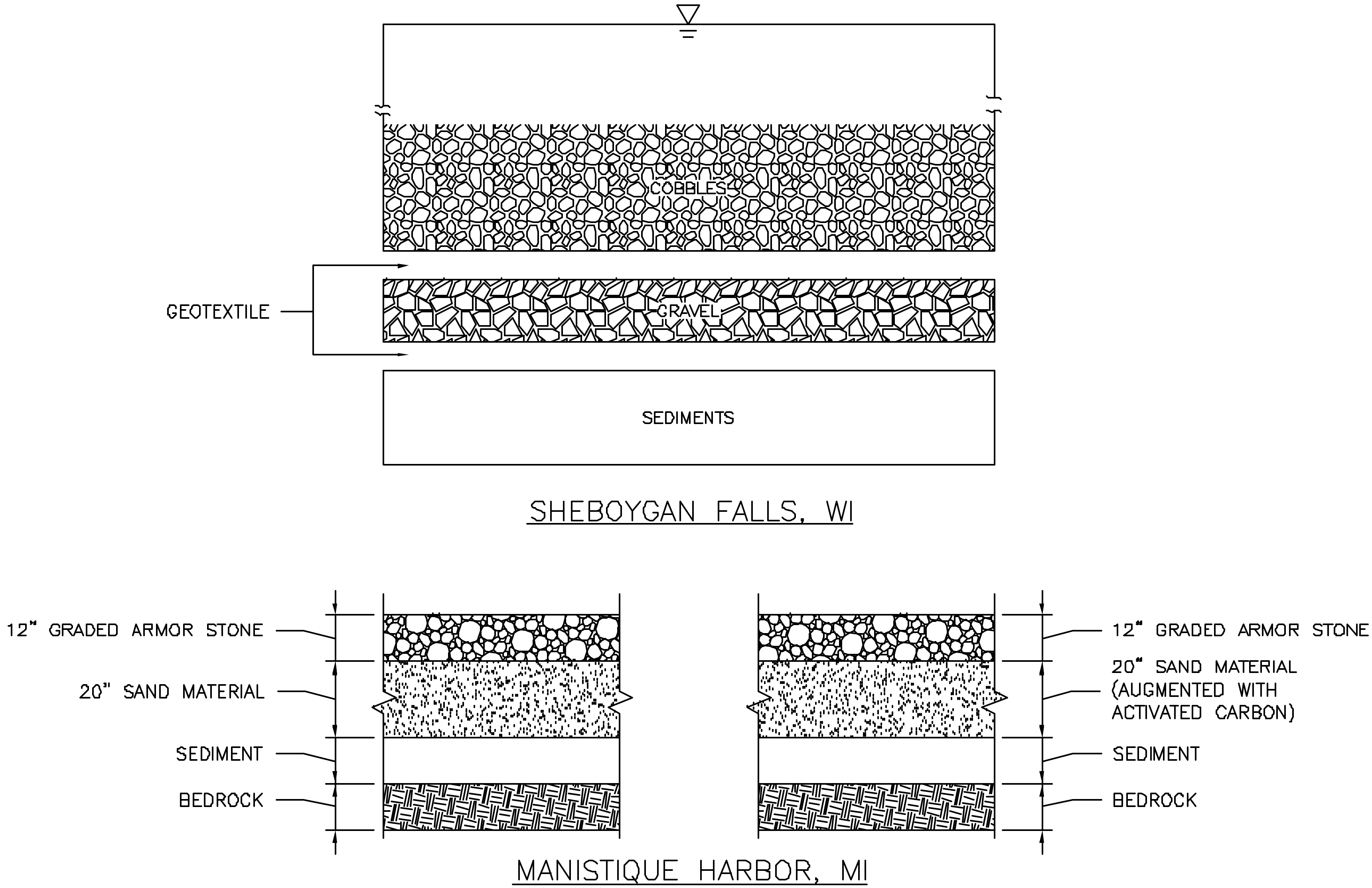


ThermoRetec

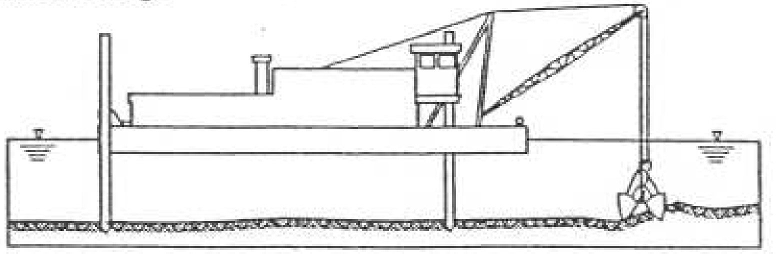
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

DATE: 09/15/00 | DRWN: N.S. | FILE: 14414G001

EXAMPLES OF ARMORED CAPS

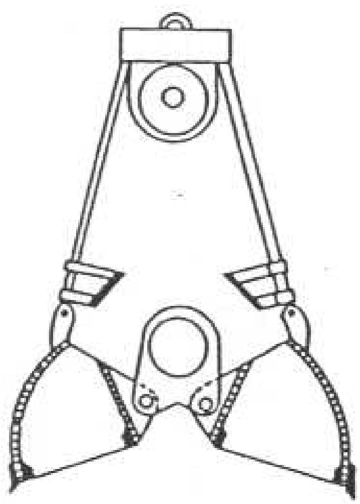
FIGURE 6-1

Mechanical dredge



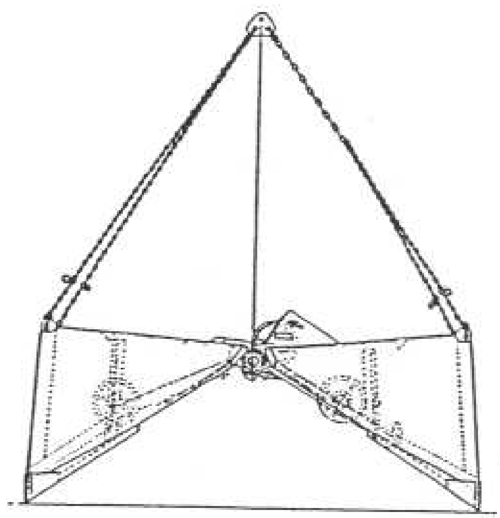
Source: USACE/USEPA (1992)

Enclosed Bucket



Source: Herbich and Brahme (1991).

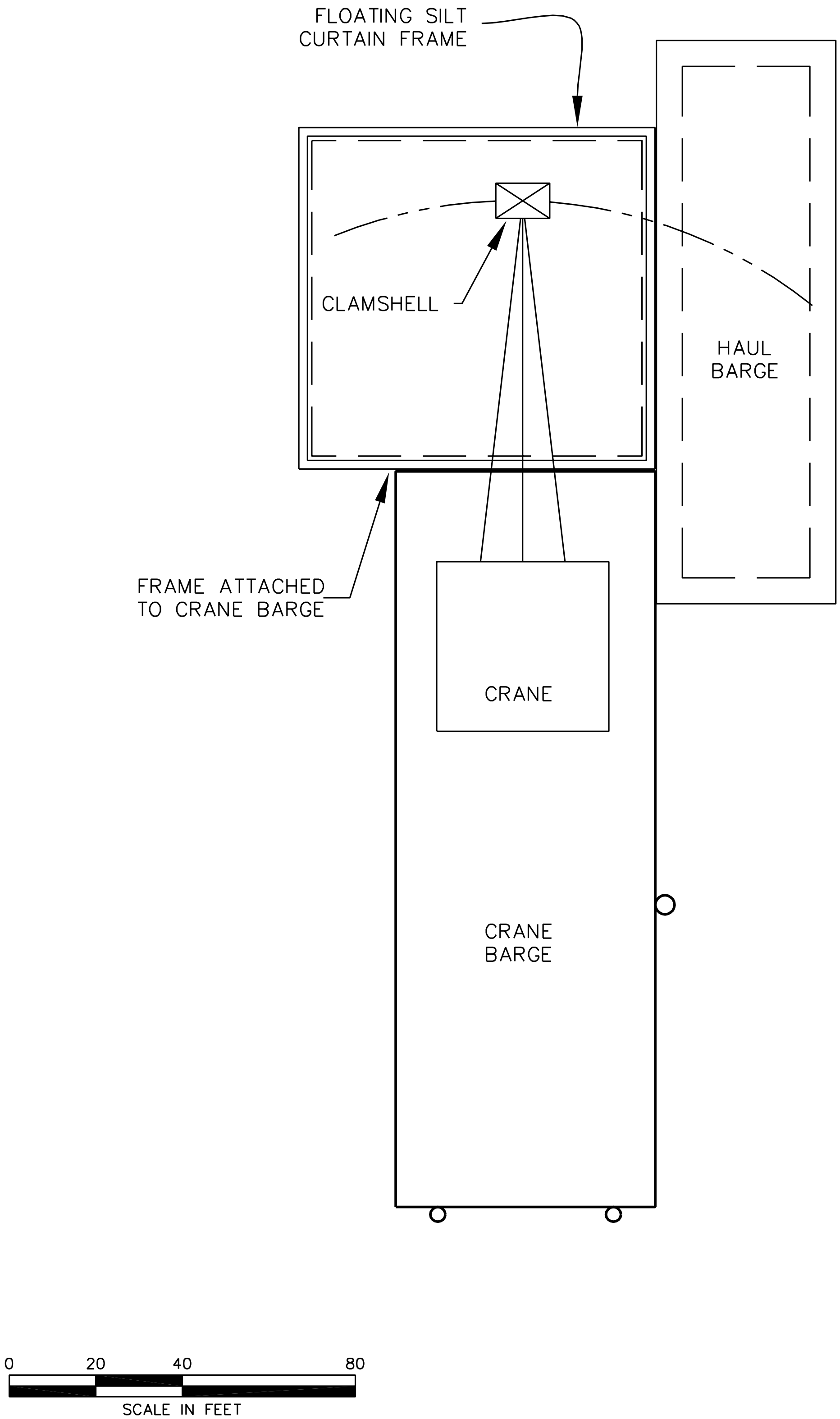
Cable Arm Bucket



Source: Cable Arm, Inc.

ThermoRetec

LOWER FOX RIVER FEASIBILITY STUDY 3-3584-900	EXAMPLES OF MECHANICAL DREDGES
CURRENT DATE 01-13-99 CADD FILE	FIGURE 6-2



ThermoRetec

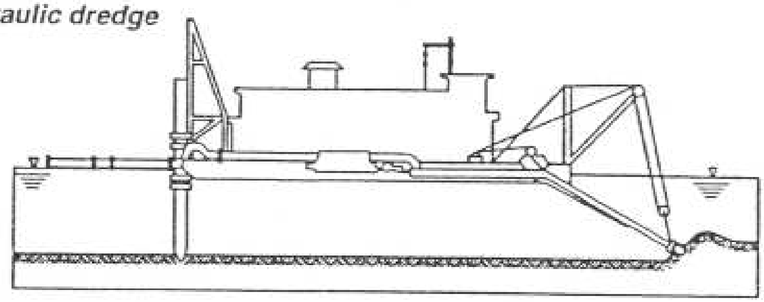
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

TYPICAL MECHANICAL DREDGE OPERATIONS

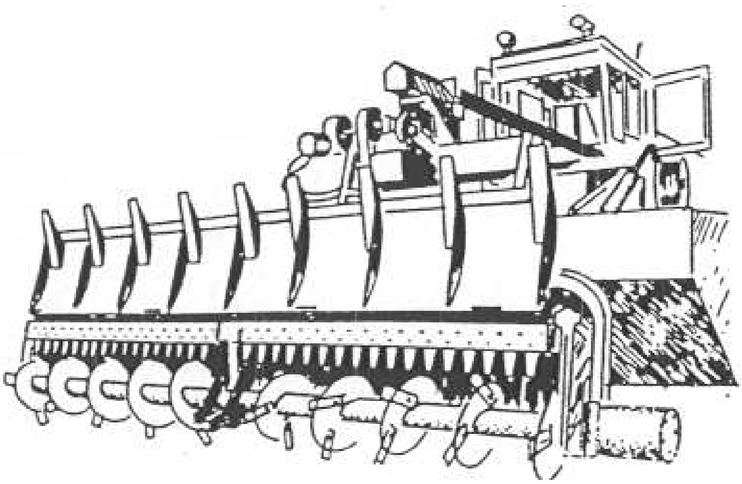
DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D004

FIGURE 6-3

Hydraulic dredge

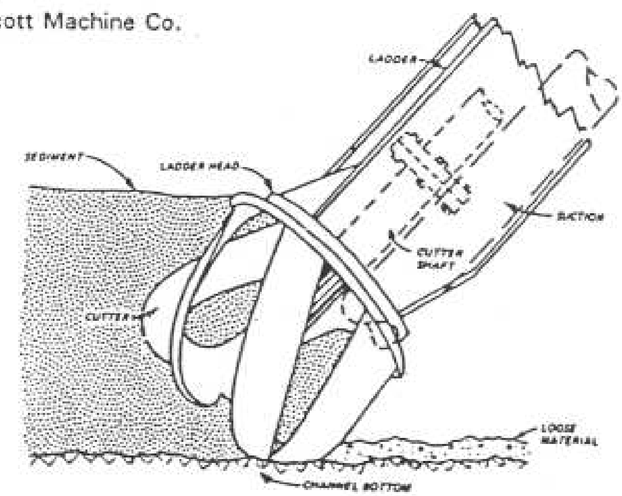


Source: USACE/USEPA (1992)



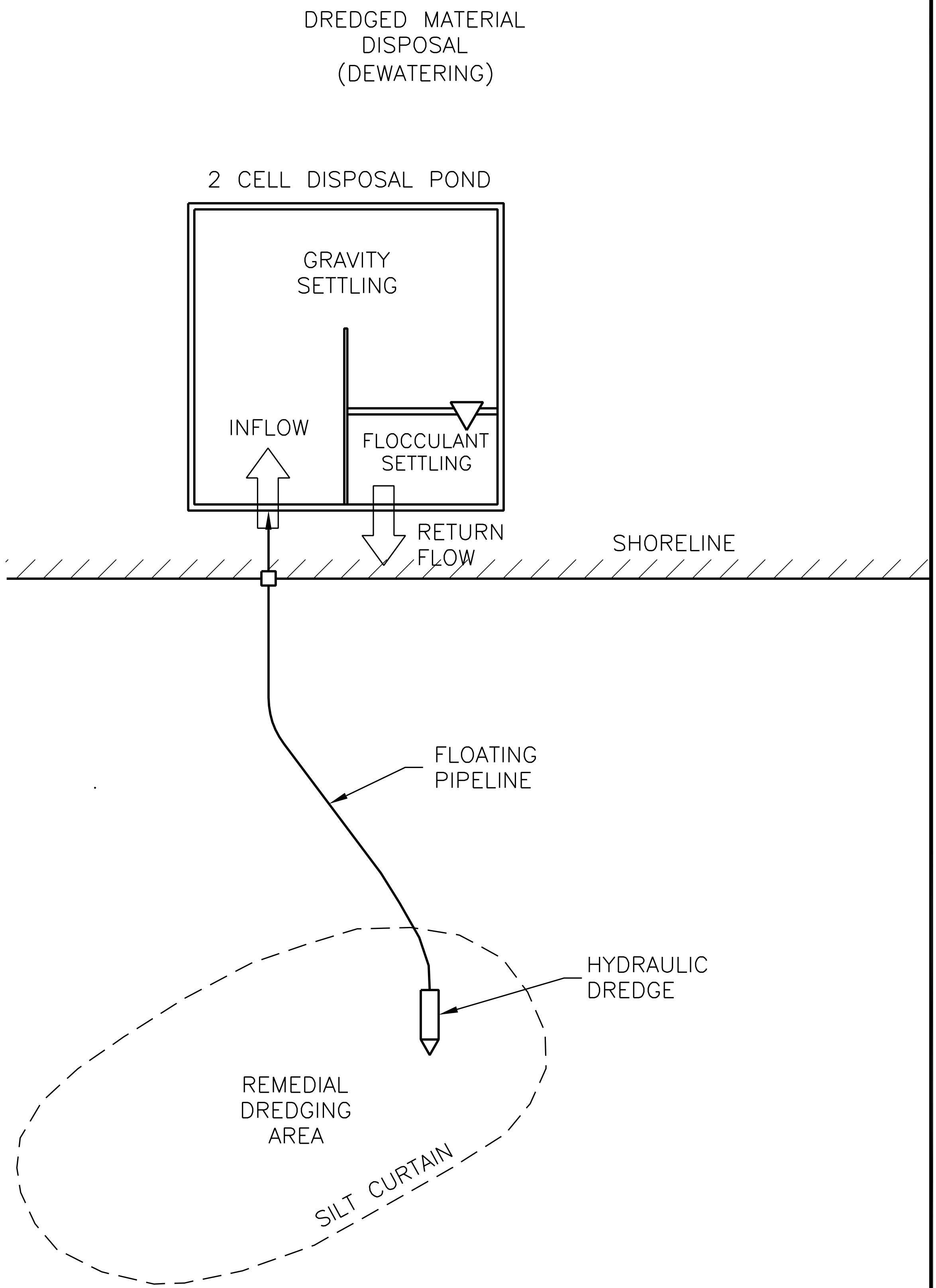
Horizontal Auger Dredge

Source: Ellicott Machine Co.



Conventional (Open Basket) Dredgehead

Source: Zappi and Hayes (1991)



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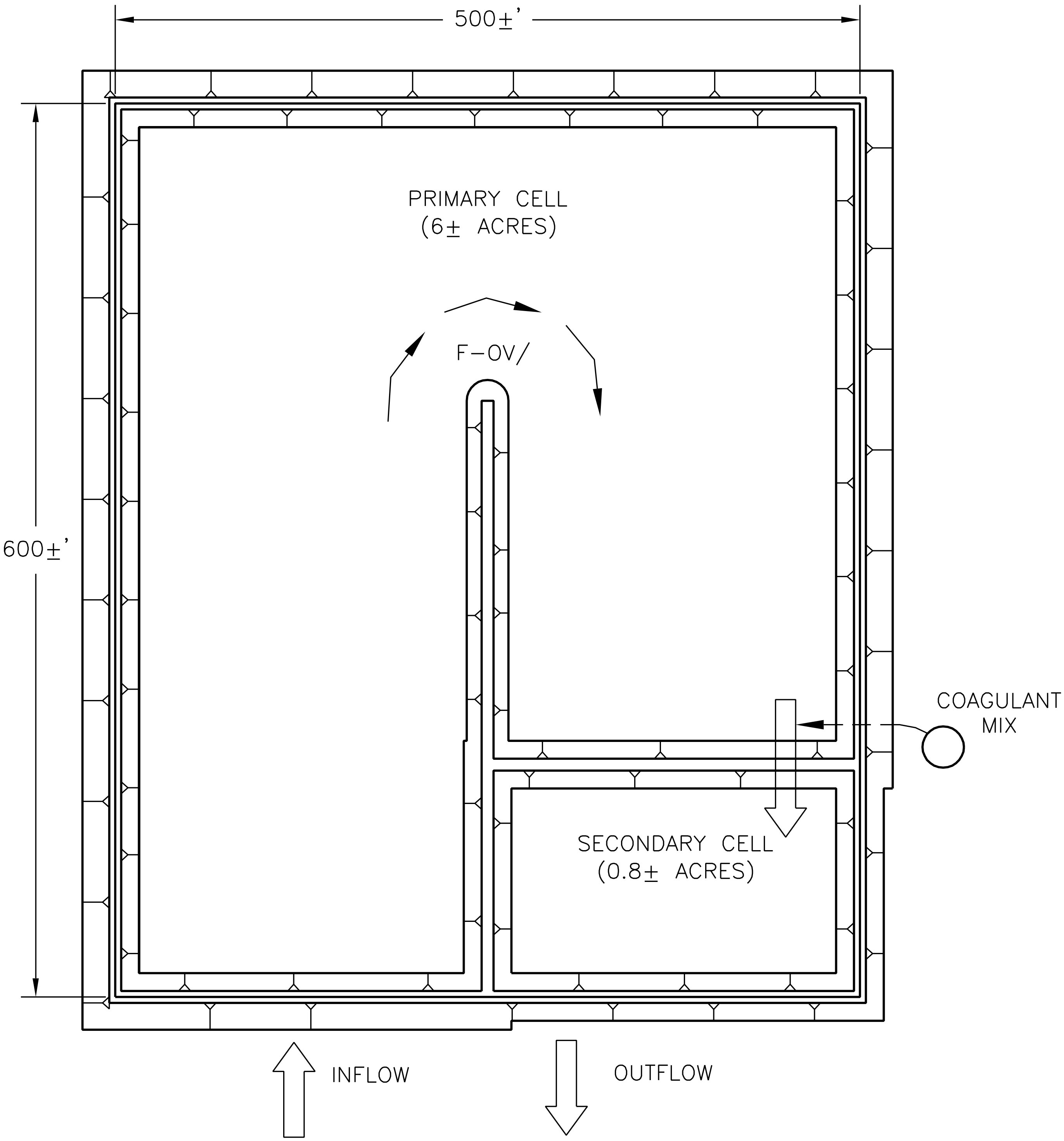
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

CONCEPTUAL HYDRAULIC DREDGING TO DEWATERING POND

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D003

FIGURE 6-5



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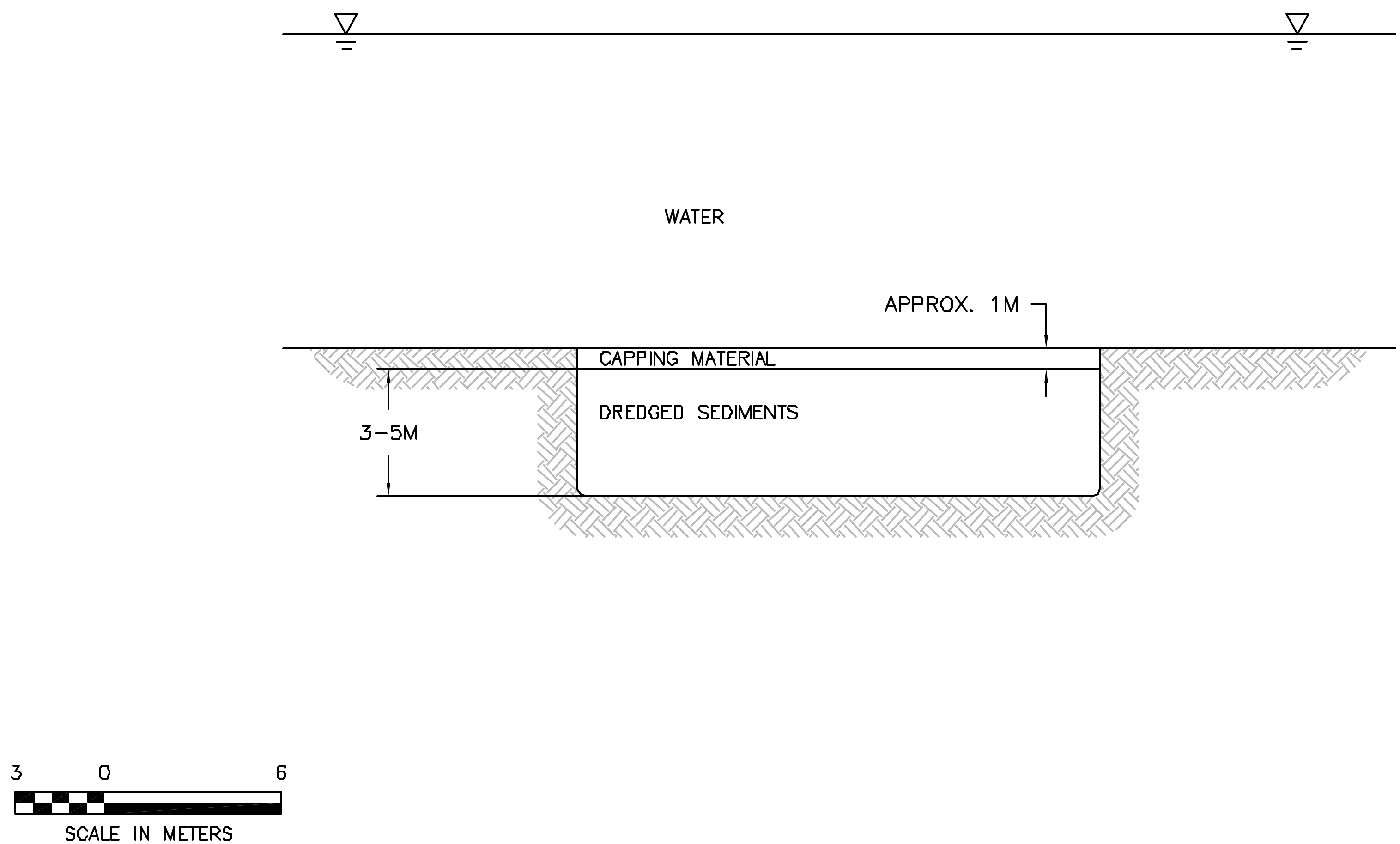
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D005

CONCEPTUAL LAYOUT OF A GRAVITY DEWATERING POND

FIGURE 6-6



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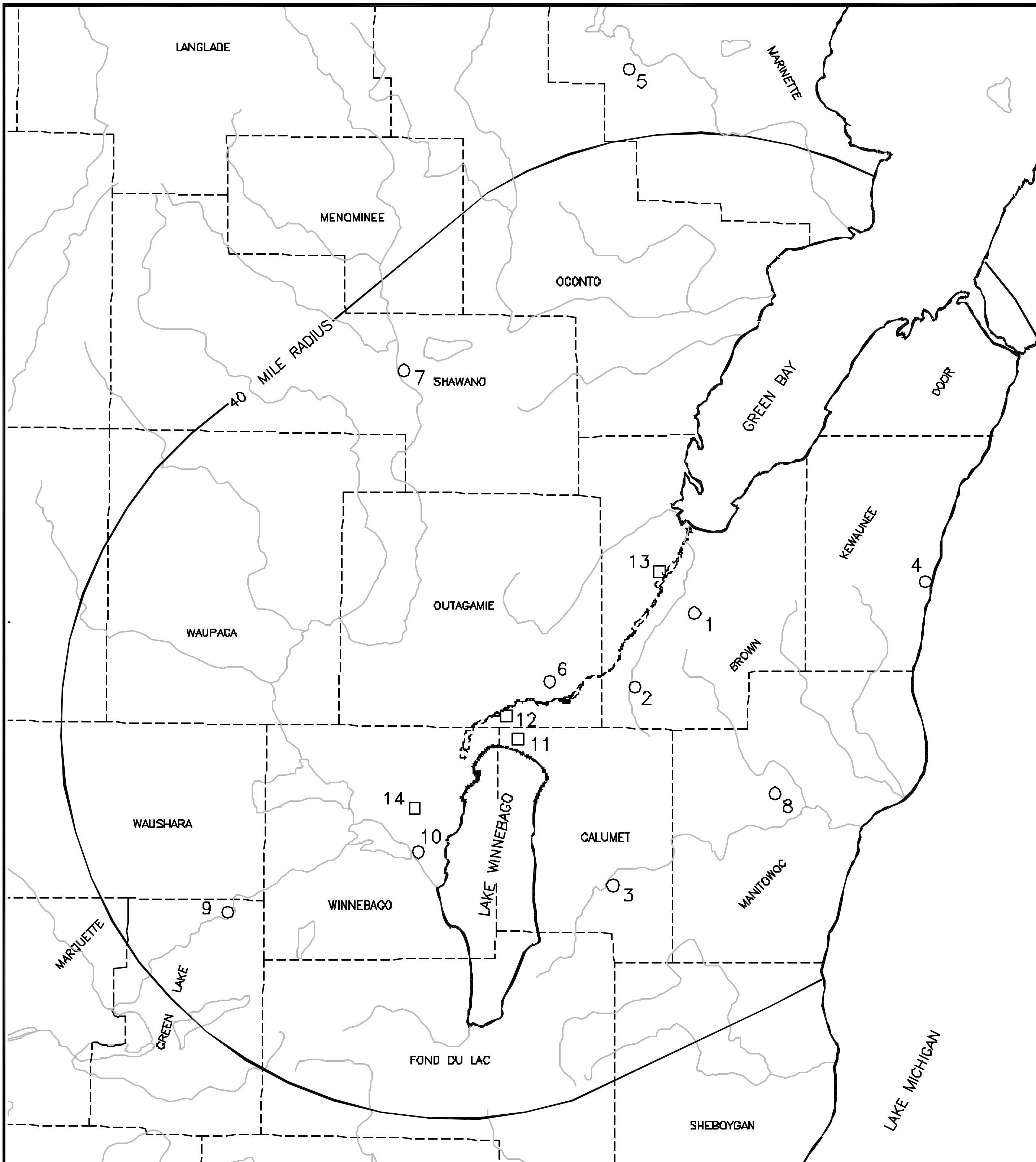
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

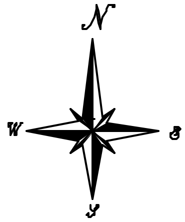
DATE: 04/19/01 | DRWN: S.E. | FILE: 14414G002

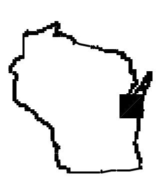
CROSS-SECTION OF CONFINED AQUATIC DISPOSAL

FIGURE 6-7



LOWER FOX RIVER GENERAL LANDFILL LOCATION MAP





LOCATION KEY

3500' 0 7000'

SCALE 1"=7000'

LEGEND

○ 21 GENERAL LOCATION MUNICIPAL LANDFILL

□ 15 GENERAL LOCATION NON MUNICIPAL LANDFILL

(NUMBERS CORRESPOND TO LANDFILLS LISTED ON TABLE 6-17 OF FEASIBILITY STUDY)

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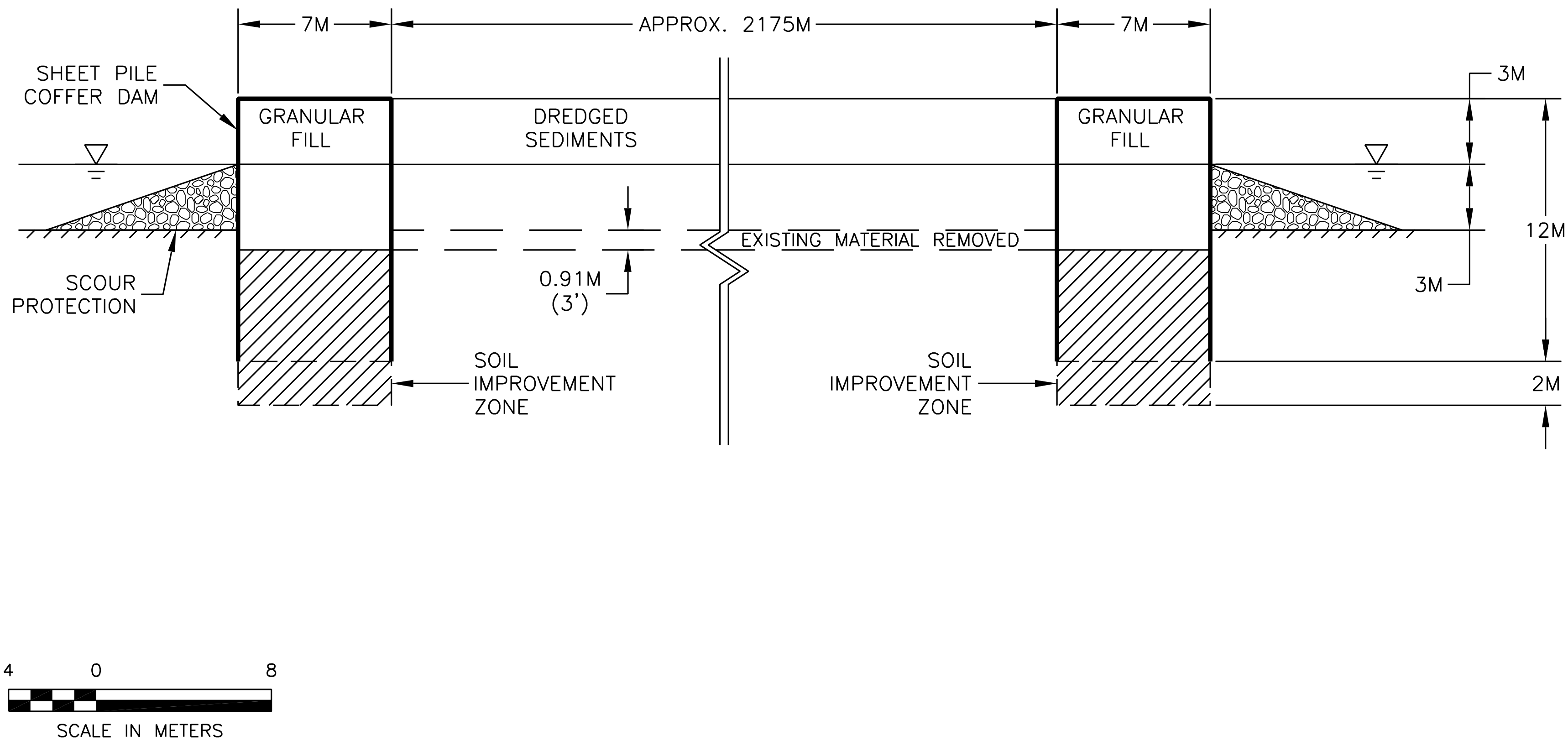
LOWER FOX RIVER FEASIBILITY STUDY WISCN-14414-535	GENERAL LANDFILL LOCATION MAP
CURRENT DATE 04/19/01 CADD FILE 14414s019	FIGURE 6-8



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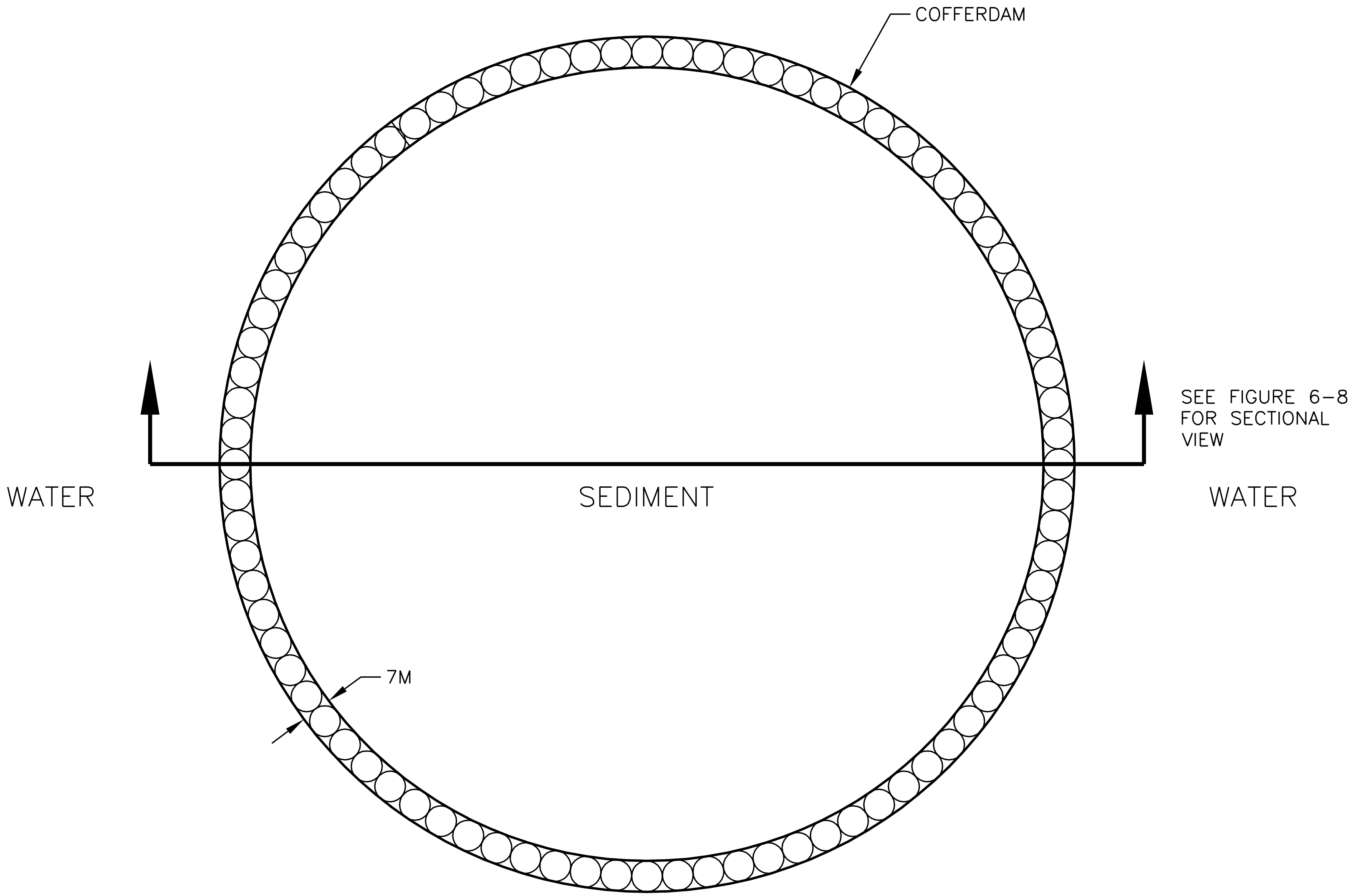
LOWER FOX RIVER
FEASIBILITY STUDY

WISCN-14414-535

DATE: 07/26/00 | DRWN: N.S. | FILE: 14414D001

CROSS-SECTION OF CELLULAR COFFERDAM CDF

FIGURE 6-9



NOT TO SCALE

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LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

PLAN VIEW OF WASTE CELLULAR COFFERDAM CDF

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D002

FIGURE 6-10

Table 6-1 Guidance and Literature Resources Used to Develop the List of Potentially Applicable Technologies for Cleanup of the Lower Fox River and Green Bay

- *Remediation Technologies Screening Matrix and Reference Guide, Second Edition* (DOD, 1994)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Final Summary Report* (EPA, 1994a)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a)
- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990)
- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995)
- *SEDTEC: A Directory of Contaminated Sediment Removal and Treatment Technologies* (SEDTEC, 1997)
- *Record of Decision, Sheboygan River and Harbor, Sheboygan, Wisconsin* (EPA, 2000a)
- *Remedial Investigation Report for Contaminated Sediment Deposits on the Fox River: Little Lake Butte des Morts to the De Pere Dam* (GAS/SAIC, 1996)
- *Feasibility Study Report for Deposits POG and N on the Fox River* (GAS/SAIC, 1997)
- *Remedial Investigation/Feasibility Study - Little Lake Butte des Morts - Sediment Deposit A* (Blasland & Bouck Engineers, P.C., 1993)
- *Engineering Evaluation/Cost Analysis: Manistique River and Harbor* (BBL, 1994)
- *Sheboygan River and Harbor Feasibility Study* (BBL, 1998)
- *Feasibility Study Report - Deposit A Little Lake Butte des Morts* (EWI Engineering Associates, Inc., 1992)
- Dredging Dallas' White Rock Lake in *World Dredging Mining and Construction,* April 1998. Describing a 20-mile-long slurry pipe run to disposal site (Sosnin, 1998).

Table 6-2 Summary of Technologies Reviewed and Retained[3]

General Response Action	Remedial Technology	Process Option
No Action	None	Not Applicable
Institutional Controls	Physical, Engineering or Legislative Restrictions	Consumption Advisories Access Restriction Dredging Moratorium
Monitored Natural Recovery	Physical Degradation	Combination of Desorption, Diffusion, Dilution, Volatilization, Resuspension, and Transport
	Biological Degradation	Dechlorination (aerobic and anaerobic)
	Physical Burial	Sedimentation
Containment	Capping	Conventional Sand Cap Sediment Clay Cap Armored Cap Composite Cap Thin-layer Cap Enhanced Cap
	Rechannelization	Construct New Channels
Removal	Dredging	Hydraulic Dredging Mechanical Dredging
	Dry Excavation	Excavator (for specific conditions)
In-situ Treatment	Biological	*In-situ* Slurry Biodegradation *In-situ* Aerobic Biodegradation *In-situ* Anaerobic Biodegradation
	Chemical	*In-situ* Slurry Oxidation Aqua MecTool™ Oxidation *In-situ* Oxidation Electrochemical Oxidation
	Physical Extractive Processes	Sediment Flushing SVE/Thermally Enhanced SVE/Bioventing Air Sparging
	Physical-Immobilization	Air Sparging MecTool™ Stabilization Vitrification Imbiber Beads™ Ground Freezing

3 **Note:** Shading designates technologies that were retained in developing remedial alternatives.

Table 6-2 Summary of Technologies Reviewed and Retained (Continued)[3]

General Response Action	Remedial Technology	Process Option
Ex-situ Treatment	Biological	Landfarming/Composting Biopiler Fungal Biodegradation Slurry-phase Biological Treatment Enhanced Biodegradation
	Chemical	Acid Extraction Solvent Extraction Slurry Oxidation Reduction/Oxidation
	Chemical/Physical	Dehalogenation Sediment Washing Radiolytic Dechlorination
	Physical	Separation Solar Detoxification Solidification
	Thermal	Incineration High-temperature Thermal Desorption Low-temperature Thermal Desorption Pyrolysis Thermal Destruction Vitrification High-pressure Oxidation
Disposal	On Site	Level Bottom Cap Confined Aquatic Disposal (CAD) Confined Disposal Facility (CDF) Nearshore Biofiltration Cell Upland Confined Fill
	Off Site	Existing Upland Landfill Dedicated New Landfill TSCA Landfill Upland Confined Fill (commercial) Upland Fill (residential)

[3] **Note:** Shading designates technologies that were retained in developing remedial alternatives.

Table 6-3 Description of Potential Remedial Technologies

GRA	Technology	Process Option	Description
No Action	*None*	Not Applicable	No active remedy (i.e., passive remediation by natural processes).
Institutional Controls	*Physical, Engineering, or Legislative Restrictions*	Consumption Advisories	Advisories to indicate that consumption of fish in the area may present a health risk.
		Access Restrictions	Constraints, such as fencing and signs, placed on property access.
		Dredging Moratorium	Restricts dredging operations.
Monitored Natural Recovery	*Physical Degradation*	Combination	Desorption, diffusion, dilution, volatilization, resuspension, and transport.
	Biological - Degradation	Dechlorination (aerobic and anaerobic)	Chlorine atoms are removed from PCB molecule by bacteria, however, toxicity reduction is not directly correlated to dechlorination.
	Physical - Burial	Sedimentation	Impacted sediments are buried to deeper intervals which are not in the biologically active zone.
Containment	*Capping*	Conventional Sand Cap	Placement of clean sand over existing contaminated bottom to physically isolate contaminants.
		Conventional Sediment/Clay Cap	Use of dredged fine-grained sediments or commercially-obtained clay materials to achieve contaminant isolation.
		Armored Cap	Cobbles, pebbles or larger material are incorporated into the cap to prevent erosion in high-energy environments, or to prevent cap breaching by bioturbators (example: membrane gabions).
		Composite Cap	Soil, media and geotextile cap over contaminated material to inhibit contaminated pore water migration and/or inhibit bioturbators.
		Thin Layer Cap	Application of a thin (1"–3") layer of clean sediments and allowing natural resorting or bioturbation to mix the contaminated and clean sediments, which results in a surface layer of impacted material within acceptable levels.
		Enhanced Cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in pore water.
	Rechannelization	Construction of New Channels	Construction of new channels to reroute surface water through non-impacted sediments or soils.
Removal	*Dredging*	Hydraulic Dredging	A rotating cutterhead loosens sediment at the suction mouth, where a centrifugal pump draws the sediment/water slurry through the pipeline. Performs efficiently in most sediments. Resuspension losses can be minimized by operational controls.
	Dry Excavation	Mechanical Dredging	A mechanical dredge consists of a barge-mounted floating crane that maneuvers a cable-suspended dredging bucket. The bucket is lowered into the sediment, and when withdrawn the cable closes the jaws of the bucket, retaining dredged material.
		Excavator	This removal option includes erecting sheet piles, or a cofferdam, around the contaminated sediments to dewater. Removal would then involve conventional excavation (backhoe) equipment.
***In-situ* Treatment**	*Biological*	*In-situ* Slurry Biodegradation	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen levels, nutrients, and pH are controlled to enhance degradation. Would require sheet piling around entire area and slurry treatment would be performed using aerators and, possibly, mixers.
		In-situ Aerobic Biodegradation	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen levels, nutrients, and pH are controlled to enhance degradation.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
In-situ Treatment (Continued)	*Biological (Continued)*	*In-situ* Anaerobic Biodegradation	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients, and pH are controlled to enhance degradation.
	Chemical	*In-situ* Slurry Oxidation	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's Reagent.
		Aqua MecTool™ Oxidation	A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton's Reagent. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		In-situ Oxidation	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
		Electrochemical Oxidation	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
	Physical-Extractive Processes	Sediment Flushing	Water or other aqueous solution is circulated through impacted sediment. An injection or infiltration process introduces the solution to the impacted area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
		SVE/Thermally Enhanced SVE/ Bioventing	An array of extraction and injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled in bioventing applications. Removal may be enhanced by heating the system.
		Air Sparging	An array of injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled to enhance biological activity.
	Physical-Immobilization	Aqua MecTool™ Stabilization	A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		Vitrification	Uses and electric current to melt soil or other earthen materials at extremely high temperatures (2,900˚–3,650 ˚F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In-situ* applications use graphite electrodes to heat soil.
		Imbiber Beads™	A "cover blanket" of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would absorb PCB vapors generated.
		Ground Freezing	An array of pipes is placed in the ground and brine at a temperature of -20˚ to -40 ˚C is circulated to freeze soil. Is only recommended for short-duration applications and to assist with excavation.
Ex-situ Treatment	*Biological*	Landfarming/ Composting	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using a windrow composter, conventional tilling equipment, or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.
		Biopiles	Excavated sediments are mixed with amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
Ex-situ Treatment (Continued)	*Biological (Continued)*	Fungal Biodegradation	Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using their lignin-degrading or wood-rotting enzyme system (example: white rot fungus).
		Slurry-phase Biological Treatment	An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced Biodegradation	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]).
	Chemical	Acid Extraction	Waste-contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent Extraction	Waste-contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
		Slurry Oxidation	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's Reagent.
		Reduction/ Oxidation	Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
	Chemical/ Physical	Dehalogenation	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition or BCD) or potassium polyethylene glycol (APEG). The mixture is heated to above 630 ˚F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.
		Sediment Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
		Radiolytic Dechlorination	Sediment is placed in alkaline isopropanol solution and gamma irradiated to a dose of <10 (~1% solution). Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere.
	Physical	Separation	Contaminated fraction of solids are concentrated through gravity, magnetic or sieving separation processes.
		Solar Detoxification	Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants.
		Solidification	The mobility of constituents in a "solid" medium are reduced through addition of immobilization additives.
	Thermal	Incineration	Temperatures greater than 1,400˚ F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.

Table 6-3 Description of Potential Remedial Technologies (Continued)

GRA	Technology	Process Option	Description
***Ex-situ* Treatment (Continued)**	*Thermal (Continued)*	High-temperature Thermal Desorption (HTTD)	Temperatures in the range of 600˚–1,200 ˚F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions.
		Low-temperature Thermal Destruction	Temperatures in the range of 200˚–600 ˚F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
		Pyrolysis	Chemical Decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
		Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process and Holoflite™ Dryer).
		Vitrification	Uses an electric current to melt soil or other earthen materials at extremely high temperatures (2.900˚–3,650 ˚F).
		High-pressure Oxidation	High temperature and pressure used to break down organic compounds. Operating temperatures Range from 150˚–600 ˚C and pressures range from 2,000–22,300 MPa (examples: wet air oxidation and supercritical water oxidation).
Disposal	*On-site Disposal*	Level-bottom Cap	Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water. Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water.
		Confined Aquatic Disposal (CAD)	Place untreated sediment within a lateral containment structure (i.e., bottom depression or subaqueous berm) and cap with clean sediment.
		Confined Disposal Facility (CDF)	Place untreated sediment in a nearshore confined disposal facility that is separated from the river by an earthen berm or other physical barrier and capped to prevent dermal contact.
		Nearshore Biofiltration Cell	Contaminated sediment is placed in a nearshore confined treatment facility (CTF) where the contents are manipulated to enhance naturally-occurring biodegradation.
		Upland Confined Fill	Place treated sediment at an on-site location. Location may require cap or other containment devices based on analytical data.
	Off-site Disposal	NR 500 WAC Landfill (county, private, industrial landfills)	Off-site disposal at a licensed commercial facility that can accept nonhazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation.
		Dedicated New Upland Landfill	A new dedicated landfill designed to contain all PCB-impacted sediments removed from the Lower Fox River.
		TSCA Subtitle C Landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation.
		Upland Confined Fill (commercial/-industrial)	Place treated or untreated sediment at an off-site location. Location may require cap or other containment devices based on analytical data.
		Upland Fill (residential/clean)	Place treated sediment at an off-site location. Requires that sediment be treated to a level that allows no restriction reuse.

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
No Action	*None*	Not Applicable	Potentially applicable.	Retained	Retainment required.	Low	Retained
Institutional Controls	*Physical, Engineering, or Legislative Restrictions*	Consumption Advisories	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
		Access Restrictions	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
		Dredging Moratorium	Potentially applicable.	Retained	Provides limited protection.	Low	Retained
Monitored Natural Recovery	*Physical Degradation*	Desorption, Diffusion, Dilution, Volatilization	Potentially applicable.	Retained	Surface sediment concentrations are generally decreasing over time, but not at depth. PCB volatilization in Green Bay indicates degradation is occurring.	Low	Retained
	Biological - Degradation	Dechlorination (aerobic and anaerobic)	Potentially applicable.	Retained	Relatively successful for sediments with high PCB levels, but little degradation occurs at lower PCB levels.	Low	Retained
	Physical Processes	Sedimentation Burial	Potentially applicable.	Retained	Deposition and reburial is occurring, but based on bed elevation changes over time, much of the sediment is resuspended.	Low	Retained
		Resuspension and Transport	Potentially applicable.	Retained	Bed elevation changes over time indicate transport is occurring.	Low	Retained
Containment	*Capping*	Conventional Sand Cap	Easily applied *in-situ*, however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Modeling will be necessary to determine if a thin-layer cap will provide adequate protection of the water column from dissolved PCBs.	Low	Retained

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
Containment (Continued)	*Capping (Continued)*	Conventional Sediment/Clay Cap	Placement of cap within the waterway may require special engineering controls. Difficult to place clay portion of a cap. Minimizes cap thickness in areas with shallow water depth.	Retained	Sediment with silt and clay is effective in limiting diffusion of contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Clay caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption. These properties increase dissolution to the overlying water column and/or recontamination of sediment within the bioactive zone (upper 10 cm).	Low	Retained
		Armored Cap	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Armoring minimizes scouring.	Low to Moderate	Retained for limited use in high-energy sections of river
		Composite Cap (geotextile)	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Use of geotextiles may not be necessary for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact.	Low to Moderate	Retained
		Thin-layer Cap	Minimizes reduction in water depth that may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation.	Retained	Effective for contaminants that are amenable to natural attenuation. PCBs are not amenable to natural attenuation.	Low	Eliminated

Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	**Screening Decision**	**Effectiveness**	**Cost**	**Screening Decision**
Containment (Continued)	*Capping (Continued)*	Enhanced Cap	Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation.	Retained	Provides similar direct contact protection as sand cap, but additives are designed to increase retention time in the cap or treat pore water. Additives used for the purpose of increasing retention time and treating pore water would have little effect on PCBs with low solubility and high sorption.	Low to Moderate	Eliminated
	Rechan-nelization	Construction of New Channels	Rerouting channels is often not feasible for the Lower Fox River.	Eliminated			
Removal	*Dredging*	Hydraulic Dredging	Produces low slurry density and results in high water treatment costs. Limited ability to remove debris.	Retained	Can effectively dredge all types of materials. Superior in minimizing sediment resuspension compared to other dredges. Low slurry density.	Low	Retained
		Mechanical Dredging	Readily available in the U.S. Vessel draft precludes operations in water with depths less than 6'. May be difficult to implement upstream of the De Pere dam due to barge access/construction issues.	Retained	Can be operated to produce low suspended solids in the water column, thereby reducing water quality impacts. Level cut and low suspended solids also provide less opportunity for recontamination of dredged areas.	Low	Retained
	Dry Excavation	Excavator	An enclosed and drained berm or sheet pile wall would need to be constructed to be water-impervious and water needs to be removed or diverted. Difficult to implement in deeper water or areas with bedrock.	Retained	Sheet pile isolates contaminated area during removal activities to minimize contamination of nearby sediments and water.	Moderate to High	Retained

Table 6-5 Screening of Potential Remedial Technologies - Treatment

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
In-situ Treatment	*Biological*	*In-situ* Slurry Biodegradation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Biodegradation has not been demonstrated to effectively remediate PCBs. No known full-scale applications.	Eliminated			
		In-situ Aerobic Biodegradation	Work performed to date has only been performed in the laboratory. Some contaminants (e.g., PCBs) generally not amenable to aerobic degradation. Has not been effective for PCBs in field demonstrations.	Eliminated			
		In-situ Anaerobic Biodegradation	Work performed to date has only been performed in the laboratory. Laboratory testing data has indicated only minor removal is achievable. Has not been effective for PCBs in field demonstrations.	Eliminated			
	Chemical	*In-situ* Slurry Oxidation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		Aqua MecTool™ Oxidation	May have difficulty injecting high air flows into caisson with standing water while preventing generation of TSS. No known completed full- or pilot-scale projects.	Eliminated			
		In-situ Oxidation	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		Electrochemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	Eliminated			
	Physical-Extractive Processes	Sediment Flushing	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications.	Eliminated			
		SVE/Thermally Enhanced SVE/ Bioventing	Technology is applicable to vadose zone soil or dewatered soil.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
In-situ Treatment (Continued)	*Physical-Extractive Processes (Continued)*	Air Sparging	Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Possible generation of exceedances through leakage from sheet pile. Targets VOCs and other readily degradable organics rather than PCBs. No known sediment applications.	Eliminated			
	Physical-Immobilization	Aqua MecTool™ Stabilization	Proprietary technology that has been used in a pilot-scale application in Wisconsin with coal tar-contaminated sediments. Previous trials with this technology created water treatment problems inside the caisson.	Eliminated			
		Vitrification	Requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	Eliminated			
		Imbiber Beads™	Not well demonstrated for remediation of bottom sediments. Removal and disposal of the blanket is not well demonstrated.	Eliminated			
		Ground Freezing	Application in presence of standing water has not been tested. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost.	Eliminated			
Ex-situ Treatment	*Biological*	Landfarming/ Composting	Requires a large amount of space. Contaminants generally not amenable to aerobic degradation. Inorganic contaminants will not be degraded.	Eliminated			
		Biopiles	Requires large upland area. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Contaminants generally not amenable to aerobic degradation.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
***Ex-situ* Treatment (Continued)**	Biological (Continued)	Fungal Biodegradation	No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	Eliminated			
		Slurry-phase Biological Treatment	Large volume of tankage required. No known full-scale applications. Contaminants generally not amenable to biodegradation. Inorganic constituents will not be degraded.	Eliminated			
		Enhanced Biodegradation	Not available on a commercial scale. PCB not amenable to biodegradation. Inorganic constituents will not be degraded.	Eliminated			
	Chemical	Acid Extraction	Commercial-scale units are in operation. Suitable for sediments contaminated with heavy metals. Not applicable to PCB-impacted sediment.	Eliminated			
		Solvent Extraction	At least one commercial unit available. Effective for treating sediments containing PCBs. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. The process is sensitive to sediment characteristics (i.e., clay content, pH). PCBs are not destroyed and may require further treatment by another technology.	Eliminated			
		Slurry Oxidation	Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	Eliminated			
		Reduction/ Oxidation	Target contaminant group for chemical redox is inorganics. Less effective against nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
***Ex-situ* Treatment (Continued)**	*Chemical/ Physical*	Dehalogenation	Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is generally not cost-effective for large volumes.	Retained	Effective for treating sediments containing PCBs. The presence of metals may affect performance. High moisture content adversely effects treatment. The process is sensitive to sediment characteristics (i.e., clay content, pH). The APEG process often needs to cycle numerous times to achieve the desired results and may cause the formation of dioxins and furans.	Moderate	Eliminated
		Sediment Washing/ Fractionation	Not an easily-accessible commercial process (limited use in the United States). Process has difficulty with fine-grained sediment. Not effective for PCBs.	Eliminated			
		Radiolytic Dechlorination	Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project.	Eliminated			
	Physical	Separation	Not effective on fine-grained sediment and in presence of high moisture content. Target compounds are SVOCs, fuels, and inorganics. Previous tests on Fox River sediments have shown no benefit in reducing contaminated sediment volumes, but it has been demonstrated as effective in improving the efficiencies of the dewatering process.	Retained	Effective for dewatering dredged material. Recent PCB mass balance studies conducted on Deposit N Fox River sediments have shown 96% of PCB mass is contained in filter cake after dewatering.	Moderate	Retained
		Solar Detoxification	The process has been successfully demonstrated at pilot scale. The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening: Implementability	Initial Screening: Screening Decision	Final Screening: Effectiveness	Final Screening: Cost	Final Screening: Screening Decision
Ex-situ Treatment (Continued)	*Physical*	Solidification	Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents with varying success. Dependent on sediment characteristics and water content.	Retained	Lime was successfully added to dewatered dredged material from the Lower Fox River demonstration projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal.	Moderate	Retained
	Thermal	Incineration	Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. May require an acid gas scrubber for treatment of air emissions.	Retained	High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics. At a minimum, consider use for TSCA-level sediments.	Very High	Retained as high-cost alternative
		High-temperature Thermal Desorption (HTTD) then Destruction	Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments.	Retained	Thermal desorption and combustion is effective with a range of SVOCs. Target contaminants for HTTD are SVOCs, PAHs, PCBs and pesticides. Destruction of organic compounds occurs within an off-gas chamber or unit that is integrated into the thermal desorption system.	High	Retained
		Low-temperature Thermal Desorption	Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments. Thermal desorption and combustion is effective with a range of SVOCs. Typically not employed with chlorinated compounds or VOCs.	Eliminated			
		Pyrolysis	High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium. Limited performance data are available for pyrolytic systems treating hazardous wastes containing PCBs, dioxins, and other organics.	Eliminated			

Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
***Ex-situ* Treatment (Continued)**	*Thermal (Continued)*	Thermal Desorption	Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Retained	Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment as well.	Low	Retained
		Vitrification	Requires less than 60% water content. Thermally treats PCBs and stabilizes metals, but at a much higher cost.	Retained	Destroys PCBs and immobilizes metals. Fundamentally, the process thermally treats PCBs and stabilizes metals. High moisture content adversely effects the treatment. Residuals are produced that must be treated and/or disposed. Recent pilot studies on Fox River sediments have shown that the process can be effective. Volume reduction to glass pellets is approximately 10:1.	High	Retained
		High-pressure Oxidation	Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction in bench- and pilot-scale testing.	Eliminated			

Table 6-6 Screening of Potential Remedial Technologies - Disposal

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
Disposal	*On-site Disposal*	Level-bottom Cap	Decreased water depth may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation.	Retained	Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Releases from impacted sediment may occur during consolidation.	Moderate	Retained
		Confined Aquatic Disposal (CAD)	CAD may not be implemented due to ban on open-water disposal in the Great Lakes, but carried forward in FS as feasible for Green Bay.	Retained	CAD sites have been successfully constructed in many urban bays. Effective for isolating contaminants such as PCBs.	Moderate	Retained
		Confined Disposal Facility (CDF)	Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit.	Retained	Risk of discharge to river or bay through outer berm or containment wall.	Moderate	Retained
		Nearshore Biofiltration Cell	Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit. Engineering design of a full-scale system may be difficult to implement due to the potential need for oxygen additions. Demonstration project on Sheboygan River sediments resulted in incomplete degradation of PCBs and concerns about full-scale engineering design.	Eliminated			
		Upland Confined Fill	Standard construction techniques. Requires available upland space.	Retained	Standard construction techniques. Requires available upland space. Long-term successful storage.	Moderate	Retained

Table 6-6 Screening of Potential Remedial Technologies - Disposal (Continued)

GRA	Technology	Process Option	Initial Screening		Final Screening		
			Implementability	Screening Decision	Effectiveness	Cost	Screening Decision
Disposal (Continued)	*Off-site Disposal*	NR 500 WAC Landfill (county, private, industrial landfills)	Sediment must pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities (re-approval pending).	Retained	EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills; however, TSCA sediments must pass paint filter test for transport and disposal. Some non-municipal landfills may require upgrades to meet NR 500 criteria.	Low to Moderate	Retained
		Dedicated New Upland Landfill	Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. Time required to site, design and construct the landfill is a consideration. If dredge slurry is pumped long distances directly to landfill, engineering and community concerns need to be addressed.	Retained	EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills. The dedicated landfill could be centrally located in an area to allow access from all areas of the river.	Moderate to High	Retained
		TSCA Subtitle C Landfill	Sediment must pass paint filter test for transport and disposal sediment must also pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities.	Retained	Commercial permitted landfill.	High	Retained
		Upland Confined Fill (commercial/-industrial)	Standard construction techniques. Treatment to Wisconsin commercial/industrial criteria.	Retained	Sediments must be treated to commercial/industrial criteria. May require liner and cap depending on constituent concentrations.	Low to Moderate	Eliminated
		Upland Fill (residential/clean)	Standard construction techniques. Treatment to Wisconsin clean fill criteria.	Retained	Sediment must meet residential fill criteria.	Low	Retained

Table 6-7 Ancillary Technologies

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Passive Dewatering	On-barge	Mechanically-dredged sediments are placed within a barge which either allows excess water to flow into river, or to accumulate in an on-board sump where it is removed and treated.	Water drained from sediment on barge into river may not meet NPDES discharge standards. Gravity-drained water may contain high concentrations of TSS. Not all river segments may be accessible to a barge. Sediments could require additional treatment to pass paint filter test.	Low	Retained
	Dewatering Lagoons/Ponds	Dredged sediments are placed within constructed lagoons where sediments are allowed to gravity settle.	Construction of ponds near river may involve removal of wooded areas. Construction costs may involve contingencies to address potential spills and leaks. Effluent water may contain high concentrations of TSS. Average annual rainfall and evaporation approximately equal. Retention time affects production rates. Based on Fox River design estimates, dewatered sediments would likely require solidification to pass paint filter test.	Low to Moderate	Retained
	Solidification	Dredged sediments are mixed with amendments (e.g., Portland cement, lime, and/or fly ash mixture) to produce a product which passes regulatory requirements (e.g., paint filter test).	Staging, mixing, and curing areas required. Solidified sediments have increased mass of unsolidified sediments. Most effective on partially-dewatered/high-solid sediments.	Moderate	Retained
Mechanical Dewatering	Centrifugation	Rapidly rotates fluid mixture to separate the components based upon mass. Flocculents are often used to increase effectiveness.	Production rate is based on size and quantity of centrifuges used to dewater. Typical production rate of a single centrifuge is 20–500 gpm. Due to handling issues, more effective on dredge spoils containing a low percent of solids.	Moderate	Retained
	Belt Press	Uses belts that compress sediments against rollers to achieve high-pressure compression and shear to remove water from dredged sediments.	Production rate is based on the size and quantity of belt presses used. Typical production rate of a single belt press is 40–100 gpm. Sediments are initially gravity-drained which could produce high concentration of TSS. PCB mass balance studies conducted on Fox River sediments have shown 96% of mass is retained in dewatered filter cake.	Moderate to High	Retained
	Hydrocyclone	Continuous operating cone-shaped device which uses centrifugal force to accelerate settling.	Production rate and minimum separation size depended upon size of hydrocyclone (larger capacity provides a larger minimum separation size). Typical production rate of a single hydrocyclone is 50–3,500 gpm.	Moderate	Retained
	Diaphragm Filter Press	Dewaters dredged sediments by passing slurry through a vertical filter. Uses inflatable diaphragms to increase pressures on sediments prior to removing sediments from filter.	Production rate is based on the size and quantity of filter presses used. Typical production rate of a single filter press is 1,200–6,000 gpm. Due to nature of operation, does not allow for continuous operation.	Moderate to High	Retained

Table 6-7 Ancillary Technologies (Continued)

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Wastewater Treatment (for mechanical dredging)	Sedimentation	Passive physical separation in a dewatering cell to remove solids.	Basic form of primary treatment used at wastewater treatment facilities. Gravity settling is used the most extensively.	Low	Retained
	Filtration	Water is fed through sand or mixed-media filter for solids retention. Gravity or pressure pumped.	Filtration media is commonly used in CDFs. Most organic compounds, especially hydrophobic ones, are generally removed with the solids.	Low	Retained
	Coagulation Aid, Flocculation and Settling	Coagulant aid added to slurry stream then flowed through clarifiers for thickening.	Coagulant and polymer flocculents used in pilot projects to promote removal of silty clay. Limited full-scale application.	Low to Moderate	Eliminated
	Adsorption Carbon Filter	Uses activated granular carbon.	Useful for removing organic substances. Spent carbon must be frequently discarded and disposed of. The Fox River demonstration projects met effluent water quality criteria without the use of carbon filters, however, carbon use should be considered.	Low to Moderate	Eliminated (but possibly add later)
	Oxidation	Oxidation of organic molecules to carbon dioxide and water by chemical or ultraviolet oxidation.	Technology is effective for removing organic compounds including PCBs.	High	Eliminated
	Mechanical	Discussed under Dewatering Process Options.			
Solid Residuals Management	Sediment	Discussed under Disposal Technologies.			
	Water	Discussed above and returned to site or transported to POTW for treatment and disposal.			
	Air Emissions	Treated on site and discharged at generation site.			
	Other Solids (i.e., PPE)	To local municipal landfill.			

Table 6-7 Ancillary Technologies (Continued)

Technology	Process Option	Description	Implementability and Effectiveness	Cost	Screening Decision
Transportation	Truck	After dewatering, stockpiled solids placed in sealed trucks by backhoes.	Portable and flexible. Readily available.	High	Retained
	Rail	Sediment placed in railcars for hauling long distances.	Limited availability. Difficult loading/unloading logistics.	High	Eliminated
	Barge	High-solids dredged material mechanically placed in barge. After dewatering, offloaded using backhoe and trucks.	Used with mechanical dredging operations. Consider dewatering limitations on barge.	Moderate	Retained
	Pipeline	Transports dredged material in slurry form directly to disposal site or treatment site if necessary.	Preferred for hydraulic dredging and transport over short distances (<3 km). Booster pumps need consideration. Must be hydraulically linked. A 20-mile-long slurry pipe run was successfully implemented over 1 year in White Rock Lake, Texas. Requires sufficient land space near dredging operations to serve as slurry transfer station between the dredge and pipeline.	Moderate	Retained
Water Quality	Containment Structures	Placement of physical barriers (silt screens, curtains, sheet pile walls) to lower TSS transport.	Mixed effectiveness. Highly dependent on site conditions.	Moderate	Retained (but not costed)
	Operator Modifications	Use slower dredging rates and speeds.	Effective, but requires monitoring. Selection of a qualified dredge operator may have the largest influence on dredge or cap implementation.	Low	Retained

Table 6-8 Deposit N Demonstration Project Summary

Parameter	Specification
Dredge Equipment	Hydraulic round cutterhead (Moray/Ultra) Rotating, variable speed 8" pump and 8" double-walled pipeline (single in 1999)
Dredge Period	November 26 to December 31, 1998 August 20 to October 14, 1999 (104 days)
Production Rate	80 cubic yards per day (average)
Hours of Operation	Treatment: 24 hours/day in 1998; 7 days/week, 10 hours/day in 1999
Area	3 acres
Water Depth	8' (average)
Volume/Mass	8,175 cy (112 pounds PCBs)
Percent Solids	0.4%–6% (average is 2%) dredge slurry
Dewatering Method	⅜" shaker screen to 12,000-gallon V-bottom tank Augered to 2- hydrocyclones, to 4 - 20,000-gallon mixing tanks, to 2 - 200-cf filter presses, then stockpiled
Water Treatment	Bag filters, sand filters, and liquid-phase carbon adsorbers
Disposal	Wayne Disposal Landfill (TSCA material) Winnebago County Landfill (non-TSCA material)
Environmental Controls	Perimeter turbidity barriers (80-mil HDPE) Silt curtain Deflection barrier (80-mil HDPE) Real-time in-river water quality monitoring
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0013 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0036 pounds/day monthly average
Monitoring	Daily water quality, air, diver-collected surface sediment, mass balance study, hourly and daily flow rates compiled from USGS
Limitations	Coal and large boulders resting on river bed nearshore—this area not dredged. Additional dredging in west lobe (3" to bedrock) produced very low percent slurry solids.
Removal Goals	Dredge sediment to within 3 inches and 6 inches of bedrock Conduct verification sampling of residuals Also removed sediment from Deposit O
Dredge Costs	$20.73 per cy dredged
Total Costs	$3.9 million ($540 per cy)

Table 6-9 SMU 56/57 Demonstration Project Summary

Year 1999 Parameter	Year 1999 Specification
Dredge Equipment	Hydraulic round cutterhead—used only a few days Hydraulic horizontal auger (IMS 5012 Versi dredge) 9' 12" pump and 12" single- and double-walled pipeline
Dredge Period	September 10 to December 12, 1999 (96 of 108 days)
Production Rate	60 cy/hr (average) 294 cy/day (average) Goal: 200 cy/hr and 900 cy/day
Hours of Operation	Treatment: 24 hours/day and 7 days/week Dredge: 4.3 hours/day (average)
Area	NA
Water Depth	2' nearshore to 14' mid-channel
Volume/Mass	31,346 cy (1,326 pounds PCBs)
Percent Solids	4.4% (average) in dredge slurry Goal: 7.5%
Dewatering Method	Passive dewatered in equalization basins, Horizontal augered/piped to shaker screens, to 7 - 20,000-gallon mixing feed tanks, to 4 - 100-cf and 2 - 200-cf filter presses, then stockpiled
Water Treatment	Equalization basin, sand/gravel filters, granular activated carbon (GAC) filter - 75,256,500 gallons treated Peak capacity 1,100 gpm $0.26/gallon or $64/cy of sediment
Disposal	On-site industrial landfill at Fort James Corp. 26,927 wet tons (11,696 dry tons) $68/cy
Environmental Controls	Anchored silt curtain (8" closed cell foam wrapped in PVC-coated fabric) in adjoining panels
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0026 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0072 pounds/day weekly average
Monitoring	Daily water quality, real-time turbidity, pre- and post-sediment cores, dewatered sediment, dredge slurry, and effluent testing (mass balance study), daily flow rates compiled from USGS
Limitations	Lower percent solids than predicted
Removal Goals	Remove all material within dredge prism to a design elevation of 565' Collect verification samples of surface residuals (only 1 of 19 subunits achieved target depth)
Dredge Costs	$27/cy dredged
Total Costs	$8.97 million ($286 per cy)

Note:
NA - Not available.

Table 6-9 SMU 56/57 Demonstration Project Summary (Continued)

Year 2000 Parameter	Year 2000 Specification
Target Goal	Remove 50,000 cy of sediment, assuming that remaining sediments have <1 ppm PCBs.
Dredge Equipment	3 hydraulic horizontal augers with submersible pumps
Dredge Period	August 23 to November 8, 2000
Production Rate	833 cy/day (average)
Hours of Operation	Treatment: 24 hours/day and 7 days/week Dredge: 24 hours/day and 7 days/week
Area	NA
Water Depth	Same in 1999/2000
Volume/Mass	50,316 cy (670 pounds PCBs; total PCBs removed 2,111 pounds)
Percent Solids	8.4% (average) in dredge slurry
Dewatering Method	Dredge slurry piped to a booster pump, then pumped to land-based facility through to vibrating shaker screens on V-bottom tank, to hydrocyclones, to a 20,000-gallon agitated pump tank, to plate-and-frame mechanical presses (2 - 200 cf)
Water Treatment	Water surge tank, cloth bag filters, sand filters, carbon absorption system, cloth bag filters 66,329,000 gallons treated
Disposal	Trucked to on-site industrial landfill at Fort James Corp. Cell 12A (6 miles away) 51,613 dry tons with 59% solids (average)
Environmental Controls	Anchored silt curtains around perimeter additional silt curtains to separate dredge areas and avoid recontamination
WPDES Effluent Limits	Mercury: 1.7 μg/L daily maximum, 0.0026 pounds/day weekly average PCBs: 1.2 μg/L daily maximum, 0.0072 pounds/day weekly average
Monitoring	Every other day water quality, real-time turbidity, pre- and post-sediment cores, filter cake, dredge slurry, effluent testing, daily flow rates compiled from USGS
Limitations	Dredge area covered with 8" sand cap (required for surface sediments between 1 and 10 ppm PCBs) after one cleanup pass to ensure protection before onset of winter Added larger filter presses and one additional dredge (total 3) to increase production rates
Removal Goals	Remove 50,000 cy of sediment within dredge prism Collect verification samples of surface residuals
Dredge Costs	NA
Total Costs	Actual dredge and on-site disposal cost $8.18 million ($159 per cy) value Cost for management and value of on-site Cell 12A ($296 per cy)

Note:
NA - Not available.

Table 6-10 Summary of Selected Wisconsin Landfills Within Approximately 40 Miles of the Lower Fox River

Facility Name	No.[4]	County	Status		Remaining Capacity [3] (cubic yards)	Notes
			Existing Landfill	Proposed Landfill		
Municipal [1]						
Brown County East	1	Brown	✓		934,875	
Brown County South	2	Brown		✓	8,025,000	b
Superior Services - Hickory Meadows	3	Calumet		✓	7,500,000	
Kewaunee County Southwest	4	Kewaunee	✓		259,367	d
Mar-Oco	5	Marinette	✓		1,080,754	
Outagamie County Southwest Division	6	Outagamie	✓		5,600,000–6,600,000	a
Shawano County Phase 2	7	Shawano	✓		716,500	a
W M W I - Ridgeview Recycling	8	Manitowoc	✓		4,770,000	a
W M W I - Valley Trail	9	Green Lake	✓		4,905,300	a
Winnebago County - Sunnyview	10	Winnebago	✓		5,015,557	
Non-Municipal [2]						
Appleton Papers, Inc. Tn of Harrison	11	Calumet	✓		unknown	
Appleton Papers, Inc. - Locks MI	12	Outagamie	✓		65,800	c
Fort James Corp. - Green Bay West	13	Brown	✓		3,972,984	
Wisconsin Tissue Mills North	14	Winnebago	✓		312,569	

Notes:

[1] Landfill is operated for the disposal of municipal solid waste and some industrial waste. May be either publicly or privately owned.

[2] Landfill is operated for the disposal of industrial waste and is privately owned.

[3] Remaining capacity as of January 1998 and proposed capacity.

[4] Landfill identification for Figure 6-7, Lower Fox River Feasibility Study.

a. Proposed or existing facilities which are expansions to an existing facility.

b. A 3,700,000-cubic-yard monofill was approved as part of this site's Feasibility Study, but this monofill is not proposed or being developed at this time.

c. Not an NR 500-approved facility; landfill modifications required prior to the acceptance of sediments.

d. Facility is a balefill; landfill modifications required prior to the acceptance of sediments.

Table 6-11 Sediment Melter Demonstration Project Summary

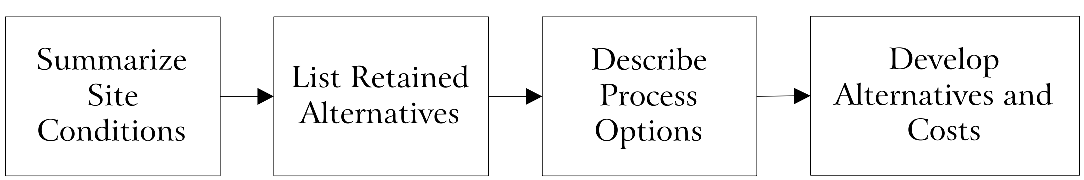
Parameter	Specification
Target Goal	Evaluate the feasibility of a vitrification technology based on standard glass furnace technology to treat contaminated Lower Fox River sediments.
Pilot Melter Equipment	Refractory lined rectangular melter measuring 10 square feet.
Vitrification Period	June 16–23, 2001 and August 11–18, 2001 on a 24-hour/day time frame.
Dryer Equipment	Bench-scale Holoflite® dryer. Drying analysis performed at Hazen Research, Inc., Golden, Colorado.
Sediments Volume	60 tons of dredged and dewatered sediments from Lower Fox River.
Percent Solids	50% by weight.
Dryer Efficiency	Dryer equipment dried sediments to 10% moisture.
Metal Separation	13 bar magnets used to recover significant amounts of magnetic material.
Flux Material	5% sodium sulfate by weight.
Melter Temperature	Ranged between 2,600 and 2,900 ˚F.
Percent Moisture (feed sediments)	Ranged between 5% and 20%.
Pilot Melter Processing Rate	2 tons/day or 170 pounds of river sediment/hour.
Environmental Controls	Air quality control equipment for treating air emissions.
Removal Efficiency	Dioxins and furans are not generated during the treatment process.
Limitations	Moisture content of river sediment affect feed rates and material handling. Moisture content greater than 20% tended to bridge in the charger and cake around the auger of the melter. Downstream end of the pilot melter system experienced plugging due to accumulation of particulates and sulfates, primarily due to use of sodium sulfate as flux.
Glass Aggregate Testing	Performed ASTM water leach test and SPLP test. The tests did not detect any dioxins, furans, PCB congeners, SVOCs, or any of the eight heavy metals in the glass aggregate.
Total Costs	Not applicable. Unit costs were developed for full-scale melter facilities. Unit cost analysis for full-scale melter units are presented in Appendix G.

7 Reach-specific Remedial Alternatives

This section of the FS develops and describes a set of potential remedial alternatives for management of contaminated sediment at each of the four river reaches identified for the Lower Fox River and each of the four zones identified for Green Bay. The alternatives were formed based upon an integration of the information and data presented in the RI Report, the BLRA Report, and Section 6 of this FS Report. The seven generic remedial alternatives described in this section were developed by assembling representative retained process options identified in Section 6. In each of the subsections below, reach-specific alternatives and zone-specific alternatives and process options are selected and developed from the list of seven generic alternatives for the project. Each subsection includes a summary of costs for each process option and each alternative, and a figure showing the amount of contaminated sediment volume remaining in place at various action levels.

Selection of remedial alternatives and process options is dependent upon the general and physical constraints found in each river reach or zone. For example, river depth can affect the feasibility of implementing mechanical dredging or the placement of a cap. Physical impediments in or on the water can also affect whether a specific piece of equipment or process option will be applicable to that reach. The reach-specific alternatives must be developed with these limitations in mind. Accordingly, the alternative development begins with a summary of the general and physical site characteristics by reach or zone. This discussion focuses on those characteristics that may affect the implementability of a specific alternative or process option.

The discussion of remedial alternatives for each reach/zone can be summarized as:



Following the discussion of site conditions, the retained list of site-specific alternatives and process options are then described, along with the justification for the specific process options used to implement those alternatives.

The final step includes a detailed discussion of the FS concept design and the costs associated with the specific alternative. The concept design for each alternative includes a specific set of process options, the assumptions made concerning staging and timing of those options, and implementation of the process. Detailed process flow diagrams are developed to visually describe each alternative from excavation or containment through disposal. Detailed costs and assumptions used to develop each remedial alternative for each reach and zone are presented in Appendix H. The detailed cost tables were developed in accordance with the EPA guidance document for developing and documenting cost estimates during feasibility studies (EPA, 2000b). Based on the cleanup action level selection criteria discussed in Section 5, cost estimates were developed for all action levels retained for each of the reaches and zones.

7.1 Basis for Selection of Remedial Alternatives

The goal of the alternative selection process was to provide a wide range of possible cleanup approaches while also limiting the number of alternatives so that the evaluation process remained manageable. In order to achieve this goal, seven generic remedial alternatives were selected and applied to each reach of the river and zone of Green Bay. These generic remedial alternatives were also applied at each of the action levels. The generic alternatives were then modified, as necessary, due to physical and capacity limitations at each of the reaches and zones.

7.1.1 Generic Remedial Alternatives

This section defines the generic remedial alternatives retained for the Lower Fox River and Green Bay, and then describes the technologies that would be applied based on application of the criteria defined in Section 6. The assembled generic remedial alternatives retained for detailed analysis are:

A. No Action,
B. Monitored Natural Recovery and Institutional Controls,
C. Dredge and Off-site Disposal,
D. Dredge to a Confined Disposal Facility (CDF),
E. Dredge and Thermal Treatment,
F. *In-situ* Capping, and
G. Dredge to a Confined Aquatic Disposal (CAD) Facility.

This suite of remedial alternatives is intended to be representative of the remedial alternatives that are available rather than inclusive of all possible approaches. The use of these alternatives in this FS does not necessarily preclude the use of other alternatives for actual cleanup activities, assuming those other alternatives are implementable and effective. A summary of the generic remedial alternatives retained for each river reach and bay zone is shown in Table 7-1. The cleanup processes carried forward as alternatives in the FS are displayed on Figures 7-1 through 7-8. The sediment volume and PCB masses requiring removal for each alternative and action level are summarized in Tables 7-2 and 7-3, respectively.

Alternative A: No Action

The no action alternative was retained as required under CERCLA and the NCP. This alternative serves as a baseline for comparison with other alternatives and involves taking no action towards a remedy, implying no active management or expectation that the RAOs will be achieved over time. The volume of PCB-impacted sediment calculated for each reach/zone and each remedial alternative is summarized in Table 7-2. Cost estimates include minimal sampling for the continued maintenance of consumption advisories.

Alternative B: Monitored Natural Recovery and Institutional Controls

The monitored natural recovery alternative was also retained as a basis for comparison with other alternatives, but involves an expectation that RAOs will be achieved in 40 years (i.e., ability to consume fish from the Lower Fox River). This alternative assumes that institutional controls will remain in place until acceptable levels of risk have been achieved. Monitored natural recovery is implied in many of these alternatives, because each remedy assumes varying amounts of protectiveness by natural processes by selecting a range of different action levels surrounding the SQT levels identified in the risk assessment (Section 3). Each action level and the amount of risk reduction provided by source removal of contaminated sediment will be compared to the amount of remaining risk and the costs associated with each action level. An active multi-metric long-term monitoring program will be implemented for the MNR alternative. Cost estimates include 40 years of monitoring (assuming 10 years of active or non-active remediation in selected areas and 30 additional years of recovery).

Alternative C: Dredge and Off-site Disposal

Removal and off-site disposal was retained for long-term source control and liability management. Disposal of dredged sediments can be effective and implementable, and provides a basis of comparison for other treatment and disposal options. In addition, this approach can be used for the management of sediment with TSCA-level concentrations (i.e., PCB concentrations greater than 50 ppm). In all cases, disposal would be at an NR 500 landfill. For the purposes of this FS, a generic tipping fee and haul distance were assumed rather than evaluating specific landfills and their available capacity or siting a new landfill. Acceptance at a nearby landfill is considered likely and is reflected by recent removal of land bans for contaminated sediment disposal in some communities.

Figures 7-1 through 7-4 provide an illustration of the process options associated with the generic dredge and off-site disposal remedial alternative.

Alternative D: Dredge to a Confined Disposal Facility (CDF)

Conceptual nearshore CDFs were sited in the Little Lake Butte des Morts and De Pere to Green Bay reaches of the Lower Fox River, and an in-water CDF was sited in Green Bay. Capacity limitations of the Lower Fox River CDFs are discussed in Section 7.1.3 and summarized in Table 7-4. The size of the CDF in Green Bay was varied to provide the necessary capacity at each action level. Nearshore CDF construction in the Lower Fox River includes placement of steel sheet piles along the waterside and a clean soil cap once the CDF has been filled to capacity. In-water CDF construction in Green Bay includes placement of contaminated sediment in an elevated cellular cofferdam and capping with clean sand. Completed CDFs could be used for recreation or habitat upon completion. Figure 7-5 provides an illustration of the process options associated with the generic dredge to a CDF alternative. This illustration also includes the removal and off-site disposal of TSCA-level sediment, which would not be placed in on-site CDFs.

Alternative E: Dredge and Thermal Treatment

Vitrification was retained as the representative thermal treatment process option. As discussed in Section 6, a multi-phased study was conducted by WDNR on sediment from the Lower Fox River to determine operational data, treatment effectiveness and cost-effectiveness of vitrification. The results from the multi-phased study conducted by WDNR demonstrate that thermal treatment is a feasible option for treatment of dredged sediment. The results from the multi-phased study are discussed in Section 6 and detailed in Appendix G. Figure 7-6 provides a schematic of the generic dredge and thermal treatment remedial alternative.

Alternative F: *In-situ* Capping

Several sand cap designs were retained in Section 6 for possible application in the Lower Fox River/Green Bay project. Design factors that influenced the final selection of an *in-situ* cap included an evaluation of capping materials and cap thickness when applied in the field. In general, sandy sediments are suitable capping material, with the additional option of armoring at locations with the potential for scouring and erosion. Geotextiles are often applied in areas with limited water depths or specialized site conditions. Laboratory tests that have been developed in the past indicate a minimum thickness of 30 cm of *in-situ* capping is required to isolate contaminated sediments (EPA, 1994a). Considering the above-mentioned design factors and physical characteristics of the Lower Fox River, a 20-inch sand cap overlain by 12 inches of graded armor stone has been selected as the representative process option for all locations. However, several cap designs may be applicable during final design and implementation. Full-scale design would require consideration of currents during storm events, vessel draft depths, wave energy, and ice scour. As discussed in Section 6, a minimum river depth of 7 to 9 feet is required for any location where a cap is proposed. Figure 7-7 illustrates the process options included in the generic *in-situ* sediment capping remedial alternative.

Alternative G: Dredge to a Confined Aquatic Disposal (CAD) Facility

Construction of a CAD is only technically feasible in Green Bay. Three possible locations were sited in the FS based on bathymetry, water depth, and currents. Each location was assumed to provide enough capacity for each action level. Construction of the CAD includes placement of contaminated sediment in a mechanically-dredged excavation and covering the sediment with 3 feet of clean sand after placement. Figure 7-8 provides an illustration of the activities associated with dredging PCB-impacted sediment and placing sediment in a CAD.

7.1.2 Retained Action Levels

The PCB remedial action levels developed and retained in Section 5 were based on the SQTs derived in the Lower Fox River/Green Bay risk assessment discussed in Section 3. The array of PCB remedial action levels are:

- **Lower Fox River -** 125, 250, 500, 1,000, and 5,000 ppb; and
- **Green Bay -** 500, 1,000, and 5,000 ppb.

A range of action levels is considered for the project to balance the feasibility of removing PCB-contaminated sediment down to each action level (implementability, effectiveness, duration, and cost) with the residual risk to human and ecological receptors after remediation. The 125 ppb and 250 ppb action levels were dropped from the Green Bay Area because the large volumes of sediment requiring removal precluded practical disposal options. The level of residual risk considered acceptable for each alternative will require a decision-making process with the support of long-term modeling efforts. One of the outcomes of developing a range of action levels and alternatives is the adoption of monitored natural recovery (MNR) when sediment is left in place that is above the SQTs. As a result, each action level and each remedial alternative will likely have an MNR component.

7.1.3 Physical and Capacity Limitations

In some cases, the generic alternative may be limited due to physical or capacity constraints. In such cases, a combination of alternatives is required to address the entire volume of impacted sediment. Combinations of alternatives required to implement a complete remedial strategy are included in the sections for each specific reach or zone. A summary of the physical and capacity limitations for each reach of the Lower Fox River is presented in Table 7-4. CDF capacity is limited by the availability of appropriate sites, cap areas are limited by hydrodynamic properties, and thermal treatment volume is limited by vitrification unit capacity and operating parameters. Capping and thermal treatment are not proposed for any zones in Green Bay, and it was assumed that CDF or CAD capacity in Green Bay is unlimited.

7.1.4 Summary of Selected Remedial Alternatives

A summary of the selected remedial alternatives for each reach of the Lower Fox River and zone of Green Bay is presented in Table 7-1, with more detail provided in the subsequent sections. Each reach of the Lower Fox River (Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay) is discussed separately. Green Bay zones 2A and 2B are combined into one remedial area based on similar site conditions and volumes/ concentrations of PCB-contaminated sediment. Green Bay zones 3A and 3B are discussed separately because of different depositional patterns and site characteristics. Green Bay Zone 4 was retained as a separate remedial area from the other zones because of low but wide-spread concentrations of PCBs located in a deeper lake environment.

7.1.5 Basis for Costs

Cost summaries for each alternative include capital costs, labor costs during construction, and long-term operation and maintenance costs (operation and maintenance for 40 years). The long-term cost estimates include interest rates at 6 percent valued at net present day worth. Cost tables also include a separate line item for 20 percent contingency costs. At WDNR's request, the total costs presented herein and carried forward in the FS do not include the 20 percent contingency costs.

Unit costs developed for dredging, treatment, long-term maintenance, disposal costs, dewatering ponds, and construction of new landfills were generated from a variety of sources including, but not limited to: the Lower Fox River pilot demonstration projects at SMU 56/57 and Deposit N, Montgomery-Watson Basis of Design Report for SMU 56/57 (Montgomery-Watson, 1998) for dewatering estimates, a thermal treatment pilot demonstration project using Fox River sediments and a *Unit Cost Study for Commercial-Scale Sediment Melter Facility, Supplement to Glass Aggregate Feasibility Study* (Minergy Corporation, 2002b) for thermal treatment unit costs, the Lower Fox River/Green Bay RI Report (RETEC, 2002a) for site conditions and *in-situ* percent solids, Ogden-Beeman and Associates (OBAI) for dredging and piping costs, and WDNR along with other state officials for local siting fees, tipping fees, disposal and acceptance to in-state landfills, construction of new landfills, and monitoring costs. Unit costs were also developed from cost estimates obtained directly from suppliers and services (i.e., sand and gravel pits, carbon filter treatment, construction of cellular cofferdam), USACE guidance documents, and experience gained from other remediation projects.

7.1.6 Section 7.1 Figures and Tables

Figures and tables for Section 7.1 follow page 7-8 and include:

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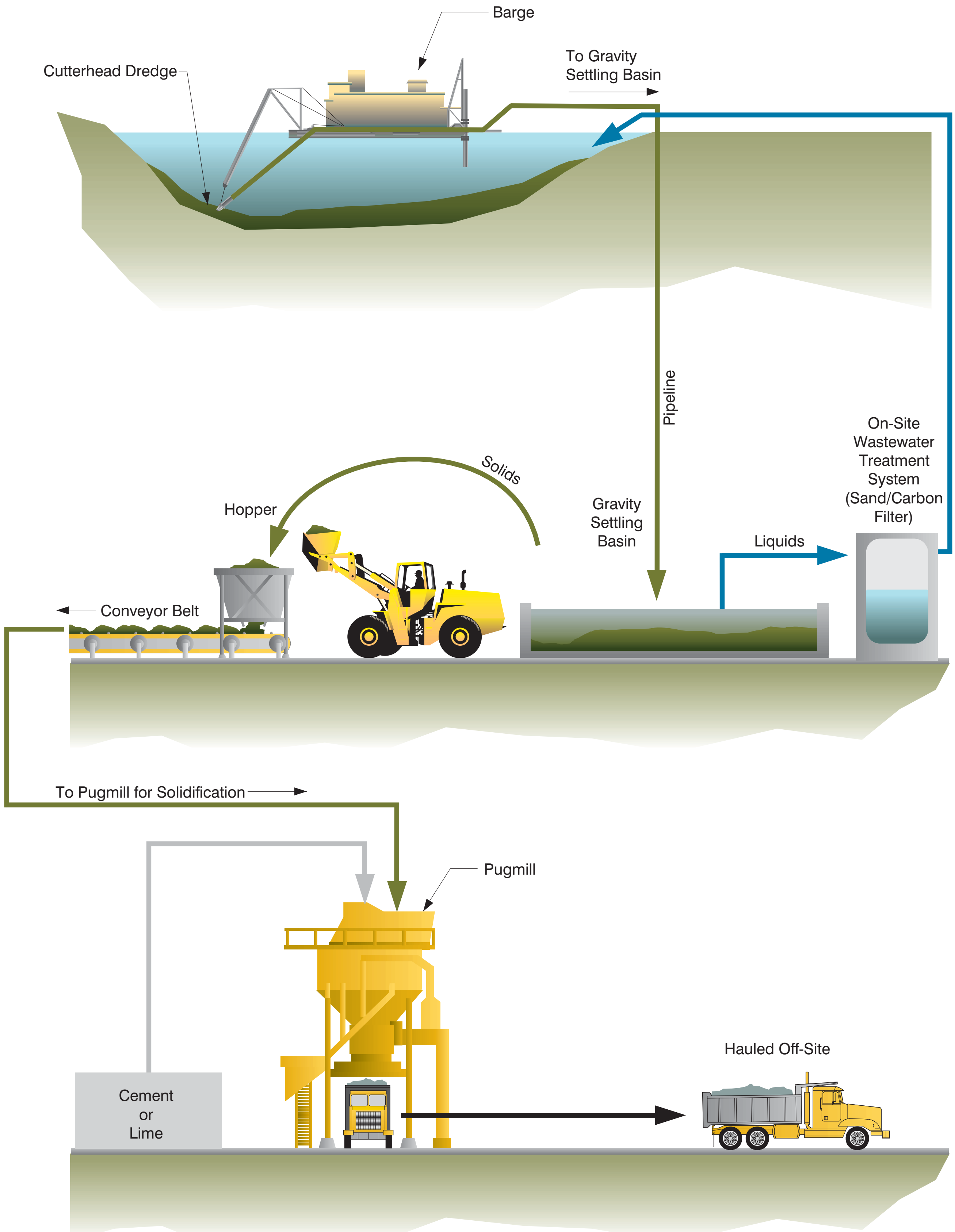
Figure 7-1 Lower Fox River Cleanup Alternative Process Dredge and Off-site Disposal



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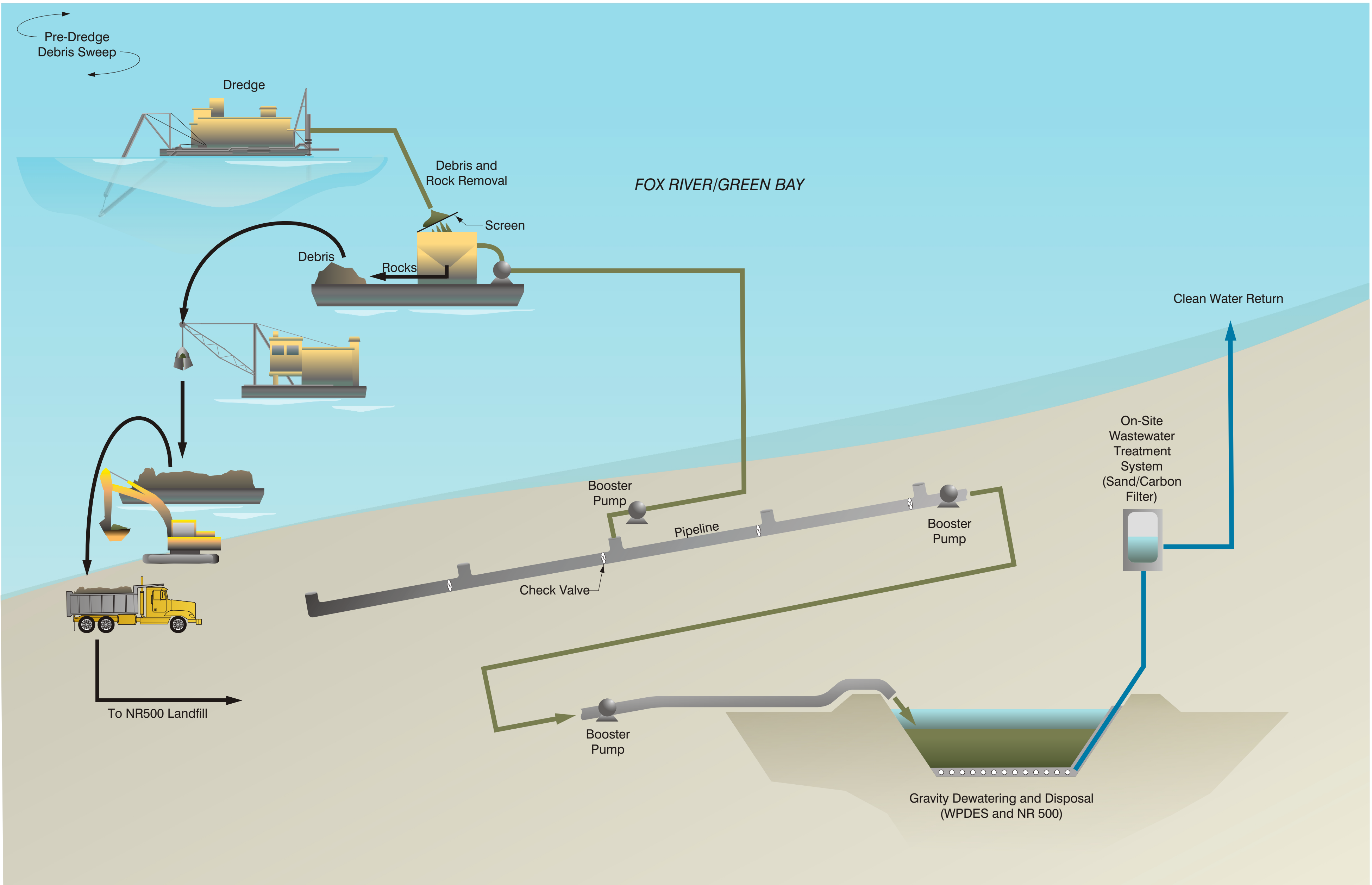
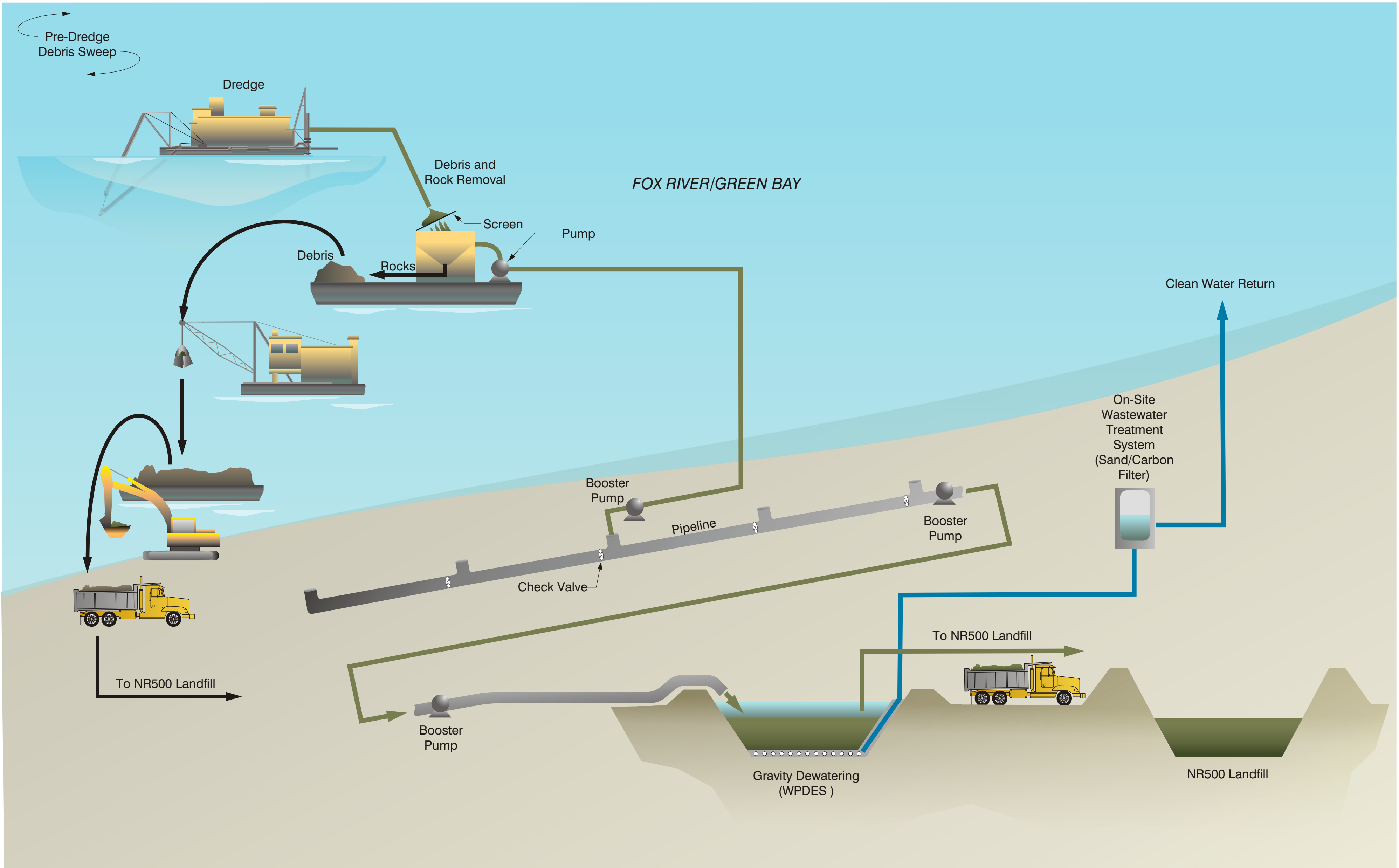
7-2 Lower Fox River Cleanup Alternative C2A
Process Dredge and Off-site Disposal



7-3 Lower Fox River Cleanup Alternative C2B
Process Dredge and Off-site Disposal



7-4 Lower Fox River Cleanup Alternative C3
Process Dredge and Off-site Disposal

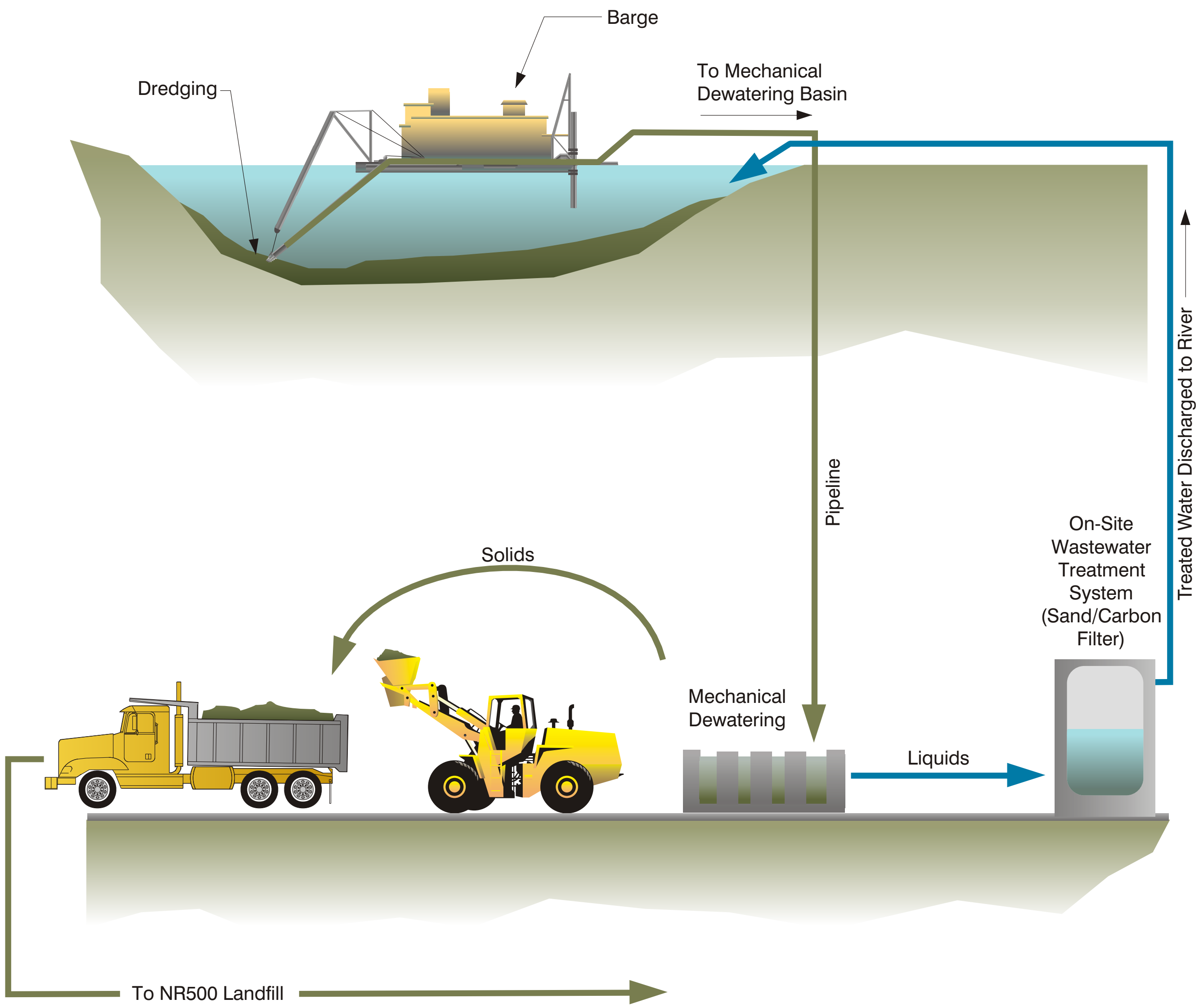
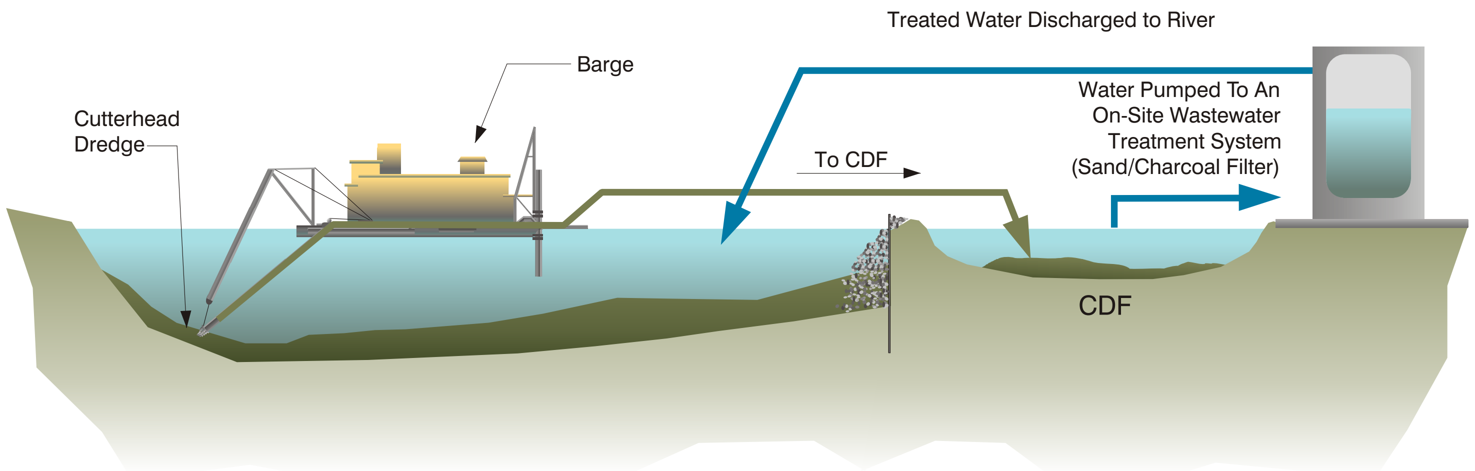
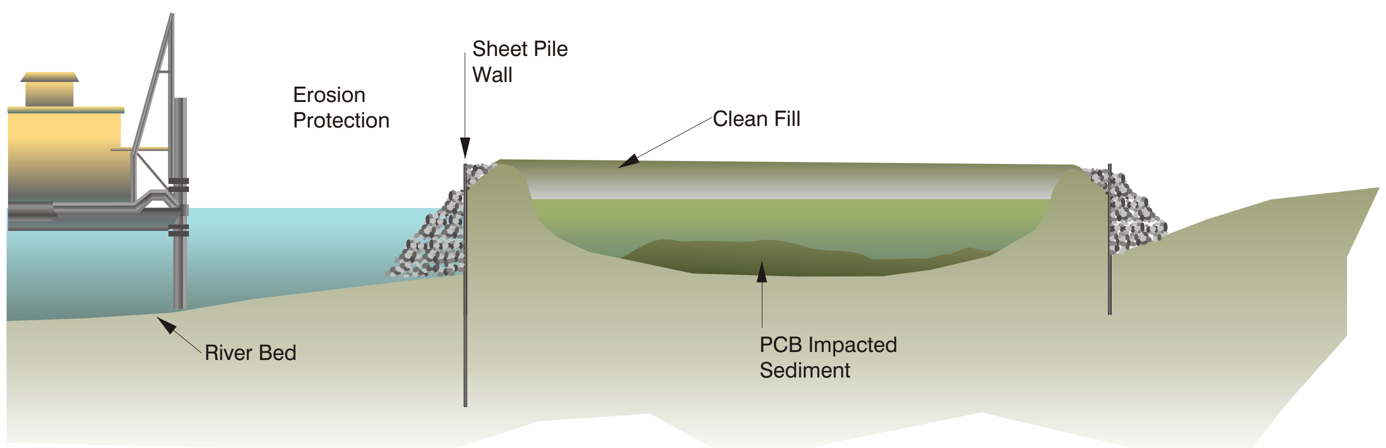


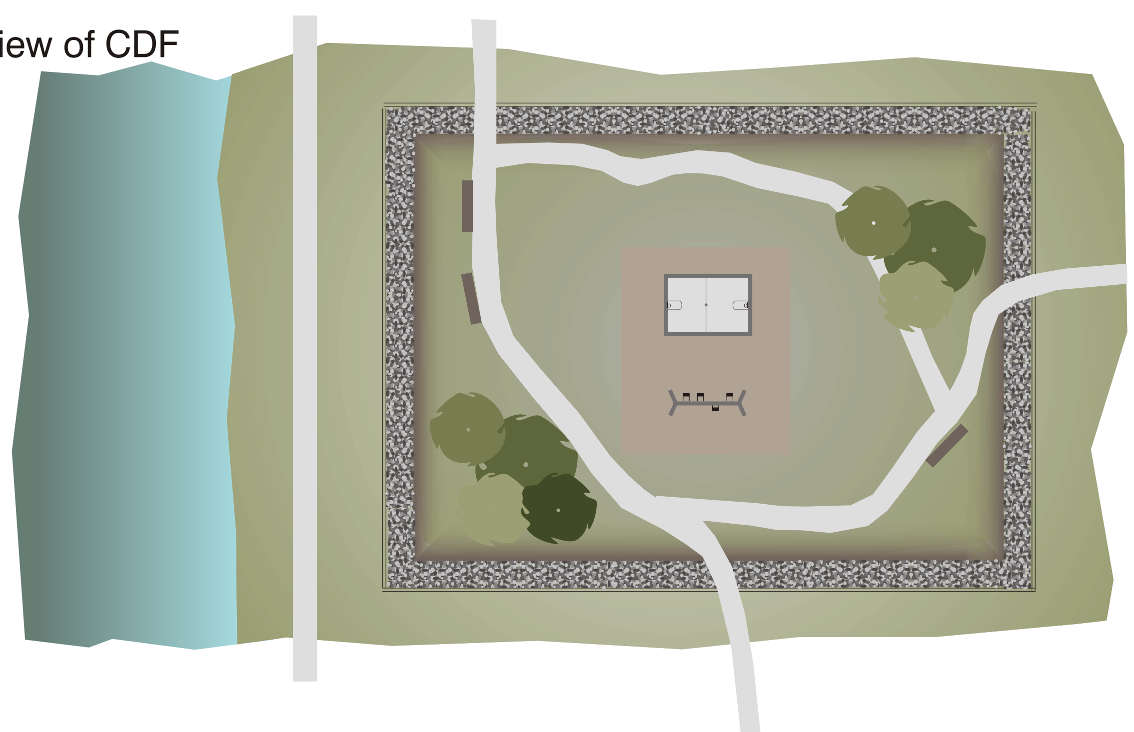
Figure 7-5. LowerFox River Cleanup Alternative Process Dredge and Disposal to Confined Disposal Facility (Non-TSCA Sediments)



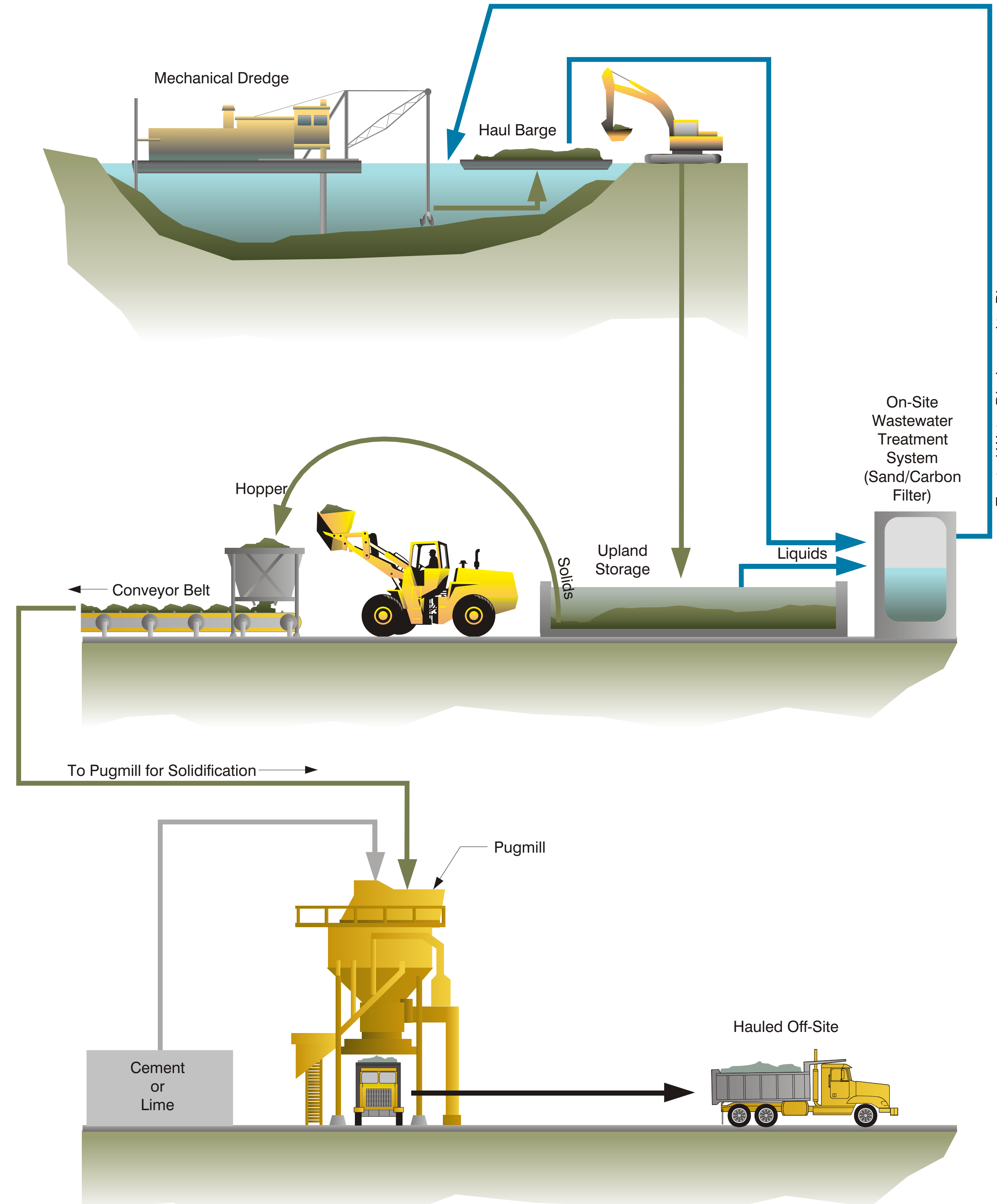
Side View of CDF



Plan View of CDF



Off-site Disposal of TSCA Sediments



7-6 Lower Fox River Cleanup Alternative
Process Dredge and Thermal Treatment

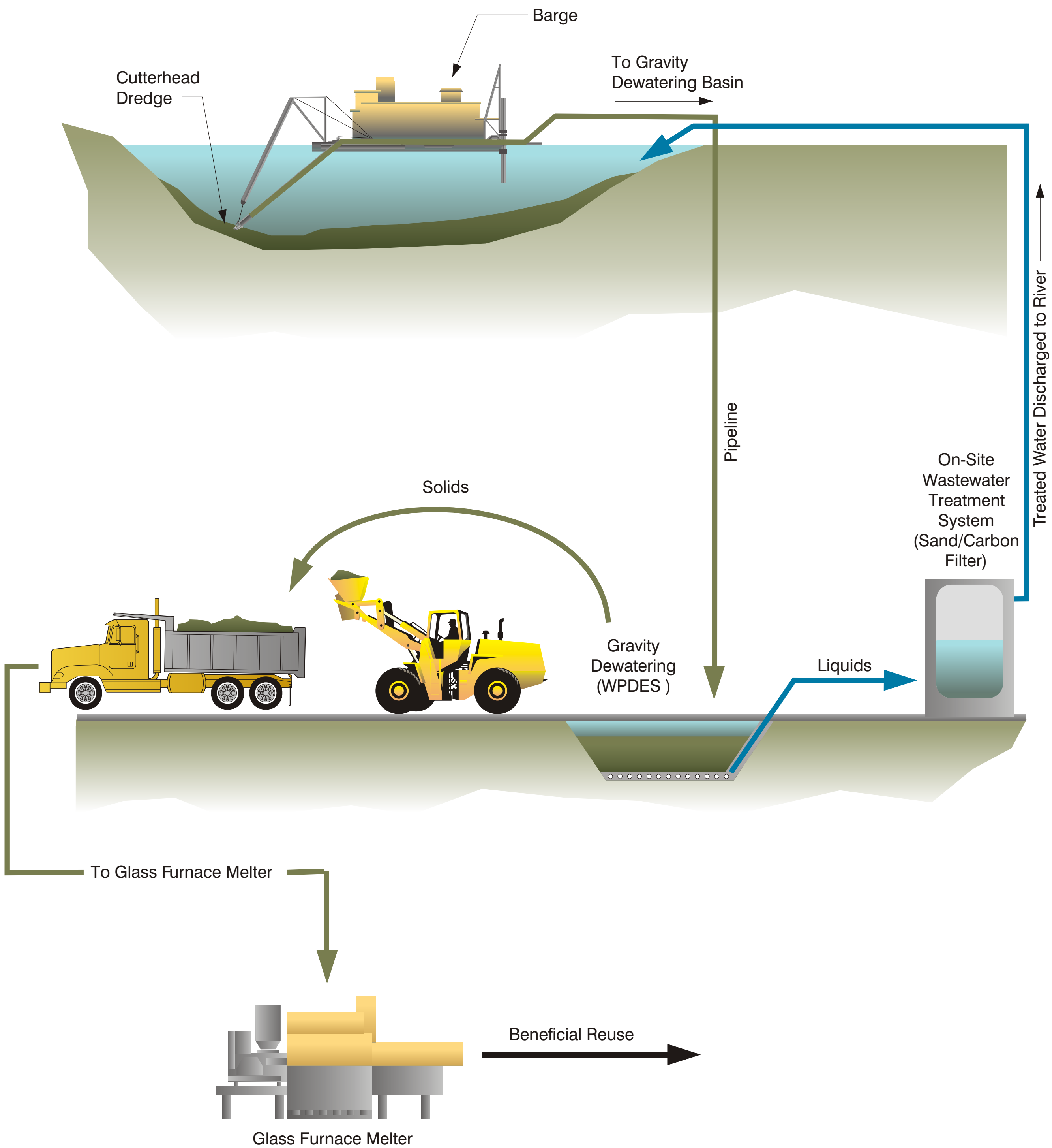
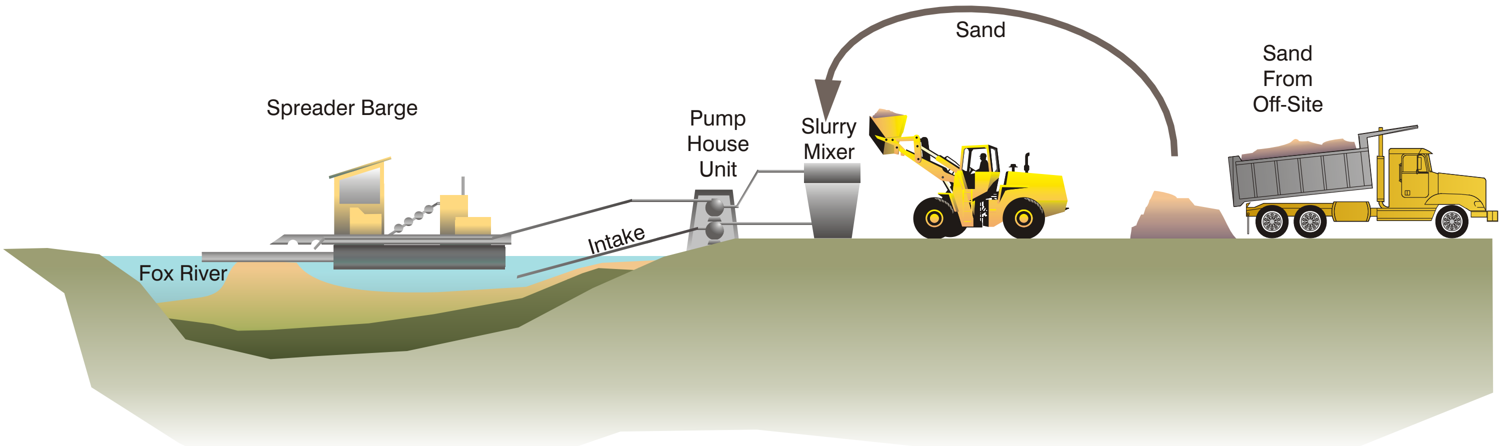


Figure 7-7. Lower Fox River Cleanup Alternative Process *In Situ* Sediment Capping



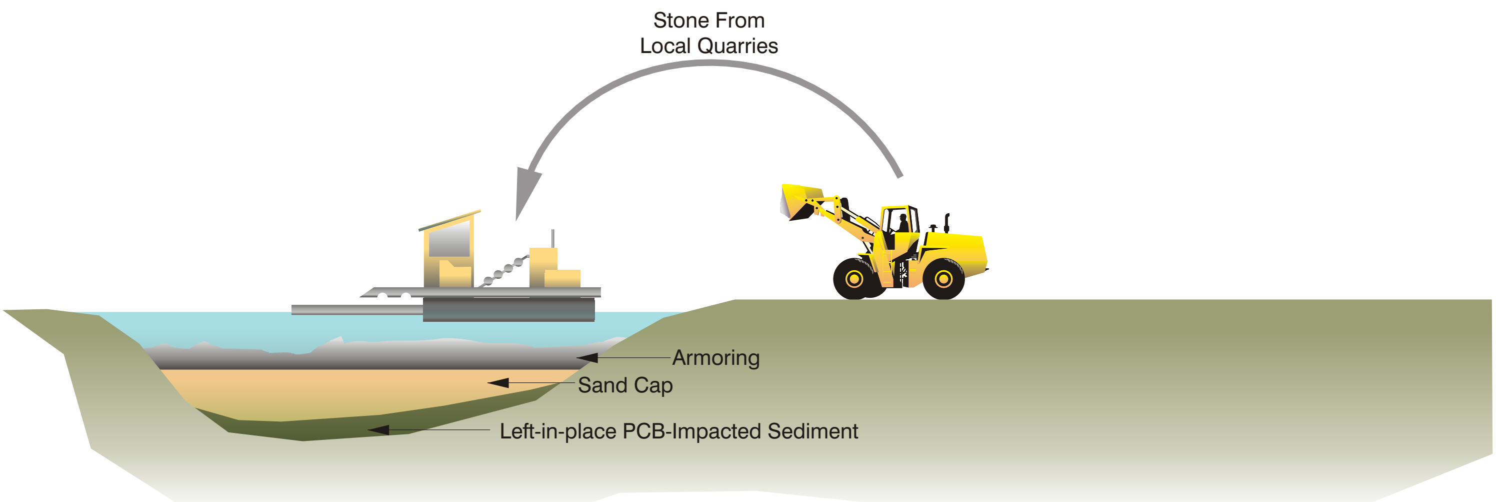


Figure 7-8. Lower Fox River Cleanup Alternative Process Sediment Cap and Partial Dredge Remaining Sediments

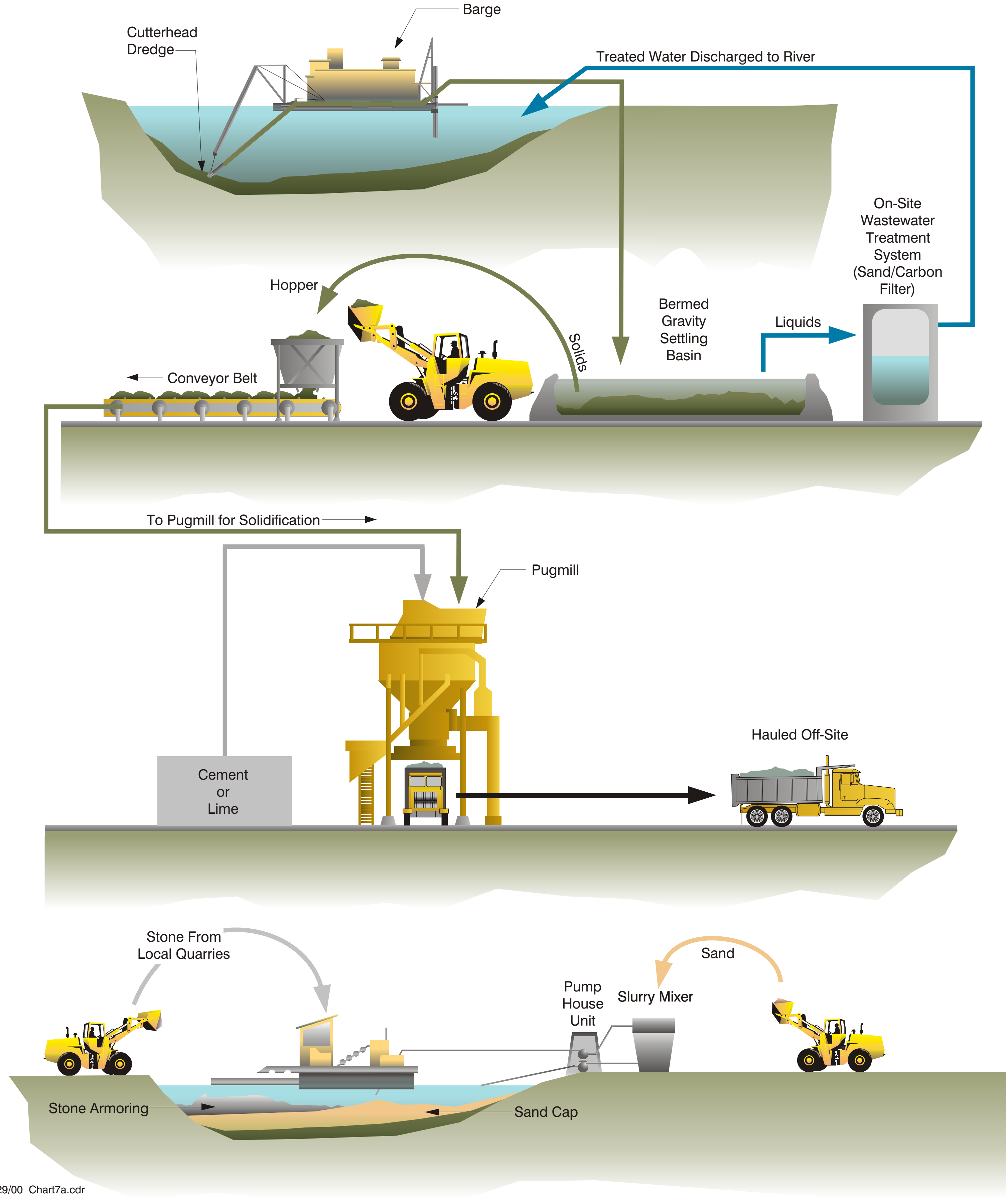


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Table 7-1 Summary of Selected Generic Remedial Alternatives

Alternative Description	Lower Fox River Reaches				Green Bay Zones			
	Little Lake Butte des Morts	Appleton to Little Rapids	Little Rapids to De Pere	De Pere to Green Bay	Zone 2	Zone 3A	Zone 3B	Zone 4
A No Action	✔	✔	✔	✔	✔	✔	✔	✔
B Monitored Natural Recovery and Institutional Controls	✔	✔	✔	✔	✔	✔	✔	✔
C Dredge and Off-Site Disposal [1, 2, 3]	✔	✔	✔	✔	✔	✔		
D Dredge to Confined Disposal Facility (CDF)	✔		✔	✔	✔	✔	✔	
E Dredge and Thermal Treatment	✔	✔	✔	✔				
F Cap in Place	✔		✔	✔				
G Dredge to Confined Aquatic Disposal (CAD) Facility					✔	✔	✔	

Notes:

[1] The Little Lake Butte des Morts Reach also includes Alternative C1 for passive dewatering and Alternative C2 for mechanical dewatering.

[2] The Little Rapids to De Pere and De Pere to Green Bay reaches both include an Alternative C1 for mechanical dredging and Alternative C2 for hydraulic dredging (with a long slurry pipeline to a dedicated NR 500 monofill). Alternative C2 is further divided into Alternative C2A for slurry pipeline directly to the dedicated NR 500 monofill and Alternative C2B utilized an intermediate passive dewatering pond prior to disposal at an existing NR 500 commercial disposal facility.

[3] The Little Rapids to De Pere and De Pere to Green Bay reaches both include an Alternative C3 for hydraulic dredging, mechanical dewatering, and ground transportation to a commercial landfill.

Table 7-2 Volume Allocation Table

Reach/Zone [2, 3]	Action Level (ppb)	Impacted Volume (cy) [6]	TSCA Volume (cy) [6]	Dredge Area (acres)	Alternative C: Dredge and Off-site Disposal (cy)	Alternative D/G: Dredge, CDF/CAD, and Off-site Disposal[1] (cy)		Alternative E: Dredge and Thermal Treatment[4] (cy)	Alternative F: Cap in Place, then Dredge to CDF and Off-site Disposal [5] (cy)		
						CDF/CAD	Off-site	Thermal Treatment	Cap	CDF	Off-site
Little Lake Butte des Morts	125	1,689,173	16,165	761	1,689,173	1,673,008	16,165	1,705,338	435,300	1,237,708	16,165
	250	1,322,818	16,165	697	1,322,818	1,306,653	16,165	1,338,984	323,701	982,952	16,165
	500	1,023,621	16,165	625	1,023,621	1,007,456	16,165	1,039,786	252,057	755,398	16,165
	1,000	784,192	16,165	526	784,192	768,027	16,165	800,358	148,646	619,381	16,165
	5,000	281,689	16,165	174	281,689	265,524	16,165	297,855	59,055	206,469	16,165
Appleton to Little Rapids	125	182,450	0	119	182,450	0	0	182,450	0	0	0
	250	80,611	0	73	80,611	0	0	80,611	0	0	0
	500	56,998	0	48	56,998	0	0	56,998	0	0	0
	1,000	46,178	0	34	46,178	0	0	46,178	0	0	0
	5,000	20,148	0	13	20,148	0	0	20,148	0	0	0
Little Rapids to De Pere	125	1,483,156	0	739	1,483,156	1,483,156	0	1,483,156	898,136	0	585,020
	250	1,171,585	0	665	1,171,585	1,171,585	0	1,171,585	760,521	0	411,065
	500	776,791	0	498	776,791	776,791	0	776,791	492,979	0	283,812
	1,000	586,788	0	328	586,788	586,788	0	586,788	416,370	0	170,418
	5,000	186,348	0	173	186,348	186,348	0	186,348	136,188	0	50,160
De Pere to Green Bay	125	6,868,500	240,778	1,130	6,868,500	2,136,771	4,731,729	7,109,278	2,187,936	2,136,771	2,543,793
	250	6,449,065	240,778	1,103	6,449,065	2,136,771	4,312,293	6,689,843	2,015,618	2,136,771	2,296,675
	500	6,169,458	240,778	1,083	6,169,458	2,136,771	4,032,687	6,410,236	1,926,748	2,136,771	2,105,939
	1,000	5,879,529	240,778	1,034	5,879,529	2,136,771	3,742,758	6,120,307	1,833,253	2,136,771	1,909,504
	5,000	4,517,391	240,778	715	4,517,391	2,136,771	2,380,620	4,758,169	1,415,350	2,136,771	965,269
Green Bay Zone 2	500	29,748,004	0	—	0	29,748,004	0	0	0	0	0
	1,000	29,322,254	0	—	0	29,322,254	0	0	0	0	0
	5,000	4,070,170	0	—	4,070,170	4,070,170	0	0	0	0	0
Green Bay Zone 3A	500	16,328,102	0	—	0	16,328,102	0	0	0	0	0
	1,000	14,410	0	—	14,410	14,410	0	0	0	0	0
Green Bay Zone 3B	500	43,625,096	0	—	0	43,625,096	0	0	0	0	0
Green Bay Zone 4	500	0	0	—	0	0	0	0	0	0	0

Notes:

[1] Alternative G applies to Green Bay zones only.

[2] Volume of *in-situ* material removed (cy) is represented in rows.

[3] Alternatives A and B are not shown on this table, but volume allocations for No Action, MNR, and Institutional Controls are the same as the Impacted Volume (cy) quantities.

[4] Assume no off-site disposal costs for treated sediments.

[5] Cap to maximum extent possible, then dredge to CDF. Take TSCA material off site.

[6] These values include any overburden material located above the impacted sediments of interest, therefore, these values may differ slightly from the values presented in Sections 2 and 5.

Table 7-3 PCB Mass Allocation Table

Reach/Zone [2]	Action Level (ppb)	Density (tons/cy) *In Situ* [3]	PCB Mass (kg) [6]	Alternative C: Dredge and Off-site Disposal (kg)	Alternative D/G: Dredge, CDF/CAD, and Off-site Disposal[1] (kg)		Alternative E: Dredge and Thermal Treatment[4] (kg)	Alternative F: Cap in Place, then Dredge to CDF and Off-site Disposal [5] (kg)		
					CDF/CAD	Off-site	Thermal Treatment	Cap	CDF	Off-site
Little Lake Butte des Morts	125	0.99	1,838	1,838	1,820	18	1,838	474	1,347	18
	250		1,814	1,814	1,792	22	1,814	444	1,348	22
	500		1,782	1,782	1,754	28	1,782	439	1,315	28
	1,000		1,715	1,715	1,680	35	1,715	325	1,355	35
	5,000		1,329	1,329	1,253	76	1,329	279	974	76
Appleton to Little Rapids	125	0.98	106	106	0	0	106	0	0	0
	250		99	99	0	0	99	0	0	0
	500		95	95	0	0	95	0	0	0
	1,000		92	92	0	0	92	56	0	36
	5,000		67	67	0	0	67	43	0	24
Little Rapids to De Pere	125	1.08	1,210	1,210	1,210	0	1,210	884	0	326
	250		1,192	1,192	371	821	274	380	371	441
	500		1,157	1,157	383	774	283	362	383	412
	1,000		1,111	1,111	385	726	284	347	385	379
	5,000		798	798	290	508	214	249	290	259
De Pere to Green Bay	125	1.05	26,620	26,620	26,620	0	26,620	0	0	0
	250		26,581	26,581	26,581	0	26,581	0	0	0
	500		26,528	26,528	26,528	0	26,528	0	0	0
	1,000		26,433	26,433	26,433	0	26,433	0	0	0
	5,000		24,950	24,950	24,950	0	24,950	0	0	0
Green Bay Zone 2	500	1.18	29,896	0	29,896	0	0	0	0	0
	1,000		29,768	0	29,768	0	0	0	0	0
	5,000		6,113	6,113	6,113	0	0	0	0	0
Green Bay Zone 3A	500	1.01	2,156	0	2,156	0	0	0	0	0
	1,000		2	2	2	0	0	0	0	0
Green Bay Zone 3B	500	1.01	4,818	0	4,818	0	0	0	0	0
Green Bay Zone 4	500	1.01	0	0	0	0	0	0	0	0

Notes:

1 Alternative G applies to Green Bay zones only.

2 If multiple disposal/treatment options were available in an alternative, PCB mass was assumed to be distributed proportional to total sediment mass.

3 Density values obtained from appendix of RI Report (2000).

4 Assume no off-site disposal costs for treated sediments.

5 Cap to maximum extent possible, then dredge to CDF. Take TSCA material off site.

6 These values include any overburden material located above the impacted sediments of interest, therefore, these values may differ slightly from the values presented in Sections 2 and 5

Table 7-4 Physical, Capacity, and Process Limitations

Reach [3]	PCB Action Level (ppb)	CDF Volume (m^3)	Cap Volume (m^3) [2]	Thermal Treatment Volume (tons) [4]
Little Lake Butte des Morts	1.25250500e+16	1,337,963 [1] 1,337,963 [1] 1,337,963 [1] 1,337,963 [1] 1,337,963 [1]	3.3229e+28	2.145500e+34
Appleton to Little Rapids	1.25250500e+16	0	0	2.145500e+34
Little Rapids to De Pere	1.25250500e+16	0	6.8560e+29	6.440001e+34
De Pere to Green Bay	1.25250500e+16	9.7480e+29	2.6550e+34	6.440001e+34

Notes:

1. The CDF dredge volume capacity in the Little Lake Butte des Morts Reach includes the Arrowhead Park CDF (750,000 cy) and the Menasha CDF (1 million cy).
2. The required cap volume decreases with higher action levels as the surface area footprint for each subsequent action level decreases.
3. No limitations for the Green Bay zones.
4. The thermal treatment volume capacity is based on vitrification unit information provided by Minergy (2002a, 2002b). The capacities assume one-250 glass tons per day integrated storage vitrification unit for Little Lake Butte des Morts and Appleton to Little Rapids reaches and two-375 glass tons per day standalone storage vitrification units for Little Rapids to De Pere and De Pere to Green Bay reaches.

7.2 Little Lake Butte des Morts Reach

An overview of the Little Lake Butte des Morts Reach and PCB-impacted sediments is shown on Figure 7-9. The retained alternatives and associated costs are presented in Table 7-5.

7.2.1 General Site Characteristics

Little Lake Butte des Morts is located principally within Winnebago County, and is bordered by the communities of Neenah, Menasha, and Appleton (Figure 7-9). Land use in the vicinity of the lake is a combination of both industrial and residential.

The river within this reach is generally broad and shallow at the southern end, narrowing and deepening as the river flows north and constricts in the vicinity of Stroebe Island near Appleton. As discussed in Section 5, most of the depositional areas identified as requiring remediation are in the southern part of the reach (deposits A, C, POG, and D) where water depths are shallow, generally between 3 and 7 feet, and flow is reduced. Water depths average about 4 to 5 feet at deposits A and B. North (downstream) of the railroad bridge, the water depth ranges from 2 feet nearshore to 13 feet in the federal channel near Stroebe Island, and then deepens to 23 feet as the river narrows at Appleton. General water depths are presented in Ocean Surveys (1998).

Average stream velocity in Little Lake Butte des Morts is 0.49 ft/s (0.15 m/s), with 100-year maximum flows predicted at 2.82 ft/s (0.86 m/s). Average and 100-year flows were given in Table 2-1. The nature and extent of PCB-impacted sediments in this reach, as summarized in the RI, includes the following:

- Maximum detected concentration - 222,722 μg/kg (avg. 15,043 μg/kg),
- Total PCB mass - 1,874 kg,
- Total PCB-impacted volume - 1,533,205 m^3, and
- Maximum PCB sample depth - 150 to 200 cm depth in Deposit E.

These quantities represent total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section will likely be larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

Physical impediments to sediment management in Little Lake Butte des Morts include the railroad bridge that transects the river between the Menasha Lock on the eastern shore and Fritse Park on the west, and the State Highway 10 bridge that crosses Deposit E. The railroad bridge is sufficiently low to prevent the on-water movement of dredging equipment between the southern and northern portions. Underwater structures that must be considered include existing water intake lines for Eggers Industries and Kimberly-Clark, located in Deposit A. The Eggers Industries line is abandoned, but the Kimberly-Clark line is still active. Neenah Slough flows through Arrowhead Park, and must be considered with any action involving deposits A, B, or C.

7.2.2 Selected Remedial Alternatives

This section defines the remedial alternatives for the Little Lake Butte des Morts Reach, and then describes the retained technologies that would be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for Little Lake Butte des Morts include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all river sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an existing NR 500 commercial disposal facility.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

E. Remove sediment with PCB concentrations exceeding the selected action level and treat this sediment using thermal treatment. Treated sediment may be beneficially reused.

F. Place a sand cap over contaminated sediments to the maximum extent practicable. Mechanically remove all TSCA sediments from cap areas prior to capping and dispose in an existing NR 500 commercial disposal facility. Dredge remaining sediment and place dredged sediment in a CDF.

Alternative G is not retained for the Little Lake Butte des Morts Reach. Construction of a CAD in Little Lake Butte des Morts is not practical in shallow water depths and limited space. The process options that can be applied to the remedial alternatives are described below.

7.2.3 Description of Process Options

Monitoring

Monitoring of physical, chemical, and biological media is applicable for Alternatives B through F. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; IJC, 1997; SMWG, 1999; Krantzberg *et al.*, 1999). The following references were used in this FS Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Washington State Department of Ecology (Ecology), *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- USACE, *Monitoring Considerations for Capping* (USACE, 1992);
- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);
- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);
- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);

- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b);

- Sediment remediation case study projects presented in Appendices B and D of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Control Options

Institutional controls appropriate to Little Lake Butte des Morts include:

- Maintenance of the fish and waterfowl consumption advisory;

- A moratorium on any future dredging within the navigation channel;

- Deed restrictions on any in-water activities that could result in sediment disturbance (e.g., marina construction or over-water development);

- Access restrictions to contaminated areas (i.e., Arrowhead Park);

- Continued restriction on the use of the Lower Fox River for domestic water supplies; and

- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal is identified for Alternatives C through F. For the Little Lake Butte des Morts Reach, the most practicable dredging option for large-scale removal is hydraulic dredging. The relatively shallow water depths and large volumes within the reach preclude wide-scale application of a mechanical dredge or excavator. However, mechanical dredging is practicable and better suited to remove the relatively small volumes (estimated at 16,000 cy) of sediment exceeding 50 mg/kg PCBs (TSCA level) that needs to be processed separately. In shallow areas with low to moderate flow velocities, dry excavation may be a cost-effective and appropriate removal technology depending upon site conditions and selected disposal sites.

Dredge Equipment. For the purposes of this FS, a hydraulic cutterhead dredge (round or horizontal auger) with a 10-inch pipeline has been selected for the remedial alternatives identified in this reach where a hydraulic dredge would be employed. While larger dredges are available, use of the 10-inch pipeline allows a greater degree of control over resuspension of contaminated sediments during removal operations, provides for a removal time frame of less than 10 years, and limits the size required of a gravity dewatering pond or structure. The operating assumption is that dredging would occur only during normal daylight hours (10 hours per day) during a normal work week (5 days per week), since Little Lake Butte des Morts includes residential areas. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Both the round and horizontal auger cutterheads are commonly employed hydraulic dredges, with multiple capable portable dredges in the small- to medium-size range available in the Great Lakes region. Required operator experience and skills are also available in the region. Sediment remedial demonstrations by public agencies (i.e., ARCS Program Remediation Guidance Document [EPA, 1994a] and Environment Canada [SEDTEC, 1997]) have highly rated the small horizontal auger dredge for contaminated sediment removal. A horizontal auger equipped with two 10-inch pipelines and a 12-inch pipeline, for example, was employed at the Manistique Superfund site and the SMU 56/57 demonstration project in the Lower Fox River, respectively. A suitable alternative is the small cutterhead dredge; the cutterhead is the only hydraulic dredge capable of effective operations if debris or compacted sediments are present. A ladder cutterhead was successfully used at the Deposit N demonstration project on the Lower Fox River.

A mechanical dredge would be employed for removal of small volumes of sediment with greater than 50 mg/kg PCBs that require separate management. A mechanical bucket can be deployed with greater accuracy and precision to minimize the volume of sediments and free water that must be managed. For this river reach, a small (3-cy) closed clamshell environmental bucket mounted on a shallow-draft (3 feet) barge could be used in the remedial alternatives. To move the sediments to shore, shallow-deck barges fitted with sideboards to contain contaminated sediments and associated water would be used.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D) (Appendix B). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream. For the purposes of this FS, silt curtains were included in the removal costs despite site performance during the Deposit N project.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass (*Sediment Technologies Memorandum*, Appendix B). However, for the purposes of this FS, over-dredge was not included in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For the majority of the alternatives utilizing hydraulic dredging in the Little Lake Butte des Morts Reach, dewatering has been configured as a two-step process using a gravity settling pond followed by solidification of solids. The water would be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. For the alternatives involving upland off-site disposal (Alternatives C and E), the gravity settling pond would be located in Arrowhead Park. For the dredge to CDF alternatives (Alternatives D and F), dewatering would be conducted directly within the CDF (discussed in detail below). A mechanical dewatering option has also been included for cost comparison in Alternative C2.

The proposed dewatering system would meet the criteria defined in Section 6 of this FS Report, in terms of production rate, effectiveness, practicability, and discharge water quality. The dewatering system would operate 24 hours per day near residential areas. Assuming adequate land space can be secured, a passive dewatering system is preferable to active mechanical dewatering because of lower noise impact to the surrounding community and reduced operational costs. Final selection of the dewatering process will be determined during the remedial design phase.

Passive Dewatering. Alternative C1 would include the construction of two approximately 9-acre gravity separation ponds in Arrowhead Park. The ponds would be enclosed with earthen berms to allow a ponding depth of 8 feet and lined with asphalt pavement. Each settling pond would receive dredged sediment in 13-week increments and, therefore, contain a full season of dredge slurry. After a pond is filled, the sediment would be allowed to dewater to 20 percent solids, based on dewatering studies (Montgomery-Watson, 1998). Residual water would be drained, treated, and discharged. Sediment would be removed in preparation for the next dredge season. If geophysical properties are a limiting factor for siting the dewatering ponds at Arrowhead Park, an alternative location or approach for dewatering would be required.

For the dewatering operations of mechanically-dredged TSCA sediment (Alternatives D and F), limited capacity barges (500 cy) would be used. Dewatering of sediments would occur by allowing the solids to gravity settle in the barge, and collecting the free water for treatment and discharge.

Solidification. The solids content after dewatering for the hydraulic or mechanical dredging is assumed to be 20 percent (weight per weight [w/w]) and may still be difficult to manage due to high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. Pozzolan is an inert material often mixed with lime to create a cemented end product. For FS costing purposes, 10 percent (w/w) lime was added as the reagent. This was the reagent added (without problems) during the Lower Fox River SMU 56/57 demonstration project (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and removed from the pond using standard earthmoving equipment . If the contractor prefers, sediment may first be removed from the settling pond and mixed with reagent in a pug mill as shown on Figures 7-1 and 7-5. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

Mechanical Dewatering. A mechanical dewatering option (Alternative C2) is included for cost comparison to passive dewatering (Little Lake Butte des Morts only). Mechanical dewatering may also be used for Alternative E. Final selection of a dewatering process will be determined during the design phase. Mechanical dewatering involves pumping the hydraulically-dredged slurry into conditioning tanks or ponds, where the slurry is adjusted to the appropriate solids content, and chemicals are added to assist in the dewatering process. Mechanical dewatering would include shaker screens and hydrocyclones or belt filter presses after initial conditioning. Based on dewatering results from both of the Lower Fox River demonstration projects, the estimated percent solids of the filter cake after shaker screen, hydrocyclones, and belt filter presses ranged between 40 and 60 percent solids (Foth and Van Dyke, 2000; Fort James *et al.*, 2001).

Treatment Process Options

Water Treatment. Prior to water discharge back to the river, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary (Foth and Van Dyke, 2000). However, additional granular activated carbon (GAC) treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC carbon treatment is $0.40 per thousand gallons of water treated.

Thermal Treatment. Several on-site treatment process options were retained from the screening process in Section 6 that are applicable to the Lower Fox River/Green Bay remediation project. However, only vitrification was selected for costing purposes because the multi-phased study conducted by WDNR has provided data which indicates that this treatment technology is a viable option.

A full-scale vitrification unit will be constructed for the Little Lake Butte des Morts Reach. The facility will be integrated into the operation of an adjacent industrial facility with which it can share resources and is equipped with on-site storage capacity. Passive dewatered sediment enters the plant and is dried to approximately 10 percent moisture in the dryer unit. The sediment is mixed with a fluxing material and fed into a large melter, capable of maintaining temperature around 2,900 °F. The sediment melts into a molten material and passes through the water bath for quenching resulting in glass aggregate.

For the purposes of this FS, sediment treatment by vitrification is assumed to occur over a time frame of 10 years. The vitrification process is assumed to operate 24 hours per day, 7 days per week, and 350 days per year. The unit will be designed to have a capacity of processing 613 tons of sediment per day and produce 250 tons of glass aggregate per day.

On-site Disposal Process Options

Two CDFs are proposed for the Little Lake Butte des Morts Reach. The first CDF is proposed as a nearshore facility at the south end of the lake at Arrowhead Park (Figure 7-10). The second CDF is proposed as a peninsula built into the river over most of Deposit POG to the northeast edge of the railroad bridge at Menasha (Figure 7-11). In both cases, the CDF design and location were selected to minimize impacts to upland riparian habitat and landowners.

The CDF at Arrowhead Park would consist of two contained structures: one in Arrowhead Park and the other encompassing Deposit A at Menasha, in front of the Kimberly-Clark facility. This arrangement accommodates a channel for the Neenah Slough. Contaminated sediments from within the slough area would be dredged into the CDF, and the shoreline backfilled with clean sediments to create a potential wetland area. Dredged sediment capacity at the Arrowhead CDF is estimated to be 750,000 cy.

The second facility at Menasha would be placed completely in-water, and would require rubblemound jetties at the southern and northern ends to protect the backwater areas from erosion. A peninsula CDF was selected in order to allow for maintenance of the existing navigation channel from the Menasha Lock. The dredged sediment capacity at the Menasha CDF is approximately 1 million cy.

The concept for all Lower Fox River CDFs is a hybrid of the solids retention and hydraulic isolation designs discussed in Section 6. PCBs are predominately tied to the solids fraction of the sediments, but may dissolve and be carried at low concentrations in pore water. As such, the design includes placement of a steel sheet pile wall driven to 30 feet below the final grade elevation into the relatively impervious clay layer underlying much of the soft sediments. Using this configuration, it should not be necessary to line the bottom of the CDF. The overall height of the CDF would be above the 100-year flood level, approximately 6 feet above the normal elevation of the river. The retention berms would be constructed with riprap to prevent flood or ice damage to the CDF.

As stated in Section 6, in-water CDFs are unlikely to be permitted for the placement of untreated TSCA-level sediments. Dredged TSCA-level sediments will be transported off-site to an appropriate disposal facility.

During hydraulic dredging, the CDF would be utilized as a gravity-settling pond, with the overflow water decanted and filtered. Upon completion of dredging, the sediment would be allowed to further settle, and eventually would be capped with 3 feet of clean sediment and revegetated. Long-term use of the CDF surface could include a park or multi-use open space. As the Lower Fox River sediments are relatively low in organic debris, a methane collection system is not expected to be needed for the CDF.

No CAD sites are feasible in this stretch of the river because of water depth, current velocity, and accessibility.

Off-site Disposal Process Options

All sediment samples collected to date from Little Lake Butte des Morts indicate that the PCB concentrations are below 500 ppm. EPA TSCA 40 CFR regulations (Parts 750 and 761) define PCB-contaminated material as containing more than 50 ppm but less than 500 ppm PCBs. Therefore, all sediment could be shipped to a landfill that conforms to the NR 500 WAC requirements and has received approval per WDNR's agreement with EPA for the disposal of TSCA-level sediments.

Capping Process Options

For the Little Lake Butte des Morts Reach, the water flow velocities are too high to allow placement of a conventional sand cap (Palermo, 1995). For the purposes of this FS, it has been assumed that an armored cap is required. As discussed in Section 7.1.1, the cap would consist of 20 inches of sand overlain with 12 inches of armoring. The areal extent of the cap would be limited to those areas where the minimum average water depth is 9 feet, so that the final water depth is no less than 6 feet in order to allow the use of recreational power boats and prevent disturbance from ice scour. Any TSCA-level sediment will be mechanically dredged prior to capping.

7.2.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for the Little Lake Butte des Morts Reach. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs (Table 7-5). Details used to develop each cost estimate are provided in Appendix

H. The process flow diagrams and dredging/capping footprints for each retained alternative are presented on Figures 7-12 through 7-20.

The following components are discussed for each alternative, when applicable:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Institutional controls and long-term monitoring.

Alternative A: No Action

As required under the NCP, a no action alternative is included for Little Lake Butte des Morts. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active remediation is employed; however, some institutional controls, such as access or resource use restrictions may be employed to reduce risks until RAOs are achieved. This alternative includes costs for 5-year fish tissue sampling events for maintenance of fish consumption advisories that are already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000, which does not include a contingency cost. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources, and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in institutional control costs include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for long-term monitoring and maintenance of institutional controls is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C: Dredge and Off-site Disposal

Alternative C includes the removal of sediments with concentrations greater than the remedial action level with a hydraulic dredge and off-site disposal of the sediments. To compare cost differences between dewatering techniques, Alternative C1 uses passive dewatering and Alternative C2 uses mechanical dewatering. Figures 7-12 and 7-13 provide the process flow diagrams for this remedial alternative while Figure 7-14 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-5. Detailed supporting costs are provided in Appendix H. The total volume of sediment to be dredged in this alternative ranges between 1,689,173 cy for 125 ppb and 281,689 cy for 5,000 ppb action levels.

Site Mobilization and Preparation. Staging for the dredging of the sediments south of the railroad bridge would be conducted at Arrowhead Park. Site mobilization and preparation at Arrowhead Park includes securing the onshore property area for equipment staging, constructing the sediment dewatering ponds, water treatment, sediment storage, and truck loading. Offshore, a docking facility for the hydraulic dredges would be constructed. Estimated property purchase and preparation costs are included in the process components.

For the purposes of the FS, staging for the dredging of the sediments north of the railroad bridge will be on property located adjacent to the Menasha Locks. This facility is solely for the purpose of docking the hydraulic dredging equipment—the dredge slurry will still be pumped to Arrowhead Park. Estimated property purchase and construction costs for the docking facility are included in the process components.

Sediment Removal. Sediment removal would be conducted using a 10-inch pipeline cutterhead hydraulic dredge. Given the volumes and operating assumptions described in Section 7.2.3, the complete removal effort would range from 12.4 years for 125 ppb to 2.1 years for 5,000 ppb action levels. Pipelines would extend directly from the dredging area to Arrowhead Park for dewatering. For longer pipeline runs, it may be necessary to utilize in-line booster pumps to pump the slurry to the Arrowhead Park dewatering facility. Silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; $35,000 costs for installing silt curtains were included in this FS. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs using hydraulic dredging are estimated to range from $37,700,000 for 125 ppb to $8,900,000 for 5,000 ppb action levels. Pre-removal of TSCA-level sediments are estimated to cost $1,700,000.

Sediment Dewatering - Alternative C1. Gravity dewatering includes land purchase, site clearing, and dewatering pond construction. Key assumptions include a 2.3 percent by volume (w/w) dredged solids concentration and 2,464 gpm water production rate for the dredge based on results from the 1999 Lower Fox River demonstration projects (Foth and Van Dyke, 2000; Montgomery-Watson, 2000). Although the recent dredging work conducted at SMU 56/57 (Fort James *et al.*, 2001) showed the average percent solids in dredge slurry was 8.4 percent w/w (range 3.5 to 14.4 percent), the lower and more conservative percent slurry solids measured during the 1999 activities was used for FS costs. Sediment dewatering would be done in a two-cell passive filtration system at Arrowhead Park. The system would accommodate 26 weeks of solids dredge production rate, plus a maximum water surge storage capacity. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in disposal costs). Dewatering costs also include pond decommissioning and site restoration at the completion of the project.

Sediment dewatering costs for Alternative C1 (primarily construction costs) are estimated at $3,200,000.

Sediment Dewatering - Alternative C2. Mechanical dewatering includes land purchase, site clearing, and construction of temporary holding ponds. Dewatering techniques will be similar to the mechanical processes used for both Fox River demonstration projects including a series of shaker screens, hydrocyclones, and belt filter presses. The final percent solids of the filter press cake was about 60 percent solids (w/w) for SMU 56/57 (Fort James *et al.*, 2001) and 40 to 50 percent solids for Deposit N (Foth and Van Dyke, 2000). No additional solidification was required. The dewatering process was simplified into a unit cost of $80 per bone dry ton assuming 50 percent solids after dewatering for the purposes of this FS.

Mechanical dewatering costs for Alternative C2 range from $36,200,000 for 125 ppb to $6,100,000 for 5,000 ppb action levels.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 568,800 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. It may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to range from $2,100,000 for 125 ppb to $1,100,000 for 5,000 ppb action levels for both dewatering methods.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to an existing NR 500 commercial disposal facility. Disposal costs also include the purchase and addition of lime reagent for solidification of dewatered sediment prior to off-site transport. The sediments would be loaded with a front-end loader into tractor-trailer end dumps fitted with bed liners or sealed gates. Each load would be manifested and weighed. Each tractor-trailer would pass through a wheel wash prior to leaving the staging area to prevent tracking soil onto nearby streets and highways.

The estimated percent solids of dewatered sediment after 6 months of setting in a passive dewatering pond is 20 percent solids (based on the SMU 56/57 Basis of Design Report [BOD] [Montgomery-Watson, 1998]). Therefore, the addition of 10 percent (w/w) lime for further solidification was added to the disposal costs. No solidification costs were added to the Alternative C2 disposal costs since the expected percent solids after mechanical dewatering is greater than 50 percent solids. Solidification costs range between $62,000,000 for 125 ppb and $10,400,000 for 5,000 ppb action levels. Lime purchase is about 20 percent of the solidification costs.

Costs of sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to range between $184,200,000 for 125 ppb and $30,900,000 for 5,000 ppb action levels for Alternative C1. Disposal costs for Alternative C2 range between $45,700,000 for 125 ppb and $7,700,000 for 5,000 ppb action levels.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of the pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre- and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time.

If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

The estimated cost for the maintenance of institutional controls and fish consumption advisory monitoring is $4,500,000. Costs for implementation monitoring during removal are included in the removal and water treatment costs. Refer to Alternative B - Monitored Natural Recovery for monitoring costs associated with long-term multimedia fish, bird, invertebrate, sediment, and surface water sampling events to determine achievement of project RAOs.

Alternative D: Dredge Sediment to Confined Disposal Facility, Off-site Disposal of TSCA Material

Alternative D includes removal of sediments to an on-site CDF for long-term disposal of the materials. As previously noted, sediments with PCB concentrations exceeding 50 ppm are not to be disposed of in a nearshore CDF. As such, this alternative utilizes mechanical dredging to remove those smaller volumes of sediment greater than 50 ppm for solidification and disposal at an existing NR 500 commercial disposal facility.

Figure 7-15 provides the process flow diagram for this remedial alternative and Figure 7-16 illustrates the locations of CDFs and the extent of residual sediment impacts following implementation of Alternative D. Table 7-5 contains the summary costs to implement Alternative D. The total volume of sediments to be dredged are similar to those identified in Alternative C.

Site Mobilization and CDF Construction. The process is staged to construct and complete dredging to the Arrowhead Park CDF, south of the railroad tracks, before proceeding to construction and dredging at the Menasha CDF. Both CDFs would be constructed for the 125, 250, and 500 ppb action levels. Only the

Arrowhead Park CDF would be constructed for the higher action levels. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing onshore and in-water CDFs (110 acres), the water treatment facility, the offshore docking facility for both the mechanical and hydraulic dredges, and site restoration. Estimated property purchase and preparation costs are included in the following process components. CDF construction will require up to 6 months prior to dredging activities.

CDF construction is estimated at $69,300,000 for both facilities and $37,300,000 for the Arrowhead facility only.

Sediment Removal. Mechanical dredging of the limited TSCA-level sediment volumes would occur prior to initiation of hydraulic dredging. Mechanical dredging would require a staging area for dredged sediments to be offloaded and transported off site. The cost for constructing the upland staging area is included in the disposal costs for management of TSCA-level sediments. Mechanical removal of the approximately 16,000 cy would require approximately 0.2 year.

Hydraulic sediment removal techniques for this alternative are equivalent to that described for Alternative C, except that dredge slurry will be pumped directly to the CDF for dewatering. The estimated time to complete hydraulic dredging ranges between 12.3 years for 125 ppb and 2 years for 5,000 ppb action levels.

Sediment removal costs by hydraulic dredging for Alternative D are estimated to range between $23,400,000 for 125 ppb and $6,500,000 for 5,000 ppb action levels. Mechanical dredging costs (for TSCA material) are estimated at $1,700,000 for all action levels.

Sediment Dewatering. Passive dewatering will occur directly within the CDF berms for hydraulic dredging. Mechanically-dredged sediment will dewater on-barge for two days prior to off-loading to the upland staging area. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements. Dewatering costs are incorporated into dredging costs.

Water Treatment. Overflow return water from the CDFs and on-barge dewatering would be treated before discharge to the river. Treatment and monitoring requirements are expected to be the same as those for Alternative C.

Water treatment costs for Alternative D are estimated to range between $2,100,000 for 125 ppb and $1,100,000 for 5,000 ppb action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of the TSCA-level sediments to an existing NR 500 commercial disposal facility. Sediment disposal to an on-site CDF incurs no costs besides CDF construction and transportation costs included in the mobilization and dredging costs.

The cost for off-site sediment disposal is estimated at $2,000,000 for all action levels.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDFs would be finished with a 3-foot cap of clean soils, and seeded and planted. Additional amenities (i.e., bike paths, wildlife habitat) were not included in the cost estimates. However, this alternative would allow development of these features and would provide a beneficial use of this area for the community. Demobilization and site restoration costs are included under the dredging and CDF construction cost estimates.

Institutional Controls and Monitoring. To ensure that the CDF is functioning as designed, surface sediment and groundwater sampling will address the primary exposure pathways of groundwater leachate and effluent seepage through the berm. Sampling will be conducted on an annual basis with decreasing intervals over time, as appropriate. Groundwater monitoring will include, at a minimum, installation of five shallow perimeter wells around the CDF (three wells downgradient, one upgradient, one in the berm/dike, and one in the CDF if possible). Wells will be sampled at a minimum of two sampling rounds (wet and dry season) per sampling year. Sampling will be conducted annually for the first 3 years and decrease to every 5 years thereafter. The actual number of monitoring wells and sampling sites will depend upon the actual configuration and design of site-specific CDFs. To verify long-term achievement of the project RAOs, refer to the *Long-term Monitoring Plan* (Appendix C) for scope and Alternative B - Monitored Natural Recovery for costs. The monitoring program will be conducted over a period of 40 years.

Long-term maintenance and monitoring of the CDF is included in the CDF construction costs. Long-term monitoring to verify achievement of project RAOs is included in Alternative B costs. The estimated cost for maintenance of institutional controls and fish consumption monitoring of the reach is $4,500,000.

Alternative E: Dredge and Thermal Treatment

Alternative E includes hydraulic dredging of sediments, passive dewatering, and treatment with an on-site integrated vitrification unit. This alternative results in the sediments being transformed into glass aggregate that has a potential for a wide variety of beneficial reuse applications. Figure 7-17 provides the process flow diagram for this remedial alternative and Figure 7-18 illustrates the extent of residual sediment impacts following implementation of Alternative E. Table 7-5 contains the summary costs to implement Alternative E. This alternative addresses the same volume of sediments as Alternative C.

Site Mobilization. Site mobilization and preparation includes securing the onshore property area for equipment staging, water treatment, and offshore docking facility for the hydraulic dredge. Site preparation would also include building or modifying an integrated vitrification unit, capable of processing an estimated 250 glass tons per day.

Sediment Removal. Separate mechanical dredging for TSCA sediments is not required under this alternative since TSCA-level sediments will be treated by the vitrification unit. Hydraulic sediment removal techniques and costs for this alternative are equivalent to that described for Alternative C. The estimated time to complete hydraulic dredging is the same as Alternative C.

Sediment Dewatering. Sediment dewatering is similar to the requirements described in Alternative C1 for construction of a passive dewatering facility. The solids content after dewatering from hydraulic dredging is assumed to be 30 percent (w/w). However, no solidification will occur prior to thermal treatment assuming that the vitrification facility is located in close proximity to the dewatering facility and the dewatered filter cake at 30 percent (w/w) solids is acceptable for processing. Sediment dewatering costs (primarily construction costs) for Alternative E are estimated at $3,200,000.

Water Treatment. Water from gravity dewatering would be treated before discharge to the river. Treatment and monitoring requirements are expected to be the same as those for Alternative C1. Water treatment costs for Alternative E are estimated to be the same as Alternative C1.

Sediment Treatment. After completion of passive dewatering (to approximately 30 percent solids), both TSCA and non-TSCA-level sediments are passed through a dryer and dried to approximately 10 percent moisture. Thermal treatment of the dried sediments involves blending the high-silt/clay sediments with fluxing materials and processing the materials in a melter as part of the vitrification process. The thermal treatment process would include appropriate treatment of air emissions. The unit cost for vitrification includes capital costs and operating costs. The capital costs include equipment, building, installation, engineering and startup costs. Operating costs include labor, utilities, and general administrative costs. The unit cost is based on an assumption that the glass aggregate resulting from treating sediments will have a resale value between the range of $2 and $25 per ton as provided by Minergy.

The cost for thermal treatment is estimated to range between $69,900,000 for 125 ppb and $11,700,000 for 5,000 ppb action levels at an estimated unit cost of $24 per ton.

Sediment Disposal. No sediment disposal as hazardous waste is necessary, as all the sediments will be treated by thermal treatment. Treated sediments transformed to glass aggregate by the thermal treatment process have a wide variety of applications. Based on analyses by product marketing specialists, the glass aggregate has a potential to be used as roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan, and construction fill (Minergy Corporation, 2002a).

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Institutional controls and monitoring will be the same as those described for Alternative C.

Alternative F: Cap to the Maximum Extent Possible, Dredge Remaining Sediments to CDF

Alternative F includes primarily *in-situ* sand capping to the maximum extent possible. Remaining sediments would be hydraulically dredged to on-site CDFs. As stated in Section 7.2.3, the capping area is limited to those areas where the average water depth is a minimum of 9 feet. TSCA-level sediments require mechanical dredging and off-site disposal prior to cap placement. The process flow diagram is depicted on Figure 7-19, and Figure 7-20 illustrates the cap locations and the extent of residual sediment impacts following implementation of Alternative F. The estimated costs are presented in Table 7-5.

Site Preparation, Cap and CDF Construction. Site preparation for dredging includes land acquisition for equipment staging, water treatment, sediment storage, truck loading, and CDF construction as discussed in Alternative D. The cap in the Little Lake Butte des Morts Reach is planned to be an armored cap composed of 20 inches of sand overlain with 12 inches of large cobble to provide erosion protection. The sand cap will be completed using a spreader barge with a 10-inch pipeline. The cap will be placed in 6-inch lifts. Armor placement would be completed using two 3-cy clamshell buckets (placement rate of 400 cy per day per bucket) for 0.7 to 3.3 years with 10-hour work shifts. Cap construction would require an upland staging area for the receipt and placement of sand and the armoring stone. The staging area will include a hopper for pumping slurry to the spreader barge. Armor stone will be delivered to the work area via barges. All other unit costs are similar to those described for the prior alternatives for the river reach. Site preparation costs for this alternative are included under the dredging and capping costs. Construction of the dewatering ponds are included in the dewatering costs.

Two CDFs would be constructed for the 125 and 250 ppb action levels to handle sediment outside of the capping footprint. Only the Arrowhead Park CDF would be constructed for the higher action levels. Although the estimated dredge volume for the 250 ppb action level would fit into one CDF with a capacity of 1 million cy, the criteria for building a second CDF was exceeded. For the purposes of this FS, if the volume of dewatered sediment (at 50 percent solids) is greater than 50 percent of the CDF storage capacity, then a second CDF will be constructed. CDF construction and costs would be similar to those described in Alternative D.

Capping costs under this alternative are estimated to range from $33,600,000 for 125 ppb to $11,700,000 for 5,000 ppb action levels. The estimated time for placement of the sand cap is 3.7 and 0.7 years to 125 ppb and 5,000 ppb action levels, respectively (1,200 cy placed per day).

Sediment Removal. Mechanical dredging of the limited TSCA-level sediment volumes would occur prior to initiation of hydraulic dredging. Mechanical removal of the approximately 16,000 cy would require approximately 0.2 year.

Hydraulic sediment removal techniques for this alternative are equivalent to those described for Alternative C for areas that will not be capped. The estimated time to complete hydraulic dredging directly to a CDF is 9.1 and 1.5 years for 125 ppb and 5,000 ppb action levels, respectively.

Sediment removal costs for hydraulic dredging are estimated to range between $18,900,000 for 125 ppb and $6,600,000 for 5,000 ppb action levels. The sediment removal cost for mechanical dredging is estimated to be $1,700,000.

Sediment Dewatering. Passive dewatering will occur directly within the CDF berms for hydraulic dredging. Mechanically-dredged sediment will dewater on-barge for 2 days prior to offloading to upland staging areas for off-site disposal.

Water Treatment. Overflow return water from the CDFs and on-barge dewatering would be treated before discharge to the river. Treatment and monitoring requirements are the same as for the prior remedial alternatives.

Water treatment costs for Alternative F are estimated to range between $1,800,000 for 125 ppb and $1,000,000 for 5,000 ppb action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of the TSCA-level sediments to an appropriate upland disposal facility.

The cost for off-site sediment disposal at an existing NR 500 commercial disposal facility is estimated at $2,000,000.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment, fencing, facilities, etc., from the staging and work areas. Demobilization and site restoration costs are included under the dredging and capping estimates.

Institutional Controls and Monitoring. Operation and maintenance monitoring would be required to ensure proper placement and maintenance of cap integrity. For this type of armored capping, monitoring will be performed to ensure that the cap is placed as intended, required capping thickness is maintained, and contaminants are isolated. The monitoring would include bathymetric or side-scan sonar profiling, sediment and cap sampling, as well as diver inspections to ensure that the cap is physically isolating impacted sediments. The monitoring program would operate for a period of 40 years with decreasing sampling intervals over time, as appropriate. Institutional controls would include deed restrictions, site access and anchoring limitations, and maintenance of the consumption advisories. A separate *Long-term Monitoring Plan* for the entire river and Green Bay is discussed in Appendix C, with costs provided in Alternative B.

Maintenance monitoring of the CDF and cap are included in the construction costs. The estimated cost for institutional controls and fish consumption monitoring of the reach is $4,500,000.

7.2.5 Section 7.2 Figures and Tables

Figures and tables for Section 7.2 follow page 7-44 and include:

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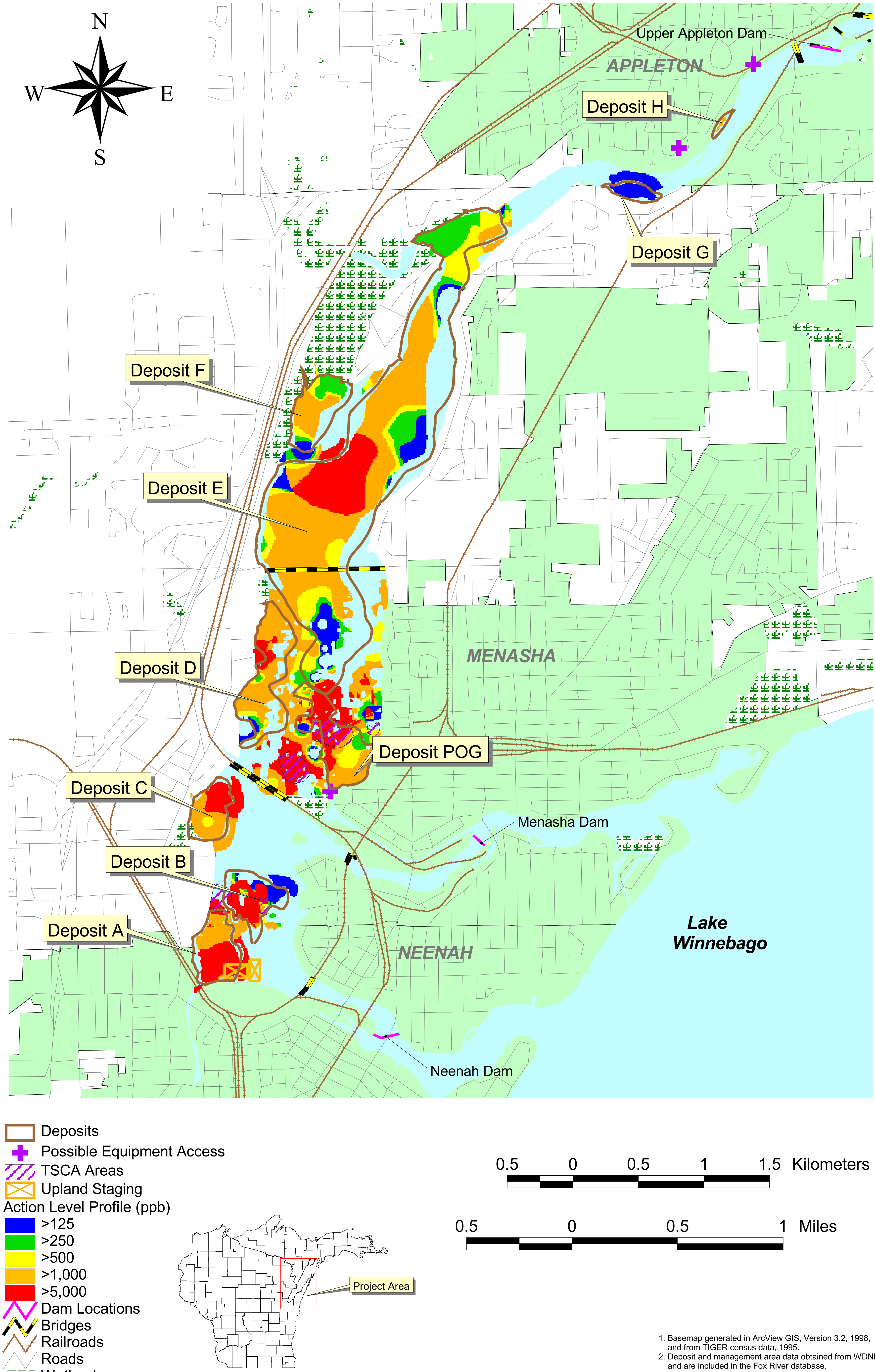

1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR. and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

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Natural Resource Technology

Lower Fox River & Green Bay Feasibility Study

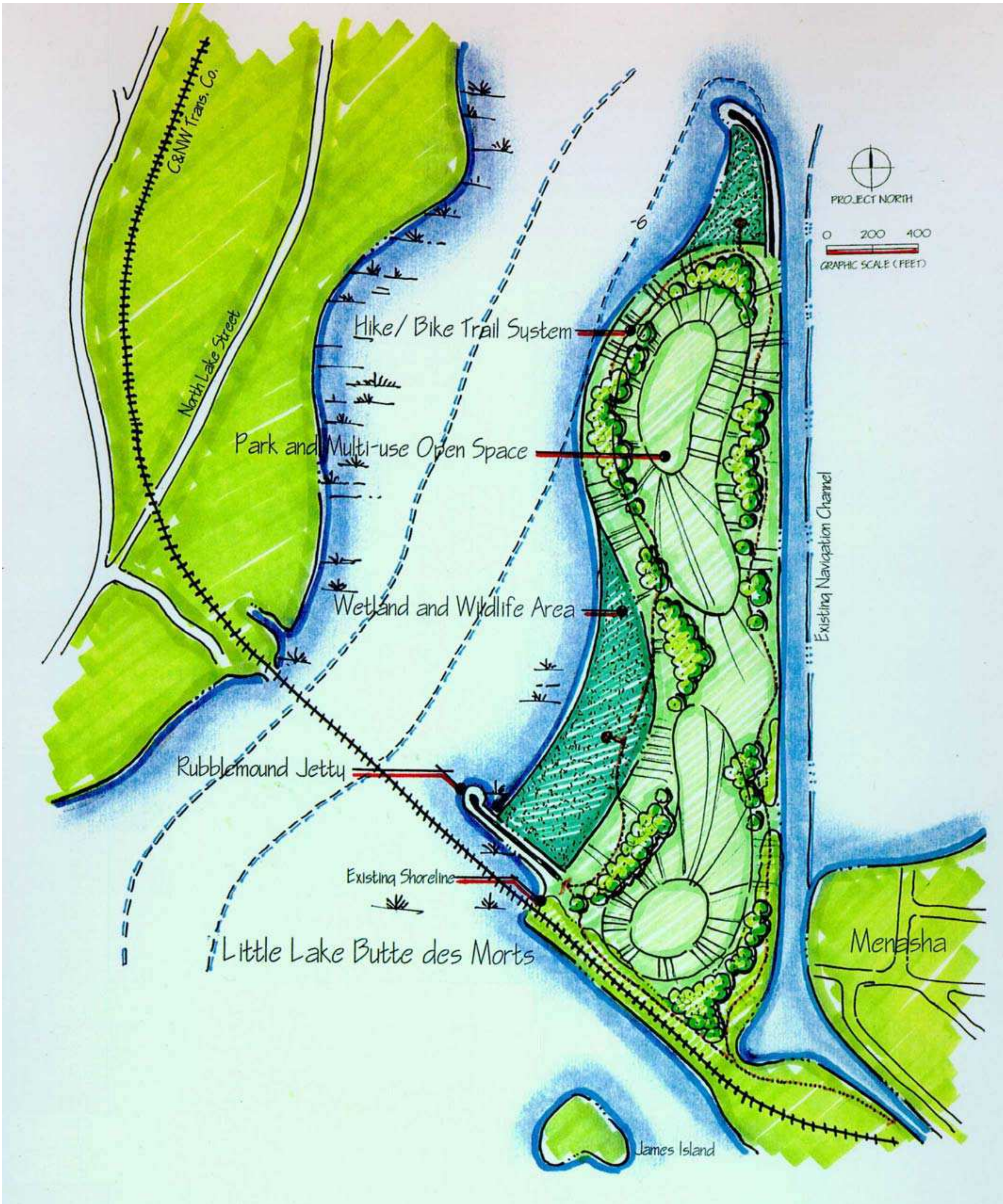
Sediment Management Area Overview: Little Lake Butte des Morts

FIGURE 7-9

REFERENCE NO: FS-14414-535-7-6
CREATED BY: SCJ
PRINT DATE: 3/12/01
APPROVED: AGF

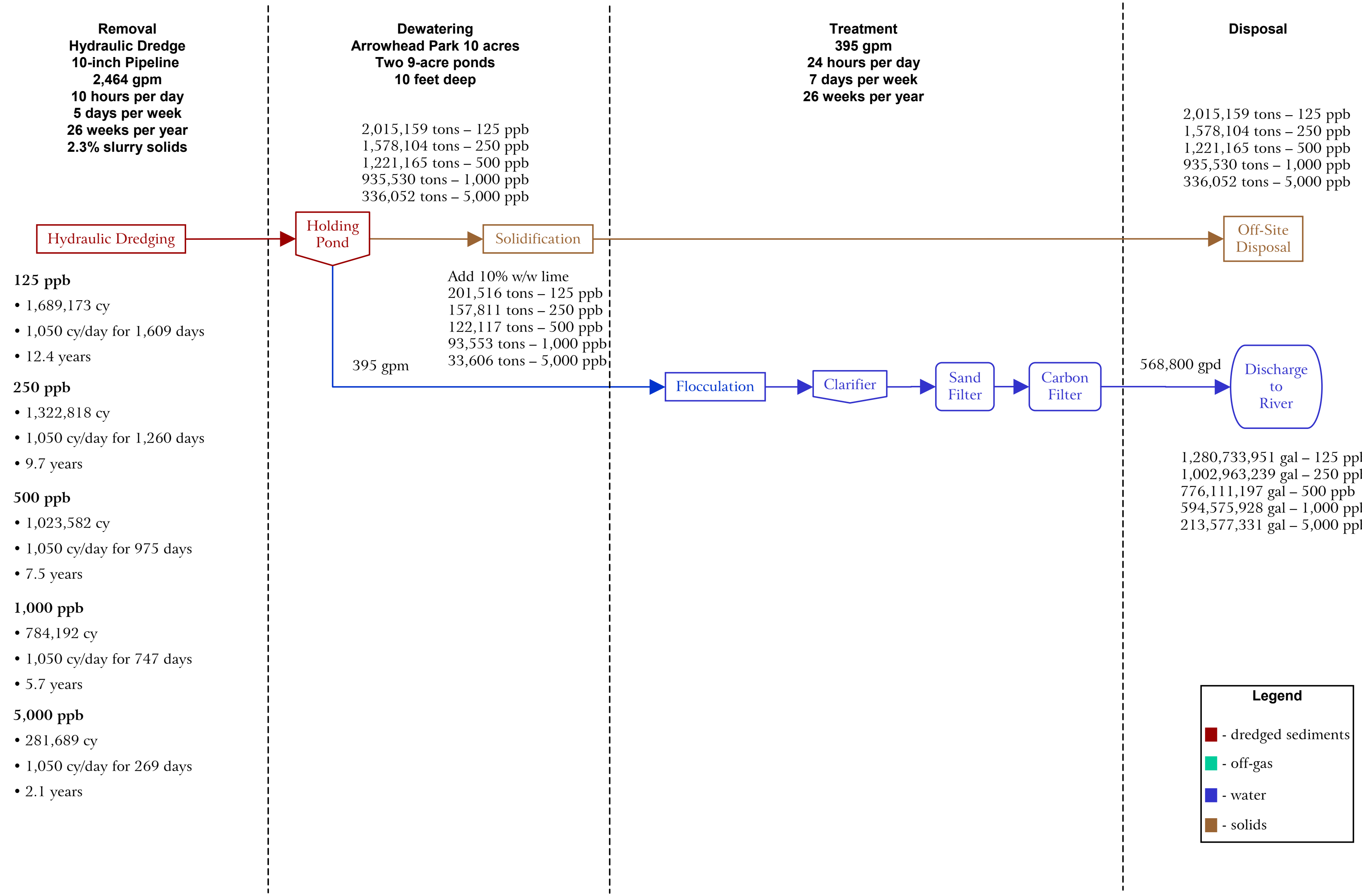
Figure 7-10 Preliminary Concept Design for the Arrowhead Confined Disposal Facility

Figure 7-11 Preliminary Concept Design for the Menasha Confined Disposal Facility



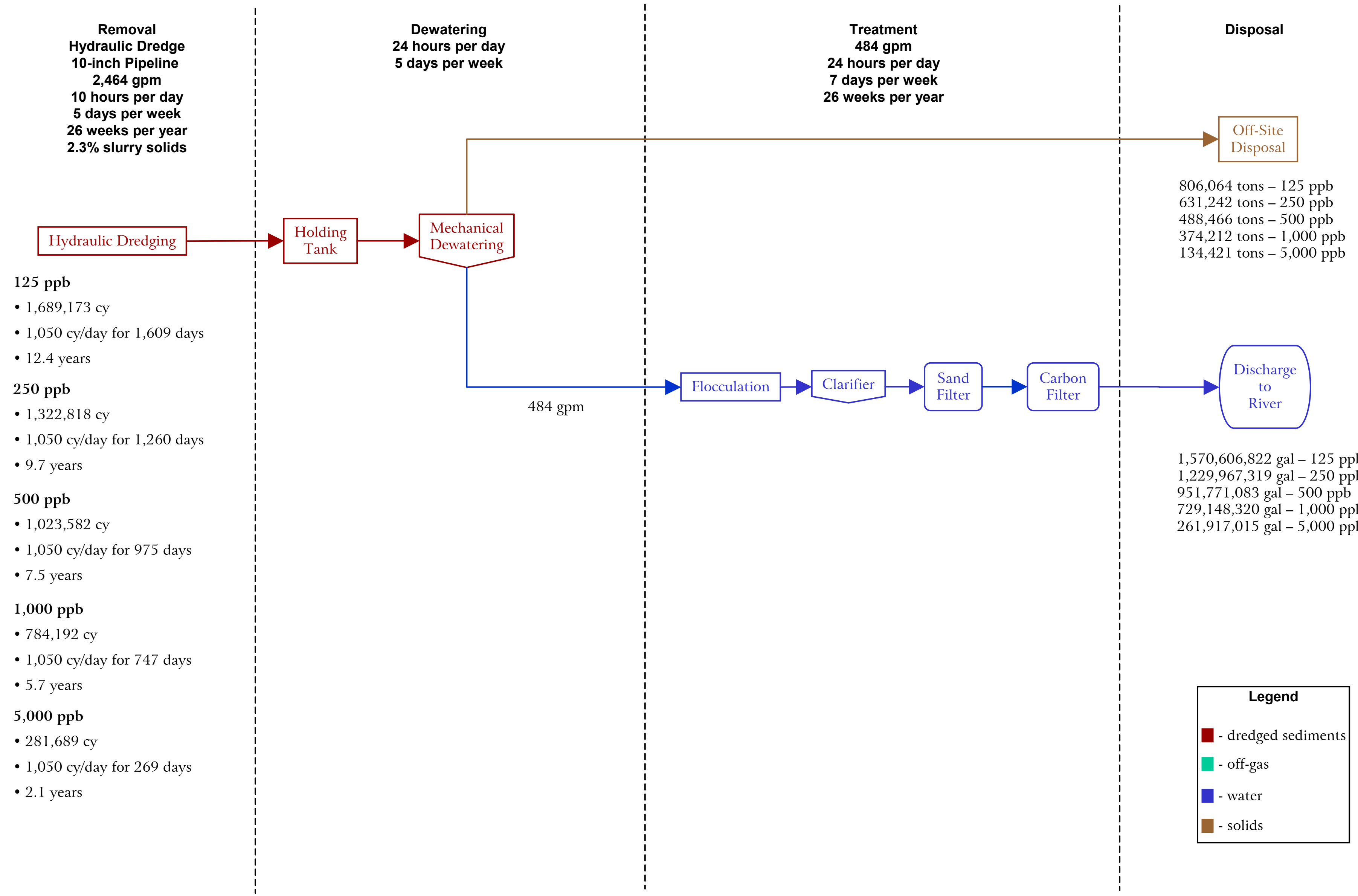
F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSP.PPT

Figure 7-12 Process Flow Diagram for Little Lake Butte des Morts - Alternative C1: Dredge Sediment with Off-site Disposal

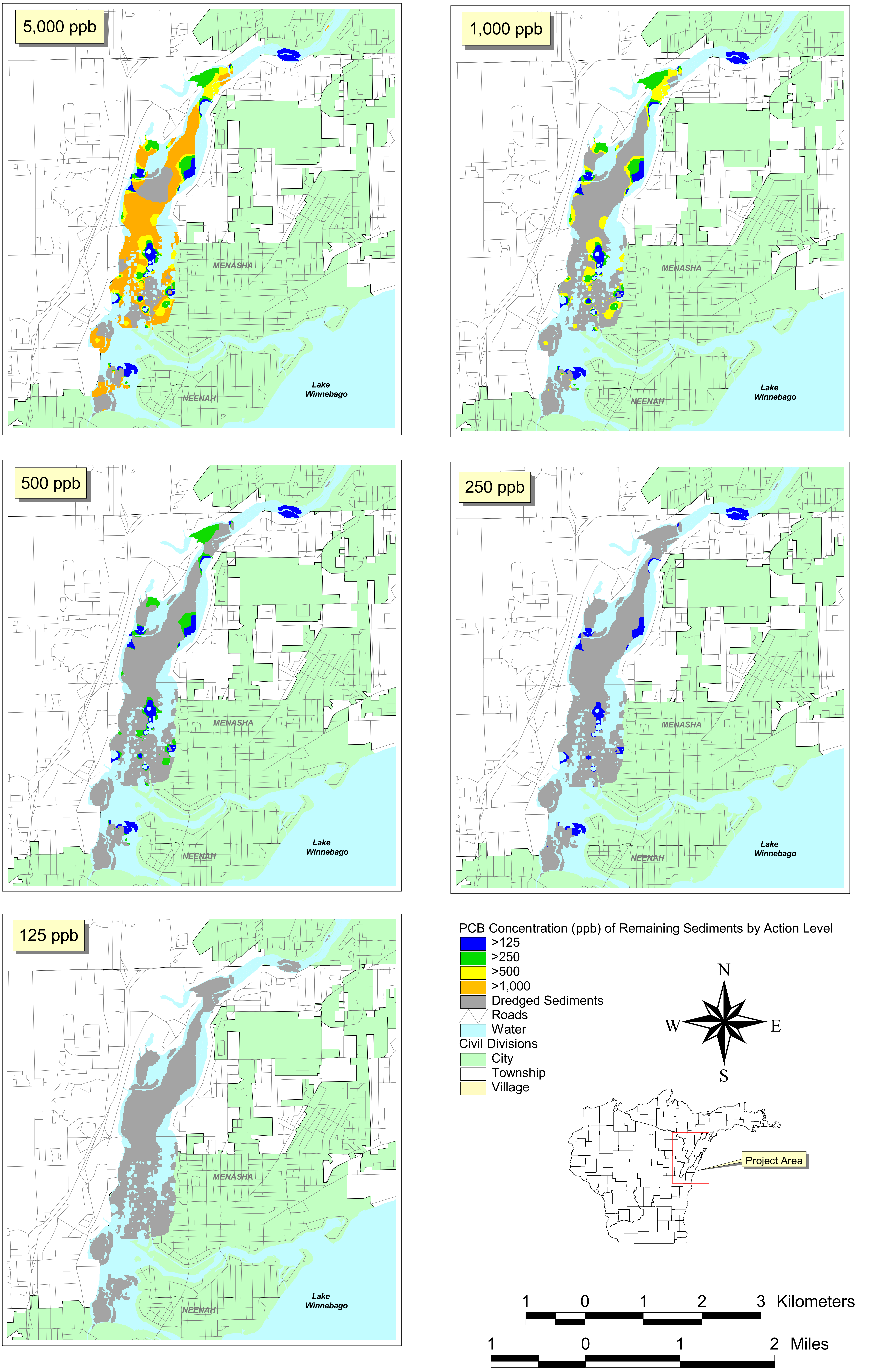


F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

Figure 7-13 Process Flow Diagram for Little Lake Butte des Morts - Alternative C2: Dredge Sediment with Off-site Disposal



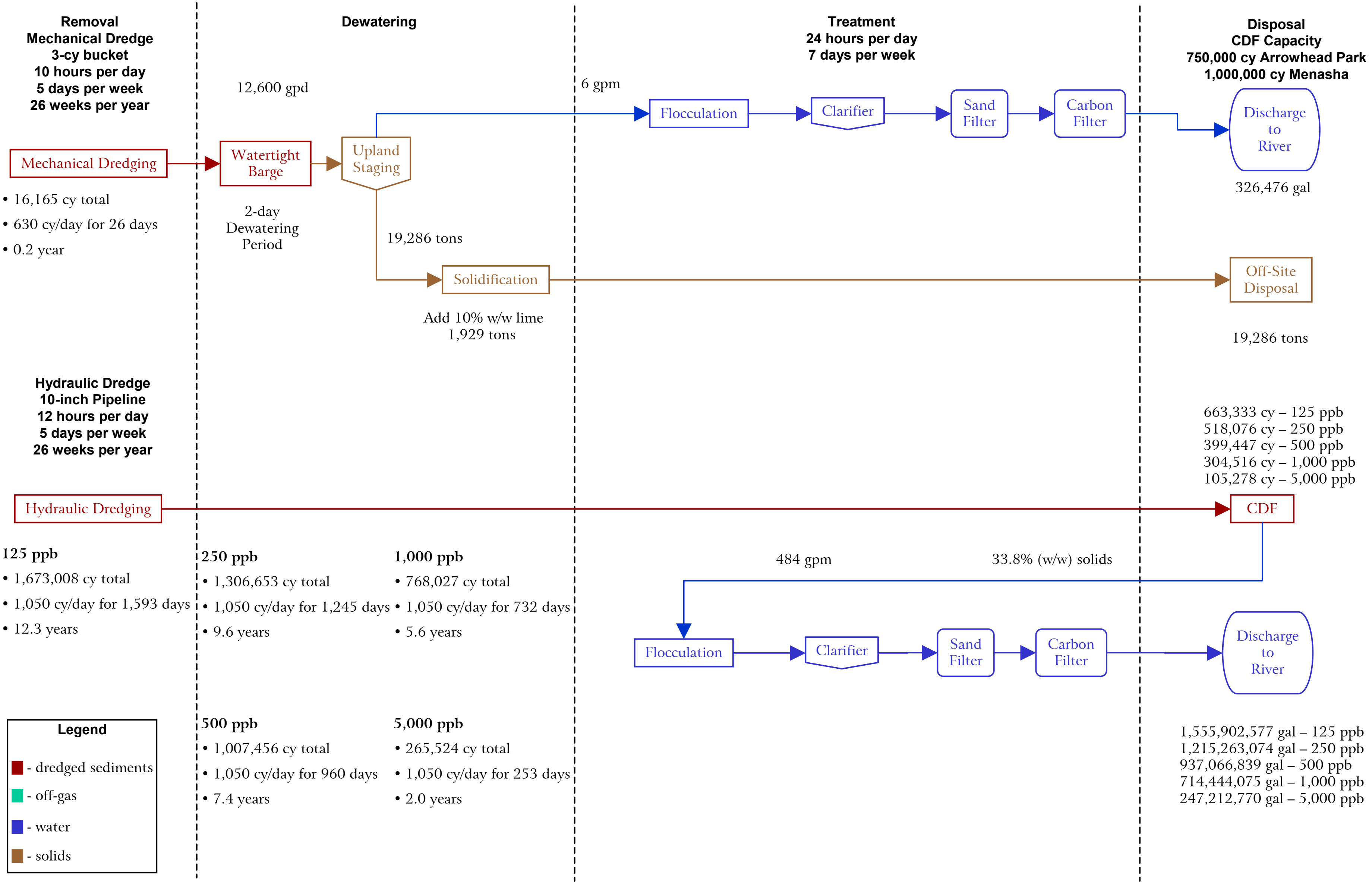
F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT



1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative C: Dredge and Off-Site Disposal: Little Lake Butte des Morts	REFERENCE NO: FS-14414-535-7-11
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-14	APPROVED: AGF

Figure 7-15 Process Flow Diagram for Little Lake Butte des Morts - Alternative D: Dredge Sediment, CDF, and Off-site Disposal



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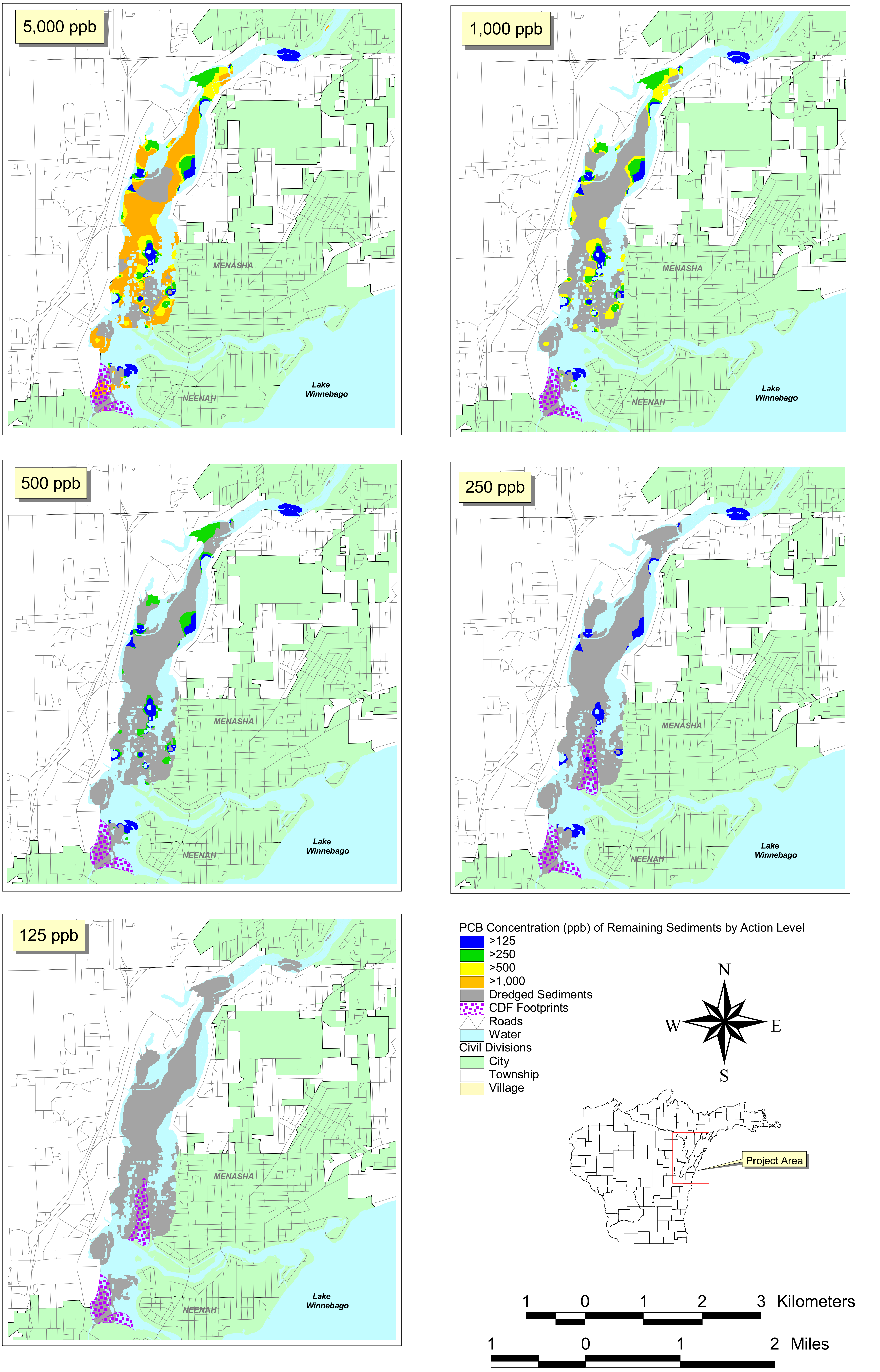
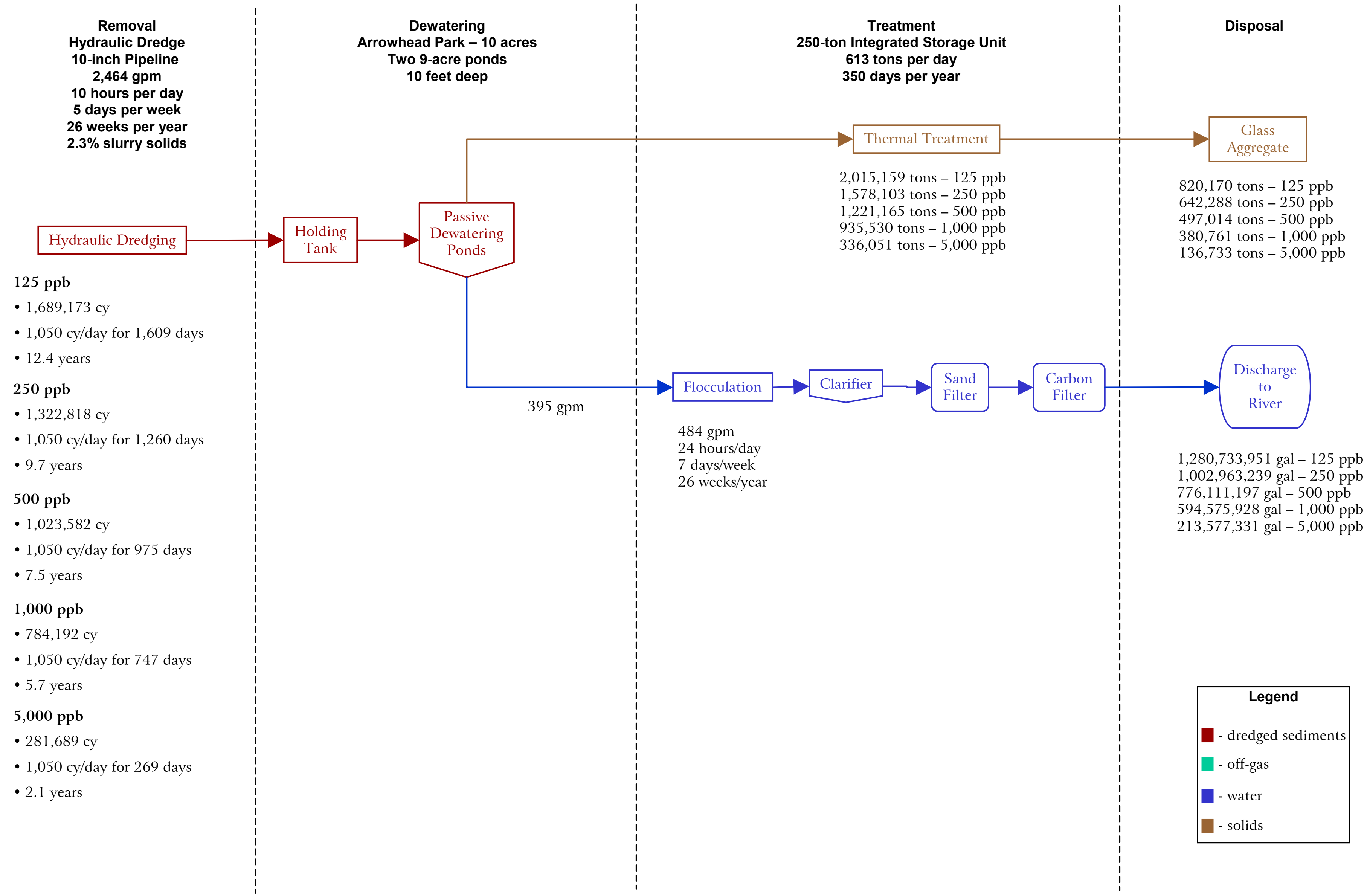


1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

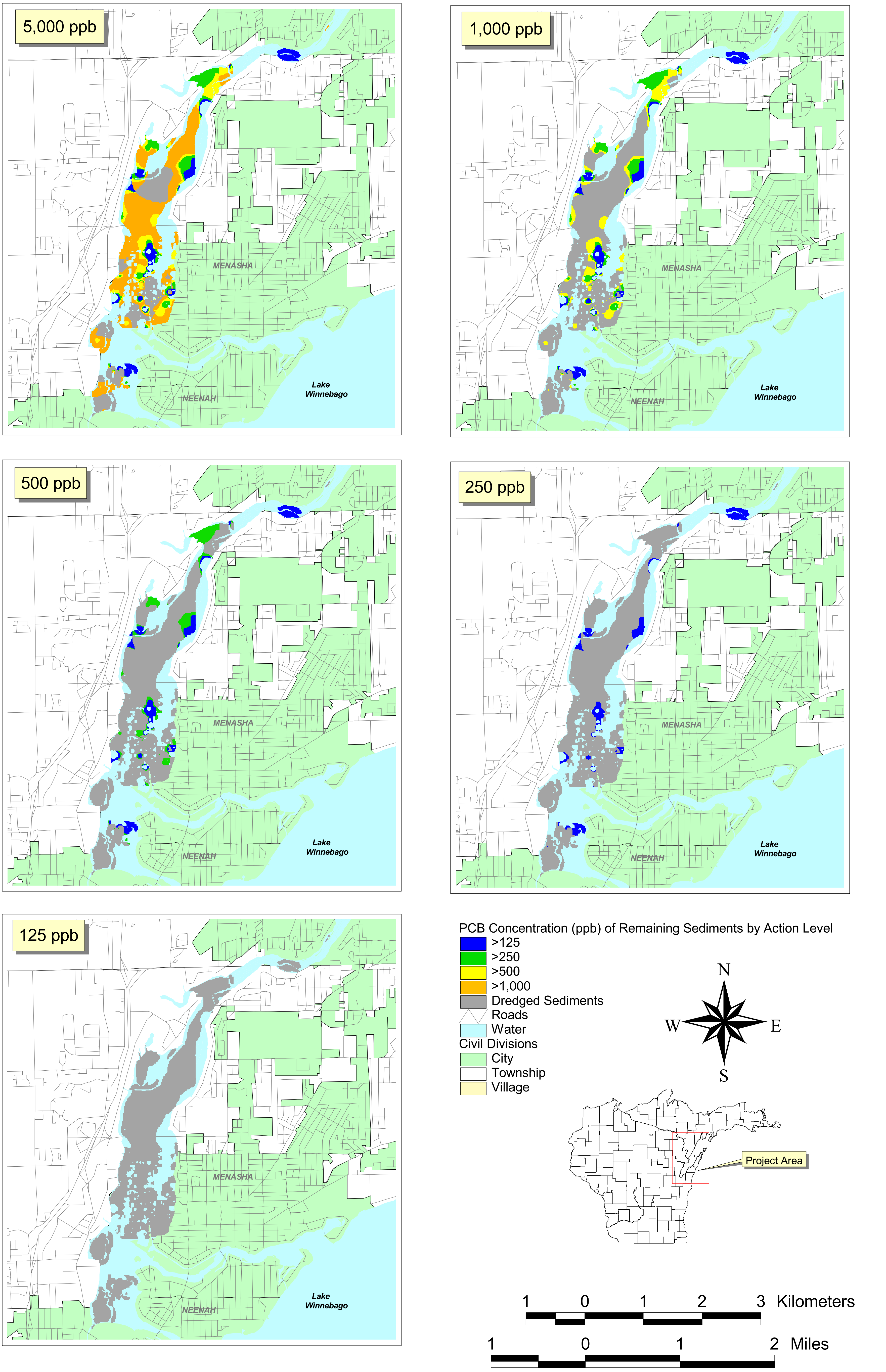
ThermoRetec	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative D: Dredge Sediment to Confined Disposal Facility: Little Lake Butte des Morts	REFERENCE NO: FS-14414-535-7-13
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-16	APPROVED: AGF

Figure 7-17 Process Flow Diagram for Little Lake Butte des Morts - Alternative E: Dredge Sediment with Thermal Treatment



Note: Additional integral elements of the vitrification unit (dryer, pollution control) are not shown as they were not estimated separate. For greater detail on the unit layout and components, refer to the Minergy Unit Cost Report (Appendix G).

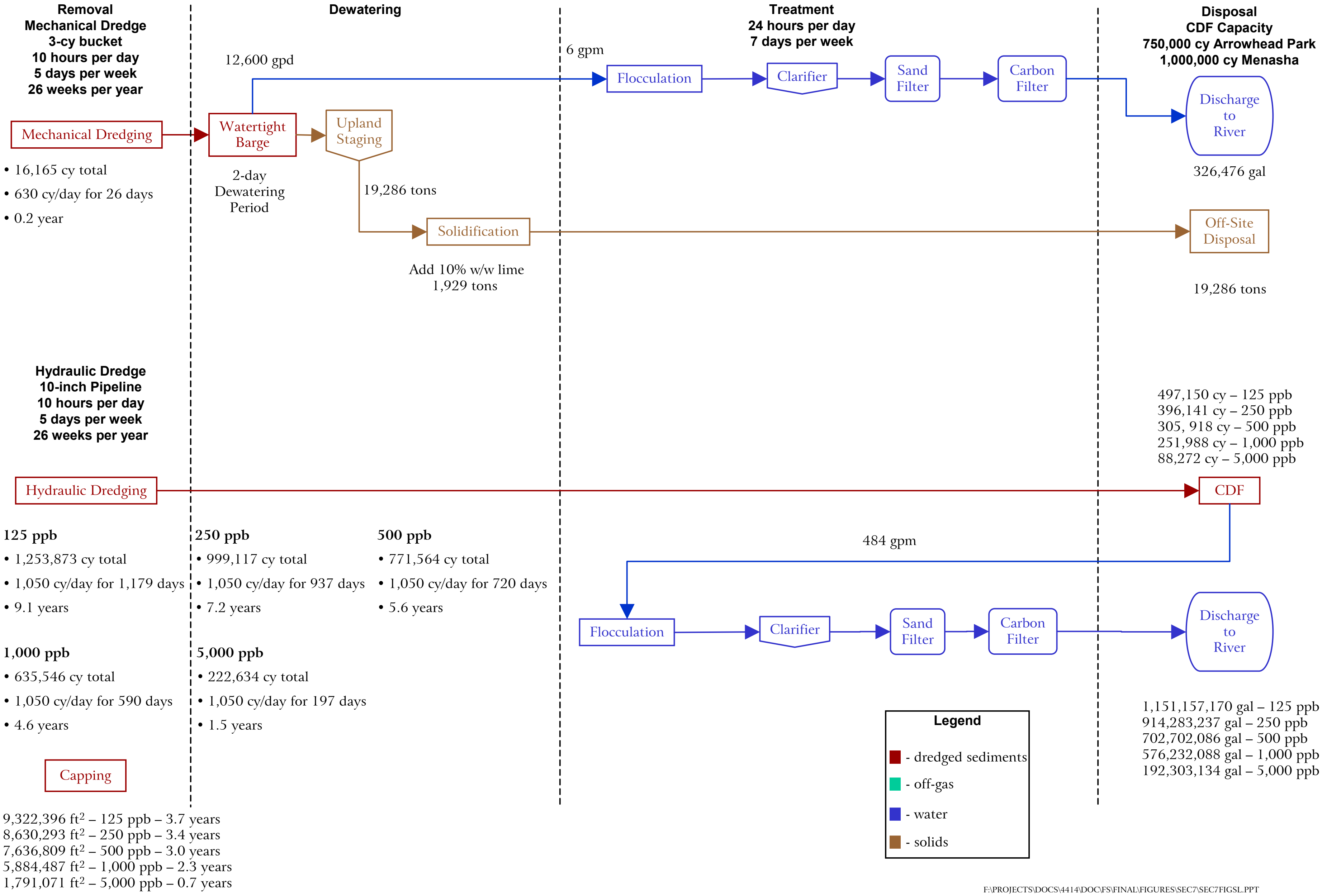
F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT



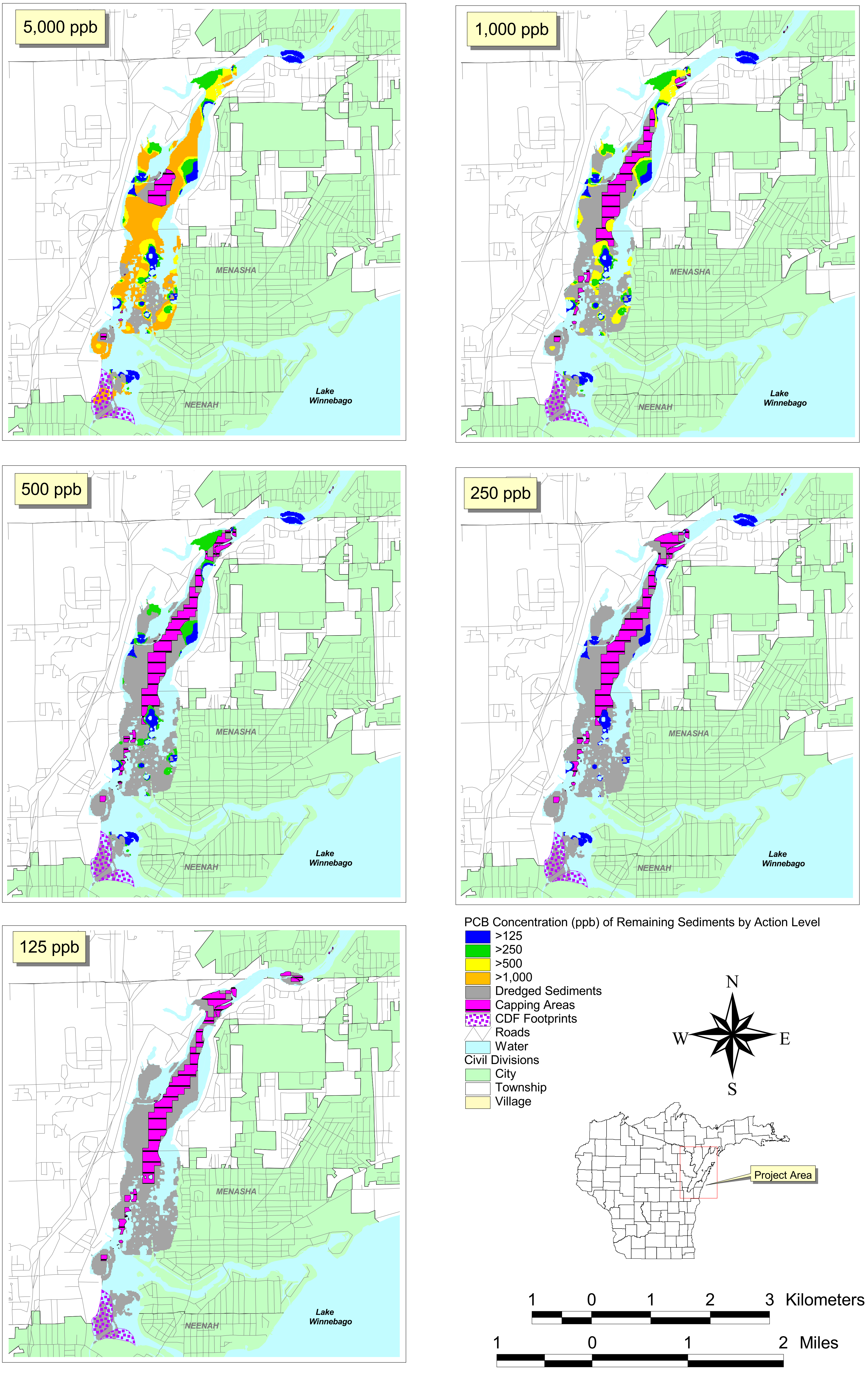
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative E: Dredge with Thermal Treatment: Little Lake Butte des Morts	REFERENCE NO: FS-14414-535-7-15
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-18	APPROVED: AGF

Figure 7-19 **Process Flow Diagram for Little Lake Butte des Morts - Alternative F: Cap Sediment to Maximum Extent Possible, Dredge to CDF, and Off-site Disposal**



F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT



1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.
3. Capping are a criteria based on a minimum 9-foot water depth.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative F: Cap to Maximum Extent Possible and Dredge to Remaining CDF: Little Lake Butte des Morts	REFERENCE NO: FS-14414-535-7-17
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-20	APPROVED: AGF

Table 7-5 Cost Summary for Remedial Alternatives - Little Lake Butte des Morts

125 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1[1]	1,689,173	16,165	$37,700,000	---	---	$3,200,000	$1,900,000	---	---	$184,200,000	$4,500,000	$231,500,000	$46,300,000	$277,800,000
C2[1]	1,689,173	16,165	$37,700,000	---	---	$36,200,000	$2,100,000	---	---	$45,700,000	$4,500,000	$126,200,000	$25,240,000	$151,440,000
D	1,689,173	16,165	$36,700,000	$1,700,000	---	---	$2,100,000	---	$69,300,000	$1,700,000	$4,500,000	$116,000,000	$23,200,000	$139,200,000
E	1,689,173	16,165	$37,700,000	---	---	$3,200,000	$1,900,000	$69,900,000	---	---	$4,500,000	$117,200,000	$23,440,000	$140,640,000
F	1,253,873	16,165	$32,300,000	$1,700,000	$33,600,000	---	$1,800,000	---	$69,300,000	$2,000,000	$4,500,000	$145,200,000	$29,040,000	$174,240,000

250 ppb

Alternative	Dredge Volume	TSCA Dredge Vol.	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1[1]	1,322,818	16,165	$32,000,000	---	---	$3,200,000	$1,600,000	---	---	$144,300,000	$4,500,000	$185,600,000	$37,120,000	$222,720,000
C2[1]	1,322,818	16,165	$32,000,000	---	---	$28,400,000	$1,800,000	---	---	$35,800,000	$4,500,000	$102,500,000	$20,500,000	$123,000,000
D	1,322,818	16,165	$31,000,000	$1,700,000	---	---	$1,800,000	---	$69,300,000	$2,000,000	$4,500,000	$110,300,000	$22,060,000	$132,360,000
E	1,322,818	16,165	$32,000,000	---	---	$3,200,000	$1,600,000	$54,700,000	---	---	$4,500,000	$96,000,000	$19,200,000	$115,200,000
F	999,117	16,165	$27,900,000	$1,700,000	$31,600,000	---	$1,600,000	---	$69,300,000	$2,000,000	$4,500,000	$138,600,000	$27,720,000	$166,320,000

500 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1[1]	1,023,621	16,165	$27,000,000	---	---	$3,200,000	$1,400,000	---	---	$111,700,000	$4,500,000	$147,800,000	$29,560,000	$177,360,000
C2[1]	1,023,621	16,165	$27,000,000	---	---	$22,000,000	$1,600,000	---	---	$27,700,000	$4,500,000	$82,800,000	$16,560,000	$99,360,000
D	1,023,621	16,165	$26,000,000	$1,700,000	---	---	$1,600,000	---	$69,300,000	$2,000,000	$4,500,000	$105,100,000	$21,020,000	$126,120,000
E	1,023,621	16,165	$27,000,000	---	---	$3,200,000	$1,400,000	$42,400,000	---	---	$4,500,000	$78,500,000	$15,700,000	$94,200,000
F	771,564	16,165	$23,700,000	$1,700,000	$28,700,000	---	$1,400,000	---	$37,300,000	$2,000,000	$4,500,000	$99,300,000	$19,860,000	$119,160,000

Table 7-5 Cost Summary for Remedial Alternatives - Little Lake Butte des Morts (Continued)

1,000 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1[1]	784,192	16,165	$22,100,000	---	---	$3,200,000	$1,300,000	---	---	$85,600,000	$4,500,000	$116,700,000	$23,340,000	$140,040,000
C2[1]	784,192	16,165	$22,100,000	---	---	$16,900,000	$1,400,000	---	---	$21,300,000	$4,500,000	$66,200,000	$13,240,000	$79,440,000
D	784,192	16,165	$21,100,000	$1,700,000	---	---	$1,400,000	---	$37,300,000	$2,000,000	$4,500,000	$68,000,000	$13,600,000	$81,600,000
E	784,192	16,165	$22,100,000	---	---	$3,200,000	$1,300,000	$32,500,000	---	---	$4,500,000	$63,600,000	$12,720,000	$76,320,000
F	635,547	16,165	$20,100,000	$1,700,000	$23,600,000	---	$1,300,000	---	$37,300,000	$2,000,000	$4,500,000	$90,500,000	$18,100,000	$108,600,000

5,000 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1[1]	281,689	16,165	$8,900,000	---	---	$3,200,000	$1,000,000	---	---	$30,900,000	$4,500,000	$48,500,000	$9,700,000	$58,200,000
C2[1]	281,689	16,165	$8,900,000	---	---	$6,100,000	$1,100,000	---	---	$7,700,000	$4,500,000	$28,300,000	$5,660,000	$33,960,000
D	281,689	16,165	$7,900,000	$1,700,000	---	---	$1,100,000	---	$37,300,000	$2,000,000	$4,500,000	$54,500,000	$10,900,000	$65,400,000
E	281,689	16,165	$8,900,000	---	---	$3,200,000	$1,000,000	$11,700,000	---	---	$4,500,000	$29,300,000	$5,860,000	$35,160,000
F	222,635	16,165	$8,000,000	$1,700,000	$11,700,000	---	$1,000,000	---	$37,300,000	$2,000,000	$4,500,000	$66,200,000	$13,240,000	$79,440,000

Note:

[1] Alternative C1 uses passive dewatering and Altenative C2 uses mechanical dewatering.

7.3 Appleton to Little Rapids Reach

An overview of the Appleton to Little Rapids Reach and PCB-impacted sediments is shown on Figure 7-21. The retained alternatives and associated costs are presented in Table 7-6.

7.3.1 General Site Characteristics

The Appleton to Little Rapids Reach is approximately 20 miles long, and is the divider between Outagamie County on the west and Brown County on the east (Figure 7-21). Much of this section of the river is agrarian, but in addition to Appleton, includes the communities of Kimberly, Kaukauna, Little Chute, and Wrightstown.

Throughout this reach, the river is characterized by a series of channels and pools controlled largely by the seven dams/locks found between the Appleton dam and the Little Rapids dam at Kaukauna. The contaminated sediment deposits are largely found in quiescent depositional pools (see Section 2). This section of the river ranges from relatively deep (8 to 12 feet), where the river narrows (i.e., the segment from Appleton to Cedars Locks), to shallow and unnavigable (i.e., at the Thousand Island Conservancy).

This reach has an average stream flow velocity of 0.79 ft/s (0.24 m/s) with an average maximum velocity of 4.36 ft/s (1.33 m/s). This reach has the greatest average flow velocities in the Lower Fox River. The nature and extent of PCB-impacted sediment in this reach, as summarized in the RI, includes the following:

- Maximum detected concentration - 77,444 μg/kg (avg. 6,406 μg/kg),
- Total PCB mass - 93 kg (after removal of Deposit N),
- Total PCB-impacted volume - 2,089,300 m^3, and
- Maximum PCB sample depth - 50 to 100 cm depth.

These quantities sum the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described in this section will likely be larger, since they account for overburden volumes above deeper sediment layers that contain PCBs.

An important impediment to sediment management (i.e., sediment removal or containment) in this reach is the dams/locks, which prevent free movement of equipment between the 22 separate sediment deposits. In this segment, only the Little Rapids Lock is operable; with the exception of the Rapide Croche Lock, which is permanently closed to restrict sea lamprey movement, all locks would require maintenance and renovation before they could be made operational. Several locks are too small to accommodate larger equipment barges. As a result, remedial actions in this reach would require multiple mobilizations of equipment around the dams.

Another important physical feature of this reach is the presence of bedrock immediately beneath the contaminated soft sediments in many areas. The presence of bedrock, and the inability to "over-dredge," could potentially impact sediment removal efficiency and cost. Residual surface concentrations (similar to the Deposit N demonstration project) may necessitate a reliance on natural recovery or capping after sediment removal.

7.3.2 Selected Remedial Alternatives

This section defines the remedial alternatives for the Appleton to Little Rapids Reach and then describes the technologies that would be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for the Appleton to Little Rapids Reach include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all river sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an existing NR 500 commercial disposal facility.

E. Remove sediment with PCB concentrations exceeding the selected action level and treat this sediment using thermal treatment. Treated sediment may be beneficially reused.

Alternatives D, F, and G were not retained because of physical constraints within this reach. Neither a CDF nor a CAD site was considered for this reach due to lack of suitable and available in-water space, and hydrodynamic properties preclude the placement of a cap. The process options that can be applied to the remedial alternatives are described below.

7.3.3 Description of Process Options

Monitoring Options

Monitoring of physical, chemical, and biological media is applicable for Alternatives B through E. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; SMWG, 1999; IJC, 1997; Krantzberg *et al.*, 1999). The following references were used in this FS Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Ecology, *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);

- USACE, *Monitoring Considerations for Capping* (USACE, 1992);

- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);

- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);

- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);

- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);

- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b); and

- Sediment remediation case study projects presented in Appendices B and C of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Control Options

Institutional controls appropriate to the Appleton to Little Rapids Reach include:

- Maintenance of the fish and waterfowl consumption advisory;
- A moratorium on any future dredging within the navigation channel;
- Deed restrictions on any in-water activities that could result in sediment disturbance (e.g., marina construction or over-water development);
- Access restrictions to contaminated areas;
- Continued restriction on the use of the Lower Fox River for domestic water supplies; and
- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal for the Appleton to Little Rapids Reach is identified for Alternatives C and E; however, the only practicable dredging option for removal is hydraulic dredging. The relatively shallow water depths within the reach and inaccessibility of the river preclude application of a mechanical dredge or land-based excavator.

Dredge Equipment. A hydraulic cutterhead dredge with a 10-inch pipeline has been selected for the remedial alternatives identified in this FS Report where a hydraulic dredge would be employed. While larger dredges are available, use of the 10-inch pipeline allows for a greater degree of control over resuspension of contaminated sediments during removal operations, provides for a removal time frame of less than 10 years, and limits the size required of a gravity dewatering pond.

An operating assumption is that dredging would occur only during normal daylight hours (10 hours per day) during a normal work week (5 days per week) since the Appleton to Little Rapids Reach includes residential areas. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year), when the average minimum temperature is above freezing.

Both the round and horizontal auger cutterheads are commonly employed hydraulic dredges, with multiple capable portable dredges in the small- to medium-size range available in the Great Lakes region. Required operator experience and skills are also available in the region. Sediment remedial demonstrations by public agencies (i.e., USACE, EPA, Environment Canada) have highly rated the small horizontal auger dredge for contaminated sediment removal. A horizontal auger equipped with two 10-inch and two 12-inch pipelines, for example, has been employed at the Manistique Superfund site and SMU 56/57 demonstration project in the Lower Fox River, respectively. A suitable alternative is the small cutterhead dredge; the cutterhead is the only hydraulic dredge capable of effective operations if debris or compacted sand are present. A ladder cutterhead dredge was successfully used at the Deposit N demonstration project on the Lower Fox River.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream. However, for the purposes of this FS, silt curtains were included in the removal costs.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not included in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For the alternatives utilizing hydraulic dredging in the Appleton to Little Rapids Reach, dewatering has been configured as a two-step process using a gravity settling pond, followed by solidification of solids. The water would be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. For the dredge and off-site disposal alternative, the gravity settling pond is assumed to be located off site in nearby farm fields leased or purchased for the project. Given that much of the upriver portion of this reach is residential, the most likely area for facility construction would be outside Wrightstown, at the downstream end of deposits W and X. The hydraulic slurry from the upstream deposits would be transported via pipeline either on the river or overland around the dams and locks.

The proposed dewatering system would meet the criteria defined in Section 6 of this FS Report in terms of production rate, effectiveness, practicability, and discharge water quality. The dewatering system would operate 24 hours per day, potentially near residential areas. A passive dewatering system is preferable to mechanical dewatering because of low noise impact to the surrounding community and reduced operational costs. Final selection of the dewatering process will be determined during the remedial design phase.

Passive Dewatering. A passive dewatering system would include the construction of two approximately 9-acre gravity separation ponds. The ponds would be enclosed laterally with earthen berms to allow a ponding depth of 8 feet, and lined with asphalt pavement. Each settling pond would receive dredged sediment in 13-week increments and therefore contain a full season of dredge slurry. After a pond is filled, the sediment would be allowed to dewater to 20 percent solids based on dewatering studies (Montgomery-Watson, 1998). Residual water would be drained, treated, and discharged. Sediment would be removed in preparation for the next dredging season.

If sufficient land space cannot be secured for construction of a gravity settling pond, then mechanical dewatering will be employed using techniques similar to the Little Lake Butte des Morts Reach.

Solidification. The solids content after dewatering from hydraulic dredging is assumed to be 20 percent (w/w) and may still be difficult to manage due to high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary, and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. For FS costing purposes, 10 percent (w/w) lime was added as the reagent based on successful use during the SMU 56/57 demonstration project (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and removed from the pond using standard earthmoving equipment. If the contractor prefers, sediment may first be removed from the settling pond and mixed with reagent in a pug mill as shown on Figures 7-1 and 7-5. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

Treatment Process Options

Water Treatment. Prior to water discharge back to the river, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary. However, additional carbon (GAC) treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC treatment is $0.40 per thousand gallons of water treated.

Thermal Treatment. Several on-site treatment process options were retained from the screening process in Section 6 that are applicable to the Lower Fox River/Green Bay remediation project. However, only vitrification was selected for costing purposes because the multi-phased study conducted by WDNR has provided data which indicates that this treatment technology is a viable option.

A separate vitrification unit will not be constructed for the Appleton to Little Rapids Reach. Dredged and dewatered sediments from the Appleton to Little Rapids Reach will be transported to the vitrification unit constructed at the Little Lake Butte des Morts Reach for processing. The facility will be integrated into the operation of an adjacent industrial facility with which it can share resources. Passive dewatered sediment enters the plant and is dried to approximately 10 percent moisture in the dryer unit. The sediment is mixed with a fluxing material and fed into a vitrification unit, capable of maintaining temperature around 2,900 °F. The sediment melts into a molten material in the unit and passes through the water bath for quenching resulting in glass aggregate.

For the purposes of this FS, sediment treatment by vitrification is assumed to occur over a time frame of 10 years in conjunction with treating dewatered sediments from Little Lake Butte des Morts Reach. The vitrification process is assumed to operate 24 hours per day, 7 days per week, and 350 days per year. The unit will be designed to have a capacity of processing 613 tons of sediment per day and produce 250 tons of glass aggregate per day.

On-site Disposal Process Options

No CDFs or CAD sites are proposed for the Appleton to Little Rapids Reach of the river. The small volume of contaminated material does not justify construction of a CDF and site conditions would likely preclude construction of a CAD site.

Off-site Disposal Process Options

All sediment samples collected to date in this reach indicate that the PCB concentrations are below 50 ppm; therefore, none of the sediment is considered TSCA material. All sediment could be shipped to a landfill that conforms to the NR 500 WAC requirements without EPA's TSCA approval letter.

Capping Process Options

No capping is proposed for the Appleton to Little Rapids Reach of the river as contaminated sediment depths are generally located in areas with less than 4 feet water depth and would be exposed to flood, propeller wash scouring, or ice scour.

7.3.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for the Appleton to Little Rapids Reach. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs (Table 7-6). Details used to develop each cost estimate are provided in Appendix H. The process flow diagrams and dredging/capping footprints for each alternative are presented on Figures 7-22 through 7-25.

The following components are discussed for each alternative, when applicable:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for the Appleton to Little Rapids Reach. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management or remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until the RAOs are achieved. The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C: Dredge with Off-site Disposal

Alternative C includes the removal of sediments above the remedial action level with a hydraulic dredge and off-site disposal of the sediments. Figure 7-22 provides the process flow diagram for this remedial alternative, while Figure 7-23 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-6. The total volume of sediment to be dredged in this alternative is 182,450; 80,611; 56,998; 46,178; and 20,148 cy for action levels of 125, 250, 500, 1,000, and 5,000 ppb, respectively.

Site Mobilization and Preparation. Staging for dredging would be conducted at several locations due to the interference of inoperable locks. Approximately five separate areas would be required for staging. Site mobilization and preparation includes securing the onshore property area for equipment staging and constructing areas for sediment dewatering, water treatment, sediment storage, and truck loading. Offshore, a docking facility for the hydraulic dredges would be constructed. Purchase and property preparation are included in the costs of the following process components.

Sediment Removal. The presence of bedrock in many areas of this reach presents potential removal difficulties that would require careful consideration when selecting dredge technologies and attainable cleanup goals. Sediment removal would be accomplished using a 10-inch pipeline cutterhead hydraulic dredge. Given the volumes and operating assumptions described in Section 7.3.3, the complete removal effort would require approximately 1.3 years for 125 ppb to 0.2 year for the 5,000 ppb action levels. Pipelines would extend from the dredging area to the dewatering area. For longer pipeline runs, it may be necessary to utilize in-line booster pumps to pump the slurry to the dewatering facility. Longer pipe runs may require periodic flushing of the lines during periods of inactivity. Silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; installation of silt curtains were included in this FS for a cost of $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs for hydraulic dredging are estimated to range between $10,100,000 for 125 ppb and $6,000,000 for 5,000 ppb action levels.

Sediment Dewatering. Gravity dewatering includes land purchase, site clearing, and dewatering pond construction. Key assumptions include an approximate 2.3 percent dredged solids concentration and an approximate 2,464 gpm water production for the dredge, based on results from the Lower Fox River demonstration projects (Foth and Van Dyke, 2000; Montgomery-Watson, 2000). Although the recent dredging work conducted at SMU 56/57 (Fort James *et al.*, 2001) showed the average percent solids in dredge slurry was 8.4 percent w/w (range 3.5 to 14.4 percent), the lower and more conservative percent slurry solids measured during the 1999 activities, was used for FS costs. Sediment dewatering would be done in a two-cell passive filtration system. The system would accommodate 26 weeks of solids dredge production rate, plus a maximum water surge storage capacity. One set of centrally-located dewatering ponds may be more than 10 miles from either end of the dredging area. Booster pumps may be required to pump dredged material to the dewatering ponds. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (covered in disposal costs). Dewatering costs also include pond demobilization and site restoration at the completion of the project. This option assumes that adequate land space can be secured for construction of gravity settling ponds; otherwise, mechanical dewatering processing will be employed similar to the Deposit N demonstration project dewatering methods.

Sediment dewatering costs are estimated at $3,000,000 for all action levels.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 568,800 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. However, it may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to range between $900,000 for 125 ppb and $800,000 for all other action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to an existing NR 500 commercial disposal facility. No TSCA-level sediments are present in this reach, as the TSCA sediments were removed as part of the demonstration project during the fall of 1998 and fall of 1999. The estimated percent solids of dewatered sediment after 6 months of passive dewatering is 20 percent solids based on dewatering studies from the SMU 56/57 BOD Report (Montgomery-Watson, 1998). The sediments would be loaded into tractor-trailer end dumps with bed liners or sealed gates using a front-end loader. Each load would be manifested and weighed. Each tractor-trailer would pass through a wheel wash prior to leaving the staging area to prevent tracking soil onto nearby streets and highways.

Costs of sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to range between $19,800,000 for 125 ppb and $2,200,000 for 5,000 ppb action levels. Solidification costs for addition of 10 percent (w/w) lime range between $6,700,000 and $743,000 for 125 ppb and 5,000 ppb action levels, respectively.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre- and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time. If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

Monitoring during implementation is included in the dredging and water treatment costs. The estimated cost for the maintenance of institutional controls and fish consumption monitoring is $4,500,000. Multimedia monitoring events and costs to determine long-term verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

Alternative E: Dredge and Thermal Treatment

Alternative E includes hydraulic dredging of sediments above the remedial action level and treatment with an integrated vitrification unit. Figure 7-24 provides the process flow diagram for this remedial alternative, while Figure 7-25 illustrates the extent of residual contamination following implementation of Alternative E. Table 7-6 contains the summary costs to implement Alternative E. This alternative addresses the same volume of sediments as Alternative C.

Site Mobilization. Site mobilization and preparation includes securing the onshore property area for equipment staging, water treatment, and an offshore docking facility for the hydraulic dredge. Site preparation would also include building or modifying an existing integrated vitrification unit, capable of processing an estimated 250 glass tons per day.

Sediment Removal. Separate mechanical dredging for TSCA sediments is not required under this alternative since TSCA-level sediments will be treated by thermal treatment. Hydraulic sediment removal techniques and costs for this alternative are equivalent to that described for Alternative C. The estimated time to complete hydraulic dredging is the same as Alternative C.

Sediment Dewatering. Sediment dewatering is similar to the requirements described in Alternative C for construction of a passive dewatering facility. The solids content after dewatering from hydraulic dredging is assumed to be 30 percent (w/w). However, no solidification will occur prior to thermal treatment assuming that the dewatered filter cake at 30 percent (w/w) solids is acceptable for processing at the vitrification facility. Sediment dewatering costs (primarily construction costs) for Alternative E are estimated at $3,000,000.

Water Treatment. Water from gravity dewatering would be treated before discharge to the river. Treatment and monitoring requirements are expected to be the same as those for Alternative C. Water treatment costs for Alternative E are expected to be the same as those for Alternative C.

Sediment Treatment. After completion of passive dewatering (to approximately 30 percent solids), non-TSCA-level sediments are passed through the dryer and dried to approximately 10 percent moisture. Thermal treatment of the dried sediments involves blending the high-silt/clay sediments with fluxing materials and processing the materials in a melter as part of the vitrification process. The thermal treatment process would include appropriate treatment of air emissions. The unit cost for thermal treatment includes capital costs and operating costs. The capital costs include equipment, building, installation, engineering, and startup costs. Operating costs include labor, utilities, and general administrative costs. The unit cost is based on an assumption that the glass aggregate resulting from treating sediments will have a resale value between a range of $2 and $25 per ton as provided by Minergy. The unit cost for sediment treatment decreases with an increase in the resale value of the glass aggregate.

The cost for thermal treatment is estimated to range between $7,700,000 for 125 ppb to $900,000 for 5,000 ppb action levels at an estimated unit cost of $24 per ton.

Sediment Disposal. No sediment disposal as hazardous waste is necessary, as all the sediments will be treated by thermal treatment. Treated sediments transformed to glass aggregate by the vitrification process have a wide variety of applications. Based on analysis by product marketing specialists, the glass aggregate has a potential to be used as roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan and construction fill (Minergy Corporation, 2002a).

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Institutional controls and monitoring will be the same as those described for Alternative C.

7.3.5 Section 7.3 Figures and Tables

Figures and tables for Section 7.3 follow page 7-74 and include:

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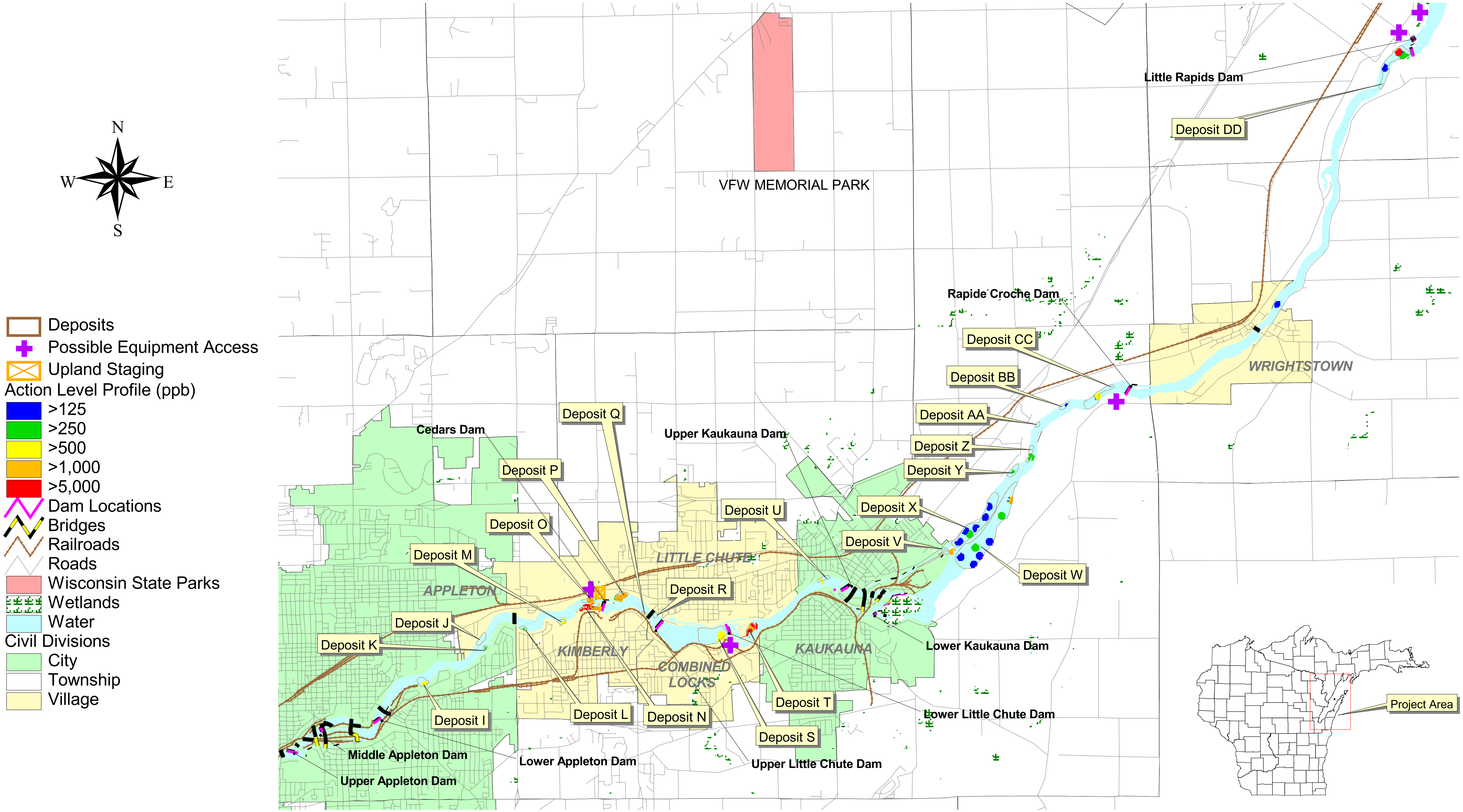
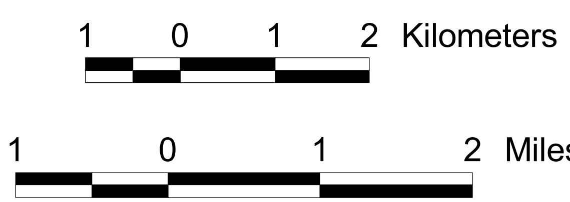
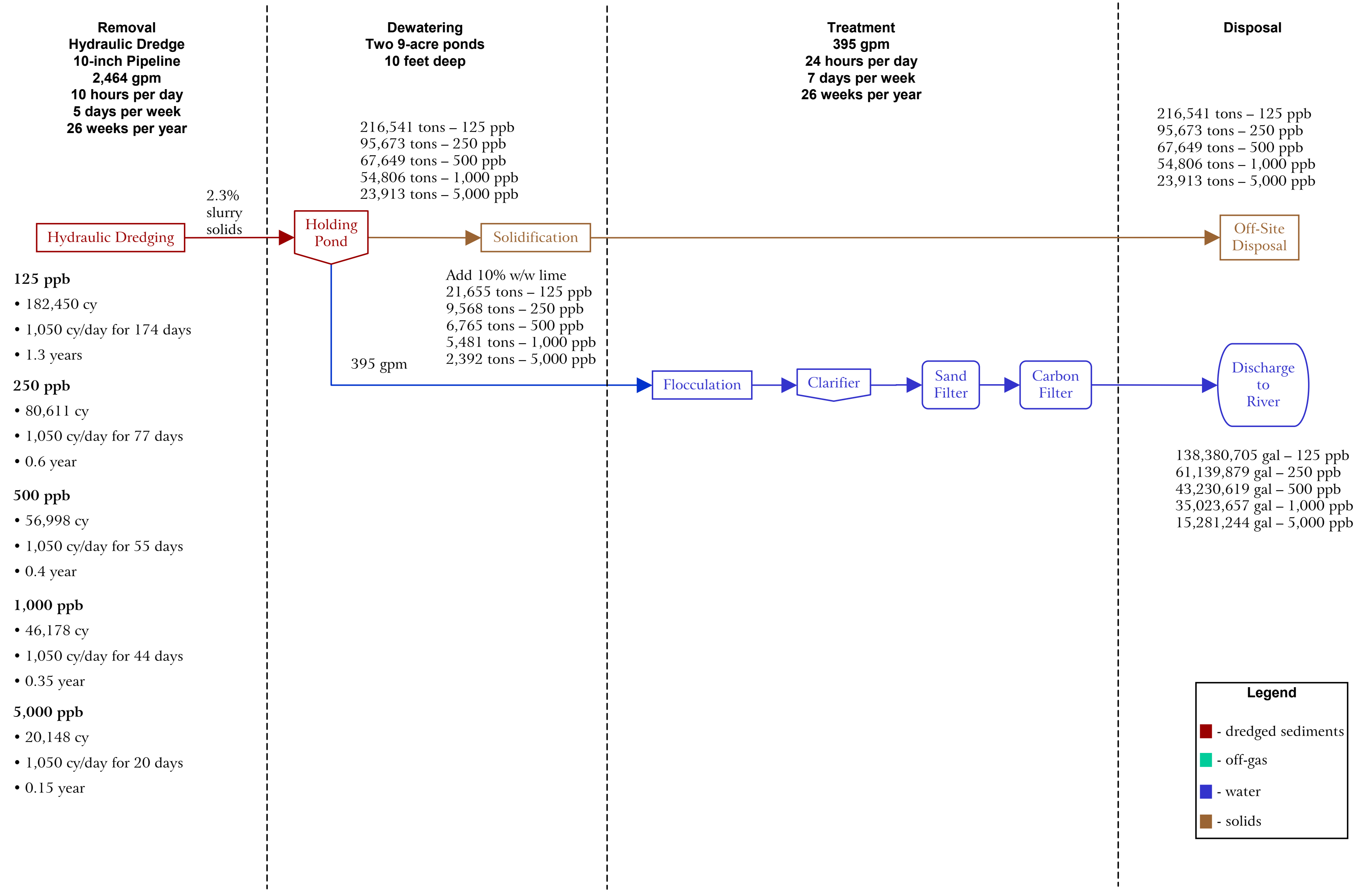




1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR. and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.
4. Former Deposit N shown for reference.

ThermoRetec	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Sediment Management Area Overview: Appleton to Little Rapids	REFERENCE NO: FS-14414-535-7-18
				CREATED BY: SCJ
				PRINT DATE: 3/12/01
			FIGURE 7-21	APPROVED: GH

Figure 7-22 Process Flow Diagram for Appleton to Little Rapids - Alternative C: Dredge Sediment with Off-site Disposal



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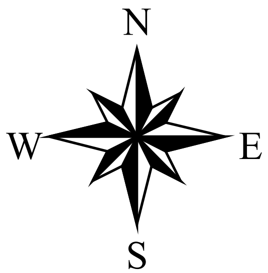
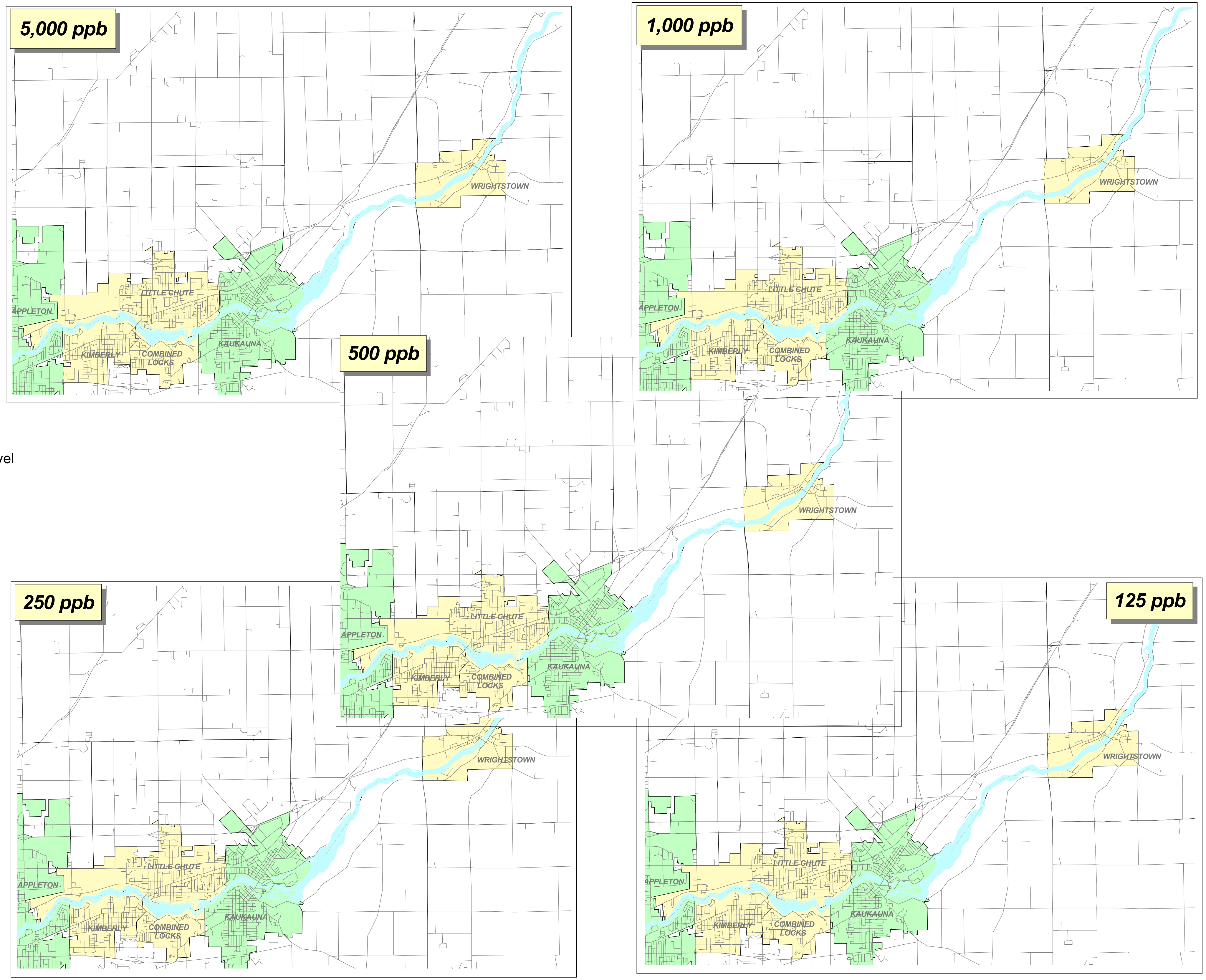


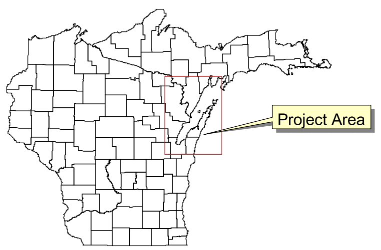


PCB Concentration (ppb) of Remaining Sediments by Action Level

- >125
- >250
- >500
- >1,000
- Dredged Sediments
- Roads
- Water

Civil Divisions

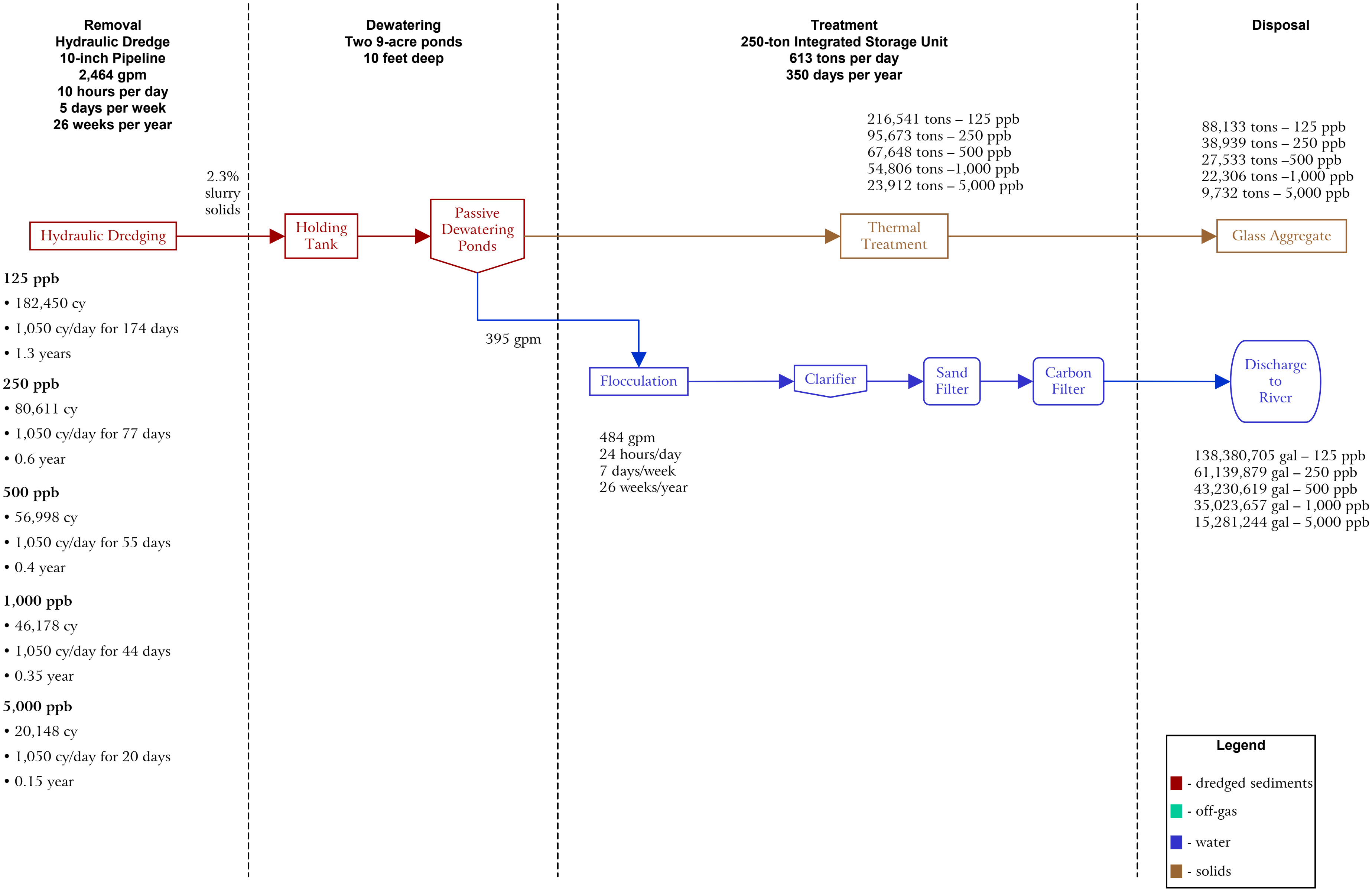
- City
- Township
- Village



1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for Lower Fox River.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative C: Dredge Sediment to Off-Site Disposal Appleton to Little Rapids	REFERENCE NO: FS14414-535-7-20
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-23	APPROVED: AGF

Figure 7-24 Process Flow Diagram for Appleton to Little Rapids - Alternative E: Dredge Sediment with Thermal Treatment



Note: Additional integral elements of the vitrification unit (dryer, pollution control) are not shown as they were not estimated separate. For greater detail on the unit layout and components, refer to the Minergy Unit Cost Report (Appendix G).

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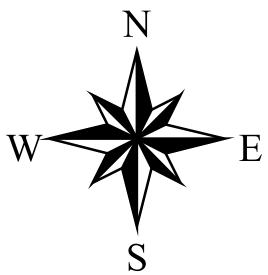
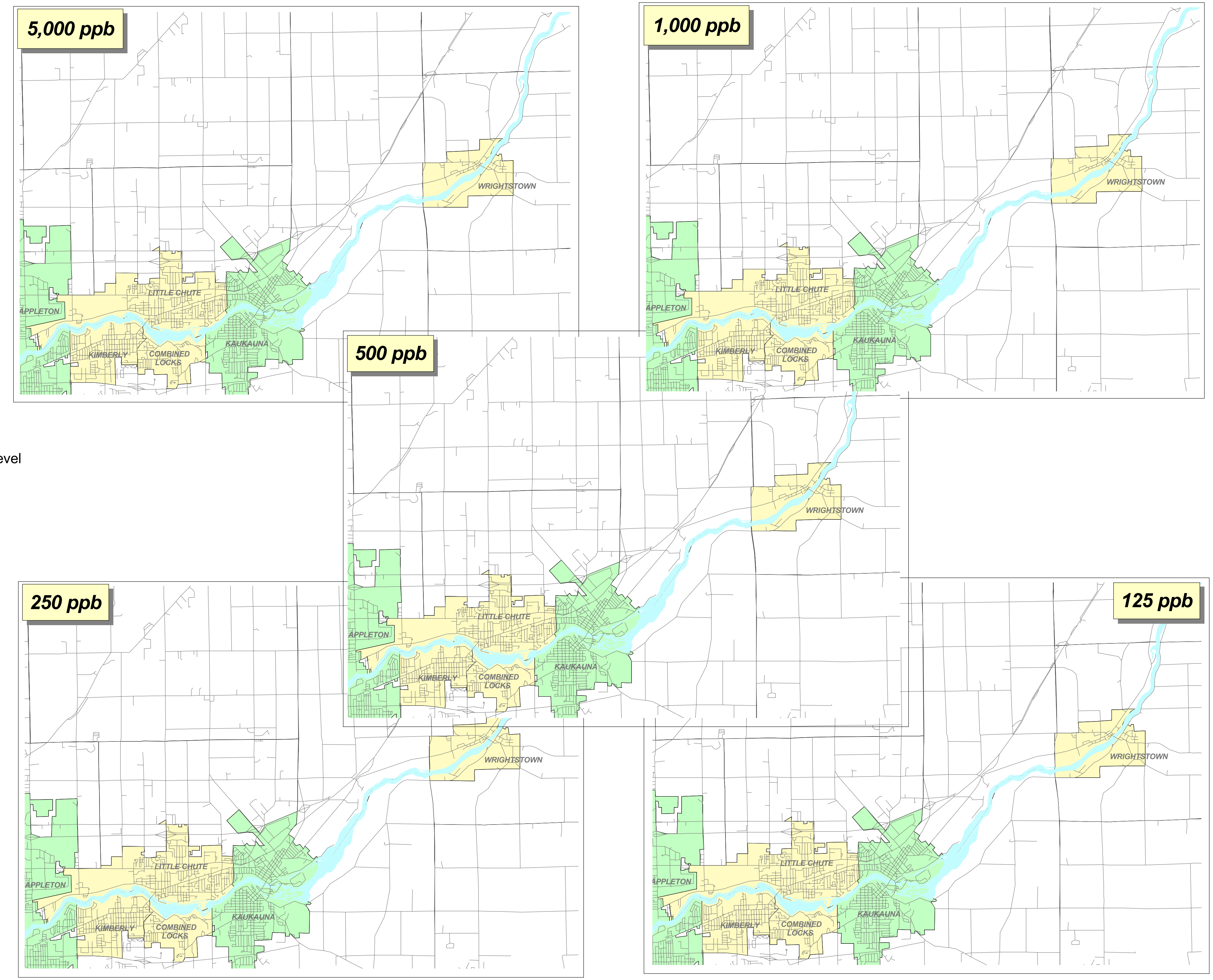
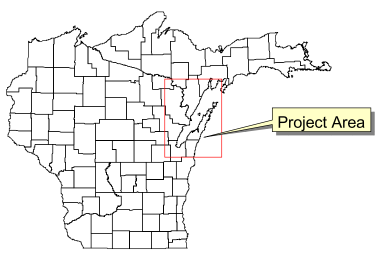


PCB Concentration (ppb) of Remaining Sediments by Action Level
- >125
- >250
- >500
- >1,000
- Dredged Sediments
- Roads
- Water

Civil Divisions
- City
- Township
- Village





1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for Lower Fox River.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative E: Dredge Sediment and Treatment Using Thermal Treatment: Appleton to Little Rapids	REFERENCE NO: FS14414-535-7-22
				CREATED BY: SCJ
				PRINT DATE: 5/11/01
			FIGURE 7-25	APPROVED: AGF

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Table 7-6 Cost Summary for Remedial Alternatives - Appleton to Little Rapids

125 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	182,450	$10,100,000	---	---	$3,000,000	$900,000	---	---	$19,800,000	$4,500,000	$38,300,000	$7,660,000	$45,960,000
E	182,450	$10,100,000	---	---	$3,000,000	$900,000	$7,700,000	---	---	$4,500,000	$26,200,000	$5,240,000	$31,440,000

250 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	80,611	$8,000,000	---	---	$3,000,000	$800,000	---	---	$8,700,000	$4,500,000	$25,000,000	$5,000,000	$30,000,000
E	80,611	$8,000,000	---	---	$3,000,000	$800,000	$3,400,000	---	---	$4,500,000	$19,700,000	$3,940,000	$23,640,000

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	56,998	$7,200,000	---	---	$3,000,000	$800,000	---	---	$6,200,000	$4,500,000	$21,700,000	$4,340,000	$26,040,000
E	56,998	$7,200,000	---	---	$3,000,000	$800,000	$2,400,000	---	---	$4,500,000	$17,900,000	$3,580,000	$21,480,000

1,000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	46,178	$6,800,000	---	---	$3,000,000	$800,000	---	---	$5,000,000	$4,500,000	$20,100,000	$4,020,000	$24,120,000
E	46,178	$6,800,000	---	---	$3,000,000	$800,000	$2,000,000	---	---	$4,500,000	$17,100,000	$3,420,000	$20,520,000

5,000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	20,148	$6,000,000	---	---	$3,000,000	$800,000	---	---	$2,200,000	$4,500,000	$16,500,000	$3,300,000	$19,800,000
E	20,148	$6,000,000	---	---	$3,000,000	$800,000	$900,000	---	---	$4,500,000	$15,200,000	$3,040,000	$18,240,000

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7.4 Little Rapids to De Pere Reach

An overview of the Little Rapids to De Pere Reach and PCB-impacted sediments is shown on Figure 7-26. The retained alternatives and associated costs are presented in Table 7-7.

7.4.1 General Site Characteristics

The Little Rapids to De Pere Reach lies wholly within Brown County and is largely agricultural for much of the upper segment. In the area of the De Pere dam, property use is principally residential, with the community of De Pere on both sides of the river and St. Norbert's College on the west bank. Most of the contaminated sediments exist in a single contiguous depositional zone (Deposit EE), approximately 5 miles in length. The entire reach is approximately 7 miles in length.

Depths throughout this reach are greater than the two upstream reaches of Little Lake Butte des Morts and Appleton to Little Rapids. The main channel depth is generally greater than 6 feet throughout most of the reach, and as deep as 18 feet at the De Pere dam. The water depth is less than 4 feet close to the shore and drops off abruptly. General water depths by river reach are given in Ocean Surveys (1998).

The average stream velocity for the Little Rapids to De Pere Reach is 0.39 ft/s (0.12 m/s). The maximum flood velocity noted here is 2.23 ft/s (0.68 m/s). Average and 100-year flows are given in Table 2-5. The nature and extent of PCB-impacted sediment in this reach, as summarized in the RI, includes the following:

- Maximum detected concentration - 54,000 μg/kg (avg. 6,292 μg/kg),
- Total PCB mass - 996 kg,
- Total PCB-impacted volume - 2,089,360 m^3, and
- Maximum PCB sample depth - 200 to 250 cm depth

These quantities represent total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described in this section will likely be larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

There are generally no physical impediments to sediment management in this reach. However, there is no access to the river that would support remedial efforts, but there are opportunities suitable for construction and maintenance of a dock and nearshore support facilities.

7.4.2 Selected Remedial Alternatives

This section defines the remedial alternatives for the Little Rapids to De Pere Reach, and then describes the technologies that would be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for the Little Rapids to De Pere Reach include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all river sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an NR 500 disposal facility.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

E. Remove sediment with PCB concentrations exceeding the selected action level and treat this sediment using thermal treatment. Treated sediment may be beneficially reused.

F. Place a sand cap over contaminated sediments to the maximum extent practicable. Mechanically remove all TSCA sediments from cap areas prior to capping and dispose in an existing NR 500 commercial disposal facility. Dredge remaining sediment and place dredged sediment in a CDF.

Alternative G was not retained, since river bathymetry and water depth limit the viability of installing a CAD site in this reach. The process options that can be applied to the remedial alternatives are described below.

7.4.3 Description of Process Options

Monitoring

Monitoring of physical, chemical, and biological media is applicable for Alternatives B through F. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; SMWG, 1999; IJC, 1997; Krantzberg *et al.*, 1999). The following references were used in this FS Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Ecology, *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- USACE*, Monitoring Considerations for Capping* (USACE, 1992);
- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);
- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);
- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);
- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b);
- Sediment remediation case study projects presented in Appendices B and C of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Control Options

Institutional controls appropriate to the Little Rapids to De Pere Reach include:

- Maintenance of the fish and waterfowl consumption advisory;
- A moratorium on any future dredging within the navigation channel;
- Deed restrictions on any in-water activities that could result in sediment disturbance (e.g., marina construction or over-water development);
- Access restrictions to contaminated areas;
- Continued restriction on the use of the Lower Fox River for domestic water supplies; and
- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal is identified for Alternatives C through F. For the Little Rapids to De Pere Reach, the only practicable dredging option for large-scale removal is hydraulic dredging. The relatively shallow water depths within the reach and accessibility concerns preclude application of a mechanical dredge.

Dredge Equipment. A hydraulic cutterhead dredge with a 10- or 12-inch pipeline has been selected for most of the remedial alternatives identified in this FS Report where a hydraulic dredge would be employed. While larger dredges are available, use of the 10- or 12-inch pipeline allows for a greater degree of control over resuspension of contaminated sediments during removal operations, provides for a removal time frame of less than 10 years, and limits the required size of a gravity dewatering pond. Alternative C2A, which includes hydraulic dredging and pumping sediment directly to a combined NR 213/NR 500 dewatering and disposal facility, Alternative C2B, which includes hydraulic dredging, passive dewatering, and transportation to a dedicated NR 500 monofill, and Alternative E, which includes hydraulic dredging, passive dewatering, and thermal treatment, utilize two dredges with 12-inch pipelines. This combination of dredges was selected so that the pipeline or the vitrification unit could be shared with the De Pere to Green Bay Reach and the cleanup could be completed within 10 years. Remedial Alternative C3, which includes hydraulic dredging, mechanical dewatering and transportation to an existing NR 500 commercial disposal facility utilizes one cutterhead dredge with 10-inch pipeline. Because the Little Rapids to De Pere Reach includes residential areas, an operating assumption is that dredging would occur only during normal daylight hours (10 hours per day) during a normal work week (5 days per week). Due to shared facilities with the De Pere to Green Bay Reach, dredging for Alternatives C2A, C2B, and E will occur 24 hours per day, 7 days per week. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Both the round and horizontal auger cutterheads are commonly employed hydraulic dredges, with multiple capable portable dredges in the small- to medium-size range available in the Great Lakes region. Required operator experience and skills are also available in this region. Sediment remedial demonstrations by public agencies (i.e., USACE, EPA, Environment Canada) have rated highly the small horizontal auger dredge for contaminated sediment removal. A horizontal auger equipped with two 10-inch pipelines and a 12-inch pipeline, for example, has been employed at the Manistique Superfund site and Lower Fox River SMU 56/57 demonstration project, respectively. A suitable alternative is the small cutterhead dredge; the cutterhead is the only hydraulic dredge capable of effective operations if debris or compacted sand are present. A ladder cutterhead dredge was successfully used at the Deposit N demonstration project on the Lower Fox River.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream. However, for the purposes of this FS, silt curtains were included in the removal costs.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For the majority of the alternatives utilizing hydraulic dredging in the Little Rapids to De Pere Reach, dewatering has been configured as a two-step process using a gravity settling pond, followed by solidification of solids. The water would be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. For the dredge and off-site disposal alternatives (Alternatives C, E, and F), the gravity settling pond would be located on nearby property. For the dredge to CDF alternative (Alternative D), dewatering would be conducted directly within the CDF (discussed below). A mechanical dewatering option has been included for Alternative C3.

The proposed dewatering system would meet the criteria defined in Section 6 of this FS Report in terms of production rate, effectiveness, practicality, and discharge water quality. The dewatering system would operate 24 hours per day near residential areas. Assuming adequate land space can be secured, a passive system is preferable to mechanical dewatering because of lower noise impact to the surrounding community and cheaper operational costs. Final selection of the dewatering process will be determined during the remedial design phase.

Passive Dewatering. For Alternatives C1 and F, the passive dewatering system would include the construction of two approximately 9-acre gravity separation ponds.

For Alternatives C2B and E, the passive dewatering system includes construction of two approximately 58-acre ponds. The ponds would be enclosed laterally with berms to allow a ponding depth of 8 feet, and lined with asphalt pavement. Each settling pond would receive dredged sediment in 13-week increments, and therefore contain a full season of dredge slurry. After a pond is filled, the sediment would be allowed to dewater to 30 percent solids based on dewatering studies (Montgomery-Watson, 1998). The residual water would be drained, treated, and discharged. The sediment will be solidified using lime or other agents prior to off-site disposal, since dewatered sediment may still be difficult to manage due to high moisture content. Sediment would be removed in preparation for the next dredging season.

Mechanical Dewatering. A mechanical dewatering option is included for Alternative C3. Mechanical dewatering involves pumping the hydraulically-dredged slurry into conditioning tanks or ponds, where the slurry is adjusted to the appropriate solids content, and chemicals are added to assist in the dewatering process. Mechanical dewatering would include shaker screens and hydrocyclones or belt filter presses after initial conditioning. Based on dewatering results from both of the Lower Fox River demonstration projects, the estimated percent solids of the filter cake after shaker screen, hydrocyclones, and belt filter presses ranged between 40 and 60 percent solids (Foth and Van Dyke, 2000; Fort James *et al.*, 2001).

Solidification. The solids content after passive dewatering for the hydraulic dredging is assumed to be 30 percent (w/w) and may still be difficult to manage due to high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary, and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. For FS costing purposes, 10 percent (w/w) lime was added as the reagent based on its successful use during the SMU 56/57 projects (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and removed from the pond using standard earthmoving equipment. If the contractor prefers, sediment may first be removed from the settling pond and mixed with reagent in a pug mill as shown on Figures 7-1 and 7-5. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

Treatment Process Options

Water Treatment. Prior to water discharge back to the river, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary (Foth and Van Dyke, 2000). However, additional carbon (GAC) treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC carbon treatment is $0.40 per thousand gallons of water treated.

Thermal Treatment. Several treatment process options were retained from the screening process in Section 6 that are applicable to the Lower Fox River/Green Bay remediation project. However, only vitrification was selected for costing purposes because the multi-phased study conducted by WDNR has provided data which indicates that this treatment technology is a viable option.

A full-scale vitrification unit will be constructed for the Little Rapids to De Pere Reach. The facility will be built as a standalone unit with on-site storage capacity and equipped with two 375 glass tons per day units. The sizing of the vitrification unit is based on the assumption that dewatered sediments from De Pere to Green Bay Reach will also undergo thermal treatment at this facility. The passively dewatered sediment enters the plant and is dried to approximately 10 percent moisture in the dryer unit. The sediment is mixed with a fluxing material and fed into a large melter, capable of maintaining temperature around 2,900 ˚F. The sediment melts into a molten material in the melter and passes through the water bath for quenching resulting in glass aggregate.

For the purposes of this FS, sediment treatment by vitrification is assumed to occur over a combined time frame of 10 years for both the Little Rapids to De Pere and De Pere to Green Bay reaches. The vitrification process is assumed to operate 24 hours per day, 7 days per week, and 350 days per year. The unit will be designed to have a capacity of 1,840 tons of sediment per day, producing 750 tons of glass aggregate per day.

On-site Disposal Process Options

The Little Rapids to De Pere Reach is relatively narrow and contains a large number of residences at the northern end of the reach. As a result, it is not considered practicable to place a CDF or CAD site in this reach. For the purposes of this FS, it was assumed that sediment from the Little Rapids to De Pere Reach would be placed upstream in the Menasha CDF in Little Lake Butte des Morts.

Off-site Disposal Process Options

All sediment samples collected to date in this reach indicate that the PCB concentrations are below 50 ppm, and therefore not considered TSCA material. All sediment could be shipped to a dedicated NR 500 monofill or existing landfill that conforms to the NR 500 WAC requirements.

Capping Process Options

Sediment in the river segments within this reach is amenable to capping. Capping is a viable alternative for most portions of this reach due to greater water depths in contaminated areas, relatively slow currents, and the lack of TSCA-level sediment. Furthermore, the reach has been identified as a depositional zone rather than an erosional zone (RETEC, 2002a), which further supports the potential for capping in this reach.

A protective cap placed in the Little Rapids to De Pere Reach would be a sand cap overlain with large cobble to provide erosion protection. The sand cap would be placed with a 10-inch tremie pipeline. Use of a tremie is preferable to placement with a split-hull barge in this reach to minimize the potential for resuspension of contaminated sediments. Placement of armor is also proposed using a barge-floated bucket.

7.4.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for the Little Rapids to De Pere Reach. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Details used to develop each cost estimate are provided in Appendix H. The process flow diagrams and dredging/capping footprints for each alternative are presented on Figures 7-27 through 7-35. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs (Table 7-7).

The following components are discussed, when applicable, within the development of each alternative:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for the Little Rapids to De Pere Reach. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management or remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until the RAOs are achieved. Costs include 5-year fish tissue sampling events for 40 years to maintain the fish consumption advisories already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream source and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C1: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

Alternative C includes the removal of sediments above the remedial action level with a hydraulic dredge and off-site disposal of the sediments. Alternative C1 trucks dewatered sediment to an existing NR 500 commercial disposal facility while Alternative C2A hydraulically pumps sediment slurry directly to a combined NR 213/NR 500 dewatering and disposal facility (discussed in the De Pere to Green Bay Reach). Alternative C2B hydraulically pumps sediment slurry to a separate NR 213 dewatering facility and trucks dewatered sediment to a dedicated NR 500 monofill. Alternative C3 utilizes mechanical dewatering and the dewatered sediment is transported to an existing NR 500 commercial disposal facility. Figure 7-27 provides the process flow diagram for this remedial alternative, while Figure 7-31 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-7. The total volume of sediment to be dredged in this alternative ranges between 1,483,156 cy for 125 ppb and 186,348 cy for 5,000 ppb action levels. Alternatives C2A and C2B would only be implemented if the corresponding C2 alternatives for the De Pere to Green Bay Reach are selected.

Site Mobilization and Preparation. Staging for the dredging of sediment would be conducted at an undetermined location. Site mobilization and preparation includes land acquisition and securing the onshore property area for equipment staging, constructing areas for sediment dewatering ponds, water treatment, sediment storage, and truck loading. An offshore docking facility for the hydraulic dredges would be constructed. Property purchase and preparation are included in the costs of the following process components.

Sediment Removal. Sediment removal would be done using a 10-inch pipeline cutterhead hydraulic dredge. Given the volumes and operating assumptions described above, the complete removal effort would require approximately 11 years for 125 ppb and 1.4 years for the 5,000 ppb action levels. Pipelines would extend directly from the dredging area to the dewatering area. For longer pipeline runs, it may be necessary to utilize in-line booster pumps to pump the slurry to the dewatering facility. Longer pipe runs may require periodic flushing of the lines during periods of inactivity. Silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; installation of silt curtains was included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs are estimated to range between $33,900,000 for 125 ppb and $6,900,000 for 5,000 ppb action levels.

Sediment Dewatering. Gravity dewatering includes land purchase, site clearing, and dewatering pond construction. Key assumptions include an approximate 4 percent dredged solids concentration and an approximate 2,464 gpm water production for the dredge, based on results from the Lower Fox River demonstration projects (Foth and Van Dyke, 2000; Montgomery-Watson, 2000). Although the recent dredging work conducted at SMU 56/57 (Fort James *et al.*, 2001) showed the average percent solids in dredge slurry was 8.4 percent w/w (range 3.5 to 14.4 percent), the lower and more conservative percent slurry solids measured during the 1999 activities was used for FS costs. Sediment dewatering would be done in a two-cell passive filtration system. The system would accommodate 26 weeks of solids dredge production rate, plus a maximum water surge storage capacity. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in sediment disposal). Dewatering costs also include pond decommissioning and site restoration at the completion of the project. Passive dewatering assumes that adequate land space can be acquired for construction of gravity settling ponds, otherwise mechanical dewatering methods will be employed. Mechanical dewatering would use methods similar to the Deposit N demonstration project including shaker screens, hydrocyclones, and belt filter presses.

Sediment dewatering costs (primarily for construction) for Alternative C1 are estimated at $3,100,000 for all action levels.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 560,000 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. However, it may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to range between $1,700,000 for 125 ppb and $900,000 for 5,000 ppb action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to a permitted facility. Disposal costs also include the purchase and addition of lime reagent for further solidification of dewatered sediment prior to off-site transport. The estimated percent solids of dewatered sediments after 6 months of passive dewatering is 30 percent (w/w) solids based on the SMU 56/57 BOD Report (Montgomery-Watson, 1998). Solidification costs for the addition of 10 percent (w/w) lime range between $60,000,000 and $7,500,000 for 125 ppb and 5,000 ppb action levels, respectively. The sediments would be loaded into tractor-trailer end dumps with bed liners or sealed gates using a front-end loader. Each load would be manifested and weighed. Each tractor-trailer would pass through a wheel wash prior to leaving the staging area to prevent tracking soil onto nearby streets and highways.

Costs of sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to range between $181,000,000 for 125 ppb and $22,700,000 for 5,000 ppb action levels.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of the pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre- and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time. If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

The estimated cost for the maintenance of institutional controls is $4,500,000. Costs for implementation monitoring during removal are included in the removal and water treatment costs. Multimedia monitoring costs for verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

Alternative C2A: Dredge with Combined Dewatering and Disposal Facility

Alternative C2A includes the removal of sediments above the remedial action level using a hydraulic dredge and hydraulically pumping the sediment slurry directly to a combined NR 213/NR 500 dewatering and disposal facility for disposal. Figure 7-28 provides the process flow diagram for this alternative while Table 7-7 provides summary costs. WDNR requested the addition of this alternative with conditional selection of Alternative C2 only if the 18-mile pipeline to the landfill is already constructed for the De Pere to Green Bay Reach.

Site Mobilization and Preparation. Staging for sediment dredging will be conducted at the Bayport or former Shell facilities. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, constructing intermediate shore-based ponds, pipelines, and booster pumps. The shore-based slurry ponds are constructed of earthen berms lined with asphalt covering 10 acres. It is assumed that docking facilities for the dredges and barges already exist at these locations. Land purchase and construction of upland staging areas are included in the dredging costs.

Sediment Removal. Sediment removal in Alternative C2A will be conducted using two 12-inch hydraulic pipeline feeder dredges with modified cutterheads and one floating 12-inch booster pump. The two feeder dredges will pump dredge slurry to an intermediate shore-based slurry pond located mid-reach. A third 16-inch cutterhead dredge located in the shore-side pond will resuspend the slurry into a 15-inch polyethylene pipe with 1.5-inch wall thickness. The inner pipe will be encased inside a 20-inch steel pipe traveling 18 miles to a dedicated NR 500 monofill. Four booster pumps will be evenly spaced along the route (28 miles with 25 feet total elevation lift). Dredging and pumping operations will continue 7 days per week, 24 hours per day, and 26 weeks per year (182 days) allowing 32 days for downtime and repairs (150 working days per year). Given the volumes and operating assumptions described above, the complete removal effort would require approximately 1.7 years for 125 ppb and 0.2 year for 5,000 ppb action levels, using two dredges. Sediment removal costs also include construction of a shore-based slurry pond and 28-mile pipeline, booster pump rental, "wintering over" of all equipment, and full-time monitoring of the pipeline. Longer pipe runs may require periodic flushing of the lines during periods of inactivity. Construction of an effluent return pipeline are included in the water treatment costs.

Installation of silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; construction of silt curtains are included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are booster pump rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs using hydraulic dredging are estimated to range between $43,300,000 for 125 ppb and $17,400,000 for 5,000 ppb action levels.

Sediment Dewatering. For Alternative C2A, passive dewatering will occur within the combined dewatering and disposal facility. Sediment dewatering costs are included in the dredging, landfill construction, and water treatment costs.

Water Treatment. Water treatment includes construction of an effluent return pipeline from the landfill to the river. Purchase costs also include equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 560,000 gallons per day for Alternative C2A.

Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Water treatment costs include pad and equipment demobilization and site restoration.

Water treatment costs for hydraulic dredging (Alternative C2A) will range between $5,100,000 for 125 ppb and $4,500,000 for 5,000 ppb action levels.

Sediment Disposal. Costs of sediment disposal at a dedicated NR 500 monofill (Alternative C2A) will range between $19,400,000 for 125 ppb and $6,000,000 for 5,000 ppb action levels which includes siting fees, construction, and site restoration costs. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and site restoration will be the same as those described in Alternative C1.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C1.

The total projected costs for Alternative C2A are approximately 70 percent lower than the Alternative C1 costs; mostly accountable in the disposal costs.

Alternative C2B: Dredge with Separate Dewatering and Disposal Facility

Alternative C2B includes the removal of sediments above the remedial action level using a hydraulic dredge and hydraulically pumping the sediment slurry to an NR 213 dewatering facility located adjacent to a dedicated NR 500 monofill. Figure 7-29 provides the process flow diagram for this alternative while Table 7-7 provides summary costs. WDNR requested the addition of this alternative for cost comparison purposes with Alternative C2A to evaluate potential cost savings associated with constructing a separate dewatering facility.

Site Mobilization and Preparation. Site mobilization and preparation will be the same as that described in Alternative C2A.

Sediment Removal. Sediment removal will be the same as described in Alternative C2A with the exception that the hydraulically dredged slurry will be pumped to an NR 213 dewatering facility located adjacent to the dedicated NR 500 monofill.

Sediment Dewatering. Passive dewatering includes land purchase, site clearing, and dewatering pond construction. Key assumptions include a 3.4 percent by volume (w/w) dredged solids concentration and 3,100 gpm water production rate for the dredge based on results from the 1999 Lower Fox River demonstration projects (Foth and Van Dyke, 2000; Montgomery-Watson, 2000). Although the recent dredging work conducted at SMU 56/57 (Fort James *et al.*, 2001) showed the average percent solids in dredge slurry was 8.4 percent (w/w) (range 3.5 to 14.4 percent), the lower and more conservative percent slurry solids measured during the 1999 activities was used for FS costs. The sediment dewatering system would be done in a two-cell passive filtration system located adjacent to the dedicated NR 500 monofill. The system would accommodate 26 weeks of solids dredge production rate, plus a maximum water surge storage capacity. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in disposal costs). Dewatering costs also include pond decommissioning and site restoration at the completion of the project. Sediment dewatering costs for Alternative C2B (primarily construction costs) are estimated at $22,100,000.

Water Treatment. Water treatment will be the same as described in Alternative C2A with the exception that the effluent lines for treated water will be constructed from the passive dewatering system.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to the dedicated NR 500 monofill. Disposal costs also include the purchase and addition of lime reagent for solidification of dewatered sediment prior to off-site transport. Sediment disposal costs for Alternative C2B range between $104,900,000 for 125 ppb and $16,800,000 for 5,000 ppb action levels which includes siting fees, construction, and site restoration costs. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and Site Restoration will be the same as those described in Alternative C2A.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C2A. The total projected costs for Alternative C2B are approximately 27 percent lower than the Alternative C1 costs; mostly accountable in the disposal costs.

Alternative C3: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

Alternative C3 includes the removal of sediments above the remedial action level using a hydraulic dredge and mechanical dewatering of the dredged sediments. Mechanically dewatered sediments will be transported to an existing NR 500 commercial disposal facility for disposal. Figure 7-30 provides the process flow diagram for this alternative while Table 7-7 provides summary costs. WDNR requested the addition of this alternative for cost comparison purposes with Alternatives C1 and C2.

Site Mobilization and Preparation. Staging for sediment dredging will be conducted at the Bayport or former Shell facilities. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, constructed intermediate shore-based ponds and mechanical dewatering facility, water treatment, sediment storage and truck loading area. Land purchase and construction of upland staging areas are included in the dredging costs.

Sediment Removal. Sediment removal in Alternative C3 will be the same as described in Alternative C1.

Sediment Dewatering. Mechanical dewatering includes land purchase, site clearing, and construction of temporary holding ponds. Dewatering techniques will be similar to the mechanical processes used for both Lower Fox River demonstration projects including a series of shaker screens, hydrocyclones, and belt filter presses. The final percent solids of the filter press cake was about 60 percent solids (w/w) for SMU 56/57 (Fort James *et al.*, 2001) and 40 to 50 percent solids for Deposit N (Foth and Van Dyke, 2000). No additional solidification was required. The dewatering process will be simplified into a unit cost of $80 per bone dry ton assuming 50 percent solids after dewatering for the purposes of this FS.

Mechanical dewatering costs for Alternative C3 range from $53,400,000 for 125 ppb to $6,800,000 for 5,000 ppb action levels.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 656,640 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Carbon filtration could be added for a unit cost of $0.040 per thousand gallons of water treated. It may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to range from $2,600,000 for 125 ppb to $1,700,000 for 5,000 ppb action levels.

Sediment Disposal. Mechanically dewatered sediments will be transported to an existing NR 500 commercial disposal facility by trucks. Costs of sediment disposal will range between $67,300,000 for 125 ppb and $8,500,000 for 5,000 ppb action levels. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and site restoration will be the same as those described in Alternative C1.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C1.

Alternative D: Dredge to a Confined Disposal Facility

Alternative D includes removal of sediments to an on-site CDF for long-term disposal of the materials. For this reach, the dredged material will be pumped to a CDF located in Little Lake Butte des Morts. Figure 7-32 provides the process flow diagram for this remedial alternative and Figure 7-31 illustrates the extent of residual sediment impacts following implementation of Alternative D. Table 7-7 contains the summary costs to implement Alternative D. The total volume of sediments to be dredged are similar to those identified in Alternative C.

Site Mobilization and CDF Construction. The Little Rapids to De Pere Reach does not have a suitable location for construction of a CDF. Placement of dredged material would preferably be placed in a downstream CDF located in the De Pere to Green Bay Reach; however, this CDF reaches capacity for all action levels. Dredged material would be pumped via pipeline to the proposed Menasha CDF located in the Little Lake Butte des Morts Reach. CDF construction and costs are discussed in Section 7.2.4 for Little Lake Butte des Morts.

Sediment Removal. Hydraulic sediment removal techniques and costs for this alternative are equivalent to that described for Alternative C. The estimated time to complete hydraulic dredging ranges between 11 years for 125 ppb and 1.4 years for 5,000 ppb action levels. Costs for construction of a long pipeline directly to a CDF are included in the De Pere to Green Bay Reach.

Sediment Dewatering. Passive dewatering will occur directly within the CDF berms for hydraulic dredging. No on-barge dewatering will be required. No dewatering costs are required.

Water Treatment. Overflow return water from the CDFs would be treated before discharge to the river. Treatment and monitoring requirements are expected to be the same as those for Alternative C.

Water treatment costs for Alternative D are estimated to range between $1,900,000 for 125 ppb and $1,000,000 for 5,000 ppb action levels.

Sediment Disposal. No off-site disposal costs (for TSCA-level sediments) are incurred for this reach. Sediment disposal to a CDF incurs no costs besides construction and closure of the CDF previously included in preparation costs.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDF would be finished with a 3-foot cap of clean soils, and seeded and planted. Additional amenities (i.e., bike paths, wildlife habitat) were not included in the cost estimates. However, this alternative would allow development of these features, and would provide a beneficial use of this area for the community. Demobilization and site restoration costs are included under the dredging and CDF construction cost estimates.

Institutional Controls and Monitoring. Institutional controls, long-term monitoring, and operations and maintenance monitoring parameters will be the same as those provided in Section 7.2.4 for the Little Lake Butte des Morts CDF, and Alternative C1 for the Little Rapids to De Pere Reach.

Alternative E: Dredge with Thermal Treatment

Alternative E includes hydraulic dredging of sediments, passive dewatering, and treatment with an on-site integrated vitrification unit. This alternative results in the sediments being transformed into glass aggregate that has potential for a wide variety of beneficial reuse applications. Figure 7-33 provides the process flow diagrams for this remedial alternative, while Figure 7-31 illustrates the extent of residual contamination following implementation of Alternative E. Table 7-7 contains the summary costs to implement Alternative E. This alternative addresses the same volume of sediments as Alternative C.

Site Mobilization. Site mobilization and preparation includes securing the onshore property area for equipment staging, water treatment, and an offshore docking facility for the hydraulic dredge. Site preparation would also include building a standalone vitrification unit capable of processing an estimated 750 glass tons per day.

Sediment Removal. Hydraulic sediment removal techniques and duration for this alternative are equivalent to that described for Alternative C. Sediment removal costs for hydraulic dredging are estimated to be the same as Alternative C2B.

Sediment Dewatering. Sediment dewatering is similar to the requirements described in Alternative C1 for construction of an NR 213 dewatering facility. The solids content after dewatering from hydraulic dredging is assumed to be 30 percent (w/w). However, no solidification will occur prior to thermal treatment assuming that the vitrification facility is located in close proximity to the dewatering facility and the dewatered filter cake at 30 percent (w/w) solids is acceptable for processing at the vitrification facility. Sediment dewatering costs (primarily construction costs) for Alternative E are estimated at $22,100,000.

Water Treatment. Water from dewatering would be treated before discharge to the river. Treatment and monitoring requirements are expected to be the same as those for Alternative C. Water treatment costs for Alternative E are estimated to be the same as Alternative C.

Sediment Treatment. After completion of passive dewatering (to approximately 30 percent solids), sediments are passed through the dryer and dried to approximately 10 percent moisture. Thermal treatment of the dried sediments involves blending the high-silt/clay sediments with fluxing materials and processing the materials in a melter as part of the vitrification process. The vitrification process would include appropriate treatment of air emissions. The unit cost for vitrification includes capital costs and operating costs. The capital costs include equipment, building, installation, engineering, and startup costs. Operating costs include labor, utilities, and general administrative costs. The unit cost is based on an assumption that the glass aggregate resulting from treating sediments will have a resale value between a range of $2 and $25 per ton as provided by Minergy. The unit cost for sediment treatment decreases with an increase in the resale value of the glass aggregate.

The cost for thermal treatment is estimated to range between $62,100,000 for 125 ppb and $7,800,000 for 5,000 ppb action levels at an estimated unit cost of $24 per ton.

Sediment Disposal. No sediments will be disposed of as hazardous waste, as all the sediments will be treated by thermal treatment. Treated sediments transformed to glass aggregate by the vitrification process have a wide variety of applications. Based on analyses by product marketing specialists, the glass aggregate has a potential to be used as roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan and construction fill (Minergy Corporation, 2002a).

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Institutional controls and monitoring will be the same as those described for Alternative C.

Alternative F: Cap to Maximum Extent Possible, Dredge Remaining Sediments with Off-site Disposal

Alternative F includes primarily capping to the maximum extent possible, with off-site disposal of dredged sediments outside of the capping footprint. As stated in Section 7.4.3, many areas meet the cap criteria defined in Section 6.5.1. The capping area encompasses Deposit EE with depths ranging from less than 6 feet to 12 feet. The process flow diagram is depicted on Figure 7-34, while Figure 7-35 illustrates capping areas and the extent of residual contamination following implementation of Alternative F. The estimated costs are presented in Table 7-7.

Site Preparation and Cap Construction. Site preparation for dredging would include construction of a dewatering area discussed in Alternative C. The cap in the Little Rapids to De Pere Reach is planned to be an armored cap composed of 20 inches of sand overlain with 12 inches of large cobble to provide erosion protection. The sand cap will be completed using a spreader barge with a 10-inch pipeline. The cap will be placed in 6-inch lifts requiring 1.2 to 4.6 years for cap placement with 10-hour work shifts (1,200 cy placed per day) (OBAI cost estimate). Armor placement would be completed using two 3-cy clamshell buckets requiring 1.1 to 4.2 years for armoring (400 cy per day per bucket working 10-hour shifts). Cap construction would require an upland staging area for the receipt and placement of sand and the armoring stone. The staging area will include a hopper for pumping slurry to the spreader barge. Armor stone will be delivered to the work area via barges. All other unit costs are similar to those described for the prior alternatives for the river reach. Site preparation costs in this alternative are included under the dredging, dewatering, and capping costs.

Capping costs under this alternative are estimated to range from $40,500,000 for 125 ppb to $15,000,000 for 5,000 ppb action levels. The estimated time for placement of the sand cap is 4.6 and 1.2 years for the 125 ppb and 5,000 ppb action levels, respectively.

Sediment Removal. Hydraulic sediment removal techniques for this alternative are equivalent to that described for Alternative C for areas that are not capped. The estimated time to complete hydraulic dredging ranges from 4.3 years for 125 ppb to 0.4 year for 5,000 ppb action levels.

Sediment removal costs for hydraulic dredging are estimated to range between $9,700,000 for 125 ppb and $3,300,000 for 5,000 ppb action levels.

Sediment Dewatering. The 9-acre gravity dewatering ponds previously described for Alternative C are applicable for Alternative F.

Sediment dewatering costs (primarily for construction) are estimated at $3,100,000 for all action levels.

Water Treatment. Overflow return water from the gravity dewatering ponds would be treated before discharge to the river. Treatment and monitoring requirements are the same as for the prior remedial alternatives.

Water treatment costs for Alternative F are estimated to range between $1,100,000 for 125 ppb and $800,000 for 5,000 ppb action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of uncapped sediments to an off-site upland disposal facility. It also includes solidification with 10 percent lime.

The cost for off-site sediment solidification and disposal at an existing NR 500 commercial disposal facility is estimated to range between $71,400,000 for 125 ppb and $6,100,000 for 5,000 ppb action levels. Off-site disposal is intended for sediments located beyond the horizontal extent of the *in-situ* cap. It is possible that these sediments could be pumped directly to a CDF located in the Little Lake Butte des Morts Reach, but this option was not included in project costs.

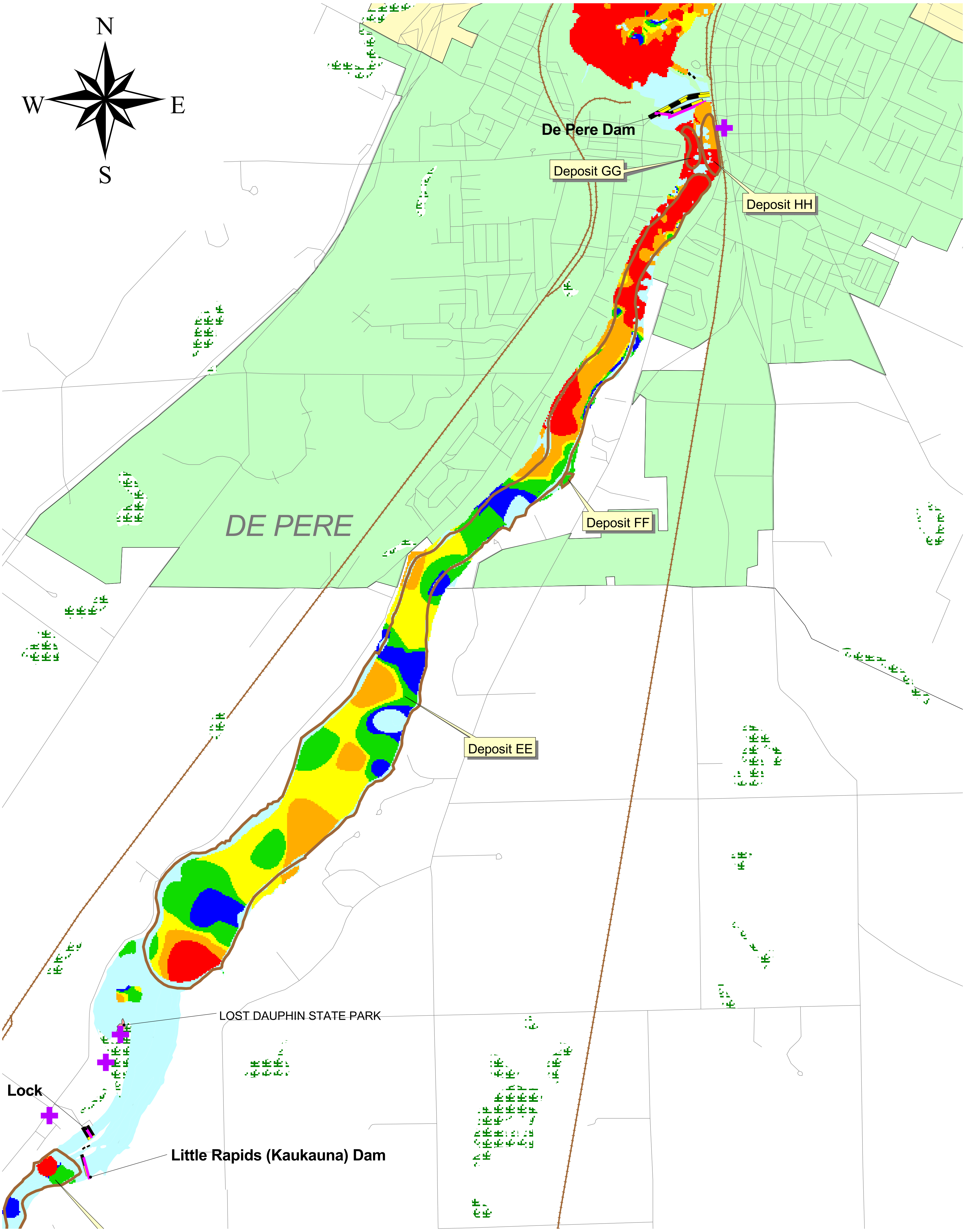
Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment, fencing, facilities, etc., from the staging and work areas. Demobilization and site restoration costs are included under the dredging and capping estimates.

Institutional Controls and Monitoring. Operation and maintenance monitoring would be required to ensure proper placement and maintenance of cap integrity. For this type of armored capping, monitoring will be performed to ensure that the cap is placed as intended, the required capping thickness is maintained, and to determine if the cap effectively isolates the contaminants. The monitoring would include bathymetric or side-scan sonar profiling, sediment and cap sampling, as well as diver inspections to ensure that the cap is physically isolating impacted sediments. The monitoring program would occur for a period of 40 years with decreasing sampling intervals over time, as appropriate. Institutional controls would include deed restrictions, site access and anchoring limitations, and maintenance of the consumption advisories. A separate *Long-term Monitoring Plan* for the entire river and Green Bay is discussed, along with cost estimates, in Appendix C.

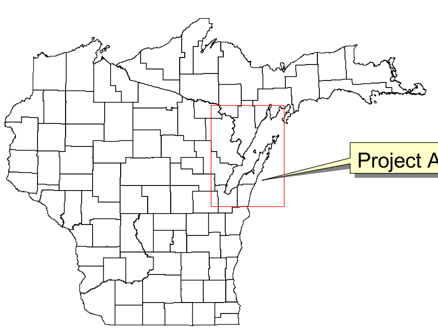
Maintenance and monitoring costs of the cap are included in the capping costs. The estimated cost for institutional controls is $4,500,000. Long-term monitoring costs for verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

7.4.5 Section 7.4 Figures and Tables

Figures and tables for Section 7.4 follow this page and include:



Deposits
Possible Equipment Access
TSCA Areas
Upland Staging
Action Level Profile (ppb)
>125
>250
>500
>1,000
>5,000
Dam Locations
Bridges
Railroads
Roads
Wisconsin State Parks
Wetlands
Water
Civil Divisions
City
Township
Village



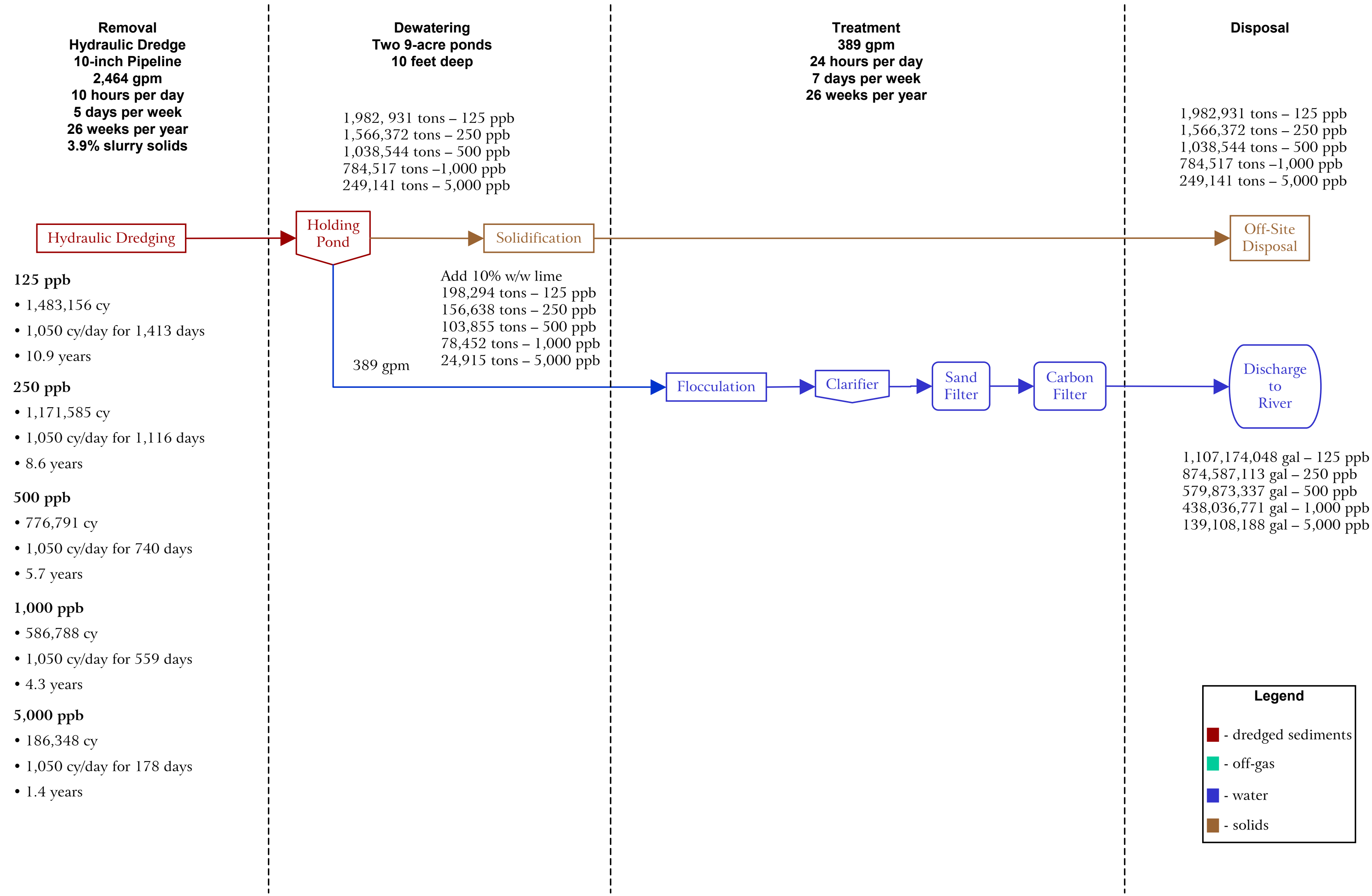
1 0 1 Kilometers

0.5 0 0.5 1 Miles

1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR. and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

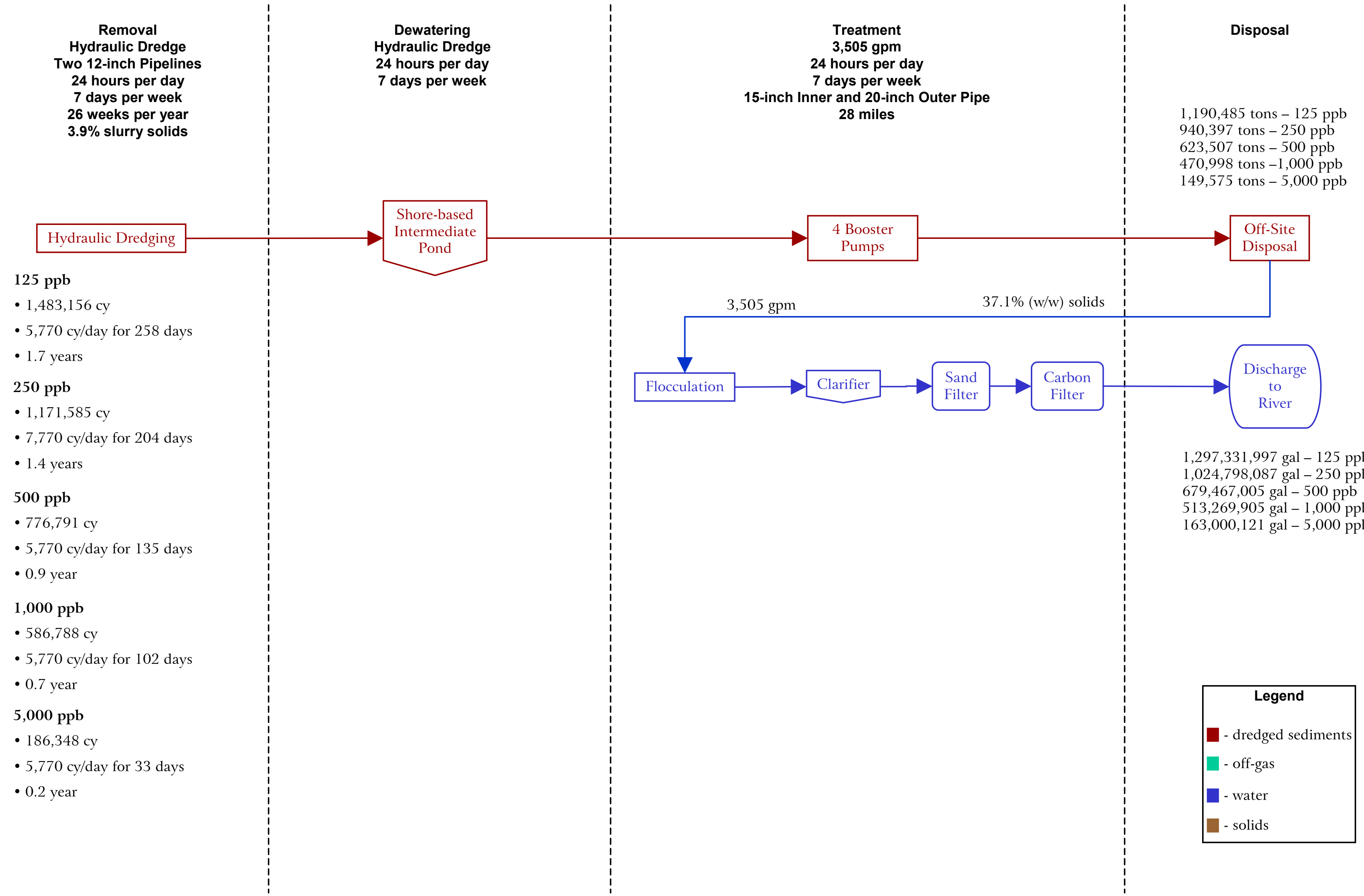
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Sediment Management Area Overview: Little Rapids to De Pere	REFERENCE NO: FS-14414-535-7-23
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-26	APPROVED: AGF

Figure 7-27 Process Flow Diagram for Little Rapids to De Pere - Alternative C1: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Passive Dewatering)



F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

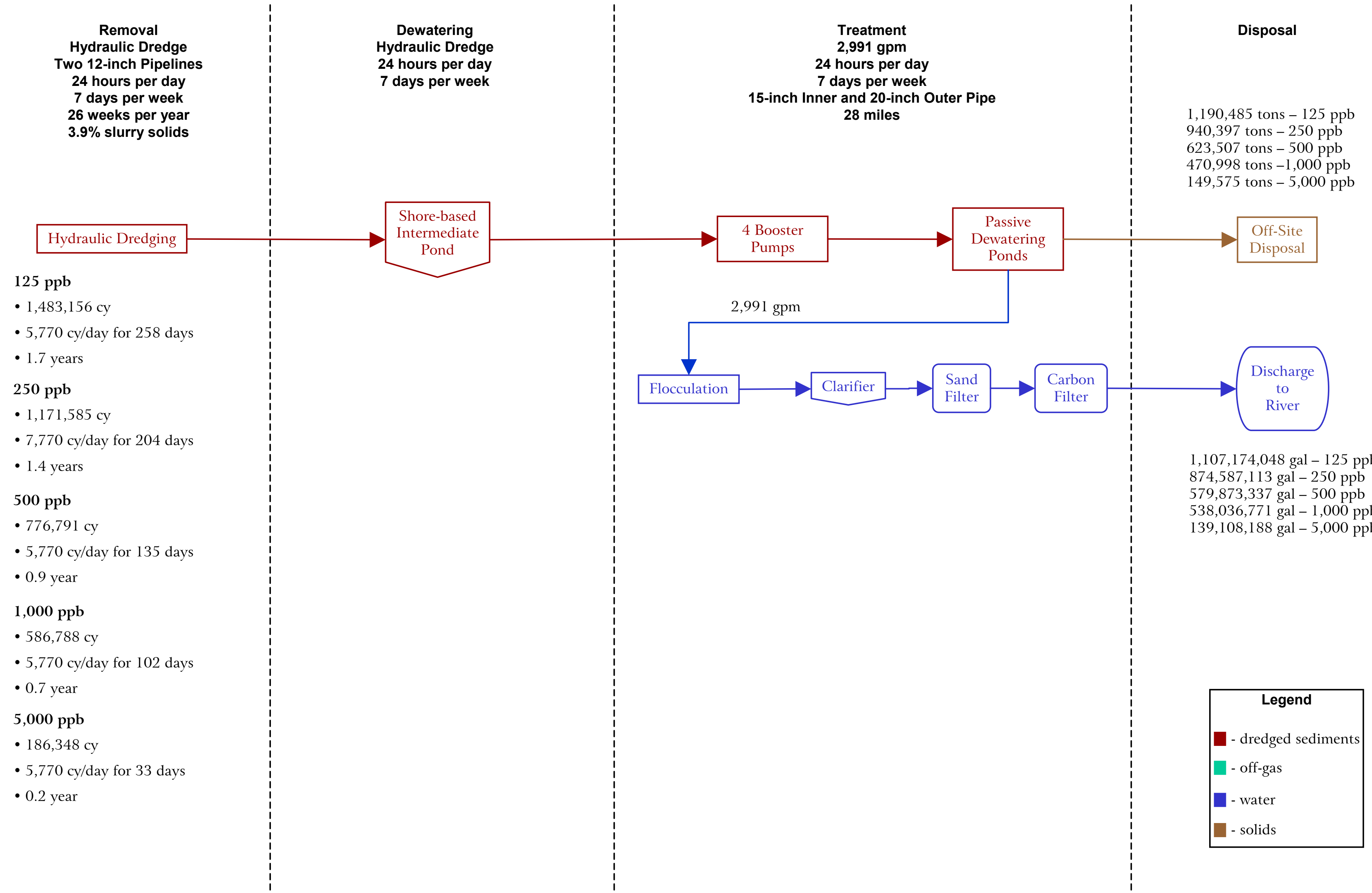
Figure 7-28 Process Flow Diagram for Little Rapids to De Pere - Alternative C2A: Dredge with Combined Dewatering and Disposal Facility



Note: Off-site disposal unit is a combined dewatering and disposal facility.

F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

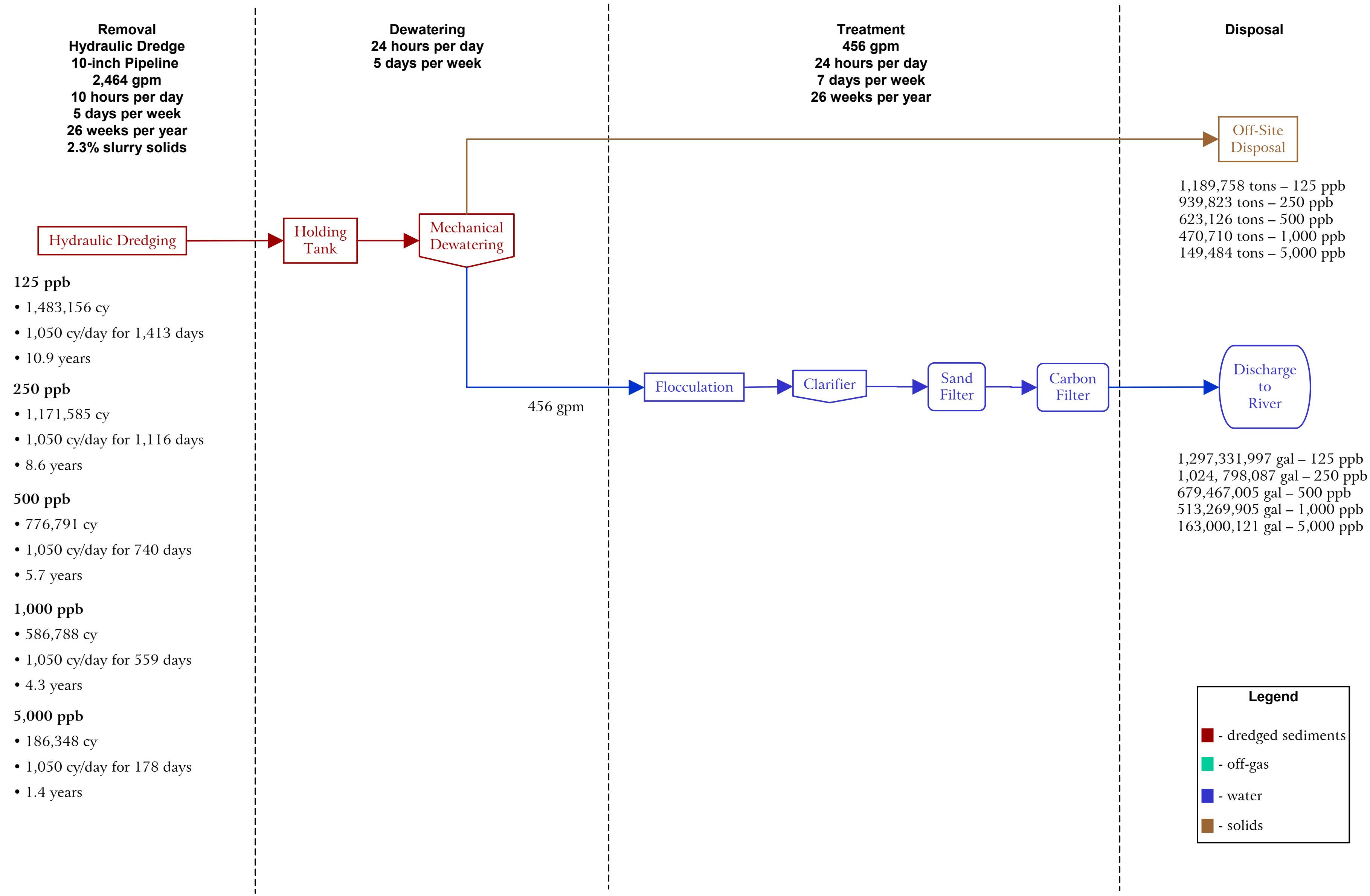
Figure 7-29 Process Flow Diagram for Little Rapids to De Pere - Alternative C2B: Dredge with Separate Dewatering and Disposal Facility



Note: Off-site disposal unit is a dedicated NR 500 monofill.

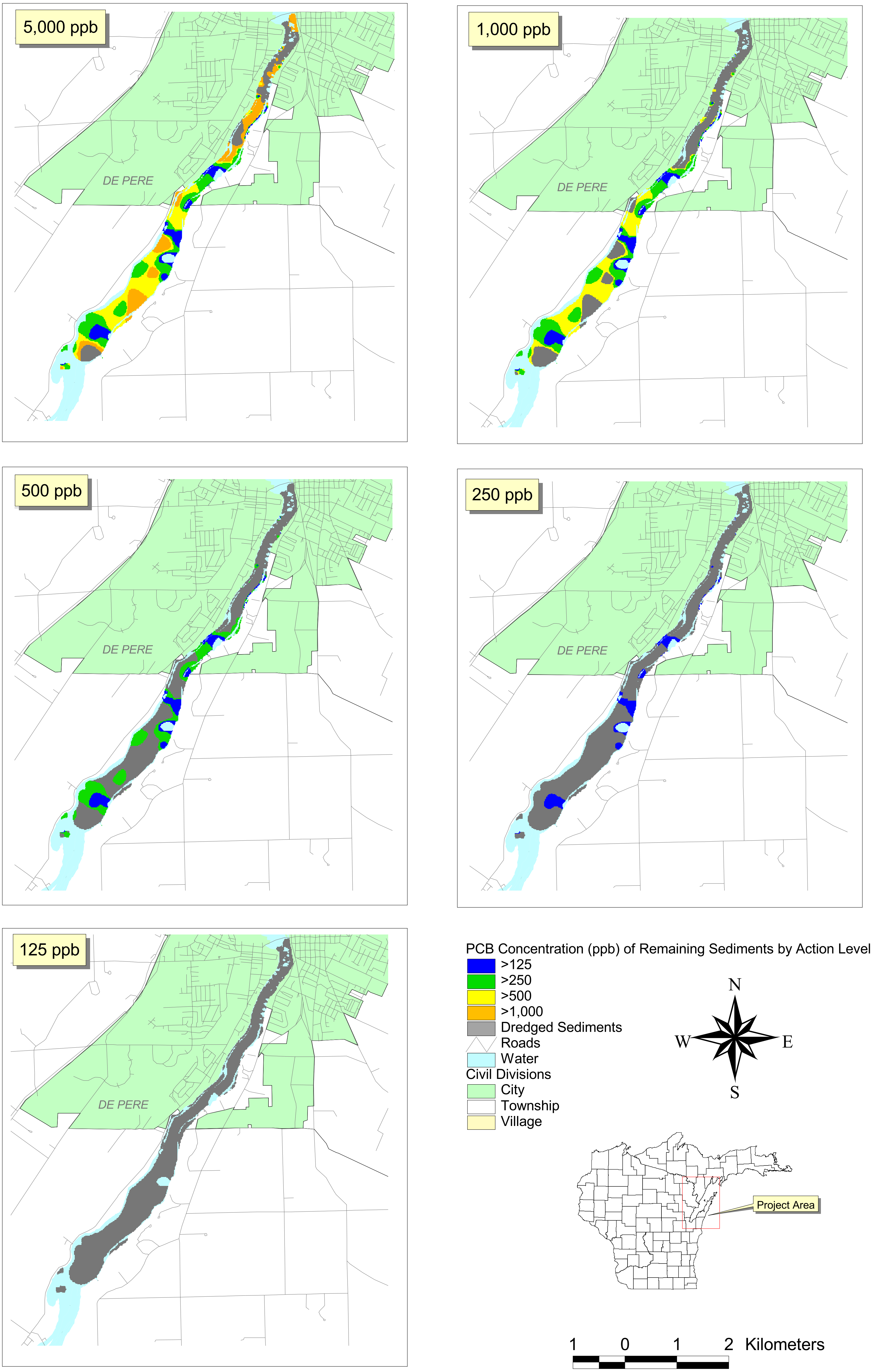
F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

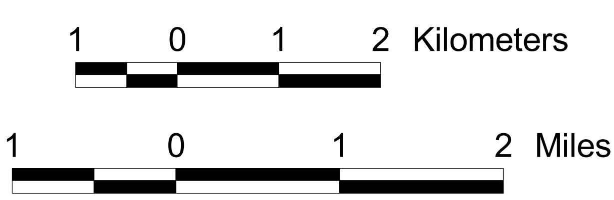
Figure 7-30 Process Flow Diagram for Little Rapids to De Pere - Alternative C3: Dredge Disposal at an Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)



Note: Off-site disposal unit is an existing NR 500 commercial disposal facility.

F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT





1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternatives C, D, and E: Little Rapids to De Pere	REFERENCE NO: FS-14414-535-7-26
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-31	APPROVED: AGF

Figure 7-32 Process Flow Diagram for Little Rapids to De Pere - Alternative D: Dredge Sediment to CDF

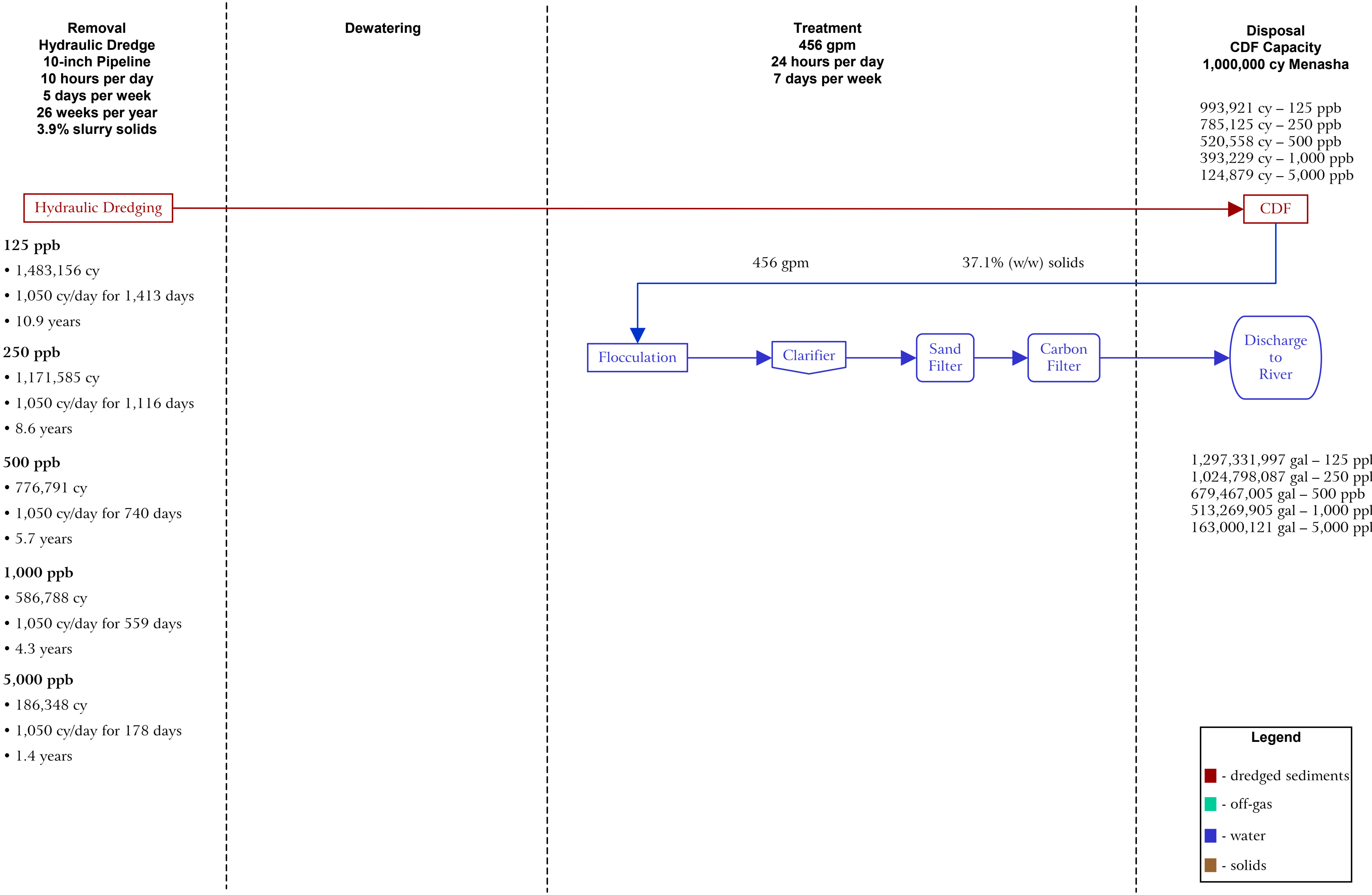
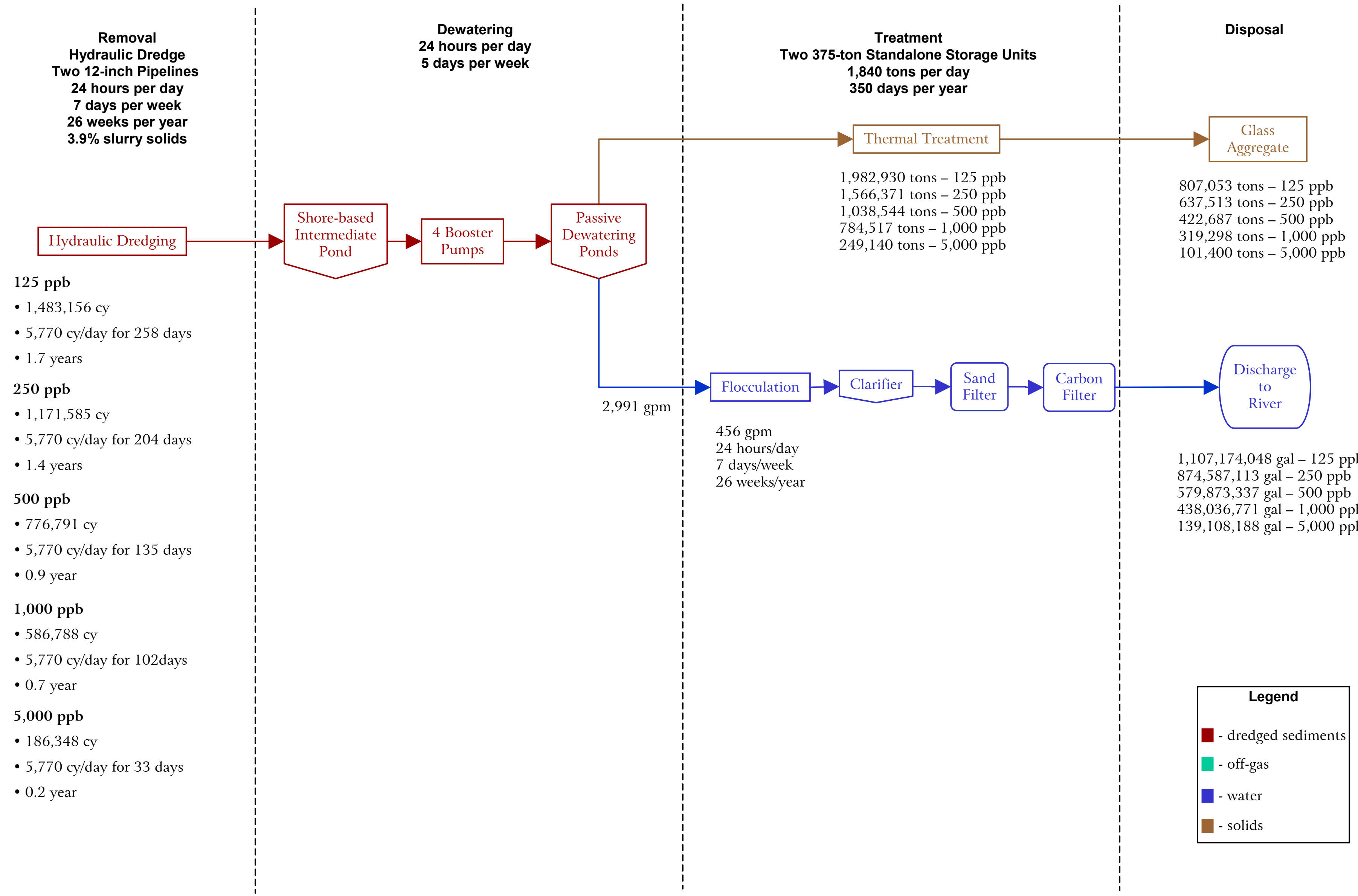


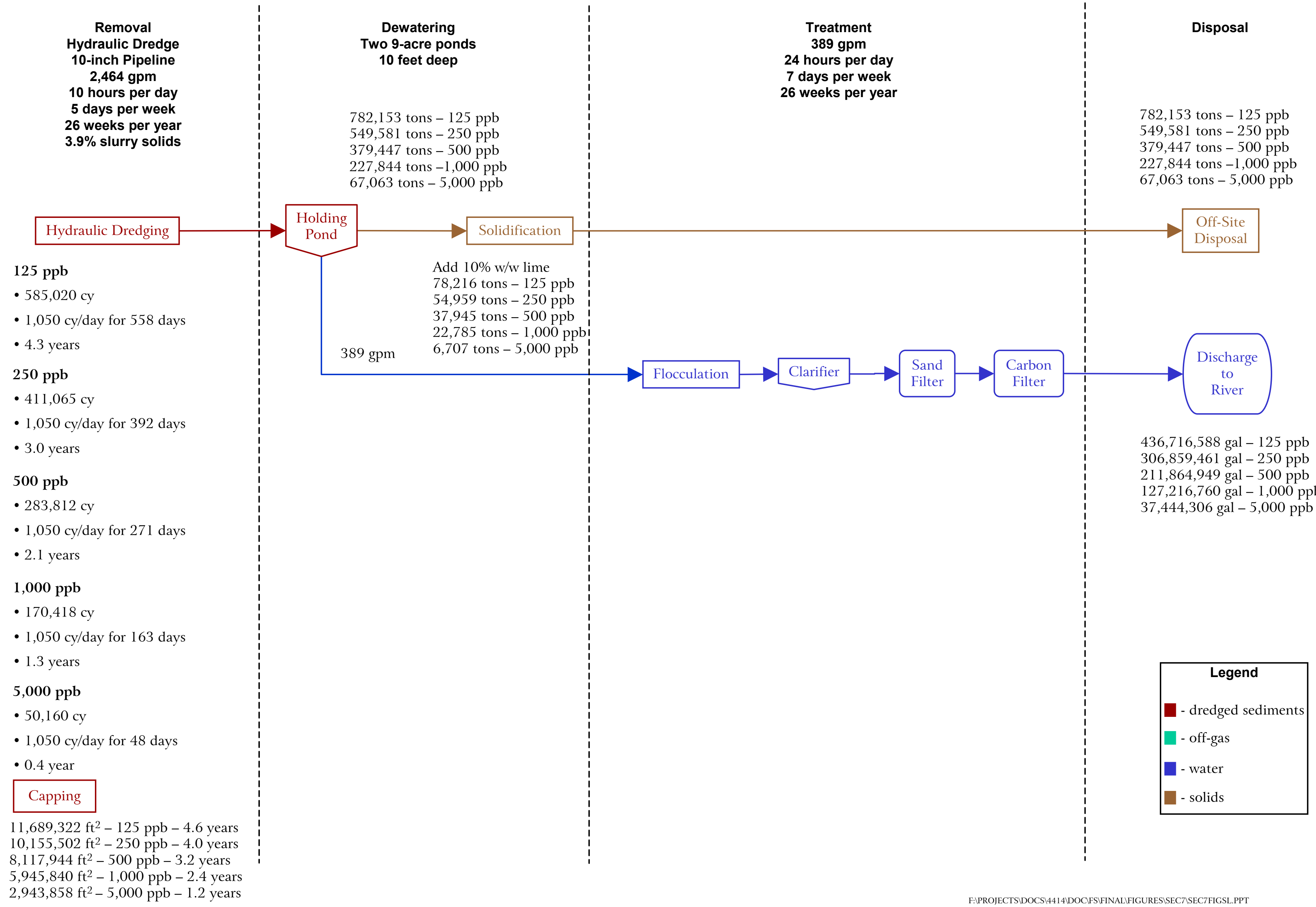
Figure 7-33 Process Flow Diagram for Little Rapids to De Pere - Alternative E: Dredge Sediment with Thermal Treatment

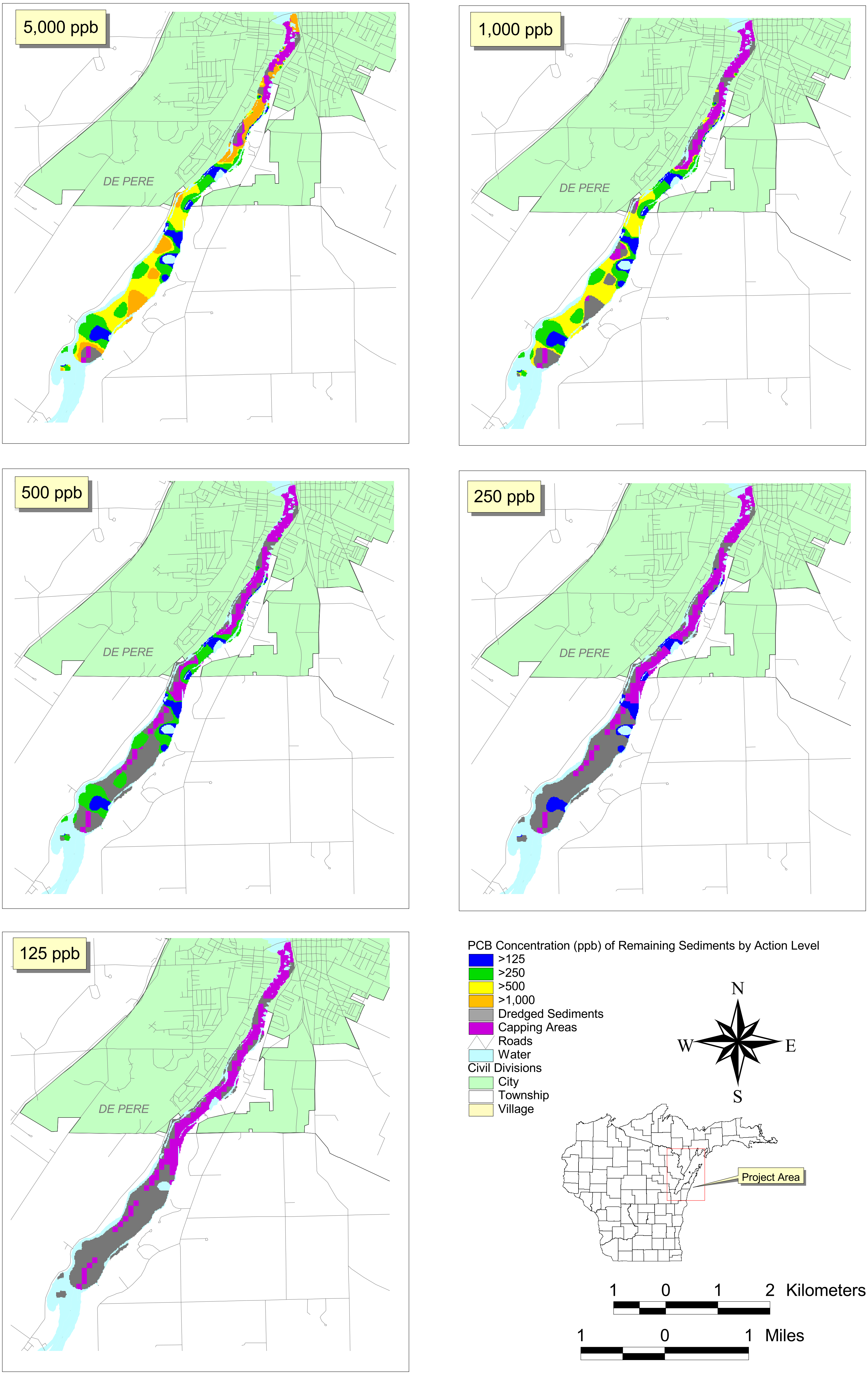


Note: Additional integral elements of the vitrification unit (dryer, pollution control) are not shown as they were not estimated separate. For greater detail on the unit layout and components, refer to the Minergy Unit Cost Report (Appendix G).

F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

Figure 7-34 Process Flow Diagram for Little Rapids to De Pere - Alternative F: Cap Sediment to Maximum Extent Possible, Dredge, and Off-site Disposal





1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.
3. Capping area criteria based on a minimum 9-foot water depth.
4. The proposed CDF is located in other reaches.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative F: Cap to Maximum Extent Possible and Dredge Remaining Sediment to CDF: Little Rapids to De Pere	REFERENCE NO: FS-14414-535-7-30
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-35	APPROVED: AGF

Table 7-7 Cost Summary for Remedial Alternatives - Little Rapids to De Pere

125 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,483,156	$33,900,000	---	---	$3,100,000	$1,700,000	---	---	$181,000,000	$4,500,000	$224,200,000	$44,840,000	$269,040,000
C2A	1,483,156	$43,300,000	---	---	---	$5,100,000	---	---	$19,400,000	$4,500,000	$72,300,000	$14,460,000	$86,760,000
C2B	1,483,156	$43,300,000	---	---	$22,100,000	$5,000,000	---	---	$104,900,000	$4,500,000	$179,800,000	$35,960,000	$215,760,000
C3	1,483,156	$33,900,000	---	---	$53,400,000	$2,600,000	---	---	$67,300,000	$4,500,000	$161,700,000	$32,340,000	$194,040,000
D	1,483,156	$33,900,000	---	---	---	$1,900,000	---	$32,000,000	---	$4,500,000	$72,300,000	$14,460,000	$86,760,000
E	1,483,156	$43,300,000	---	---	$22,100,000	$10,700,000	$62,100,000	---	---	$4,500,000	$142,700,000	$28,540,000	$171,240,000
F	585,020	$23,100,000	---	$40,500,000	$3,100,000	$1,100,000	---	---	$71,400,000	$4,500,000	$143,700,000	$28,740,000	$172,440,000

250 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,171,585	$28,600,000	---	---	$3,100,000	$1,500,000	---	---	$143,000,000	$4,500,000	$180,700,000	$36,140,000	$216,840,000
C2A	1,171,585	$37,600,000	---	---	---	$4,900,000	---	---	$16,200,000	$4,500,000	$63,200,000	$12,640,000	$75,840,000
C2B	1,171,585	$37,600,000	---	---	$22,100,000	$4,900,000	---	---	$83,700,000	$4,500,000	$152,800,000	$30,560,000	$183,360,000
C3	1,171,585	$28,600,000	---	---	$42,200,000	$2,400,000	---	---	$53,100,000	$4,500,000	$130,800,000	$26,160,000	$156,960,000
D	1,171,585	$28,600,000	---	---	---	$1,700,000	---	$32,000,000	---	$4,500,000	$66,800,000	$13,360,000	$80,160,000
E	1,171,585	$37,600,000	---	---	$22,100,000	$10,500,000	$49,100,000	---	---	$4,500,000	$123,800,000	$24,760,000	$148,560,000
F	411,065	$19,500,000	---	$36,000,000	$3,100,000	$1,000,000	---	---	$50,200,000	$4,500,000	$114,300,000	$22,860,000	$137,160,000

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	776,791	$20,500,000	---	---	$3,100,000	$1,300,000	---	---	$94,800,000	$4,500,000	$124,200,000	$24,840,000	$149,040,000
C2A	776,791	$30,100,000	---	---	---	$4,700,000	---	---	$12,100,000	$4,500,000	$51,400,000	$10,280,000	$61,680,000
C2B	776,791	$30,100,000	---	---	$22,100,000	$4,700,000	---	---	$56,900,000	$4,500,000	$118,300,000	$23,660,000	$141,960,000
C3	776,791	$20,500,000	---	---	$28,000,000	$2,100,000	---	---	$35,200,000	$4,500,000	$90,300,000	$18,060,000	$108,360,000
D	776,791	$20,500,000	---	---	---	$1,400,000	---	$32,000,000	---	$4,500,000	$58,400,000	$11,680,000	$70,080,000
E	776,791	$30,100,000	---	---	$22,100,000	$10,300,000	$32,500,000	---	---	$4,500,000	$99,500,000	$19,900,000	$119,400,000
F	283,812	$14,600,000	---	$30,100,000	$3,100,000	$900,000	---	---	$34,600,000	$4,500,000	$87,800,000	$17,560,000	$105,360,000

Table 7-7 Cost Summary for Remedial Alternatives - Little Rapids to De Pere (Continued)

1,000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	586,788	$14,800,000	---	---	$3,100,000	$1,100,000	---	---	$71,600,000	$4,500,000	$95,100,000	$19,020,000	$114,120,000
C2A	586,788	$24,700,000	---	---	---	$4,600,000	---	---	$10,100,000	$4,500,000	$43,900,000	$8,780,000	$52,680,000
C2B	586,788	$24,700,000	---	---	$22,100,000	$4,600,000	---	---	$44,000,000	$4,500,000	$99,900,000	$19,980,000	$119,880,000
C3	586,788	$14,800,000	---	---	$21,200,000	$2,000,000	---	---	$26,600,000	$4,500,000	$69,100,000	$13,820,000	$82,920,000
D	586,788	$14,800,000	---	---	---	$1,200,000	---	$32,000,000	---	$4,500,000	$52,500,000	$10,500,000	$63,000,000
E	586,788	$24,700,000	---	---	$22,100,000	$10,300,000	$24,600,000	---	---	$4,500,000	$86,200,000	$17,240,000	$103,440,000
F	170,418	$9,800,000	---	$23,800,000	$3,100,000	$900,000	---	---	$20,800,000	$4,500,000	$62,900,000	$12,580,000	$75,480,000

5,000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	186,348	$6,900,000	---	---	$3,100,000	$900,000	---	---	$22,700,000	$4,500,000	$38,100,000	$7,620,000	$45,720,000
C2A	186,348	$17,400,000	---	---	---	$4,500,000	---	---	$6,000,000	$4,500,000	$32,400,000	$6,480,000	$38,880,000
C2B	186,348	$17,400,000	---	---	$22,100,000	$4,500,000	---	---	$16,800,000	$4,500,000	$65,300,000	$13,060,000	$78,360,000
C3	186,348	$6,900,000	---	---	$6,800,000	$1,700,000	---	---	$8,500,000	$4,500,000	$28,400,000	$5,680,000	$34,080,000
D	186,348	$6,900,000	---	---	---	$1,000,000	---	$32,000,000	---	$4,500,000	$44,400,000	$8,880,000	$53,280,000
E	186,348	$17,400,000	---	---	$22,100,000	$10,100,000	$7,800,000	---	---	$4,500,000	$61,900,000	$12,380,000	$74,280,000
F	50,160	$5,200,000	---	$15,000,000	$3,100,000	$800,000	---	---	$6,100,000	$4,500,000	$34,700,000	$6,940,000	$41,640,000

7.5 De Pere to Green Bay Reach (Green Bay Zone 1)

An overview of the De Pere to Green Bay Reach and the PCB-impacted sediment distribution is shown on Figure 7-36. The retained alternatives and associated costs are presented in Table 7-8.

7.5.1 General Site Characteristics

This section of the Lower Fox River is the most heavily developed, and includes numerous communities. The river reach between the De Pere dam and the mouth of the river at Green Bay is a combination of both residential and industrial development.

The river is broad and shallow at the upper end, becoming narrow and deep as it approaches the mouth of the river. In the downstream portion, the federal channel has been routinely dredged to maintain a navigation depth of 24 feet. River depths outside of the federal channel range from 4 to 12 feet from De Pere to the Fort James-West facility and up to 20-foot depths between the Fort James-West facility and the mouth of the river. General water depths by river reach are given in Ocean Surveys (1998).

Stream velocity in this reach is the lowest of the four reaches, with an average stream velocity of 0.26 ft/s (0.08 m/s) (Table 2-5). This slow river flow is likely partly responsible for the depositional characteristic of the river below the De Pere dam. The nature and extent of PCB-impacted sediment in this reach, as summarized in the RI, includes the following:

- Maximum detected concentration - 710,000 μg/kg (avg. 21,722 μg/kg),
- Total PCB mass - 26,639 kg,
- Total PCB-impacted volume - 5,549,330 m^3, and
- Maximum PCB sample depth - 300 to 350 cm depth.

These quantities represent the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section will likely be larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

Below the De Pere dam, there are no locks or dams that would impede dredging equipment. There are seven bridges over the river to Green Bay. However, none of the bridges represent an impediment to vessel and equipment movement within the reach. Other physical impediments to removal actions in this reach include the numerous bulkhead lines, old docks, and potential underwater archeological sites (e.g., historic barges—indicated as "ruins" on the navigational charts). Costs of removing these impediments were not estimated. Any future specific action plans must consider the potential for impact to operations due to such impediments.

7.5.2 Selected Remedial Alternatives

This section defines the remedial alternatives for the De Pere to Green Bay Reach, and then describes the technologies that will be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for the De Pere to Green Bay Reach include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all river sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an NR 500 commercial disposal facility.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

E. Remove sediment with PCB concentrations exceeding the selected action level and treat this sediment using thermal treatment. Treated sediment may be beneficially reused.

F. Place a sand cap over contaminated sediments to the maximum extent practicable. Mechanically remove all TSCA sediments from cap areas prior to capping and dispose in an existing NR 500 commercial disposal facility. Dredge remaining sediment and place dredged sediment in a CDF.

Alternative G was not retained since river bathymetry, water currents, and river utilization preclude construction of an appropriate CAD site. The process options that can be applied to the remedial alternatives are described below.

7.5.3 Description of Process Options

Monitoring

Monitoring of physical, chemical, and biological media is applicable for Alternatives B through F. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; SMWG, 1999; IJC, 1997; Krantzberg *et al.*, 1999). The following references were used in this FS Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Ecology, *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- USACE, *Monitoring Considerations for Capping* (USACE, 1992);
- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);
- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);
- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);
- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b);
- Sediment remediation case study projects presented in Appendices B and C of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Controls

Institutional controls appropriate to the De Pere to Green Bay Reach include:

- Maintenance of the fish and waterfowl consumption advisory;
- A moratorium on any future dredging within the navigation channel;
- Deed restrictions on any in-water activities that could result in sediment disturbance (i.e., marina construction or over-water development);
- Access restrictions to contaminated areas;
- Continued restriction on the use of the Lower Fox River for domestic water supplies; and
- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water use advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal is identified for Alternatives C through F. Remediation area boundaries and sediment management areas are shown on Figure 7-36. For the De Pere to Green Bay Reach, both mechanical and hydraulic dredging are practicable. Mechanical dredging is better suited to remove the relatively small volumes (248,000 cy) exceeding 50 mg/kg PCBs TSCA levels identified as part of Alternatives C, D, and F. Mechanical dredging significantly reduces the water management needs, which is necessary due to the limited upland space availability on this reach. It has been proposed that all dredging in the De Pere to Green Bay Reach be performed with a mechanical dredge with the exception of Alternatives C2A, C2B, C3, and E. Alternative C2A includes hydraulic dredging and pumping sediment directly to a combined NR 213/NR 500 dewatering and disposal facility while Alternative C2B includes hydraulic dredging, passive dewatering, and sediment disposal at a dedicated NR 500 monofill. Alternative C3 includes hydraulic dredging, mechanical dewatering, and off-site disposal at an existing NR 500 commercial disposal facility. Alternative E includes hydraulic dredging, passive dewatering, and thermal treatment. Hydraulic dredging along with passive dewatering has been proposed for Alternative C2B for cost comparison with Alternative C2A. Hydraulic dredging along with mechanical dewatering has been proposed for Alternative C3.

Dredge Equipment. Three dredges using 8-cy Cable Arm™ buckets have been selected for the remedial alternatives identified in this reach where a mechanical dredge is employed. The De Pere to Green Bay Reach includes both residential and industrial areas. In residential areas, immediately downstream of the De Pere dam, the operating assumption is that dredging will occur only during normal daylight hours (12 hours per day) during a normal work week (5 days per week). In industrial areas, dredging may occur 24 hours per day and 7 days per week. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Hydraulic dredging for Alternatives C2, C3, and E will be performed using two 12-inch pipeline dredges with a cutterhead. A floating pipeline from the dredges will connect to a shore-side containment cell. A shore-based cutterhead dredge and double-walled pipeline will pump the sediment from the shoreside cell directly to a dedicated NR 500 monofill for Alternative C2A. For Alternative C2B, the sediment slurry will be pumped to an NR 213 dewatering facility located adjacent to the dedicated NR 500 monofill before transporting the dewatered sediments to the dedicated NR 500 monofill for disposal. The sediment slurry will be pumped to a shoreside containment cell for mechanical dewatering and dewatered sediments transported to an existing NR 500 commercial disposal facility for disposal for Alternative C3. For Alternative E, the passive dewatered sediments will be transported to a melter unit for thermal treatment. This operation will minimize the need for upland offloading, staging, and truck loading facilities. The operating assumption for hydraulic dredging is that dredging and pumping will occur 24 hours per day and 7 days a week to minimize the need for pipeline flushing during down periods. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year).

Long Slurry Pipe Runs. Dredged material generated during hydraulic dredging for Alternatives C2A and C2B will be pumped long distances as dredge slurry and either placed directly into a dedicated NR 500 monofill (approximated distance of 28 miles for the purposes of this FS) or into an NR 213 dewatering facility located adjacent to the proposed landfill. A long pipeline run of dredge slurry was successfully implemented at White Rock Lake, Texas (Sosnin, 1998). In 1998, approximately 3 million cy of sediment were dredged from White Rock Lake, the largest municipal lake in the United States located in Dallas, Texas, and pumped 20 miles in a 24-inch steel pipeline to an active sand and gravel quarry for disposal. The community was opposed to dredged material disposal in their neighborhoods, so the pipeline was threaded through city neighborhoods, under a freeway, under lakes and a golf course to the upland disposal site (Sosnin, 1998). The pipeline, formerly used as a natural gas pipeline, was outfitted with a leak detection system, telemetry signals between dredge and flow meters, automatic flow control systems, one high-pressure, large-capacity groundwater dredge pump (1,500 horsepower, 8 feet per second, and 400 psi), and two booster pumps (11,000 gpm). The used pipeline was purchased for approximately $5 million and the total construction cost was about $13.5 million; the pipeline operated for 1 year (Weathersbee, 2001). Overall, the system required minimal maintenance, no plugging was encountered and no back-flushing was needed since a consistent flow was maintained by diverting clean lake water to the pump (Hagler, 2001).

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream. However, for the purposes of this FS, silt curtains were included in the removal costs.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For all mechanical dredging alternatives, it is proposed that dewatering be conducted on-barge and in upland staging areas. Dewatering has been configured as a two-step process using gravity settling, followed by solidification of solids.

Passive Dewatering. Each 2,000-cy barge load of mechanically dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and collected. Sediment will then be transferred into one of three asphalt-paved upland staging areas for additional dewatering, solidification, and loading into trucks for off-site shipment. These upland staging areas will each be approximately 0.5 acre in size, surrounded with a 6-inch curb, and graded to a water collection sump. All water collected from the barges and the upland staging area will be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. The upland staging areas may be located at the Bayport facility near the mouth of the Lower Fox River or at the former Shell facility near the middle of this reach.

For the dredge to CDF alternatives (Alternatives D and F), dewatering will occur directly within the CDF. For Alternative C2A, hydraulically-dredged sediment will be pumped directly to a dedicated NR 500 monofill. Dewatering will occur directly within a PCB landfill cell. Decant water for each of these alternatives will be treated and returned to the river. For Alternatives C2B and E, hydraulically dredged sediment will be dewatered in an NR 213 dewatering facility. The NR 213 dewatering facility will be similar to the dewatering facility specified in the Little Rapids to De Pere Reach for Alternative C1. A mechanical dewatering option is included for Alternative C3. Mechanical dewatering involves pumping the hydraulically dredged slurry into conditioning tanks or ponds, where the slurry is adjusted to the appropriate solids content and chemicals are added to assist in the dewatering process. Mechanical dewatering would include shaker screens and hydrocyclones or belt filter presses after initial conditioning. Based on dewatering results from both of the Lower Fox River demonstration projects, the estimated percent solids of the filter cake after shaker screen, hydrocyclones, and belt filter presses ranged between 40 and 60 percent solids (Foth and Van Dyke, 2000; Fort James *et al.*, 2001).

These proposed dewatering systems will meet the criteria defined in Section 6 of this FS Report, in terms of production rate, effectiveness, practicality, and discharge water quality. Final selection of the dewatering process will be determined during the remedial design phase.

Solidification. The solids content after mechanical dredging and dewatering (Alternatives C1, D, and F) is assumed to be 34 percent (w/w) or similar to *in-situ* density, based on *in-situ* solids content from the RI Report (RETEC, 2002a), and may still be difficult to manage due to high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary, and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. For FS costing purposes, 10 percent (w/w) lime was added as the reagent based on its successful use during the SMU 56/57 project (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and loaded into trucks using standard earthmoving equipment. If the contractor prefers, sediment may be mixed with the reagent in a pug mill as shown on Figure 7-1. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

For Alternative C2A, hydraulically-dredged sediment will be pumped directly to a dedicated NR 500 monofill without solidification. For Alternative C2B, dewatering will occur in a dewatering cell adjacent to the PCB landfill prior to placement in a landfill. Wastewater will be treated and returned to the river (discussed below). The solids content after dewatering in the landfill is assumed to reach 50 percent (w/w). For Alternative C3, solidification will not be required as the solids content after mechanical dewatering is estimated to range between 40 and 60 percent solids (Foth and Van Dyke, 2000; Fort James *et al.*, 2001). For Alternative E, it is assumed that the melter unit for thermal treatment will be located in close proximity to the NR 213 dewatering facility precluding the need for solidification of dewatered sediments.

Treatment Process Options

Water Treatment. Prior to water discharge back to the river, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary (Foth and Van Dyke, 2000). However, additional GAC treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC treatment is $0.40 per thousand gallons of water treated.

Thermal Treatment. Several on-site treatment process options were retained from the screening process in Section 6 that are applicable to the Lower Fox River/Green Bay remediation project. However, only vitrification was selected for costing purposes because the multi-phased study conducted by WDNR has provided data which indicates that this treatment technology is a viable option.

For the purposes of this FS, thermal treatment of the dewatered sediments from De Pere to Green Bay is assumed to occur at the full-scale vitrification unit constructed for the Little Rapids to De Pere Reach. The facility will be built as a standalone unit with on-site storage capacity and equipped with two 375 glass tons per day units. The passively dewatered sediment enters the plant and is dried to approximately 10 percent moisture in the dryer unit. The sediment is mixed with a fluxing material and fed into a large melter, capable of maintaining temperature around 2,900 °F. The sediment melts into a molten material in the melter and passed through the water bath for quenching resulting in glass aggregate.

For the purposes of this FS, sediment treatment by vitrification is assumed to occur over a time frame of 10 years in conjunction with treating dewatered sediments from the Little Rapids to De Pere Reach. The vitrification process is assumed to operate 24 hours per day, 7 days per week, and 350 days per year. The unit will be designed to have the capacity to process 1,840 tons of sediment per day and produce 750 tons of glass aggregate per day.

On-site Disposal Process Options

Three CDFs are currently proposed for the De Pere to Green Bay Reach. All three CDFs are nearshore facilities located immediately downstream of the De Pere dam (Figure 7-37). In all cases, the CDF location was selected to minimize impacts to upland riparian landowners. The total capacity of these facilities is 1,275,000 cy, which is lower than the estimated dredge volumes for each action level. Other possible CDF locations could include an area within the bulkhead line just south of the Former Shell facility or a location at Cat Island.

The concept for all Lower Fox River CDFs is a hybrid of the solid retention and hydraulic isolation designs discussed in Section 6. PCBs are predominately tied to the solids fraction of the sediments, but may dissolve and be carried at low concentrations in pore water. As such, the construction includes placement of a steel sheet pile wall driven to 30 feet below the final grade elevation into the relatively impervious clay layer underlying much of the soft sediments. Using this configuration, it should not be necessary to line the bottom of the CDF. The overall height of the CDF will be above the 100-year flood level—approximately 6 feet above the normal river elevation. The retention berms will be constructed with appropriately-sized shot rock and riprap to prevent flood or ice damage to the CDF.

In keeping with design criteria given in Section 6, there will be no placement of untreated TSCA-level sediments in any CDF. Dredged TSCA-level sediments must first be thermally treated prior to placement in the CDF or taken to an appropriate off-site disposal facility.

During mechanical dredging, the CDF itself will act as a collection system for excess water, with the overflow water decanted and filtered. Upon completion of dredging, the sediment is allowed to further settle, and is eventually capped with 3 feet of clean sediments and revegetated. Long-term use of CDF surface can include a park or multi-use open space. As the Lower Fox River sediments are relatively low in organic debris, a methane collection system has not been included as part of the concept design.

The Bayport CDF located near the mouth of the Lower Fox River currently accepts dredged material from local maintenance dredging projects and is expected to operate for another 40 years. A separate line item is included for closure of the Bayport CDF with the expectation that it will receive PCB-impacted sediments.

No confined aquatic disposal (CAD) sites are considered for this reach because of physical impediments, active large vessel traffic, and continued maintenance of navigational channels.

Off-site Disposal Process Options

Total PCB concentrations in sediment within this reach are generally below 500 ppm, the maximum allowable PCB concentration for designation as TSCA material. EPA TSCA 40 CFR Regulations (Parts 750 and 761) define PCB-contaminated material as containing more than 50 ppm, but less than 500 ppm PCBs. Sediment below 500 ppm may be disposed of at landfills which conform to the NR 500 WAC requirements and has received approval per WDNR's agreement with EPA for the disposal of TSCA-level sediments. Any remaining sediments above 500 ppm can be accepted at existing NR 500 commercial disposal facilities, but must have EPA concurrence. Local landfill options and unit costs were defined in Section 6.4.5 of this FS Report.

Capping Process Options

Within the De Pere to Green Bay Reach, several areas met the criteria defined in Section 6.4.4 of this FS Report for placement of a cap. These locations were selected based on levels of contaminants, site bathymetry, and location of navigational channels. The proposed cap will be constructed so that the TSCA-level sediments are mechanically dredged prior to capping. The cap in the De Pere to Green Bay Reach is planned to be an armored sand cap composed of 20 inches of sand overlain with 12 inches of large cobble to provide erosion protection (Palermo, 1995). The armored cap will not be placed in the navigational channels.

7.5.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for the De Pere to Green Bay Reach. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs (Table 7-8). Details used to develop each cost estimate are provided in Appendix H. The process flow diagrams and dredging/capping footprints for each alternative are presented on Figures 7-38 through 7-48.

The following components are discussed, when applicable, within the development of each alternative:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for the De Pere to Green Bay Reach. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management or remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until RAOs are achieved. This alternative includes costs for fish tissue sampling events every 5 years (for 40 years) for continued maintenance of fish consumption advisories already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C1: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

Alternative C includes the removal of sediments above the remedial action level using multiple mechanical (Alternative C1) or hydraulic (Alternatives C2A, C2B and C3) dredges and off-site disposal of the sediments. Figures 7-38 through 7-41 provide the process flow diagrams for remedial Alternatives C1, C2A, C2B, and C3, while Figure 7-42 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-8. The total volume of sediment to be dredged in this alternative ranges between 6,868,000 cy for 125 ppb and 4,517,391 cy for 5,000 ppb action levels. The scope and cost to implement Alternative C2 and C3 are discussed separately below.

A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Site Mobilization and Preparation. Staging for the dredging of sediments will be conducted at the Bayport or former Shell facilities. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, water treatment, sediment solidification, and truck loading. It is assumed that docking facilities for the dredges and barges already exist at these locations. Purchase and property preparation are included in the costs.

Sediment Removal. Due to the limited upland space available on this reach for water management purposes, all sediment removal in Alternative C1 would be done with the mechanical dredge. Given the volumes and operating assumptions described above, the complete removal effort would require approximately 9.3 years for 125 ppb and 6.1 years for 5,000 ppb action levels, using three dredges. Sediment removal will be conducted using three 8-cy closed, clamshell buckets that require a staging area for the mechanically-dredged sediments to be offloaded and transported off site. The cost for constructing the upland staging area is included in dewatering and disposal. For this alternative, TSCA-level sediment is not managed separately and will be incorporated into the existing NR 500 commercial disposal facility landfill along with other sediments, with EPA approval. Silt curtains around the dredging area are included to minimize sediment resuspension downstream of the dredging operation; installation of silt curtains are included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are barge rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs using mechanical buckets are estimated to range between $100,500,000 for 125 ppb to $67,200,000 for 5,000 ppb action levels. The major cost differences between the mechanical and hydraulic removal technologies is apparent in the disposal costs.

Sediment Dewatering. For Alternative C1, passive dewatering will be conducted on-barge and in upland staging areas. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges to upland staging areas. Sediment will then be transferred onto an asphalt-paved upland staging area where any free water will be collected. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime (increase solids content from 34 to 50 percent) to satisfy hauling and disposal requirements (included in disposal costs).

Sediment dewatering costs generally include land purchase, site clearing, and construction of shore-based staging areas. Therefore, barge dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 82,000 gallons per day for Alternative C1. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. However, it may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. Water treatment costs include pad and equipment demobilization and site restoration.

Water treatment costs for mechanical dredging are estimated to range between $700,000 for 125 ppb and $500,000 for 5,000 ppb action levels.

Sediment Disposal. For Alternative C1, sediment disposal includes the loading and transportation of the sediment to an existing NR 500 commercial disposal facility listed in Table 6-6. Disposal costs also include the purchase and addition of lime reagent for solidification of dewatered material prior to off-site transport. The estimated percent solids of dewatered sediment is 34 percent solids based on the SMU 56/57 BOD Report (Montgomery-Watson, 1998). Therefore, the addition of 10 percent (w/w) lime reagent for further solidification was added to disposal costs. Lime can be purchased for $60 per ton and mixed into sediment for about $25 per ton. Solidification costs for adding 10 percent lime reagent, including purchase, range between $222,000,000 and $31,000,000 for the 125 ppb and 5,000 ppb action levels, respectively. Lime reagent purchase is about 20 percent of the solidification costs. The sediments would be loaded into tractor-trailer end dumps with bed liners or sealed gates with a front-end loader. Each load would be manifested and weighed. Each tractor-trailer would pass through a wheel wash prior to leaving the staging area to prevent tracking soil onto nearby streets and highways. After unloading at the designated disposal facility, each tractor-trailer would pass through a wheel wash and return to the staging area for another load. A separate line item of $4,200,000 net present worth is included for the closure of the Bayport CDF in 40 years.

Costs for sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to range between $659,200,000 for 125 ppb and $434,700,000 for 5,000 ppb action levels.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging and treatment estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre-and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time. If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

The estimated cost for the maintenance of institutional controls and fish consumption monitoring is $4,500,000. Implementation monitoring during dredging is included in the removal and water treatment costs. Long-term multimedia monitoring events and costs for verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

Alternative C2A: Dredge with Combined NR 213/NR 500 Dewatering and Disposal Facility

Alternative C2A includes the removal of sediments above the remedial action level using hydraulic dredging and hydraulic pumping of sediment slurry directly to a combined NR 213/NR 500 dewatering and disposal facility for off-site disposal. Figure 7-39 provides the process flow diagrams for remedial Alternative C2A and Figure 7-42 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C2A are provided in Table 7-8. The total volume of sediment to be dredged in this alternative ranges between 6,868,000 cy for 125 ppb and 4,517,391 cy for 5,000 ppb action levels.

Site Mobilization and Preparation. Staging for sediment dredging will be conducted at the Bayport or former Shell facilities. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, constructing intermediate shore-based ponds, pipelines, and booster pumps. The shore-based slurry ponds are constructed of earthen berms lined with asphalt covering 10 acres. It is assumed that docking facilities for the dredges and barges already exist at these locations. Land purchase and construction of upland staging areas are included in the dredging costs.

Sediment Removal. Sediment removal in Alternative C2A will be conducted using two 12-inch hydraulic pipeline feeder dredges with modified cutterheads and one floating 12-inch booster pump. The two feeder dredges will pump dredge slurry to an intermediate shore-based slurry pond located mid-reach. A third 16-inch cutterhead dredge located in the shore-side pond will resuspend the slurry into a 15-inch polyethylene pipe with 1.5-inch wall thickness. The inner pipe will be encased inside a 20-inch steel pipe traveling 18 miles to a dedicated NR 500 monofill. Four booster pumps will be evenly spaced along the route (28 miles with 25 feet total elevation lift). Dredging and pumping operations will continue 7 days per week, 24 hours per day, and 26 weeks per year (182 days) allowing 32 days for downtime and repairs (150 working days per year). Given the volumes and operating assumptions described above, the complete removal effort would require approximately 8 years for 125 ppb and 5.2 years for 5,000 ppb action levels, using two dredges. Sediment removal costs also include construction of a shore-based slurry pond and 28-mile pipeline, booster pump rental, "wintering over" of all equipment, and full-time monitoring of the pipeline. Longer pipe runs may require periodic flushing of the lines during periods of inactivity. Construction of an effluent return pipeline are included in the water treatment costs.

Installation of silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; construction of silt curtains are included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are booster pump rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs using hydraulic dredging are estimated to range between $109,400,000 for 125 ppb and $76,000,000 for 5,000 ppb action levels. The major cost differences between the mechanical and hydraulic removal technologies are apparent in the disposal costs.

Sediment Dewatering. For Alternative C2A, passive dewatering will occur within the combined dewatering and disposal facility. Sediment dewatering costs are included in the dredging, landfill construction, and water treatment costs.

Water Treatment. Water treatment includes construction of an effluent return pipeline from the landfill to the river. Purchase costs also include equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 5,131,000 gallons per day for Alternative C2A. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Water treatment costs include pad and equipment demobilization and site restoration.

Water treatment costs for hydraulic dredging (Alternative C2A) will range between $7,700,000 for 125 ppb and $6,500,000 for 5,000 ppb action levels.

Sediment Disposal. Costs of sediment disposal at a dedicated NR 500 monofill (Alternative C2A) will range between $70,200,000 for 125 ppb and $47,500,000 for 5,000 ppb action levels which includes siting fees, construction, and site restoration costs. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and site restoration will be the same as those described in Alternative C1.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C1.

The total projected costs for Alternative C2A are approximately 70 percent lower than the Alternative C1 costs; mostly accountable in the disposal costs.

Alternative C2B: Dredge with Separate Dewatering and Disposal Facility

Alternative C2B includes the removal of sediments above the remedial action level using hydraulic dredging and hydraulic pumping of sediment slurry to an NR 213 dewatering facility located adjacent to a dedicated NR 500 monofill for off-site disposal. Figure 7-40 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C2B are provided in Table 7-8. The total volume of sediment to be dredged in this alternative ranges between 6,868,000 cy for 125 ppb and 4,517,391 cy for 5,000 ppb action levels.

Site Mobilization and Preparation. Site mobilization and preparation will be the same as that described in Alternative C2A.

Sediment Removal. Sediment removal will be the same as described in Alternative C2A with the exception that the hydraulically dredged slurry will be pumped to an NR 213 dewatering facility located adjacent to the dedicated NR 500 monofill.

Sediment Dewatering. Passive dewatering includes land purchase, site clearing, and dewatering pond construction. Key assumptions include a 3.6 percent by volume (w/w) dredged solids concentration and 3,100 gpm water production rate for the dredge based on results from the 1999 Lower Fox River demonstration projects (Foth and Van Dyke, 2000; Montgomery-Watson, 2000). Although the recent dredging work conducted at SMU 56/57 (Fort James *et al.*, 2001) showed the average percent solids in dredge slurry was 8.4 percent (w/w) (range 3.5 to 14.4 percent), the lower and more conservative percent slurry solids measured during the 1999 activities was used for FS costs. The sediment dewatering system would be done in a two-cell passive filtration system located adjacent to the dedicated NR 500 monofill. The system would accommodate 26 weeks of solids dredge production rate, plus a maximum water surge storage capacity. It is assumed that the final sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in disposal costs). Dewatering costs also include pond decommissioning and site restoration at the completion of the project. Sediment dewatering costs for Alternative C2B (primarily construction costs) are estimated at $19,900,000.

Water Treatment. Water treatment will be the same as described in Alternative C2A with the exception that the effluent lines for treated water will be constructed from the passive dewatering system.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to the dedicated NR 500 monofill. Disposal costs also include the purchase and addition of lime reagent for solidification of dewatered sediment prior to off-site transport. Sediment disposal costs for Alternative C2B range between $419,200,000 for 125 ppb and $277,100,000 for 5,000 ppb action levels which includes siting fees, construction, and site restoration costs. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and Site Restoration will be the same as those described in Alternative C2A.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C2A. The total projected costs for Alternative C2B are approximately 27 percent lower than the Alternative C1 costs; mostly accountable in the disposal costs.

Alternative C3: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

Alternative C3 includes the removal of sediments above the remedial action level using Hydraulic dredging and onshore mechanical dewatering of sediments. Mechanical dewatered sediments will be transported to an existing NR 500 commercial disposal facility for disposal. Figure 7-41 provides the process flow diagrams for remedial Alternative C3 and Figure 7-42 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C3 are provided in Table 7-8. The total volume of sediment to be dredged in this alternative ranges between 6,868,500 cy for 125 ppb and 4,517,391 cy for 5,000 ppb action levels.

Site Mobilization and Preparation. Staging for sediment dredging will be conducted at the Bayport or former Shell facilities. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, constructed intermediate shore-based ponds and mechanical dewatering facility, water treatment, sediment storage and truck loading area. Land purchase and construction of upland staging areas are included in the dredging costs.

Sediment Removal. Sediment removal in Alternative C3 will be conducted using two 12-inch hydraulic pipeline feeder dredges with modified cutterheads. Dredging and pumping operations will continue 7 days per week, 24 hours per day, and 26 weeks per year (182 days) allowing 32 days for downtime and repairs (150 working days per year). The hydraulically dredged slurry will be pumped to a shore-based mechanical dewatering facility. Given the volumes and operating assumptions described above, the complete removal effort would require approximately 8 years for 125 ppb and 5.2 years for 5,000 ppb action levels, using two dredges.

Installation of silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation; construction of silt curtains are included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are booster pump rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration a the conclusion of operations.

Sediment removal costs using hydraulic dredging are estimated to range between $85,400,000 for 125 ppb and $57,200,000 for 5,000 ppb action levels. The major cost differences between the mechanical and hydraulic removal technologies are apparent in the disposal costs.

Sediment Dewatering. Mechanical dewatering includes land purchase, site clearing, and construction of temporary holding ponds. Dewatering techniques will be similar to the mechanical processes used for both Lower Fox River demonstration projects including a series of shaker screens, hydrocyclones, and belt filter presses. The final percent solids of the filter press cake was about 60 percent solids (w/w) for SMU 56/57 (Fort James *et al.*, 2001) and 40 to 50 percent solids for Deposit N (Foth and Van Dyke, 2000). No additional solidification was required. The dewatering process will be simplified into a unit cost of $80 per bone dry ton assuming 50 percent solids after dewatering for the purposes of this FS.

Mechanical dewatering costs for Alternative C3 range from $217,700,000 for 125 ppb to $143,200,000 for 5,000 ppb action levels.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 568,800 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. Carbon filtration could be added for a unit cost of $0.040 per thousand gallons of water treated. It may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to range from $6,400,000 for 125 ppb to $5,200,000 for 5,000 ppb action levels.

Sediment Disposal. Mechanically dewatered sediments will be transported to an existing NR 500 commercial disposal facility by trucks. Costs of sediment disposal will range between $277,000,000 for 125 ppb and $182,900,000 for 5,000 ppb action levels. A separate line item of $4,200,000 is included for closure of the Bayport CDF in 40 years.

Demobilization and Site Restoration. Demobilization and site restoration will be the same as those described in Alternative C1.

Institutional Controls and Monitoring. Monitoring activities and costs will be comparable to those described in Alternative C1.

Alternative D: Dredge and Disposal to a Confined Disposal Facility, Off-site Disposal of TSCA Sediment

Alternative D includes removal of sediments above the remedial action level to an on-site CDF for long-term disposal of the materials. As previously noted, sediments with PCB concentrations exceeding 50 ppm are not to be disposed of in a nearshore CDF. As such, this alternative utilizes mechanical dredging to remove those smaller volumes of sediment greater than 50 ppm for solidification and disposal at an existing NR 500 commercial disposal facility.

Figure 7-43 provides the process flow diagrams for this remedial alternative, while Figure 7-44 illustrates the location of the CDFs and the extent of residual contamination following implementation of Alternative D. Table 7-8 contains the summary costs to implement Alternative D. The total volume of sediments to be dredged are similar to those identified in Alternative C. This alternative also includes line item costs for closure of the Bayport CDF in 40 years for $4,200,000 net present worth.

Site Preparation and CDF Construction. For the concept level FS, the process is staged to construct and complete dredging to the nearshore CDF facilities located immediately downstream of the De Pere dam. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing the CDFs, a water treatment facility, and offshore docking facility for the mechanical dredge. The total capacity of these CDF facilities is lower than the proposed dredge volumes. Other possible CDF locations could include an area within the bulkhead line just south of the former Shell facility or a location at the Cat Islands. CDF construction will require up to 6 months for completion prior to dredging. CDF construction is estimated at $39,200,000.

Sediment Removal. Mechanical dredging of the limited TSCA-level sediment volumes would occur prior to initiation of mechanical dredging of sediments to a CDF. Sediment removal techniques and costs for this alternative are equivalent to those described for Alternative C1. The estimated time to complete mechanical dredging range between 9.3 years for 125 ppb and 6.1 years for 5,000 ppb action levels.

Sediment Dewatering. Passive dewatering will occur directly within the CDF berms for sediments transported to the CDF. The remaining dredged sediments will dewater on-barge for 2 days prior to offloading to the upland staging area as described in Alternative C1. Sediment dewatering costs are included in the sediment removal and treatment costs.

Water Treatment. Overflow return water from the CDFs and on-barge dewatering would be treated before discharge to the river. Monitoring requirements are expected to be the same as those for Alternative C1.

Water treatment costs for Alternative D are estimated to range between $1,200,000 for 125 ppb and $1,000,000 for 5,000 ppb action levels.

Sediment Disposal. Sediment disposal includes the loading and transportation of the TSCA-level and non-TSCA-level sediments to a facility listed in Table 6-6.

The cost for off-site sediment disposal at an existing NR 500 commercial disposal facility is estimated to range between $422,800,000 for 125 ppb to $244,600,000 for 5,000 ppb action levels for sediments that exceed the CDF capacity.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDFs would be finished with a 3-foot cap of clean soils, and seeded and planted. Additional amenities (i.e., bike paths, wildlife habitat) were not included in the cost estimates. However, this alternative would allow development of these features and would provide a beneficial use of this area for the community. Demobilization and site restoration costs are included under the dredging and dewatering estimates.

Institutional Controls and Monitoring. To ensure that the CDF is functioning as designed, near-site sediment and water sampling would be conducted on an annual basis (included in CDF construction costs). Long-term monitoring is defined in the proposed monitoring plan (Appendix C) for verification of project RAOs and costs are provided in Alternative B - Monitored Natural Recovery. The monitoring program will be conducted over a period of 40 years.

The estimated cost for institutional controls is $4,500,000.

Alternative E: Dredge with Thermal Treatment

Alternative E includes hydraulic dredging of sediments, passive dewatering, and treatment with an on-site integrated vitrification unit. This alternative results in the sediments being transformed into glass aggregate that has potential for a wide variety of beneficial reuse applications. Figure 7-45 provides the process flow diagrams for this remedial alternative, while Figure 7-46 illustrates the extent of residual contamination after implementing Alternative E. Table 7-8 contains the summary costs to implement Alternative E. This alternative addresses the same volume of sediments as Alternative C. Alternative E also includes a line item for site closure of the Bayport CDF when capacity is reached in 40 years. Bayport closure costs are $4,200,000 net present worth.

Site Mobilization. Site mobilization and preparation includes securing the onshore property area for equipment staging, water treatment, and offshore docking facility for the hydraulic dredge. Site preparation would also include building a standalone vitrification unit capable of processing an estimated 750 glass tons per day.

Sediment Removal. Hydraulic sediment removal techniques, duration, and costs for this alternative are equivalent to those described for Alternative C2.

Sediment Dewatering. Sediment dewatering is similar to the requirements described in Alternative C2B.

Water Treatment. Water treatment will be the same as described in Alternative C2A with the exception that the effluent lines for treated water will be constructed from the passive dewatering system. Monitoring requirements are expected to be the same as those for Alternative C. Water treatment costs for Alternative E are estimated to be the same as those for Alternative C.

Sediment Treatment. After completion of passive dewatering (to approximately 30 percent solids), both TSCA and non-TSCA-level sediments are passed through the dryer and dried to approximately 10 percent moisture. Thermal treatment of the dried sediments involves blending the high-silt/clay sediments with fluxing materials and processing the materials in a melter as part of the vitrification process. The vitrification process would include appropriate treatment of air emissions. The unit cost for thermal treatment includes capital costs and operating costs. The capital costs include equipment, building, installation, engineering, and startup costs. Operating costs include labor, utilities, and general administrative costs. The unit cost is based on an assumption that the glass aggregate resulting from treating sediments will have a resale value between a range of $2 and $25 per ton as provided by Minergy. The unit cost for sediment treatment decreases with an increase in the resale value of the glass aggregate.

The cost for thermal treatment is estimated to range between $253,600,000 for 125 ppb and $166,800,000 for 5,000 ppb action levels at an estimated unit cost of $24 per ton.

Sediment Disposal. No sediments will be disposed of as hazardous waste, as all the sediments will be treated by thermal treatment. Treated sediments transformed to glass aggregate by the vitrification process have a wide variety of applications.

Based on analysis by product marketing specialists, the glass aggregate has a potential to be used as roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan, and construction fill (Minergy Corporation, 2002a).

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of the pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Alternative F: Cap to Maximum Extent Possible, Dredge Remaining Sediments for On-site and Off-site Disposal

Alternative F includes primarily *in-situ* capping, but also includes dredging of sediments above the remedial action level to CDFs and existing NR 500 commercial disposal facilities. Within the De Pere to Green Bay Reach, several areas met the criteria defined in Section 6.4.4 of this FS Report for placement of a cap. The capping area encompasses sediment containing TSCA-level sediments which require mechanical dredging prior to cap placement. Contaminated sediment will be capped to the maximum extent possible; remaining sediments outside the cap footprint will be excavated to CDFs. When CDF capacity is reached, leftover sediment will be hauled to off-site disposal facilities. The process flow diagram is depicted on Figure 7-47 while Figure 7-48 illustrates the location of sediment caps and the extent of residual contamination following implementation of Alternative F. The estimated costs are presented in Table 7-8. The estimated time for placement of the sand cap is 8.3 and 4.9 years for the 125 ppb and 5,000 ppb action levels, respectively. The estimated time for placement of armoring over the cap is 7.5 to 4.5 years, respectively.

Site Preparation, Cap, and CDF Construction. Site preparation for capping and dredging would include upland staging areas for temporary storage of capping materials and dewatering as discussed in Alternative C1. The cap in the De Pere to Green Bay Reach is planned to be an armored cap composed of 20 inches of sand overlain with 12 inches of large cobble to provide erosion protection. The sand cap will be completed using a spreader barge with a 10-inch pipeline. The cap will be placed in 6-inch lifts (1,200 cy placed per day working 10-hour shifts). Armor placement would be completed using two clamshell buckets placing 400 cy per day per bucket. A 3-cy bucket was selected for costing purposes (OBAI Cost Estimate). Cap construction would require an upland staging area for the receipt and placement of sand and the armoring stone. The staging area will include a hopper for pumping slurry to the spreader barge. Armor stone will be delivered to the work area via barges. All other unit costs are similar to those described for the prior alternatives for the river reach. Site preparation costs in this alternative are included under the dredging and capping costs. CDF construction would be similar to those described in Alternative D.

Capping costs under this alternative are estimated to range from $67,800,000 to $42,900,000. CDF construction costs are estimated to be $39,200,000 for all action levels.

Sediment Removal. Remaining sediments above the remedial action level outside of the capping areas will be removed by mechanical dredging using three 8-cy clamshell buckets. Mechanical dredging of the limited TSCA-level sediment volumes would occur prior to initiation of capping and dredging sediments to the CDF. The estimated time to complete dredging ranges between 6.3 years for 125 ppb and 4.2 years for 5,000 ppb action levels using three dredges.

Sediment removal costs for dredging are estimated to range between $69,500,000 for 125 ppb and $47,100,000 for 5,000 ppb action levels.

Sediment Dewatering. The sediments dredged to the CDF will be dewatered and treated as described under Alternative D. Additional sediments will dewater on-barge for 2 days prior to offloading to upland staging areas for off-site disposal. Sediment dewatering costs are included in the removal and water treatment costs.

Water Treatment. Overflow return water from the CDFs and the water from on-barge dewatering would be treated before discharge to the river. Monitoring requirements are the same as for the prior remedial alternatives. Water treatment costs for Alternative F are estimated to be similar to those for Alternative C1.

Sediment Disposal. Sediment disposal includes the loading and transportation of the TSCA-level and non-TSCA-level sediments to an appropriate off-site facility. Sediments would require solidification with 10 percent lime prior to transport.

The cost for off-site sediment solidification and disposal at an existing NR 500 commercial disposal facility is estimated to range between $246,300,000 for 125 ppb and $95,500,000 for 5,000 ppb action levels.

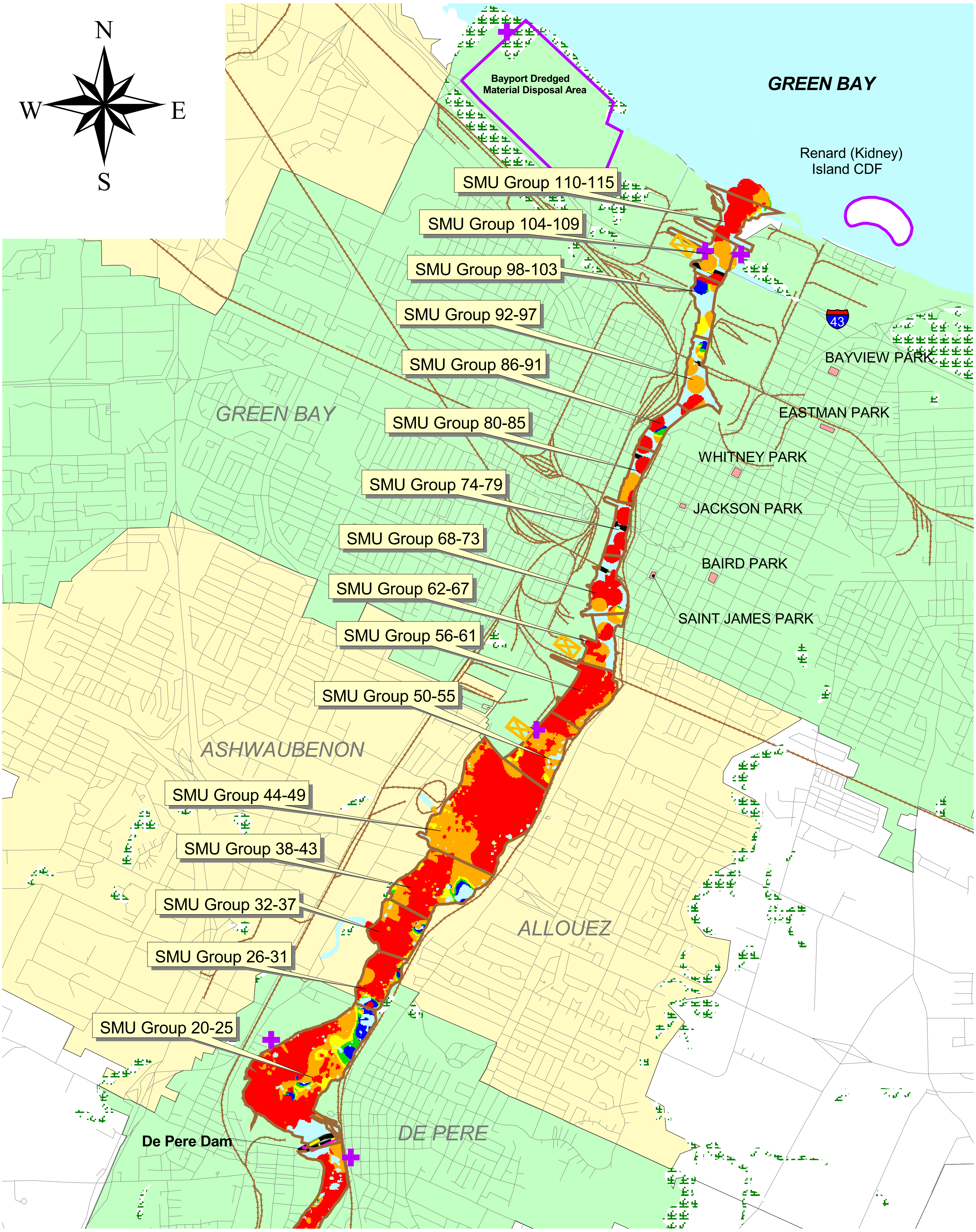
Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. Demobilization and site restoration costs are included under the dredging and capping estimates.

Institutional Controls and Monitoring. Annual monitoring will be performed to ensure that the cap is placed as intended, the required capping thickness is maintained, and contaminants are isolated. The monitoring program will include bathymetric surveys, camera profiles, and core sampling and will be conducted over a period of 40 years. Institutional controls would include deed restrictions, site access and anchoring limitations, and maintenance of the consumption advisories. A separate *Long-term Monitoring Plan* for the entire river and Green Bay is discussed in Appendix C.

The estimated cost for institutional controls is $4,500,000. Monitoring for cap integrity is included in the capping costs. Long-term monitoring scope and costs for verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

7.5.5 Section 7.5 Figures and Tables

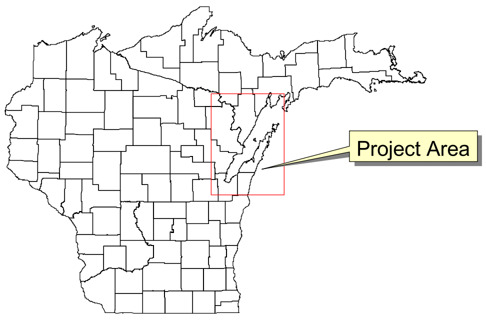
Figures and tables for Section 7.5 follow page 7-146 and include:



Sediment Management Units
Possible Equipment Access
TSCA Areas
Upland Staging
Action Level Profile (ppb)
>125
>250
>500
>1,000
>5,000
Dam Locations
Bridges
Railroads
Roads
Wisconsin State Parks
Wetlands
Water
Civil Divisions
City
Township
Village

1 0 1 2 Kilometers

1 0 1 Miles

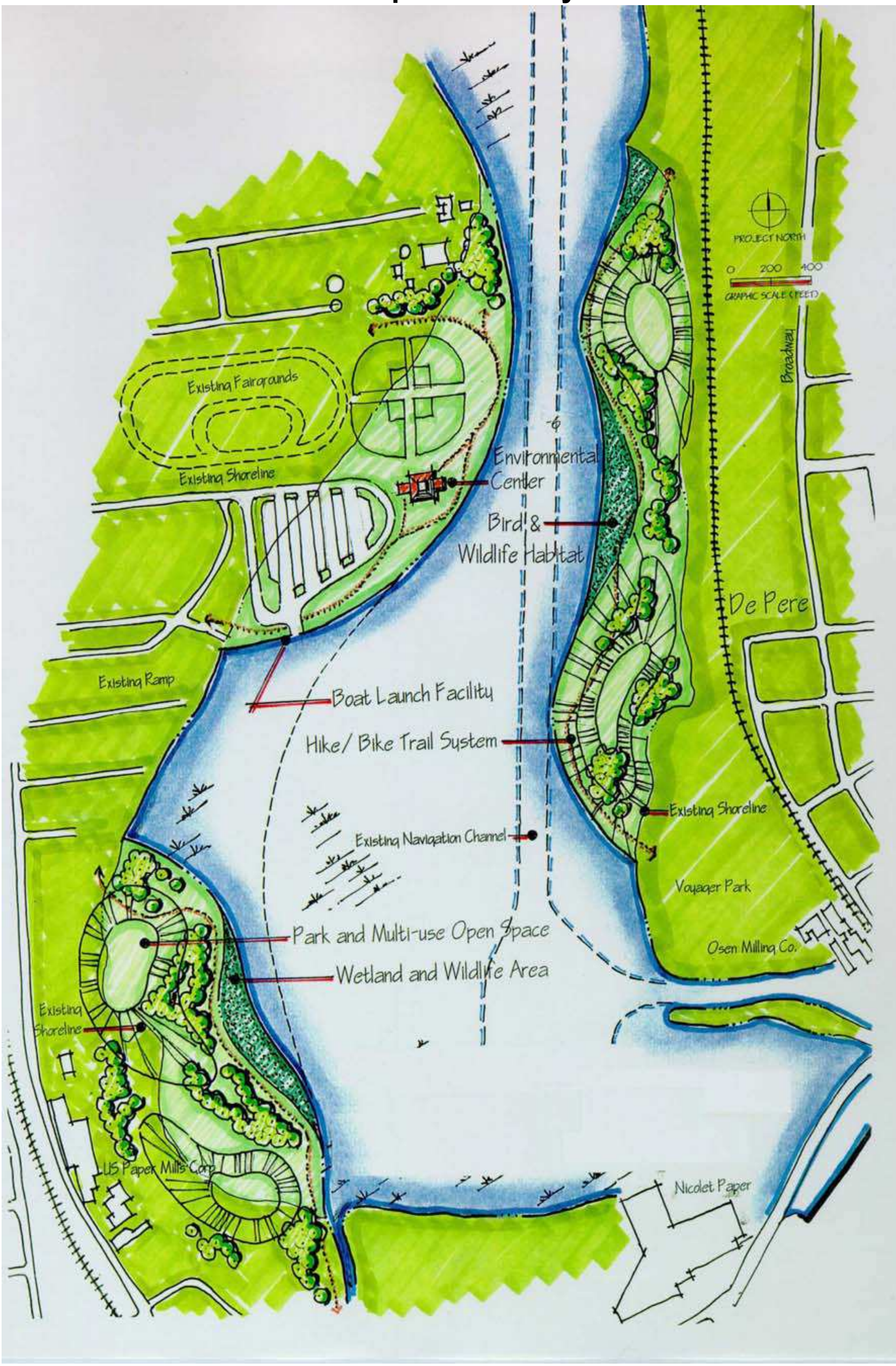


1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR. and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to 350 cm for lower Fox River.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Sediment Management Area Overview: De Pere to Green Bay	REFERENCE NO: FS-14414-535-7-31 CREATED BY: SCJ PRINT DATE: 3/13/01 APPROVED: AGF

FIGURE 7-36

Figure 7-37 Preliminary Concept Design for the De Pere Confined Disposal Facility



F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSP.PPT

Figure 7-38 Process Flow Diagram for De Pere to Green Bay - Alternative C1: Dredge with Disposal at an Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

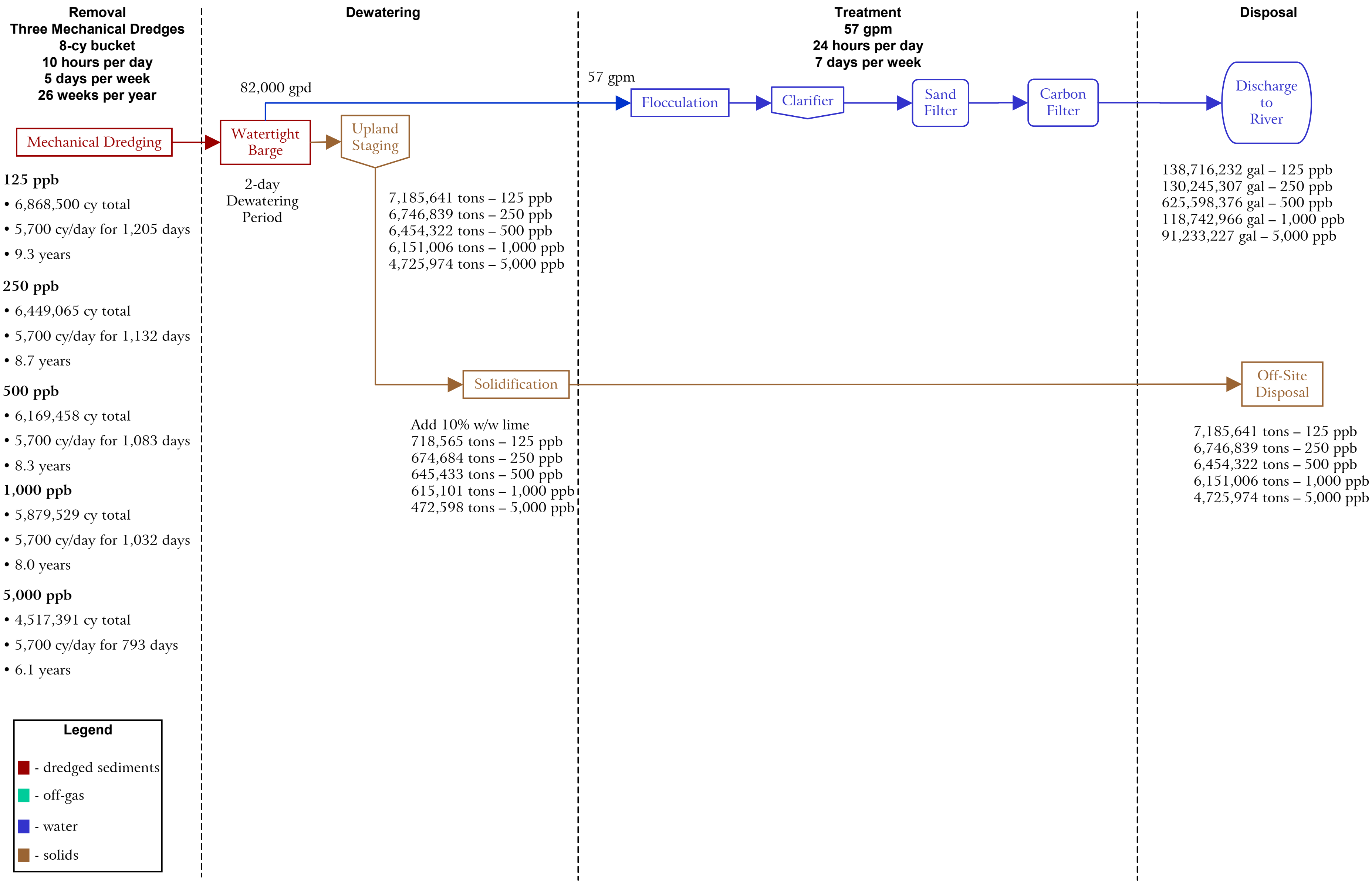
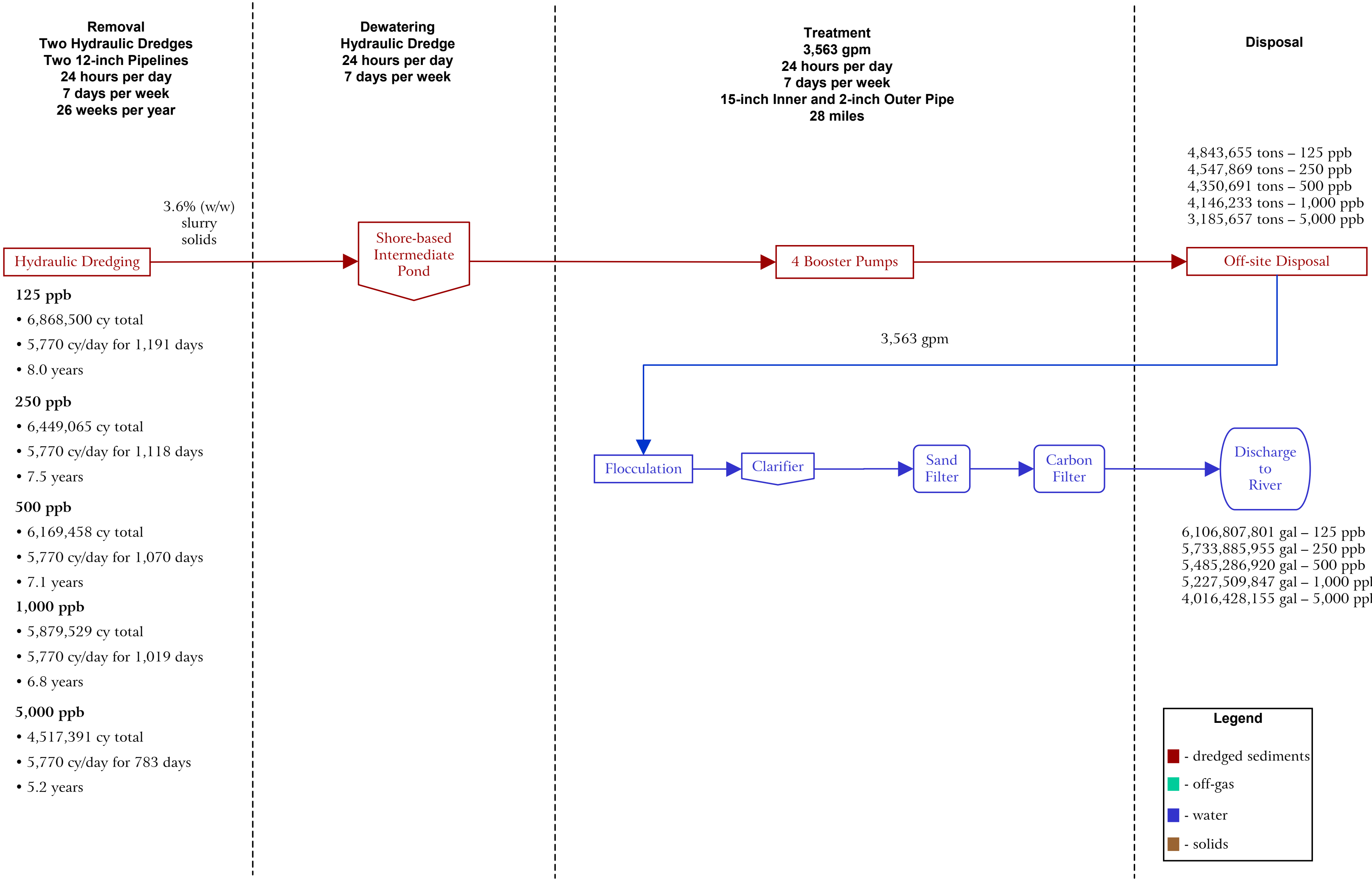


Figure 7-39 Process Flow Diagram for De Pere to Green Bay - Alternative C2A: Dredge with Combined Dewatering and Disposal Facility



Note: Off-site disposal unit is a combined dewatering and disposal facility.

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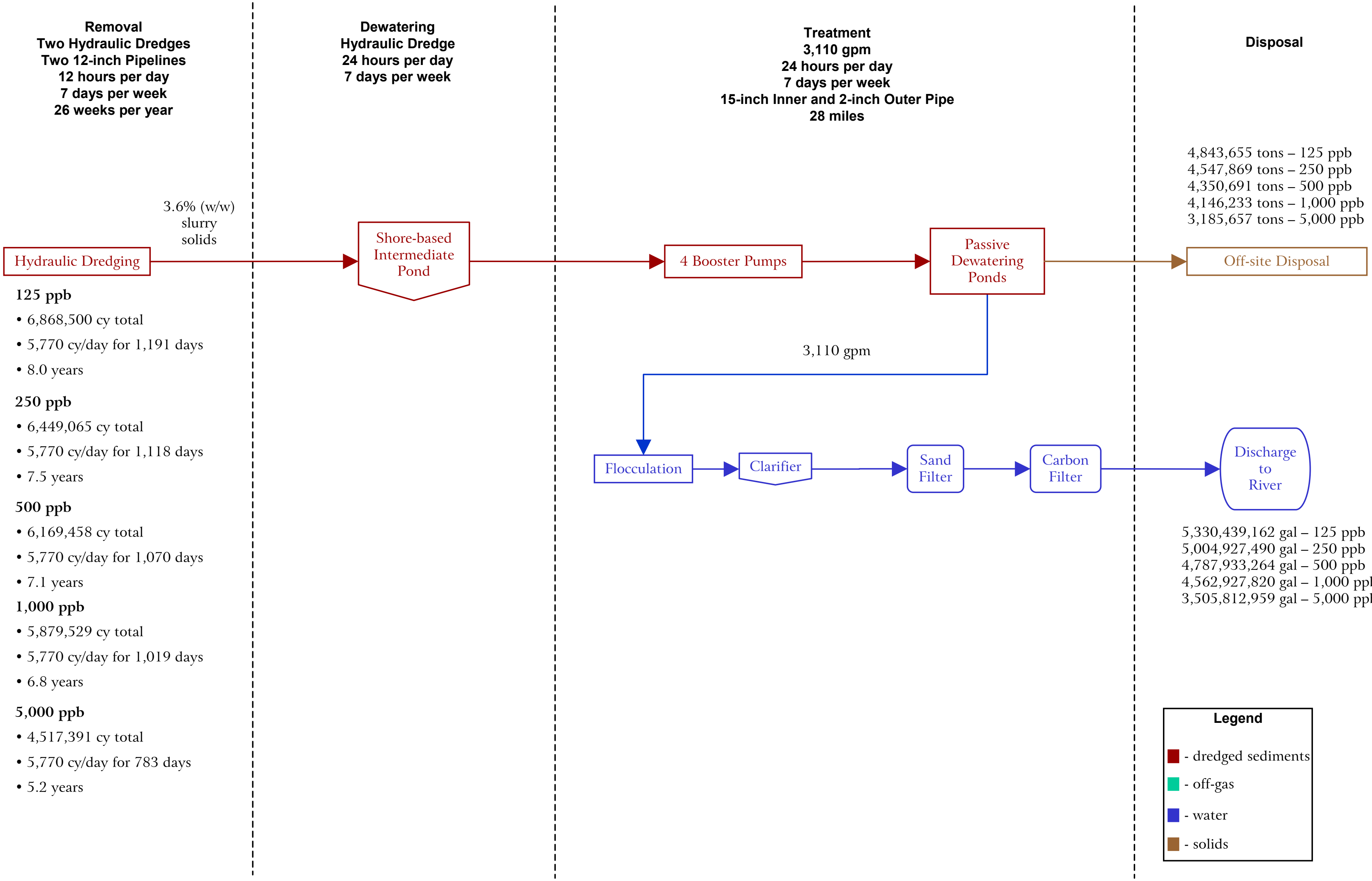
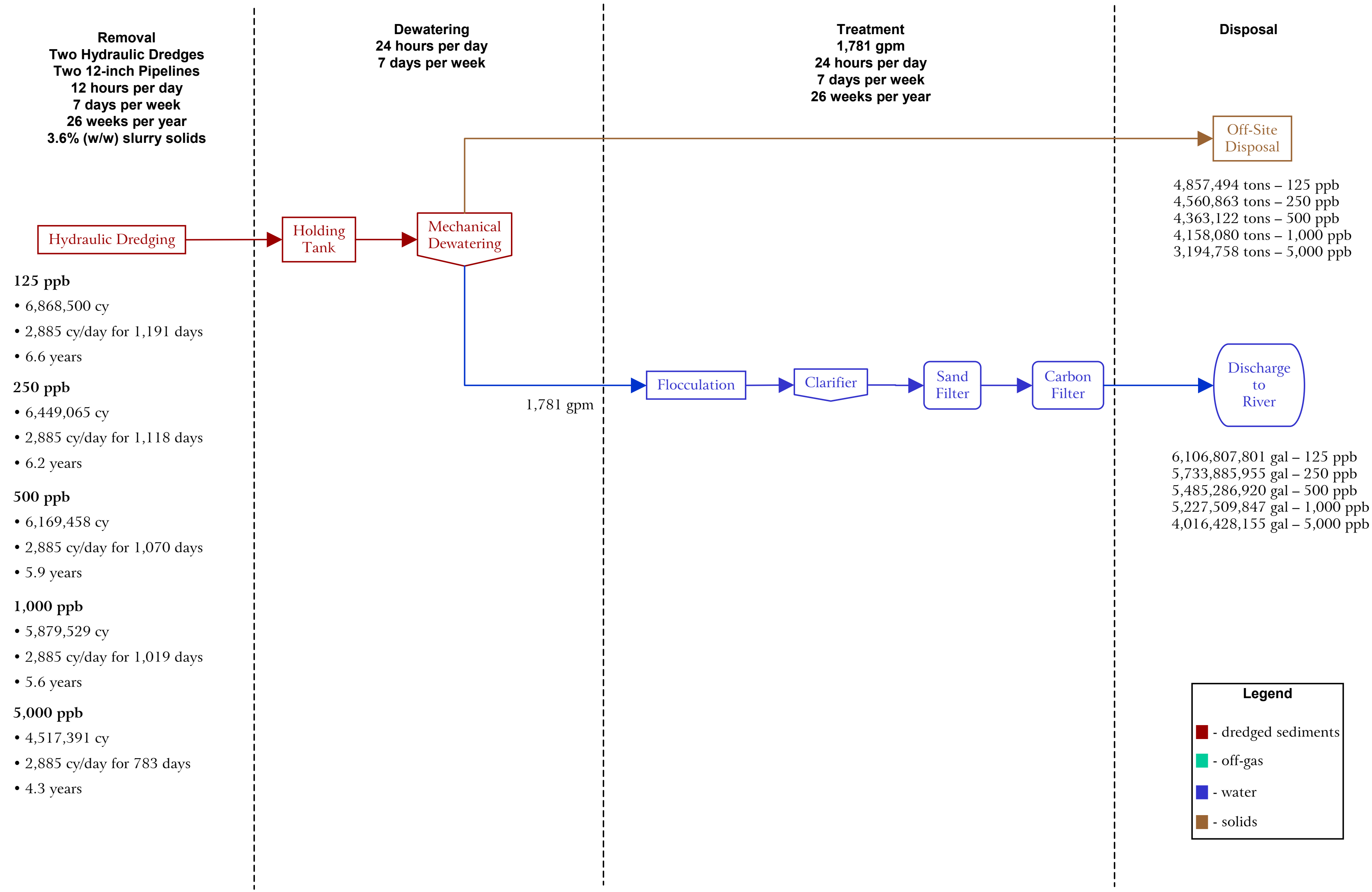
Figure 7-40 **Process Flow Diagram for De Pere to Green Bay - Alternative C2B: Dredge with Separate Dewatering and Disposal Facility**



Note: Off-site disposal unit is a dedicated NR 500 monofill.

F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT

Figure 7-41 **Process Flow Diagram for De Pere to Green Bay - Alternative C3: Dredge Disposal at an Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)**



Note: Off-site disposal unit is an existing NR 500 commercial disposal facility.

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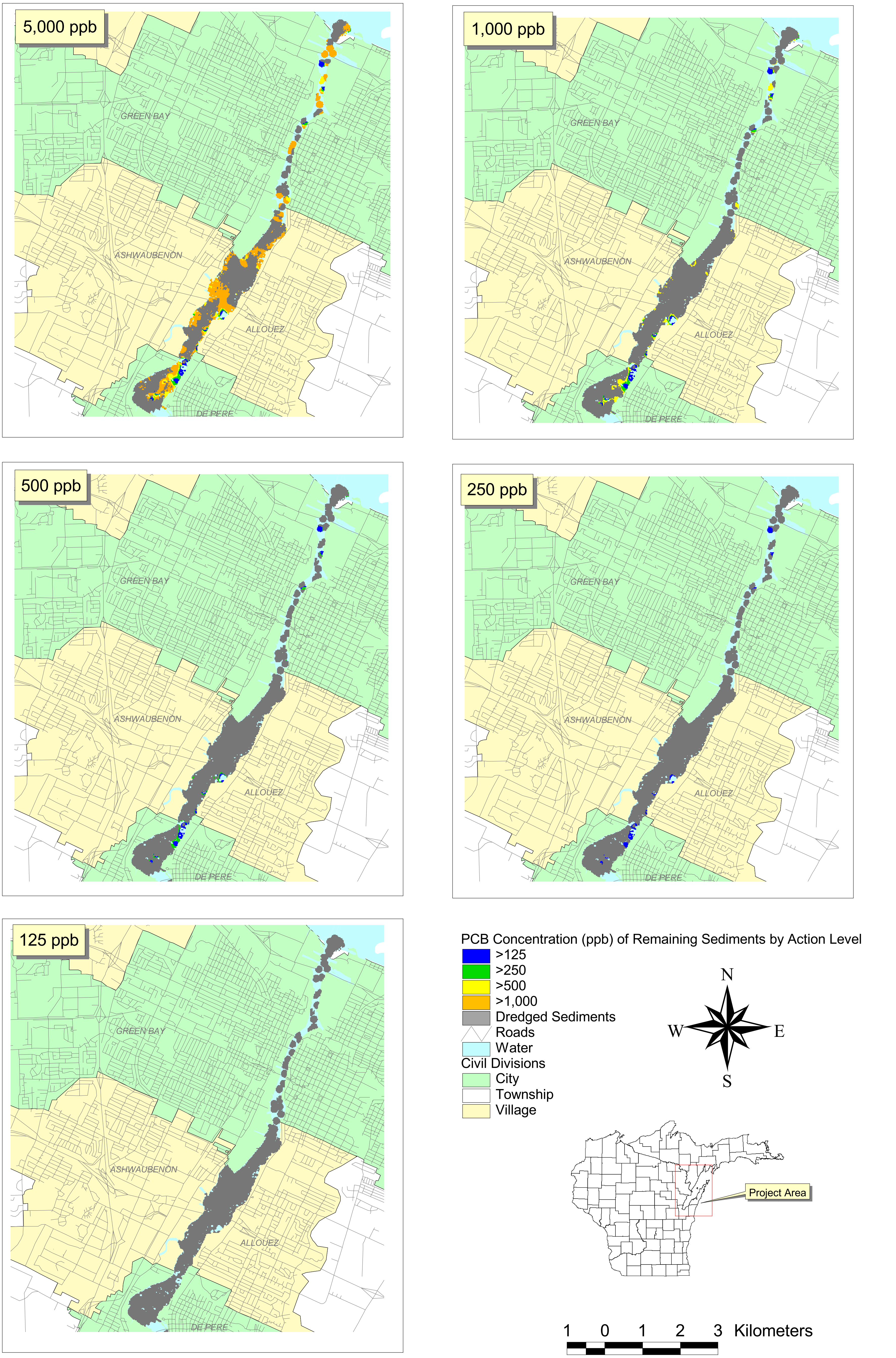
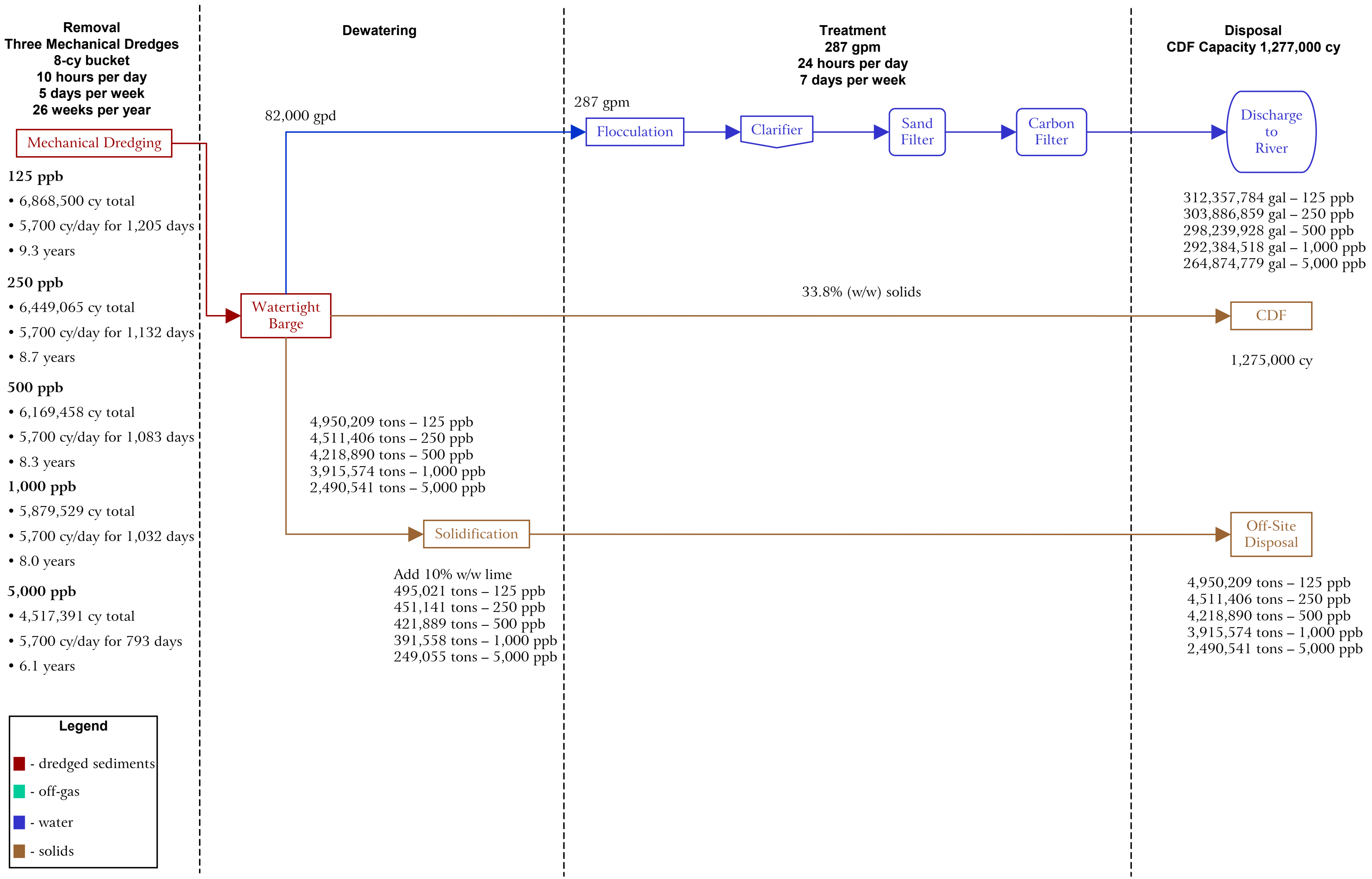
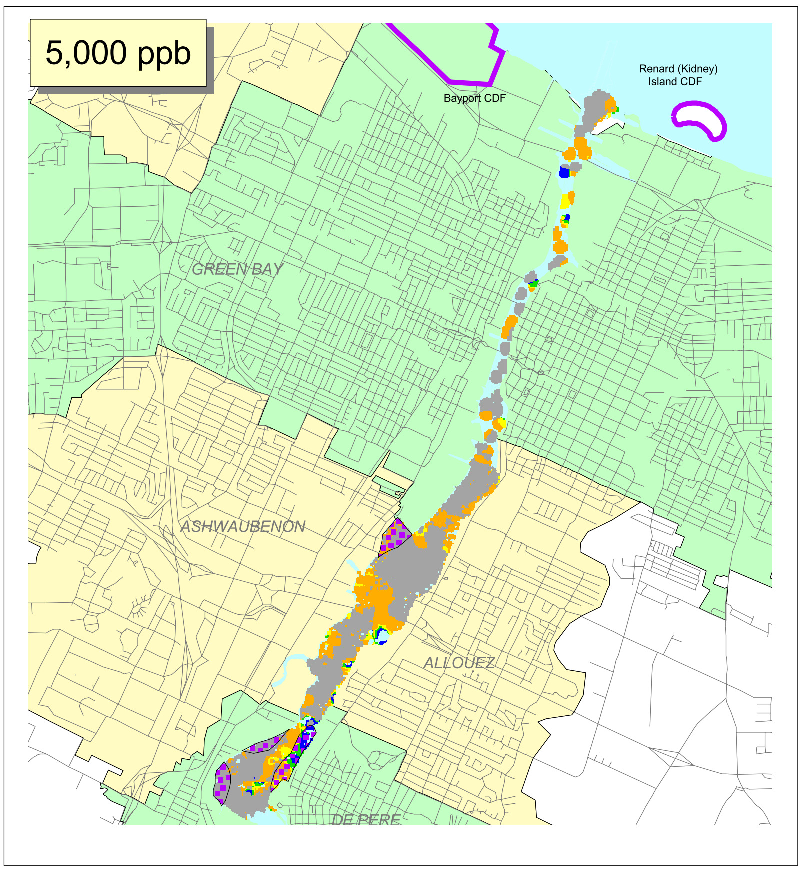


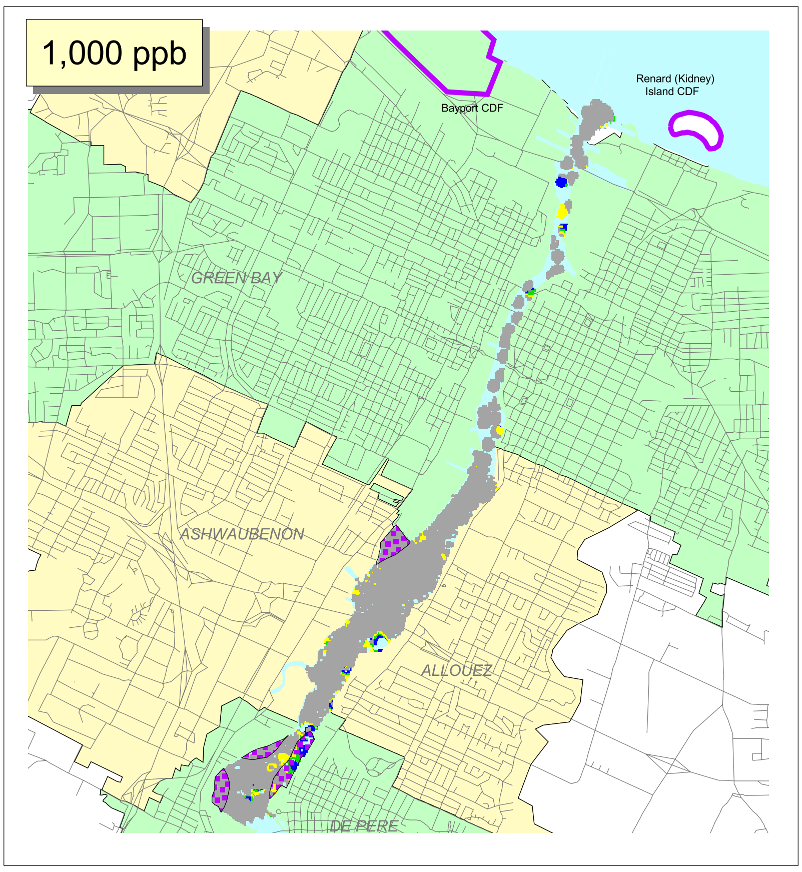
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.

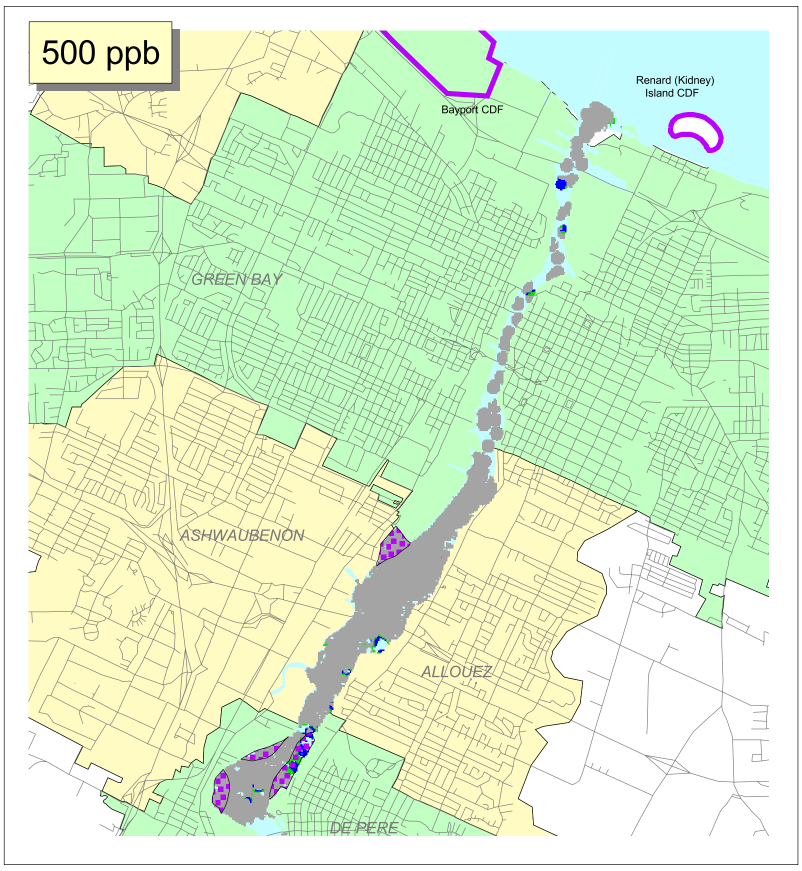
ThermoRetec *Smart Solutions. Positive Outcomes.*	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative C: Dredge and Off-Site Disposal De Pere to Green Bay	REFERENCE NO: FS-14414-535-7-35
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-42	APPROVED: AGF

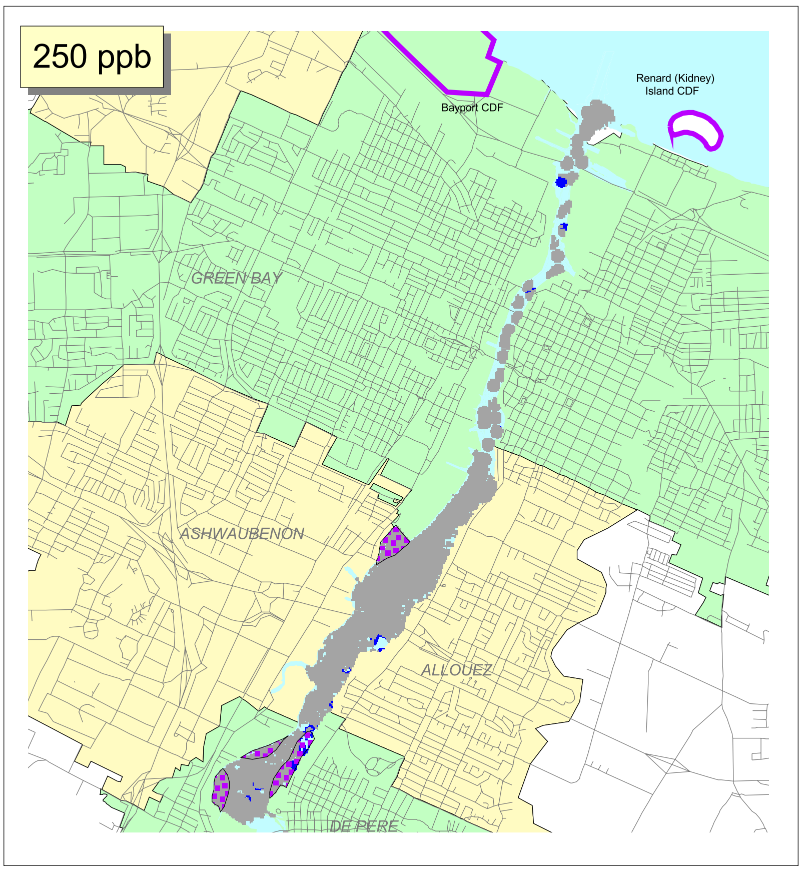
Figure 7-43 Process Flow Diagram for De Pere to Green Bay - Alternative D: Dredge Sediment, CDF, and Off-site Disposal

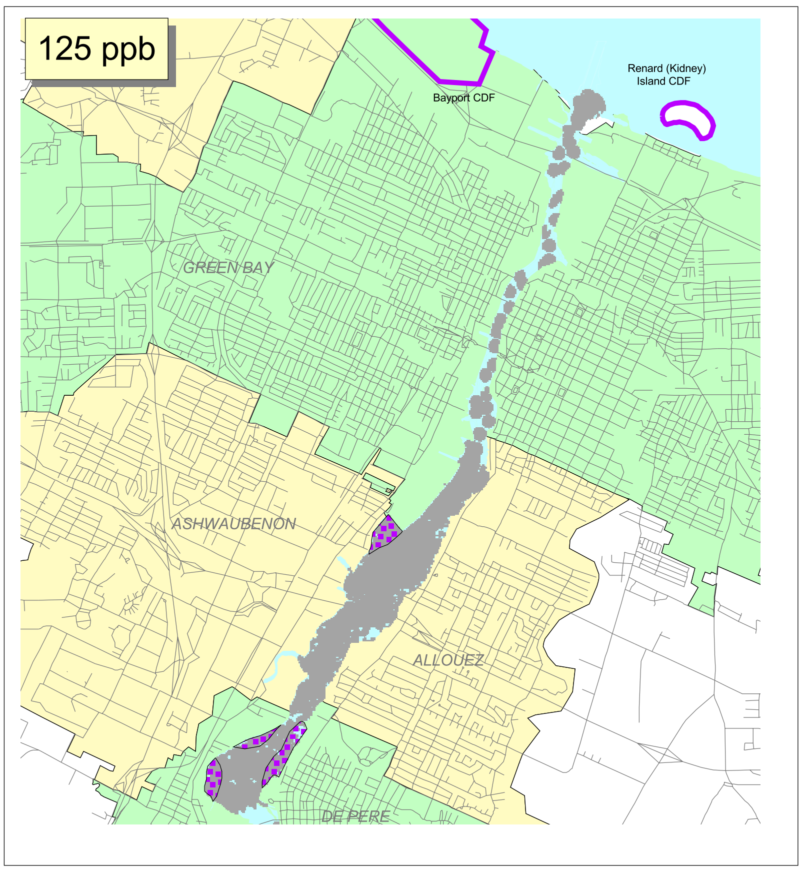






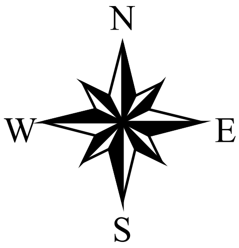


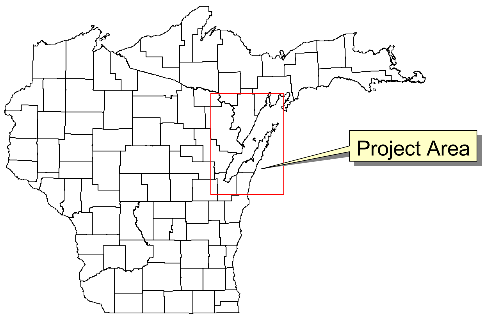


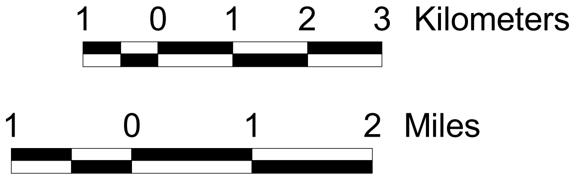


PCB Concentration (ppb) of Remaining Sediments by Action Level
- >125
- >250
- >500
- >1,000
- Dredged Sediments
- CDF Footprints
- Roads
- Water

Civil Divisions
- City
- Township
- Village



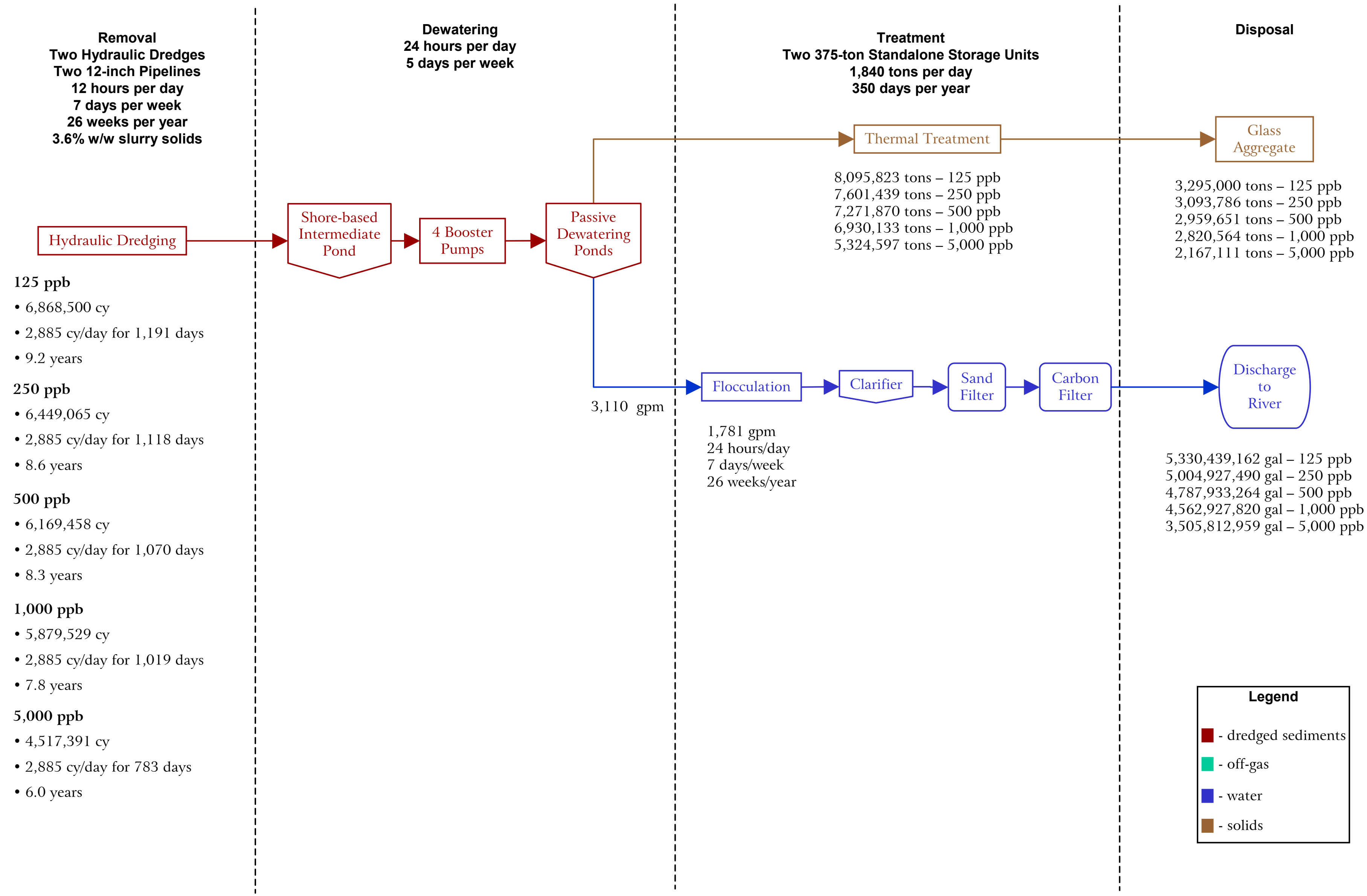




1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative D: Dredge Sediment to Confined Disposal Facility De Pere to Green Bay	REFERENCE NO: FS-14414-535-7-37
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-44	APPROVED: AGF

Figure 7-45 **Process Flow Diagram for De Pere to Green Bay - Alternative E: Dredge Sediment with Thermal Treatment**



Note: Additional integral elements of the vitrification unit (dryer, pollution control) are not shown as they were not estimated separate. For greater detail on the unit layout and components, refer to the Minergy Unit Cost Report (Appendix G).

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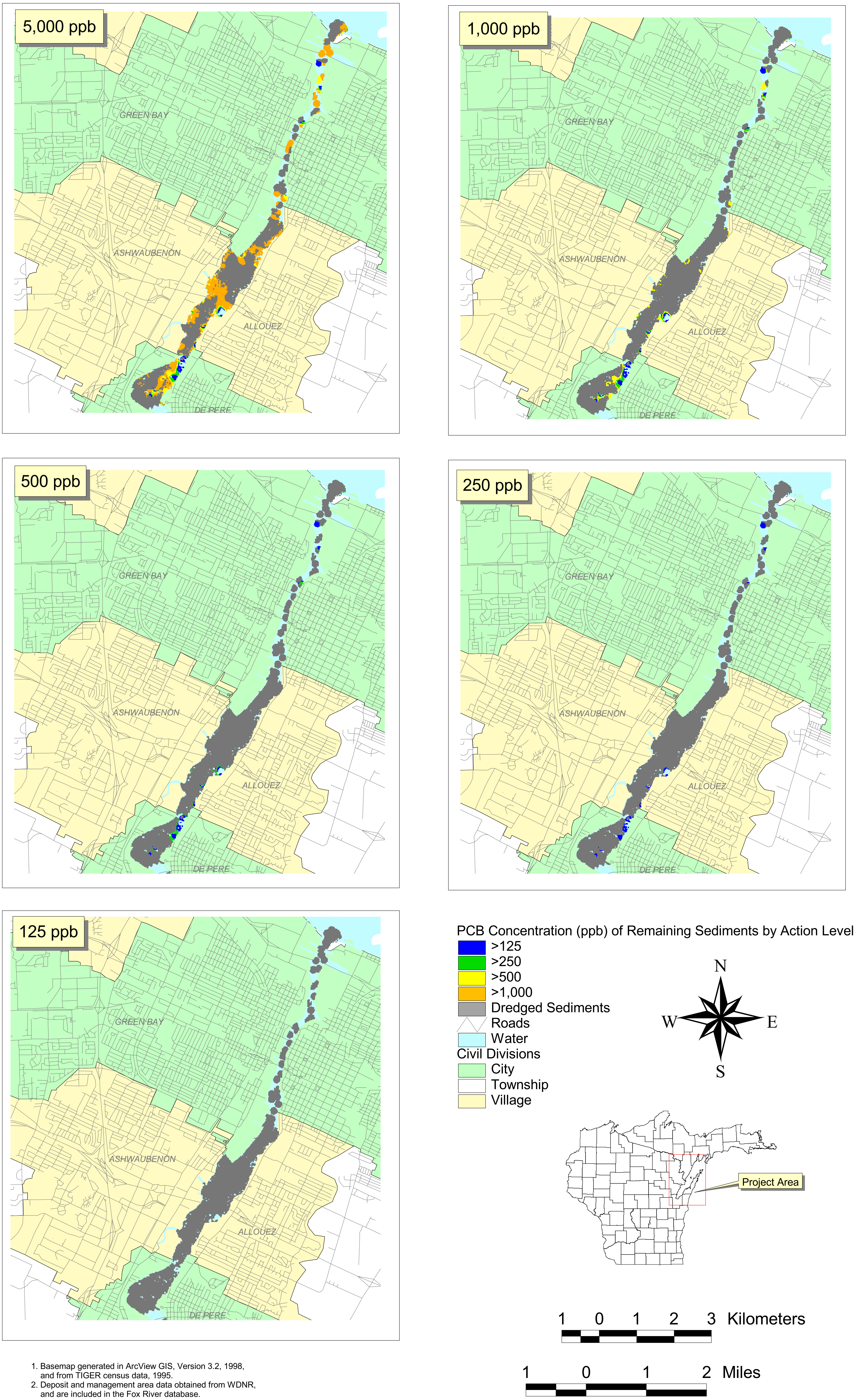
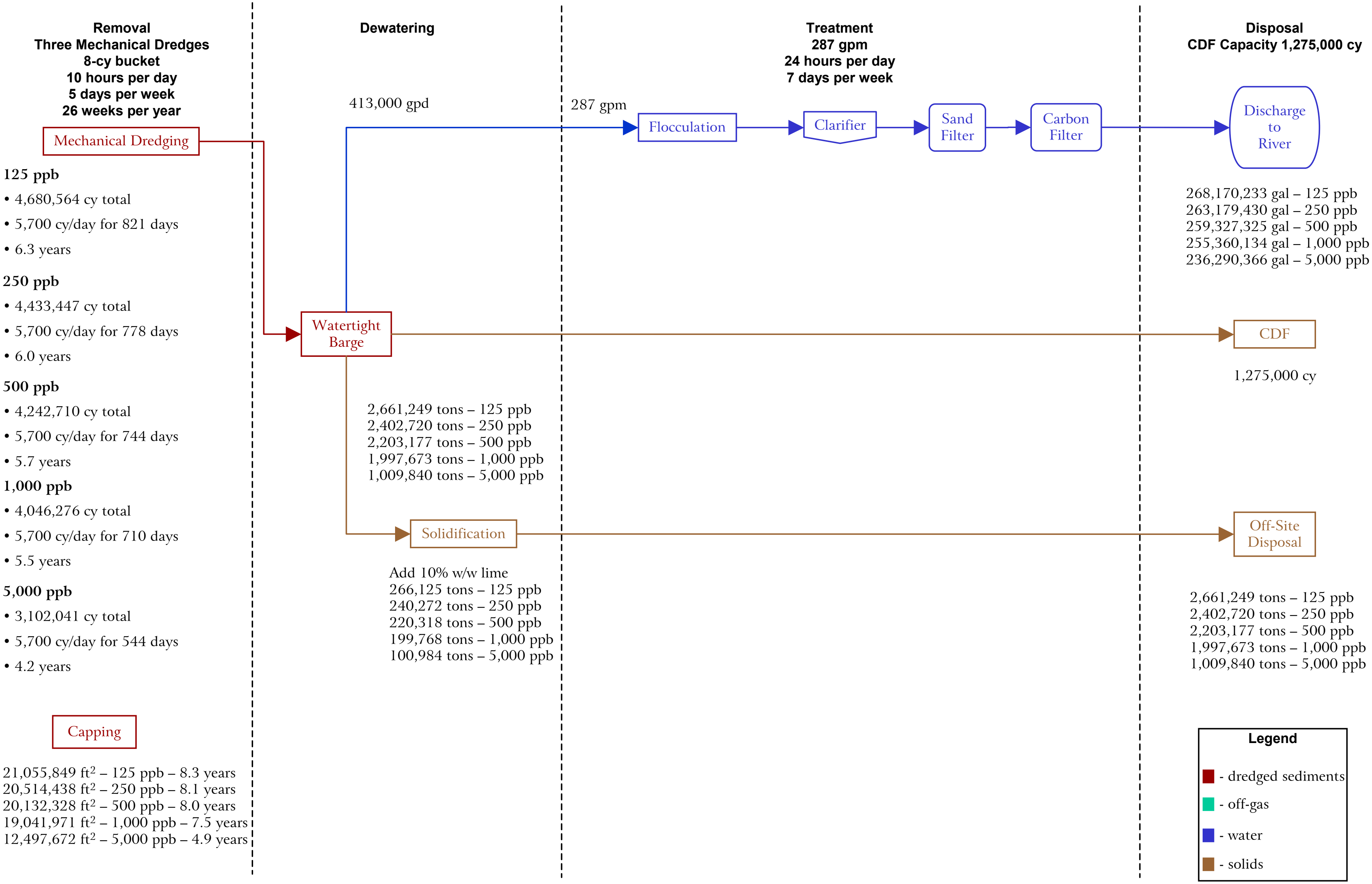


1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative E: Dredge with Thermal Treatment De Pere to Green Bay	REFERENCE NO: FS-14414-535-7-39
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-46	APPROVED: AGF

Figure 7-47 Process Flow Diagram for De Pere to Green Bay - Alternative F: Cap Sediment to Maximum Extent Possible, Dredge, CDF, and Off-site Disposal



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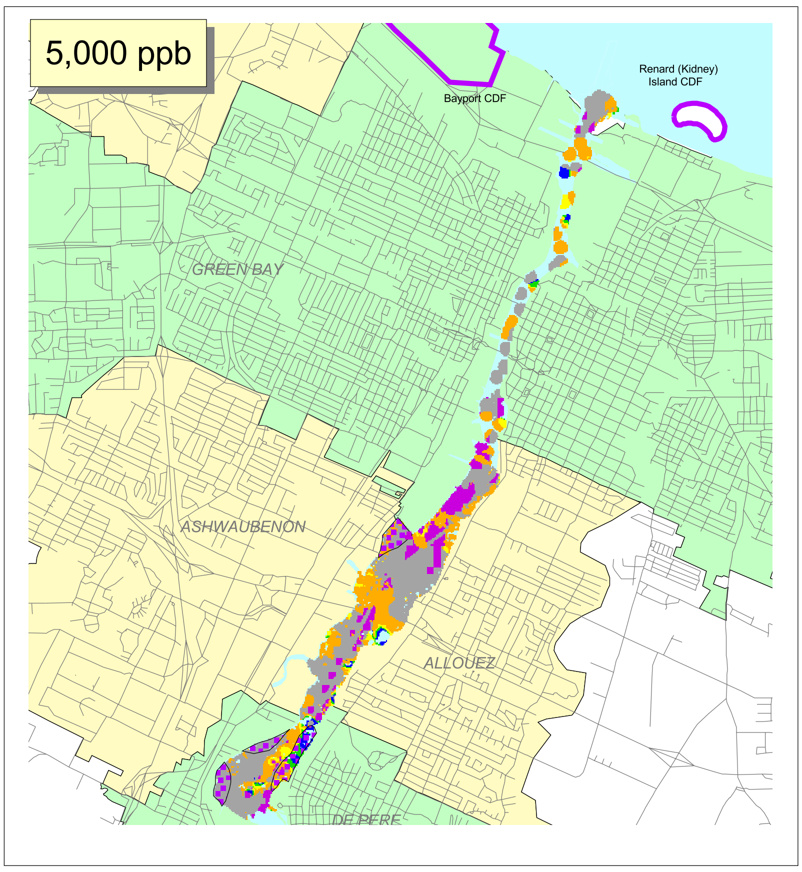
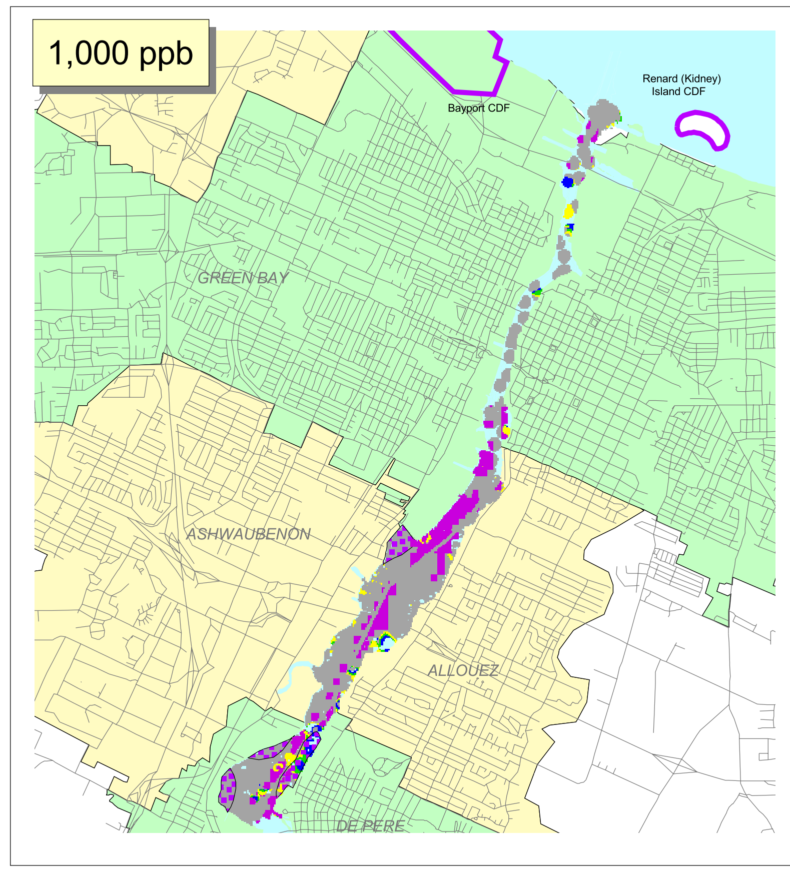
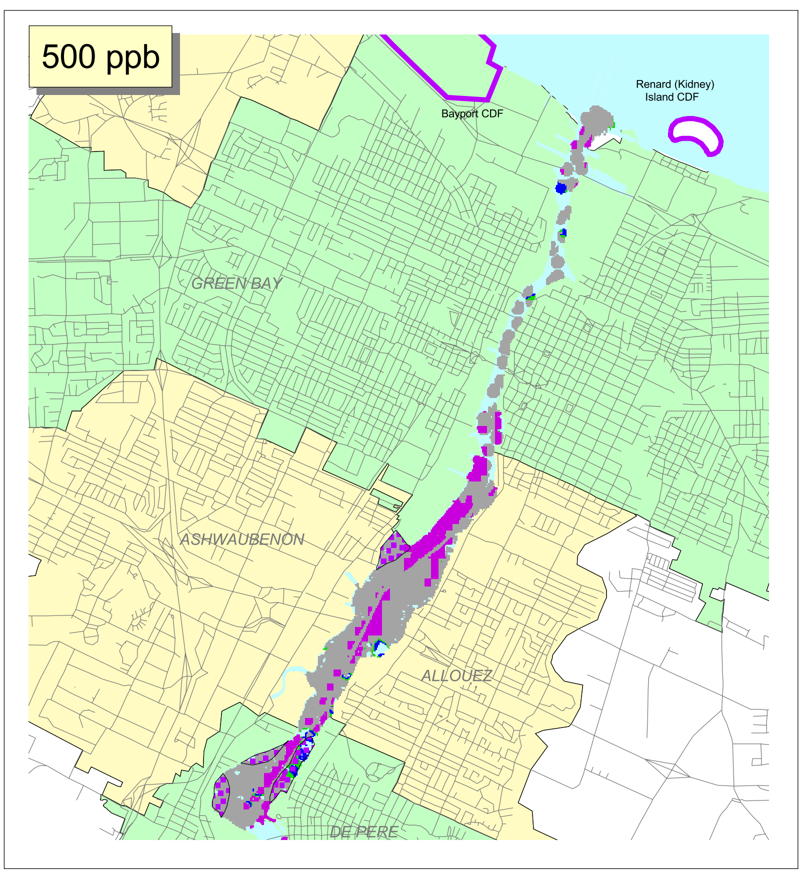
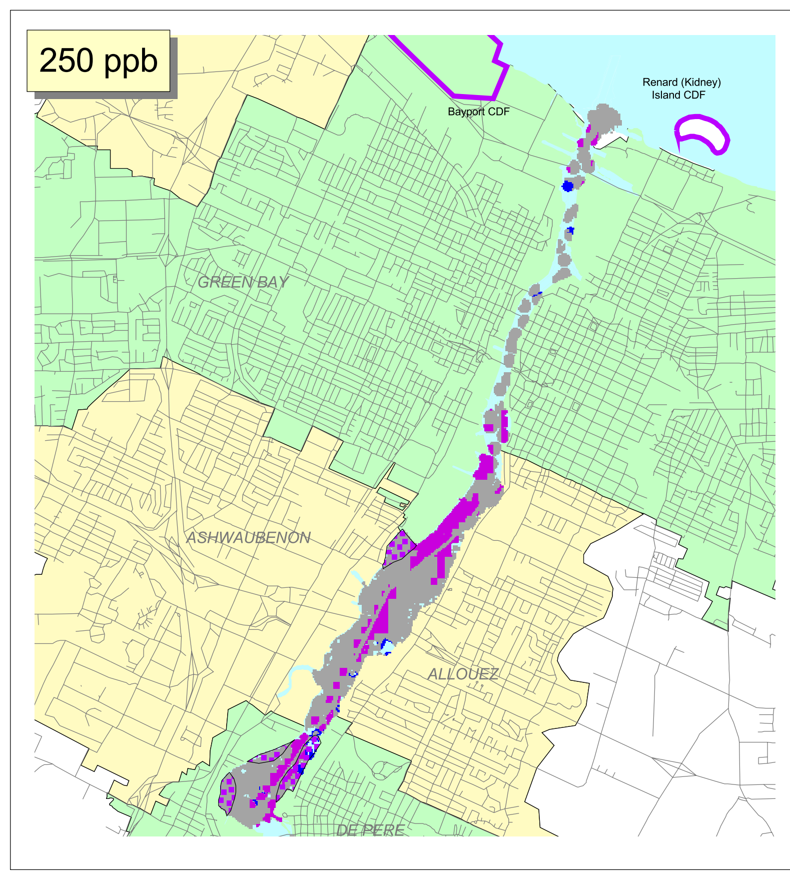
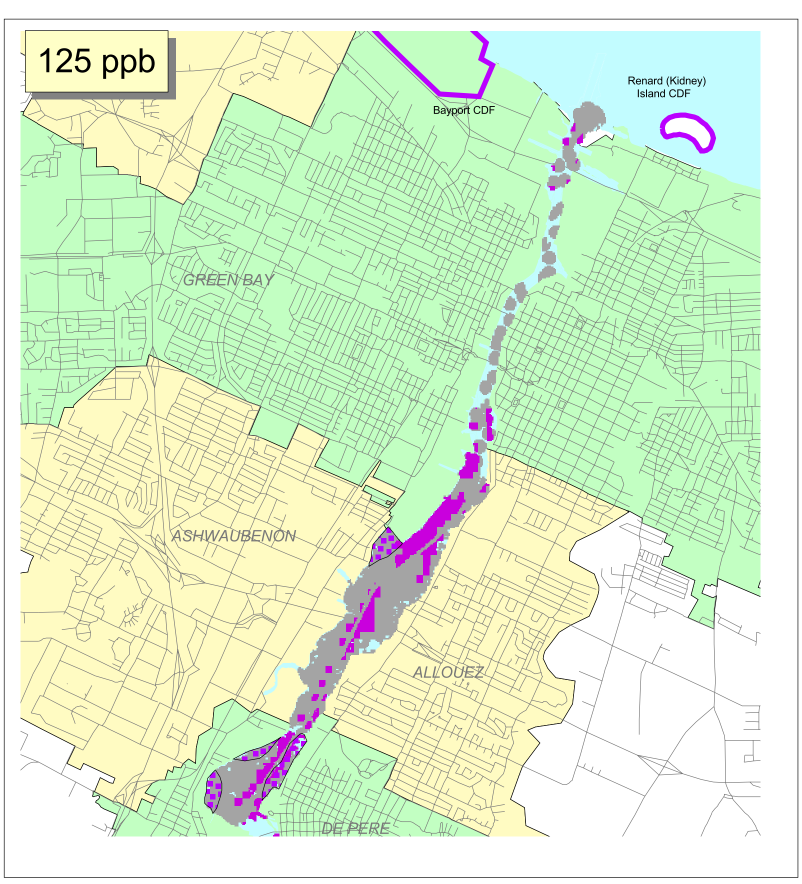




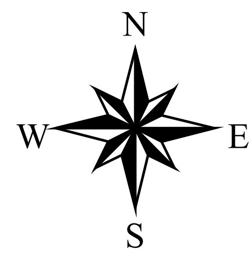


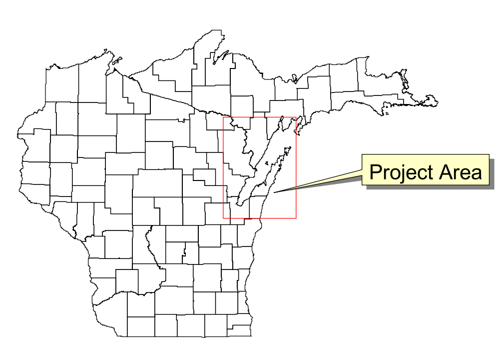


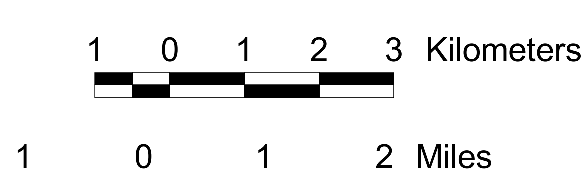


PCB Concentration (ppb) of Remaining Sediments by Action Level
- >125
- >250
- >500
- >1,000
- Dredged Sediments
- Capping Areas
- CDF Footprints
- Roads
- Water

Civil Divisions
- City
- Township
- Village







1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.
3. Capping area criteria based on a minimum 9-foot water depth.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternative F: Cap to Maximum Extent Possible and Dredge Remaining Sediment to CDF De Pere to Green Bay	REFERENCE NO: FS-14414-535-7-41 CREATED BY: SCJ PRINT DATE: 3/13/01 APPROVED: AGF
			FIGURE 7-48	

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Table 7-8 Cost Summary for Remedial Alternatives - De Pere to Green Bay (Green Bay Zone 1)

125 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,868,500	240,778	---	$100,500,000	---	---	$700,000	---	---	$659,200,000	$4,500,000	$4,200,000	$769,100,000	$153,820,000	$922,920,000
C2A	6,868,500	240,778	$109,400,000	---	---	---	$7,700,000	---	---	$70,200,000	$4,500,000	$4,200,000	$196,000,000	$39,200,000	$235,200,000
C2B	6,868,500	240,778	$109,400,000	---	---	$19,900,000	$7,300,000	---	---	$419,200,000	$4,500,000	$4,200,000	$564,500,000	$112,900,000	$677,400,000
C3	6,868,500	240,778	$85,400,000	---	---	$217,700,000	$6,400,000	---	---	$277,000,000	$4,500,000	$4,200,000	$595,200,000	$119,040,000	$714,240,000
D	6,868,500	240,778	---	$100,500,000	---	---	$1,200,000	---	$39,200,000	$462,200,000	$4,500,000	$4,200,000	$611,800,000	$122,360,000	$734,160,000
E	6,868,500	240,778	$109,400,000	---	---	$19,900,000	$12,900,000	$253,600,000	---	---	$4,500,000	$4,200,000	$404,500,000	$80,900,000	$485,400,000
F	4,680,565	240,778	---	$69,500,000	$67,800,000	---	$1,100,000	---	$39,200,000	$246,300,000	$4,500,000	$4,200,000	$432,600,000	$86,520,000	$519,120,000

250 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,449,065	240,778	---	$94,600,000	---	---	$700,000	---	---	$619,100,000	$4,500,000	$4,200,000	$723,100,000	$144,620,000	$867,720,000
C2A	6,449,065	240,778	$104,500,000	---	---	---	$7,500,000	---	---	$66,200,000	$4,500,000	$4,200,000	$186,900,000	$37,380,000	$224,280,000
C2B	6,449,065	240,778	$104,500,000	---	---	$19,900,000	$7,100,000	---	---	$393,900,000	$4,500,000	$4,200,000	$534,100,000	$106,820,000	$640,920,000
C3	6,449,065	240,778	$81,500,000	---	---	$204,400,000	$6,200,000	---	---	$260,200,000	$4,500,000	$4,200,000	$561,000,000	$112,200,000	$673,200,000
D	6,449,065	240,778	---	$94,600,000	---	---	$1,100,000	---	$39,200,000	$422,800,000	$4,500,000	$4,200,000	$566,400,000	$113,280,000	$679,680,000
E	6,449,065	240,778	$104,500,000	---	---	$19,900,000	$12,800,000	$238,100,000	---	---	$4,500,000	$4,200,000	$384,000,000	$76,800,000	$460,800,000
F	4,433,446	240,778	---	$66,000,000	$66,200,000	---	$1,100,000	---	$39,200,000	$222,700,000	$4,500,000	$4,200,000	$403,900,000	$80,780,000	$484,680,000

500 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,169,458	240,778	---	$90,600,000	---	---	$600,000	---	---	$592,400,000	$4,500,000	$4,200,000	$692,300,000	$138,460,000	$830,760,000
C2A	6,169,458	240,778	$100,900,000	---	---	---	$7,300,000	---	---	$63,500,000	$4,500,000	$4,200,000	$180,400,000	$36,080,000	$216,480,000
C2B	6,169,458	240,778	$100,900,000	---	---	$19,900,000	$7,000,000	---	---	$377,000,000	$4,500,000	$4,200,000	$513,500,000	$102,700,000	$616,200,000
C3	6,169,458	240,778	$78,500,000	---	---	$195,600,000	$6,000,000	---	---	$249,000,000	$4,500,000	$4,200,000	$537,800,000	$107,560,000	$645,360,000
D	6,169,458	240,778	---	$90,600,000	---	---	$1,100,000	---	$39,200,000	$396,600,000	$4,500,000	$4,200,000	$536,200,000	$107,240,000	$643,440,000
E	6,169,458	240,778	$100,900,000	---	---	$19,900,000	$12,700,000	$227,800,000	---	---	$4,500,000	$4,200,000	$370,000,000	$74,000,000	$444,000,000
F	4,242,710	240,778	---	$63,300,000	$65,100,000	---	$1,100,000	---	$39,200,000	$204,500,000	$4,500,000	$4,200,000	$381,900,000	$76,380,000	$458,280,000

Table 7-8 Cost Summary for Remedial Alternatives - De Pere to Green Bay (Green Bay Zone 1) (Continued)

1,000 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	5,879,529	240,778	---	$86,500,000	---	---	$600,000	---	---	$564,800,000	$4,500,000	$4,200,000	$660,600,000	$132,120,000	$792,720,000
C2A	5,879,529	240,778	$96,900,000	---	---	---	$7,200,000	---	---	$60,700,000	$4,500,000	$4,200,000	$173,500,000	$34,700,000	$208,200,000
C2B	5,879,529	240,778	$96,900,000	---	---	$19,900,000	$6,900,000	---	---	$359,400,000	$4,500,000	$4,200,000	$491,800,000	$98,360,000	$590,160,000
C3	5,879,529	240,778	$75,100,000	---	---	$186,400,000	$5,900,000	---	---	$237,400,000	$4,500,000	$4,200,000	$513,500,000	$102,700,000	$616,200,000
D	5,879,529	240,778	---	$86,500,000	---	---	$1,100,000	---	$39,200,000	$369,600,000	$4,500,000	$4,200,000	$505,100,000	$101,020,000	$606,120,000
E	5,879,529	240,778	$96,900,000	---	---	$ 19,900,000	$12,500,000	$217,100,000	---	---	$4,500,000	$4,200,000	$355,100,000	$71,020,000	$426,120,000
F	4,046,276	240,778	---	$60,500,000	$61,900,000	---	$1,100,000	---	$39,200,000	$185,700,000	$4,500,000	$4,200,000	$357,100,000	$71,420,000	$428,520,000

5,000 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	4,517,391	240,778	---	$67,200,000	---	---	$500,000	---	---	$434,700,000	$4,500,000	$4,200,000	$511,100,000	$102,220,000	$613,320,000
C2A	4,517,391	240,778	$76,000,000	---	---	---	$6,500,000	---	---	$47,500,000	$4,500,000	$4,200,000	$138,700,000	$27,740,000	$166,440,000
C2B	4,517,391	240,778	$76,000,000	---	---	$19,900,000	$6,300,000	---	---	$277,100,000	$4,500,000	$4,200,000	$388,000,000	$77,600,000	$465,600,000
C3	4,517,391	240,778	$57,200,000	---	---	$143,200,000	$5,200,000	---	---	$182,900,000	$4,500,000	$4,200,000	$397,200,000	$79,440,000	$476,640,000
D	4,517,391	240,778	---	$67,200,000	---	---	$1,000,000	---	$39,200,000	$244,600,000	$4,500,000	$4,200,000	$360,700,000	$72,140,000	$432,840,000
E	4,517,391	240,778	$76,000,000	---	---	$19,900,000	$11,900,000	$166,800,000	---	---	$4,500,000	$4,200,000	$283,300,000	$56,660,000	$339,960,000
F	3,102,041	240,778	---	$47,100,000	$42,900,000	---	$1,000,000	---	$39,200,000	$95,500,000	$4,500,000	$4,200,000	$234,400,000	$46,880,000	$281,280,000

Note:
[1] Bayport closure costs are present value costs based on closure 40 years from the present

7.6 Green Bay Zone 2

An overview of the Green Bay zones and PCB-impacted sediments is shown on Figure 7-49. The retained alternatives and associated costs for Zone 2 are presented in Table 7-9.

7.6.1 General Site Characteristics

This zone extends from the mouth of the Lower Fox River to a line perpendicular with the long axis of the bay about 7.6 miles from the mouth of the river. Zone 2 is bounded by the city of Green Bay at the south end, and is further divided into "east" and "west" segments by a line trending northeast connecting the mouth of the Lower Fox River through Chambers Island. Zone 2A is located on the west side of this line while Zone 2B is located on the east side of this line.

The bathymetry of Zone 2 is generally shallow, with all water depths less than 26.5 feet. The navigation channel lies almost entirely within Zone 2A. There are a number of shallow areas located on the west side of this zone. Water levels within the Great Lakes have been decreasing since the mid-1990s. In 1999, water level elevations dropped to about 175.96 meters (577.30 feet), about 43 cm (17 inches) below the average levels for December (USACE, 2000a).

The nature and extent of PCB-impacted sediment in this zone, as summarized in the RI, includes the following:

- Maximum detected concentration - 799 μg/kg (avg. 324 μg/kg),
- Total PCB mass - 31,394 kg,
- Total PCB-impacted volume - 39,580,000 m^3, and
- Maximum PCB sample depth - 30 to 50 cm depth.

These quantities represent the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section are likely larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

7.6.2 Selected Remedial Alternatives

This section defines the remedial alternatives for Zone 2 and then describes the technologies that would be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for Green Bay Zone 2 include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an existing NR 500 commercial disposal facility.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

G. Remove sediments with PCB concentrations greater than the selected action level and place in an on-site CAD facility.

Alternatives E and F were not retained since bay bathymetry, water currents, and bay utilization for navigation preclude construction of an appropriate sand cap and sediment volumes are too large for effective use of thermal treatment. The process options that can be applied to the remedial alternatives are described below.

7.6.3 Description of Process Options

Monitoring

Monitoring of physical, chemical, and biological media is applicable for Alternatives B, C, D, and G. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; SMWG, 1999; IJC, 1997; Krantzberg *et al.*, 1999). The following references were used in this FS

Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Ecology, *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- USACE, *Monitoring Considerations for Capping* (USACE, 1992);
- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);
- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);
- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);
- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b);
- Sediment remediation case study projects presented in Appendices B and C of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Overall, baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Controls

Institutional controls appropriate to Green Bay include:

- Maintenance of the fish and waterfowl consumption advisory;
- A moratorium on any future dredging within the navigation channel;
- Deed restrictions on any in-water activities that could result in sediment disturbance (e.g., marina construction or over-water development);
- Access restrictions to contaminated areas; and
- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water use advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal is identified for Alternatives C, D, and G. Remediation area boundaries and sediment management areas are shown on Figure 7-49. For Green Bay Zone 2, mechanical dredging is more practicable because water depth is adequate and water treatment volumes are minimized. Mechanical dredging significantly reduces the water management needs and reduced water management is necessary due to the limited upland space availability.

A 12-cy Cable Arm™ bucket has been selected for the remedial alternatives identified in this reach. The operating assumption is that dredging will occur only during normal daylight hours (12 hours per day) during a normal work week (5 days per week). In industrial areas, dredging may occur 24 hours per day and 6 days per week; however, this option was not included in the FS. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation.

Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D) (Appendix B). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream. However, for the purposes of this FS, silt curtains were included in the removal costs.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not included in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For all mechanical dredging alternatives, it is proposed that dewatering be conducted on-barge and in upland staging areas. Dewatering has been configured as a two-step process using gravity settling followed by solidification of solids.

Passive Dewatering. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and collected. Sediment will then be transferred into one of three asphalt-paved upland staging areas for additional dewatering, solidification, and loading into trucks for off-site shipment. These upland staging areas will each be approximately 0.5 acre in size, surrounded with a 6-inch curb, and graded to a water collection sump. All water collected from the barges and the upland staging area will be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. The upland staging areas may be located at the Bayport facility near the mouth of the Lower Fox River or at other locations that have yet to be determined.

For the dredge to CDF alternative (Alternative D), dewatering will occur directly within the CDF. Decant water for this alternative will be treated and returned to the bay.

These proposed dewatering systems will meet the criteria defined in Section 6 of this FS Report, in terms of production rate, effectiveness, practicality, and discharge water quality. Final selection of the dewatering process will be determined during the remedial design phase.

Solidification. The solids content after mechanical dredging and dewatering is assumed to be about 50 percent (w/w) or similar to *in-situ* density, based on *in-situ* solids content from the RI Report (RETEC, 2002a). This dewatered sediment may still be difficult to manage due to the high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary, and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. For FS cost estimating purposes, 10 percent (w/w) lime was added as the reagent based on its successful use during the SMU 56/57 project (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and loaded into trucks using standard earthmoving equipment. If the contractor prefers, sediment may be mixed with the reagent in a pug mill as shown on Figures 7-1 and 7-5. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

Treatment Process Options

Water Treatment. Prior to water discharge back to the bay, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary. However, additional carbon (GAC) treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC carbon treatment is $0.40 per thousand gallons of water treated.

On-site Disposal Process Options

The CDF currently proposed for Green Bay is a cellular cofferdam located near the Cat Island chain. The CDF size was varied with each action level to accommodate the total volume of dredged sediment. The new Green Bay CDF will be constructed as three separate islands in accordance with the design proposed by the USACE (USACE, 1999) to encourage natural resedimentation and restoration around the structures. Several in-water and upland CDF sites were proposed in a 1985 Environmental Impact Study (USACE, 1985) for Green Bay Harbor, but most were eliminated from further consideration because of environmental concerns by the USFWS (as cited in USACE, 1985). Only the Cat

Island restoration area and Kidney Island expansion were retained for further consideration.

The newly constructed free-standing CDF structures will be closed with a 3-foot sand cap and riprap placed around the edges to provide additional protection from storm events. The final construction will also include habitat areas for shallow submerged and emergent vegetation as shown on the proposed conceptual design (Figure 7-50). While the top layer is not designed to be an impermeable cap, selection of appropriate plant species will be considered (i.e., shallow roots) to ensure physical integrity of the cap.

The Renard Island CDF, located near the mouth of the Lower Fox River, is a 55-acre diked impoundment with a design capacity of 1,200,000 cy. The facility consists of a kidney-shaped stone dike with an interior steel sheet pile cutoff wall to prevent seepage to surrounding surface waters (USACE, 1985). The CDF reached capacity after receiving a deposit of dredged sediment in 1996. Construction costs include final closure of the Renard Island CDF in addition to constructing a new CDF. Closure of Renard Island will include placement of a 3-foot-thick clean soil cap, seeding, mitigation, and long-term monitoring for 40 years.

Within Green Bay, three potential confined aquatic disposal (CAD) sites were identified. The CAD was sized for each action level to accommodate the total volume of dredged sediment. CAD site locations were selected in areas with adequate water depths (25-meter depth) and low bottom surface water velocities. Ideal locations for CAD sites are in “null-zones” where circulation patterns create areas with net deposition, instead of erosion and scour. These areas were selected from the HydroQual vector diagrams presented in Section 2 (Figures 2-11 and 2-12). Contaminated sediment will be excavated by mechanical dredging, transferred to a haul barge and placed in the CAD site by either split-hull bottom dump or pumped in via pipeline if finer-scale placement is required.

Off-site Disposal Process Options

Total PCB concentrations in sediment within this zone are below 50 ppm, therefore none of the sediment is considered TSCA material. All sediment could be shipped to landfills which conform to the NR 500 WAC requirements. Local landfill options and unit costs were defined in Section 6.4.8 of this FS Report.

Capping Process Options

No capping is proposed for Green Bay because bottom water currents, storm events, vessel traffic, maintenance of navigational channels, and potential ice scour preclude effective placement and long-term integrity.

7.6.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for Green Bay Zone 2. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs. Details used to develop each cost estimate are provided in Appendix H. The process flow diagrams and dredging footprints for each alternative are presented on Figures 7-51 through 7-53.

The following components are discussed, when applicable, within the development of each alternative:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for Green Bay Zone 2. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management of remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until RAOs are achieved. This alternative includes fish tissue sampling events every 5 years for 40 years for maintenance of fish consumption advisories already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C: Dredge with Off-site Disposal

Alternative C includes the removal of sediments above the remedial action level using multiple mechanical dredges and off-site disposal of the sediments. Costs for Alternative C were developed only for the 5,000 ppb action level because volumes for the other action levels are too large to consider off-site disposal. For example, sediment volumes for the 1,000 ppb action level are 29 million cy. This is about 28 percent of the total capacity of all existing landfills in the state of Wisconsin (Appendix E). Figure 7-51 provides the process flow diagram for this remedial alternative, while Figure 7-52 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-9. The total volume of sediment to be dredged in this alternative is 4,070,000 cy for the 5,000 ppb action level.

Site Mobilization and Preparation. Staging for the dredging of sediments will be conducted at the Bayport facility. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, water treatment, sediment solidification, and truck loading. It is assumed that docking facilities for the mechanical dredge and barges already exist at these locations. Purchase and property preparation are included in the costs.

Sediment Removal. Due to the limited upland space available for water management purposes, all sediment removal will be conducted with a mechanical dredge. Given the volumes and operating assumptions described above, the complete removal effort would require approximately 1.1 years using seven 12-cy closed, clamshell buckets. While it would be more practical to use four dredges and extend the dredging time, the seven-dredge approach provides consistency and relative comparability with the other Green Bay zones. During the remedial design phase, fewer dredges may be selected. Operations will require a staging area for the mechanically-dredged sediments to be offloaded and transported off site. The cost for constructing the upland staging area is included in dewatering and disposal costs. Silt curtains around the dredging area are included to minimize sediment resuspension downstream of the dredging operation; these costs are included in the FS for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are barge rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs are estimated to be $48,700,000 for the 5,000 ppb action level.

Sediment Dewatering. All dewatering will be conducted on-barge and in upland staging areas. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges to upland staging areas. For the off-site disposal alternative, sediment will then be transferred onto an asphalt-paved upland staging area where any free water will be collected. It is assumed that the sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in disposal costs). Sediment dewatering costs are included in the sediment removal (for land construction), water treatment (equipment), and disposal costs (for solidification).

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 404,640 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the bay. It may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. Water treatment costs also include pad and equipment demobilization and construction management. Land acquisition and site restoration costs are included in the removal costs.

Water treatment costs are estimated to be $700,000 for the 5,000 ppb action level.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to a facility listed in Table 6-6. Disposal costs also include the purchase and addition of lime reagent for solidification of dewatered sediment prior to off-site transport (Montgomery-Watson, 1998). The sediments would be loaded into tractor-trailer end dumps with bed liners or sealed gates using a front-end loader. Each load would be manifested and weighed. Each tractor-trailer would pass through a wheel wash prior to leaving the staging area to prevent tracking soil onto nearby streets and highways. After unloading at the designated disposal facility, each tractor-trailer would pass through a wheel wash and return to the staging area for another load. This alternative includes a separate line item of $15,500,000 for closure of the Renard Island CDF.

The estimated percent solids of dewatered sediment after passive dewatering is expected to equal the *in-situ* percent solids of material prior to mechanical dredging, which is 29.3 percent (w/w) (Appendix of RI Report, RETEC, 2002a). After solidification with 10 percent lime (w/w), the material is estimated to have 60 percent (w/w) solids content. Solidification costs for the 5,000 ppb action level are $149,000,000 (22 percent of cost is for purchase of lime).

Costs of sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to be $437,800,000 for the 5,000 ppb action level.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of pre-construction. Demobilization and restoration costs are included within the above dredging estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre- and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time. If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

The estimated cost for the maintenance of institutional controls and fish consumption advisory monitoring is $4,500,000. Costs for implementation monitoring during removal are included in the dredging costs. Long-term monitoring costs to determine verification of project RAOs are included in Alternative B - Monitored Natural Recovery.

Alternative D: Dredge Sediment to Confined Disposal Facility

Alternative D includes removal of sediments to an on-site cellular cofferdam CDF for long-term disposal of the materials. The cellular cofferdam CDF location is identified on Figure 7-52. TSCA-level sediments are not present in this zone.

Figure 7-53 provides the process flow diagram for this remedial alternative. Table 7-9 contains the summary costs to implement Alternative D. The total volume of sediment to be dredged ranges between 29,748,004 and 4,070,170 cy for action levels of 500 and 5,000 ppb, respectively.

Site Mobilization and CDF Construction. For the concept level FS, the process is staged to construct and complete dredging to the cellular cofferdam CDF described in Section 7.6.3. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing the CDF, a water treatment facility, and an offshore docking facility for the mechanical dredge. Property purchase and preparation are included in the costs of the following process components.

CDF construction is estimated at $476,000,000 and $97,100,000 for action levels of 500 and 5,000 ppb, respectively. This alternative also includes separate line item costs for closure of Renard Island estimated at $15,500,000, approximately $4,200,000 of which is purchase and placement of the 3-foot-sand cap.

Sediment Removal. Sediment removal will be conducted using seven 12-cy closed clamshell buckets requiring 8.2 and 1.1 years for action levels of 500 and 5,000 ppb, respectively. Dredged sediment will be transferred from the mechanical buckets directly to 24 barges and 8 tugboats.

Sediment removal costs are estimated at $327,500,000 and $48,700,000 for action levels of 500 and 5,000 ppb, respectively.

Sediment Dewatering. Passive dewatering will occur directly within the CDF structure; however, most of the short-term dewatering will occur on transfer barges for 1 to 2 days after mechanical dredging and prior to disposal. Dewatering costs are included in the dredging effort.

Water Treatment. Free water collected on barges and overflow return water from the CDF would be treated before discharge to the bay. Treatment and monitoring requirements are expected to be similar to those specified for Alternative C.

Water treatment costs for Alternative D are estimated at $1,200,000 and $700,000 for action levels of 500 and 5,000 ppb, respectively.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDF would be finished with a 3-foot cap of clean soils, then seeded and planted. Additional amenities (i.e., wildlife habitat) were not included in the cost estimates. However, this alternative would allow for development of these newly-created upland habitat features. Demobilization and site restoration costs are included under the dredging estimates.

Sediment Disposal. No off-site disposal of sediments is anticipated for this alternative. Dredged sediments will be placed directly into the CDF without solidification. Placement costs are included in the dredging and construction costs.

Institutional Controls and Monitoring. To ensure that the CDF is functioning as designed, near-site sediment and water sampling would be conducted on an annual basis. The monitoring program will be conducted over a period of 40 years.

The estimated cost for institutional controls and consumption advisory monitoring is $4,500,000. Long-term operation and maintenance monitoring of the CDF are included in the CDF construction costs, and costs for long-term remedy monitoring of Green Bay are included in Alternative B.

Alternative G: Dredge Sediment to Confined Aquatic Disposal

Alternative G includes removal of sediments to a CAD facility for long-term disposal of the materials. The proposed CAD location is identified on Figure 7-52.

Figure 7-53 provides the process flow diagram for this remedial alternative. Table 7-9 contains the summary costs to implement Alternative G. The total volume of sediment to be dredged in this alternative ranges between 29,748,004 and 4,070,170 cy for action levels of 500 and 5,000 ppb, respectively.

Site Mobilization and CAD Construction. For the concept level FS, the process is staged to complete dredging to the CAD as described in Section 7.6.3. Details of the conceptual CAD design are provided on Figure 7-50. Site mobilization and preparation includes securing the onshore property area for equipment staging, sand purchase, long-term operation and maintenance, an offshore docking facility for the mechanical dredge, and winterizing equipment each year.

The CAD site will be constructed by excavating an in-water cavity approximately 3 to 5 meters deep using either mechanical or hydraulic dredges. Contaminated sediment will be placed in the deep water cavity using either split-hull bottom barges or pipelines. After placement, the CAD site will be capped with 3 feet of clean sand (included in construction costs). Capping requires six barges, four tugboats, and a shore-based source of sand within 20 miles of the CAD site.

CAD construction is estimated at $358,700,000 and $54,600,000 for action levels of 500 and 5,000 ppb, respectively. These estimates include CAD closure and long-term operation and maintenance costs.

Sediment Removal. Sediment removal will be conducted using seven 12-cy closed, clamshell buckets requiring 8 years for 500 ppb and 1.1 years for 5,000 ppb action levels. Two additional years will be required for cap placement over the disposal site. Dredged sediment will be transferred from the mechanical buckets directly to 24 dump barges and eight tugboats and barged to the disposal site. Sediment removal time frame and costs are similar to those described for Alternative D for Zone 2.

Sediment Dewatering. All dewatering will be conducted on-barge. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and managed. Sediment dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Overflow return water from the barges would be treated before discharge to the bay. Monitoring requirements are expected to be similar to those specified for Alternative C.

Water treatment costs for Alternative G are estimated at $1,200,000 and $700,000 for action levels of 500 and 5,000 ppb, respectively.

Sediment Disposal. No off-site disposal of sediments is anticipated for this alternative. Sediments will be placed into on-site CAD facilities. Disposal costs are included in the CAD construction and dredging costs.

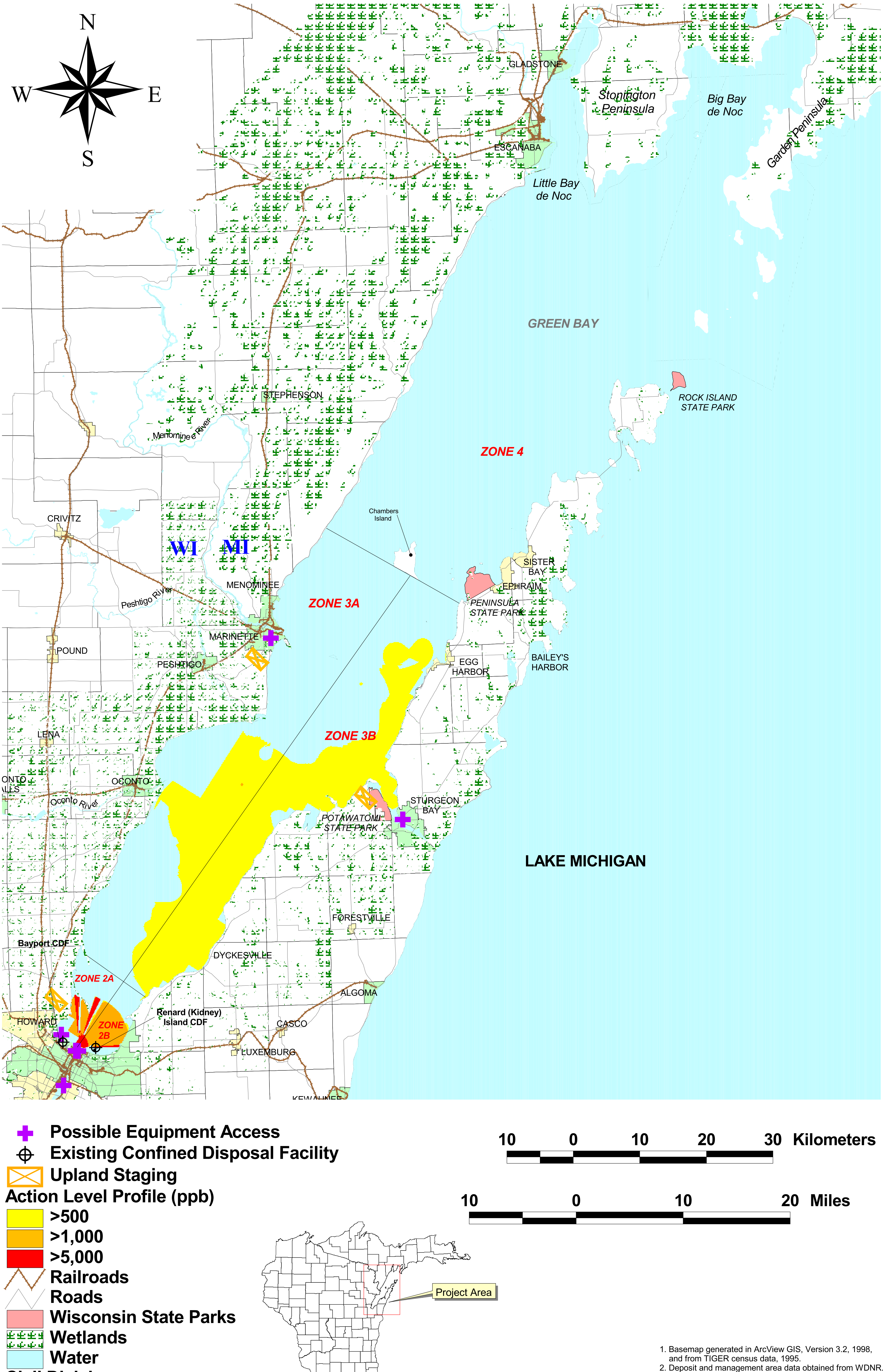
Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CAD would be finished with a 3-foot cap of clean soils to isolate the contaminated sediments. Demobilization and site restoration costs are included under CAD construction and dredging estimates.

Institutional Controls and Monitoring. To ensure that the CAD site is functioning as designed, surface and subsurface sediment sampling will be conducted to address potential upward chemical migration through the cap and structural integrity of the containment structure. Sampling will be conducted at 3- to 5-year intervals, with decreasing intervals over time, if warranted. The actual number of sampling locations will depend upon the actual configuration and size of the CAD site. To verify achievement of the project RAOs, selected elements of the *Long-term Monitoring Plan* (Appendix C) will also be implemented.

The estimated cost for institutional controls and advisory monitoring is $4,500,000. Long-term operation and maintenance monitoring is included in the CAD construction costs and long-term remedy monitoring of Green Bay is included in Alternative B.

7.6.5 Section 7.6 Figures and Tables

Figures and tables for Section 7.6 follow this page and include:



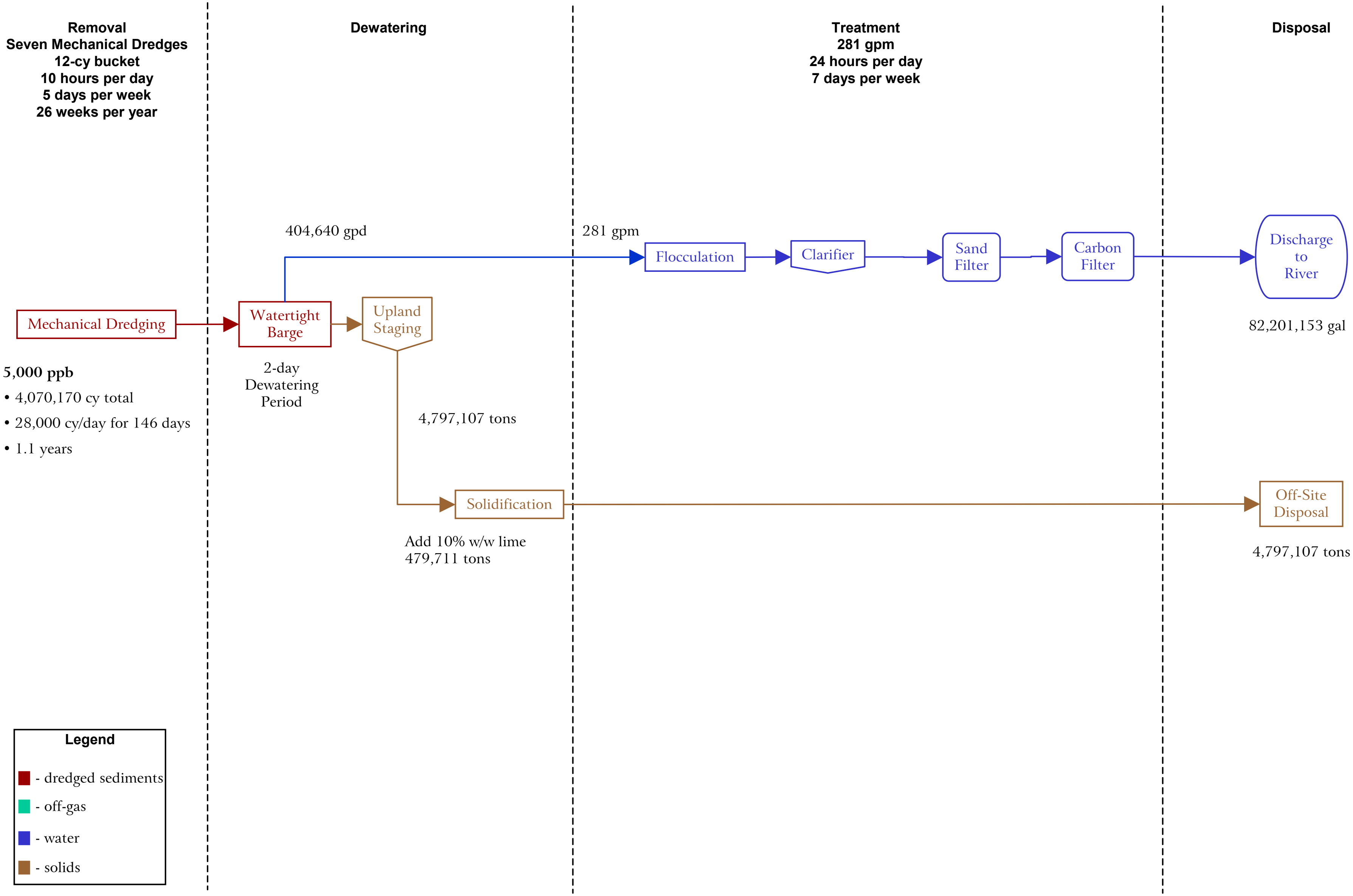
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR. and are included in the Fox River database.
3. Action level profiles for PCBs considered for all depth layers up to >30 cm for Green Bay.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Sediment Management Area Overview: Green Bay	REFERENCE NO: FS-14414-535-7-42
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-49	APPROVED: AGF

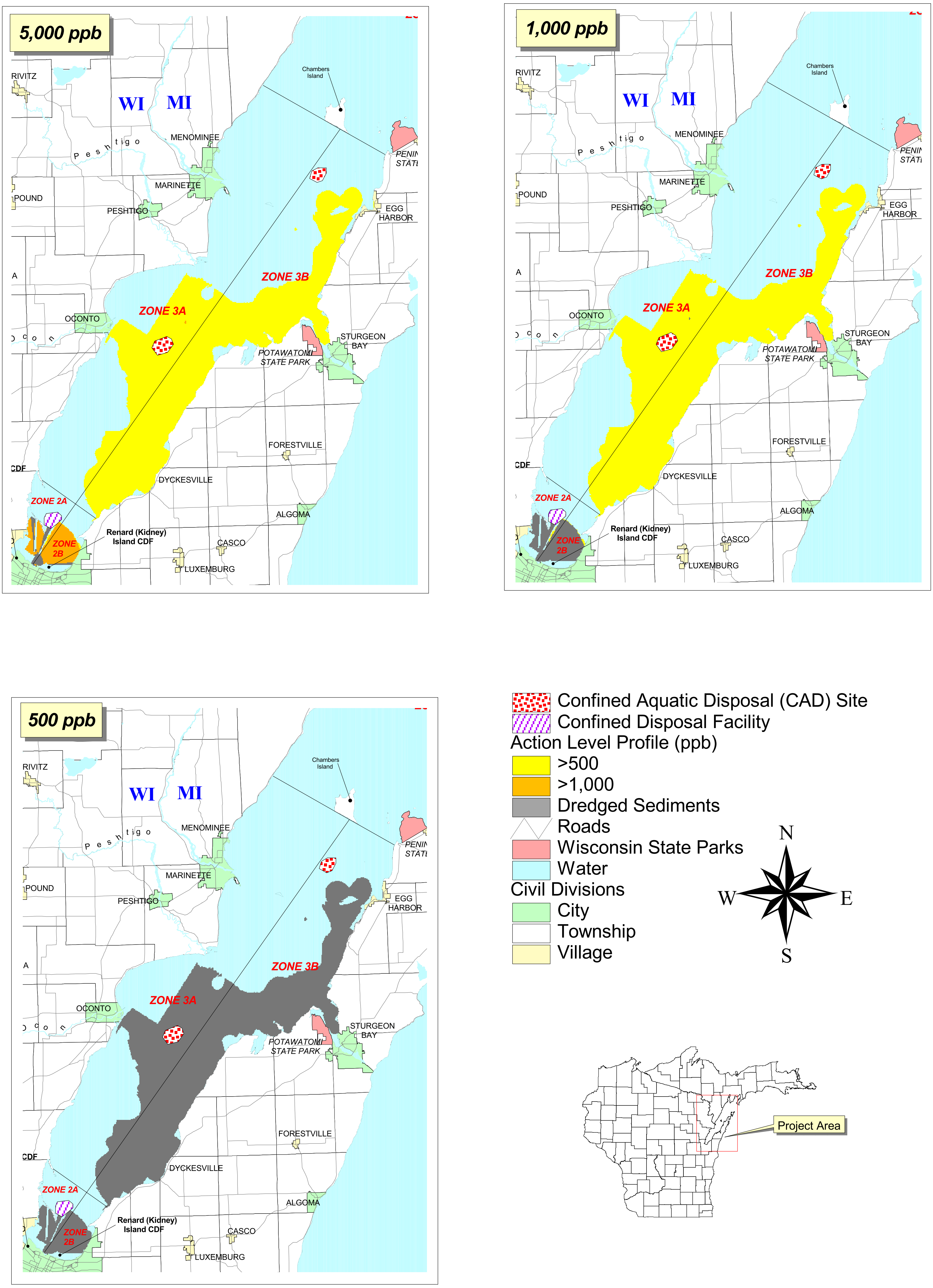
Figure 7-50 Preliminary Concept Design for the Green Bay Confined Disposal Facility - Cat Island Chain

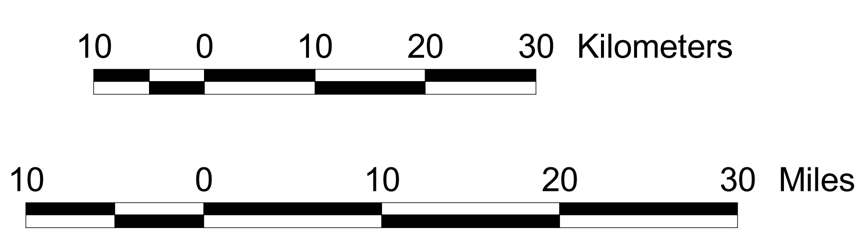
F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\FIGURE 7-50.PDF

Figure 7-51 Process Flow Diagram for Green Bay Zone 2 - Alternative C: Dredge Sediment and Off-site Disposal



F:\PROJECTS\DOCS\4414\DOC\FS\FINAL\FIGURES\SEC7\SEC7FIGSL.PPT





1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER census data, 1995.
2. Deposit and management area data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Alternatives C, D, and G; Zones 2 and 3 Green Bay	REFERENCE NO: FS14414-535-7-45
				CREATED BY: SCJ
				PRINT DATE: 3/13/01
			FIGURE 7-52	APPROVED: GH

Figure 7-53 Process Flow Diagram for Green Bay Zone 2 - Alternatives D and G: Dredge Sediment to CDF/CAD

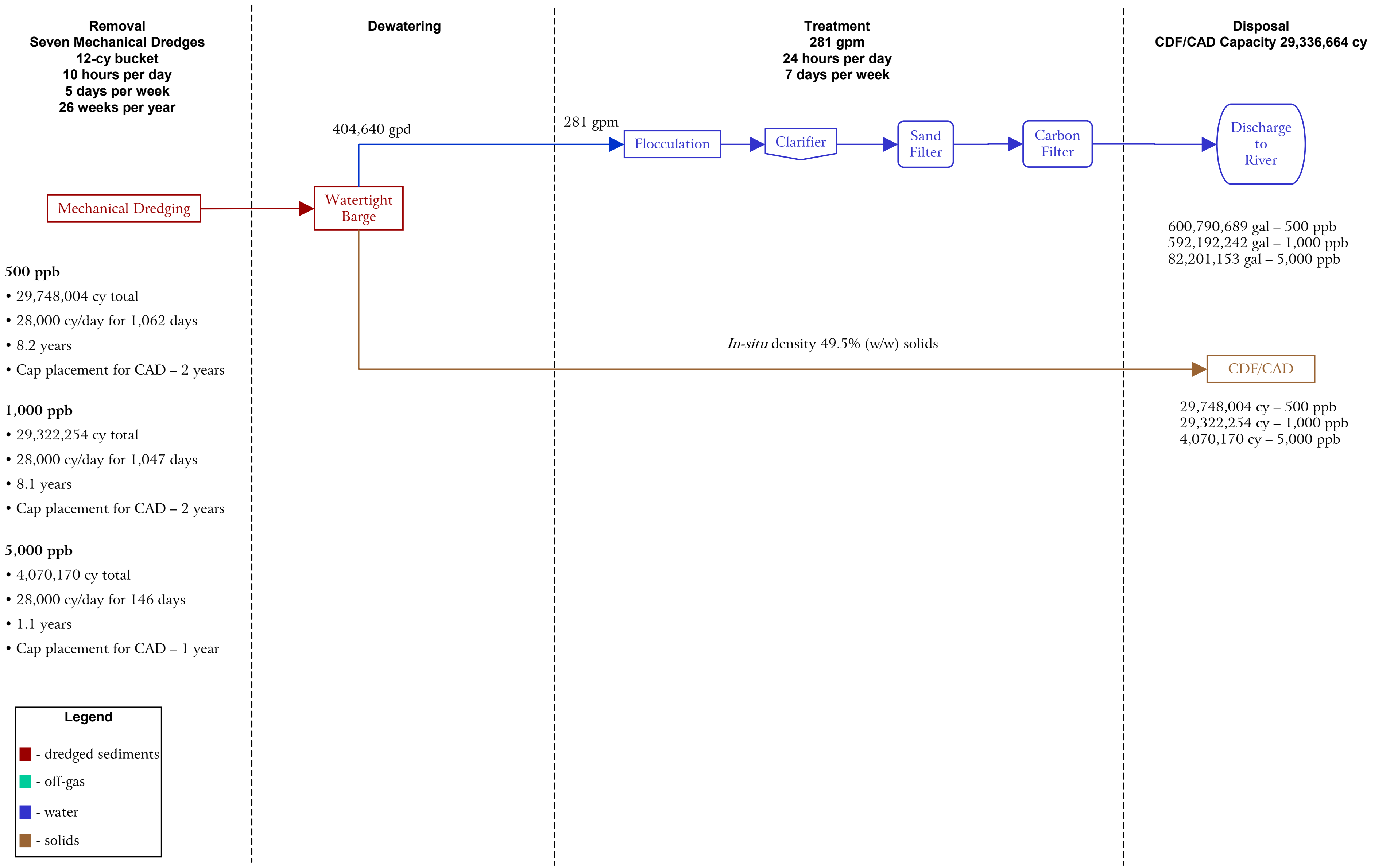


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Table 7-9 Cost Summary for Remedial Alternatives - Green Bay Zone 2

500 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	29,748,004	$327,500,000	$1,200,000	---	$476,000,000	$15,500,000	---	$4,500,000	$824,700,000	$164,940,000	$989,640,000
G	29,748,004	$327,500,000	$1,200,000	$358,700,000	---	$15,500,000	---	$4,500,000	$707,400,000	$141,480,000	$848,880,000

1,000 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	29,322,254	$322,900,000	$1,200,000	---	$470,000,000	$15,500,000	---	$4,500,000	$814,100,000	$162,820,000	$976,920,000
G	29,322,254	$322,900,000	$1,200,000	$353,700,000	---	$15,500,000	---	$4,500,000	$697,800,000	$139,560,000	$837,360,000

5,000 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	4,070,170	$48,700,000	$700,000	---	---	$15,500,000	$437,800,000	$4,500,000	$507,200,000	$101,440,000	$608,640,000
D	4,070,170	$48,700,000	$700,000	---	$97,100,000	$15,500,000	---	$4,500,000	$166,500,000	$33,300,000	$199,800,000
G	4,070,170	$48,700,000	$700,000	$54,600,000	---	$15,500,000	---	$4,500,000	$124,000,000	$24,800,000	$148,800,000

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7.7 Green Bay Zone 3A

An overview of the Green Bay zones and PCB-impacted sediments is shown on Figure 7-49. The retained alternatives and associated costs are presented in Table 7-10.

7.7.1 General Site Characteristics

Zone 3 extends from the east-west line marking the northern boundary of Zone 2 to a line just below Chambers Island. Using the mouth of the Lower Fox River as a reference point, Zone 3 starts about 7.6 miles north of the mouth and ends 53.9 miles north of the mouth at Chambers Island (46.3 miles long). Zone 3 is further divided into "east" and "west" segments by a line trending northeast connecting the mouth of the Lower Fox River through Chambers Island. Zone 3A is located on the west side of this line while Zone 3B is located on the east side of this line.

The depth of water in this zone is generally greater than 30 feet deep and ranges from about 41 feet at the boundary between zones 2 and 3 to 110 feet just west of Chambers Island, near the boundary between zones 3 and 4. In this zone, there are four shallow shoals located along the west side and two areas where shallow water extends for a distance into the east side of the bay.

The nature and extent of PCB-impacted sediment in this zone, as summarized in the RI, includes the following:

- Maximum detected concentration - 1,017 μg/kg (avg. 322 μg/kg),
- Total PCB mass - 19,156 kg,
- Total PCB-impacted volume - 211,700 000 m^3, and
- Maximum PCB sample depth - 30 to 50 cm depth.

These quantities represent the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section are likely larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

7.7.2 Selected Remedial Alternatives

This section defines the remedial alternatives for Green Bay Zone 3A and then describes the technologies that will be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for Green Bay Zone 3A include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

C. Remove all sediment with PCB concentrations greater than the selected action level and dispose of dredged sediment in an existing NR 500 commercial disposal facility.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

G. Remove sediments with PCB concentrations greater than the selected action level and place in an on-site CAD facility.

Alternatives E and F were not retained for this zone because bathymetry, water currents, and the quantity of contaminated sediment preclude cost-effective construction of an *in-situ* cap or thermal treatment. The process options that can be applied to the remedial alternatives are described below.

7.7.3 Description of Process Options

Monitoring

Monitoring of physical, chemical, and biological media is applicable for Alternatives B, C, D, and G. The no action alternative may also require monitoring of fish tissue for maintenance of pre-existing fish consumption advisories. As discussed in the technology screening process, monitoring is grouped into five categories: 1) baseline monitoring prior to remediation to establish baseline conditions for future comparisons, 2) monitoring during implementation, 3) post-verification monitoring to verify completion of a remedy, 4) long-term construction monitoring of containment facilities and sediment caps to verify continued source control and physical integrity, and 5) long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs. Numerous reference documents confirmed the necessity of a well-developed monitoring plan in order to verify the success of an implemented remedy, to measure the effectiveness and stability of source control measures, and to verify the achievement of project RAOs (EPA, 1998a, 1994a; SMWG, 1999; IJC, 1997; Krantzberg *et al.*, 1999). The following references were used in this FS Report to assess the types and applicability of monitoring options commonly used on sediment remediation projects:

- Ecology, *Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);
- USACE, *Monitoring Considerations for Capping* (USACE, 1992);
- EPA and USACE, *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- USACE, *Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites* (Fredette *et al.*, 1990);
- *Guidance for Subaqueous Dredged Material Capping* (Palermo, 1995);
- *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1: Fish Sampling and Analysis* (EPA, 1995a);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994a);
- *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b); and
- Sediment remediation case study projects presented in Appendices B and C of the FS.

Specific monitoring programs will be developed for each remedial alternative and will likely include physical, chemical, and biological monitoring components. Baseline monitoring generally includes water, sediment, and tissue quality sampling. Monitoring during implementation includes air and surface water sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the remediation project. Source control monitoring includes groundwater and surface sediment sampling around the containment facility to confirm proper maintenance, stability, and chemical isolation. Long-term monitoring focuses primarily on fish, bird, and invertebrate tissue sampling and reproductive assessments, but also includes sediment and water sampling for chemical quality. The proposed *Long-term Monitoring Plan* for the Lower Fox River and Green Bay remediation project is presented in Appendix C.

Institutional Controls

Institutional controls appropriate to Green Bay Zone 3A include:

- Maintenance of the fish consumption advisory;
- A moratorium on any future dredging within the navigation channel;
- Deed restrictions on any in-water activities that could result in sediment disturbance (e.g., marina construction or over-water development);
- Access restrictions to contaminated areas; and
- A long-term (40-year) monitoring program for sediments, water, bird, and fish PCB, DDE, and mercury levels.

Implementation of these institutional controls will likely require an active public education program for the fish, waterfowl, and domestic water advisories. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Access and use restrictions would also apply to local Indian tribes. Finally, federal action may be necessary on any dredging moratoriums within the federal navigation channel.

Removal Process Options

Sediment removal is identified for Alternatives C, D, and G. Remediation area boundaries and sediment management areas are shown on Figure 7-49. For Green Bay, mechanical dredging is more practicable because water depth is adequate and water treatment volumes are minimized. Mechanical dredging significantly reduces the water management needs, and reduced water management is necessary due to the limited upland space availability.

A 12-cy Cable Arm™ bucket has been selected for the remedial alternatives identified in this reach. The operating assumption is that dredging will occur only during normal daylight hours (10 hours per day) during a normal work week (5 days per week). In industrial areas, dredging may occur 24 hours per day and 6 days per week; however, this option was not included in the FS. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D) (Appendix B).

Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and curtain design; and therefore may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream (Foth and Van Dyke, 2000). However, for the purposes of this FS, silt curtains were included in the removal costs.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For all mechanical dredging alternatives, it is proposed that dewatering be conducted on-barge and in upland staging areas. Dewatering has been configured as a two-step process using gravity settling followed by solidification of solids.

Passive Dewatering. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and collected. Sediment will then be transferred into one of three asphalt-paved upland staging areas for additional dewatering, solidification, and loading into trucks for off-site shipment. These upland staging areas will each be approximately 0.5 acre in size, surrounded with a 6-inch curb, and graded to a water collection sump. All water collected from the barges and the upland staging area will be treated using flocculation, clarification, and sand filtration prior to discharge back to the river. The upland staging areas may be located at the Bayport facility near the mouth of the Lower Fox River or at other locations that have yet to be determined.

For the dredge to CDF alternative (Alternative D), dewatering will occur directly within the CDF. Decant water for this alternative will be treated and returned to the bay.

These proposed dewatering systems will meet the criteria defined in Section 6 of this FS Report, in terms of production rate, effectiveness, practicality, and discharge water quality. Final selection of the dewatering process will be determined during the remedial design phase.

Solidification. The solids content after mechanical dredging and dewatering is assumed to be about 50 percent (w/w) or similar to *in-situ* density, based on *in-situ* solids content from the RI Report (RETEC, 2002a). This dewatered sediment may still be difficult to manage due to the high moisture content. Prior to any off-site shipment, the sediment would be solidified to improve handling and to satisfy requirements for solid waste hauling on public roads and disposal, if necessary. It was assumed that solidification was necessary, and that the sediment would be solidified with the addition of cement, lime, pozzolan, or other appropriate reagents. For FS cost estimating purposes, 10 percent (w/w) lime was added as the reagent based on its successful use during the SMU 56/57 demonstration project (Montgomery-Watson, 1998, 2000). The sediment will be mixed with the reagent and loaded into trucks using standard earthmoving equipment. If the contractor prefers, sediment may be mixed with the reagent in a pug mill as shown on Figures 7-1 and 7-5. Numerous other cost-effective reagents are available that may be tested and used for implementation of a remedial action.

Treatment Process Options

Water Treatment. Prior to water discharge back to the bay, supernatant water would pass through flocculation, clarification, and sand filtration systems. Based on the acceptable performance of the sand filter unit during the Deposit N demonstration project, no additional water treatment is deemed necessary (Foth and Van Dyke, 2000). However, additional carbon (GAC) treatment may be added to the treatment train during removal operations if effluent water quality criteria is exceeded. The estimated unit cost for GAC carbon treatment is $0.40 per thousand gallons of water treated.

On-site Disposal Process Options

The CDF currently proposed for Green Bay is a cellular cofferdam located near the Cat Island chain. The CDF size was varied with each action level to accommodate the total volume of dredged sediment. The new Green Bay CDF will be constructed as three separate islands in accordance with the design proposed by the USACE (USACE, 1999) to encourage natural resedimentation and restoration around the structures. Several in-water and upland CDF sites were proposed in a 1985 Environmental Impact Study (USACE, 1985) for Green Bay Harbor, but most were eliminated from further consideration because of environmental concerns by the USFWS (as cited in USACE, 1985). Only the Cat Island restoration area and Kidney Island expansion were retained for further consideration.

The newly constructed free-standing CDF structures will be closed with a 3-foot sand cap and riprap placed around the edges to provide additional protection from storm events. The final construction will also include habitat areas for shallow submerged and emergent vegetation as shown on the proposed conceptual design (Figure 7-50). While the top layer is not designed to be an impermeable cap, selection of appropriate plant species will be considered (i.e., shallow roots) to ensure physical integrity of the cap.

The Renard Island CDF, located near the mouth of the Lower Fox River, is a 55-acre diked impoundment with a design capacity of 1,200,000 cy. The facility consists of a kidney-shaped stone dike with an interior steel sheet pile cutoff wall to prevent seepage to surrounding surface waters (USACE, 1985). The CDF reached capacity after receiving a deposit of dredged sediment in 1996. Construction costs include final closure of the Renard Island CDF in addition to constructing a new CDF. Closure of Renard Island will include placement of a 3-foot-thick clean soil cap, seeding, mitigation, and long-term monitoring for 40 years.

Within Green Bay, three potential CAD sites were identified. The CAD was sized for each action level to accommodate the total volume of dredged sediment. CAD site locations were selected in areas with adequate water depths (25-meter depth) and low bottom surface water velocities. Ideal locations for CAD sites are in "null-zones" where circulation patterns create areas with net deposition, instead of erosion and scour. These areas were selected from the HydroQual vector diagrams presented in Section 2 (Figures 2-11 and 2-12). Contaminated sediment will be excavated by mechanical dredging, transferred to a haul barge and placed in the CAD site by either split-hull bottom dump or pumped in via pipeline if finer-scale placement is required.

Off-site Disposal Process Options

Total PCB concentrations in sediment within this zone are below 50 ppm, therefore none of the sediment is considered TSCA-level material. All sediment could be disposed of at landfills which conform to the NR 500 WAC requirements. Local landfill options and unit costs were defined in Section 6.5.5 of this FS Report.

Capping Process Options

No capping is proposed for Green Bay because bottom water currents, storm events, vessel traffic, maintenance of navigational channels, and potential ice scour preclude effective placement and long-term integrity.

7.7.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for Green Bay Zone 3A. Each remedial alternative includes a description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth include a line item for 20 percent contingency costs (Table 7-10). Details used to develop each cost estimate are provided in Appendix H.

The following components are discussed, when applicable, within the development of each alternative:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for Green Bay Zone 3A. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management of remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until RAOs are achieved. This alternative includes fish tissue sampling every 5 years for 40 years for maintenance of fish consumption advisories already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources, and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for long-term monitoring and maintenance of institutional controls is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative C: Dredge and Dispose of Sediment in Off-site Landfill

Alternative C includes the removal of sediments above the remedial action level using multiple mechanical dredges and off-site disposal of the sediments. Costs for Alternative C were developed only for the 1,000 ppb action level because volumes for the 500 ppb action level are too large to consider off-site disposal and sediments were not measured above the 5,000 ppb action level. Figure 7-54 provides the process flow diagram for this remedial alternative, while Figure 7-52 illustrates the extent of residual contamination following implementation of Alternative C. The summary costs to implement Alternative C are provided in Table 7-10. The total volume of sediment to be dredged in this alternative is 14,410 cy.

Site Mobilization and Preparation. Staging for the dredging of sediments will be conducted at the Bayport facility. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing areas for sediment staging, water treatment, sediment solidification, and truck loading. It is assumed that docking facilities for the mechanical dredge and barges already exist at these locations. Purchase and property preparation are included in the dredging costs.

Sediment Removal. Due to the limited upland space available for water management purposes, all sediment removal will be done with a mechanical dredge. Sediment removal will be conducted using seven 12-cy closed, clamshell buckets that require about 0.6 day to complete, given the volumes and operation assumptions presented in Section 7.7.3. While it would be more practical to use fewer dredges and extend the dredging time, the seven-dredge approach provides consistency and relative comparability with the other Green Bay zones. During the remedial design phase, fewer dredges may be selected. Removal requires a staging area for the mechanically-dredged sediments to be offloaded and transported off site. The cost for constructing the upland staging area is included in dewatering and disposal. Silt curtains around the dredging area may be included to minimize sediment resuspension downstream of the dredging operation and were included in the cost tables for $35,000. Buoys and other waterway markers would be installed around the perimeter of the work area to prevent entry of unauthorized boats within the removal work zone. Other capital items included in the sediment removal costs are barge rental and movement, construction of upland staging areas, water quality monitoring, post-removal sediment bathymetric surveys to ensure achievement of the removal action, and site restoration at the conclusion of operations.

Sediment removal costs are estimated to be $4,600,000 for the 1,000 ppb action level.

Sediment Dewatering. All dewatering will be conducted on-barge and in upland staging areas. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges to upland staging areas. Sediment will then be transferred onto an asphalt-paved upland staging area where any free water will be collected. It is assumed that the sediment would require solidification with 10 percent (w/w) lime to satisfy hauling and disposal requirements (included in disposal costs). Sediment dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Water treatment includes purchase of equipment and materials for flocculation, clarification, and sand filtration. Water treatment would be conducted 24 hours per day, 7 days per week during the dredging season. Discharge water is estimated at 411,840 gallons per day. Daily discharge water quality monitoring is included in the cost estimate. Treated water would be sampled and analyzed to verify compliance with the appropriate discharge requirements prior to discharge back to the river. It may be necessary to add carbon filtration to the treatment train if effluent criteria are not met. Carbon filtration could be added for a unit cost of $0.40 per thousand gallons of water treated. Water treatment costs also include pad and equipment demobilization and site restoration.

Water treatment costs are estimated to be $600,000 for the 1,000 ppb action level.

Sediment Disposal. Sediment disposal includes the loading and transportation of the sediment to a facility listed in Table 6-6. The sediments would be loaded into tractor-trailer end dumps with bed liners or sealed gates with a front-end loader. Each load would be manifested and weighed. Prior to leaving the staging area, each tractor-trailer would pass through a wheel wash to prevent tracking soil onto nearby streets and highways. After unloading at the designated disposal facility, each tractor-trailer would pass through a wheel wash and return to the staging area for another load.

The estimated percent solids of dewatered sediment after passive dewatering is expected to equal the *in-situ* percent solids of material prior to mechanical dredging, which is 14.4 percent (w/w) (Appendix of RI Report, RETEC, 2002a). After solidification with 10 percent lime (w/w), the material is estimated to have 60 percent solids content (Montgomery-Watson, 1998). Solidification costs for the 1,000 ppb action level are $449,000 (24 percent of cost is for the purchase of lime).

Costs of sediment solidification and disposal at an existing NR 500 commercial disposal facility are estimated to be $1,300,000 for the 1,000 ppb action level.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. All work pads and other permanent structures would be removed and the site would be graded to its original condition. Vegetated areas would be replanted to a state similar to that of the pre-construction. Demobilization and restoration costs are included within the above dredging, dewatering, and treatment estimates.

Institutional Controls and Monitoring. Baseline monitoring includes primarily water, sediment, and tissue sampling during pre- and post-remedial sampling events. Monitoring during implementation includes surface water and limited air sampling to assess downstream and off-site transport of contaminants. Verification monitoring includes surface and possibly subsurface sediment sampling to ensure compliance with the target goals of the project. Long-term monitoring includes surface water, surface sediment, and biological tissue sampling to determine residual risks and impacts over time. If residual risks remain in the sediment above the risk-based SQTs after remediation, then the long-term monitoring plan described in the MNR alternative will be followed (i.e., media, frequency, location, duration) until the project RAOs are achieved or until a policy decision is made. The proposed *Long-term Monitoring Plan* (LTMP) is detailed in Appendix C. Elements of the LTMP may be implemented for each action level regardless of the remedial outcome in order to verify achievement of the RAOs. The sampling program may continue indefinitely under this process option, but for the purposes of the FS it has been estimated at 40 years.

The estimated cost for the maintenance of institutional controls and advisory monitoring is $4,500,000. Implementation monitoring during active dredging is included in the dredging costs. Long-term remedy monitoring of Green Bay to assess achievement of project RAOs are included in Alternative B - Monitored Natural Recovery.

Alternative D: Dredge Sediment to Confined Disposal Facility

Alternative D includes removal of sediments to an on-site cellular cofferdam CDF for long-term disposal of the materials. Costs for this alternative were developed for the 500 ppb action level only. It did not seem prudent to construct a CDF for the small volume of sediments above the 1,000 ppb action level, and no sediments were measured above the 5,000 ppb action level. The cellular cofferdam CDF location is identified on Figure 7-52.

Figure 7-55 provides the process flow diagram for this remedial alternative. Table 7-10 contains the summary costs to implement Alternative D. The total volume of sediment to be dredged in this alternative is 16,328,102 cy.

Site Mobilization and CDF Construction. For the concept level FS, the process is staged to construct and complete dredging to the cellular cofferdam CDF described in Section 7.7.3. Site mobilization and preparation includes securing the onshore property area for equipment staging, water treatment, and an offshore docking facility for the mechanical dredge.

CDF construction is estimated at $285,000,000, which includes operation and maintenance costs for 40 years.

Sediment Removal. Mechanical sediment removal techniques for this alternative are equivalent to those described for Alternative C. The removal time frame using seven 12-cy closed clamshell buckets is 4.5 years.

Sediment removal costs are estimated at $181,800,000 for the 500 ppb action level.

Sediment Dewatering. All dewatering will be conducted on-barge and in the CDF. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and managed. Sediment dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Overflow return water from the barges and CDF would be treated before discharge to the bay. Treatment and monitoring requirements are expected to be similar to those specified for Alternative C.

Water treatment costs for Alternative D are estimated at $3,000,000.

Sediment Disposal. No off-site sediment disposal is anticipated for this alternative. Sediments will be placed directly into the CDF and placement costs are included in the dredging and construction costs. Percent solids content is expected to be the same as *in-situ* percent solids prior to dredging. No solidification costs were added.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDF would be finished with a 3-foot cap of clean soils to isolate the contaminated sediments. However, this alternative would allow for development of these newly-created upland habitat features. Demobilization and site restoration costs are included under the dredging estimates.

Institutional Controls and Monitoring. To ensure that the CDF is functioning as designed, near-site sediment and water sampling would be conducted on an annual basis. The monitoring program will be conducted over a period of 40 years.

The estimated cost for institutional controls is $4,500,000. Long-term operation and maintenance monitoring of the CDF is included in the CDF construction costs. Long-term monitoring of Green Bay to verify achievement of the project RAOs is included in Alternative B - Monitored Natural Recovery.

Alternative G: Dredge Sediment to Confined Aquatic Disposal

Alternative G includes removal of sediments to a CAD facility for long-term disposal of the materials. Costs for this alternative were developed for the 500 ppb action level only. It did not seem prudent to construct a CAD site for the small volume of sediment above the 1,000 ppb action level, and no sediments were measured above the 5,000 ppb action level. The proposed CAD location is identified on Figure 7-52.

Figure 7-55 provides the process flow diagram for this remedial alternative. Table 7-10 contains the summary costs to implement Alternative G. The total volume of sediment to be dredged in this alternative is 16,328,102 cy for the 500 ppb action level.

Site Mobilization and CAD Construction. For the concept level FS, the process is staged to complete dredging to the CAD as described in Section 7.7.3. Details of the conceptual CAD design are provided on Figure 6-7. Site mobilization and preparation includes securing the onshore property area for equipment staging, purchase of sand, long-term operation and maintenance, an offshore docking facility for the mechanical dredge, and winterizing equipment each year.

The CAD site will be constructed by excavating an in-water cavity approximately 3 to 5 meters deep using either mechanical or hydraulic dredges. Contaminated sediment will be placed in the deep water cavity using either split-hull bottom barges or pipelines. After placement, the CAD site will be capped with 3 feet of clean sand (included in construction costs). Capping requires six barges, four tugboats, and a shore-based source of sand within 20 miles of the CAD site.

CAD construction is estimated at $199,800,000 for the 500 ppb action level, which includes CAD closure and long-term operation and maintenance costs.

Sediment Removal. Sediment removal will be conducted using seven 12-cy closed, mechanical buckets requiring 4.5 years at the 500 ppb action level. Two additional years will be required for cap placement (included in CAD construction costs). Dredged sediment will be transferred directly from mechanical dredges to 24 bottom-dump barges and eight tugboats for direct transfer to the disposal site. Sediment removal time frame and costs are similar to those described for Alternative D.

Sediment Dewatering. All dewatering will be conducted on-barge. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and managed. Sediment dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Overflow return water from the barges would be treated before discharge to the bay. Treatment and monitoring requirements are expected to be similar to those specified for Alternative C.

Water treatment costs for Alternative G are estimated at $3,000,000 for the 500 ppb action level.

Sediment Disposal. On-site disposal costs are included in the CAD construction and dredging costs. Percent solids content of dewatered sediments at the time of disposal are expected to be the same as *in-situ* percent solids prior to mechanical dredging, and no solidification costs are included.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CAD would be finished with a 3-foot cap of clean soils to isolate the contaminated sediments. Demobilization and site restoration costs are included under the dredging and construction estimates.

Institutional Controls and Monitoring. To ensure that the CAD site is functioning as designed, surface and subsurface sediment sampling will be conducted to address potential upward chemical migration through the cap and structural integrity of the containment structure. Sampling will be conducted at 3- to 5-year intervals, with decreasing intervals over time, if warranted. The actual number of sampling locations will depend upon the actual configuration and size of the CAD site. To verify achievement of the project RAOs, selected elements of the *Long-term Monitoring Plan* (Appendix C) will also be implemented.

The estimated cost for institutional controls is $4,500,000. Long-term operation and maintenance monitoring of the CAD site (approximately $6 million) is included in the CAD construction costs. Implementation monitoring during dredging is incorporated into the removal costs. Long-term remedy monitoring of Green Bay to verify achievement of the project RAOs is included in Alternative B - Monitored Natural Recovery.

7.7.5 Section 7.7 Figures and Tables

Figures and tables for Section 7.7 follow this page and include:

Figure 7-54 Process Flow Diagram for Green Bay Zone 3A - Alternative C: Dredge Sediment and Off-site Disposal

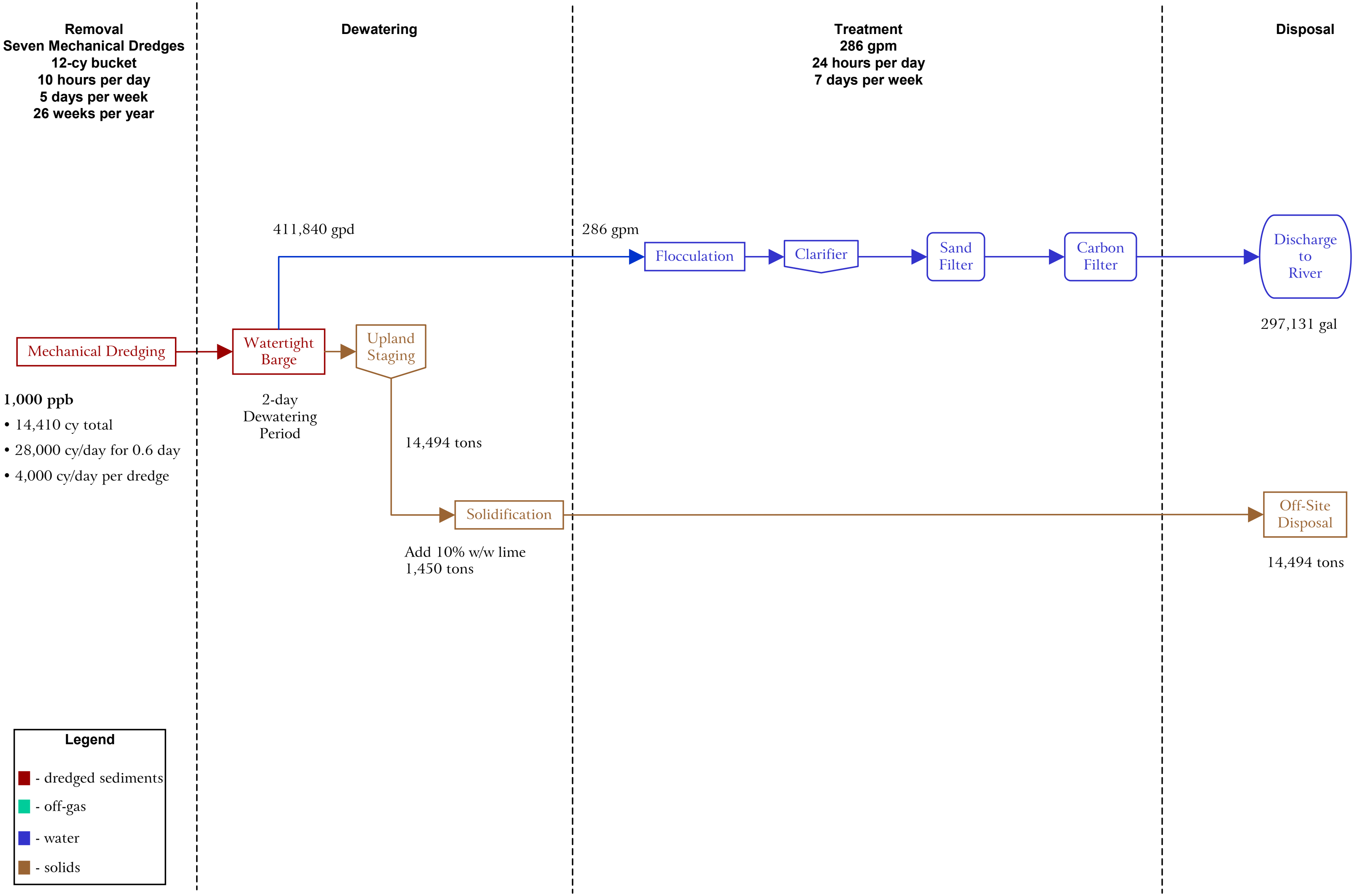

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Figure 7-55 Process Flow Diagram for Green Bay Zone 3A - Alternatives D and G: Dredge Sediment to CDF/CAD

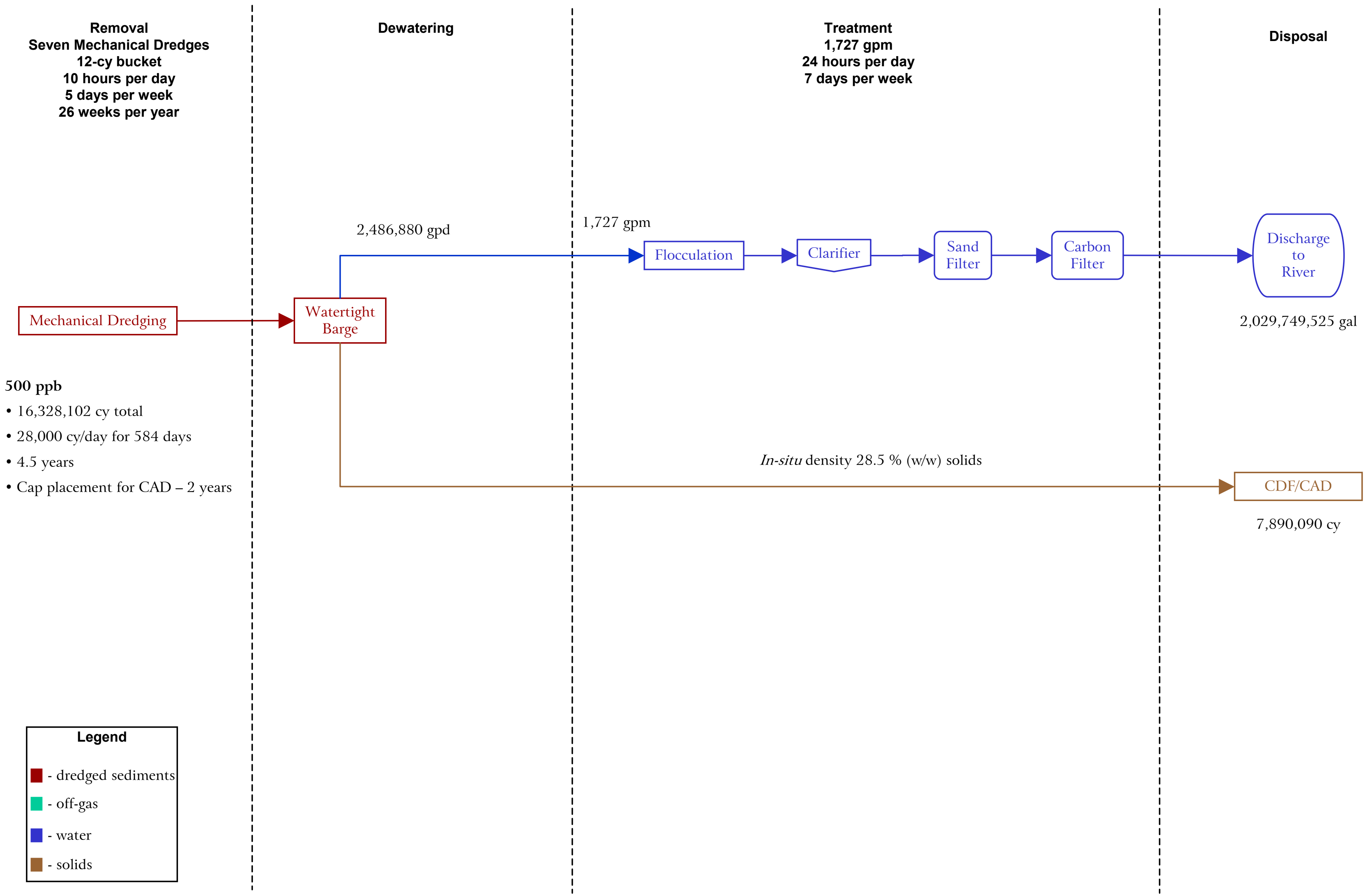

Table 7-10 Cost Summary for Remedial Alternatives - Green Bay Zone 3A

500 ppb [1]

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	16,328,102	---	$181,800,000	---	$3,000,000	---	$285,000,000	---	$4,500,000	$474,300,000	$94,860,000	$569,160,000
G	16,328,102	---	$181,800,000	---	$3,000,000	$199,800,000	---	---	$4,500,000	$389,100,000	$77,820,000	$466,920,000

1,000 ppb [1]

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	14,410	---	$4,600,000	---	$600,000	---	---	$1,300,000	$4,500,000	$11,000,000	$2,200,000	$13,200,000

Note:

[1] No sediments measured above 5,000 ppb in this zone.

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7.8 Green Bay Zone 3B

An overview of the Green Bay zones and PCB-impacted sediments is shown on Figure 7-49. The retained alternatives and associated costs for Zone 3B are presented in Table 7-11.

7.8.1 General Site Characteristics

General site characteristics for Zone 3B are the same as those described for Green Bay Zone 3A in Section 7.7.1. The only action level for this zone is 500 ppb. The nature and extent of PCB-impacted sediment in this zone, as summarized in the RI, includes the following:

- Maximum detected concentration - 1,302 μg/kg (avg. 448 μg/kg),
- Total PCB mass - 16,823 kg,
- Total PCB-impacted volume - 224,469,000 m^3, and
- Maximum PCB sample depth - 30 to 50 cm depth.

These quantities represent the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section will likely be larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

7.8.2 Selected Remedial Alternatives

This section defines the remedial alternatives for Green Bay Zone 3B and then describes the technologies that will be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for Green Bay Zone 3B include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

D. Remove sediment with PCB concentrations exceeding the selected action level and place non-TSCA sediments in an on-site nearshore CDF. Transport TSCA sediments (greater than 50 ppm PCBs) to an existing NR 500 commercial disposal facility.

G. Remove sediment with PCB concentrations greater than the selected action level and place in an on-site CAD facility.

Alternatives C, E and F were not retained for this zone because bathymetry, water currents, ice scour limitations, and the quantity of contaminated sediment preclude cost-effective construction of an *in-situ* cap, thermal treatment, or off-site disposal. The process options that can be applied to the remedial alternatives are described below.

7.8.3 Description of Process Options

Monitoring

Short-term and long-term monitoring options in this reach are the same as those described previously for the Lower Fox River reaches and Green Bay zones.

Institutional Controls

Institutional controls in this zone are the same as those described previously for Green Bay zones 2 and 3A.

Removal Process Options

Sediment removal is identified for Alternatives D through G. Remediation area boundaries and sediment management areas are shown on Figure 7-49. For Green Bay, mechanical dredging is more practicable because water depth is adequate and water treatment volumes are minimized. Mechanical dredging significantly reduces the water management needs, and reduced water management is necessary due to the limited upland space availability.

A 12-cy Cable Arm™ bucket has been selected for the remedial alternatives identified in this reach. The operating assumption is that dredging will occur only during normal daylight hours (12 hours per day) during a normal work week (5 days per week). In industrial areas, dredging may occur 24 hours per day and 6 days per week; however, this option was not included in the FS. Winter weather conditions are likely to preclude operations; as a result, dredging is assumed to occur only between April and October (26 weeks per year) when the average minimum temperature is above freezing.

Containment Systems. In-water containment systems placed around the dredging area are commonly implemented on both mechanical and hydraulic dredging projects to minimize sediment resuspension downstream of the dredging operation. Typical containment barrier systems range from expensive sheet pile walls (i.e., GM Foundry, Bayou Bonfouca), to silt curtains (i.e., West Eagle Harbor, Bayou Bonfouca, River Raisin), and inexpensive oil booms (PSNS Pier D). Silt curtains are the most commonly used containment device for lakes, rivers, and estuaries, but are prone to disturbance from passing ships, strong winds, and currents. Effectiveness of silt curtains depends upon local site conditions, bottom substrate, and design, and may not be applicable for every site. Silt curtains were used at both the Lower Fox River demonstration projects. Based on the successful performance of the dredging operations and curtains at Deposit N, use of silt curtains was discontinued during the second removal phase with minimal water quality exceedances measured downstream (Foth and Van Dyke, 2000). However, for the purposes of this FS, silt curtains were included in the removal costs despite the site performance during the Deposit N project.

Over-dredge. All dredging is assumed to occur within a defined footprint to a fixed cut depth. When possible, approximately 8 inches of over-dredge of material beyond the estimated maximum depth of impacted sediment will likely be implemented to ensure complete removal of the targeted contaminant mass. However, for the purposes of the FS, over-dredge was not in volume or cost estimates to allow comparability and consistency between different action levels and reaches.

Dewatering Process Options

For all mechanical dredging alternatives, it is proposed that dewatering be conducted on-barge and in upland staging areas.

Passive Dewatering. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and collected. All water collected from the barges and the CDF will be treated using flocculation, clarification, and sand filtration prior to discharge back to the river.

These proposed dewatering systems will meet the criteria defined in Section 6 of this FS Report, in terms of production rate, effectiveness, practicality, and discharge water quality. Final selection of the dewatering process will be determined during the remedial design phase.

Treatment Process Options

Water treatment of effluent prior to discharge includes the same processes previously described for Green Bay zones 2 and 3A.

On-site Disposal Process Options

The CDF currently proposed for Green Bay is a cellular cofferdam located near the Cat Island chain. The CDF size was varied with each action level to accommodate the total volume of dredged sediment. The new Green Bay CDF will be constructed as three separate islands in accordance with the design proposed by the USACE (USACE, 1999) to encourage natural resedimentation and restoration around the structures. Several in-water and upland CDF sites were proposed in a 1985 Environmental Impact Study (USACE, 1985) for Green Bay Harbor, but most were eliminated from further consideration because of environmental concerns by the USFWS (as cited in USACE, 1985). Only the Cat

Island restoration area and Kidney Island expansion were retained for further consideration.

The newly constructed free-standing CDF structures will be closed with a 3-foot sand cap and riprap placed around the edges to provide additional protection from storm events. The final construction will also include habitat areas for shallow submerged and emergent vegetation as shown on the proposed conceptual design (Figure 7-50). While the top layer is not designed to be an impermeable cap, selection of appropriate plant species will be considered (i.e., shallow roots) to ensure physical integrity of the cap.

The Renard Island CDF, located near the mouth of the Lower Fox River, is a 55-acre diked impoundment with a design capacity of 1,200,000 cy. The facility consists of a kidney-shaped stone dike with an interior steel sheet pile cutoff wall to prevent seepage to surrounding surface waters (USACE, 1985). The CDF reached capacity after receiving a deposit of dredged sediment in 1996. Construction costs include final closure of the Renard Island CDF in addition to constructing a new CDF. Closure of Renard Island will include placement of a 3-foot-thick clean soil cap, seeding, mitigation, and long-term monitoring for 40 years.

Within Green Bay, three potential CAD sites were identified as previously described for Green Bay zones 2 and 3A.

Off-site Disposal Process Options

No off-site disposal was considered for the zone because of the large sediment volumes requiring removal. Only on-site disposal options were considered.

Capping Process Options

No capping is proposed for Green Bay because bottom water currents, storm events, vessel traffic, maintenance of navigational channels, and potential ice scour preclude effective placement and long-term integrity (Palermo, 1995).

7.8.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for Green Bay Zone 3B. Each remedial alternative includes a process description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth in this FS include a line item for 20 percent contingency costs. Details used to develop each cost estimate are provided in Appendix H.

The following components are discussed, when applicable, within the development of each alternative:

- Site mobilization and preparation,
- Sediment removal,
- Sediment dewatering,
- Water treatment,
- Sediment disposal,
- Demobilization and site restoration, and
- Long-term monitoring/institutional controls.

Alternative A: No Action

As required under the NCP, a no action alternative is included for Green Bay Zone 3B. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management of remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until RAOs are achieved. This alternative includes fish tissue sampling events every 5 years for 40 years for maintenance of the fish consumption advisories currently in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);
- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);
- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and
- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative D: Dredge Sediment to Confined Disposal Facility

Alternative D includes removal of sediments to an on-site cellular cofferdam CDF for long-term disposal of the materials. Costs for this alternative were developed for the 500 ppb action level only since no sediments were measured above the higher action levels. The cellular cofferdam CDF location is identified on Figure 7-52. TSCA-level sediments are not present in this zone.

Figure 7-56 provides the process flow diagram for this remedial alternative. Table 7-11 contains the summary costs to implement Alternative D. The total volume of sediment to be dredged in this alternative is 43,625,096 cy for the 500 ppb action level.

Site Mobilization and CDF Construction. For the concept level FS, the process is staged to construct and complete dredging to the cellular cofferdam CDF near the Cat Island chain described above. Site mobilization and preparation includes securing the onshore property area for equipment staging, constructing the CDF, a water treatment facility, and an offshore docking facility for the mechanical dredge. Property purchase and preparation are included in the construction costs.

CDF construction is estimated at $667,700,000, which includes long-term operation and maintenance costs.

Sediment Removal. Mechanical sediment removal techniques for this alternative are equivalent to those described for Green Bay Zone 3A. The estimated time to complete mechanical dredging is 12 years using seven mechanical dredges.

Sediment removal costs are estimated at $478,600,000.

Water Treatment. Free water collected on barges and overflow return water from the CDF would be treated before discharge to the bay. Treatment and monitoring requirements are expected to be similar to those specified for the Green Bay Zone 3A.

Water treatment costs for Alternative D are estimated at $4,700,000.

Sediment Disposal. No off-site sediment disposal is anticipated for this alternative. Sediments will be placed directly into the CDF without solidification. Placement costs are included in the dredging costs. Percent solids are expected to be the same as *in-situ* percent solids prior to mechanical dredging.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CDF would be finished with a 3-foot cap of clean soils, and seeded and planted (included in the construction costs). Additional amenities (i.e., wildlife habitat) were not included in the cost estimates. However, this alternative would allow for development of these newly-created upland habitat features. Demobilization and site restoration costs are included under the dredging and CDF construction estimates.

Institutional Controls and Monitoring. To ensure that the CDF is functioning as designed, near-site sediment and water sampling would be conducted on an annual basis. The monitoring program will be conducted over a period of 40 years.

The estimated cost for institutional controls is $4,500,000. Long-term operation and maintenance monitoring of the CDF is included in the CDF construction costs. Implementation monitoring during dredging is included in the removal costs. Long-term remedy monitoring of Green Bay to verify achievement of the project RAOs is included in Alternative B - Monitored Natural Recovery.

Alternative G: Dredge Sediment to Confined Aquatic Disposal

Alternative G includes removal of sediments to a CAD facility for long-term disposal of the materials. Costs for this alternative were developed for the 500 ppb action level only since no sediments were measured above the higher action levels. The proposed CAD locations are identified on Figure 7-52.

Figure 7-56 provides the process flow diagram for this remedial alternative. Table 7-11 contains the summary costs to implement Alternative G. The total volume of sediment to be dredged in this alternative is 43,625,096 cy.

Site Mobilization and CAD Construction. For the concept level FS, the process is staged to complete dredging to the CAD as described in Section 7.6.3. Details of the conceptual CAD design are provided on Figure 6-7. Site mobilization and preparation includes securing the onshore property area for equipment staging, sand purchase, long-term operation and maintenance, offshore docking facility for the mechanical dredge, and winterizing of equipment each year. The CAD site will be constructed by excavating an in-water cavity approximately 3 to 5 meters deep using either mechanical or hydraulic dredges. Contaminated sediment will be placed in the deep water cavity using either split-hull bottom barges or pipelines. After placement, the CAD site will be capped with 3 feet of clean sand (included in construction costs). Capping requires six barges, four tugboats, and a shore-based source of sand within 20 miles of the CAD site.

CAD construction is estimated at $523,100,000 for the 500 ppb action level, which includes CAD closure and long-term operation and maintenance costs.

Sediment Removal. Mechanical sediment removal techniques for this alternative are equivalent to those described for Alternative D. Sediment removal time frame and costs are similar to those described for Alternative D.

Sediment Dewatering. All dewatering will be conducted on-barge. Each 2,000-cy barge load of dredged sediment will be filled in 1 day and will dewater for 2 days on the barge. Free water will be pumped from the watertight barges and managed.

Sediment dewatering costs are included in the sediment removal and water treatment costs.

Water Treatment. Overflow return water from the barges would be treated before discharge to the bay. Monitoring requirements are expected to be similar to those specified for the Lower Fox River reaches.

Water treatment costs for Alternative G are estimated at $4,700,000.

Sediment Disposal. On-site disposal costs are included in the CAD construction and dredging costs. Percent solids content of dewatered sediments at the time of disposal are expected to be the same as the *in-situ* percent solids prior to mechanical dredging. No solidification costs were added.

Demobilization and Site Restoration. Demobilization and site restoration involves removing all equipment (i.e., fencing, facilities) from the staging and work areas. The CAD would be finished with a 3-foot cap of clean soils to isolate the contaminated sediments (included in construction costs). Demobilization and site restoration costs are included under the CAD construction and dredging estimates.

Institutional Controls and Monitoring. Institutional controls and monitoring will be equivalent to those described previously for zones 2 and 3A.

The estimated cost for institutional controls is $4,500,000. Long-term operation and maintenance monitoring of the CAD site is included in CAD construction costs. Implementation monitoring during dredging is incorporated into the removal costs. Long-term remedy monitoring of Green Bay to verify achievement of the project RAOs is included in Alternative B - Monitored Natural Recovery.

7.8.5 Section 7.8 Figures and Tables

Figures and tables for Section 7.8 follow page 7-216 and include:

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Figure 7-56 Process Flow Diagram for Green Bay Zone 3B - Alternatives D and G: Dredge Sediment to CDF/CAD

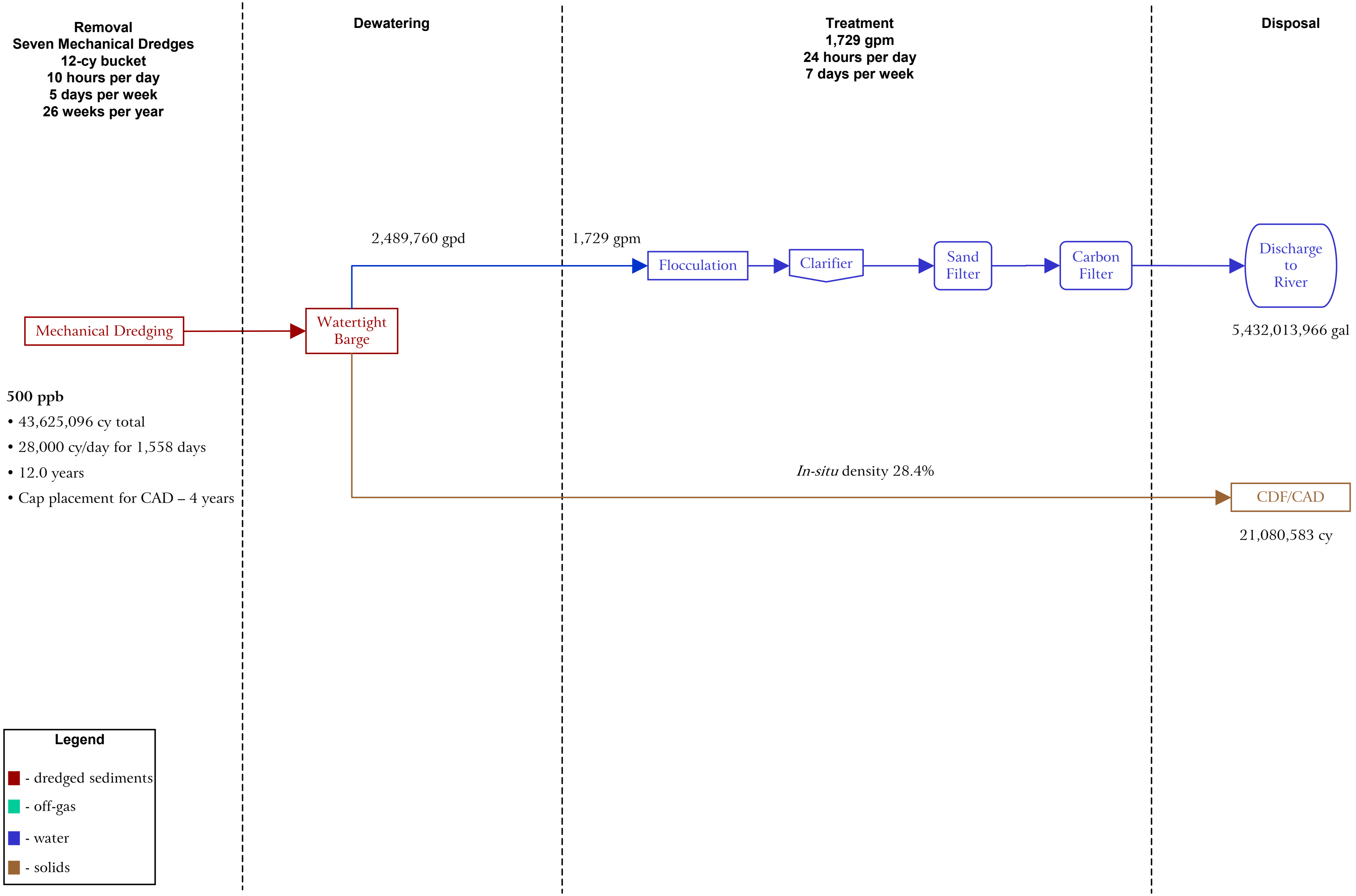

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Table 7-11 Cost Summary for Remedial Alternatives - Green Bay Zone 3B

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	43,625,096	---	$478,200,000	---	$4,700,000	---	$667,700,000	---	$4,500,000	$1,155,100,000	$231,020,000	$1,386,120,000
G	43,625,096	---	$478,600,000	---	$4,700,000	$523,100,000	---	---	$4,500,000	$1,010,900,000	$202,180,000	$1,213,080,000

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7.9 Green Bay Zone 4

An overview of the Green Bay zones and PCB-impacted sediments is shown on Figure 7-49. The retained alternatives and associated costs are presented in Table 7-12.

7.9.1 General Site Characteristics

Zone 4 includes the remainder of Green Bay north of Chambers Island. Zone 4 extends to approximately 63.1 miles from the south side of Chambers Island to the northern shores of Big Bay de Noc.

A significant portion of this zone, from Chambers Island to just south of Big and Little bays de Noc, has water depths exceeding 30 feet. In the vicinity of Big and Little bays de Noc, the water depths decrease and shallow areas with water depths of less than 30 feet are predominant. A number of shoals are located in this zone.

The nature and extent of PCB-impacted sediment in this zone, as summarized in the RI, includes the following:

- Maximum detected concentration - 751 μg/kg (avg. 54 μg/kg),
- Total PCB mass - 1,959 kg,
- Total PCB-impacted volume - 146,551,000 m^3, and
- Maximum PCB sample depth - 10 to 30 cm depth.

These quantities represent the total volumes/masses represented in each modeled depth layer (RETEC, 2002a). Required dredge volumes described later in this section will likely be larger since they account for overburden volumes above deeper sediment layers that contain PCBs.

7.9.2 Selected Remedial Alternatives

This section defines the remedial alternatives for Green Bay Zone 4, and then describes the technologies that will be applied based upon application of the criteria defined in Section 6. The remedial alternatives retained for Green Bay Zone 4 include the following:

A. No action.

B. Monitored natural recovery of the system with the expectation that institutional controls will be removed within 40 years.

Alternatives C, D, E, F, and G were not retained because no sediments were present in these zones greater than the 500 ppb PCB action level for Green Bay.

Table 7-1 presents a summary of the remedial alternatives for Green Bay Zone 4. The process options that can be applied to the remedial alternatives are described below.

7.9.3 Description of Process Options

Monitoring

Short-term and long-term monitoring options in this zone are the same as those described previously for other Green Bay zones.

Institutional Controls

Institutional controls in this zone are the same as those described previously for other Green Bay zones.

7.9.4 Development of Alternatives and Associated Costs

This section describes the remedial alternatives developed for Green Bay Zone 4. Each remedial alternative includes a description, a process flow diagram, and a summary cost table. Summary costs presented as net present worth costs in this FS include a line item for 20 percent contingency costs. Details used to develop each cost estimate are provided in Appendix H.

The following components are discussed, when applicable, within the development of each alternative:

- Institutional controls, and
- Long-term monitoring.

Alternative A: No Action

As required under the NCP, a no action alternative is included for Green Bay Zone 4. This alternative involves taking no action and relying on natural processes, such as natural attenuation, dispersion, dilution, and sedimentation to reduce contaminant quantities and/or concentrations and control contaminant migration processes. This alternative implies that no active management of remediation is employed; however, some institutional controls, such as access or resource use restrictions, may be employed to reduce risks until RAOs are achieved. This alternative includes costs for fish tissue sampling every 5 years for 40 years for maintenance of the consumption advisories already in place.

The estimated cost for no action and maintenance of consumption advisories currently in place is $4,500,000. Engineered cost evaluations typically include a

20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

Alternative B: Monitored Natural Recovery/Institutional Controls

The monitored natural recovery option will include a long-term monitoring program (40-year) for measuring PCB, DDE, and mercury levels in water, sediment, invertebrates, fish, and birds. The monitoring program will be developed to effectively measure achievement of and progress towards the project RAOs expected in 40 years. Monitoring components will likely be collected between 2- and 5-year intervals for the first 10 years, and will include pre- and post-remedy sampling events to establish baseline conditions. Monitoring frequency may be modified after 5 years based on the initial monitoring results. More specifically, the monitoring program will likely include (see Appendix C for the proposed *Long-term Monitoring Plan* for the project):

- Surface water quality sampling at several stations along the reach to determine the downstream transport of PCB mass into Green Bay (RAOs 1 and 4);

- Fish and waterfowl tissue sampling of several species and size classes to determine the residual risk of PCB and mercury consumption to human receptors (RAO 2);

- Fish (several species and size classes), bald eagle, and invertebrate tissue sampling to determine the residual risk of PCB, DDE, and mercury uptake to environmental receptors (RAO 3);

- Population studies of birds (bald eagles and double-crested cormorants) to assess the residual effects of PCBs, DDE, and mercury on reproductive viability (RAO 3); and

- Surface sediment sampling in MNR areas to assess potential recontamination from upstream sources and status of attenuation of sediments (RAO 4).

Until the project RAOs have been achieved, institutional controls will be required to prevent exposure of human and biological receptors to contaminants. Institutional controls may also be implemented in combination with many of the proposed remedial alternatives, and may include monitoring, access restrictions, deed restrictions, dredging moratoriums, fish consumption advisories, and domestic water supply restrictions. Deed and access restrictions may require local or state legislative action to prevent any development in contaminated areas of the river. Items included in costs for institutional control include public education programs for fish or health advisories, 5-year fish tissue collection efforts for maintenance of consumption advisories, and deed restrictions.

The estimated cost for institutional controls and long-term monitoring is $9,900,000. Engineered cost evaluations typically include a 20 percent contingency cost added to the remedy costs, as shown in the cost tables as a separate line item.

7.9.5 Section 7.9 Table

The table for Section 7.9 follows this page:

Table 7-12 Cost Summary for Remedial Alternatives - Green Bay Zone 4

Table 7-12 Cost Summary for Remedial Alternatives - Green Bay Zone 4

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000

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8 Alternative-specific Risk Assessment

This section presents an analysis of the potential for risk reduction associated with the proposed remedial action levels presented in the previous two sections of the FS. Central to the selection of any potential remedy for the river and bay is the ability of the remedy to reduce or eliminate risks to human health and the environment. This evaluation includes both active remedial actions such as capping or removal, but also passive actions such as natural recovery and assumes that all remedial actions would have the same risk reduction at the same action level. For example, at a 250 ppb action level, capping achieves the same level of risk reduction as dredging. This Alternative-specific Risk Assessment (ASRA), therefore, is an action level-specific risk assessment.

The ASRA builds upon the risks, remedial action objectives, and remedial action levels defined in Sections 2, 3, 4, and 5 of the FS. Risks from exposure of humans and environmental receptors within the river and bay for PCBs were presented in the Baseline Risk Assessment for the Lower Fox River and Green Bay (BLRA) (Section 3). Sediment quality thresholds (SQTs) were also presented in the BLRA that, along with estimates of PCB mass and sediment volumes from the Remedial Investigation (Section 2), were used to define remedial action levels in Section 5.

Evaluation of residual risks associated with implementation of a specific remedial action level in sediments requires the ability to estimate the changes over time of total PCBs in water, sediment, and fish as a result of the action. None of the remedial action levels identified provide 100 percent protection immediately after remediation (or initiation of monitored natural recovery) for all of the human or ecological receptors in the Lower Fox River or Green Bay. The key assumption of remediation is that sediment transport and burial over time would achieve further reductions in risk. This is also applicable to the evaluation of passive remedial management; risk reduction under monitored natural recovery.

Mathematical fate, transport, and bioaccumulation models provide a means for estimating the changes in PCB concentrations over time. Using those projections, the level of estimated risk reduction and the time it takes to achieve that risk reduction, can be used as metrics for comparing the efficacy of the remedial action levels in each river reach and bay zone.

The subsections below define:

- What are the metrics for the RAOs used to evaluate risk reduction?
- What are the mathematical models used to project the levels of PCBs in water, sediment, and fish tissue concentrations over time?
- What remedial action levels, or combinations of action levels, are modeled?
- How do the projections for different action levels affect risk in each reach/zone (i.e., comparison against the RAOs)?
- Are there post-remedial risks for other chemicals of concern (COCs) identified in the BLRA (i.e., DDE and mercury)?

These questions provide the foundation for the ASRA. The RAO metrics, models, evaluation process, PCB risk reduction, and risk from other COCs are described below for each river reach and bay zone. It is emphasized here, and will be reiterated throughout this section, that risk reduction predictions are meant to be compared in a relative, and not an absolute sense. The relationship between the predictive models and the estimated PCB concentrations in both sediments and fish tissue are described in Table 8-1.

8.1 Remedial Action Objectives

for the Lower Fox River and Green Bay were defined in Section 4. WDNR and EPA articulated their project expectations into explicit, measurable statements (e.g., number of years to remove fish consumption advisories) in order to evaluate the expected performance of each alternative and each action level. The RAOs and project expectations were defined as follows:

- *RAO 1 - Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.*

  The metric for RAO 1 is that PCBs measured in surface waters are at or below surface water quality criteria. The values used for surface water quality are the human health value defined in NR 105 WAC for drinking water (0.003 ng/L) and wildlife (0.12 ng/L). The drinking water value is actually a surface water value protective of human health at a lifetime cancer risk level of 10^{-5} from the consumption of fish which bioaccumulate PCBs from surface waters. However, it should be noted that these are not ARARs. Additionally, while not a specific criterion, the projected concentrations are also compared to current maximum outflow concentrations from Lake Winnebago.

- *RAO 2 - Protect humans who consume fish from exposure to COCs that exceed protective levels.*

  The metric for RAO 2 is stated as the removal of fish consumption advisories in the Lower Fox River and Green Bay. The metrics below are only one set of goals for risk management decision making, but are used in the FS for relative comparison between alternatives and action levels.

  - Recreational anglers can safely eat fish 10 years after completion of a remedy; and

  - High-intake fish consumers can safely eat fish 30 years after completion of a remedy.

  Within the BLRA, human health risks were estimated for multiple potential exposure scenarios. These included recreational and high-intake fish consumers, risk levels for cancer ranging from 10^{-4} to 10^{-6}, and a noncancer HI of 1.0, for both the Reasonable Maximum Exposure (RME) and the Central Tendency Exposure (CTE). A threshold based on a 10^{-5} cancer risk level indicates that individuals eating fish with this threshold concentration over a lifetime could contract cancer at the rate of one case in 100,000 people. A threshold based on an HI of 1.0 indicates individuals eating fish with this threshold concentration over a lifetime should not experience any adverse noncancer effects. These risks were expressed in Section 7.4.2 of the BLRA in terms of safe total PCB levels in whole walleye, yellow perch, and carp. For the ASRA, the time to achieve these human health fish tissue thresholds by action level was estimated using model projections.

  For the evaluation and comparison of risk under different action levels, four whole fish thresholds were selected by WDNR and EPA for the protection of human health:

  - Recreational angler - walleye, RME, HI is 1.0 (noncancer) (288 μg/kg);

- Recreational angler - walleye, RME, 10^{-5} cancer risk (106 μg/kg);

- High-intake fish consumer - walleye, RME, HI is 1.0 (noncancer) (181 μg/kg); and

- High-intake fish consumer - walleye, RME, 10^{-5} cancer risk (65 μg/kg).

Human health risks in the BLRA were based upon consumption of fillets. As the models (FRFood and GBFood) predict whole fish tissue PCB concentrations, it was necessary to establish fillet-to-whole body ratios from the FRDB and the scientific literature. The relationship between fillets and whole body concentrations is given in Table 8-2.

This does not imply other risk levels could not be used for risk management; these risk levels and time frames are used simply for consideration and comparison between remedial options, along with other evaluation criteria. Additional risk thresholds are used for comparison over time as discussed in later portions of this section.

- *RAO 3 - Protect ecological receptors from exposure to COCs above protective levels.*

  In the BLRA, ecological risks were estimated for specific receptor/receptor groups (e.g., benthic infauna, fish, piscivorous birds). Concentrations of total PCBs in water, sediment, or fish known to affect the selected receptors were used to calculate apparent risks. This included both the "No Observed Apparent Effect Concentration" (NOAEC) and the "Lowest Observed Apparent Effect Concentration" (LOAEC). For the affected fish, bird, and mammal groups, NOAEC and LOAEC risks can be expressed as total PCB threshold concentrations in whole fish (carp, walleye, alewife, shiners, shad). The relationship between the NOAEC/LOAEC, fish tissue concentration, and sediment concentration is defined in Section 7.4.3 of the BLRA.

  For the ASRA, the time to achieve these ecological whole fish thresholds for a specific action level was estimated using model projections (discussed below). For the evaluation and comparison of risk under different action levels, two ecological thresholds were selected by both WDNR and EPA:

- Carnivorous bird deformity - NOAEC based on carp, whole fish (121 μg/kg); and

- Piscivorous mammal - NOAEC based on carp, whole fish (50 μg/kg).

While these are only potential metrics, these values were compared to an equivalent time period to the high-intake fish consumer (30 years post-remediation) with the potential goal that there would be no risk to these receptors within this time frame following remediation. These RAOs are simply used to compare remedial options on the same basis. However, additional thresholds are used for comparison over time in later sections.

- *RAO 4 - Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.*

  While mass is not specifically related to risk, it is a metric for transport of risk downstream. Mass transport will be presented qualitatively as a comparison between specific action levels, but is only applied to the last reach of the river, De Pere to Green Bay. The last reach accounts for all of the mass transport from materials upstream and downstream of the De Pere dam. Between action levels, projected sediment loading will be compared to 30 years total. In addition, the Lake Winnebago loading rate (18 kg/yr) and the other tributaries to Green Bay loading rate (10 kg/yr) will be used to compare action level results over time. Loading rates from all sources are presented in Section 5.1 of the RI Report (RETEC, 2002a).

- *RAO 5 - Minimize the downstream movement of PCBs during implementation of the remedy.*

  This RAO was evaluated in Sections 6 and 7 of the FS, and will not be further discussed here.

In summary, the metrics lists above are used for relative screening of alternatives, but may not necessarily be the same criteria used to select a final remedy by the resource agencies. Expectations may change or be revised over the course of the project and through the public review process, but for now, they initially provide a useful framework to compare and evaluate the action levels. They also provide performance criteria that can be used as measurement tools during development of the *Long-term Monitoring Plan* (Appendix C). RAOs 1 through 3 are applied to all river reaches. For Green Bay, only RAOs 2 and 3 were evaluated. RAO 4 is applied only to the De Pere to Green Bay Reach.

8.2 Lower Fox River/Green Bay Modeling

Computer models have been developed and used in the FS to project changes in total PCBs in water, sediment, and fish over time. These models are mathematical representations of transport and transfer of PCBs between the sediments, water, and uptake into the food webs described in Section 3 of the FS. While the models discussed below are useful for comparing between potential action alternatives, there should be no mistaking that utility for precision. All the models are calibrated over a short time frame (6 years or less), but projected over 100 years. While there is a reasonable assurance that the relative trends are accurate, there are no assurances that the predictions are precise. In other words, comparisons are relatively reliable, but absolute estimates may not be accurate and should not be strictly relied upon.

The relationship between the models, their projected output, and how the output is used in evaluating risks, is shown in Table 8-1. The bed maps produced as part of the Remedial Investigation are the foundation of the modeling inputs. The surface sediment total PCB concentrations for the baseline and action levels discussed in Section 5 are used as the inputs to both hydrodynamic models: the Whole Fox Lower River Model (wLFRM) and the Enhanced Green Bay Toxics Model (GBTOXe). These two models project total PCB concentrations in water and sediment which are used to evaluate risks as defined in RAOs 1 and 4. The output from the two fate models are used by the bioaccumulation models: Fox River Food (FRFood) and Green Bay Food (GBFood). The projected whole fish tissue concentrations of PCBs are used to evaluate risks as defined in RAOs 2 and 3.

The structure of each of these models is briefly described below. A complete description of all the models used in the RI and FS is given in the companion document *Model Documentation Report for the Lower Fox River and Green Bay* (WDNR, 2001). The uncertainties associated with the predictions of long-term residual risks need to be considered. The uncertainties associated with the selection of specific receptors and the thresholds at which those receptors are thought to be placed at risk are discussed in the BLRA. Model uncertainties include the assumptions built into the mass transport models used to predict long-term water and sediment trends, and the associated risks for those river reaches and Green Bay zones. These uncertainties are discussed in Section 8.5.

8.2.1 Whole Lower Fox River Model (wLFRM)

The Whole Lower Fox River Model (wLFRM) was developed by WDNR from two models previously developed for the analysis of flow in the Lower Fox River: the Upper Fox River (UFR) model, which covered the river between Lake Winnebago and the De Pere dam; and the Lower Fox River (LFR) model, which extended from the De Pere dam to the mouth of the river. The wLFRM retains the spatial resolution of the UFR/LFR models, but allows the simulation of the entire Lower Fox River from Lake Winnebago to the mouth of the river using a single model. The wLFRM is calibrated with data collected between 1989 and 1995. Calibration consisted of comparisons between the data and model results for total suspended solids, dissolved/particulate PCBs in water, sediment bed elevation, and net sediment burial rate.

The wLFRM is used to simulate the fate and transport of solids and PCBs in the water and sediments in the Lower Fox River. The model predicts the movement of solids and PCBs among these various model segments. In addition, the model simulates the concentration of organic carbon in the water column. Transport mechanisms in the wLFRM include advection, dispersion, volatilization, deposition, and resuspension. Deposition is a function of particle size or density with different settling rates to represent sand-, silt-, and clay-size particles. The settling rate for clay-size particles can also be used to simulate the settling of low-density organic matter. Resuspension is based on surface water velocity and the effect of sediment bed armoring over time.

The results from the wLFRM are used as input to other the three models. Area-weighted average concentrations of total PCBs and carbon in water and sediments are output for the bioaccumulation models. Results from above the De Pere dam are used as input to the FRFood model. Results from below the De Pere dam to the mouth of the river are used as input to both the FRFood and GBFood models. Finally, the predicted solids and PCB discharges at the mouth of the river are used as inputs to the GBTOXe model. Each of these three models is discussed below.

8.2.2 Enhanced Green Bay Toxics(GBTOXe) Model

The Enhanced Green Bay Toxics Model (GBTOXe) was developed by HydroQual to simulate the fate and transport of PCBs in Green Bay for the RI/FS. GBTOXe is an enhanced version of an existing WASP4-based toxics model developed as part of the Green Bay Mass Balance Study by Bierman *et al.* (1992) and updated by DePinto *et al.* (1993). Enhancements include a higher spatial resolution and linkage to a hydrodynamics model (GBHYDRO) and a sediment transport model (GBSED) of Green Bay. GBTOXe was calibrated against 1989–1990 GLNPO PCB and carbon data.

GBTOXe is used to model total PCBs and three phases of carbon in the water column and sediments. The carbon phases considered are dissolved, biotic, and particulate detritus. Modeled sediment layers represent biologically active sediments, biologically inactive sediments, and a sink to which PCBs are permanently buried through deposition. Sediment segment volumes are assumed to be constant with time. PCB transport mechanisms include advection, dispersion, volatilization, deposition, resuspension of sorbed phase, and pore water exchange. GBTOXe accounts for sediment bed armoring. Output from GBTOXe includes area-weighted (sediments) or volume-weighted (water column) averages of total PCBs and carbon as input to the bioaccumulation models.

8.2.3 Fox River Food (FRFood) Model

The FRFood bioaccumulation model, based on the Gobas model (1993), is a mathematical description of PCB transfer within the food web of the Lower Fox River and the first two zones of Green Bay (zones 1 and 2). The model is designed to take the output of sediment and water concentrations of PCBs from wLFRM and GBTOXe to estimate concentrations in multiple trophic levels in the aquatic food web (i.e., benthic insects, phytoplankton, zooplankton, and fish). This food web model is functionally similar to, and spatially overlaps with, the food web model for Green Bay (GBFood), with the exception that the FRFood model can be run in reverse where the inputs are fish concentrations and the outputs are predicted sediment concentrations.

FRFood is based upon the algorithms originally developed for Lake Ontario PCBs (Gobas, 1993). Since then, the model has been used extensively throughout the Great Lakes, including derivation of bioaccumulation factors, bioconcentration factors, and food chain multipliers in the development of the Great Lakes Water Quality Initiative (GLWQI) criteria (EPA, 1993, 1994a, 1994b). The model was first used for projecting sediment quality thresholds in the 1996 RI/FS for the Upper Fox River (GAS/SAIC, 1996), and has since been used for setting action levels at the Sheboygan River (EVS, 1998), and for predicting long-term effects on biota at the Hudson River, New York (EPA, 2000c).

FRFood is used to estimate PCB concentrations in the food webs leading to forage fish (e.g., shiners, gizzard shad, alewife), benthic fish (e.g., carp), and game fish (perch, walleye) in the river. Water column and sediment PCB concentrations were provided by wLFRM. The model was calibrated using site-specific data from the Fox River Database (FRDB), and from scientific literature-derived values for the various physiological, bioenergetic, and toxicokinetic parameters in the model. FRFood was also used to estimate sediment quality thresholds of Section 7 of the BLRA.

8.2.4 Green Bay Food (GBFood) Model

The GBFood bioaccumulation model is a mathematical description of contaminant transfer within the food web of Green Bay zones 1 through 4. The food web is comprised of the primary energy transfer pathways from the exposure sources (sediment and water) to the fish species of interest, described in Section 4.4. These pathways include: chemical uptake across the gill surface, chemical uptake from food and chemical losses due to excretion, and growth dilution. The mathematical descriptions are generic (common to all aquatic food webs) and were updated as part of this FS.

GBFood is used in the ASRA to estimate PCB concentrations in the food webs leading to brown trout and walleye in zones 2 through 4 of Green Bay. Carp were not evaluated in GBFood as the model was not constructed to include that fish. This was accomplished by specifying values for the various physiological, bioenergetic, and toxicokinetic parameters in the model and the PCB exposure levels in sediments and water. The parameter values were derived from peer-reviewed studies published in the literature and/or site-specific data. The sediment and water column PCB concentrations were provided by wLFRM and GBTOXe model outputs.

8.3 Description of Detailed Analysis Process

8.3.1 Lower Fox River and Green Bay Total PCB Residual Risk Evaluation

Remedial action levels considered for each of the river reaches include no action, 125, 250, 500, 1,000, and 5,000 ppb. Action levels for the FS were discussed in Section 5. The discussion of action levels relative to the process options (i.e., hydraulic dredging, capping, etc.), the quantity of contaminated sediment, and costs will be discussed in Section 10. Only residual risks associated with implementation of a specific action level are discussed in this section. The residual risks associated with no action are discussed in the BLRA, and the non-interpolated total PCB sediment concentrations that were evaluated as part of this assessment are presented in Table 8-3 by river reach and bay zone.

For modeling in the FS, the same action levels were applied to each river reach. For example, under the No Action alternative the models were run assuming that no action had occurred on all four river reaches.

Unlike the river, not all remedial action levels are considered for Green Bay and not all areas of Green Bay are considered for remediation. Remedial action levels carried forward in the transport model for Green Bay zones 2 and 3A included

500 and 1,000 ppb, the only remedial action level considered for Green Bay Zone 3B was 500 ppb, and no remedial action was considered for Green Bay Zone 4.

Finally, remedial action levels evaluated for each bay zone considered the potential for different remedial actions between the river and the bay. Remedial combinations for modeling were selected by WDNR as shown below:

Lower Fox River Cleanup Level (ppb)	Green Bay		
	No Action	500	1000
No Action	✓	—	—
125	✓	✓	✓
250	✓	✓	✓
500	✓	✓	✓
1000	✓	—	✓
5000	✓	—	—

8.3.2 Non-PCB COC Residual Risk Evaluation

In addition to total PCBs, residual post-remediation risk results from the other two chemicals of concern (COCs) identified in the BLRA, mercury and DDD/DDE/DDT, were evaluated for each remedial action level immediately following remediation. The risks to human health and the environment from these other COCs were most often much less than those posed by PCBs. For clarification, in general mercury was measured above risk levels in both sediments and tissues. DDD and DDT were measured above risk levels in sediment, however, only DDE was measured above risk levels in tissues.

As discussed above, the primary tool for evaluating residual PCB exposure assuming different action levels was modeling surface water, sediment, and wildlife tissue concentrations over a 100-year period following remediation. In contrast, the primary tool for evaluating residual mercury and DDD/DDE/DDT exposure was simply the degree of co-location with removed PCBs in the sediment. The degree of this co-location was determined by plotting the distribution of the compounds in the FRDB relative to the total PCB base maps and the locations of sediments to be addressed as identified in Section 5. The implementation of the alternatives described in Section 7 is assumed to result in the removal or isolation of the non-PCB contaminants along with the PCBs assuming that all of the COCs are co-located. The no action alternatives result in the same residual risks as those identified in the BLRA. No action sediment concentrations of mercury, p,p'-DDD, p,p'-DDE, and p,p'-DDT are presented in Table 8-4. Residual risks to human health and the environment may remain for the action levels that do not remove all areas of contaminated sediment and these are discussed in the reach and zone discussions below. Residual surface sediment concentrations of mercury and DDE as they relate to residual PCB levels by action level are presented on Figures 8-1 through 8-8 for the Lower Fox River and Figures 8-9 and 8-10 for Green Bay.

8.4 Reach- and Zone-specific Risk Assessment

This section discusses the long-term future residual risk associated with each remedial action level, or combination of remedial action levels, in each of the river reaches and bay zones evaluated. Specifically, the associated risks are discussed in terms of the number of years needed before the specific goals of the RAOs outlined above in Section 8.1 are met. RAOs 1 and 4 are not evaluated for any of the Green Bay zones.

Long-term residual risk in the river was determined through using the wLFRM model to derive future water and sediment concentrations and the FRFood model to derive future fish tissue concentrations. Similarly, long-term residual risk in the bay was determined through the GBTOXe model to derive future water and sediment concentrations and the GBFood model to derive future fish tissue concentrations.

RAO 1: Water Quality. For the evaluation of RAO 1, projected surface water total PCB concentrations for each action level were compared to selected thresholds (Table 8-5). The thresholds for surface water, as previously discussed, are the Wisconsin NR 105 water (0.003 ng/L) and wildlife criteria (0.12 ng/L), and the current maximum concentration measured in Lake Winnebago (13 ng/L). These thresholds are compared to the modeled concentrations for each river reach and action level.

The potential risk management goal of meeting human health and ecological thresholds for RAOs 2 and 3 is no risk to any receptors 30 years after remediation has been completed. For consistency, the surface water concentrations 30 years after remediation were noted and compared between action levels. The number of years to reach the surface water thresholds and the surface water concentrations 30 years after remediation are presented in Table 8-5.

RAO 2 and RAO 3: Human Health and Ecological Risk: Human health receptors considered were recreational anglers and high-intake fish consumers. Ecological receptors evaluated included: carp as the surrogate representative for benthic fish, walleye as the surrogate representative of pelagic fish, Forster's terns as the surrogate representative of piscivorous birds, bald eagles as the surrogate representative of carnivorous birds, and mink as the surrogate representative for piscivorous mammals. For the four river reaches and four Green Bay zones, human health and ecological thresholds evaluated by action level are presented in Tables 8-6 through 8-9 and Tables 8-10 through 8-13, respectively.

For the initial evaluation of RAOs 2 and 3, all human health and ecological risk thresholds evaluated in the baseline risk assessment were included: 30 human health thresholds and 15 ecological thresholds. As previously discussed, the risk levels of the human health thresholds were a noncancer HI of 1.0, and cancer risk levels of 10^{-4}, 10^{-5}, and 10^{-6}. The risk levels of the ecological thresholds were NOAECs and LOAECs.

For the final evaluation of RAOs 2 and 3 risks presented in this section, the focus was on just a few select human health and ecological thresholds which were selected by WDNR and EPA: four human health and seven ecological thresholds. For human health, these thresholds were the RME concentration in walleye assuming consumption by recreational anglers and high-intake fish consumers at a noncancer HI of 1.0, and at a cancer risk level of 10^{-5} (i.e., four thresholds total). These human health thresholds (RAO 2) and the years required to meet them assuming different action levels are contained in Table 8-14 (Lower Fox River) and Table 8-15 (Green Bay). The ecological thresholds selected for discussion were the sediment threshold for sediment invertebrates (only evaluated in the river reaches) and the following whole fish tissue thresholds: gizzard shad or alewife concentrations resulting in no or low adverse hatching success or deformity in piscivorous birds, the carp (river) or walleye (bay) concentrations resulting in no adverse deformities in carnivorous birds, and the carp (river) or walleye or alewife (bay) concentrations resulting in no adverse reproductive or survival effects on piscivorous mammals. These ecological thresholds (RAO 3) and the years required to meet them assuming different action levels are contained in Table 8-16 (Lower Fox River) and Table 8-17 (Green Bay). As stated previously, there are potential risk management goals used in the FS. Alternate management goals may be selected by WDNR and EPA.

For each river reach and bay zone, the number of years to reach these human health and ecological remedial action objective thresholds are discussed below. With each decrease in remedial action level, there is a corresponding decrease in the number of years that it takes to meet a threshold. Overall goals of the remedial action level(s) are that recreational anglers will be able to eat walleye within 10 years following remediation with no cancer or noncancer risks, that high-intake consumers will be able to eat walleye within 30 years following remediation with no cancer or noncancer risks, and that there will be no adverse risks to ecological receptors within 30 years following remediation. Based on these potential remedial goals, action levels that achieve these goals are summarized in the conclusion of each reach/bay discussion below.

Although this risk analysis is useful for comparing relative residual risk resulting from each action level and for comparing the relative risk between areas, there are inherent uncertainties associated with the magnitude of residual risk projected 100 years into the future and, therefore, the number of years required to meet the stated remedial action objectives. For example, while the baseline human health and ecological risk assessment concluded that there are potential risks to piscivorous birds, the forward projection of these risks suggests that in the Little Lake Butte des Morts and Appleton to Little Rapids reaches and for all remedial action levels, risks to piscivorous birds do not persist for more than 1 year, even for the No Action alternative. In the Little Rapids to De Pere and De Pere to Green Bay reaches, the only piscivorous bird threshold that is not met within 1 year is the no deformity threshold. A full discussion of this and other uncertainties associated with the forward projection of sediment and fish tissue concentrations and assessment of residual risk is presented in Section 8.5. In part, to address these uncertainties a monitoring program following remediation will be implemented as described in Appendix C.

RAO 4: Mass Transport to Green Bay. For RAO 4, projected mass loads by action levels at the mouth of the Fox River were compared to the background total PCB loadings identified in the Remedial Investigation. The PCB loading rate to the Lower Fox River from Lake Winnebago is 18 kg/yr. The combined loading rate for all tributaries to Green Bay is estimated at 102 kg/yr (see RI Section 5.1.2.1). Overall, the sediment PCB loading discussion focused on comparing relative reductions in sediment loading with each increase in the action level applied. The sediment PCB loading rates 30 years after remediation are presented in Table 8-18.

8.4.1 Little Lake Butte des Morts

Residual PCB Levels

RAO 1 - Surface Water Quality. As presented in Table 8-5, the surface water criteria of 0.003 ng/L are projected to never be met no matter what action level is selected. The wildlife criteria of 0.12 ng/L is not met within 100 years for either the no action or 5,000 ppb action level, yet it is projected to be met within 100 years for the other action levels: 52 years (1,000 ppb), 39 years (500 ppb), 19 years (250 ppb), and 16 years (125 ppb). As compared to the Lake Winnebago current maximum concentration of PCBs in surface water (13 ng/L), under the No Action alternative this concentration is met within 4 years, under an action level of 5,000 ppb this concentration is projected to be met within 1 year,[4] and for all of the other action levels, this concentration is met immediately following remediation. Thirty years after remediation, it is estimated that surface water total PCB concentrations range from 0.04 ng/L (125 ppb) to 2.99 ng/L (no action).

RAO 2 - Human Health. As indicated in Table 8-14, remedial action levels as high as 1,000 ppb are projected to result in the attainment of fish threshold concentrations within 1 year following remediation. For noncancer risks, fish thresholds are estimated to be met within a year up to a remedial action level of 1,000 ppb. Noncancer risks at the 5,000 ppb action level represent a risk reduction of approximately 40 percent as compared to no action. For cancer risks, the only remedial action levels that result in fish thresholds being met within a year are the 250 and 125 ppb action levels. As compared to the No Action alternative, the projected 5,000, 1,000, and 500 ppb action levels result in a cancer risk reduction of approximately 31, 87, and 92 percent, respectively.

For the 125 and 250 ppb action levels, all fish thresholds except the high-intake fish consumer cancer risk threshold (71 μg/kg) are projected to be met in less than a year. For the 500 ppb action level, within 1 year there are no noncancer risks to recreational anglers and high-intake fish consumers; however, cancer risks persist for 5 years (recreational intake) to 10 years (high intake). For the 1,000 ppb action level, noncancer risks are estimated to persist for less than 1 year (recreational angler) to 4 years (high-intake fish consumer); cancer risks persist for 9 years (recreational angler) to 14 years (high-intake fish consumer). For the 5,000 ppb action level projections, noncancer risk of fish consumption persists for 29 years (recreational intake) to 40 years (high intake) and cancer risk of fish consumption persists for 57 years (recreational intake) to 70 years (high intake). For the No Action alternative, noncancer risks of fish consumption are estimated to persist for 51 years (recreational intake) to 65 years (high intake) and cancer risk of fish consumption persists for 84 years (recreational intake) to 100 years (high intake).

With the goals in mind of 10 years for safe fish consumption by recreational anglers and 30 years for safe fish consumption by high-intake consumers, only projections for remedial action levels of 1,000 ppb or less result in meeting these goals. The 1,000 and 500 ppb action levels differ by approximately 37 percent

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[4] A projection of "1 year following remediation" is a model output, and should not necessarily be literally interpreted. PCBs will remain at a steady level in the current age population of fish for 3 to 6 years. The next generation of fish would show the projected PCB reduction. Thus, while the model projects risk reduction in 1 year, in the real world this would be up to 6 years.

and the 125 and 250 ppb action levels do not differ, in terms of the level of risk reduction achieved.

RAO 3 - Ecological Health. As indicated in Table 8-16, the range of remedial action levels are projected to result in either thresholds being met within a year following remediation (i.e., carnivorous bird deformity assuming the 250 or 125 ppb action level and all piscivorous bird thresholds at all action levels), or thresholds not being met within 100 years (i.e., sediment concentrations protective of sediment invertebrates assuming no action or a remedial action level of 5,000 ppb and the piscivorous mammal NOAEC assuming no action). As compared to the 5,000 ppb action level, other action level projections result in a risk reduction to carnivorous birds of 79 percent (1,000 ppb action level) and 87 percent (500 ppb action level), and a risk reduction to piscivorous mammals of 71 percent (1,000 ppb), 75 percent (500 ppb), 91 percent (250 ppb), and 93 percent (125 ppb). As compared to the 1,000 ppb action level, the projections for other action levels result in a risk reduction to sediment invertebrates of 13 percent (500 ppb), 57 percent (250 ppb), and 65 percent (125 ppb).

Estimates for the attainment of the carnivorous bird threshold under action levels which result in risk for more than 1 year ranges from 9 years (500 ppb action level) to 100 years (no action). Attainment of the piscivorous mammal threshold ranges from 7 years (125 ppb action level) to more than 100 years (no action). The sediment invertebrate threshold is only met within 100 years for remedial action levels of 1,000 ppb or less, where achieving this threshold ranges from 21 years (125 ppb action level) to 60 years (1,000 ppb action level).

With the goal in mind of 30 years for no adverse ecological risks, only remedial action levels of 250 or 125 ppb result in meeting this goal. The 250 and 125 ppb action levels only differ by approximately 3 percent in terms of the level of risk reduction achieved. The action levels of 5,000, 1,000, and 500 ppb do not result in achievement of the stated goal, and the 125 ppb action level is not appreciably more protective than the 250 ppb action level.

RAO 4 - Sediment Transport. As presented in Table 8-18, 30 years following remediation, the sediment PCB loading rates for the action levels as compared to the No Action alternative represent sediment PCB loading reductions of 44 percent (5,000 ppb), 94 percent (1,000 ppb), 96 percent (500 ppb), 98 percent (250 ppb), and 99 percent (125 ppb). Compared to the Lake Winnebago sediment PCB loading rate of 18 kg/yr, the No Action alternative results in meeting this rate in 17 years, the 5,000 ppb action level results in meeting this rate in 7 years, and for all of the other action levels this rate is met immediately following remediation.

Residual Mercury and DDE Levels

The distribution and concentrations of mercury and DDE in sediments and degree of co-location with PCBs within the Little Lake Butte des Morts Reach are shown on Figure 8-1 (mercury and PCBs) and Figure 8-2 (DDE and PCBs). These figures clearly indicate that mercury and DDE are both extensively co-located with PCBs.

The only area which contains mercury, but not PCBs, is the eastern side of this reach near the connection with Lake Winnebago. Regardless of the remedial action level selected, mercury concentrations here remain in the range of 1 to 5 mg/kg. Even with no remedial action in this reach, mercury concentrations do not exceed 5 mg/kg. These residual concentrations of mercury may pose a risk to water column and benthic invertebrates as well as piscivorous birds.

Under the No Action alternative, DDE concentrations may be more than 1,000 μg/kg. Under the 5,000 ppb action level, DDE concentrations drop to 25 to 100 μg/kg and these DDE concentrations in sediment are still present, although smaller in area, under the 1,000 and 500 ppb action alternatives. At the 250 and 125 ppb action levels, no DDE is present in the sediment. Because all areas of DDE contamination are co-located with PCBs, residual risk from DDE will not exceed residual risks from PCBs.

Conclusion

Based upon the evaluations presented above, the remedial action levels of 1,000 and 250 ppb will meet the stated goals of the RAOs.

8.4.2 Appleton to Little Rapids

Residual PCB Levels

RAO 1 - Surface Water Quality. As presented in Table 8-5, the drinking water criteria of 0.003 ng/L is never met no matter what action level is selected. The wildlife criteria of 0.12 ng/L is not met within 100 years for either the no action or 5,000 ppb action level, yet it is met within 100 years for the other action levels: 52 years (1,000 ppb), 40 years (500 ppb), 21 years (250 ppb), and 19 years (125 ppb). As compared to the Lake Winnebago current maximum concentration of PCBs in surface water (13 ng/L), under the No Action alternative this concentration is met within 4 years, and for all of the other action levels this concentration is met immediately following remediation. Thirty years after remediation, surface water total PCB concentrations range from 0.04 ng/L (125 ppb) to 2.76 ng/L (No Action).

RAO 2 - Human Health. As indicated in Table 8-14, projections for remedial action levels as high as 1,000 ppb can result in the attainment of fish threshold concentrations within 1 year[5] following remediation. For noncancer risks, fish thresholds are met within 1 year following remediation up to a remedial action level of 250 ppb for recreational anglers. As compared to the No Action alternative, the 5,000, 1,000, and 500 ppb action level projections result in a noncancer risk reduction of approximately 34, 89, and 91 percent, respectively. Cancer thresholds are not met within 1 year. As compared to the No Action alternative, the 5,000, 1,000, 500, 250, and 125 ppb action levels result in a cancer risk reduction of approximately 37, 80, 83, 90, and 92 percent, respectively.

For the 125 ppb action level, there are no noncancer risks within 1 year, and cancer risks are estimated to persist for 5 years (recreational intake) to 8 years (high intake). For the 250 ppb action level, noncancer risks persist for less than 1 year (recreational intake) to 2 years (high intake) and cancer risks persist for 7 years (recreational intake) to 9 years (high intake). For the 500 ppb action level, within 1 year there are no estimated noncancer risks to recreational anglers, but high-intake fish consumer noncancer risks persist for 5 years. For the 1,000 ppb action level, noncancer risks persist for 4 years (recreational intake) to 7 years (high intake) and cancer risks persist for 14 years (recreational intake) to 17 years (high intake). For the 5,000 ppb action level, noncancer risks persist for 26 years (recreational intake) to 37 years (high intake), and cancer risks persist for 42 years (recreational intake) to 65 years (high intake). For the No Action alternative, noncancer risks persist for 40 years (recreational intake) to 55 years (high intake), and cancer risks persist for 70 years (recreational intake) to 89 years (high intake).

With the goals in mind of 10 years for safe fish consumption by recreational anglers and 30 years for safe fish consumption by high-intake consumers after completion of an active remedy, only a remedial action level of 500 ppb or less result in meeting these goals. The 500, 250, and 125 ppb action levels only differ by approximately 6 percent in terms of the level of risk reduction achieved. Effectively, therefore, an action level of 500 ppb may be appropriate for this reach and this RAO. The action levels of 5,000 and 1,000 ppb never meet the stated goals, and the 250 and 125 ppb action levels are not appreciably more protective than the 500 ppb action level.

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[5] A projection of "1 year following remediation" is a model output, and should not necessarily be literally interpreted. See footnote 1 in Section 8.4.1, RAO 3 for a discussion.

RAO 3 - Ecological Health. As indicated in Table 8-16, the range of remedial action level projections results in thresholds being met within 7 to 100 years following remediation, with the exception of piscivorous mammal thresholds which are met in less than 1 year for all action levels. As compared to no action, the 5,000, 1,000, 500, 250, and 125 ppb action levels, respectively, result in an estimated risk reduction of 23, 76, 79, 87, and 90 percent for carnivorous birds, respectively; a risk reduction of 11, 66, 71, 82, and 85 percent for piscivorous mammals, respectively; and a risk reduction of 22, 65, 71, 80, and 84 percent for sediment invertebrates, respectively. Attainment of the carnivorous bird threshold ranges from 7 years (125 ppb action level) to 71 years (No Action). Attainment of the piscivorous mammal and sediment thresholds range from 15 years (125 ppb action level) to 100 years (No Action).

With the goal in mind of 30 years for no adverse ecological risks, only a remedial action level of 500 ppb or less is projected to meet this goal. The 1,000 and 500 ppb, and 250 and 125 ppb action levels only differ by approximately 7 and 5 percent, respectively, in terms of the level of risk reduction achieved. The 500 and 250 ppb action levels differ by approximately 50 percent in terms of the level of risk reduction achieved. The 250 and 125 ppb action levels differ by approximately 8 percent in terms of the level of risk reduction achieved. Therefore, an action level of either 500 or 250 ppb may be appropriate for this reach and this RAO. The action levels of 5,000 and 1,000 ppb never result in the achievement of the stated goal, and the 125 ppb action level is not appreciably more protective than the 250 ppb action level.

RAO 4 - Sediment Transport. As presented in Table 8-18, 30 years following remediation the sediment PCB loading rates for the action levels as compared to the No Action alternative represent sediment PCB loading reductions of 42 percent (5,000 ppb), 93 percent (1,000 ppb), 95 percent (500 ppb), 98 percent (250 ppb), and 99 percent (125 ppb).

Residual Mercury and DDE Levels

The distribution and concentrations of mercury and DDE and degree of co-location with PCBs within the Appleton to Little Rapids Reach are shown on Figure 8-3 (mercury and PCBs) and Figure 8-4 (DDE and PCBs). These figures indicate that mercury and DDE are predominantly co-located with PCBs, but that there is one area at which mercury and DDE are both located, but not PCBs. Additionally, much of the PCB sediment contamination in this reach has already been remediated.

The only area which contains mercury and DDE is a small area in the middle of the reach located on the eastern side of the river. Regardless of the remedial action level, mercury concentrations in this area are approximately 1 to 5 mg/kg and DDE concentrations are approximately 25 to 100 μg/kg. These concentrations suggest no risk from DDE, but the potential risk of mercury to sediment invertebrates, as well as piscivorous and carnivorous birds.

Conclusion

Based upon the evaluations presented above, the remedial action levels of 500 and 250 ppb will meet the stated goals of the RAOs for this reach.

8.4.3 Little Rapids to De Pere

Residual PCB Levels

RAO 1 - Surface Water Quality. As presented in Table 8-5, the drinking water criteria of 0.003 ng/L is never met no matter what action level is selected. The wildlife criteria of 0.12 ng/L is not met within 100 years for either the no action or 5,000 ppb action level, yet it is met within 100 years for the other action levels: 65 years (1,000 ppb), 54 years (500 ppb), 40 years (250 ppb), and 27 years (125 ppb). As compared to the Lake Winnebago current maximum concentration of PCBs in surface water (13 ng/L), under the No Action alternative this concentration is met within 9 years, under an action level of 5,000 ppb this concentration is met within 2 years, and for all of the other action levels this concentration is met immediately following remediation. Thirty years after remediation, surface water total PCB concentrations range from 0.08 ng/L (125 ppb) to 5.37 ng/L (no action).

RAO 2 - Human Health. As indicated in Table 8-14, no remedial action level estimates result in the attainment of fish threshold concentrations within 1 year following remediation and assuming no action, the only threshold that is met in less than 100 years is the recreational angler noncancer risk threshold (288 μg/kg). For noncancer risks, fish thresholds are met within 1 year[6] following remediation up to a remedial action level of 125 ppb for high-intake fish consumers, and up to a remedial action level of 500 ppb for recreational anglers. As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action levels result in a noncancer risk reduction of approximately 79, 86, 93, and 95 percent, respectively. As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action levels result in a cancer risk reduction of approximately 62, 74, 83, and 88 percent, respectively.

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[6] A projection of "1 year following remediation" is a model output, and should not necessarily be literally interpreted. See footnote 1 in Section 8.4.1, RAO 3 for a discussion.

For the 125 ppb action level, noncancer risks are estimated to persist for 2 years (recreational intake) to 4 years (high intake), and cancer risks persist for 9 years (recreational intake) to 15 years (high intake). For the 250 ppb action level, noncancer risks are estimated to persist for 2 years (recreational intake) to 7 years (high intake) and cancer risks are estimated to persist for 14 years (recreational intake) to 20 years (high intake). For the 500 ppb action level, the noncancer risks are estimated to persist for 5 years (recreational intake) to 12 years (high intake) and cancer risks are estimated to persist for 20 years (recreational intake) to 29 years (high intake). For the 1,000 ppb action level, noncancer risks are estimated to persist for 9 years (recreational intake) to 17 years (high intake) and the cancer risks are estimated to persist for 30 years (recreational intake) to 42 years (high intake). For the 5,000 ppb action level, noncancer risks are projected to persist for 52 years (recreational intake) to 67 years (high intake), and cancer risks are projected persist for 92 years (recreational intake) to 100 years (high intake). For the No Action alternative, the only threshold that is met in less than 100 years is the threshold for the recreational consumption of walleye which is achieved in 92 years.

With the goals in mind of 10 years for safe fish consumption by recreational anglers and 30 years for safe fish consumption by high-intake consumers, only a remedial action level of 125 ppb results in meeting these goals in this reach.

RAO 3 - Ecological Health. As indicated in Table 8-16, the range of remedial action level projections results in thresholds being met within 1 year following remediation (e.g., piscivorous bird deformity and hatching success for all action levels, except for deformity NOAEC under no action) or thresholds not being met within 100 years (e.g., carnivorous bird, piscivorous mammal, and sediment invertebrate thresholds under the No Action alternative, and the sediment and piscivorous mammal thresholds under the 5,000 ppb action level). As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action levels estimate a risk reduction to carnivorous birds of 71, 84, 89, and 95 percent, respectively. As compared to the 1,000 ppb action level, the 500, 250, and 125 ppb action levels result in a risk reduction to piscivorous mammals of 28, 42, and 65 percent, respectively, and a risk reduction to sediment invertebrates of 29, 39, and 65 percent, respectively. Attainment of the carnivorous bird threshold for the 125 ppb action level to the 5,000 ppb action level ranges from 4 to 76 years, respectively. Attainment of the piscivorous mammal threshold for the 125 ppb action level to the 1,000 ppb action level ranges from 15 to 43 years, respectively. Attainment of the sediment threshold for the 125 ppb action level to the 1,000 ppb action level ranges from 16 to 46 years, respectively.

With the goal in mind of 30 years for no adverse ecological risks, only a remedial action level of 250 ppb or less meets this goal. The 250 and 125 ppb action levels differ by approximately 45 percent in terms of the level of risk reduction achieved. Therefore, the action levels recommended that may be appropriate for this reach and this RAO are 250 and 125 ppb. The action levels of 5,000, 1,000, and 500 ppb should be dropped because they never result in the achievement of the stated goal.

RAO 4 - Sediment Transport. As presented in Table 8-18, 30 years following remediation the sediment PCB loading rates for the action levels as compared to the No Action alternative represent sediment PCB loading reductions of 55 percent (5,000 ppb), 93 percent (1,000 ppb), 96 percent (500 ppb), 97 percent (250 ppb), and 99 percent (125 ppb).

Residual Mercury and DDE Levels

The distribution and concentrations of mercury and DDE and degree of co-location with PCBs within the Little Rapids to De Pere Reach are shown on Figure 8-5 (mercury and PCBs) and Figure 8-6 (DDE and PCBs). These figures indicate that mercury and DDE are predominantly co-located with PCBs.

The residual risk from mercury is about the same for the No Action alternative and the 5,000 ppb action level, although while concentrations of mercury may be as high as 10 mg/kg under both scenarios, the area of contamination is dramatically reduced with remedial action. Under either of these scenarios, mercury may be a risk to all ecological assessment endpoints evaluated except for piscivorous mammals and insectivorous birds (for which there were no data). Under the 1,000, 500, and 250 ppb remedial action levels, mercury levels are consistently between 1 and 5 mg/kg, which like the concentrations found in the Little Lake Butte des Morts Reach, may pose risk to invertebrates and piscivorous birds. At the 125 ppb action level, mercury concentrations of 0 to 1 mg/kg are found in the sediment, but these concentrations are not expected to result in any adverse risk.

Beginning with the 5,000 ppb remedial action level and remaining through the 125 ppb action level, DDE concentrations are between 1 and 25 μg/kg in the sediment and suggest no residual risk to ecological receptors.

Conclusion

Based upon the evaluations presented above, the remedial action level of 125 ppb will meet the stated goals of the RAOs for this reach.

8.4.4 De Pere to Green Bay

Residual PCB Levels

RAO 1 - Surface Water Quality. As presented in Table 8-5, the drinking water criteria of 0.003 ng/L is never met no matter what action level is selected. The wildlife criteria of 0.12 ng/L is not met within 100 years for either the no action or 5,000 ppb action level, yet it is met within 100 years for the other action levels: 69 years (1,000 ppb), 65 years (500 ppb), 40 years (250 ppb), and 27 years (125 ppb). As compared to the Lake Winnebago current maximum concentration of PCBs in surface water (13 ng/L), under the No Action alternative this concentration is not met within 100 years, under an action level of 5,000 ppb this concentration is met within 2 years, and for all of the other action levels this concentration is met immediately following remediation. Thirty years after remediation, surface water total PCB concentrations range from 0.09 ng/L (125 ppb) to 21.08 ng/L (no action).

RAO 2 - Human Health. As indicated in Table 8-14, the No Action alternative model output results in none of the thresholds being met within 100 years. As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action level estimates result in a noncancer risk reduction of approximately 73, 81, 88, and 92 percent, respectively. As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action levels result in a cancer risk reduction of approximately 48, 60, 76, and 83 percent, respectively.

For the 125 ppb remedial action level, noncancer risks are projected to persist for 7 years (recreational and high intake), and cancer risks are projected to persist for 15 years (recreational intake) to 20 years (high intake). For the 250 ppb action level, noncancer risks are projected to persist for 8 years (recreational intake) to 14 years (high intake), and cancer risks are projected to persist for 20 years (recreational intake) to 29 years (high intake). For the 500 ppb action level, noncancer risks are estimated to persist for 14 years (recreational intake) to 20 years (high intake), and cancer risks are estimated to persist for 34 years (recreational intake) to 45 years (high intake). For the 1,000 ppb action level, noncancer risks are projected to persist for 20 years (recreational intake) to 30 years (high intake) and cancer risks are projected to persist for 45 years (recreational intake) to 59 years (high intake). For the 5,000 ppb action level, modeled noncancer risks persist for 79 years (recreational intake) to 100 years (high intake), and modeled cancer risks persist for 100 years (recreational and high intake).

With the goals in mind of 10 years for safe fish consumption by recreational anglers, and 30 years for safe fish consumption by high-intake consumers following completion of an active remedy, none of the remedial action levels results in meeting these goals. The 250 and 125 ppb action levels come closest to achieving this goal, and differ by less than 10 percent in terms of the level of risk reduction achieved. Therefore, an action level of 250 ppb may be appropriate for this reach and this RAO.

RAO 3 - Ecological Health. As indicated in Table 8-16, the range of remedial action level projections results in thresholds being met within 1 year following remediation i.e., all piscivorous bird thresholds with the exception of the piscivorous bird NOAEC under the no action and 5,000 ppb action levels), or thresholds not being met within 100 years i.e., the carnivorous bird, piscivorous mammal, and sediment invertebrate thresholds under the No Action alternative). As compared to the 5,000 ppb action level, the 1,000, 500, 250, and 125 ppb action levels result in a risk reduction to carnivorous birds of 75, 82, 91, and 94 percent, respectively; a risk reduction to piscivorous mammals of 55, 66, 83, and 86 percent, respectively; and a risk reduction to sediment invertebrates of 60, 75, 86, and 94 percent, respectively. Excluding the No Action alternative, attainment of the carnivorous bird threshold ranges from 5 to 79 years, attainment of the piscivorous mammal threshold ranges from 14 to 100 years, and attainment of the sediment threshold ranges from 6 to 93 years for the 125 and 5,000 ppb action levels, respectively.

With the goal in mind of 30 years for no adverse ecological risks, only a remedial action level of 250 or 125 ppb results in meeting this goal. The 250 and 125 ppb action levels differ by approximately 33 percent in terms of the level of risk reduction achieved. Therefore, either action level may be appropriate for this reach and this RAO. The 5,000, 1,000, and 500 ppb action levels never result in the achievement of the stated goal.

RAO 4 - Sediment Transport. As presented in Table 8-18, 30 years following remediation the sediment PCB loading rates for the action levels as compared to the No Action alternative represent sediment PCB loading reductions of 86 percent (5,000 ppb), 98 percent (1,000 ppb), 99 percent (500 ppb), 99 percent (250 ppb), and 100 percent (125 ppb). Compared to the combined sediment PCB loading rate of the other tributaries to Green Bay (10 kg/yr), the No Action alternative results in not meeting this rate within 100 years, the 5,000 ppb action levels results in meeting this rate in 24 years, the 1,000 ppb action level results in meeting this rate in 4 years, the 500 and 250 ppb action levels result in meeting this rate in 1 year, and the 125 ppb action level meets this rate immediately following remediation.

Residual Mercury and DDE Levels

The distribution and concentrations of mercury and DDE and degree of co-location with PCBs within the De Pere to Green Bay Reach are shown on Figure 8-7 (mercury and PCBs) and Figure 8-8 (DDE and PCBs). These figures clearly indicate that mercury and DDE are highly co-located with PCBs.

Under the 5,000, 1,000, and 500 ppb remedial action levels, mercury concentrations are consistently between 1 and 5 mg/kg, which like the concentrations found in the Little Lake Butte des Morts Reach, may pose risk to invertebrates and piscivorous birds. At the 250 and 125 ppb action levels, mercury concentrations of 0 to 1 mg/kg are found in the sediment, but these concentrations are not expected to result in any adverse risk.

DDE concentrations in sediment are found to be reduced with each level of remedial action. At the 5,000 ppb remedial action level, DDE concentrations of 25 to 100 μg/kg in the sediment may be present. At the 1,000 and 500 ppb action levels, these DDE concentrations are reduced to 1 to 25 μg/kg. At the 250 and 125 ppb action levels, DDE concentrations are less than 1 μg/kg. No action DDE concentrations in the sediment are 25 to 100 μg/kg and based on the risk assessment evaluation, these concentrations were found to pose risk to benthic invertebrates, benthic and pelagic fish, and piscivorous and carnivorous birds. Presumably, these risks decrease as the concentrations in the sediment decrease.

Conclusion

Based upon the evaluations presented above, none of the remedial action levels meets all goals, but remedial action levels of 250 and 125 ppb will meet the stated goals of the ecological RAOs.

8.4.5 Green Bay Zone 2

Residual PCB Levels

The remedial action levels considered for this zone included no action, 500, and 1,000 ppb.

RAO 2 - Human Health. As indicated in Table 8-15, none of the human health thresholds are met within 100 years no matter what remedial action level is used in the river or the bay.

RAO 3 - Ecological Health. As indicated in Table 8-17, the piscivorous bird LOAEC ecological thresholds are met in less than 1 year,[7] and the piscivorous bird deformity NOAEC and the carnivorous bird and piscivorous mammal thresholds are not met within 100 years no matter what remedial action level is used in the river or the bay. The only thresholds that are met within 100 years are the piscivorous bird NOAECs. Lower Fox River remedial action levels of 125 and 250 ppb did not affect the length of time required to meet the no observed deformity or hatching success thresholds for piscivorous birds in Green Bay; rather, the length of time was dependent only on the Green Bay action level. The deformity NOAEC threshold is met in the following number of years: 25 years (assuming a Green Bay action level of 500 ppb) and 28 years (assuming a Green Bay action level of 1,000 ppb). For the Lower Fox River remedial action level of 500 ppb, it takes 26 years (Green Bay action level of 500 ppb) and 29 years (Green Bay action level of 1,000 ppb), respectively. For the Lower Fox River remedial action level of 1,000 ppb, it takes 30 years (Green Bay action level of 1,000 ppb) to meet the deformity threshold. Assuming no action in Green Bay, the deformity NOAEC threshold is not met in less than 100 years. The piscivorous bird hatching success NOAEC was met in less than 1 year, except where the Green Bay action level was 1,000 ppb (1,000 ppb action level on the Lower Fox River) or where there was no action in Green Bay (for all Lower Fox River action levels).

Residual Mercury and DDE Levels

The distribution and concentrations of mercury and DDE and degree of co-location with PCBs within the De Pere to Green Bay Reach are shown on Figure 8-9 (mercury and PCBs) and Figure 8-10 (DDE and PCBs). These figures indicate that mercury and DDE are highly co-located with PCBs, and that these compounds are widely dispersed in terms of area, but not in terms of frequency of occurrence. In the 11 samples that were analyzed, mercury was detected in 9 samples, and p,p'-DDD, p,p'-DDE, and p,p'-DDT were never detected (Table 8-4).

Under the no action remedial action level, mercury concentrations are consistently between non-detect and 5 mg/kg, which may pose risk to invertebrates and piscivorous birds. At the 1,000 and 500 ppb action levels, mercury concentrations of up to 1 mg/kg are found in the sediment, but these concentrations are not expected to result in any adverse risk.

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7 A projection of "1 year following remediation" is a model output, and should not necessarily be literally interpreted. See footnote 1 in Section 8.4.1, RAO 3 for a discussion.

8.4.6 Green Bay Zone 3A

Residual PCB Levels

The remedial action levels considered for this zone included no action, 500, and 1,000 ppb.

RAO 2 - Human Health. As indicated in Table 8-15, none of the human health thresholds are met within 100 years no matter what remedial action level is used in the river or the bay.

RAO 3 - Ecological Health. As indicated in Table 8-17, all of the piscivorous bird ecological thresholds, except no observed piscivorous bird deformities, are met in less than 1 year, and the carnivorous bird and piscivorous mammal thresholds are not met within 100 years no matter what remedial action level is used in the river or the bay. Lower Fox River remedial action levels of 125, 250, 500, and 1,000 ppb did not affect the length of time required to meet the no observed piscivorous bird deformity threshold in Green Bay assuming Green Bay action levels of 500 and 1,000 ppb. Rather, the length of time was dependent only on the Green Bay action level. This threshold is met in the following number of years: 8 years (assuming a Green Bay action level of 500 ppb) and 11 years (assuming a Green Bay action level of 1,000 ppb). The number of years to reach this threshold assuming no action in Green Bay ranges from 43 years (with Lower Fox River action levels of 125, 250, 500, and 1,000 ppb), 44 years (with a Lower Fox River action level of 5,000 ppb), to 51 years (assuming no action on the river).

Residual Mercury and DDE Levels

Assuming action levels of 500 and 1,000 ppb or no action in Green Bay Zone 3A, mercury is of potential risk to piscivorous birds and DDE is of no potential risk. These BLRA conclusions are based limited data: 2 sediment samples, 1 benthic fish, 12 pelagial fish, 3 carnivorous birds, and modeled concentrations in piscivorous and carnivorous birds, and piscivorous mammals. No data were available for insectivorous birds. As indicated on Figures 8-9 and 8-10 and in Table 8-4, of the two sediment samples analyzed, mercury and DDD/DDE/DDT were not detected.

8.4.7 Green Bay Zone 3B

Residual PCB Levels

The remedial action levels considered for this zone included no action and 500 ppb.

RAO 2 - Human Health. As indicated in Table 8-15, the only human health threshold that is met in less than 100 years is the noncancer threshold for recreational anglers. This threshold is only met when Green Bay Zone 3B is remediated to an action level of 500 ppb and the Lower Fox River is remediated to either 125, 250, or 500 ppb. Under these different Lower Fox River action levels, it takes 99 years to reach the threshold.

RAO 3 - Ecological Health. As indicated in Table 8-17, all of the piscivorous bird ecological thresholds, except no observed piscivorous bird deformities, are met in less than 1 year, and the carnivorous bird and piscivorous mammal thresholds are not met within 100 years no matter what remedial action level is used in the river or the bay. Lower Fox River remedial action levels of 125, 250, 500, and 1,000 ppb did not affect the length of time required to meet the no observed piscivorous bird deformity threshold in Green Bay assuming a Green Bay action level of 500 ppb. Rather, the length of time was dependent only on the Green Bay action level. This threshold is met in 7 years assuming a Green Bay action level of 500 ppb (Lower Fox River action levels of 125, 250, and 500 ppb). The number of years to reach this threshold assuming no action in Green Bay ranges from 32 years (with as Lower Fox River action levels of 125, 250, 500, and 1,000 ppb), to 33 years (with a Lower Fox River action level of 5,000 ppb), to 38 years assuming no action on the river.

Residual Mercury and DDE Levels

Assuming an action level of 500 ppb or no action in Green Bay Zone 3B, mercury is of risk to benthic invertebrates and potential risk to pelagial fish, and piscivorous and carnivorous birds. DDE is a potential risk for pelagic fish, and piscivorous and carnivorous birds. These BLRA conclusions are based on limited data: 4 sediment samples, 1 benthic fish, 4 pelagial fish, 20 piscivorous birds, and modeled concentrations in piscivorous and carnivorous birds, and piscivorous mammals. No data were available for insectivorous birds. As indicated on Figures 8-9 and 8-10 and in Table 8-4, of the four sediment samples analyzed, DDD/DDE/DDT were not detected, mercury was only detected in one of the samples, and the samples were not collected in areas of known PCB contamination.

8.4.8 Green Bay Zone 4

Residual PCB Levels

No remedial action levels were considered for this zone. Only the No Action alternative was carried forward in the FS.

RAO 2 - Human Health. As indicated in Table 8-15, none of the human health thresholds are met within 100 years no matter what remedial action level is used in the river.

RAO 3 - Ecological Health. As indicated in Table 8-17, all of the piscivorous bird ecological thresholds are met in less than 1 year except for the deformity NOAEC, and the carnivorous bird and piscivorous mammal thresholds are not met within 100 years no matter what remedial action level is used in the river. The deformity NOAEC for piscivorous birds is met within 5 years at all Lower Fox River action levels.

Residual Mercury and DDE Levels

Assuming no action in Green Bay Zone 4, mercury is of potential risk to piscivorous and carnivorous birds, and DDE is a potential risk for pelagic fish and carnivorous birds. These BLRA conclusions are based on limited data: 4 sediment samples, 20 pelagial fish, and modeled concentrations in piscivorous and carnivorous birds, and piscivorous mammals. No data were available for benthic fish or insectivorous birds. As indicated on Figures 8-9 and 8-10 and in Tables 8-3 and 8-4, of the four sediment samples analyzed, DDD/DDE/DDT were not detected, mercury was only detected in one of the samples, and PCB concentrations were less than 500 μg/kg.

Conclusion

For all of Green Bay (zones 2, 3A, 3B, and 4), based upon the evaluations presented above, none of the action levels meet the state goals of the human health RAO. The only ecological RAO goals that are met within 100 years are the piscivorous bird hatching success NOAEC and LOAEC, and the piscivorous bird deformity LOAEC. Additionally, the piscivorous bird deformity NOAEC is met within 100 years in all zones except Zone 2.

8.5 Uncertainty Analysis

There is always considerable uncertainty in using a long-term predictive model to forecast risks to human health and the environment. While the wLFRM has been shown to be a reasonably accurate tool for forecasting changes to surface sediment concentrations and mass export of PCBs to Green Bay (WDNR, 1997), there remains uncertainty in the actual magnitude of the changes predicted by the model. These same uncertainties also apply to the GBTOXe model. These uncertainties reside in the models themselves, the assumptions used for each of the functional action levels, and the application of the actual data to the models. An assumption of the models that are used to project sediment loading rates and water, sediment, and tissue concentrations is that no matter what remedial action level is selected, the remediation will take 10 years. A result of this assumption is that all of the model runs start and occur within the same hydrograph time frame. Therefore, water flow rates are consistent for each action level—high and low flow events occur at the same week for each action level. While this simplifies the comparison of residual PCB concentrations and load rates, it is understood that not all remedial action levels will take 10 years to implement. However, the uncertainties are mitigated by the fact that the alternative-specific risk assessment is intended solely to provide a relative level of residual risk between each of the proposed action levels, and not necessarily to provide 100 percent accurate predictions. Within this context, the models employed and the accompanying assumptions are adequate for the purposes of this FS.

Additional uncertainty results from the time between achieving an RAO human health or ecological threshold, and the time until risk reduction is actually observed. While total PCB concentrations in sediments may be at the selected action level concentration, it may take several years before fish show changes in total PCB body concentrations/mass. This uncertainty can be mitigated by a well-designed post-remediation sediment and fish tissue monitoring program (Appendix C).

Use of the wLFRM shows that over time most of the sediment is transported downstream, but this may still result in short-term increased risks to some organisms.

Finally, residual risks posed by the COCs other than total PCBs, are based upon the data in the FRDB. The distribution plots may be skewed by uneven, biased sampling for these other constituents.

8.6 Section 8 Figures and Tables

Figures and tables for Section 8 follow page 8-32 and include:

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Natural Resource Technology

Lower Fox River & Green Bay Feasibility Study

Surface Sediment Total PCB and Mercury Distribution: Little Lake Butte des Morts Reach

FIGURE 8-1

FIGURE NO:	FS8-1
CREATED BY:	SCJ
PRINT DATE:	1/18/01
APPROVED:	AGF

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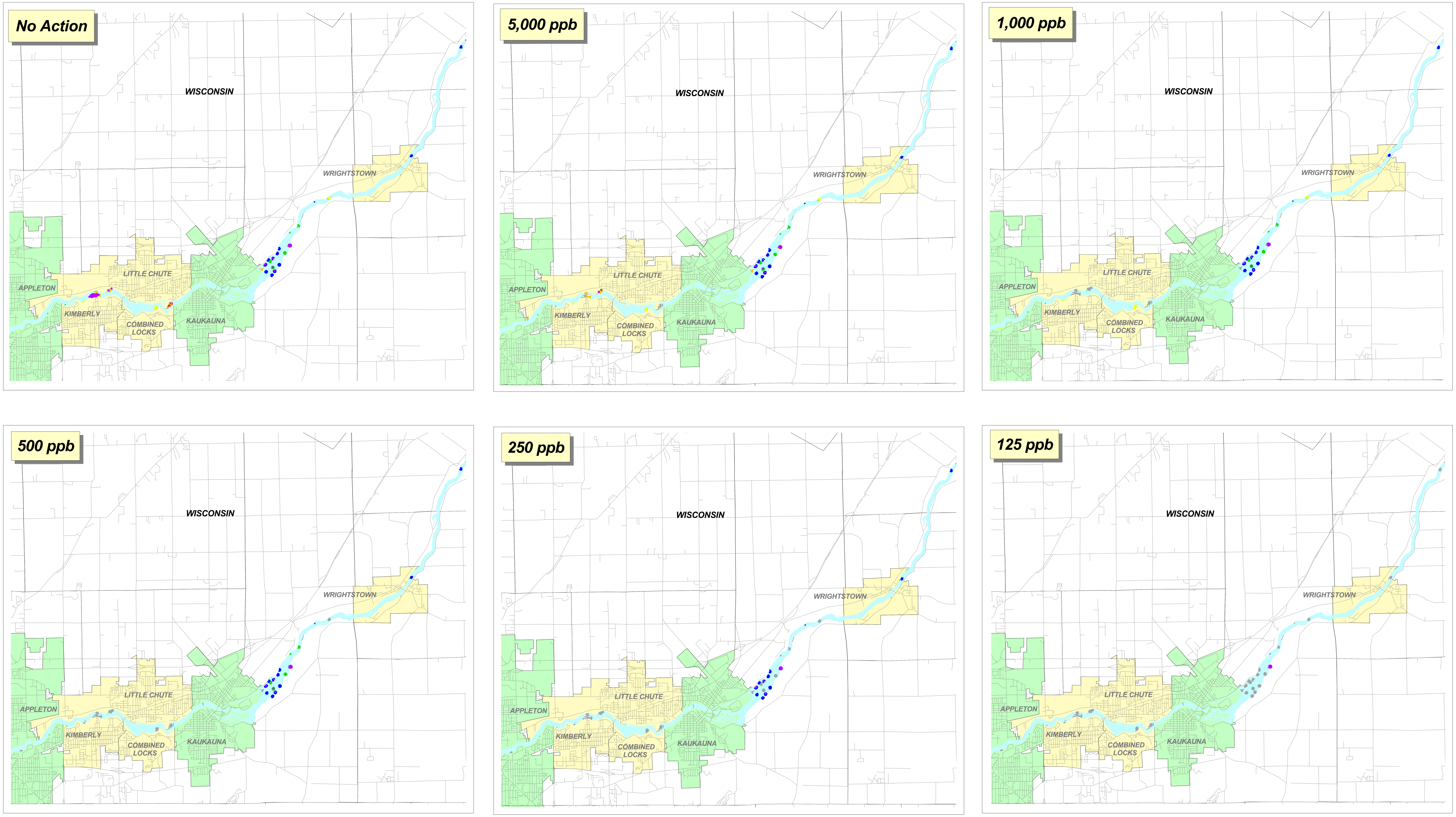
Surface Sediment Total PCB and DDE Distribution: Little Lake Butte des Morts Reach

FIGURE 8-2

FIGURE NO:	FS8-2
CREATED BY:	SCJ
PRINT DATE:	1/18/01
APPROVED:	AGF



PCB Concentrations (ug/kg)
- > 125
- > 250
- > 500
- > 1,000
- > 5,000
- Dredged Sediments

Mercury (mg/kg)
- 0 - 1
- 1 - 5
- 5 - 7
- 7 - 10

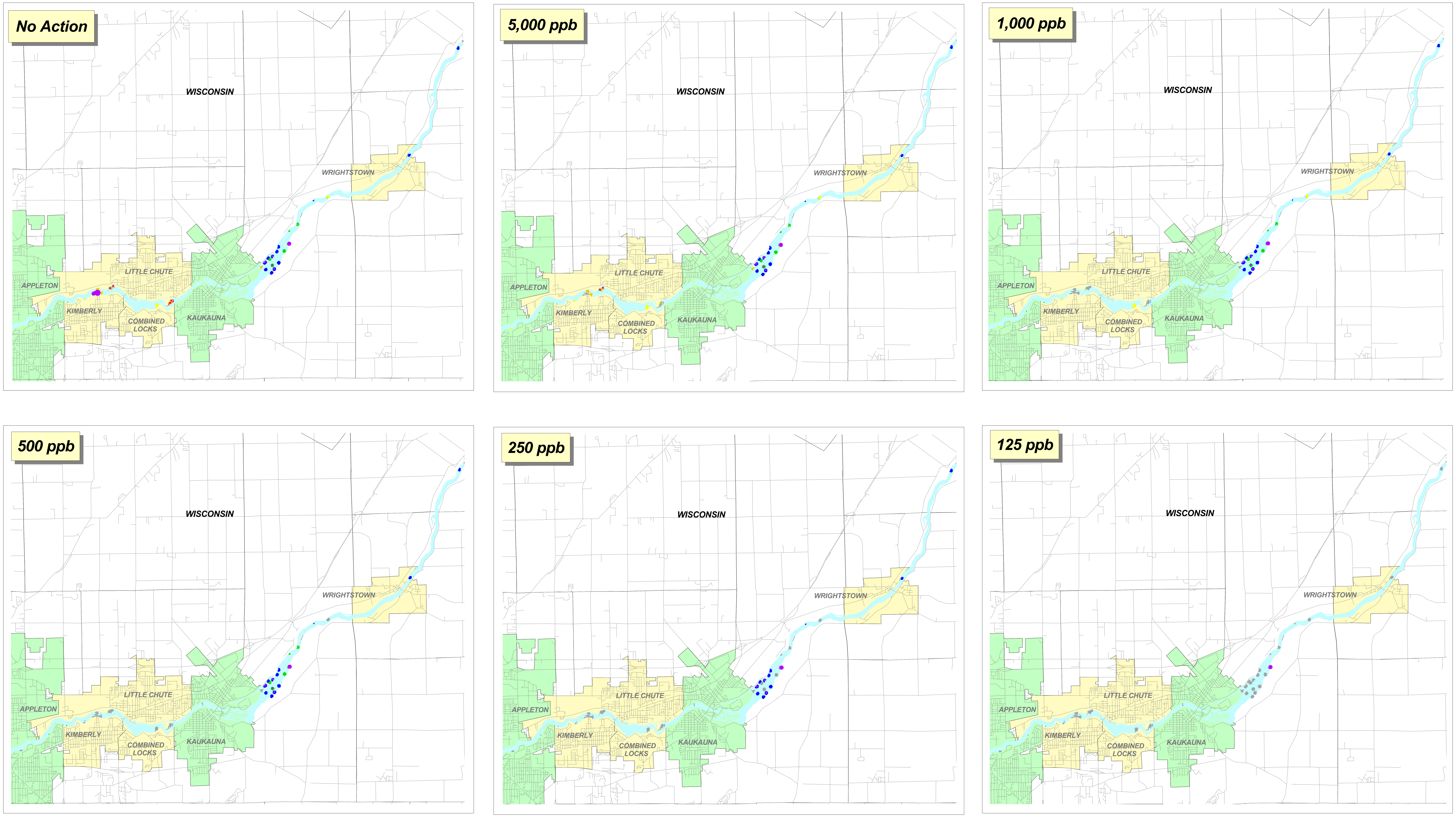
Roads
Water

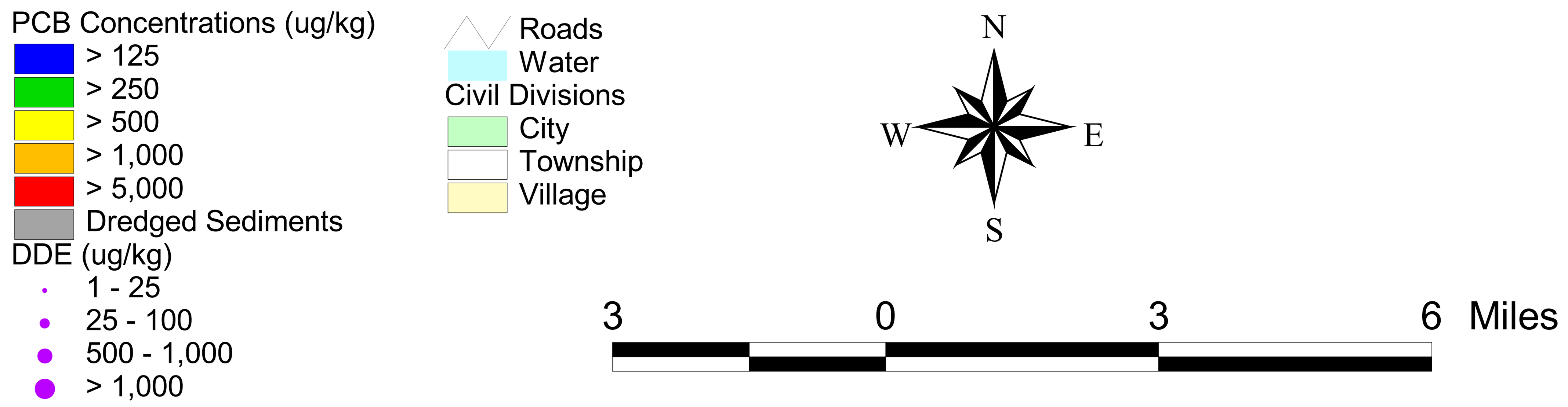
Civil Divisions
- City
- Township
- Village

N
W E
S

3 0 3 6 Miles

Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Surface Sediment Total PCB and Mercury Distribution: Appleton to Little Rapids Reach	FIGURE NO: FS8-3
			CREATED BY: SCJ
			PRINT DATE: 1/18/01
		FIGURE 8-3	APPROVED: AGF





ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Lower Fox River & Green Bay Feasibility Study	Surface Sediment Total PCB and DDE Distribution: Appleton to Little Rapids Reach	FIGURE NO: FS8-4
				CREATED BY: SCJ
				PRINT DATE: 1/18/01
			FIGURE 8-4	APPROVED: AGF

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Surface Sediment Total PCB and Mercury Distribution: Little Rapids to De Pere Reach

FIGURE 8-5

FIGURE NO: FS8-5
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Lower Fox River & Green Bay Feasibility Study

Surface Sediment Total PCB and DDE Distribution: Little Rapids to De Pere Reach

FIGURE 8-6

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Lower Fox River & Green Bay Feasibility Study

Surface Sediment Total PCB and Mercury Distribution: De Pere to Green Bay Reach

FIGURE 8-7

FIGURE NO:	FS8-7
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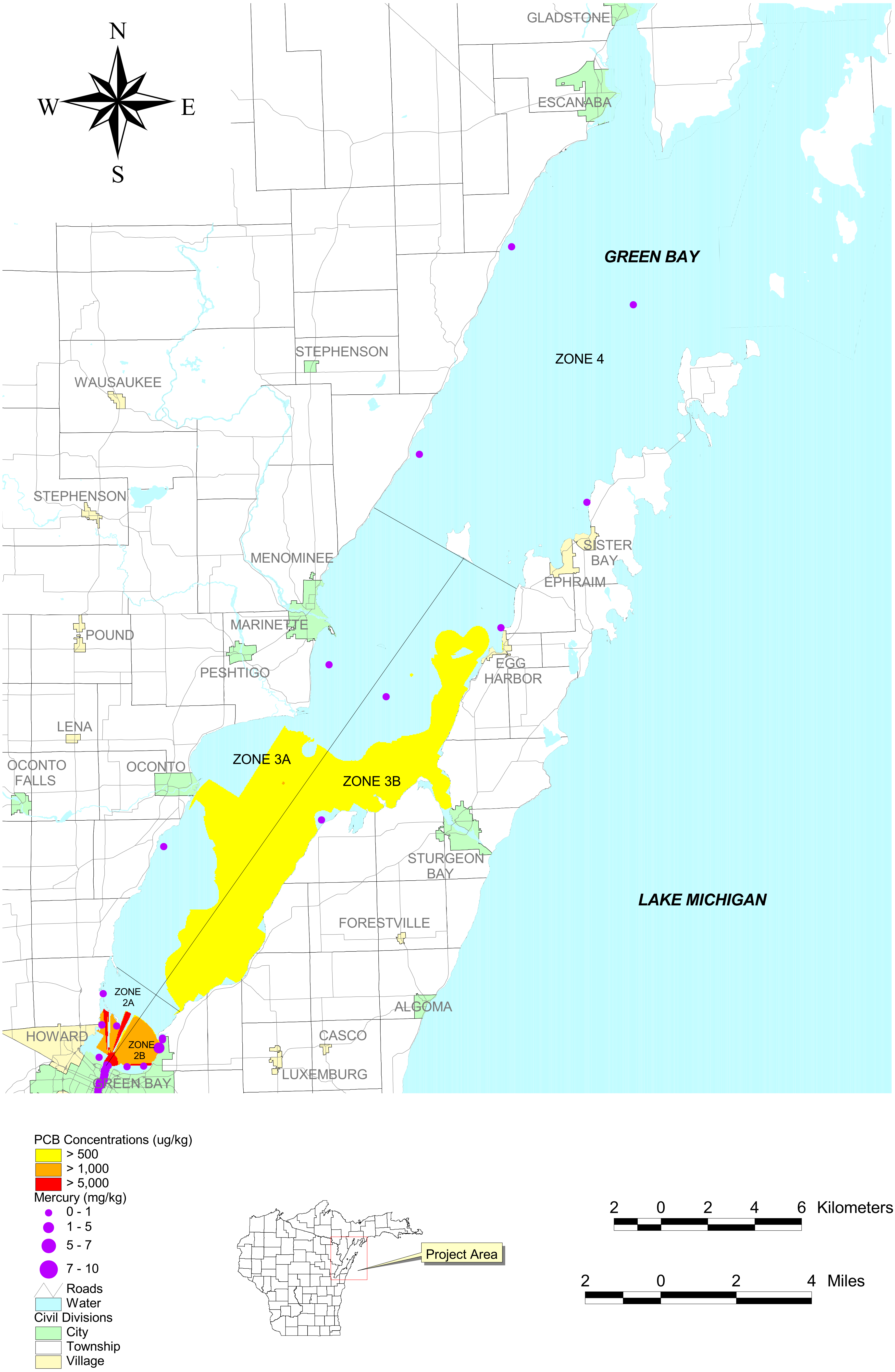
Lower Fox River & Green Bay Feasibility Study

Surface Sediment Total PCB and DDE Distribution: De Pere to Green Bay Reach

FIGURE 8-8

FIGURE NO:	FS8-8
CREATED BY:	SCJ
PRINT DATE:	1/18/01
APPROVED:	AGF



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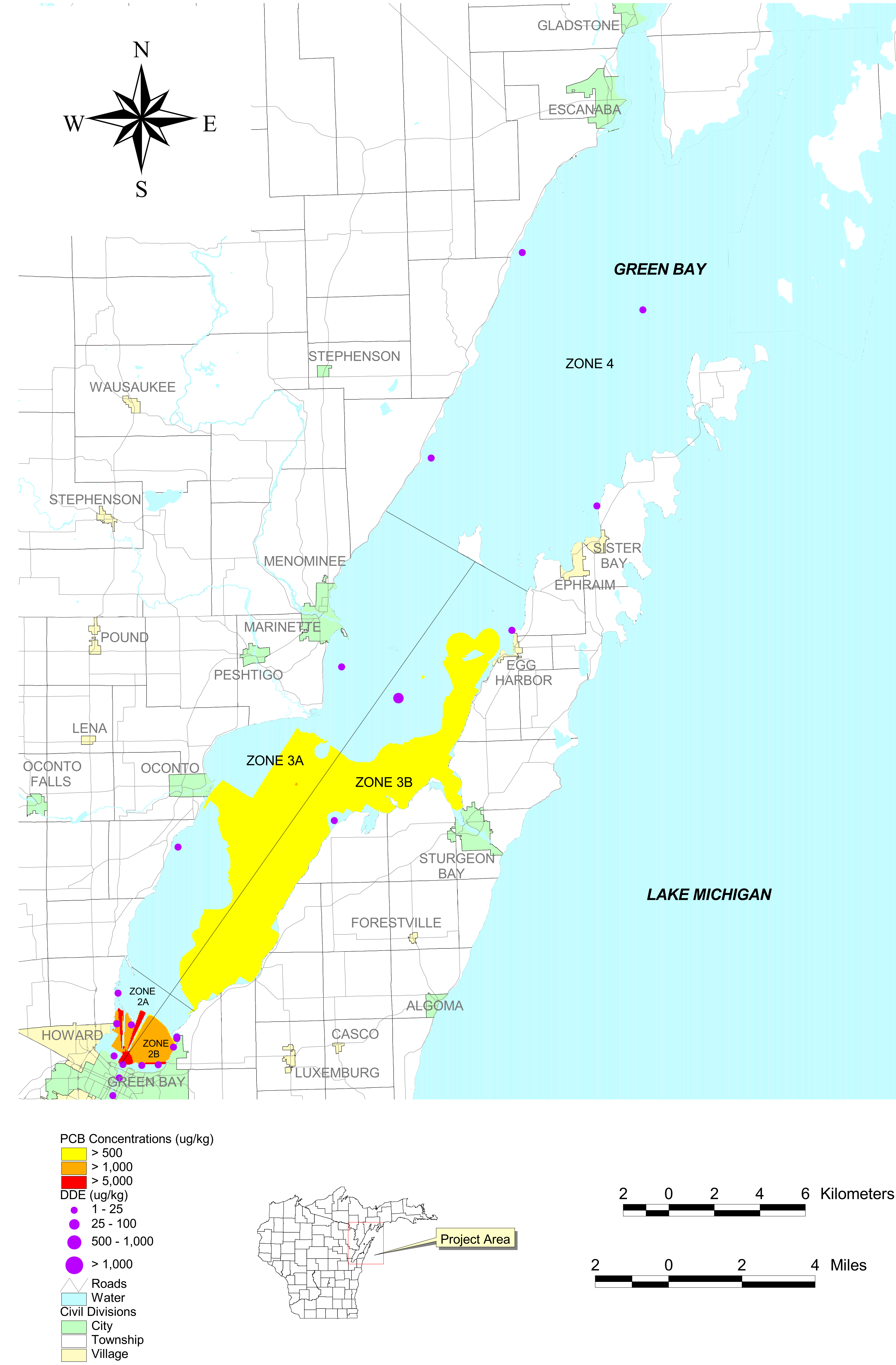
Lower Fox River &
Green Bay Feasibility Study

SURFACE SEDIMENT PCB AND MERCURY DISTRIBUTION IN GREEN BAY

DATE: 05/03/01	FILE: FS8GB	FIGURE 8-9



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Lower Fox River & Green Bay Feasibility Study

SURFACE SEDIMENT PCB AND DDE DISTRIBUTION IN GREEN BAY

DATE: 05/03/01 | FILE: FS8GB | FIGURE 8-10

Table 8-1 Relationship of Models Used for Risk Projections in the Lower Fox River or Green Bay

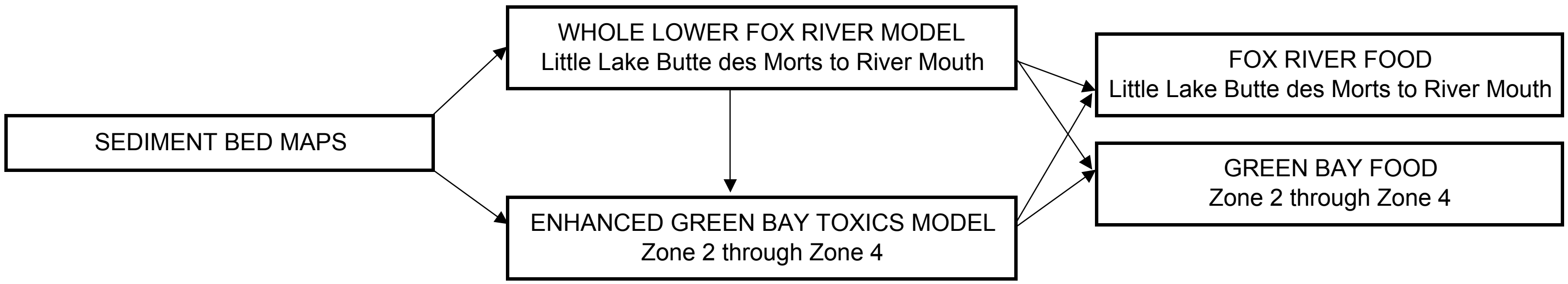
	BASELINE AND REMEDIAL CONDITIONS	FATE AND TRANSPORT MODELS	BIOACCUMULATION MODELS
MODEL			
OUTPUT	• Baseline and Remedial Action Level Surface Sediment Concentrations • Surface-weighted Average Concentrations • Residual DDE and Mercury Risks (RAO 2 & 3)	• Total PCBs in Water (RAO 1) • Total PCBs in Sediments (RAO 3) • Downstream PCB Transport (RAO 4)	• Total PCBs in Forage Fish (RAO 3) Alewife, shiners, shad • Total PCBs in Benthic Fish (RAO 2 & 3) Carp • Total PCBs in Piscivorous Fish (RAO 2 & 3) Walleye, perch
DOCUMENTATION	*Remedial Investigation* *Technical Memorandum 2e* *Technical Memorandum 2e Addendum* *Technical Memorandum 2f*	*Model Documentation Technical Memo* *wLFRM Model Documentation Report (Appendix B)* *GBTOXe Model Documentation Report (Appendix C)*	*Baseline Risk Assessment* *FRFood Model Documentation Report (Appendix D)* *GBFood Model Documentation Report (Appendix E)*
APPLICATION	*Remedial Investigation* *Baseline Risk Assessment* *Feasibility Study*	*Baseline Risk Assessment* *Feasibility Study*	*Baseline Risk Assessment* *Feasibility Study*

Table 8-2 Whole Body Fish Tissue Concentrations Estimated for Human Health Effects at a 10^{-5} Cancer Risk and a Hazard Index of 1.0

	Fish Parameters	Whole Fish Tissue Concentrations			
	Fillet-to-whole Fish Ratio	Recreational Anglers: Avgerage of Michigan Studies (West *et al.*, 1989; West *et al.*, 1993)		High-intake Fish Consumers: Average of Low-income Minority Anglers and Hmong Anglers (West *et al.*, 1993; Hutchison and Kraft, 1994)	
		RME µg/kg	CTE µg/kg	RME µg/kg	CTE µg/kg
Risk-based Fillet Fish Concentrations (µg/kg) for Risk of 10^{-5} *		18	120	12	63
Whole Fish Thresholds for Risk of 10^{-5}					
Carp	0.53	***34***	***226***	***23***	***119***
Walleye	0.17	***106***	***706***	***71***	***371***
Yellow Perch	0.17	***106***	***706***	***71***	***371***
Risk-based Fillet Fish Concentrations (µg/kg) for HI of 1.0		49	200	31	101
Whole Fish Thresholds for HI of 1.0					
Carp	0.53	***92***	***377***	***58***	***191***
Walleye	0.17	***288***	***1,176***	***181***	***594***
Yellow Perch	0.17	***288***	***1,176***	***181***	***594***

Notes:

* ***Whole fish thresholds for cancer risks of 10^{-4} and 10^{-6} are an order of magnitude higher, and lower, respectively.***
RME indicates reasonable maximum exposure and CTE indicates central tendency exposure.
Whole fish thresholds are **bolded** and in *italics*.

Table 8-3 No Action Non-interpolated Sediment Concentrations of Total PCBs (µg/kg)

Reach or Zone	Number of Samples	Number of Detects	Mean	95% UCL
Little Lake Butte des Morts	302	294	10,724	22,848
Appleton to Little Rapids	131	122	6,751	15,267
Little Rapids to De Pere	209	203	4,782	10,543
De Pere to Green Bay (Green Bay Zone 1)	290	285	4,184	5,510
Green Bay Zone 2	15	14	251	720
Green Bay Zone 3A	15	13	376	518
Green Bay Zone 3B	40	35	542	809
Green Bay Zone 4	31	27	83	117

Table 8-4 No Action Sediment Concentrations of Mercury and DDT/DDD/DDE

Reach or Zone	Analyte	Units	Number of Samples	Number of Detects	Mean	95% UCL	
Little Lake Butte des Morts	Mercury	mg/kg	86	71	1.0	1.4	
	p,p'-DDD	μg/kg	23	4	17.8	19	*
	p,p'-DDE	μg/kg	20	0			
	p,p'-DDT	μg/kg	20	2	13.0	50.0	**
Appleton to Little Rapids	Mercury	mg/kg	10	10	0.8	1.7	
	p,p'-DDD	μg/kg	10	2	1.0	1.7	**
	p,p'-DDE	μg/kg	10	0			
	p,p'-DDT	μg/kg	10	1		3.4	***
Little Rapids to De Pere	Mercury	mg/kg	74	74	3.5	4.0	
	p,p'-DDD	μg/kg	20	5	1.5	2.8	**
	p,p'-DDE	μg/kg	19	4	12.5	22.0	*
	p,p'-DDT	μg/kg	14	3	16.5	20.0	*
De Pere to Green Bay (Green Bay Zone 1)	Mercury	mg/kg	92	89	1.0	1.4	
	p,p'-DDD	μg/kg	22	3	1.2	4.5	**
	p,p'-DDE	μg/kg	22	1		1.9	***
	p,p'-DDT	μg/kg	22	0			
Green Bay Zone 2	Mercury	mg/kg	11	9	0.5	1.5	*
	p,p'-DDD	μg/kg	11	0			
	p,p'-DDE	μg/kg	11	0			
	p,p'-DDT	μg/kg	11	0			
Green Bay Zone 3A	Mercury	mg/kg	2	0			
	p,p'-DDD	μg/kg	2	0			
	p,p'-DDE	μg/kg	2	0			
	p,p'-DDT	μg/kg	2	0			
Green Bay Zone 3B	Mercury	mg/kg	4	1		0.2	***
	p,p'-DDD	μg/kg	4	0			
	p,p'-DDE	μg/kg	4	0			
	p,p'-DDT	μg/kg	4	0			
Green Bay Zone 4	Mercury	mg/kg	4	1		0.11	***
	p,p'-DDD	μg/kg	4	0			
	p,p'-DDE	μg/kg	4	0			
	p,p'-DDT	μg/kg	4	0			

Notes:

* Maximum concentration not the 95% UCL.
** Minimum and maximum concentration.
*** Only concentration.

Table 8-5 Projected Surface Water Concentrations - RAO 1

A. RAO 1: Years to Reach Comparative Surface Water Concentrations

River Reach	Comparative Surface Water Total PCB Concentrations (ng/L)[1]	Action Level (ppb)					
		No Action	5,000	1,000	500	250	125
Little Lake Butte des Morts	drinking water criteria (0.003 ng/L)	>100	>100	>100	>100	>100	>100
	wildlife criteria (0.12 ng/L)	>100	>100	52	39	19	16
	Lake Winnebago maximum concentration (13 ng/L)	4	1	<1	<1	<1	<1
Appleton to Little Rapids	drinking water criteria (0.003 ng/L)	>100	>100	>100	>100	>100	>100
	wildlife criteria (0.12 ng/L)	>100	>100	52	40	21	19
	Lake Winnebago maximum concentration (13 ng/L)	4	<1	<1	<1	<1	<1
Little Rapids to De Pere	drinking water criteria (0.003 ng/L)	>100	>100	>100	>100	>100	>100
	wildlife criteria (0.12 ng/L)	>100	>100	65	54	40	27
	Lake Winnebago maximum concentration (13 ng/L)	9	2	<1	<1	<1	<1
De Pere to Green Bay	drinking water criteria (0.003 ng/L)	>100	>100	>100	>100	>100	>100
	wildlife criteria (0.12 ng/L)	>100	>100	69	65	40	27
	Lake Winnebago maximum concentration (13 ng/L)	>100	2	<1	<1	<1	<1

Note:

[1] Wildlife criteria comes from NR 105 WAC and the Lake Winnebago concentration is the current concentration.

B. RAO 1: Surface Water Total PCB Concentrations - 30 Years Post-remediation (ng/L)[1]

River Reach	Action Level (ppb)					
	No Action	5,000	1,000	500	250	125
Little Lake Butte des Morts	2.99	1.67	0.18	0.13	0.05	0.04
Appleton to Little Rapids	2.76	1.59	0.19	0.14	0.06	0.04
Little Rapids to De Pere	5.37	2.36	0.37	0.24	0.14	0.08
De Pere to Green Bay	21.08	2.60	0.42	0.28	0.15	0.09

Note:

[1] 30 years post-remediation for all action levels.

Table 8-6 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Little Lake Butte des Morts Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	8	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	20	8	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	14	2	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	14	4	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	20	9	<1	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	20	9	<1	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	29	11	<1	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	55	34	<1	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	40	17	<1	<1	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	58	35	2	<1	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	51	29	<1	<1	<1	<1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	70	46	5	2	<1	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	71	46	5	2	<1	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	77	54	8	4	<1	<1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	65	40	4	<1	<1	<1
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	100	67	14	10	2	<1
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	84	57	9	5	<1	<1
92	carp	human health	CTE hazard index of 1.0	recreational angler	>100	77	17	14	4	2
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	100	70	14	10	4	2
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	>100	95	25	21	8	5
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	95	25	20	9	7
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	37	33	15	11
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	51	42	20	17
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	70	61	34	30
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	58	50	25	20
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	70	64	34	30
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	>100	>100
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	18	8	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	17	8	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	20	8	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	32	14	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	34	15	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	42	22	<1	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	100	67	14	9	< 1	< 1
50	carp	ecological	NOAEC	piscivorous mammal	>100	100	29	25	9	7
223	sediment	ecological	TEL	sediment invertebrate	>100	>100	60	52	26	21

Notes:

1 Sediment concentration is presented in units of mg/kg OC.

2 Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

Table 8-7 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Appleton to Little Rapids Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	<1	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	2	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	12	5	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	9	2	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	9	2	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	17	9	<1	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	17	9	<1	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	20	9	<1	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	39	26	4	2	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	34	17	2	<1	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	42	30	5	3	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	40	26	4	<1	<1	<1
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	55	37	9	7	2	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	55	39	9	7	2	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	62	42	12	9	4	2
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	55	37	7	5	2	<1
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	76	55	17	15	9	7
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	70	42	14	11	7	5
92	carp	human health	RME hazard index of 1.0	recreational angler	87	65	21	17	12	6
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	89	65	17	15	9	8
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	78	84	30	25	17	14
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	100	92	33	26	17	14
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	100	43	37	23	14
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	100	57	45	29	23
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	80	65	42	35
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	100	70	55	34	27
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	89	80	50	42
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	>100	60
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	81
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	12	4	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	12	5	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	15	8	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	20	11	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	21	12	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	33	17	2	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	71	55	17	15	9	7
50	carp	ecological	NOAEC	piscivorous mammal	100	89	34	29	18	15
771	sediment	ecological	TEL	sediment invertebrate	81	63	28	24	16	13

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

Table 8-8 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Little Rapids to De Pere Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	2	<1	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	4	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	30	4	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	30	10	<1	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	34	14	<1	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	51	20	2	<1	<1	<1
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	51	20	2	<1	<1	<1
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	59	29	2	<1	<1	<1
377	carp	human health	CTE hazard index of 1.0	recreational angler	70	34	4	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	80	42	8	2	<1	<1
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	77	38	5	<1	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	92	52	9	5	2	2
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	100	52	9	2	<1	<1
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	100	52	9	4	<1	<1
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	58	14	5	2	<1
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	67	17	12	7	4
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	77	22	14	9	4
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	92	30	20	14	9
92	carp	human health	RME hazard index of 1.0	recreational angler	>100	90	30	17	12	7
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	100	42	29	20	15
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	40	27	20	14
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	62	45	36	15
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	55	42	34	20
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	67	54	43	25
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	90	80	65	45
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	100	92	79	55
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	70
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	>100	95
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	<1	<1	<1	<1	<1	<1
4,083	gizzard shad	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	gizzard shad	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	gizzard shad	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	20	4	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	22	5	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	45	20	<1	<1	<1	<1
760	carp	ecological	NOAEC	fish	39	14	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	42	15	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	61	25	2	<1	<1	<1
408	gizzard shad	ecological	NOAEC	piscivorous bird deformity	2	<1	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	>100	76	22	12	8	4
50	carp	ecological	NOAEC	piscivorous mammal	>100	>100	43	31	25	15
596	sediment	ecological	TEL	sediment invertebrate	>100	>100	46	33	28	16

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

Table 8-9 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): De Pere to Green Bay Reach

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	<1	<1	<1	<1	<1	<1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	100	4	<1	<1	<1	<1
2,260	carp	human health	CTE 10^{-4} cancer risk level	recreational angler	>100	<1	<1	<1	<1	<1
1,190	carp	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	>100	8	<1	<1	<1	<1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	>100	27	2	<1	<1	<1
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	>100	36	4	<1	<1	<1
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	42	7	4	2	2
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	42	7	4	2	2
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	51	9	5	4	2
377	carp	human health	CTE hazard index of 1.0	recreational angler	>100	22	5	<1	<1	<1
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	65	15	9	7	4
340	carp	human health	RME 10^{-4} cancer risk level	recreational angler	>100	38	5	2	<1	<1
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	79	20	14	8	7
230	carp	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	52	10	5	2	2
226	carp	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	52	11	5	2	2
189	carp	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	100	14	7	4	2
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	100	30	20	14	7
119	carp	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	79	20	14	8	5
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	100	45	34	20	15
92	carp	human health	RME hazard index of 1.0	recreational angler	>100	92	29	17	9	7
71	walleye	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	100	59	45	29	20
58	carp	human health	RME hazard index of 1.0	high-intake fish consumer	>100	100	54	29	17	11
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	80	70	51	31
34	carp	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	58	45	27	17
23	carp	human health	RME 10^{-5} cancer risk level; CTE 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	70	59	38	22
12	carp	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	92	87	61	42
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	100	100	100	77
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100
3	carp	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	>100	>100	>100	>100
2	carp	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	91	<1	<1	<1	<1	<1
7,600	carp	ecological	LOAEC	fish	8	<1	<1	<1	<1	<1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
1,207	carp	ecological	LOAEC	carnivorous bird deformity	>100	7	<1	<1	<1	<1
1,147	carp	ecological	LOAEC	carnivorous bird hatching success	>100	8	<1	<1	<1	<1
760	walleye	ecological	NOAEC	fish	>100	42	7	4	2	<1
760	carp	ecological	NOAEC	fish	>100	15	<1	<1	<1	<1
709	carp	ecological	NOAEC	carnivorous bird hatching success	>100	17	<1	<1	<1	<1
500	carp	ecological	LOAEC	piscivorous mammal	>100	27	2	<1	<1	<1
408	alewife	ecological	NOAEC	piscivorous bird deformity	100	9	<1	<1	<1	<1
121	carp	ecological	NOAEC	carnivorous bird deformity	>100	79	20	14	7	5
50	carp	ecological	NOAEC	piscivorous mammal	>100	100	45	34	17	14
632	sediment	ecological	TEL	sediment invertebrate	>100	93	37	23	13	6

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

CTE - Central Tendency Exposure

LOAEC - Lowest Observed Adverse Effect Concentration

NOAEC - No Observed Adverse Effect Concentration

RME - Reasonable Maximum Exposure

TEL - Threshold Effect Level

Table 8-10 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 2

A. Organized by Fox River Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb		Fox River 500 ppb			Fox River 250 ppb			Fox River 125 ppb		
					Green Bay	Green Bay	Green Bay (ppb)		Green Bay (ppb)			Green Bay (ppb)			Green Bay (ppb)		
					No Action	No Action	No Action	1,000	No Action	1,000	500	No Action	1,000	500	No Action	1,000	500
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	45	34	32	< 1	32	< 1	< 1	32	< 1	< 1	32	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	83	62	60	3	60	2	2	60	2	2	60	2	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	>100	>100	>100	61	>100	59	55	>100	58	54	>100	58	53
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	>100	>100	>100	75	>100	75	71	>100	74	70	>100	74	69
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	> 100	>100	99	>100	99	99	>100	99	99	>100	99	99
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	> 100	>100	99	>100	99	99	>100	99	99	>100	99	99
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	> 100	>100	>100	>100	>100	99	>100	99	99	>100	99	99
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	30	24	23	3	23	< 1	< 1	23	< 1	< 1	23	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	>100	>100	>100	57	>100	55	51	>100	54	50	>100	54	50
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	>100	>100	>100	64	>100	63	59	>100	62	58	>100	62	57
760	walleye	ecological	NOAEC	fish	>100	> 100	>100	40	>100	39	34	>100	38	33	>100	37	33
760	alewife	ecological	NOAEC	fish	>100	75	74	7	73	6	5	73	6	5	73	6	5
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	> 100	>100	99	>100	99	99	>100	99	99	>100	99	99
500	walleye	ecological	LOAEC	mink	>100	> 100	>100	94	>100	94	91	>100	93	90	>100	93	90
500	alewife	ecological	LOAEC	mink	>100	80	83	10	80	10	9	80	10	8	80	9	8
408	alewife	ecological	NOAEC	piscivorous bird deformity	>100	>100	>100	30	>100	29	26	>100	28	25	>100	28	25
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	> 100	>100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100

Table 8-10 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 2 (Continued)

B. Organized by Green Bay Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Green Bay No Action						Green Bay 1,000 ppb				Green Bay 500 ppb		
					Fox River (ppb)						Fox River (ppb)				Fox River (ppb)		
					No Action	5,000	1,000	500	250	125	1,000	500	250	125	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	45	34	32	32	32	32	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	83	62	60	60	60	60	3	2	2	2	< 1	2	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	>100	>100	>100	>100	>100	>100	61	59	58	58	55	54	53
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	>100	>100	>100	>100	>100	>100	75	75	74	74	71	70	69
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	99	99	99	99	99	99	99
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	99	99	99	99	99	99	99
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	>100	>100	99	99	99	99	99
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	30	24	23	23	23	23	3	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	>100	>100	>100	>100	>100	89	57	55	54	54	51	50	50
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	>100	>100	>100	>100	>100	>100	64	63	62	62	59	58	57
760	walleye	ecological	NOAEC	fish	>100	>100	> 100	>100	>100	>100	40	39	38	37	34	33	33
760	alewife	ecological	NOAEC	fish	>100	75	74	73	73	73	7	6	6	6	5	5	5
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	>100	> 100	>100	>100	>100	99	99	99	99	99	99	99
500	walleye	ecological	LOAEC	mink	>100	>100	> 100	>100	>100	>100	94	94	93	93	91	90	90
500	alewife	ecological	LOAEC	mink	>100	83	80	80	80	80	10	10	10	9	9	8	8
408	alewife	ecological	NOAEC	piscivorous bird deformity	>100	>100	>100	>100	>100	>100	30	29	28	28	26	25	25
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100

Table 8-11 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 3A

A. Organized by Fox River Remedial Action Level

Media Threshold Concentration (µg/kg)[1]	Media[2]	Threshold Type	Risk Level	Receptor	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb		Fox River 500 ppb			Fox River 250 ppb			Fox River 125 ppb		
					Green Bay No Action	Green Bay No Action	Green Bay (ppb)		Green Bay (ppb)			Green Bay (ppb)			Green Bay (ppb)		
							No Action	1,000	No Action	1,000	500	No Action	1,000	500	No Action	1,000	500
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	2	2	2	< 1	2	< 1	< 1	2	< 1	>100	2	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	25	19	18	5	18	5	4	18	5	4	18	5	4
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	99	99	99	60	99	60	55	99	60	55	99	60	55
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	99	99	99	75	99	74	70	99	74	69	99	74	69
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	90	89	>100	88	>100	>100	88	>100	>100	88	>100	>100
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	91	89	>100	89	>100	>100	89	36	>100	89	>100	>100
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	>100	>100	57	>100	>100	57	>100
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	99	99	99	57	99	57	51	99	56	51	99	56	50
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	99	99	99	64	99	63	59	99	63	58	99	63	58
760	walleye	ecological	NOAEC	fish	>100	84	82	31	82	>100	>100	82	>100	>100	82	>100	>100
760	alewife	ecological	NOAEC	fish	6	5	5	< 1	5	< 1	< 1	5	2	< 1	5	2	< 1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	90	89	>100	89	>100	>100	89	>100	>100	88	>100	>100
500	walleye	ecological	LOAEC	mink	>100	>100	> 100	80	>100	79	75	>100	79	75	>100	79	75
500	alewife	ecological	LOAEC	mink	35	30	29	7	29	< 1	5	29	7	5	29	7	5
408	alewife	ecological	NOAEC	piscivorous bird deformity	51	44	43	11	43	11	8	43	11	8	43	11	8
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	> 100	>100	>100	> 100	>100	>100	>100	>100	>100	>100

Table 8-11 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 3A (Continued)

B. Organized by Green Bay Remedial Action Level

Media Threshold Concentration (µg/kg)[1]	Media[2]	Threshold Type	Risk Level	Receptor	Green Bay No Action						Green Bay 1,000 ppb				Green Bay 500 ppb		
					Fox River (ppb)						Fox River (ppb)				Fox River (ppb)		
					No Action	5,000	1,000	500	250	125	1,000	500	250	125	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	2	2	2	2	2	2	< 1	< 1	< 1	< 1	< 1	99	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	25	19	18	18	18	18	5	5	5	5	4	4	4
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	99	99	99	99	99	99	60	60	60	60	55	55	55
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	99	99	99	99	99	99	75	74	74	74	70	69	69
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	90	89	88	88	88	99	99	99	99	99	99	99
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	91	89	89	89	89	99	99	99	99	99	99	99
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	99	99	57	57	99	99	99
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	99	99	99	99	99	99	57	57	56	56	51	51	50
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	99	99	99	99	99	99	64	63	63	63	59	58	58
760	walleye	ecological	NOAEC	fish	>100	84	82	82	82	82	99	99	99	99	99	99	99
760	alewife	ecological	NOAEC	fish	6	5	5	5	5	5	< 1	< 1	2	2	< 1	< 1	< 1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	90	89	89	89	88	99	99	99	99	99	99	99
500	walleye	ecological	LOAEC	mink	>100	>100	> 100	>100	>100	>100	80	79	79	79	75	75	75
500	alewife	ecological	LOAEC	mink	35	30	29	29	29	29	7	< 1	7	7	5	5	5
408	alewife	ecological	NOAEC	piscivorous bird deformity	51	44	43	43	43	43	11	11	11	11	8	8	8
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100	>100	> 100	>100	>100

Table 8-12 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 3B

A. Organized by Fox River Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb	Fox River 500 ppb		Fox River 250 ppb		Fox River 125 ppb	
					Green Bay No Action	Green Bay No Action	Green Bay No Action	Green Bay (ppb)		Green Bay (ppb)		Green Bay (ppb)	
								No Action	500	No Action	500	No Action	500
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	< 1	< 1	< 1	< 1	< 1	< 1	< 1	3	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	59	51	51	50	13	50	13	50	13
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	67	57	56	56	16	56	16	56	16
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	99	84	83	83	31	82	31	82	31
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	99	84	83	83	31	83	31	83	31
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	99	99	98	98	47	98	47	99	46
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	97	95	95	98	95	99	95	98
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	99	>100	99	>100	99
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	58	50	49	49	13	49	13	49	13
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	62	53	52	52	14	52	14	52	14
760	walleye	ecological	NOAEC	fish	97	79	78	77	27	77	26	77	26
760	alewife	ecological	NOAEC	fish	5	5	4	4	< 1	4	< 1	4	1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	99	84	83	83	31	83	31	83	31
500	walleye	ecological	LOAEC	mink	90	99	99	99	65	99	65	99	65
500	alewife	ecological	LOAEC	mink	25	22	21	21	4	21	4	21	4
408	alewife	ecological	NOAEC	piscivorous bird deformity	38	33	32	32	7	32	7	32	7
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	> 100	>100	>100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	> 100	>100	>100	>100	>100

Table 8-12 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 3B (Continued)

B. Organized by Green Bay Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Green Bay No Action						Green Bay 500 ppb		
					Fox River (ppb)						Fox River (ppb)		
					No Action	5,000	1,000	500	250	125	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	3	3	3	3	3	3	< 1	< 1	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	59	51	51	50	50	50	13	13	13
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	67	57	56	56	56	56	16	16	16
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	99	84	83	83	82	82	31	31	31
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	99	84	83	83	83	83	31	31	31
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	99	99	98	98	98	98	47	47	46
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	97	95	95	95	95	98	98	98
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	>100	>100	99	99	99
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	58	50	49	49	49	49	13	13	13
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	62	53	52	52	52	52	14	14	14
760	walleye	ecological	NOAEC	fish	97	79	78	77	77	77	27	26	26
760	alewife	ecological	NOAEC	fish	5	5	4	4	4	4	1	< 1	< 1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	99	52	83	83	83	83	31	31	31
500	walleye	ecological	LOAEC	mink	90	99	99	99	99	99	65	65	65
500	alewife	ecological	LOAEC	mink	21	22	21	21	21	21	4	4	4
408	alewife	ecological	NOAEC	piscivorous bird deformity	38	33	32	32	32	32	7	7	7
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100	> 100	>100	>100

Table 8-13 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds Are Met): Green Bay Zone 4

A. Organized by Fox River Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb	Fox River 500 ppb	Fox River 250 ppb	Fox River 125 ppb
					Green Bay No Action	Green Bay No Action	Green Bay No Action	Green Bay No Action	Green Bay No Action	Green Bay No Action
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	< 1	< 1	< 1	< 1	< 1	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	91	81	86	86	86	86
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	99	99	99	99	99	99
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	91	81	80	80	80	80
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	99	95	94	94	94	94
760	walleye	ecological	NOAEC	fish	99	99	99	99	99	99
760	alewife	ecological	NOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	>100	> 100	>100	>100	>100
500	walleye	ecological	LOAEC	mink	>100	>100	> 100	>100	>100	>100
500	alewife	ecological	LOAEC	mink	< 1	< 1	< 1	< 1	< 1	< 1
408	alewife	ecological	NOAEC	piscivorous bird deformity	5	5	5	5	5	5
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100

Table 8-13 Remedial Action Levels and Attainment of Human Health and Ecological Thresholds (Years until Thresholds are Met): Green Bay Zone 4 (Continued)

B. Organized by Green Bay Remedial Action Level

Media Threshold Concentration (µg/kg) [1]	Media [2]	Threshold Type	Risk Level	Receptor	Green Bay No Action					
					Fox River (ppb)					
					No Action	5,000	1,000	500	250	125
7,060	walleye	human health	CTE 10^{-4} cancer risk level	recreational angler	< 1	< 1	< 1	< 1	< 1	< 1
3,710	walleye	human health	CTE 10^{-4} cancer risk level	high-intake fish consumer	< 1	< 1	< 1	< 1	< 1	< 1
1,176	walleye	human health	CTE hazard index of 1.0	recreational angler	91	81	86	86	86	86
1,060	walleye	human health	RME 10^{-4} cancer risk level	recreational angler	99	99	99	99	99	99
710	walleye	human health	RME 10^{-4} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
706	walleye	human health	CTE 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
588	walleye	human health	CTE hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
371	walleye	human health	CTE 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
288	walleye	human health	RME hazard index of 1.0	recreational angler	>100	>100	> 100	>100	>100	>100
181	walleye	human health	RME hazard index of 1.0	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
106	walleye	human health	RME 10^{-5} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
71	walleye	human health	RME 10^{-5} cancer risk level; RME 10^{-6} cancer risk level	high-intake fish consumer; recreational angler	>100	>100	> 100	>100	>100	>100
37	walleye	human health	CTE 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
11	walleye	human health	RME 10^{-6} cancer risk level	recreational angler	>100	>100	> 100	>100	>100	>100
7	walleye	human health	RME 10^{-6} cancer risk level	high-intake fish consumer	>100	>100	> 100	>100	>100	>100
7,600	walleye	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
7,600	alewife	ecological	LOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
4,083	alewife	ecological	LOAEC	piscivorous bird deformity	< 1	< 1	< 1	< 1	< 1	< 1
3,879	alewife	ecological	LOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
2,399	alewife	ecological	NOAEC	piscivorous bird hatching success	< 1	< 1	< 1	< 1	< 1	< 1
1,207	walleye	ecological	LOAEC	carnivorous bird deformity	91	81	80	80	80	80
1,147	walleye	ecological	LOAEC	carnivorous bird hatching success	99	95	94	94	94	94
760	walleye	ecological	NOAEC	fish	99	99	99	99	99	99
760	alewife	ecological	NOAEC	fish	< 1	< 1	< 1	< 1	< 1	< 1
709	walleye	ecological	NOAEC	carnivorous bird hatching success	>100	>100	> 100	>100	>100	>100
500	walleye	ecological	LOAEC	mink	>100	>100	> 100	>100	>100	>100
500	alewife	ecological	LOAEC	mink	< 1	< 1	< 1	< 1	< 1	< 1
408	alewife	ecological	NOAEC	piscivorous bird deformity	5	5	5	5	5	5
121	walleye	ecological	NOAEC	carnivorous bird deformity	>100	>100	> 100	>100	>100	>100
50	walleye	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100
50	alewife	ecological	NOAEC	mink	>100	>100	> 100	>100	>100	>100

Table 8-14 RAO 2: Years to Reach Human Health Thresholds for Lower Fox River Remedial Action Levels

River Reach	Whole Fish Threshold Concentration (µg/kg)	Fish	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
Little Lake Butte des Morts	288	walleye	RME hazard index of 1.0	recreational angler	51	29	<1	<1	<1	<1
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	65	40	4	<1	<1	<1
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	84	57	9	5	<1	<1
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	100	70	14	10	4	2
Appleton to Little Rapids	288	walleye	RME hazard index of 1.0	recreational angler	40	26	4	<1	<1	<1
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	55	37	7	5	2	<1
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	70	42	14	11	7	5
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	89	65	17	15	9	8
Little Rapids to De Pere	288	walleye	RME hazard index of 1.0	recreational angler	92	52	9	5	2	2
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	67	17	12	7	4
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	92	30	20	14	9
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	100	42	29	20	15
De Pere to Green Bay	288	walleye	RME hazard index of 1.0	recreational angler	>100	79	20	14	8	7
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	100	30	20	14	9
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	100	45	34	20	15
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	100	59	45	29	20

Table 8-15 RAO 2: Years to Reach Human Health Thresholds for Green Bay Remedial Action Levels

Green Bay Zone	Whole Fish Threshold Concentration (µg/kg)	Fish Species	Risk Level	Receptor	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb		Fox River 500 ppb			Fox River 250 ppb			Fox River 125 ppb		
					Green Bay No Action	Green Bay No Action	Green Bay (ppb)		Green Bay (ppb)			Green Bay (ppb)			Green Bay (ppb)		
							No Action	1,000	No Action	1,000	500	No Action	1,000	500	No Action	1,000	500
2	288	walleye	RME hazard index of 1.0	recreational angler	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
3A	288	walleye	RME hazard index of 1.0	recreational angler	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
3B	288	walleye	RME hazard index of 1.0	recreational angler	>100	>100	>100	NC	>100	NC	99	>100	NC	99	>100	NC	99
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
4	288	walleye	RME hazard index of 1.0	recreational angler	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC
	181	walleye	RME hazard index of 1.0	high-intake fish consumer	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC
	106	walleye	RME 10^{-5} cancer risk level	recreational angler	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC
	71	walleye	RME 10^{-5} cancer risk level	high-intake fish consumer	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC

Note:
NC - Not Considered.

Table 8-16 RAO 3: Years to Reach Ecological Thresholds for Lower Fox River Remedial Action Levels

River Reach	Media Threshold Concentration (µg/kg) [1]	Media [2]	Risk Level	Receptor	Remedial Action Level (ppb)					
					No Action	5,000	1,000	500	250	125
Little Lake Butte des Morts	4,083	gizzard shad	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	3,879	gizzard shad	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	2,399	gizzard shad	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	408	gizzard shad	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	121	carp	NOAEC	carnivorous bird deformity	100	67	14	9	<1	<1
	50	carp	NOAEC	piscivorous mammal	>100	100	29	25	9	7
	223	sediment	TEL	sediment invertebrate	>100	>100	60	52	26	21
Appleton to Little Rapids	4,083	gizzard shad	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	3,879	gizzard shad	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	2,399	gizzard shad	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	408	gizzard shad	NOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	121	carp	NOAEC	carnivorous bird deformity	71	55	17	15	9	7
	50	carp	NOAEC	piscivorous mammal	100	89	34	29	18	15
	771	sediment	TEL	sediment invertebrate	81	63	28	24	16	13
Little Rapids to De Pere	4,083	gizzard shad	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	3,879	gizzard shad	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	2,399	gizzard shad	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	408	gizzard shad	NOAEC	piscivorous bird deformity	2	<1	<1	<1	<1	<1
	121	carp	NOAEC	carnivorous bird deformity	>100	76	22	12	8	4
	50	carp	NOAEC	piscivorous mammal	>100	>100	43	31	25	15
	596	sediment	TEL	sediment invertebrate	>100	>100	46	33	28	16
De Pere to Green Bay	4,083	alewife	LOAEC	piscivorous bird deformity	<1	<1	<1	<1	<1	<1
	3,879	alewife	LOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	2,399	alewife	NOAEC	piscivorous bird hatching success	<1	<1	<1	<1	<1	<1
	408	alewife	NOAEC	piscivorous bird deformity	100	9	<1	<1	<1	<1
	121	carp	NOAEC	carnivorous bird deformity	>100	79	20	14	7	5
	50	carp	NOAEC	piscivorous mammal	>100	100	45	34	17	14
	632	sediment	TEL	sediment invertebrate	>100	93	37	23	13	6

Notes:

[1] Sediment concentration is presented in units of mg/kg OC.

[2] Fish concentrations are whole body.

Table 8-17 RAO 3: Years to Reach Ecological Thresholds for Green Bay Remedial Action Levels

Green Bay Zone	Threshold Type	Fish Species	Thresholds Name	Whole Fish Threshold Concentration (µg/kg)	Fox River No Action	Fox River 5,000 ppb	Fox River 1,000 ppb		Fox River 500 ppb			Fox River 250 ppb			Fox River 125 ppb		
					Green Bay No Action	Green Bay No Action	Green Bay (ppb)		Green Bay (ppb)			Green Bay (ppb)			Green Bay (ppb)		
							No Action	1,000	No Action	1,000	500	No Action	1,000	500	No Action	1,000	500
2	Ecological	alewife	Forster's tern deform. LOAEC	4,083	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
		alewife	Forster's tern hatch suc. LOAEC	3,879	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
		alewife	Forster's tern hatch suc. NOAEC	2,399	30	24	23	3	23	< 1	< 1	23	< 1	< 1	23	< 1	< 1
		alewife	Forster's tern deform. NOAEC	408	>100	>100	>100	30	>100	29	26	>100	28	25	>100	28	25
		walleye	bald eagle deform. NOAEC	121	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
		walleye	mink NOAEC	50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
		alewife	mink NOAEC	50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
3A	Ecological	alewife	Forster's tern deform. LOAEC	4,083	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
		alewife	Forster's tern hatch suc. LOAEC	3,879	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
		alewife	Forster's tern hatch suc. NOAEC	2,399	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
		alewife	Forster's tern deform. NOAEC	408	51	44	43	11	43	11	8	43	11	8	43	11	8
		walleye	bald eagle deform. NOAEC	121	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
		walleye	mink NOAEC	50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
		alewife	mink NOAEC	50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
3B	Ecological	alewife	Forster's tern deform. LOAEC	4,083	< 1	< 1	< 1	NC	< 1	NC	< 1	< 1	NC	< 1	< 1	NC	< 1
		alewife	Forster's tern hatch suc. LOAEC	3,879	< 1	< 1	< 1	NC	< 1	NC	< 1	< 1	NC	< 1	< 1	NC	< 1
		alewife	Forster's tern hatch suc. NOAEC	2,399	< 1	< 1	< 1	NC	< 1	NC	< 1	< 1	NC	< 1	< 1	NC	< 1
		alewife	Forster's tern deform. NOAEC	408	38	33	32	NC	32	NC	7	32	NC	7	32	NC	7
		walleye	bald eagle deform. NOAEC	121	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
		walleye	mink NOAEC	50	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
		alewife	mink NOAEC	50	>100	>100	>100	NC	>100	NC	>100	>100	NC	>100	>100	NC	>100
4	Ecological	alewife	Forster's tern deform. LOAEC	4,083	< 1	< 1	< 1	NC	< 1	NC	NC	< 1	NC	NC	< 1	NC	NC
		alewife	Forster's tern hatch suc. LOAEC	3,879	< 1	< 1	< 1	NC	< 1	NC	NC	< 1	NC	NC	< 1	NC	NC
		alewife	Forster's tern hatch suc. NOAEC	2,399	< 1	< 1	< 1	NC	< 1	NC	NC	< 1	NC	NC	< 1	NC	NC
		alewife	Forster's tern deform. NOAEC	408	5	5	5	NC	5	NC	NC	5	NC	NC	5	NC	NC
		walleye	Bald eagle deform. NOAEC	121	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC
		walleye	mink NOAEC	50	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC
		alewife	mink NOAEC	50	>100	>100	>100	NC	>100	NC	NC	>100	NC	NC	>100	NC	NC

Note:
NC - Not Considered

Table 8-18 RAO 4: Sediment Loading Rates - 30 Years Post-remediation (kg/yr)

River Reach	Action Level (ppb)					
	No Action	5,000	1,000	500	250	125
Little Lake Butte des Morts	11.33	6.35	0.66	0.49	0.18	0.15
Appleton to Little Rapids	11.33	6.55	0.78	0.57	0.23	0.17
Little Rapids to De Pere	21.25	9.54	1.46	0.94	0.54	0.32
De Pere to Green Bay	75.27	10.51	1.67	1.10	0.61	0.34

9 Detailed Analysis of Remedial Alternatives

This section presents the detailed analysis of individual remedial alternatives for the river reaches and Green Bay zones that were developed in Section 7 of this FS Report. A total of seven possible remedial alternatives (Alternatives A through G) are compared to nine evaluation criteria designed to address CERCLA remediation requirements. Figure 9-1 provides a schematic view of the detailed analysis as described in the EPA RI/FS Guidance (EPA, 1988). As described in the EPA RI/FS Guidance, the detailed analysis for individual alternatives consists of the following three sets of analysis involving nine evaluation criteria:

- **Threshold Criteria**
  - Overall protection of human health and the environment
  - Compliance with ARARs

- **Balancing Criteria**
  - Long-term effectiveness and permanence
  - Reduction of toxicity, mobility and volume through treatment
  - Short-term effectiveness
  - Implementability (technical and administrative feasibility)
  - Cost

- **Regulatory/Community Criteria**
  - State acceptance
  - Community acceptance

These nine evaluation criteria are intended to provide a framework for assessing the risks, costs and benefits for each remedial alternative, individually. The next step, conducted in Section 10, is a comparative analysis among the alternatives to assess the relative performance of each alternative with respect to each evaluation criterion and action level, and to identify the key tradeoffs between them.

9.1 Description of the Detailed Analysis Process

This section describes the detailed analysis process. Subsections are organized according to the primary criteria introduced at the start of this section. The evaluation is accomplished by considering each remedial alternative in terms of the criteria. With respect to the Balancing Criteria, the evaluation is conducted by proposing a number of questions directly related to each criteria, as a means of considering and thoroughly evaluating the river reach and Green Bay zone alternatives. In summary, the seven generic remedial alternatives developed for the Lower Fox River and Green Bay include:

A. No Action,
B. Monitored Natural Recovery and Institutional Controls,
C. Dredge and Off-site Disposal,
D. Dredge to On-site CDF,
E. Dredge and Thermal Treatment,
F. *In-situ* Cap to Maximum Extent Possible, and
G. Dredge to CAD site.

Sections 9.2, 9.3, and 9.4 describe the Threshold Criteria, the Balancing Criteria, and the Regulatory/Community Acceptance Criteria, respectively. However, the regulatory/community acceptance criteria will be addressed during the public comment period as described in Section 9.4.

9.2 Threshold Criteria

Threshold criteria serve as essential determinations that should be met by any remedial alternative in order to be eligible for selection. They serve as primary project goals for a remediation project. The threshold criteria are primarily addressed through the development of the remedial alternatives in Sections 6 and 7, and within the context of the detailed risk assessment in Section 8.

9.2.1 Overall Protection of Human Health and the Environment

The criterion, Overall Protection of Human Health and the Environment, is first addressed in Section 7 of this FS Report through the identification of the methods used to reduce the potential for adverse exposures to contaminated sediments. Section 8 of this FS Report continues the discussion of protecting human health and the environment in a detailed risk analysis for each of the remedial alternatives.

As discussed in Section 8, the primary risk to human health associated with the contaminated sediments is consumption of fish. The primary risk to the environment is bioaccumulation of PCBs from the consumption of fish, or direct ingestion/consumption of sediments for invertebrates. Protection of human health and the environment is achieved to varying degrees for each remedial alternative by selecting protective SQT risk levels, remedial action levels, and response actions. In this section, protection of human health and the environment is evaluated by residual risk in surface sediments using three lines of evidence:

- The projected number of years required to reduce PCB sediment loads and improve surface water quality based on residual PCB concentrations in surface sediments (surface-weighted averaging after completion of a remedy);

- The projected number of years required to consistently reach safe consumption of fish; and

- The projected number of years required to consistently reach surface sediment concentrations protective of fish or other biota.

The residual concentrations and duration of residual risk will be dependent upon the sediment action level selected for a particular alternative (detailed in Section 10). For this evaluation, the residual risk associated with each remedial alternative is provided in the screening tables under "Magnitude and Type of Residual Risk," and the values presented in these tables are for recreational anglers and carp-eating carnivorous birds and mammals. A summary of estimated "overall protection of human health and the environment" for each alternative is presented in Section 8.

The alternative-specific risk assessment (presented in Section 8 of the FS) estimated the number of years to consistently reach protective human health and environment thresholds after completion of a remedy. The term "consistently met" refers to the last time the predicted model results exceed the protective threshold in the modeled 100-year time frame. Several different receptors, risk levels, and media were presented, each with a different sediment threshold concentration. In order to continue forward with evaluations of risk in Sections 9 and 10 of the FS, a total of four human health and two environmental thresholds (based on fish tissue levels) were carried forward in the FS to facilitate risk comparison between alternatives and action levels. These key remedial thresholds include:

- **Human Health:** recreational angler, RME, HI is 1.0 (noncancer) for walleye (288 μg/kg PCBs);

- **Human Health:** recreational angler, RME, 10^{-5} cancer risk level for walleye (106 μg/kg PCBs);

- **Human Health:** high-intake fish consumer, RME, HI is 1.0 (noncancer) for walleye (181 μg/kg PCBs);
- **Human Health:** high-intake fish consumer, RME, 10^{-5} cancer risk level for walleye (71 μg/kg PCBs);
- **Environmental Health:** NOAEC carnivorous bird deformity from carp (121 μg/kg PCBs); and
- **Environmental Health:** NOAEC piscivorous mammal from carp (50 μg/kg PCBs).

These remedial thresholds represent fish tissue concentrations that are protective of human health and biotic receptors. Residual surface sediment concentrations required to meet these thresholds were predictive elements included in the PCB transport and bioaccumulation models used in the Lower Fox River and Green Bay. Outputs of the model were expressed as the number of years required to meet the protective fish tissue levels (based on residual sediment concentrations of an action level).

9.2.2 Compliance with ARARs and TBCs

Section 4 of this FS Report introduces the federal and state Applicable or Relevant Appropriate Requirements (ARARs) (Tables 4-2 and 4-3). Some of the listed ARARs and TBCs identify guidance and reference documents that apply to the management of the impacted sediments and the construction of containment structures in aquatic environments. The screening conducted in this section is for those ARARs and TBCs that relate to actions taken to implement the remedial alternatives.

Approval for, and performance of, the remedial alternatives will require that the actions taken comply with the ARARs and TBCs, to the extent practicable. The following subsections provide a summary of these issues with respect to: chemical-specific ARARs/TBCs, action-specific ARARs/TBCs, and location-specific ARARs/TBCs.

Chemical-specific ARARs/TBCs

Chemical-specific ARARs/TBCs apply to elements of the remedial alternatives which relate to the management of PCBs. The following subsections provide a summary of the issues related to compliance with chemical-specific ARARs/TBCs applicable to sediment remediation and the measures to be employed to attain compliance. For the purposes of this FS, there are no chemical-specific ARARs related to the removal and/or management of Lower Fox River sediments. Only chemical-specific TBCs exist.

Surface Water Quality. ARARs/TBCs for this area relate to maintaining surface water during remedial actions and long-term goals of achieving surface water quality after remedy completion. Specific approaches identified to address these ARARs/TBCs include:

- **Wisconsin State Water Quality Criteria.** Wisconsin's surface water quality criteria (NR 100) are TBCs for a sediment remediation project. Water quality criteria are intended to be protective of both human health (through fish tissue) and the environment (wildlife).

- **Federal Clean Water Act.** Since the project area includes "water of the United States," surface water quality criteria apply. However, EPA has approved Wisconsin's water quality criteria as compliance standards.

Sediment Quality. The state of Wisconsin has the authority to calculate sediment quality criteria on a site-specific basis. However, for the purposes of this RI/FS, state surface water quality criteria were the valued endpoints of concern for long-term protection of human health and the environment instead of sediment quality. Water quality criteria are considered TBCs for the project. Sediment concentrations that are protective of human and biological endpoints were predicted through transport and bioaccumulation models for surface water and residual fish tissue levels.

Location-specific ARARs/TBCs

Location-specific ARARs/TBCs apply to certain types of remedial alternatives, many related to site-specific development and disposal restrictions (i.e., navigational constraints). The following subsections provide a summary of the issues related to compliance with location-specific ARARs/TBCs and the measures to be employed to attain compliance.

CDF Construction (Floodplain or In-water). ARARs/TBCs for this area relate to construction requirements, siting, and control measures to minimize impacts to the environment. Specific approaches identified to address these ARARs/TBCs include:

- **Wisconsin Statutes Chapter 30 - Permit in Navigable Waters.** A bulkhead line is required prior to placing deposits in navigable waters. If a legislative bulkhead line or lakebed grant is issued, then these areas cease to be waters of the state and the title is transferred to a local municipality.

- **TBCs for Placement of PCB Sediments in CDFs.** CDF construction within bulkhead lines or lakebed grant areas could not be approved under the waste management program siting process of licensed landfills, but could be approved under a low-hazard waste exemption in the waste management program statutes (but likely limited to non-TSCA dredged material).

Upland Disposal Facility Construction. ARARs/TBCs for this area relate to construction and disposal requirements for sensitive areas. Specific approaches include:

- New facility construction will be located outside of navigable waters and floodplains as permitted by the WDNR waste management program (Lynch, 1998).

- Any off-site licensed landfill disposal site would have to comply with codified locational restrictions, including setback requirements from surface waters and floodplains.

Action-specific ARARs/TBCs

Action-specific ARARs/TBCs apply to implementation of the remedial alternatives. The following subsections provide a summary of the issues related to compliance with action-specific ARARs/TBCs and the measures to be employed to attain compliance.

Dredge and On-site Fill. ARARs/TBCs for this area relate to removal of sediments and the placement of sediments in a CDF or CAD site, or placement of a cap. The requirements specifically relate to protection of water quality, aquatic and wildlife habitat, and wetland areas. Specific approaches identified to address these ARARs/TBCs include:

- **Federal 33 USC 403, 33 CFR 320 through 330, and 40 CFR 230 - Excavation or Dredging of Contaminated Sediments.** Dredge and fill activities must comply with Section 10 of the Rivers and Harbors Act, Sections 301 and 404 of the Clean Water Act, and USACE regulations.

- **TBCs for Dredging and Filling of Water Bodies:**

  - WDNR 1990 Report of the Technical Subcommittee on Determination of Dredge Material Suitability of In-Water Disposal: specific habitat and wetland areas will be identified for each of the cap or CDF locations to allow for the development of protective measures and other compensatory actions.

  - Proposed capping of sediments with concentrations of 50 mg/kg or greater has not been perceived by the EPA as providing adequate protection to human health and the environment.

  - The EPA Wetlands Action Plan requires no net loss of remaining wetlands.

PCB-contaminated Media. ARARs/TBCs for this area relate to proper management of the PCB-contaminated sediments including handling and disposal. Specific approaches identified to address these ARARs/TBCs include:

- **Federal TSCA (40 CFR 761).** Remedial activities involving TSCA-level sediments (less than 50 ppm PCBs and defined as PCB waste) will employ protective features to provide containment so as to prevent releases. Any ARARs specific to TSCA would be limited to PCB wastes with greater than 50 ppm concentrations. For dredged material with PCB concentrations less than 50 ppm, state rules apply, but TSCA does not.

- **TBCs for Handling of PCB-contaminated Media.** EPA concurrence is required to dispose of dredged materials containing PCBs at concentrations greater than 50 mg/kg in Wisconsin landfills (Adamkus, 1995):

  - With EPA approval, WDNR has authority to regulate disposal of dredged materials containing concentrations less than 500 mg/kg; and

  - Disposal facility operations plan must be modified prior to upland acceptance of PCB dredged materials with concentrations greater than 50 mg/kg.

Dredged materials that are placed within a facility are subject to the regulatory authority of the WDNR Waste Management Program (Lynch, 1998).

Proposed capping of sediments with concentrations of 50 mg/kg or greater has not been perceived by the EPA as providing adequate protection to human health and the environment.

Surface Water Quality. ARARs and TBCs for this area relate to discharges to surface water from dredging operations, in-water construction, or wastewater resulting from sediment dewatering. Specific approaches identified to address these ARARs/TBCs include:

- **NR 200 WAC, NR 212 through 220 WAC - Wisconsin Pollution Discharge Elimination System (WPDES).** A Construction Site Stormwater Discharge Permit is required when construction activities disturb greater than 5 acres of land.

  Discharge limitations for the Lower Fox River Deposit N WPDES Permit included, but were not limited to:

  - TSS not to exceed daily maximum concentration of 10 mg/L (monthly average of 5 mg/L);
  - PCBs daily total discharge mass limits not to exceed 0.0036 pounds;
  - PCBs daily total discharge concentration limit not to exceed 1.2 μg/L per day; and
  - Other parameters included: heavy metals, select PAHs, pesticides, dioxins, pH, ammonia, BOD, and oil/grease.

- **NR 207 WAC - Water Quality Antidegradation.** Discharge of effluent water cannot contain COC concentrations which exceed concentrations found in the Lower Fox River.

- **Federal TSCA (40 CFR 761).** Remedial activities involving TSCA-level sediments (less than 50 ppm total suspended solids) must monitor:

- Dissolved oxygen concentrations,
- Flow rates,
- Thermal properties of effluent and receiving waters, and
- pH.

In Section 761.50(a)(3), no discharger may discharge effluent containing PCBs to a treatment works or to navigable waterways unless the PCB concentration is less than 3 μg/L in accordance with an NPDES permit.

Air Emissions. ARARs for this area relate to air emissions from remedial activities. Specific approaches identified to address these ARARs include:

- **NR 157 WAC - Management of PCBs and Products Containing PCBs.** Facilities used for the incineration of PCBs require written approval from the WDNR prior to being established.

  Facility must meet the minimum requirements of the following operational parameters:

  - Dwell time (2 seconds),
  - Temperature (2,000 °F),
  - Turbulence, and
  - Excess oxygen (3%).

  Facility must have scrubber to remove hydrochloric acid from exhaust gas.

- **NR 400 through 499 WAC - Air Pollution Control.** Depending on location and size of the thermal treatment unit, specific maximum particulate concentrations are regulated.

- **Clean Air Act, 40 CFR Part 761 - PCB Storage and Disposal.** PCB air emissions from incineration (i.e., thermal treatment) cannot exceed 0.01 gram PCB per kg of PCB treated.

- **Clean Air Act, 40 CFR Part 50.** Establishes ambient air quality standards for the protection of public health.

Upland Disposal Facility Construction. ARARs/TBCs for this area relate to construction and disposal requirements, siting, and control measures to minimize impacts to the environment. Disposal in a solid waste landfill is applicable to both non-TSCA level and TSCA-level PCB-contaminated dredged material. Specific approaches identified to address these ARARs/TBCs include:

- **Wisconsin Statutes, Chapter 289 - Landfill Siting and Approval Process.** Disposal of dredged material in a licensed solid waste landfill is subject to the landfill approval process (Chapter 289 Statutes and Chapters NR 500 to 520 WAC).

  Specific design and construction requirements for a new solid waste landfill (or a "monofill" dedicated specifically to PCB sediments) are found in NR 504. WDNR has indicated that these requirements may also apply to the construction of an upland confined disposal facility (also described as a "wet" landfill).

  If temporary passive dewatering ponds are used, the performance requirements of Chapter NR 213 ("Lining of Industrial Lagoons and Design of Storage Structures") may apply. Alternatively, if WDNR decides to regulate passive dewatering ponds as a "solid waste processing facility," the requirements of the NR 500 series of rules may apply.

  No licensed hazardous waste landfills (Chapter 291 Statutes and NR 600 to 690 WAC) currently exist in the state of Wisconsin. However, permit requirements and the siting process would be similar to the solid waste landfill process.

  Solid wastes may be exempt from landfill siting requirements of WAC NR 500 through 520 if a "new" (i.e., treated material) is produced and meets the low-hazard exemption standards.

- **Wisconsin Statutes, Chapter 289 - Low-hazard Waste Grant of Exemption Disposal Site Process.** Low-hazard waste grant of exemption must meet authority (Section 289.43(8), Statutes) and public meeting requirements (Section 289.54, Statutes) set forth in state regulations.

  Placement in a low-hazard exemption disposal site applies to non-TSCA level dredged material only.

Transportation and Handling. ARARs/TBCs for this area relate to the transportation and handling of PCB-containing sediments during remedial activities. Specific approaches identified to address these ARARs/TBCs include:

- **49 CFR Parts 172 and 173 - General Requirements and Provisional Shipping Requirements for PCB-containing Material.** Transport vehicle transporting greater than 1,001 pounds of PCB waste must display Class 9 placards.

- **TBCs for Transportation of PCB-contaminated Media.** Establishes city, county, and state highway weight restrictions.

Worker Safety. ARARs for this area relate to protection of workers that are exposed, or potentially exposed to, hazardous materials. Specific approaches identified to address these ARARs include:

- **29 CFR Part 1910 - Occupational Safety and Health Administration:**

  - 1910.120(e)(3) and 1910.120(f) - Workers with such actual or potential contacts will be required to conform to the standards for hazardous material workers including participation in a medical monitoring program and current certifications for training in hazardous materials exposures.

  - 1910.132, 1910.134, and 1920.138 - Personal protective equipment (PPE) will be employed to ensure that workers are not exposed to adverse conditions during the work.

  - 1910.120(h) - Real-time monitoring will be conducted to ensure that work zones are properly delineated and that workers are wearing the proper PPE.

  - 1910.95 - Noise levels that exceed an 8-hour time-weighted average (TWA) of 85 decibels require hearing protection.

  - 1910.120(m) - Work areas will have adequate lighting to allow workers to identify hazards.

  - 1910 Subpart S - All electrical power must have a ground fault circuit interrupter and be approved for the class of hazard.

- 1910.147 - Operations where the unexpected energization or startup of equipment or release of stored energy could cause injury to personnel will be protected by the implementation of a lockout/tagout program.

- 1910.21 through 1910.32 and 1910.104 through 1910.107 - Requirements to help prevent falls will be implemented.

- 1910.151(c) - Operations involving the potential for eye injury, splash, etc., must have approved eyewash units locally available.

Effects of EPA-initiated Cleanups on ARARs

An EPA-led cleanup under CERCLA authority would not have to formally comply with Wisconsin procedural regulatory requirements for any dredging, storage, dewatering, or disposal activities that occurred within the limits of the project area. The limits of the project area would be defined in the proposed cleanup plan, but would closely conform to the limits of contamination. EPA's cleanup plans would have to consider and include the substantive requirements of state regulatory codes.

Any costs associated with a cleanup, such as dewatering, storage, handling, or disposal that took place outside of the defined limits of the project area would have to comply with all state regulatory requirements.

9.2.3 ARARs Applicable to Process Options Included in the Remedial Alternatives for the River and Bay

The specific remedial alternatives presented in Section 7 for each river reach and Green Bay zone are developed from the retained process options and technologies identified in Section 6. The ARARs and TBCs presented above in Section 9.2.2 are applicable to at least one process option used in the remedial alternatives. The No Action and Institutional Control alternatives are also evaluated here since these alternatives do not rely on other process options. The following subsections present a summary of significant ARARs and TBCs that must be addressed prior to and during the remedial work.

No Action

The No Action alternative has one primary TBC that relates to this alternative. The Water Quality Standards for Wisconsin Surface Waters define water use for protection of public health and propagation of fish, shellfish, and wildlife. These standards will be used over time to monitor the changing (diminishing) concentrations of PCBs in the Lower Fox River and Green Bay.

Monitored Natural Recovery/Institutional Controls

Concerning compliance with ARARs and TBCs, the MNR and Institutional Controls alternative is similar to the No Action alternative. The Water Quality Standards for Wisconsin Surface Waters will be used as TBCs to monitor surface water for the changing concentration of PCBs in the Lower Fox River and Green Bay. Other important ARARs/TBCs include fish consumption advisories which limit the consumption of fish containing PCBs by sensitive populations and institutional controls in which limitations or restrictions are placed on recreational and irrigation usage.

Containment

The containment technology involves *in-situ* capping of the river sediments with a synthetic liner, or a layer of sand, clay, or rock. Most of the ARARs/TBCs for the river reach alternatives that include capping are similar to CDF disposal alternatives. In addition, permits are required prior to filling any navigable water (Wisconsin Statute Chapter 30). Other important TBCs include the permanence of the cap when factoring in the cap thickness, river velocity, and the scouring effects of ships and boats passing over the cap. The containment process option is in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative.

Removal

There are two removal technologies utilized in the dredging alternatives: hydraulic dredging and mechanical dredging. The ARARs/TBCs that are directly related to the removal of sediment from the Lower Fox River and Green Bay are the same for both removal technologies and can be placed into two groups: protection of surface water (NR 322, 200, and 220 through 297 WAC) and permits and fees to remove sediment (NR 346 and 347 WAC). The surface water ARARs/TBCs limit the discharge of PCBs and TSS into the receiving water bodies so that the water quality is not adversely affected. The removal process options are in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative.

Ex-situ Treatment

Thermal treatment is a process option retained for most of the river reaches and bay zones. ARARs specific to this technology relate to the air emission and permitting requirements of thermal treatment units (40 CFR 701 and NR 400 through 499 WAC). In addition, there are performance requirements of the thermal unit from NR 157 WAC that the thermal unit must meet in order to efficiently treat PCB sediments. The *ex-situ* treatment process option is in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative.

Dewatering and Water Treatment

There are three types of dewatering technologies utilized for the dredging alternatives. These include mechanical dewatering, passive dewatering, and solidification. There is also effluent water from the mechanical and passive dewatering technologies that must be managed. The WPDES permit requirements (NR 200 and 220 through 297 WAC) sets forth requirements for the discharge of water to POTWs and to navigable waters (i.e., Lower Fox River). Permits for previous remedial activities on the Lower Fox River provide an indication of the treatment requirements to discharge effluent water to the Lower Fox River or a POTW. Another requirement of the WPDES permit is the Construction Site Stormwater Discharge Permit which will be required for the construction of dewatering ponds. Another potential important ARAR (NR 108 WAC) involves the construction of a wastewater treatment facility specifically to treat water from remedial activities. This ARAR requires WDNR review of wastewater treatment facility designs and specifications. The passive dewatering ponds are also managed under the wastewater treatment ARAR (NR 213 WAC) which sets effluent permit limitations associated with wastewater treatment facilities. There are no ARARs at this time that pertain to the solidification of dredged materials other than general construction ARARs, such as OSHA requirements, which are applicable for each process option. The dewatering and water treatment process options are in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative.

Disposal

There are two primary disposal options of PCB sediments removed from the Fox River and Green Bay. These include in-water disposal (i.e., the construction of a CDF or CAD site) and disposal in an upland landfill or newly constructed landfill for TSCA and non-TSCA level sediments. A low-hazard waste grant of exemption landfill can also be considered for non-TSCA level dredged material. ARARs/TBCs specific to this process option include the siting requirements for a landfill (Wisconsin Statutes Chapter 289) and obtaining lakebed and riverbed grants for CDF constructions from the Legislature and riparian landowners. There are also general design requirements for in-water construction (NR 322 WAC) that must also be met. General disposal requirements of PCB-containing dredged material are simplified with the agreement between the EPA and WDNR for placement of TSCA-level PCB-containing material (greater than 50 ppm PCBs) in a state-licensed landfill. The agreement allows the placement of PCB-containing material up to 500 mg/kg in an NR 500 WAC-regulated landfill as long as the landfill operations permit is modified. However, only public municipal landfills receive long-term liability protection for accepting PCB-impacted dredged material. This TSCA waiver agreement is not applicable to CDF or CAD sites. Placement of dredged material into CDFs could be approved under the low-hazard waste grant of exemption process. The disposal process options are in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative.

Transportation

There are three primary transportation methods for PCB sediment upland disposal alternatives. These include trucking of dredged material to a disposal facility, pumping of sediments to a dewatering and disposal facility, and barging of dredged sediments to a dewatering/treatment location. ARARs and TBCs that are important to this process option include the requirements to prevent spills and releases of PCB materials (NR 140 and 157 WAC). The following two ARARs are applicable only to the trucking of dredged material to a disposal facility. The Department of Transportation (DOT) has detailed requirements on the shipping of PCB materials. NR 157 WAC also has shipping requirements that include licensing of transporters of PCBs as transporters of hazardous wastes. The transportation process options are in compliance with ARARs when the applicable ARARs in Section 9.2.2 are attained through proper implementation of a remedial alternative. ARARs and TBCs related to in-water transportation activities (i.e., piping and barging) include the protection of surface water (NR 322, 200, and 220 through 297 WAC). The surface water ARARs/TBCs limit the potential discharge of PCBs into receiving water bodies from potential barge overflows or pipeline breaks.

9.3 Balancing Criteria

Balancing criteria are included in the detailed analysis of alternatives because these five variables (long-term effectiveness, reduction, short-term effectiveness, implementability, and cost) are important components that often define the major trade-offs between alternatives. They serve as important elements of project goals that require careful consideration for successful implementation and long-term success of a remediation project. The five balancing criteria are evaluated for each remedial alternative in Tables 9-1 through 9-8 for each river reach and Green Bay zone, respectively. Detailed information pertaining to the residual risk for each remedial alternative is presented in Section 8. The following subsections provide a description of the criteria evaluated in this portion of the detailed analysis.

9.3.1 Long-term Effectiveness and Permanence

Long-term effectiveness and permanence provides a means of evaluating the final risk at the site where remedial work has been completed. By evaluating each remedial alternative with respect to this criteria, it is possible to determine the effectiveness of each remedial alternative and the risks associated with the untreated residuals. The following questions were used to evaluate the long-term effectiveness of each alternative:

- What residuals remain after completion of the remedy? Examples of residuals include solid residues after thermal treatment, sediments that spill from trucks and machinery, suspended solids during removal, and unremoved sediments with concentrations of COC above the cleanup goals.

- What is the magnitude of the residual risk?

- What institutional and/or engineering controls are needed?

- Are the controls reliable?

- What are the operations and maintenance requirements?

9.3.2 Reduction of Toxicity, Mobility, or Volume Through Treatment

Reduction of toxicity, mobility, or volume through treatment provides a means of evaluating the permanence of each remedial alternative in reducing the toxicity, mobility, or volume of PCBs within the river and bay sediments. By evaluating each remedial alternative with respect to this criteria, it is possible to determine the effectiveness of the alternative in destroying, reducing the mass, immobilizing, or reducing the volume of PCBs. The following questions were used to evaluate the long-term effectiveness of each alternative:

- Is the treatment portion of the remedy reversible?
- How does the remedy address toxicity, mobility, and volume?
- To what extent are COCs destroyed?
- Does the remedy rely on treatment or containment?

9.3.3 Short-term Effectiveness

Short-term effectiveness provides a means of evaluating the risk at the site while remedial work is being completed. By evaluating each remedial alternative with respect to this criteria, it is possible to determine the effectiveness of each remedial alternative as they relate to risks posed to on-site workers, nearby residences, and downstream resources associated with the untreated residuals. The following questions were used to evaluate the short-term effectiveness of each alternative:

- What are the major risks to community, and what are the applicable control procedures?
- What are the major risks to remediation workers, and what are the applicable control procedures?
- What are the environmental impacts during construction and implementation of the remedy?
- What is the estimated duration of the remedial action?

9.3.4 Implementability

Implementability refers to the technical and administrative feasibility of implementing the remedial alternative. By evaluating each remedial alternative with respect to this criteria, it is possible to determine the necessary services, supplies, permits, approvals, fees, and physical requirements that must be met to execute the alternative. The following questions were used to evaluate the feasibility and effectiveness of each alternative during implementation:

- Can the technology reliably meet cleanup goals? This criteria is also addressed in Section 7 of this FS Report.
- Are there site-specific technology limitations? The site-specific limitations are addressed for each alternative as described in Section 7 of this FS Report.
- What are the major uncertainties with implementation of the remedy?
- Can effectiveness of a remedy be monitored?
- Is a backup remedy necessary and implementable?
- Can required approvals be obtained from other agencies?

- Is the technology available?
- Is a remedy administratively feasible (approvals, permits, fees)?

9.3.5 Total Cost

Total costs include the capital costs, indirect costs, and annual operation and monitoring costs. Capital costs involve the actual cost to conduct the remedial work including land rights, material costs, and equipment costs. Indirect costs include engineer design costs, permit costs, and costs to cover unforseen contingencies. Annual operation and maintenance costs are the costs to annually monitor a site until closure, the costs associated with operating a long-term remediation system (i.e., electricity), and the labor costs involved in the above activities. Cost effectiveness refers to the relative cost to implement a remedy that will meet the risk reduction goals of the project. The following questions were used to provide a cost comparison for each alternative:

- What are the total costs involved with this alternative?
- Does the alternative meet the risk reduction goals for the project and how cost effectively does it meet these goals?

The total cost for each of the remedial alternatives is summarized in Tables 9-1 through 9-8. Appendix H contains the detailed cost spreadsheets for each of the remedial alternatives.

9.4 Community and Regulatory Acceptance

The regulatory/community acceptance criteria are not detailed in this FS Report. However, this RI/FS project for the Lower Fox River and Green Bay is being conducted under direct supervision by Wisconsin Department of Natural Resources and U.S. EPA Region 5. Both agencies have been involved with the data collection and analysis efforts, and development of the remedial alternatives and expectations presented in this FS report. Both the state and federal agencies support the evaluation of alternatives and action levels presented in this FS report. As noted on Figure 9-1, community acceptance of these criteria are assessed through substantial public involvement at work shops, public meetings, and working groups, some of which have been completed, and will be completed through the upcoming public comment period. The public comment period will involve public meetings where comments will be solicited by the WDNR on the contents of the RI, RA, and FS reports. Several trustee groups including NOAA, USFWS, and local tribe communities have also been involved in the review and development of the RI/FS reports prior to public release.

The recently completed pilot projects on the Fox River at Deposit N and SMU 56/57 provide examples of communication with the local communities and residents in the selection and implementation of sediment remediation projects. The experience showed that a strong commitment to ongoing communication and outreach efforts greatly facilitated the public input, coordination, and the design of the projects. The agencies received positive feedback on the use of public meetings, media interviews, fact sheets, brochures, the internet, and other methods of disseminating information. Based on the experience of the pilot projects and with previous RI/FS outreach, local concerns are expected to parallel many of the issues explored in the analysis of the CERCLA evaluation criteria such as protectiveness, effectiveness, implementability, and cost. In addition, the community can be expected to have interest in issues such as disturbance and potential risk to local residents, traffic, and noise.

The PCB mass balance study conducted during Deposit N dredging activities (Water Resources Institute, 2000) demonstrated that short-term risks of downstream PCB transport during dredging could be controlled and minimized to less than 1 percent of the PCB mass removed. This study estimated that 96 percent of the PCB mass removed 17 kg (37 pounds) from the deposit was contained in press cake material (ready for off-site disposal) and that less than 0.01 percent (0.2 grams) of the PCB mass removed was discharged back to the river. The downstream concentrations observed during the dredging activity were comparable to background concentrations observed at other times of the year (summer peaks, high-flow peaks) and from other river activities such as passing ship traffic.

A similar community involvement effort was not conducted for the SMU 56/57 demonstration project (in the community of Aswaubenon) in part because this project was in a predominantly industrial area, not near residential properties. Nevertheless, there were extensive informational efforts for the SMU 56/57 project. Upon project completion, most citizens were supportive of the project. During the 2000 dredging activities, there were numerous tours and informational meetings for the media and local communities. Additionally, it was ensured that transportation of dredge spoils from the dredge location to the local disposal facility did not go through residential areas. Similar to Deposit N, there were no significant disruptions to the local community or activities on the river. These projects were well received by the communities.

9.5 Detailed Analysis of Remedial Alternatives for the Lower Fox River and Green Bay

Tables 9-1 through 9-8 provide the detailed screening of the remedial alternatives for each river reach and bay zone respectively. Each table includes the screening of each alternative retained in Section 7 by the nine primary criteria introduced in this section. The evaluation is performed by contrasting each alternative with the questions identified for each primary criteria, regardless of action level. A comparison of action levels within each alternative and between different alternatives is presented in Section 10. Implementation costs associated with each action level are detailed in Section 7. The important evaluation points projected in the tables are summarized below for each remedial alternative. Since the primary concepts evaluated for each alternative are the same regardless of the reach or zone, the four river reaches and four Green Bay zones are summarized together below.

9.5.1 Alternative A - No Action

This alternative involves no active remedy and long-term monitoring to evaluate potential system recovery over time. A detailed evaluation of this alternative is described in Tables 9-1 through 9-8 for each river reach and bay zone using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

Since no active remediation would be undertaken, the site would remain in its current state, with any changes occurring only through natural processes. The Lower Fox River and Green Bay fate/transport and bioaccumulation models predicted that this alternative will not protect human health or the environment over time (in 30 years). Routine monitoring would be performed to maintain the fish consumption advisories already in place.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Since this alternative includes no remedial actions, the magnitude of residual risks remains the same, with any future changes occurring only through natural processes. This alternative is the least-cost alternative, but provides limited adequacy and reliability in terms of long-term risk controls, source control and reduction of exposure pathways. Costs include institutional controls such as fish consumption advisories that would likely remain in place for over 40 years.

9.5.2 Alternative B - Monitored Natural Recovery and Institutional Controls

This alternative involves no active remedy but does incur the expectation that natural processes will contribute to the recovery of the system. Under this alternative, institutional controls will remain in place until the project objectives are eventually obtained. A long-term monitoring plan will be developed to verify natural recovery of the system. A detailed evaluation of this alternative is described in Tables 9-1 through 9-8 for each river reach and bay zone using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

According to EPA, natural recovery as a remedy is appropriate at sites where the levels of contamination are relatively low, the area of contamination is large, and natural recovery is proceeding at a high rate. The time trends analysis (RI report, RETEC, 2002a) conducted for the Lower Fox River and Green Bay suggests that PCB levels are declining in surface sediments, but no change is occurring at depth. Mass balance work conducted on the Lower Fox River and Green Bay determined, quantitatively, that PCB transport (including Lake Michigan), settling, resuspension, burial, and volatilization mechanisms were all involved (Raghunathan, De Pinto *et al.*, 1994). Empirical data, recently supplied for the fate and transport models, suggest that PCB-contaminated sediments are being transported within the Lower Fox River and into low-level deposits that are widely distributed in Green Bay. Among other lines of evidence, analysis of bathymetry data generated by the USACE show significant movement of sediments in the navigational channels.

Although empirical data may show a slow decline of PCBs in sediment, water, and fish tissues, this alternative may not provide long-term protection of human health and the environment. The transport and bioaccumulation models for the Lower Fox River and Green Bay predict that No Action will require greater than 30 years to consistently reach protective fish tissue thresholds.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Implementation of an active remedy would likely involve a natural recovery component. If a large PCB mass is removed (i.e., source control of sediments) then natural recovery processes may continue after completion of an active remedy thereby continuing the decline of PCB levels in sediment, surface water, and biota. This recovery would be monitored through implementation of a long-term monitoring plan. Some natural processes may accelerate after removal of sediments (i.e., dredging) such as low areas in the river bottom that would likely fill more rapidly. Thus, residual contaminated sediments would be rapidly buried.

The MNR alternative has the lowest total cost among alternatives, but is not cost effective as a standalone remedy because MNR does not meet most of the RAOs in 30 years. Some of the RAOs (i.e., surface water quality criteria) are not met in 100 years. In addition, MNR does not significantly reduce the volume, toxicity, or mobility of COCs throughout the deposit profile over time.

9.5.3 Alternative C - Dredge and Off-site Disposal

This alternative involves physical removal of sediments from the river or bay and off-site disposal of dewatered sediments to a landfill willing to accept dredged sediments. Sediments will be hydraulically or mechanically dredged, then dewatered and solidified, as necessary, prior to off-site disposal. A detailed evaluation of this alternative is described in Tables 9-1 through 9-7 for each river reach and bay zone using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

Based on evidence from other sites, dredging is capable of reducing overall sediment contaminant concentrations, reducing exposure pathways, and reducing long-term risks to human health and the environment, as shown in several case studies (Appendix B). By definition, dredging can serve as an effective source control measure by removing a significant portion of sediment mass and volume from a system. The Lower Fox River and Green Bay modeling results predicts that protective fish tissue levels can be met in 30 years following remedy completion.

Short-term compliance with ARARs and TBCs is expected. The two pilot demonstration projects conducted at Deposit N and SMU 56/57 in the Lower Fox River successfully met monitoring requirements during dredging including: downstream turbidity and PCB levels, effluent water quality, and air quality at compliance boundaries. No ARARs or TBCs were exceeded in the pilot projects.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Depending upon the action level selected for this alternative, residual risk can be two to twenty times lower than the No Action alternative. Dredging with off-site disposal does not destroy or treat material containing PCBs, therefore, PCB volume and toxicity are not reduced. However, effective containment and isolation in a permitted landfill would effectively reduce the mobility of COCs. Reduced mobility and elimination of an exposure pathway would effectively eliminate aquatic exposure and thus reduce the human and ecological risks associated with the consumption of fish.

Short-term Effectiveness. Potential short-term risks associated with dredging do exist. Some of these risks observed on many sediment remediation projects include: the removal, physical disturbance, and/or alteration of aquatic habitats, possible suspension and escape of sediments containing PCBs, and temporary disturbance of silt curtains. Monitoring activities undertaken at other sediment remediation sites (see Appendix B) indicate that potential short-term risks associated with dredging are possible due to the suspension and escape of sediments containing PCBs during dredging (surface water, sediment trap, and caged fish results). For air monitoring, although increases in ambient air PCB concentrations were observed near the sediment dewatering area, estimated PCB emissions were found to be relatively small and insignificant relative to human exposure and risk. The maximum PCB air levels detected at the sediment processing site did not exceed 80 percent of the protective 70-year cancer risk level.

Measurements of water quality downstream of dredging operations during both the Deposit N and SMU 56/57 demonstration projects reported turbidity measurements consistently below or equal to background values during dredging operations (however the cutterhead dredge at Deposit N only operated for 10 minutes every hour). Based on monitoring of Deposit N, PCB mass loss via downstream transport during dredging operations was estimated to be less than 1 percent of the total PCB mass removed from the deposits. These measurements were comparable to the daily contribution of PCB mass from upstream sources to the project area. In summary, in-water control measures can effectively prevent adverse downstream transport of COCs during dredging operations.

The PCB mass balance study conducted during Deposit N dredging activities (Water Resources Institute, 2000) demonstrated that short-term risks of downstream PCB transport during dredging could be controlled and minimized to less than 1 percent of the PCB mass removed. This study estimated that 96 percent of the PCB mass removed 17 kg (37 pounds) from the deposit was contained in press cake material (ready for off-site disposal) and that less than 0.01 percent (0.2 grams) of the PCB mass removed was discharged back to the river. The downstream concentrations observed during the dredging activity were comparable to background concentrations observed at other times of the year (summer peaks, high-flow peaks) and from other river activities such as passing ship traffic.

Long-term Effectiveness. Removal of impacted sediments provides the most long-term effectiveness compared to other alternatives. Long-term operation and maintenance would not be required after removal.

Technical Implementability. This would be a relatively large dredging project (up to 8 million cy in the river and 25 million cy in Green Bay), without precedent in Wisconsin, although other similar sized projects are currently planned or proposed throughout the United States. Dredging projects of similar size have been implemented internationally (1 million cy in Minamata Bay, Japan) verifying the feasibility of conducting, managing and coordinating a large remedial action. Dry excavation of sediment could provide a suitable and cost-effective alternative to proposed wet excavation methods (using hydraulic and mechanical techniques) but would likely be limited to shallow areas that are easily accessible by land-based equipment. Site-specific use of dry excavation techniques will be evaluated during the remedial design. Construction of a containment structure for dewatering of the dredge prism may adversely affect nearshore habitats and wetlands when compared to wet excavation techniques.

Unexpected site conditions (i.e., wood debris, hard underlying material, debris, cobbles) may have contributed to the inability to meet design goals during the 1999 SMU 56/57 horizontal auger dredging activities. Equipment difficulties and the presence of large debris significantly slowed the pilot test progress. The auger cutterhead dredge produced a sediment slurry with 4.5 percent solids; much lower than the design specifications, however, in 2000, the dredge slurry averaged 8 percent solids. Debris was encountered during dredging, which hindered progress and production rates.

The two pilot projects on the Lower Fox River successfully demonstrated the implementability of environmental dredging, water treatment, and disposal of PCB-contaminated sediment. Both projects extended past the original time schedule due to late season startups. The work was postponed over the intervening winter months and completed the following year. The projects demonstrated the availability of necessary equipment and contractors to perform and oversee this type of work.

Administrative Implementability. As expressed in some of the public comments (April 1999), local siting of landfills for the disposal of PCB sediments is an extremely important factor that has tremendous impact of the cost and implementability of this alternative. Local governments generally support the use of existing local landfills and siting of new landfills, to the extent practicable, but recognize that siting of new landfills is a lengthy process involving multiple layers of cities, towns, villages, and counties. This FS fully anticipates that an in-state landfill will be identified for this alternative, but recognizes that inherent uncertainties exist with this assumption. Additional disposal sites, such as out-of-state landfills and newly constructed CDFs may be necessary to match capacity and volume needs.

With EPA approval, the State of Wisconsin has created a viable in-state alternative for the disposal of PCB-contaminated sediments from the Lower Fox River and Green Bay. In-state licensed landfills can accept TSCA-level sediments (greater than 50 mg/kg PCBs) with long-term protection from liability. Long-term liability protection is also extended to in-state municipal (i.e., county) landfills that accept PCB-impacted sediments with less than 50 ppm PCBs.

Some of the required permits, fees, and approvals required to administratively implement a sediment removal and dewatering operation include: dredging contract fees and bonds (NR 346 WAC), a WDNR permit or authorization from the Legislature to remove material from navigable waters, submittal of a Remedial Action Plan and design document for acquisition of a state permit, and proper manifests and placards for transporting PCB wastes. Construction of an industrial wastewater facility may also be necessary.

Under NR 346 WAC (Dredging Contract Fees), a contract fee of $1 is charged for the removal of material from natural lakes. The contractor removing sediments must have a performance bond which would be used to correct any undesirable environmental conditions caused by improper removal of material.

Under NR 108 WAC (Plans and Specifications), construction of an industrial wastewater facility or an industrial pretreatment facility requires approval of final plans and specifications for the facility by the WDNR. Final plans and specifications must be submitted a minimum of 90 days prior to commencement of construction. A 30-day supply of chemicals is required on site to insure against ineffective treatment, shortages, and delays. Design requirements are established on a case-by-case basis, with incorporation of containment and isolation features necessary to protect water resources. The site could be placed in a floodplain, but still designed to protect resources. Design requirements (Chapters NR 500 to 520 WAC) often include a multi-foot clay liner, leachate collection system, intermediate cover and drainage systems, and a final cover system. Handling areas will be lined and covered.

Under NR 157 WAC criteria (Management of PCBs), transporters of PCB wastes must be licensed for transport of hazardous wastes. PCB wastes must be contained to prevent leakage/spillage, and the transporter is responsible for cleanup of all spillage of PCB wastes. Presence of a spill containment program is required for handling of PCB-containing materials. Under 40 CFR Part 761 (Disposal of PCB Remediation Waste), PCB wastes may require management and transport under a Uniform Hazardous Waste Manifest. Development of a new disposal facility, or expansion of an existing one, is subject to the Wisconsin landfill siting process (Chapter 289 Statutes and Chapters 500 to 520 WAC). Wisconsin's landfill siting process includes the following elements: initial site inspection and report, feasibility report, plan of operation, construction inspections, construction documentation and initial licensure, site closure documentation, and demonstration of financial responsibility and long-term care. Under the Wisconsin State Statutes Chapter 289 (Landfill Siting and Approval Process), local approval may be required prior to siting of a new facility (if petitioned, WDNR may waive requirements).

Under NR 200 WAC criteria (WPDES), effluent water resulting from the dewatering of the dredged sediments will be treated by filtration and flocculation for solids removal. Carbon adsorption may be required in addition to solids removal in order to meet WPDES effluent criteria. Application to discharge pollutants must be on file with the WDNR a minimum 180 days prior to discharge commencement date.

Under Wisconsin Statutes Chapter 30 (Permit in Navigable Waters), a permit is required from the WDNR or authorization from the legislature prior to removing material from navigable waters.

Under NR 322 WAC criteria (Sediment Control During Construction Activities), erosion control measures must be implemented. Silt curtains must be utilized around the perimeter of the work zone to minimize the downstream migration of suspended particles.

For two of the river reaches, Little Rapids to De Pere and the De Pere to Green Bay, one of the proposed alternatives is to hydraulically dredge up to 5,700,000 cy and pump the material through a dedicated pipeline that is approximately 18 miles in length, to a newly constructed receiving landfill. The concept of directly pumping PCB-containing sediments through an urban, residential area for several years to an upland landfill may have several hurdles to overcome including land use, traffic constrictions, community acceptance, and spill controls. However, this alternative is feasible but would be difficult to implement without community support. Construction of another long pipeline has been successfully implemented in Dallas, Texas. This 25-mile pipeline pumped dredge slurry over a year from White Rock Lake through city neighborhoods to a former gravel pit disposal site with two booster pumps (Sosnin, 1998).

The total cost to implement the Dredge and Off-site Disposal alternative is generally more expensive than either the Capping or On-site Disposal alternatives. It is also less cost-effective at meeting risk reduction goals than Capping or On-site

Disposal alternatives for action levels at and below 1,000 ppb (which meet most of the goals in 30 years).

As summarized in the *Sediment Technologies Memorandum* (Appendix B), dredging costs ranged from $280 to $525 per cubic yard for planning, dredging, dewatering, monitoring, and disposal costs for the two demonstration projects.

9.5.4 Alternative D - Dredge and CDF Disposal

This alternative involves physical removal of sediments and long-term disposal of sediments to a newly constructed confined disposal facility (CDF). Sediments will be hydraulically dredged and pumped directly to the CDF or mechanically dredged and placed in the CDF for passive dewatering, then capped. The CDF would be constructed on site as a nearshore or in-water facility dedicated to long-term confinement of sediments. A detailed evaluation of this alternative is described in Tables 9-1 through 9-7 for each of the reaches and zones using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

Dredging with direct placement to a CDF would effectively isolate the contaminant mass and therefore provide long-term protection of human health and the environment. Previous USACE and regional studies have shown that CDFs can eliminate the exposure pathways involving ingestion or direct contact with sediment, and subsequent bioaccumulation up the food chain, as long as the CDF containment structure remains intact. Based on monitoring results of other CDFs constructed around the country (see Appendix B), a well-designed CDF structure can effectively isolate COCs and comply with project ARARs. The Lower Fox River and Green Bay modeling results predict that protective fish tissue levels can be met in 30 years following remedy completion.

Short-term compliance with ARARs and TBCs is expected. The two pilot demonstration projects conducted at Deposit N and SMU 56/57 in the Lower Fox River successfully met monitoring requirements during dredging including: downstream turbidity and PCB levels, effluent water quality, and air quality at compliance boundaries. Long-term compliance with ARARs and TBCs related to siting a new CDF is expected prior to construction of new CDF. Monitoring conducted around existing CDFs in Arrowhead Park, Bayport, and Kidney Island show that chemical-specific ARARs and TBCs can be met with effective containment structures.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Residual risks are generally two to twenty times lower than the No Action alternative. However, the removal of sediments during dredging and construction of a CDF may result in relatively long-term changes to the substrate characteristics, and thus the habitat value of the site. In-water placement of a CDF will result in acreage loss of shallow subtidal habitat areas.

Dredging to a CDF does not destroy or treat material containing PCBs, therefore, PCB volume or toxicity is not reduced. However, containment of dredged sediment can effectively isolate the material and eliminate the mobility of COCs. Effective containment could likely reduce the toxicity of the COCs by eliminating the exposure pathway. Short-term environmental risks and controls are similar to those identified for Alternative C.

Construction operations occurring within the river would have a temporary effect on commercial and recreational boating. However, as noted during construction at Deposit N and at SMU 56/57, the physical construction sites themselves drew tourists to the sites. Thus, a net benefit can also be achieved.

Technologies utilized for dredging and on-site disposal are not expected to be different than those identified in Alternative C. In-water CDFs have been successfully constructed through the United States (see Appendix B) and the ability to construct a containment berm and surface cap is well established. No operational difficulties or limited availability is expected that would affect the technical feasibility of this alternative. Segregation of TSCA level sediment would be necessary prior to disposal in a CDF. Administrative implementability would depend on community acceptance of nearshore or in-water disposal of the dredged materials and habitat loss.

9.5.5 Alternative E - Dredge and *Ex-situ* Thermal Treatment

This alternative involves physical removal of sediments and irreversible thermal treatment of sediment coupled with destruction of resulting air emissions. A detailed evaluation of this alternative is described in Tables 9-1 through 9-7 for each reach and zone using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

Dredging with treatment should reduce the bioavailability of PCBs in sediments by removing and eliminating the source of toxicity. Protection of human health and the environment is dependent on the project design and successful implementation of the dredging project (discussed above). Regarding compliance with ARARs, thermal treatment is capable of meeting the air quality ARARs for

PCB air emissions, according to unit specifications and implementation on other projects (see Waukegan Harbor in Appendix B).

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Thermally-treated sediments will achieve long-term effectiveness and permanence. This alternative is the only remedial option that destroys material containing PCBs, therefore, it is the only alternative that reduces the toxicity, volume, and mobility of COCs. This alternative may be costly, but permanently eliminates the risks posed by contaminated sediments. However, thermal treatment by vitrification is not widely used in the United States. This technology also requires significant capital investment.

Under NR 400 through 499 WAC criteria(Air Pollution Control), a construction permit is required for the construction/relocation of a thermal treatment unit. A general operation permit is required prior to the operation of a thermal treatment unit, and an annual emission fee is required if total annual emissions of all air contaminants are less than 5 tons.

The total cost to implement the Dredge and Treat alternative is more expensive than other alternatives with active remedies. This alternative is also less cost effective at meeting risk reduction goals at most action levels. As the action level becomes lower, this alternative becomes less cost effective.

9.5.6 Alternative F - Cap to the Maximum Extent Possible

This alternative involves physical isolation and immobilization of sediments from the water column and biota. This isolation is achieved by placement of an armored sand cap over surface sediments creating *in-situ* containment. This alternative is defined as *in-situ* capping to the maximum extent possible because capping is not practical or implementable in some areas (i.e., navigational channels with frequent dredging needs or minimum water depths to prevent disturbance). A capping alternative was not developed for the Green Bay zones because of the large areal extent of impacted sediments requiring capping and the lack of sufficient local capping material. A detailed evaluation of this alternative is described in Tables 9-1 through 9-4 for each reach and zones using the nine evaluation criteria described above.

Threshold Criteria (Protection and Compliance)

Previous USACE and other site-specific studies have shown that sand cap containment and armoring can effectively reduce the bioavailability and bioaccumulation of PCBs to aquatic organisms by blocking the transport of PCBs from surface sediments into the overlying water column (see Appendix D).

Containment can provide long-term protection of human health and the environment as long as the system remains intact. This requirement includes preservation and maintenance of the 17 locks and 12 dams located along the Lower Fox River. Monitoring of the cap structure will be required (e.g., sediment cores, caged biota) to ensure containment and structural integrity. The Lower Fox River and Green Bay modeling results predict that protective fish tissue levels can be achieved in 30 years following remedy completion.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Capping is moderately cost-effective when compared to dredging alternatives, but requires long-term deed restrictions, site access restrictions, and long-term monitoring to ensure cap integrity. There is a long-term liability associated with *in-situ* containment of impacted sediments, however, if a conventional cap is placed with the intent of enhanced natural recovery instead of containment, then long-term reduction of contaminant volume and toxicity may be enhanced. Although capping does not reduce or actively treat PCB-contaminated material, it can effectively reduce the mobility of PCBs in a sediment deposit.

In-situ capping does not destroy or treat material containing PCBs, therefore, PCB volume or toxicity is not reduced. However, containment of dredged sediment can effectively isolate the material and eliminate the mobility of COCs. Effective containment could likely reduce the toxicity of the COCs by eliminating the exposure pathway.

Use of proper engineering controls, project planning and design, and contingency plans should mitigate the potential short-term risks associated with resuspended sediment. It is expected that all ARARs and TBCs associated with the implementation of the remedy would be achievable. Environmental impacts and risk to workers during construction and implementation are expected to be low due to the limited disturbance of the impacted material. Potential downstream transport of suspended solids or COCs during placement will be lower for this alternative compared to dredging options. Placement of a cap is technically and administratively implementable, however, physical limitations of the site will limit the practical extent of cap placement. Cap placement in a federally-authorized navigational channel would require special approval by an act of Congress and would be administratively difficult. For the purposes of this FS, navigational channels will be dredged and not capped. The Capping alternative is presented in combination with other dredging and MNR alternatives for all reaches because physical site restrictions prevent cap placement everywhere. Although this alternative is administratively feasible, the large quantity of material required for cap placement will require coordination and acceptance by the community and local industries for land acquisition needed for staging areas.

Cap placement will result in long-term site access and deed restrictions to ensure no disturbances of the cap by passing vessels, ice scour, or other aquatic activities. Long-term maintenance of a sand cap may also potentially impact future commerce or recreational use of the river.

Long-term effectiveness of a cap could be compromised by large-scale flood events, ice scour, vessel draft, or dam removal or failure. These issues can be mitigated by periodic addition of new capping material, armoring the cap with coarser material to minimize future scour potential, or removing the cap entirely and dredging the area. Long-term effectiveness could also be compromised by PCB migration through the cap via groundwater advective processes, but potential groundwater migration would be considered during the design phase. In summary, capping would be less protective as a long-term solution when compared to sediment removal.

The total cost to implement the Capping alternative is generally similar to other remedies for relatively small volumes and considerably less expensive than other remedies for large removal volumes. Capping is generally more cost effective than dredging and similar to on-site disposal alternatives for meeting risk reduction goals. However, as stated above, long-term maintenance and monitoring of a cap will be required.

9.5.7 Alternative G - Dredge to CAD Site

This alternative involves removal of contaminated sediment and placement of material in a confined aquatic disposal site (considered for Green Bay only). This remedy includes mechanical or slurry placement of dredged material in an excavation and covering the material with a sand cap to create a containment cell in an underwater environment. A detailed evaluation of this alternative is described in Tables 9-5 through 9-7 for Green Bay zones 2, 3A and 3B.

Threshold Criteria (Protection and Compliance)

Previous USACE studies and dredge disposal monitoring programs (see Appendix B) have shown that sand cap containment in a CAD site, with natural confinement on the sides and bottom of the excavation, can effectively reduce the bioavailability and bioaccumulation of PCBs to aquatic organisms by blocking the transport of PCBs from surface sediments into the overlying water column. Containment can provide long-term protection of human health and the environment as long as the system remains intact. Monitoring of the CAD structure will be required (e.g., sediment cores) to ensure containment and structural integrity. The Lower Fox River and Green Bay modeling results predict that protective fish tissue thresholds can be achieved in 30 years following remedy completion.

Balancing Criteria (Effectiveness, Reduction, Implementability, Cost)

Construction of a CAD site is moderately cost effective when compared to dredging alternatives but requires long-term deed restrictions, site access restrictions, and long-term monitoring to ensure cap integrity. There is a long-term liability associated with in-water containment of contaminated sediments.

Dredging to a CAD site does not destroy or treat material containing PCBs; therefore, PCB volume or toxicity is not reduced. However, containment of dredged sediment can effectively isolate the material and eliminate the mobility of COCs. Effective containment could likely reduce the toxicity of the COCs by eliminating the exposure pathway. Construction of a CAD site and placement of impacted sediments in the disposal site is implementable and has been constructed at numerous sites around the country, many in the New York-Boston area. The same equipment used for dredging can be used to construct the CAD site. Under Wisconsin Statutes Chapter 30 (Permit in Navigable Waters), a permit must be issued by the WDNR or Legislature prior to placing deposits in navigable waters. Implementability is dependent on the Wisconsin Legislature passing a lakebed grant for the use of a CAD site as a disposal site for dredged material.

The total cost to implement the Dredge to CAD Site alternative in Green Bay is generally similar to other active remedies with similar volumes. The total cost to construct a CAD site and transport dredged material to the CAD site is approximately 17 percent less than the cost to construct a freestanding confined disposal facility.

9.6 Summary of Detailed Analysis

The detailed analysis provided in this section provides the basis for the decision-making tools presented in the comparative analysis in Section 10. Each alternative was evaluated against the two threshold and five balancing criteria in detail. Included in this evaluation was the identification and compliance measures for ARARs and TBCs that were chemical, action, and location specific for process options that make up each remedial alternative. Each detailed evaluation was conducted independently and emphasized differences, rather than similarities, that exist between the remedial alternatives within a river reach. These differences will be used in the comparative analysis in Section 10 to provide alternative-specific advantages and disadvantages when comparing alternatives within a river reach.

9.7 Section 9 Figure and Tables

The figure and tables for Section 9 follow page 9-34 and include:

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Figure 9-1 Criteria for Detailed Analyses of Alternatives

Overall Protection of Human Health and the Environment

- How Alternative Provides Human Health and Environmental Protection

Compliance with ARARs

- Compliance and Chemical-specific ARARs
- Compliance with Action-specific ARARs
- Compliance with Location-specific ARARs
- Compliance with Other Criteria, Advisories, and Guidelines

Long-term Effectiveness and Performance

- Magnitude of Residual Risk
- Adequacy and Reliability of Controls

Reduction of Toxicity, Mobility, and Volume through Treatment

- Treatment Process Used and Materials Treated
- Amount of Hazardous Materials Destroyed or Treated
- Degree of Expected Reductions in Toxicity, Mobility, and Volume
- Degree to Which Treatment is Irreversible
- Type and Quantity of Residuals Remaining after Treatment

Short-term Effectiveness

- Protection of Community During Remedial Actions
- Protection of Workers During Remedial Actions
- Environmental Impacts
- Time Until Remedial Action Objectives are Achieved

Implementability

- Ability to Construct and Operate the Technology
- Reliability of the Technology
- Ease of Undertaking Additional Remedial Actions, if Necessary
- Ability to Monitor Effectiveness of Remedy
- Ability to Obtain Approvals from Other Agencies
- Coordination with Other Agencies
- Availability of Off-site Treatment, Storage, and Disposal Services and Capacity
- Availability of Necessary Equipment and specialists
- Availability of Prospective Technologies

Cost

- Capital Costs
- Operating and Maintenance Costs
- Present Worth Cost

State[1] Acceptance

Community[1] Acceptance

Note:

1 These criteria are assessed in the RI/FS Report and the proposed plan.

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Table 9-1 Detailed Analysis of Alternatives Summary - Little Lake Butte des Morts Reach

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will require 51 to 84 years to continually meet safe fish consumption levels for recreational anglers. No action will require >100 years to consistently meet safe ecological levels for carp. Surface water quality will not be met in 100 years. PCB loading rates will equal Lake Winnebago inputs in 17 years.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to no action.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project RAOs.	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredge and Off-site Disposal	Remedy will require <1 to 57 years to consistently meet safe fish consumption levels after completion of remedy. Remedy will require <1 to 100 years to consistently meet safe ecological levels for carp. Surface water quality for wildlife will be met in 16 to >100 years, other criteria will not be met in 100 years. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transport to disposal facility. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risks from spillage during transport will be minimized by the solidification of sediments, use of truck routes, and spill prevention control and countermeasures plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Same as Alternative C, except on-site CDF will require long-term monitoring to ensure source control and containment.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when confined within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. PCB air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative E: Dredge and Thermal Treatment	Same as Alternative C, except treated residuals are available for beneficial reuse.	Off-gas and particulate emissions from thermal treatment units are effectively controlled by scrubbers and other pollution control devices. Uncertainty involving the adequacy and reliability of thermal treatment units include difficulties in maintaining optimum moisture content of feed material and treatment temperature during the treatment process.	Thermal treatment destroys the COCs, therefore sediments are irreversibly treated.	Water treatment residuals consist of flocculation sludges and filter sands. Thermal treatment residuals include metals/inorganics and rocks unable to pass through the treatment unit. Thermal treatment residuals also include condensate water. Actual quantities are dependent upon sediment volumes removed.	Toxicity, mobility, and volume of COCs present in sediments are reduced by irreversible thermal treatment.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transportation to designated reuse area. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Air emission controls for thermal treatment will be provided. Risks from fuel spills, fire, and explosions related to thermal treatment will be controlled through implementation of contingency plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative F: *In-situ* Capping	Same as Alternative C, except *in-situ* sand cap will require long-term monitoring to ensure containment.	Capped sediments will require long-term institutional controls which may limit recreational activities and boat access through the capped area. Uncertainty involving the adequacy and reliability of caps include disturbance from river currents, boat passage and draft, and ice scour. Winter weather may delay necessary repair or maintenance of cap. Long-term monitoring and maintenance will be required for the cap to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	No treatment residuals are included in this alternative, unless dredging occurs in uncapped areas. Treatment residuals from dredged material will be the same as Alternative C.	Toxicity and volume reductions beyond natural degradation do not occur as a result of capping. Mobility of COCs are reduced for capped sediments.	Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-1 Detailed Analysis of Alternatives Summary - Little Lake Butte des Morts Reach (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since an active remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Green Bay.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) utilizing silt curtains to reduce downstream transport of COCs. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	2.1 to 12.4 years estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering and water treatment.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments,. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$116,700,000 for Alternative C1 or $66,200,000 for Alternative C2
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	2.2 to 12.5 years estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering, water treatment, and CDF capping, and up to 6 months for CDF construction.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$68,000,000
Alternative E: Dredge and Thermal Treatment	Environmental impacts consist of release of COCs from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	2.1 to 12.4 years estimated to complete sediment removal and thermal treatment (assuming 6 working months per year).	Alternative is technically implementable and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Air emission restrictions could affect feasibility. Backup remedy is not required for thermal treatment.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Air emissions permits will be required for the thermal treatment of sediments. Local permits such as building permits, curb cut permits, etc. may also be required.	The technology and associated goods and services are commercially available to thermally treat the COCs. However, thermal treatment units are not available but need to be built to treat all dredged sediment.	$63,600,000
Alternative F: *In-situ* Capping	Environmental releases will be minimized during capping by: 1) utilizing placement techniques that minimize TSS; and 2) utilizing silt curtains to reduced downstream transport of COCs. The construction of a river bottom cap will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. Noise will be mitigated with a buffer zone and by limiting work hours. Capping may alter river use availability.	1.7 to 12.5 years are estimated to complete sediment removal. 0.7 to 3.7 years estimated to complete cap placement and 0.7 to 3.3 years for armoring (assuming 6 working months per year).	Alternative is technically feasible and can reliably meet the cleanup goals. However, the cap can only be placed in areas with adequate water depth; sediments outside of the capping footprint must be dredged. Effectiveness is measured by sampling capped sediments, ambient air quality, and river water. Capped sediment deposits can be: 1) recapped; 2) removed and contained in off-site disposal facility; or 3) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. A lake bed permit may be required from the Wisconsin Legislature to construct a river cap. Local permits such as building permits, curb cut permits, etc. may also be required.	Off-site disposal facilities are commercially available. Technology and associated goods and services are available to cap sediment deposits.	$90,500,000

Notes:

1 Alternative G was not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^{5} cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (1,000 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-2 Detailed Analysis of Alternatives Summary - Appleton to Little Rapids Reach

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type of Quantity of Treatment Residual	Reductions in Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will require 51 to 84 years to consistently reach safe fish consumption levels for recreational anglers. No action will require >71 years to consistently meet safe ecological levels for carp. Surface water quality will not be met in 100 years.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project Remedial Action Objectives (RAOs).	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredging and Off-site Disposal	Remedy will require <1 to 42 years to consistently meet safe fish consumption levels for recreational anglers after completion of remedy. Remedy will require 7 to 89 years to consistently reach safe ecological levels. Surface water quality for wildlife will be met in 19 to >100 years, other criteria will not be met in 100 years. Duration of residual risk is dependent upon the selected action level. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	As successfully demonstrated during the 1999 Lower Fox River demonstration dredging project at Deposit N, inhalation and disturbance risks to the community can be minimized by: 1) coordination with and involvement of the community; 2) limiting work hours; 3) establishing buffer zones around the work areas; and 4) ambient air monitoring. Risk to workers will be minimized with a site-specific health and safety program.
Alternative E: Dredge and Thermal Treatment	Same as Alternative C, except treated residuals are available for beneficial reuse.	Off-gas and particulate emissions from thermal treatment units are effectively controlled by scrubbers and other pollution control devices. Uncertainty involving the adequacy and reliability of thermal treatment units include difficulties in maintaining optimum moisture content of feed material and treatment temperature during the treatment process.	Thermal treatment destroys the COCs, therefore sediments are irreversibly treated.	Water treatment residuals consist of flocculation sludges and filter sands. thermal treatment treatment residuals include metals/inorganics and ocks unable to pass through the treatment unit. Thermal treatment residuals also include condensate water. Actual quantities are dependent upon sediment volumes removed.	Toxicity, mobility, and volume of COCs present in sediments are reduced by irreversible thermal treatment.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transportation to designated reuse area. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Air emission controls for thermal treatment will be provided. Risks from fuel spills, fire, and explosions related to thermal treatment will be controlled through implementation of contingency plans. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-2 Detailed Analysis of Alternatives Summary - Appleton to Little Rapids Reach (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include a remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Green Bay.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. As successfully demonstrated during the 1999 Lower Fox River demonstration dredging project at Deposit N, environmental releases can be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runoff; 3) utilizing removal techniques that minimize TSS; and 4) ambient air monitoring. Silt curtains were installed around the dredge areas to minimize downstream transport of COCs in the river, but were deemed unnecessary based on water quality monitoring results. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	0.2 to 1.3 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering and water treatment.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments,. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$20,100,000
Alternative E: Dredge and Thermal Treatment	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	0.2 to 1.3 years are estimated to complete sediment removal and thermal treatment (assuming 6 working months per year).	Alternative is technically implementable and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Air emission restrictions could affect feasibility. Backup remedy is not required for thermal treatment.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Air emissions permits will be required for the thermal treatment of sediments. Local permits such as building permits, curb cut permits, etc. may also be required.	The technology and associated goods and services are commercially available to thermal treat the COCs. However, thermal treatment units are not available but need to be built to treat all dredged sediment.	$17,100,000

Notes:

1 Alternatives D, F, and G were not retained for this reach.
2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^5 cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.
3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).
4 For relative comparison between alternatives, costs for only one action level are presented (1,000 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-3 Detailed Analysis of Alternatives Summary - Little Rapids to De Pere Reach

Alternative [1]	Long-term Effectiveness and Permanence: Magnitude and Type of Residual Risk [2]	Long-term Effectiveness and Permanence: Adequacy and Reliability of Controls	Reduction of Toxicity, Mobility, and Volume: Irreversibility of the Treatment	Reduction of Toxicity, Mobility, and Volume: Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, and Volume: Reduction of Toxicity, Mobility, or Volume	Short-term Effectiveness: Risk to Community and Workers and Controls
Alternative A: No Action	No action will require 92 to >100 years to consistently meet safe fish consumption levels for recreational anglers. No action will require >100 years to reach safe ecological levels for carp. Surface water quality will not be met in 100 years.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project RAOs.	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredging and Off-site Disposal	Remedy will require 2 to 92 years to consistently meet safe fish consumption levels for recreational anglers after completion of a corrective remedy. Remedy will require <1 to >100 years to consistently reach safe ecological levels for carp. Surface water quality for wildlife will be met in 27 to >100 years, other criteria will not be met in 100 years. Duration of residual risk is dependent upon the selected action level. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transport to disposal facility. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risks from spillage during transport will be minimized by the solidification of sediments, use of truck routes, and spill prevention control and countermeasures plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Same as Alternative C, except on-site CDF will require long-term monitoring to ensure source control and containment.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when confined within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative E: Dredge and Thermal Treatment	Same as Alternative C, except treated residuals are available for beneficial reuse.	Off-gas and particulate emissions from thermal treatment units are effectively controlled by scrubbers and other pollution control devices. Uncertainty involving the adequacy and reliability of thermal treatment units include difficulties in maintaining optimum moisture content of feed material and treatment temperature during the treatment process.	Thermal treatment destroys the COCs, therefore sediments are irreversibly treated.	Water treatment residuals consist of flocculation sludges and filter sands. Thermal treatment residuals include metals/inorganics and rocks unable to pass through the treatment unit. Thermal treatment residuals also include condensate water. Actual quantities are dependent upon sediment volumes removed.	Toxicity, mobility, and volume of COCs present in sediments are reduced by irreversible thermal treatment.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transportation to designated reuse area. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Air emission controls for thermal treatment will be provided. Risks from fuel spills, fire, and explosions related to thermal treatment will be controlled through implementation of contingency plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative F: *In-situ* Capping	Same as Alternative C, except *in-situ* sand cap will require long-term monitoring to ensure containment.	Capped sediments will require long-term institutional controls which may limit recreational activities and boat access through the capped area. Uncertainty involving the adequacy and reliability of caps include disturbance from river currents, boat passage and draft, and ice scour. Winter weather may delay necessary repair or maintenance of cap. Long-term monitoring and maintenance will be required for the cap to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	No treatment residuals are included in this alternative, unless dredging occurs in uncapped areas. Treatment residuals from dredged material will be the same as Alternative C.	Toxicity and volume reductions beyond natural degradation do not occur as a result of capping. Mobility of COCs are reduced for capped sediments.	Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-3 Detailed Analysis of Alternatives Summary - Little Rapids to De Pere Reach (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Green Bay.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) utilizing silt curtains to reduce downstream transport of COCs. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	1.4 to 10.9 years are estimated for Alternatives C1 and C3, and 0.2 to 1.7 years for Alternative C2 to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering and water treatment.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments,. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$95,100,000 for Alternative C1, $43,900,000 for Alternative C2A, $99,900,000 for Alternative C2B, or $69,100,000 for Alternative C3
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	1.4 to 10.9 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering, water treatment, and CDF capping, and up to 6 months for CDF construction.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$52,500,000
Alternative E: Dredge and Thermal Treatment	Environmental impacts consist of release of COCs from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	1.4 to 10.9 years are estimated to complete sediment removal and thermal treatment (assuming 6 working months per year).	Alternative is technically implementable and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Air emission restrictions could affect feasibility. Backup remedy is not required for thermal treatment.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for the discharge of dewatering effluent. Air emissions permits will be required for the thermal treatment of sediments. Local permits such as building permits, curb cut permits, etc. may also be required.	The technology and associated goods and services are commercially available to thermal treat the COCs. However, thermal treatment units are not available but need to be built to treat all dredged sediments.	$86,200,000
Alternative F: *In-situ* Capping	Environmental releases will be minimized during capping by: 1) utilizing placement techniques that minimize TSS; and 2) utilizing silt curtains to reduced downstream transport of COCs. The construction of a river bottom cap will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. Noise will be mitigated with a buffer zone and by limiting work hours. Capping may alter river use availability.	0.4 to 4.3 years are estimated to complete sediment removal. 1.2 to 4.6 years are estimated to complete cap placement and 1.1 to 4.2 years for armoring (assuming 6 working months per year).	Alternative is technically feasible and can reliably meet the cleanup goals. However, the cap can only be placed in areas with adequate water depth; sediments outside of the capping footprint must be dredged. Effectiveness is measured by sampling capped sediments, ambient air quality, and river water. Capped sediment deposits can be: 1) recapped; 2) removed and contained in off-site disposal facility; or 3) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. A lake bed permit may be required from the Wisconsin Legislature to construct a river cap. Local permits such as building permits, curb cut permits, etc. may also be required.	Off-site disposal facilities are commercially available. Technology and associated goods and services are available to cap sediment deposits.	$62,900,000

Notes:

1 Alternative G was not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^{5} cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (1,000 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-4 Detailed Analysis of Alternatives Summary - De Pere to Green Bay Reach (Green Bay Zone 1)

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will require >100 years to consistently meet safe fish consumption levels for recreational anglers. No action will require >100 years to consistently reach safe ecological levels for carp. Surface water quality will not be met in 100 years. PCB loading rates into Green Bay will not equal tributary loading rates in 100 years.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project RAOs.	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredging and Off-site Disposal	Remedy will require 7 to >100 years to consistently meet safe fish consumption levels after completion of remedy. Remedy will require 5 to >100 years to consistently reach safe ecological levels for carp. Surface water quality for wildlife will be consistently met in 27 to >100 years. PCB loading rates into Green Bay will consistently equal tributary loading rates in <1 to 36 years following remedy completion. Duration of residual risk is dependent upon the selected action level. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	As successfully demonstrated during the 2000 Lower Fox River demonstration dredging project at SMU 56/57, inhalation and disturbance risks to the community can be minimized by: 1) coordination with and involvement of the community; 2) limiting work hours; 3) establishing buffer zones around the work areas; and 4) ambient air monitoring. Risk to workers will be minimized with a site-specific health and safety program.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Same as Alternative C, except on-site CDF will require long-term monitoring to ensure source control and containment.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative E: Dredge and Thermal Treatment	Same as Alternative C, except treated residuals are available for beneficial reuse.	Off-gas and particulate emissions from thermal treatment units are effectively controlled by scrubbers and other pollution control devices. Uncertainty involving the adequacy and reliability of thermal treatment units include difficulties in maintaining optimum moisture content of feed material and treatment temperature during the treatment process.	Thermal treatment destroys the COCs, therefore sediments are irreversibly treated.	Water treatment residuals consist of flocculation sludges and filter sands. Thermal treatment residuals include metals/inorganics and large rocks and boulders unable to pass through the treatment unit. Thermal treatment residuals also include condensate water. Actual quantities are dependent upon sediment volumes removed.	Toxicity, mobility, and volume of COCs present in sediments are reduced by irreversible thermal treatment.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transportation to designated reuse area. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Air emission controls for thermal treatment will be provided. Risks from fuel spills, fire, and explosions related to thermal treatment will be controlled through implementation of contingency plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative F: *In-situ* Capping	Same as Alternative C, except *in-situ* sand cap will require long-term monitoring to ensure containment.	Capped sediments will require long-term institutional controls which may limit recreational activities and boat access through the capped area. Uncertainty involving the adequacy and reliability of caps include disturbance from river currents, boat passage and draft, and ice scour. Winter weather may delay necessary repair or maintenance of cap. Long-term monitoring and maintenance will be required for the cap to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	No treatment residuals are included in this alternative, unless dredging occurs in uncapped areas. Treatment residuals from dredged material will be the same as Alternative C.	Toxicity and volume reductions beyond natural degradation do not occur as a result of capping. Mobility of COCs are reduced for capped sediments.	Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-4 Detailed Analysis of Alternatives Summary - De Pere to Green Bay Reach (Green Bay Zone 1) (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Green Bay.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. As successfully demonstrated during the 2000 SMU 56/57 demonstration dredging project, environmental releases can be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runoff; 3) utilizing removal techniques that minimize TSS; and 4) ambient air monitoring. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	6.1 to 9.3 years are estimated for Alternative C1 and 5.2 to 8.0 years for Alternatives C2 and C3 to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering and water treatment.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$660,600,000 for Alternative C1, $173,500,000 for Alternative C2A, $491,800,000 for Alternative C2B, or $513,500,000 for Alternative C3
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	6.1 to 9.3 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering, water treatment, and CDF capping, and up to 6 months for CDF construction.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$505,100,000
Alternative E: Dredge and Thermal Treatment	Environmental impacts consist of release of COCs from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	5.2 to 8.0 years are estimated to complete sediment removal and thermal treatment (assuming 6 working months per year).	Alternative is technically implementable and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Air emission restrictions could affect feasibility. Backup remedy is not required for thermal treatment.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Air emissions permits will be required for the thermal treatment of sediments. Local permits such as building permits, curb cut permits, etc. may also be required.	The technology and associated goods and services are commercially available to thermal treat the COCs. However, thermal treatment units are not available but need to be built to treat all dredged sediment.	$355,100,000
Alternative F: *In-situ* Capping	Environmental releases will be minimized during capping by: 1) utilizing placement techniques that minimize TSS; and 2) utilizing silt curtains to reduced downstream transport of COCs. The construction of a river bottom cap will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. Noise will be mitigated with a buffer zone and by limiting work hours. Capping may alter river use availability.	4.2 to 6.3 years are estimated to complete sediment removal. 4.9 to 8.3 years are estimated to complete cap placement and 4.5 to 7.5 years for armoring (assuming 6 working months per year).	Alternative is technically feasible and can reliably meet the cleanup goals. However, the cap can only be placed in areas with adequate water depth; sediments outside of the capping footprint must be dredged. Effectiveness is measured by sampling capped sediments, ambient air quality, and river water. Capped sediment deposits can be: 1) recapped; 2) removed and contained in off-site disposal facility; or 3) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. A lake bed permit may be required from the Wisconsin Legislature to construct a river cap. Local permits such as building permits, curb cut permits, etc. may also be required.	Off-site disposal facilities are commercially available. Technology and associated goods and services are available to cap sediment deposits.	$357,100,000

Notes:

1 Alternative G was not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^{5} cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (1,000 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-5 Detailed Analysis of Alternatives Summary - Green Bay Zone 2

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will not meet safe fish consumption levels for recreational anglers in 100 years (first meet nor consistently meet), regardless of the action taken in the Lower Fox River. No action will not meet safe ecological levels for walleye in 100 years, regardless of the action taken in the Lower Fox River. Surface water quality was not evaluated.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project Remedial Action Objectives (RAOs).	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredging and Off-site Disposal	Remedy will not consistently meet safe fish consumption levels in 100 years after completion of remedy. Remedy will require >100 years to consistently reach safe ecological levels for walleye, regardless of the action taken in the Lower Fox River. Risk reduction is projected for alewife levels (see Section 8). Duration of residual risk is dependent upon the selected action level. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transport to disposal facility. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risks from spillage during transport will be minimized by the solidification of sediments, use of truck routes, and spill prevention control and countermeasures plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Same as Alternative C, except on-site CDF will require long-term monitoring to ensure source control and containment.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when confined within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Same as Alternative C, except on-site CAD site will require long-term monitoring to ensure source control and containment.	Sediments placed within a CAD will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CADs include lack of liner and potential difficulties in maintaining a hydraulic gradient to ensure containment of pore water. Institutional controls are reliable if properly enforced. Long-term monitoring and maintenance will be required for the CAD to document and maintain the effectiveness of the containment. Permanent deed and access restrictions will be required.	No treatment of sediments is included in this alternative.	No treatment of sediments is included in this alternative. Water treatment residuals consist of flocculation sludges and filter sands used in the water treatment process. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are placed within confined disposal facility.	Risks to community and workers are potentially caused by air emissions from construction equipment and discharges to water from sediment removal and management. Risks to community will be minimized by utilizing silt curtains and not working during residence high-occupancy times such as evenings and weekends. Risks during transport will be minimized by the solid nature of the material and spill prevention control and countermeasures plans. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-5 Detailed Analysis of Alternatives Summary - Green Bay Zone 2 (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Lake Michigan.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) utilizing silt curtains to reduce downstream transport of COCs. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	1.1 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering and water treatment.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments,. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$507,200,000 (for 5,000 ppb action level)
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	1.1 to 8.2 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering, water treatment, and CDF capping.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$814,100,000
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Environmental impacts consist of noise and release of COCs from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water to be discharged off site; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) by removing material in an upstream-to-downstream fashion to prevent recontamination of remediated areas. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CAD will also initially create a loss of habitat for aquatic organisms along with changes in water flow patterns. Noise will be mitigated with a buffer zone and by limiting work hours. CADs may alter river use availability and aesthetics for riparian owners.	1.1 to 8.2 years are estimated to complete sediment removal (assuming 6 working months per year). 1 to 2 additional years estimated for CAD cap placement.	Alternative can reliably meet the cleanup goal. The cleanup goal for this alternative is a risk-based number derived from the risk of residual sediments. The magnitude and risk of the residual sediments is outlined in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, surface water, and sand cap after placement.	Alternative is administratively feasible, however, legislative authority may be required prior to constructing a CAD (Wisconsin Statute 30 Lakebed Grant). Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for the discharge of dewatering effluent. Local permits such as building permits, zoning permits, etc. may also be required.	Potential CAD construction areas exist and technology and associated goods and services are available to construct CADs. Sufficient upland areas can be secured to operate staging and water treatment activities.	$697,800,000

Notes:

1 Alternatives E and F were not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^{5} cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (1,000 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-6 Detailed Analysis of Alternatives Summary - Green Bay Zone 3A

Alternative[1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk[2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will not meet (first meet nor consistently meet) safe fish consumption levels for recreational anglers in 100 years, regardless of the action taken in the Lower Fox River. No action will not meet safe ecological levels for walleye in 100 years, regardless of the action taken in the Lower Fox River. Surface water quality was not evaluated.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project RAOs.	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative C: Dredging and Off-site Disposal	Remedy will not consistently meet safe fish consumption levels in 100 years after completion of remedy. Remedy will require >100 years to reach safe ecological levels for walleye. Some ecological levels for bird deformities associated with alewife consumption (discussed in Section 8) will be met in <30 years following remedy completion. Duration of residual risk is dependent upon the selected action level. Off-site landfill will require long-term monitoring and liability.	The alternative relies on engineering controls at the off-site disposal facility. Uncertainty involving the adequacy and reliability of NR 500 landfills includes the possible, but unlikely, failure of the containment liner, leachate collection, or leak detection system. Properly designed and managed NR 500 landfills provide reliable controls for long-term disposal. Long-term monitoring and maintenance is included in operation of off-site NR 500 landfill.	No treatment of sediments is included in this alternative, except for dewatering.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are solidified and placed within a lined disposal facility.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment, dewatering operations, and transport to disposal facility. Risks to community will be minimized by establishing buffer zones around the work areas and limiting work hours. Ambient air monitoring may be required. Risks from spillage during transport will be minimized by the solidification of sediments, use of truck routes, and spill prevention control and countermeasures plans. Risk to workers will be minimized with a site-specific health and safety program.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Same as Alternative C, except on-site CDF will require long-term monitoring to ensure source control and containment.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when confined within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Same as Alternative C, except on-site CAD site will require long-term monitoring to ensure source control and containment.	Sediments placed within a CAD will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CADs include lack of liner and potential difficulties in maintaining a hydraulic gradient to ensure containment of pore water. Institutional controls are reliable if properly enforced. Long-term monitoring and maintenance will be required for the CAD to document and maintain the effectiveness of the containment. Permanent deed and access restrictions will be required.	No treatment of sediments is included in this alternative.	No treatment of sediments is included in this alternative. Water treatment residuals consist of flocculation sludges and filter sands used in the water treatment process. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are placed within confined disposal facility.	Risks to community and workers are potentially caused by air emissions from construction equipment and discharges to water from sediment removal and management. Risks to community will be minimized by utilizing silt curtains and not working during residence high-occupancy times such as evenings and weekends. Risks during transport will be minimized by the solid nature of the material and spill prevention control and countermeasures plans. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-6 Detailed Analysis of Alternatives Summary - Green Bay Zone 3A (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Lake Michigan.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative C: Dredging and Off-site Disposal	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water prior to discharge; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) utilizing silt curtains to reduce downstream transport of COCs. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms.	0.6 day is estimated to complete sediment removal.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments,. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. Local permits such as building permits, curb cut permits, etc. may also be required.	Dredging equipment and off-site disposal facilities are commercially available.	$11,000,000 (for 1,000 ppb action level)
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	4.5 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for final dewatering, water treatment, and CDF capping.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$474,300,000 (for 500 ppb action level)
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Same as Alternative C, except on-site CAD site will require long-term monitoring to ensure source control and containment. The construction of a CAD will also initially create a loss of habitat for aquatic organisms along with changes in water flow patterns.	4.5 years are estimated to complete sediment removal (assuming 6 working months per year). 2 additional years estimated for CAD cap placement.	Alternative can reliably meet the cleanup goal. The cleanup goal for this alternative is a risk-based number derived from the risk of residual sediments. The magnitude and risk of the residual sediments is outlined in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, surface water, and sand cap after placement.	Alternative is administratively feasible, however, legislative authority may be required prior to constructing a CAD (Wisconsin Statute 30 Lakebed Grant). Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for the discharge of dewatering effluent. Local permits such as building permits, zoning permits, etc. may also be required.	Potential CAD construction areas exist and technology and associated goods and services are available to construct CADs. Sufficient upland areas can be secured to operate staging and water treatment activities.	$389,100,000 (for 500 ppb action level)

Notes:

1 Alternatives E and F were not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^5 cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (500 ppb) action level when applicable. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent conting

Table 9-7 Detailed Analysis of Alternatives Summary - Green Bay Zone 3B

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will not meet (first meet nor consistently meet) safe fish consumption levels for recreational anglers in 100 years, regardless of the action taken in the Lower Fox River. No action will not meet safe ecological levels in 100 years, regardless of the action taken in the Lower Fox River. Surface water quality was not evaluated.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project Remedial Action Objectives (RAOs).	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Remedy will require >100 years to consistently meet safe fish consumption levels after completion of remedy, regardless of the action taken on the Lower Fox River. Remedy will require >100 years to reach safe ecological levels for walleye. Some alewife protective levels related to bird deformities will be met in <30 years following completion of a remedy (discussed in Section 8). Surface water quality was not evaluated. Duration of residual risk is dependent upon the selected action level.	Sediments placed within a CDF will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CDFs include lack of liner or leachate collection system, minor water seepage, and potential difficulties in maintaining a hydraulic gradient to ensure containment of leachate. Long-term monitoring and maintenance will be required for the CDF to document and maintain the effectiveness of the containment.	No treatment of sediments is included in this alternative.	Water treatment residuals consist of flocculation sludges and filter sands. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when confined within the CDF.	Risks to community and workers are potentially caused by air emissions and excessive noise from construction equipment and dewatering operations. Risks to community will be minimized by establishing buffer zones around work areas and limiting work hours. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program. The constructed CDF, when completed, may provide recreational park space for the community.
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Same as Alternative D, except on-site CAD site will require long-term monitoring to ensure source control and containment.	Sediments placed within a CAD will require long-term institutional controls such as land use restrictions to prevent disturbance of the sediments. Uncertainty involving the adequacy and reliability of CADs include lack of liner and potential difficulties in maintaining a hydraulic gradient to ensure containment of pore water. Institutional controls are reliable if properly enforced. Long-term monitoring and maintenance will be required for the CAD to document and maintain the effectiveness of the containment. Permanent deed and access restrictions will be required.	No treatment of sediments is included in this alternative.	No treatment of sediments is included in this alternative. Water treatment residuals consist of flocculation sludges and filter sands used in the water treatment process. Actual quantities are dependent upon sediment volumes removed.	Toxicity and volume reductions are minimal due to disposal. Mobility of COCs are reduced when sediments are placed within confined disposal facility.	Risks to community and workers are potentially caused by air emissions from construction equipment and discharges to water from sediment removal and management. Risks to community will be minimized by utilizing silt curtains and not working during residence high-occupancy times such as evenings and weekends. Risks during transport will be minimized by the solid nature of the material and spill prevention control and countermeasures plans. Ambient air monitoring may be required. Risk to workers will be minimized with a site-specific health and safety program.

Table 9-7 Detailed Analysis of Alternatives Summary - Green Bay Zone 3B (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Lake Michigan.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000
Alternative D: Dredge to a Confined Disposal Facility (CDF)	Environmental impacts consist of COC releases from removed sediments into the air and water. Environmental releases will be minimized during remediation by following the same control measures outlined in Alternative C. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CDF will also initially create a loss of habitat for aquatic organisms along with changes in river flow patterns. The constructed CDF, when completed, may provide additional habitat for near shore wildlife. CDFs may alter river use availability and aesthetics for riparian owners.	12 years are estimated to complete sediment removal (assuming 6 working months per year). 1 additional year estimated for dewatering, water treatment, and CDF capping.	Alternative is technically feasible and can reliably meet the cleanup goals. The cleanup goal is a risk-based number derived from residual sediments. Magnitude and risk of residual sediments are discussed in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, and river water. Backup remedy is not required for off-site land disposal. CDFs can be: 1) removed and contained in off-site disposal facility, or 2) removed and treated *ex situ*.	Alternative is administratively feasible. Water quality permits from the WDNR and the USACE are likely to be required for sediment removal. Discharge permits (i.e., NPDES/WPDES) will likely be required for dewatering effluent. Landfill construction/operation permits will be required for any disposal facility. A lake bed permit may be required from the Wisconsin Legislature to construct a CDF. Local permits such as building permits, curb cut permits, etc. may also be required.	Potential CDF construction areas exist and technology and associated goods and services are available to construct CDFs.	$1,155,100,000
Alternative G: Dredge to a Contained Aquatic Disposal (CAD) Facility	Environmental impacts consist of noise and release of COCs from removed sediments into the air and water. Environmental releases will be minimized during remediation by: 1) treating water to be discharged off site; 2) controlling stormwater runon and runoff; 3) utilizing removal techniques that minimize TSS; and 4) by removing material in an upstream-to-downstream fashion to prevent recontamination of remediated areas. Environmental impacts of sediment removal will likely include a temporary loss of habitat for aquatic organisms. The construction of a CAD will also initially create a loss of habitat for aquatic organisms along with changes in water flow patterns. Noise will be mitigated with a buffer zone and by limiting work hours. CADs may alter river use availability and aesthetics for riparian owners.	12 years are estimated to complete sediment removal (assuming 6 working months per year). 4 additional years estimated for CAD cap placement.	Alternative can reliably meet the cleanup goal. The cleanup goal for this alternative is a risk-based number derived from the risk of residual sediments. The magnitude and risk of the residual sediments is outlined in Section 8. Effectiveness is measured by sampling limit of excavation, ambient air quality, wastewater effluent, surface water, and sand cap after placement.	Alternative is administratively feasible, however, legislative authority may be required prior to constructing a CAD (Wisconsin Statute 30 Lakebed Grant). Water quality permits from the WDNR and the USACE are likely to be required to remove the sediment. Discharge permits (i.e., NPDES/WPDES) will likely be required for the discharge of dewatering effluent. Local permits such as building permits, zoning permits, etc. may also be required.	Potential CAD construction areas exist and technology and associated goods and services are available to construct CADs. Sufficient upland areas can be secured to operate staging and water treatment activities.	$1,010,900,000

Notes:

1 Alternatives C, E, and F were not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^{5} cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (500 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

Table 9-8 Detailed Analysis of Alternatives Summary - Green Bay Zone 4

Alternative [1]	Long-term Effectiveness and Permanence		Reduction of Toxicity, Mobility, and Volume			Short-term Effectiveness
	Magnitude and Type of Residual Risk [2]	Adequacy and Reliability of Controls	Irreversibility of the Treatment	Type and Quantity of Treatment Residual	Reduction of Toxicity, Mobility, or Volume	Risk to Community and Workers and Controls
Alternative A: No Action	No action will not meet (first meet nor consistently meet) safe fish consumption levels for recreational anglers in 100 years, regardless of the action taken on the Lower Fox River. No action will not meet safe ecological levels in 100 years, regardless of the action taken in the Lower Fox River. Surface water quality was not evaluated.	The no action alternative does not include engineering or institutional controls. Long-term fish tissue monitoring will be required to evaluate status of consumption advisories already in place.	No action is reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy.
Alternative B: Monitored Natural Recovery and Institutional Controls	Similar to No Action alternative.	Enforcement of institutional controls may be difficult along the entire length of the reach. Fish advisories in particular are difficult to enforce. Restrictions on dredging and in-water construction activities and recreational uses are more readily enforced. Long-term sediment, river water quality, and tissue monitoring will be required to evaluate system recovery over time and achievement of project Remedial Action Objectives (RAOs).	MNR and institutional controls are reversible.	Residuals do not exist under this alternative.	Minimal reductions of toxicity, mobility, and volume of COCs through naturally-occurring processes.	There are no short-term risks associated with this remedy. Monitored natural recovery will likely require many years, therefore institutional controls will remain in-place until the project RAOs are met.

Table 9-8 Detailed Analysis of Alternatives Summary - Green Bay Zone 4 (Continued)

Alternative [1]	Short-term Effectiveness		Implementability			Cost
	Environmental Impacts of Remedy and Controls	Duration of Short-term Risks [3]	Technical Feasibility	Administrative Feasibility	Availability	Estimated Costs [4]
Alternative A: No Action	Since a remedy is not part of the No Action alternative, there are no environmental impacts associated with the remedy.	No Action alternative does not include a remedy.	Although no action is technically feasible, it will not meet the cleanup goals.	No action is likely not administratively feasible.	Technologies, goods, and services are available to monitor tissue quality.	$4,500,000
Alternative B: Monitored Natural Recovery and Institutional Controls	Since a remedy is not part of the MNR and Institutional Controls alternative, there are no environmental impacts associated with implementation of the remedy.	MNR and Institutional Controls alternative does not include an active remedy.	Although MNR is technically feasible, it will likely not meet the cleanup goals of unrestricted fish consumption in 40 years or less. MNR will likely not significantly reduce the mass transport of PCBs to Lake Michigan.	Institutional controls are likely not administratively feasible.	Technologies, goods, and services are available to monitor sediments, water, and tissue.	$9,900,000

Notes:

1 Alternatives C, D, E, F, and G were not retained for this reach.

2 Human health risk threshold concentrations include: RME hazard index of 1.0 and RME 10^5 cancer risk level for walleye (recreational angler). Ecological risk threshold concentrations include: the NOAEC bird deformity and NOAEC piscivorous mammal for carp.

3 Duration of short-term risks are included for the range of applicable action levels. Expect 2 months each for mobilization and demobilization for each alternative based on Deposit N project (Foth and Van Dyke, 2001).

4 For relative comparison between alternatives, costs for only one action level are presented (500 ppb) action level. Refer to Section 7 of the FS for costs associated with other action levels. Remedy costs do not include 20 percent contingency costs.

10 Comparative Analysis of Alternatives

This section presents the final analysis of the alternative screening process incorporating the risks, implementation methods, costs, and action level options screened in the previous sections of the FS. This final section is a comparative analysis among the eight potential remedial alternatives to assess the relative performance of each alternative with respect to four of the CERCLA balancing criteria presented in Section 9 (EPA, 1988 RI/FS Guidance Document). It synthesizes all of the findings presented in the RI, FS, and RA documents for the Lower Fox River and Green Bay RI/FS. The purpose of the comparative analysis is to weigh the relative performance of each alternative against a particular criterion and to determine which alternatives perform consistently well or consistently better in relation to the criterion of interest. A sub-component of this comparison is that for each remedial alternative, a range of action levels is presented resulting in varying levels of effort, protection, and risk reduction (discussed in Section 8). By carrying forward a range of action levels for each alternative, this section creates a three-dimensional comparative analysis between evaluation criteria, remedial alternative, and action level.

Following a description of the comparative process, the comparative analysis for each of the four river reaches are described separately below as they relate to the remedial action objectives. The Green Bay zones are discussed together as Green Bay since most of the outcomes are the same, regardless of the zone. A summary of the comparative measures used in the evaluation process are presented in Table 10-1. A summary of the total cost and anticipated risk reduction associated with each alternative is presented in Tables 10-2 and 10-3 for the Lower Fox River and Green Bay, respectively.

10.1 Description of Comparative Analysis Process

This section compares the predicted performance of: 1) each reach-specific and bay-specific alternative at each action level in relation to specific evaluation criteria; and 2) each action level on a river- and bay-wide basis in relation to specific evaluation criteria. This comparison builds upon the detailed analysis conducted in Section 9 in which each alternative was analyzed independently without consideration of other alternatives and the risk assessment summary in Section 8 in which each action level was evaluated independently. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative and action level relative to one another, so that the key trade-offs can be identified. This section does not, however, recommend any specific alternative or action level. Final selection will be the responsibility of the resource managers to balance the trade-offs identified in this section and select a final remedy option.

The comparative analysis focuses on synthesizing the evaluation in Section 9 into readily accessible decision-making tools. To accomplish this, numerical measures were used to evaluate how each alternative compares relative to all others with respect to addressing each of the following questions:

- How long after remediation is completed would it take to achieve sediment concentrations resulting in acceptable risk to humans and ecological receptors?

- What is the level of disruption to local communities associated with the construction of each alternative?

- What is the mass of PCBs removed from the Lower Fox River?

- What is the cost of implementing each alternative?

- What is the incremental cost of reducing risk for each alternative?

- How long after remediation is completed would it take to achieve surface water concentrations resulting in acceptable risk to humans and ecological receptors?

- What is the amount of PCBs being transported to Green Bay in the water column as suspended solids following implementation of the alternative?

Each of these issues, and the quantitative measures identified to evaluate the alternatives, are discussed in Table 10-1. In summary, the array of parameters included in the comparative analysis for both the Lower Fox River and Green Bay includes the following components:

- **Remedial Alternatives**
  - A: No Action
  - B: Monitored Natural Recovery and Institutional Controls
  - C: Dredge and Off-site Disposal (C1, C2, and C3 where options are provided[8])
  - D: Dredge to a CDF
  - E: Dredge and Thermal Treatment
  - F: Cap in Place (to the maximum extent possible)
  - G: Dredge to a CAD Facility

- **PCB Action Levels**
  - No Action
  - 125 ppb
  - 250 ppb
  - 500 ppb
  - 1,000 ppb
  - 5,000 ppb

- **Evaluation Parameters (Associated CERCLA Balancing Criterion)**
  - Years to Reach Protective Human Health Levels (long-term effectiveness and permanence)
  - Years to Reach Protective Ecological Health Levels (long-term effectiveness and permanence)
  - Number of Years to Implement Remedy (short-term effectiveness)
  - PCB Mass Removed (reduction of toxicity, mobility and volume)
  - Total Cost (cost)
  - Cost Effectiveness (cost)
  - Years to Reach Ecologically Protective Surface Water Quality (long-term effectiveness and permanence)
  - PCB Sediment Loading to Green Bay (long-term effectiveness and permanence)

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[8] Alternative C or C1 is hydraulic dredging for Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere.
Alternative C or C1 is mechanical dredging for De Pere to Green Bay and the Green Bay zones.
Alternative C2 is mechanical dewatering for Little Lake Butte des Morts Reach.
Alternative C2A is hydraulic dredging pumped directly to a combined dewatering and disposal facility, and Alternative C2B is passive dewatering and disposal at a dedicated NR 500 monofill for the Little Rapids to De Pere and the De Pere to Green Bay reaches.
Alternative C3 is mechanical dewatering and disposal at an existing NR 500 commercial disposal facility for the Little Rapids to De Pere and De Pere to Green Bay reaches.

As discussed in Section 8, none of the alternatives considered in this FS are projected to meet surface water criteria (RAO 1) that is protective to human health drinking water standards within the modeled time horizon (100 years). As such, the ability to achieve this portion of RAO 1 cannot be used in a comparative analysis to distinguish the various alternatives. However, the ability to achieve wildlife criteria (0.12 ng/L) within 30 years following remediation is discussed under ecological health. In addition, the minimization of contaminant releases during active remediation (RAO 5) was not considered since reliable, comparable, quantitative data are not available for this purpose.

Project expectations for the Lower Fox River and Green Bay project have been summarized as five remedial action objectives previously described in Sections 4 and 8 of the FS. Within each of these remedial action objectives, both WDNR and EPA have quantified their project expectations into numerical values (i.e., number of years to remove fish consumption advisories) in which to evaluate the expected performance of each alternative and each action level. These expectations may change or be revised over the course of the project and through the public review process, but for now, they provide a useful framework to compare and evaluate the alternatives. These quantifiable expectations are described in Section 8.

From the array of risk levels and protective sediment quality thresholds presented in Section 8, several key thresholds were carried forward in the FS for relative comparison between alternatives. These thresholds were selected by both WDNR and EPA as important risk evaluation criteria that relate to the remedial action objectives (RAOs) for the project:

- **Human Health**
  - Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, HI is 1.0 (noncancer) (288 μg/kg);

  - Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, 10^{-5} cancer risk (106 μg/kg);

  - Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish, RME, HI is 1.0 (noncancer) (181 μg/kg); and

- Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish, RME, 10^{-5} cancer risk (71 μg/kg).

Because many of the recreational angler thresholds are met within 30 years following cleanup without implementation of an active remedy, the high-intake fish consumer threshold was added to the comparative analysis.

- **Ecological Health**
  - Achieve protective levels in 30 years following cleanup based on carnivorous bird deformity - NOAEC based on carp, whole fish (121 μg/kg);
  - Achieve protective levels in 30 years following cleanup based on protection of piscivorous mammals (mink) - NOAEC based on carp, whole fish (50 μg/kg); and
  - Achieve surface water quality for the protection of wildlife (0.12 ng/L) in 30 years following cleanup.

- **PCB Transport to Green Bay**
  - Achieve PCB loads from the Lower Fox River (De Pere to Green Bay Reach) into Green Bay that are equivalent to PCB loads from the sum of other tributaries (10 kg/yr).

The projected time required to meet these thresholds based on the action levels selected are discussed in the following sections for each reach and zone.

10.2 Summary of Alternatives

The seven generic remedial alternatives retained for detailed analysis are:

A. No Action,
B. Monitored Natural Recovery and Institutional Controls,
C. Dredge and Off-site Disposal,
D. Dredge to a Confined Disposal Facility (CDF),
E. Dredge and Thermal Treatment,
F. *In-situ* Capping, and
G. Dredge to a Confined Aquatic Disposal (CAD) Facility.

The no action alternative was retained as required under CERCLA and the NCP. This alternative serves as a baseline for comparison with other alternatives and involves taking no action towards a remedy, implying no active management or expectation that the RAOs will be achieved over time.

The monitored natural recovery alternative was also retained as a basis for comparison with other alternatives, but involves an expectation that RAOs will be achieved in 30 years (i.e., ability to consume fish from the Lower Fox River). This alternative assumes that institutional controls will remain in place until acceptable levels of risk have been achieved. Monitored natural recovery is implied in many of these alternatives, because each remedy assumes varying amounts of protectiveness by natural processes by selecting a range of different action levels surrounding the SQT levels identified in the risk assessment (Section 3). Each action level and the amount of risk reduction provided by source removal of contaminated sediment will be compared to the amount of remaining risk and the costs associated with each action level.

Dredge and off-site disposal includes hydraulic and/or mechanical dredging, passive followed by solidification or mechanical dewatering, and truck hauling to an existing or newly-constructed landfill.

Dredge to a CDF includes hydraulic dredging and piping or mechanical dredging and offloading to a newly-constructed nearshore or freestanding CDF. Nearshore CDF construction in the Lower Fox River includes placement of steel sheet piles along the waterside and a clean soil cap once the CDF has been filled to capacity. In-water CDF construction in Green Bay includes placement of contaminated sediment in an elevated cellular cofferdam and capping with clean sand.

Vitrification was retained as the representative thermal treatment process option. It involves hydraulic dredging, passive dewatering followed by thermal treatment by a shore-based unit. Sediment treated by thermal treatment is transformed into glass aggregate that has the potential for a wide variety of beneficial reuse applications.

Thermal treatment was selected as the *ex-situ* thermal treatment process option because the multi-phased study conducted by WDNR has provided data which indicates that this treatment technology is a viable option.

Several sand cap designs were retained in Section 6 for possible application in the Lower Fox River. Design factors that influenced the final selection of an *in-situ* cap included an evaluation of capping materials and cap thickness when applied in the field. In general, sandy sediments are suitable capping material, with the additional option of armoring at locations with the potential for scouring and erosion. Contaminated sediments will be left in place and covered with a 20-inch sand cap overlain by 12 inches of graded armor stone. Sediments located within navigational channels will be dredged, dewatered and taken to an upland disposal site.

Construction of a CAD is only technically feasible in Green Bay. Three possible locations were sited in the FS based on bathymetry, water depth, and currents. Each location was assumed to provide enough capacity for each action level. Construction of the CAD includes placement of contaminated sediment in a mechanically-dredged excavation and covering the sediment with 3 feet of clean sand after placement.

10.3 Comparative Analysis of Alternatives - Little Lake Butte des Morts Reach

The comparative analysis of alternatives for the Little Lake Butte des Morts Reach is presented on Figures 10-1 and 10-2. The following discussion provides a set of observations made as a result of the comparative analysis:

- **Human Health.** Figure 10-1 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for recreational anglers can be removed. A general target has been established that these recreational advisories be removed within 10 years following cleanup. Active remedies implemented to the 1,000 ppb action level will satisfy this goal. The largest reductions in time to achieve protective levels is observed between the 5,000 and 1,000 ppb action levels. Figure 10-1 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for high-intake fish consumers can be removed. A general target has been established that these advisories be removed within 30 years following cleanup. Active remedies satisfy this goal for action levels 125 through 1,000 ppb with the largest reduction in time to achieve protective levels occurring between the 5,000 and 1,000 ppb action levels.

- **Ecological Health.** Figure 10-1 also illustrates the time required to meet ecologically protective levels. A general target has been established that safe ecological levels should be met within 30 years following cleanup. Active remedies will meet protective levels within the modeled time frame for the 1,000 ppb action level and below, for all alternatives. The largest reduction in time to reach protective levels is observed between the 5,000 and 1,000 ppb action levels.

Figure 10-1 illustrates the time to meet ecologically protective levels based on surface water quality. A general target has been established that safe ecological levels should be met within 30 years following cleanup. Active remedies achieve this target for the 125 and 250 ppb action levels and are marginally above the target for the 500 ppb action level (39 years).

- **Implementation Duration.** Figure 10-2 illustrates the implementation duration for each alternative at each action level. A general target goal has been set to perform the cleanup within a 10-year period. Only the 125 ppb action level does not satisfy this target. All the alternatives have approximately equivalent cleanup durations that vary by action level.

- **PCB Mass Removed.** Figure 10-2 illustrates that alternatives involving dredging remove the same PCB mass at each action level, while the capping alternative (Alternative F) removes slightly less PCB mass. The largest reduction in PCB mass is observed between 5,000 and 1,000 ppb action levels, while any further decrease in the action level does not significantly increase the PCB mass removed (less than 7%).

- **Total Cost.** The total cost to implement an active remedy represents a fivefold cost increase compared to MNR (Alternative B) estimated at $9.9 million (Table 10-2). It can be seen on Figure 10-2 that Alternative E is generally the lowest cost active remedy, while dredging to a CDF and dredge and off-site disposal with mechanical dewatering (Alternatives D and C2) are slightly more expensive, with C1 being the most expensive. Alternative D appears to be least sensitive to changes in action level. At the 1,000 ppb action level, Alternative E is estimated to be the least-cost approach at $64 million with Alternative C2 at 66 million, Alternative D at $68 million, Alternative F at $90 million, and Alternative C1 at $117 million.

- **Cost Effectiveness.** In order to evaluate the cost effectiveness of each alternative at each action level, the incremental cost per year reduction in time to remove fish consumption advisories (for recreational anglers) relative to the Institutional Controls alternative (Alternative B) was calculated using the cancer risk data. Due to the uniformity in the time to remove fish consumption advisories, these data are closely aligned to the total cost data. Thermal Treatment (Alternative E) is the most cost-effective remedy, and 1,000 ppb is the most cost-effective PCB action level that meets protective thresholds.

10.4 Comparative Analysis of Alternatives - Appleton to Little Rapids Reach

The comparative analysis of alternatives for the Appleton to Little Rapids Reach is presented on Figures 10-3 and 10-4. The following discussion provides a set of observations resulting from the comparative analysis:

- **Human Health.** Figure 10-3 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for recreational anglers can be removed. A general target has been established that these recreational advisories be removed within 10 years following cleanup. Each active remedy satisfies this goal for action levels 125 through 1,000 ppb, except for the cancer risk time frame which is marginally above the target for the 500 ppb (11 years) and 1,000 ppb (14 years) action levels. The largest reduction in the time to reach protective levels is observed between the 5,000 to 1,000 ppb action levels. Figure 10-3 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for high-intake fish consumers can be removed. A general target has been established that these advisories be removed within 30 years following cleanup. Active remedies satisfy this goal for action levels 125 through 1,000 ppb with the largest reduction in time to achieve protective levels occurring between the 5,000 and 1,000 ppb action levels.

- **Ecological Health.** Figure 10-3 also illustrates the time required to meet ecologically protective levels. These data indicate that protective levels will not be reached within 71 to over 100 years with no active remedy (Alternatives A and B). Active remedies will meet protective levels within the 30-year time frame for the 1,000 ppb action level and below, except for the piscivorous mammal that is marginally above 30 years (34 years) at the 1,000 ppb action level. For the 500 ppb action level, the time to reach protective ecological levels varies between 15 and 29 years. For 250 ppb, the time varies between 9 and 18 years and for 125 ppb, the time varies between 7 and 15 years.

Figure 10-3 illustrates the time to meet ecologically protective levels based on surface water quality. A general target has been established that safe ecological levels should be met within 30 years following cleanup. Active remedies achieve this target for the 125 and 250 ppb action levels and are marginally above the target for the 500 ppb action level (40 years).

- **Implementation Duration.** Figure 10-4 illustrates the implementation duration for each alternative at each action level. A general target has been set to perform the cleanup within a 10-year period. All of the alternatives at each action level easily satisfy this target with the maximum implementation duration being 1.3 years.

- **PCB Mass Removed.** Figure 10-4 illustrates that alternatives involving dredging remove the same PCB mass at each action level. The largest reduction in PCB mass is observed between the No Action and 5,000 ppb action levels (63% removed), while further decrease in the action level incrementally increases the PCB mass removed. Only 10 percent of the mass is contained between the 125 and 500 ppb action levels. For Alternatives C and E, the PCB mass removed varies from 67 kg at 5,000 ppb to 105 kg at 250 ppb.

- **Total Cost.** The total cost to implement an active remedy represents a 5- to 20-fold cost increase compared to the MNR alternative (Alternative B) estimated at $9.9 million (Table 10-2). Dredging to an off-site landfill (Alternative C) is a slightly higher cost approach when compared to thermal treatment (Alternative E). Alternative E appears to be the least sensitive to changes in action level. For example, at the 1,000 ppb action level, Alternative E is estimated to be the least-cost approach at $17 million with Alternative C at $20 million.

- **Cost Effectiveness.** In order to evaluate the cost effectiveness of each alternative at each action level, the incremental cost per year reduction in time to remove fish consumption advisories (for recreational anglers) relative to the MNR alternative (Alternative B) was calculated using the cancer risk data. Due to the uniformity in the time to remove fish consumption advisories, these data are closely aligned to the total cost data. Thermal Treatment (Alternative E) is the most cost-effective remedy, and 1,000 ppb is the most cost-effective PCB action level that meets protective thresholds.

10.5 Comparative Analysis of Alternatives - Little Rapids to De Pere Reach

The comparative analysis of alternatives for the Little Rapids to De Pere Reach is presented on Figures 10-5 and 10-6. The following discussion provides a set of observations made as a result of the comparative analysis:

- **Human Health.** Figure 10-5 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for recreational anglers can be removed. A general target has been established that these recreational advisories be removed within 10 years following cleanup. Each active remedy satisfies this goal based on noncancer risk for action levels 125 through 1,000 ppb. The goal is satisfied for only the 125 ppb action level based on cancer risk, while the result is marginally above the goal for the 250 ppb (14 years) and 500 ppb (20 years) action levels. The largest reductions are observed between the 5,000 and 1,000 ppb action levels. Figure 10-9 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for high-intake fish consumers can be removed. A general target has been established that these advisories be removed within 30 years following cleanup. Active remedies satisfy this goal for action levels 125 through 1,000 ppb, except for the cancer risk scenario at the 1,000 ppb action level where the goal is not achieved for 42 years. The largest reduction in time to achieve protective levels occurs between the 5,000 and 1,000 ppb action levels.

- **Ecological Health.** Figure 10-5 also illustrates the time required to meet ecologically protective levels. The no action alternatives (Alternatives A and B) do not reach protective levels within the modeled time frame (100 years). Active remedies will meet protective levels within the 30-year target time frame for action levels 125 through 500 ppb, except for the piscivorous mammal scenario at the 500 ppb action level where the goal is not achieved for 31 years.

  Figure 10-5 illustrates the time to meet ecologically protective levels based on surface water quality. A general target has been established that safe ecological levels should be met within 30 years following cleanup. Active remedies achieve this target for the 125 ppb action level and are marginally above the target for the 250 ppb action level (40 years).

- **Implementation Duration.** Figure 10-6 illustrates the implementation duration for each alternative at each action level. A general target has been set to perform the cleanup within a 10-year period. Only the 125 ppb action level does not satisfy this target for all of the active remedies (Alternatives C1, D, and E). For each action level, the Dredge and Pipe to Landfill and Capping alternatives (Alternatives C2 and F) have the lowest implementation durations when compared to other alternatives.

- **PCB Mass Removed.** Figure 10-6 illustrates that all removal alternatives (Alternatives C1 through E) remove the same PCB mass at each action level, while capping (Alternative F) removes significantly less PCB mass. Significant reductions in PCB mass are observed at the 5,000 and 1,000 ppb action levels. Ninety-two percent of the PCB mass is removed at the 1,000 ppb action level while further decreases in the action level do not significantly increase the PCB mass removed. For Alternatives C1 through E, the PCB mass removed varies from 798 kg at 5,000 ppb to 1,192 kg at 250 ppb.

- **Total Cost.** The total cost to implement an active remedy represents a 4- to 25-fold cost increase compared to the MNR alternative (Alternative B) estimated at $9.9 million. Among the active remedies, dredging to a CDF (Alternative D) has the lowest cost at all action levels (except 5,000 ppb) (Table 10-2). Alternative D also appears to be least sensitive to changes in action level. Alternatives D, F, C3, E, C2B, and C1 are incrementally more expensive, with Alternative C1 being the most expensive. For example, at the 1,000 ppb action level, Alternative C2A is estimated to be the least-cost approach at $44 million. Alternative D is estimated to cost $53 million, Alternative F is estimated to cost $63 million, Alternative C3 is estimated at $69 million, Alternative E is estimated at $86 million, Alternative C2B is estimated at $100 million, and Alternative C1 estimated at $95 million.

- **Cost Effectiveness.** In order to evaluate the cost effectiveness of each alternative at each action level, the incremental cost per year reduction in time to remove fish consumption advisories (for recreational anglers) relative to the Institutional Controls alternative (Alternative B) was calculated using the cancer risk data. Due to the uniformity in the time to remove fish consumption advisories, these data are closely aligned to the total cost data. Alternatives C2A and D are the most cost-effective remedies, and 1,000 ppb is the most cost-effective PCB action level that meets protective thresholds.

10.6 Comparative Analysis of Alternatives - De Pere to Green Bay Reach

The comparative analysis of alternatives for the De Pere to Green Bay Reach is presented on Figures 10-7 and 10-8. The following provides a set of observations made as a result of the comparative analysis:

- **Human Health.** Figure 10-7 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for recreational anglers can be removed. A general target has been established that these recreational advisories be removed within 10 years following cleanup. Each active remedy will satisfy this goal, based on noncancer risk, for action levels of 125 and 250 ppb. Based on cancer risk, this goal is not achieved with the minimum time of 15 years to reach protective levels at the 125 ppb action level. The largest reduction in time to reach protective levels is observed between 5,000 and 1,000 ppb action levels for cancer risk and noncancer risk. Figure 10-9 illustrates the time required following cleanup to reduce human health risk to below acceptable levels such that consumption advisories for high-intake fish consumers can be removed. A general target has been established that these advisories be removed within 30 years following cleanup. Active remedies achieve the cancer risk target at the 125 and 250 ppb action levels and for the 125 through 1,000 ppb action levels for noncancer risk.

- **Ecological Health.** Figure 10-7 also illustrates the time required to meet ecologically protective levels. Protective levels will not be reached within the modeled time frame (100 years) with no active remedy (Alternatives A and B). Active remedies will meet protective levels within the 30-year target time frame for action levels 125 through 1,000 ppb based on carnivorous bird deformity. Based on the piscivorous mammal, the target will be achieved for the 125 and 250 ppb action levels while marginally above the target for the 500 ppb action level (34 years).

  Figure 10-7 illustrates the time to meet ecologically protective levels based on surface water quality. A general target has been established that safe ecological levels should be met within 30 years following cleanup. Active remedies achieve this target for the 125 ppb action level and are marginally above the target for the 250 ppb action level (40 years).

- **Implementation Duration.** Figure 10-8 illustrates the implementation duration for each alternative at each action level. A general target has been set to perform the cleanup within a 10-year period. All of the alternatives satisfy this target at each action level with Alternative C2 having the shortest duration.

- **PCB Mass Removed.** Figure 10-8 illustrates that removal alternatives (Alternatives C1 through E) remove the same PCB mass at each action level, while capping (Alternative F) removes slightly less PCB mass. The 5,000 ppb action level removes 94 percent of the PCB mass in this reach, while any further decrease in the action level does not significantly increase the PCB mass removed. For Alternatives C1 through E, the mass removed varies from 24,950 kg at 5,000 ppb to 26,581 kg at 250 ppb.

- **Total Cost.** The total cost to implement an active remedy represents a 20- to 85-fold cost increase over the MNR alternative (Alternative B), estimated at $9.9 million. It can be seen on Figure 10-8 that dredging directly to a combined NR 213/NR 500 dewatering and disposal facility (Alternative C2A) is the lowest cost. Alternative C2A is also the least sensitive to changes in action level (Table 10-2). Other dredging and capping alternatives are incrementally more expensive, with Alternative C1 being the most expensive. For example, at the 1,000 ppb action level, Alternative C2A is estimated to be the least-cost approach at $174 million, with Alternative F at $357 million, and Alternative D at $505 million. Alternative E is estimated at $355 million, Alternative C2B is estimated at $492 million, Alternative C3 is estimated at $514 million, and Alternative C1 is estimated to cost $660 million .

- **Cost Effectiveness.** In order to evaluate the cost effectiveness of each alternative at each action level, the incremental cost per year reduction in time to remove fish consumption advisories (for recreational anglers) relative to the MNR alternative (Alternative B) was calculated using the cancer risk data. Due to the uniformity in the time to remove fish consumption advisories, these data are closely aligned to the total cost data. Dredging (Alternative C2A) is the most cost-effective remedy, and 125 and 250 ppb are the most cost-effective PCB action levels that meet protective thresholds.

10.7 Comparative Analysis of Alternatives - Green Bay, All Zones

The comparative analysis of alternatives for Green Bay Zone 2 (Table 8-10 and Figure 10-9), Green Bay Zone 3A (Table 8-11 and Figure 10-10), and Green Bay Zone 3B (Table 8-12 and Figure 10-11) show that regardless of the action taken in the Lower Fox River (excluding no action), there is very little effect (measured as reduced risk) on Green Bay for the human health and ecological scenarios considered. The following discussion provides a set of observations resulting from the comparative analysis:

- **Human Health.** Tables 8-10 through 8-13 illustrate the time required following cleanup in Green Bay to reduce human health risk to below acceptable levels such that consumption advisories for recreational anglers can be removed. A general target has been established that these recreational advisories be removed within 10 years following cleanup. None of the Green Bay active remedies will satisfy this goal. Removal actions conducted in Zone 3B (Alternatives D and G) will reduce the expected time frame to reach protective levels to 99 years for a Fox River action level of 500, 250, or 125 ppb.

- **Ecological Health.** Tables 8-10 through 8-13 also illustrate the time required to meet ecologically protective levels. A general target has been established that these protective ecological levels will be reached within 30 years following cleanup (a total of 40 years). None of the Green Bay active remedies will satisfy this goal for the ecological scenarios considered.

- **Implementation Duration.** Figures 10-9, 10-10, and 10-11 illustrate the implementation duration for each alternative at each action level. A general target has been set to perform the cleanup within a 10-year period. Most of the alternatives satisfy this target. In Green Bay Zone 2, removal to the 1,000 ppb action level will take five times longer than the next highest action level of 5,000 ppb. In Green Bay Zone 3B, the time required to remove sediment to the 500 ppb action level requires slightly more than 10 years, but equipment size and quantity can be modified during the remedial design to complete removal actions within the targeted time frame of 10 years.

- **PCB Mass Removed.** Figures 10-9, 10-10, and 10-11 illustrate that removal alternatives (Alternatives C, D, and G) remove the same PCB mass at each action level. In Green Bay Zone 2, sediment removal to the 1,000 ppb action level removes six times as much PCB mass as the next highest action level of 5,000 ppb (basically there is not much mass above the 5,000 ppb action level). In Green Bay Zone 3A, significantly more PCB mass is removed at the 500 ppb action level as compared with the 1,000 ppb action level. Only one action level is carried forward for Green Bay Zone 3B.

- **Total Cost.** The total cost to implement an active remedy represents a 100-fold to 1,200-fold cost increase over the MNR alternative (Alternative B), estimated at $9.9 million (Table 10-3). It can be seen on Figures 10-9, 10-10, and 10-11 that dredging directly to a CAD site (Alternative G) is the lowest cost active alternative.

- **Cost Effectiveness.** As discussed above, human health and ecologically protective levels are generally not achieved for Green Bay within the modeled time frame. As a result, it was not possible to perform calculations regarding cost-effectiveness.

10.8 Comparative Analysis of Action Levels on a System-wide Basis

The FS and associated modeling efforts have focused on evaluating system-wide action levels; however, as can be seen from the projections, the same action level provides markedly different degrees of RAO achievement. In order to facilitate future decision-making processes and the inherent trade-offs between cleanup cost and achieving RAOs, this section provides the tools that will be necessary during future decision-making efforts for the entire system. Future modeling efforts may be required to fully evaluate the effect of different action levels for each reach or zone, but the following discussion provides a rationale for focusing those modeling efforts.

Figures 10-12 and 10-13 compare the time to achieve protective levels for human health and ecological receptors for all four river reaches. General targets have been established that: 1) recreational fish consumption advisories be removed within 10 years following cleanup; 2) high-intake fish consumption advisories be removed within 30 years following cleanup; and 3) that achievement of safe ecological levels occurs within 30 years. For the MNR alternative, these thresholds are expected to be met in 20 years and 40 years, respectively.

Based on the 100-year modeled projections illustrated on Figures 10-12 and 10-13, it appears that the Appleton to Little Rapids Reach will likely show some reduced risk by natural recovery processes when compared to other river reaches; the Little Lake Butte des Morts Reach will show less improvement without an active remedy. However, neither of these reaches will meet protective levels in the targeted time frame without an active remedy. The other two reaches, Little Rapids to De Pere Reach and De Pere to Green Bay Reach, will not show appreciable improvement (reduced risk) by monitored natural recovery processes alone. Physical site conditions such as: the quantity and volume of PCB mass present in these reaches, the size of the reach, vessel traffic, storm events, and hydraulic exchange of water flow with Green Bay contribute to the long-term fate of contaminants that limit the long-term effectiveness of natural recovery processes. As shown on Figure 10-12, the action levels required to satisfy the targeted time frame of 10 years following remediation include: 1,000 ppb in Little Lake Butte des Morts, 250 ppb in Appleton to Little Rapids, and 125 ppb in Little Rapids to De Pere. The De Pere to Green Bay Reach will not achieve protective levels for 15 years at the 125 ppb action level. The time to reach protective levels would be 7 to 15 years for each of the aforementioned river reaches. At these same action levels, the time to reach ecologically protective levels based on the piscivorous mammal would be approximately 29, 18, 15, and 18 years, respectively. The protectiveness of these action levels would have to be verified by modeling specifically for this selected group of action levels.

The objective of RAO 4 is to reduce PCB sediment loading to Green Bay and ultimately Lake Michigan. Figure 10-14 illustrates the modeled sediment loading to Green Bay for each Fox River action level. These data indicate that the largest decrease occurs between the no action and 5,000 ppb action level. There is also a substantial decrease between the 5,000 and 1,000 ppb actions levels, but only marginal reductions thereafter. A general target has been established to reduce PCB sediment loading to Green Bay from Fox River to below the PCB sediment loading contributed to Green Bay by all other tributaries combined (10 kg/year). This target is achieved immediately following cleanup for the 125, 250, and 500 ppb action levels. For the 1,000 ppb action level, the target level is achieved in 4 years and it is also achieved in 24 years for the 5,000 ppb action level. The target PCB loading to Green Bay is not achieved for the no action approach in Fox River. The PCB loading to Green Bay from the Fox River also drops below the upstream loading contributed by Lake Winnebago (18 kg/year) in less than 24 years for all action levels, except that this level is never achieved using the No Action alternative.

10.9 Comparative Analysis Summary

In summary, this FS does not select the "best" remedial alternative and action level for implementation in the Lower Fox River and Green Bay. Final selection of a remedial alternative and action level will depend on several decision-making factors including long-term land use restrictions, community support, residual risks, and implementation factors discussed in Sections 8 and 9 of the FS. However, the comparative analysis does present the relative performance of each alternative and related action level relative to each criterion. This analysis summarizes key highlights of these comparisons. For example, the largest reductions in time to reach protective levels for a particular PCB action level relative to the next highest action level and the most cost-effective action level relative to the number of years required to remove recreational fish consumption advisories are described below. Key findings for each reach and zone are summarized below.

- **Little Lake Butte des Morts Reach**

    - At a minimum, the 1,000 ppb PCB action level will be required to meet protective human health and ecological thresholds in 10 and 30 years after remedy completion. The 5,000 ppb action level will not meet protective thresholds in this time frame.

    - Ecologically protective surface water concentrations are achieved within the 30-year target for the 125 and 250 ppb action levels.

    - Most of the PCB mass is removed at the 1,000 ppb action level (93%). Only 7 percent of the PCB mass is contained in the combined action levels of 125, 250, and 500 ppb.

    - The Dredge and Off-site Disposal, Thermal Treatment, and Dredge to CDF alternatives (Alternatives C2, E, and D) at the 1,000 ppb action level are the lowest cost alternatives relative to the time required to remove recreational fish consumption advisories.

- **Appleton to Little Rapids Reach**

    - At a minimum, the 500 ppb PCB action level will be required to meet protective human health and ecological thresholds in 30 years after remedy completion. The 250 ppb action level will be required to meet the 10-year time frame. The 1,000 and 5,000 ppb action levels will not meet protective thresholds in this time frame.

- Ecologically protective surface water concentrations are achieved within the 30-year target for the 125 and 250 ppb action levels. The 500 ppb action level is marginally above the target at about 40 years.

- The bulk of PCB mass is removed at the 1,000 ppb action level (87%). The remaining PCB mass (13%) is contained in the combined 125, 250, and 500 ppb action levels.

- The Thermal Treatment alternative (Alternative E) at the 1,000 ppb PCB action level is the lowest cost alternative relative to the time required to remove recreational fish consumption advisories.

- **Little Rapids to De Pere Reach**

  - At a minimum, the 500 ppb PCB action level will be required to meet protective human health and ecological thresholds in 30 years after remedy completion. The 125 ppb action level is required to meet the 10-year time frame. The 5,000 and 1,000 ppb action levels will not meet protective thresholds in this time frame.

  - Ecologically protective surface water concentrations are achieved within the 30-year target for the 125 ppb action level. The 250 ppb action level is marginally above the target at about 40 years.

  - The bulk of PCB mass is removed at the 1,000 ppb action level (92%). Most of the remaining PCB mass (8%) is below the 250 ppb action level (99%).

  - The Dredge and Off-site Disposal at a Combined NR 213/NR 500 Dewatering and Disposal Facility alternative (Alternative C2A), the Dredge to CDF alternative (Alternative D), Thermal Treatment alternative (Alternative E), and Capping alternative (Alternative F) at the three lowest PCB action levels (125, 250, and 500 ppb) are the lowest cost alternatives relative to the time required to remove recreational fish consumption advisories.

- **De Pere to Green Bay Reach**

  - At a minimum, the 250 ppb PCB action level will be required to meet protective human health and ecological thresholds in 30 years after remedy completion. The no action level will meet the 10-year time frame. The 5,000 and 1,000 ppb action levels will not meet protective thresholds in this time frame.

  - Ecologically protective surface water concentrations are achieved within the 30-year target for the 125 ppb action level.

  - The bulk of PCB mass is removed at the 5,000 ppb action level (94%). The remaining PCB mass (6%) is below the 1,000 ppb action level (99%).

  - The Dredge and Off-site Disposal at a Combined NR 213/NR 500 Dewatering and Disposal Facility alternative (Alternative C2A), the Dredge and CDF alternative (Alternative D), the Thermal Treatment alternative (Alternative E), and the Capping alternative (Alternative F) at the three lowest PCB action levels (125, 250, and 500 ppb) are the lowest cost alternatives relative to the time required to remove recreational fish consumption advisories.

  - PCB sediment loading to Green Bay from all the Lower Fox River reaches achieves the target of 10 kg/yr within a reasonable time frame (24 years or less) for all action levels, except the No Action alternative which does not achieve the target within the modeled time frame.

- **Green Bay, All Zones**

  - None of the action levels implemented in the Lower Fox River shows a decrease in long-term fish tissue concentrations in Green Bay. The lower action levels (125, 250, 500, and 1,000 ppb of the Lower Fox River) do not significantly change the outcome of Green Bay fish tissue concentrations. As discussed in Section 8, this is partly because the majority of PCB mass is removed at the 1,000 ppb action level in Green Bay.

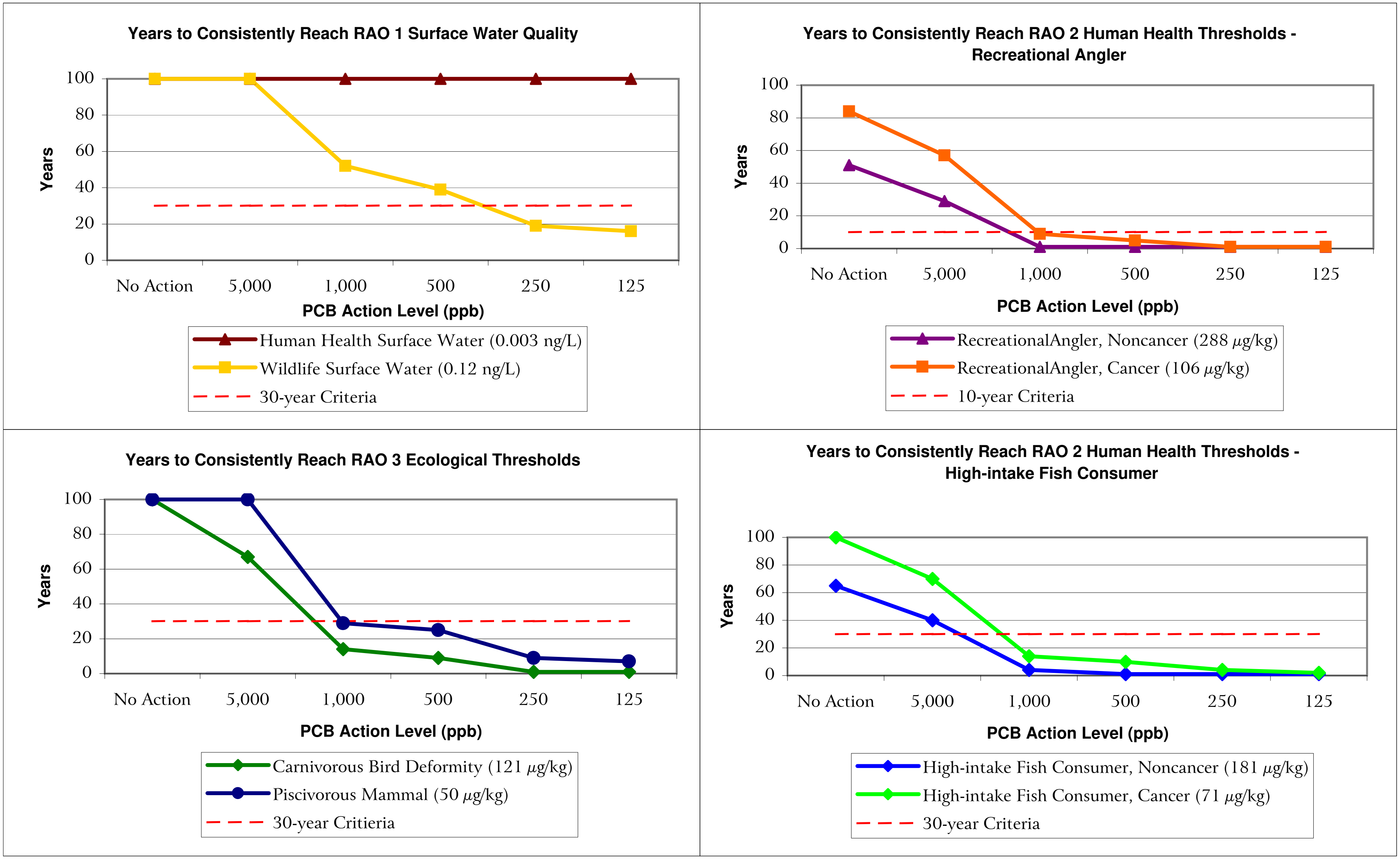
- None of the PCB action levels implemented in Green Bay will meet protective human health and ecological thresholds in 30 years after remedy completion. In Green Bay Zone 3B, removal to the 500 ppb action level will show a reduction in the number of years required to meet protective levels, but not within the targeted time frame.

- The bulk of PCB mass is removed at the 1,000 ppb action level (95%) for Green Bay Zone 2. The remaining PCB mass (5%) is incrementally contained in the lower action levels (125, 250, and 500 ppb). The bulk of PCB mass is removed at the 125 ppb action level (100%) for Green Bay zones 3 and 4. Less than 15 and 30 percent of the PCB mass would be removed at the 500 ppb action level in Green Bay zones 3A and 3B, respectively. The large volume of sediments in Green Bay coupled with the relatively low levels of PCB concentrations indicates that a large quantity of PCB mass resides in Green Bay. However, this PCB mass is widely distributed and dispersed in Green Bay at relatively low concentrations.

10.10 Section 10 Figures and Tables

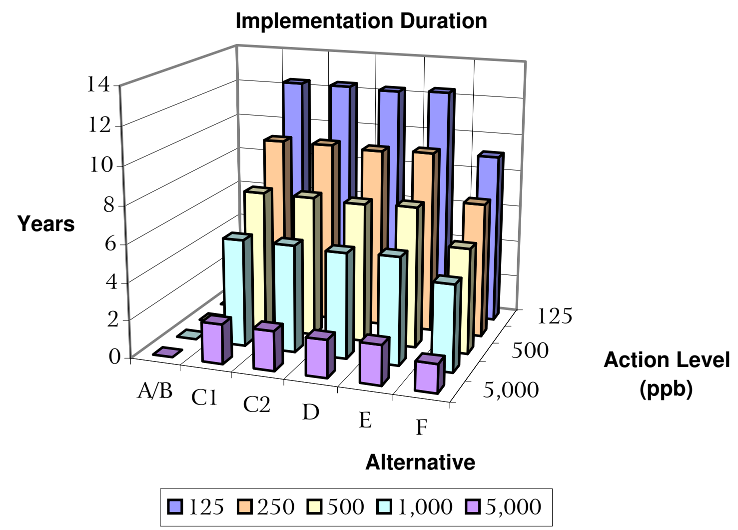
Figures and tables for Section 10 follow page 10-22 and include:

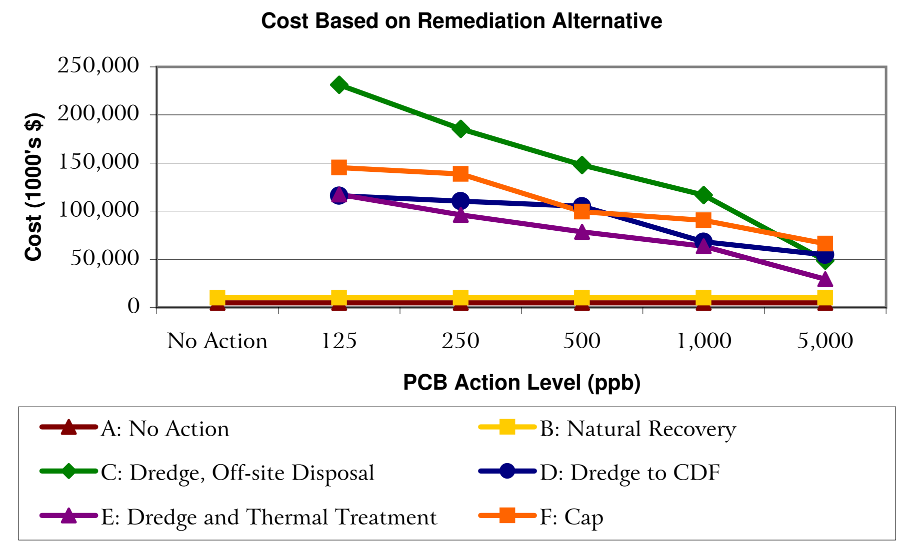
Figure 10-1 Comparison of Human Health and Ecological Protectiveness - Little Lake Butte des Morts to Appleton Reach

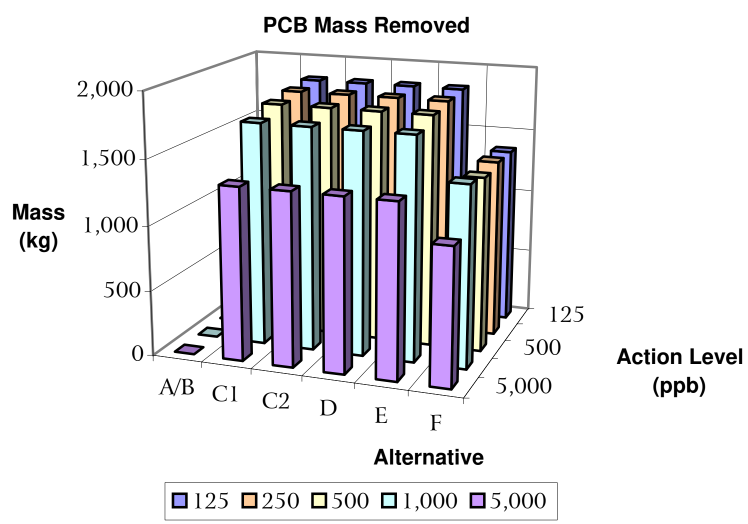


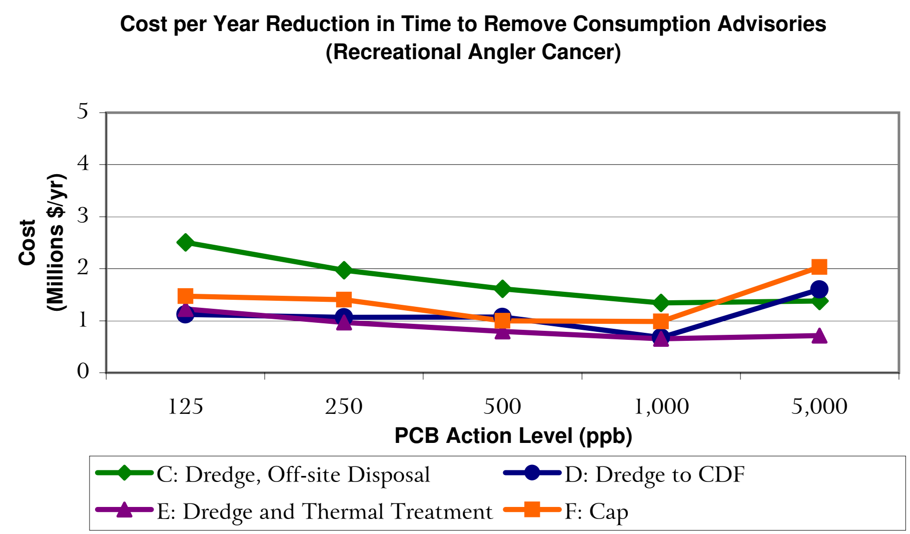
Note: Remedial alternatives C, D, E, and F have the same risk reduction when compared across the same action levels. Therefore, the different remedial alternatives are not displayed separately on the risk reduction graphs (except No Action).

Figure 10-2 Comparison of Cleanup Duration, Mass Removal, and Cost - Little Lake Butte des Morts









Note: 20% contingency costs not included. Alternative C1 costs used.

"Cost per year" is the calculated additional cost per year for implementing any action level other than MNR. $\left[\frac{Cost\ Alt\ x - Cost\ Alt\ B}{Time\ B - Time\ x}\right]$

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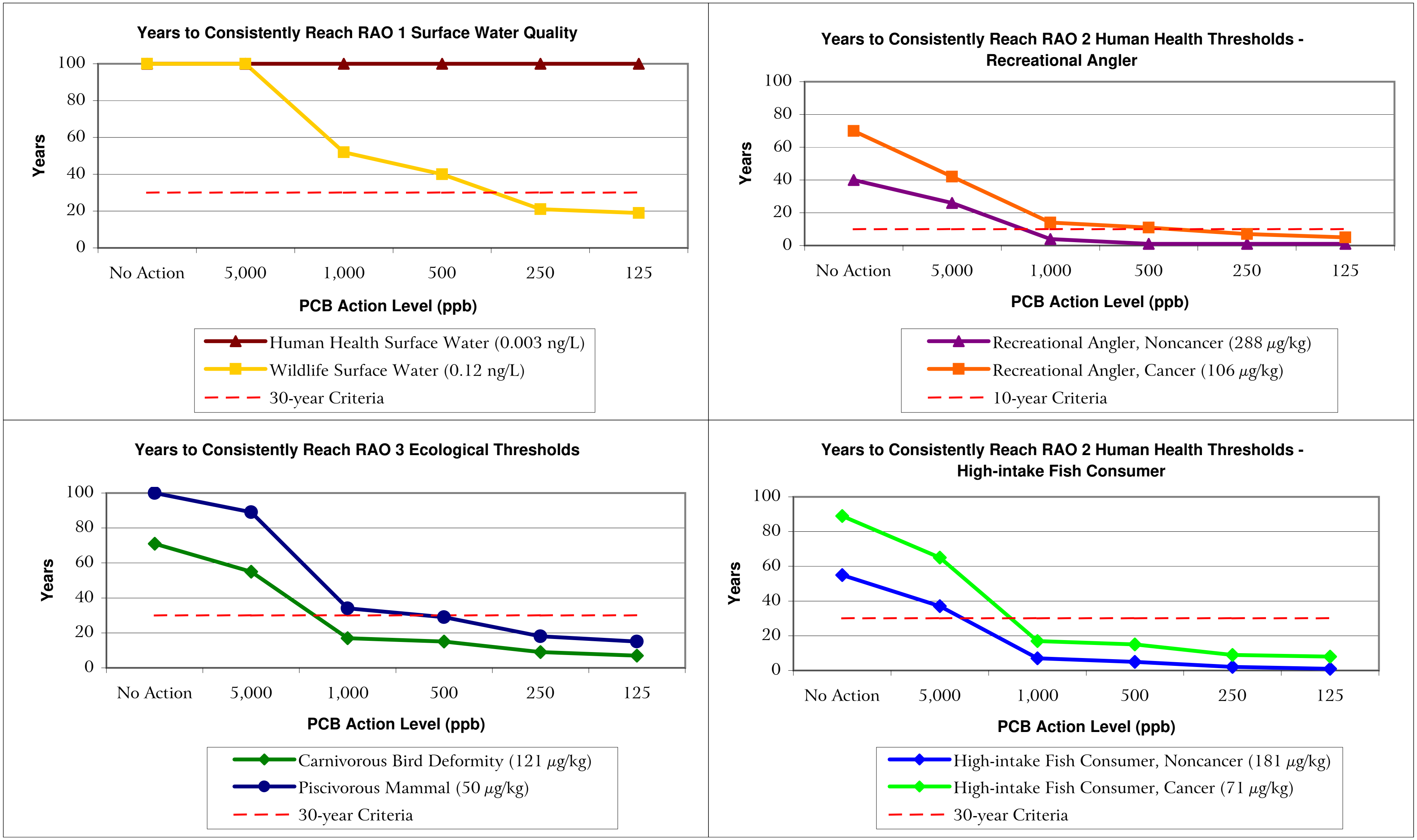
Figure 10-3 Comparison of Human Health and Ecological Protectiveness - Appleton to Little Rapids Reach



Note: Remedial alternatives C, D, E, and F have the same risk reduction when compared across the same action levels. Therefore, the different remedial alternatives are not displayed separately on the risk reduction graphs (except No Action).

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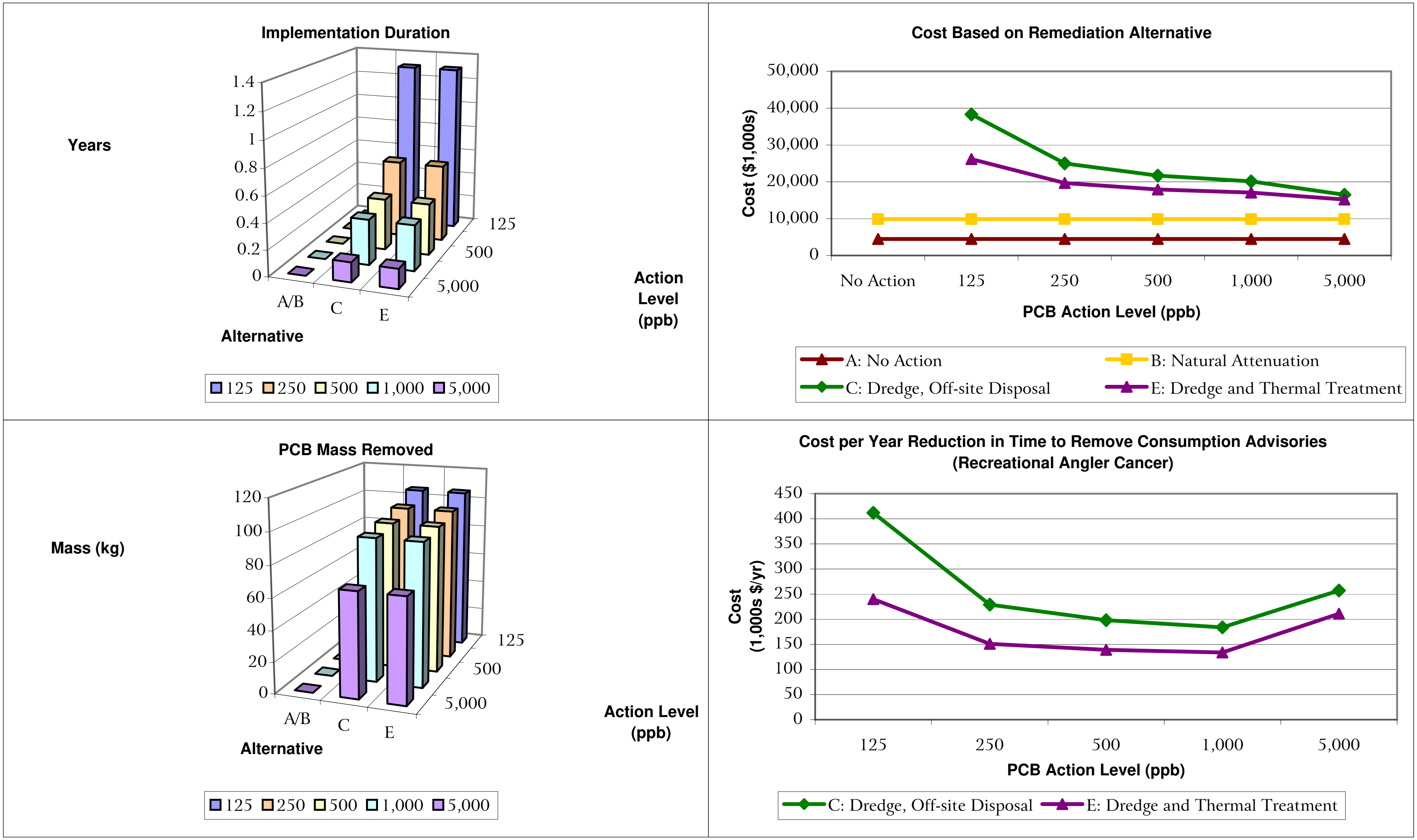
Figure 10-4 Comparison of Cleanup Duration, Mass Removal, and Cost - Appleton to Little Rapids Reach



Note: 20% contingency costs not included.

"Cost per year" is the calculated additional cost per year for implementing any action level other than MNR. $\left[\frac{Cost\ Alt\ x - Cost\ Alt\ B}{Time\ B - Time\ x}\right]$

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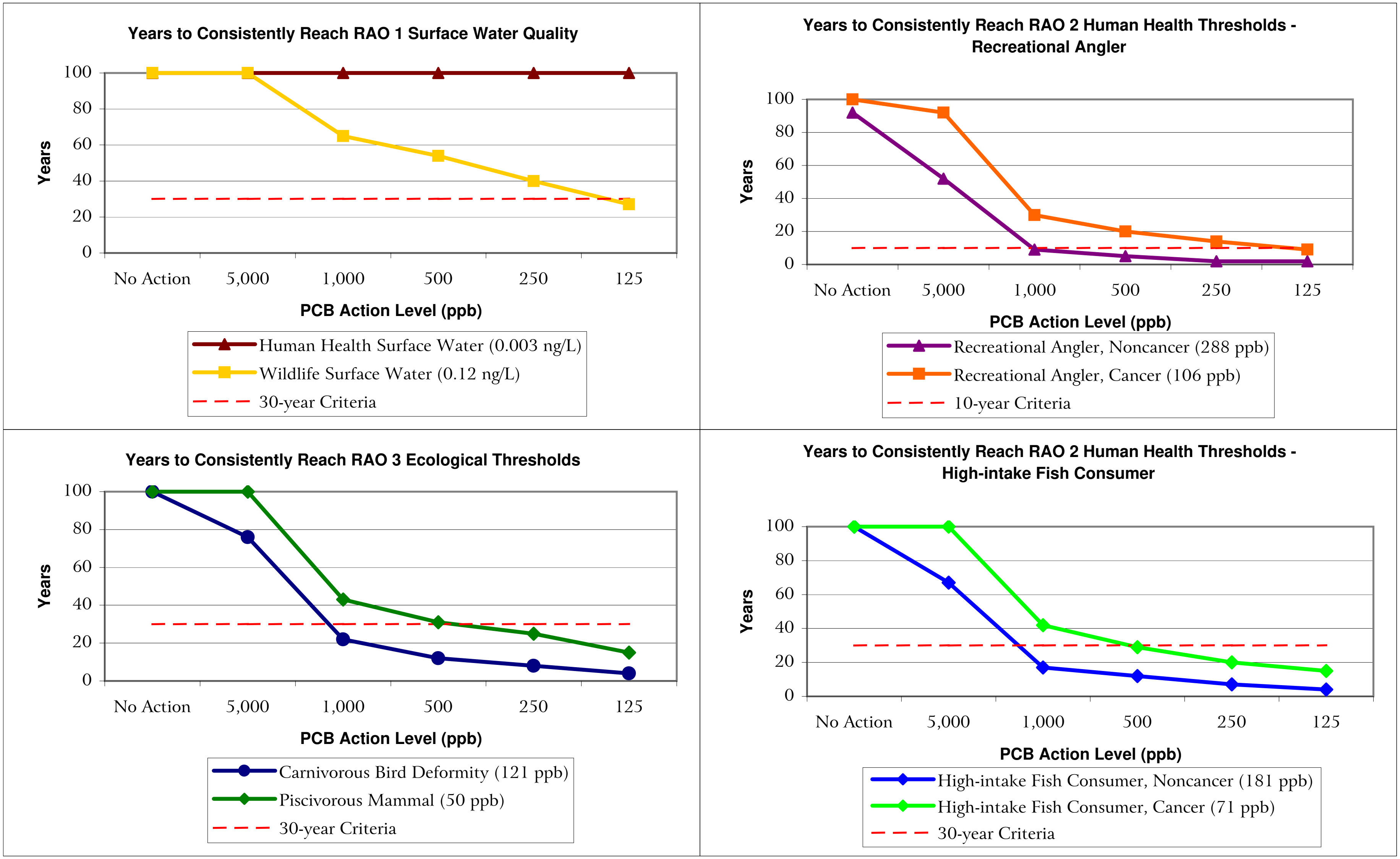
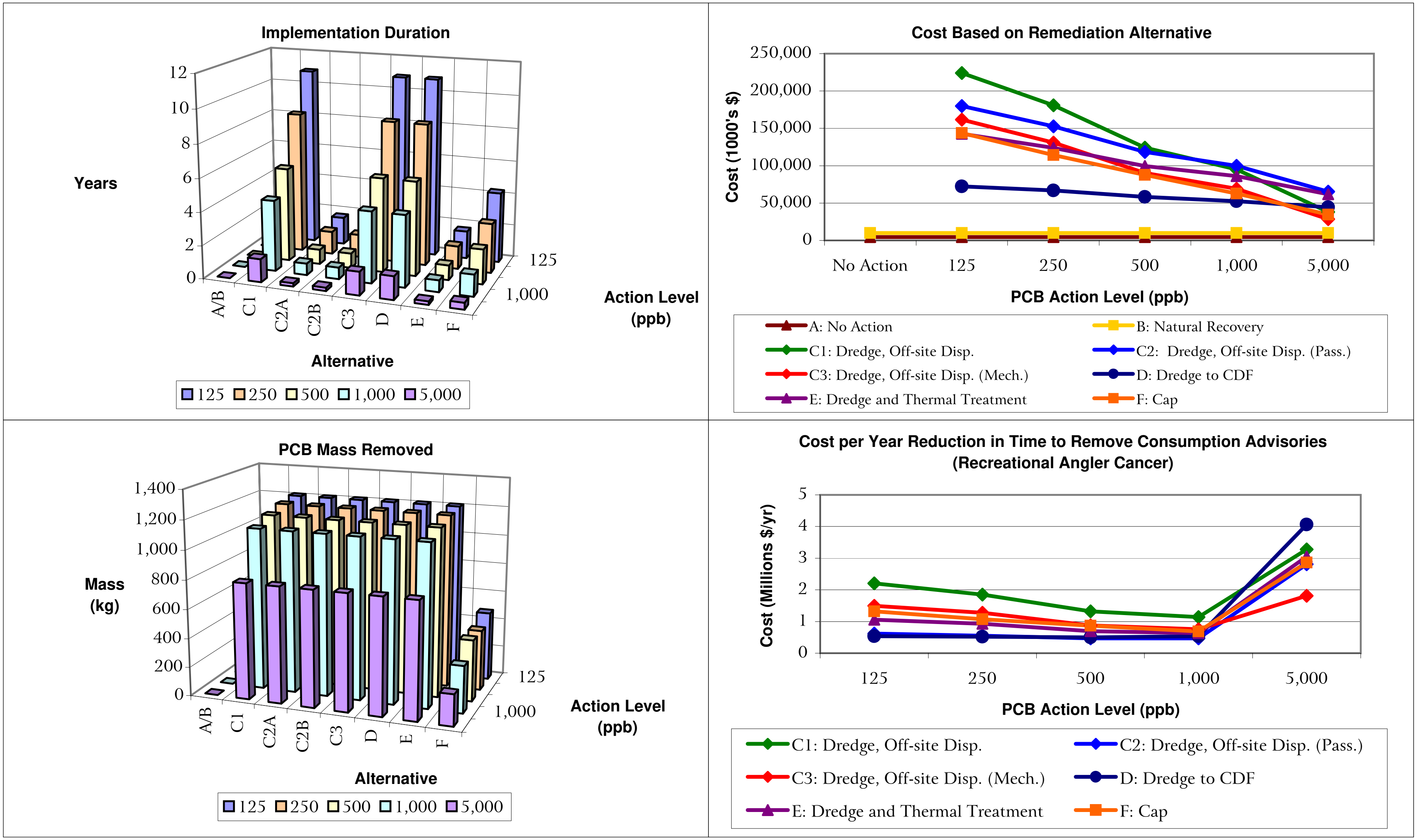
Figure 10-5 Comparison of Human Health and Ecological Protectiveness - Little Rapids to De Pere Reach



Note: Remedial alternatives C, D, E, and F have the same risk reduction when compared across the same action levels. Therefore, the different remedial alternatives are not displayed separately on the risk reduction graphs (except No Action).

Figure 10-6 Comparison of Cleanup Duration, Mass Removal, and Cost - Little Rapids to De Pere Reach



Note: 20% contingency costs not included. Alternative C2B costs used.

"Cost per year" is the calculated additional cost per year for implementing any action level other than MNR. $\left[\frac{Cost\ Alt\ x - Cost\ Alt\ B}{Time\ B - Time\ x}\right]$

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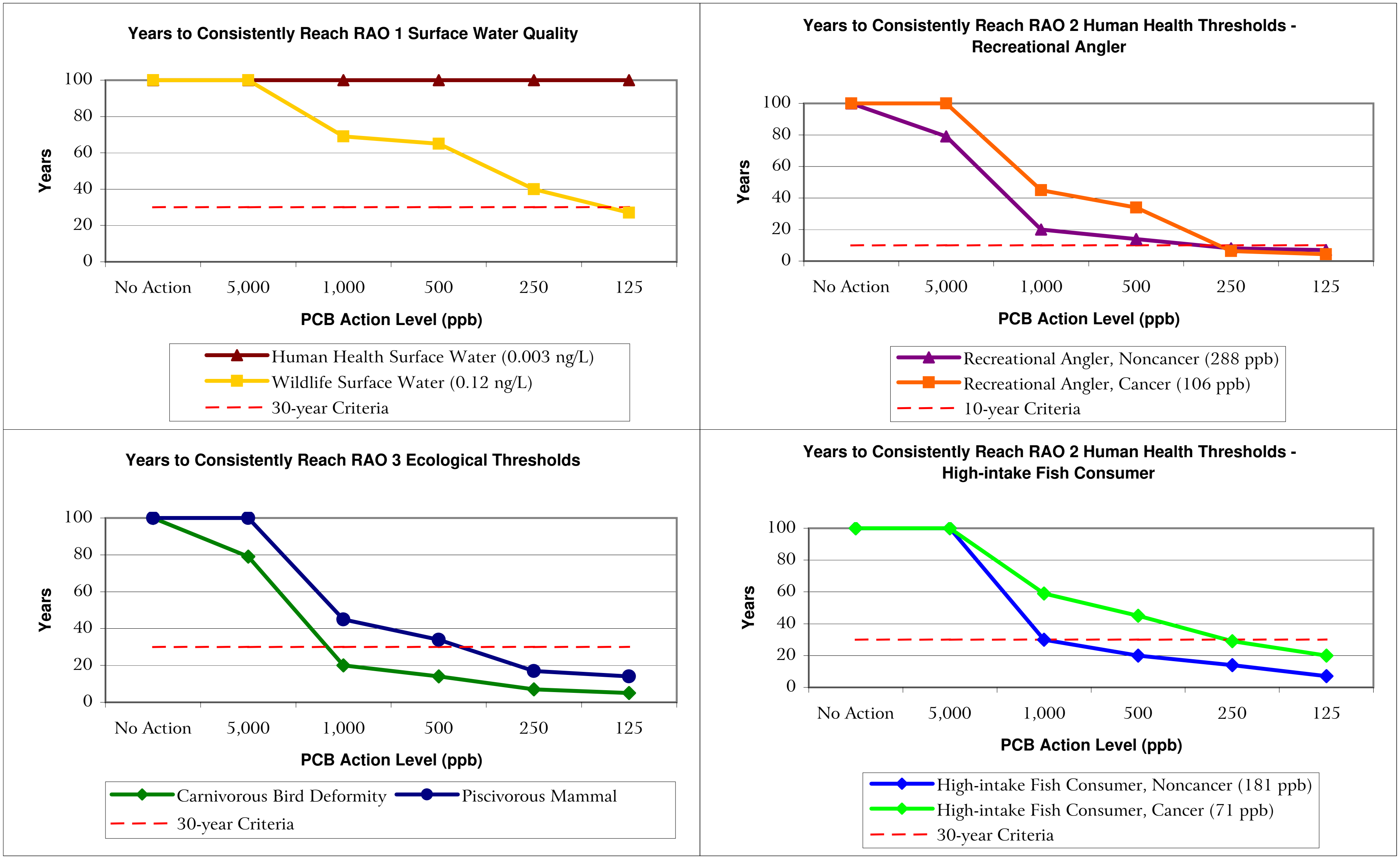
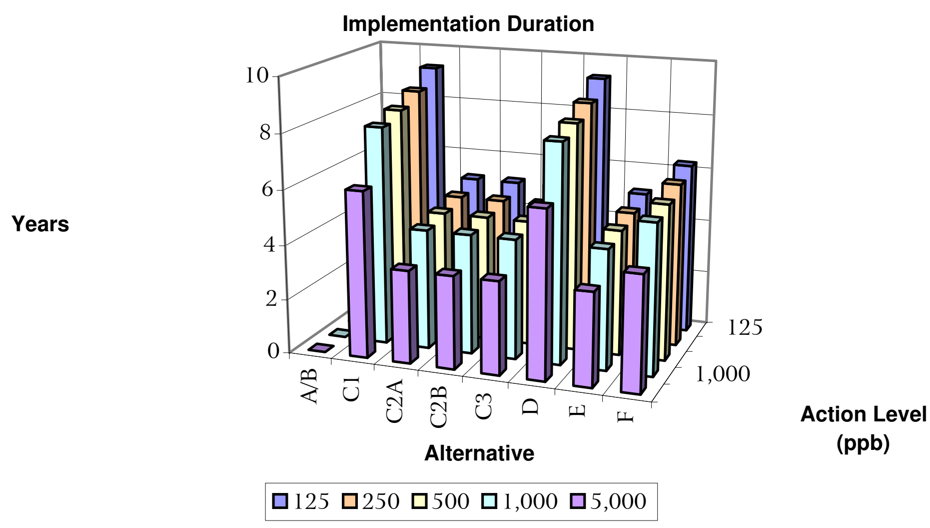
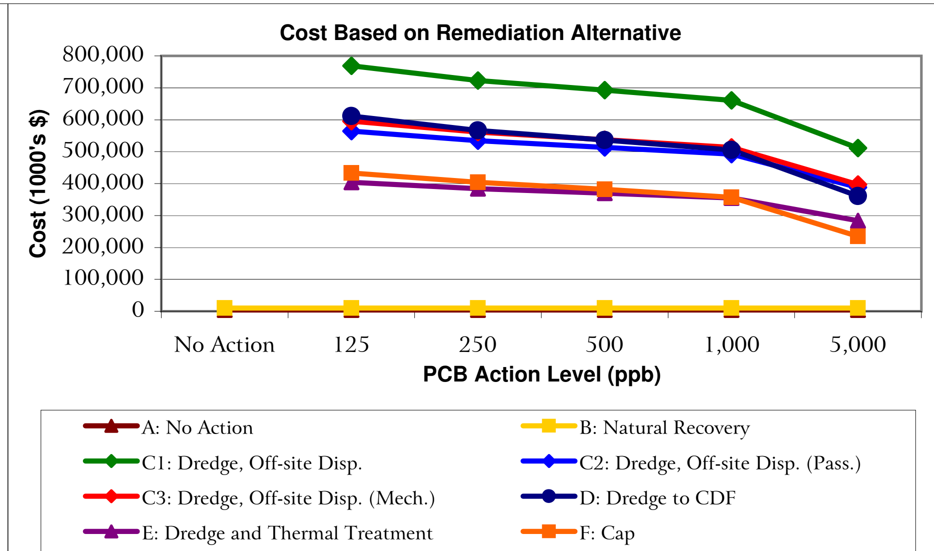
Figure 10-7 Comparison of Human Health and Ecological Protectiveness - De Pere to Green Bay Reach

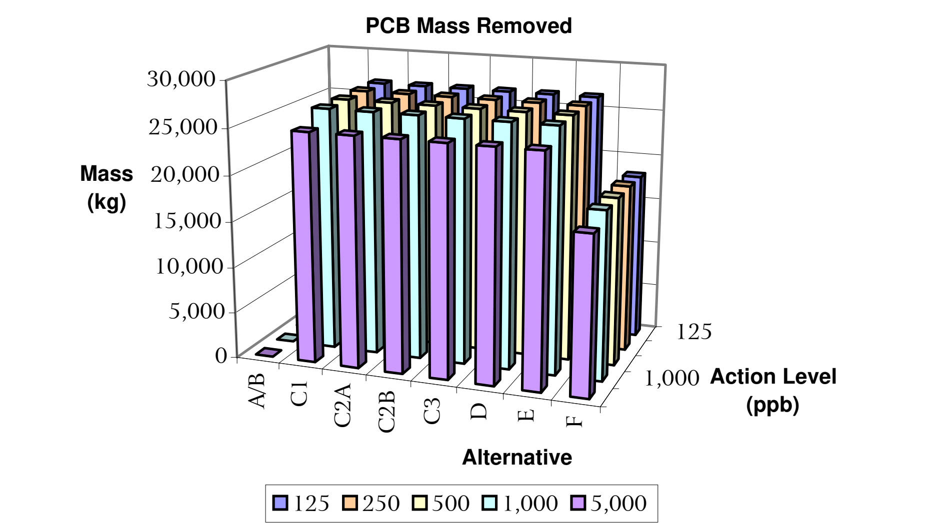


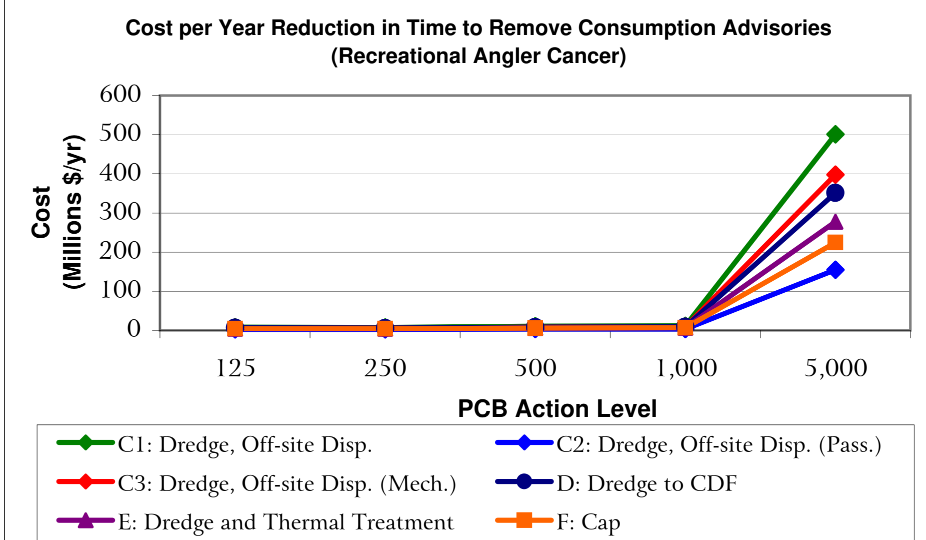
Note: Remedial alternatives C, D, E, and F have the same risk reduction when compared across the same action levels. Therefore, the different remedial alternatives are not displayed separately on the risk reduction graphs (except No Action).

Figure 10-8 Comparison of Cleanup Duration, Mass Removal, and Cost - De Pere to Green Bay Reach (Green Bay Zone 1)









Note: 20% contingency costs not included. Alternative C2B costs used.

"Cost per year" is the calculated additional cost per year for implementing any level other than MNR. $\left[\frac{\textit{Cost Alt x} - \textit{Cost Alt B}}{\textit{Time B} - \textit{Time x}}\right]$

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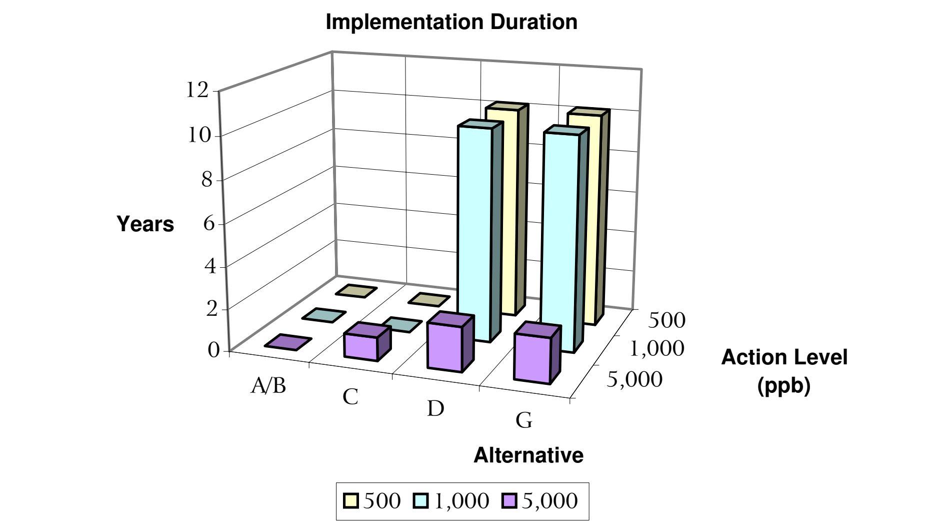
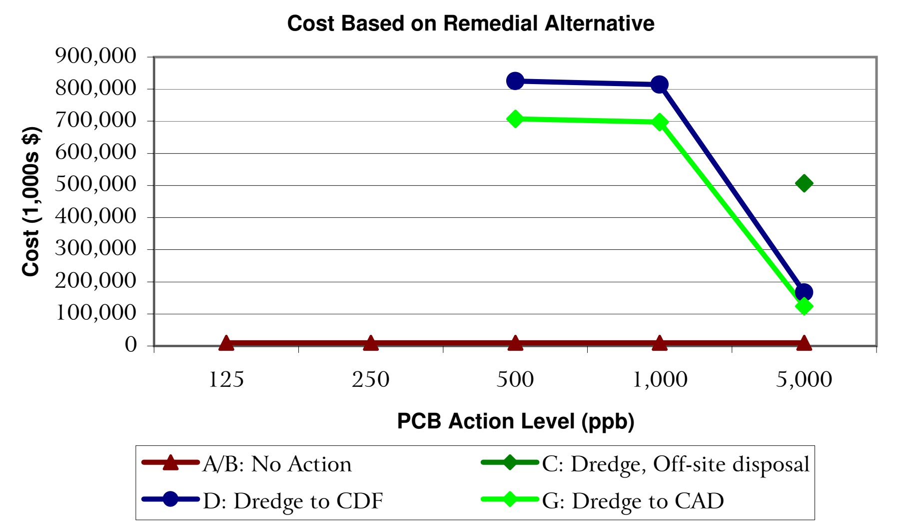
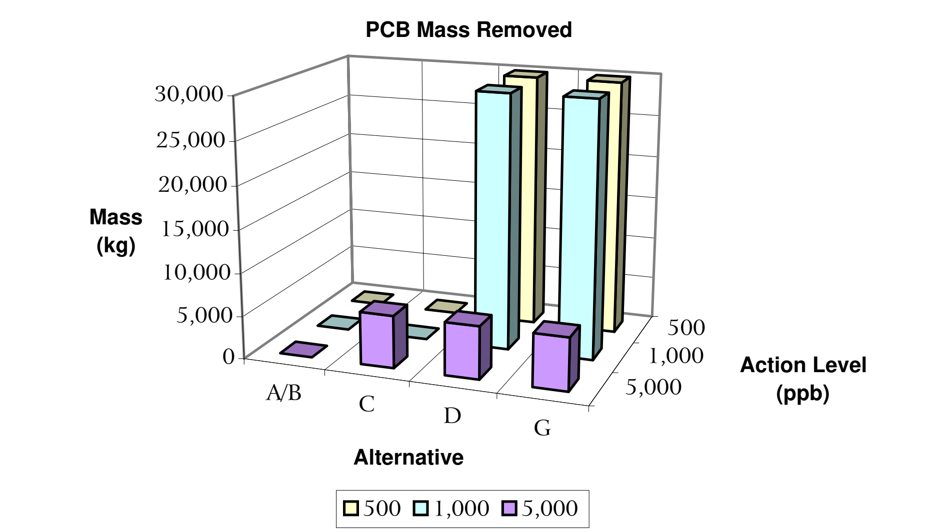
Figure 10-9 Comparison of Cleanup Duration, Mass Removal, and Cost - Green Bay Zone 2



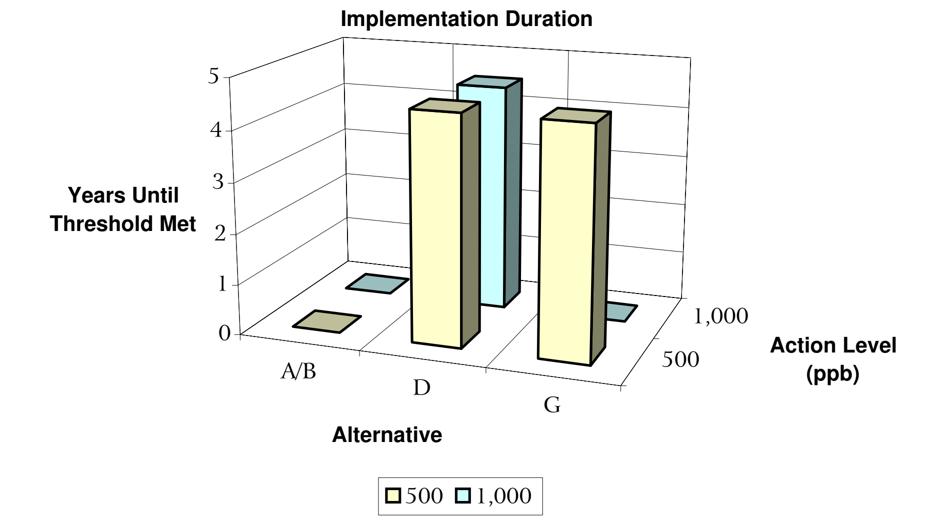


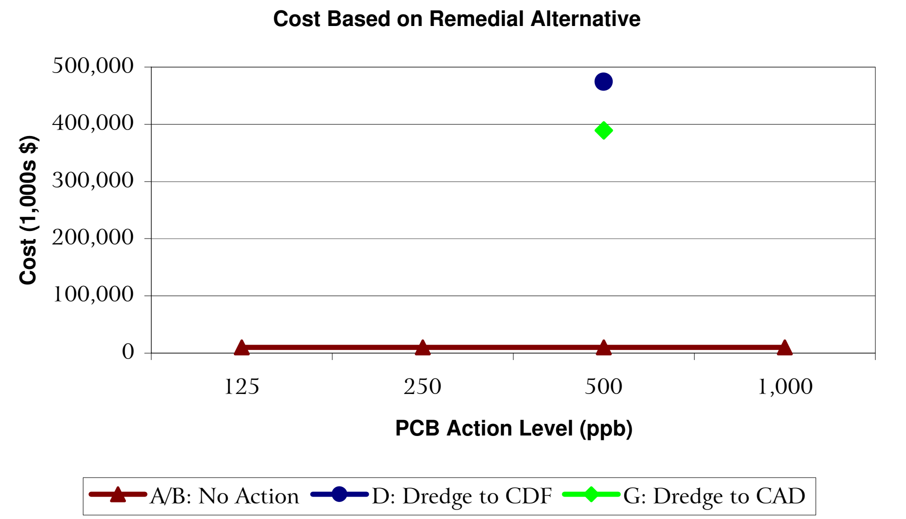


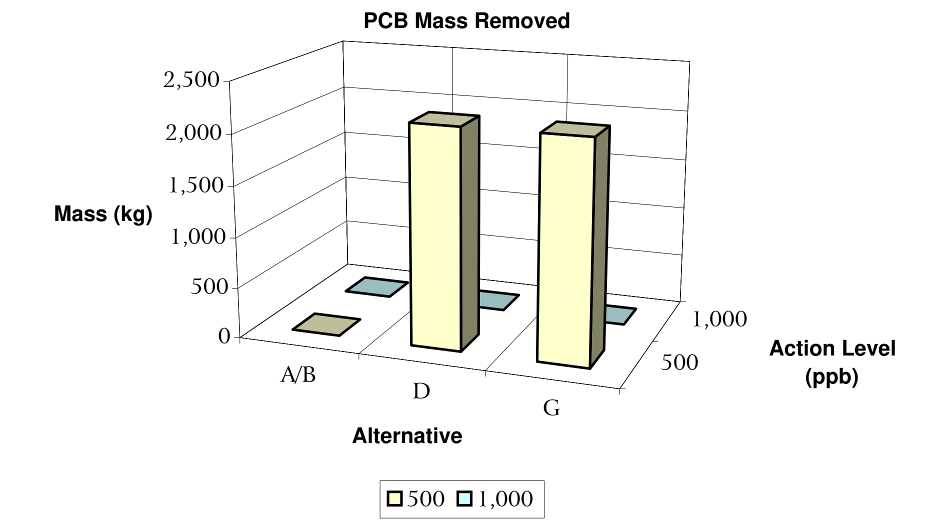
No Cost per year calculated due to thresholds never being met in 100 years.

Note: 20% contingency costs not included.

Figure 10-10 Comparison of Cleanup Duration, Mass Removal, and Cost - Green Bay Zone 3A



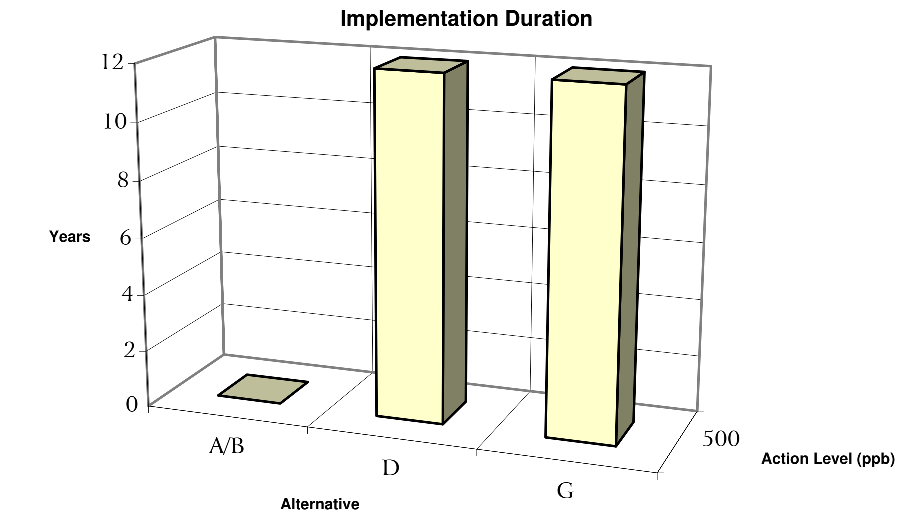


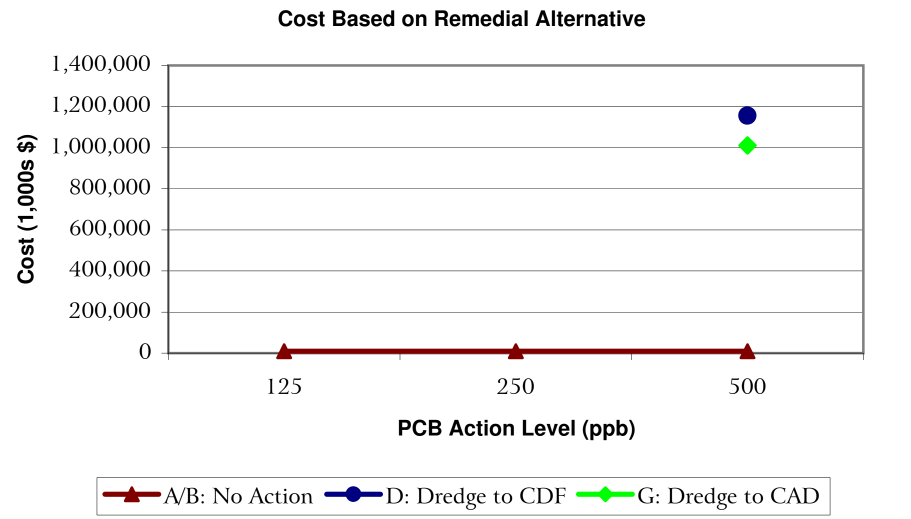


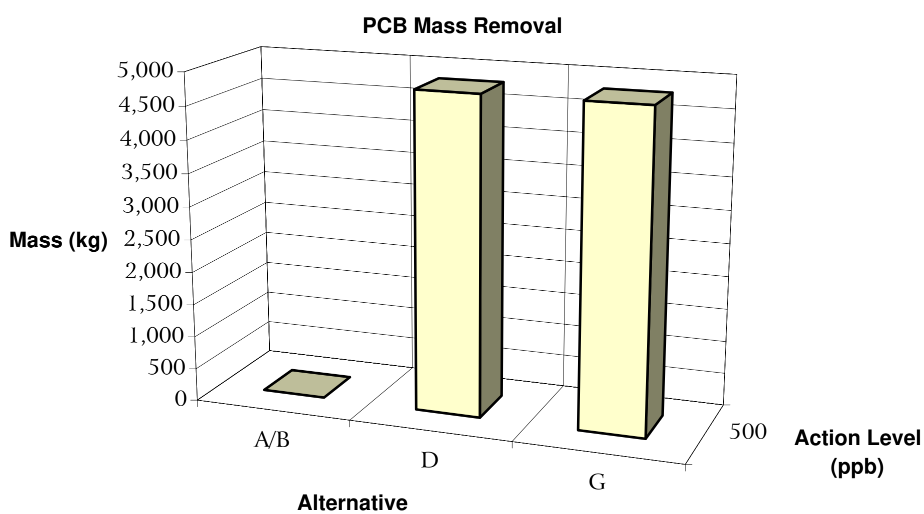
No Cost per year calculated due to thresholds never being met in 100 years.

Note: 20% contingency costs not included.

Figure 10-11 Comparison of Cleanup Duration, Mass Removal, and Cost - Green Bay Zone 3B







No Cost per year calculated due to thresholds never being met in 100 years.

Note: 20% contingency costs not included.

Figure 10-12 Comparison of Human Health Protectiveness - All Reaches

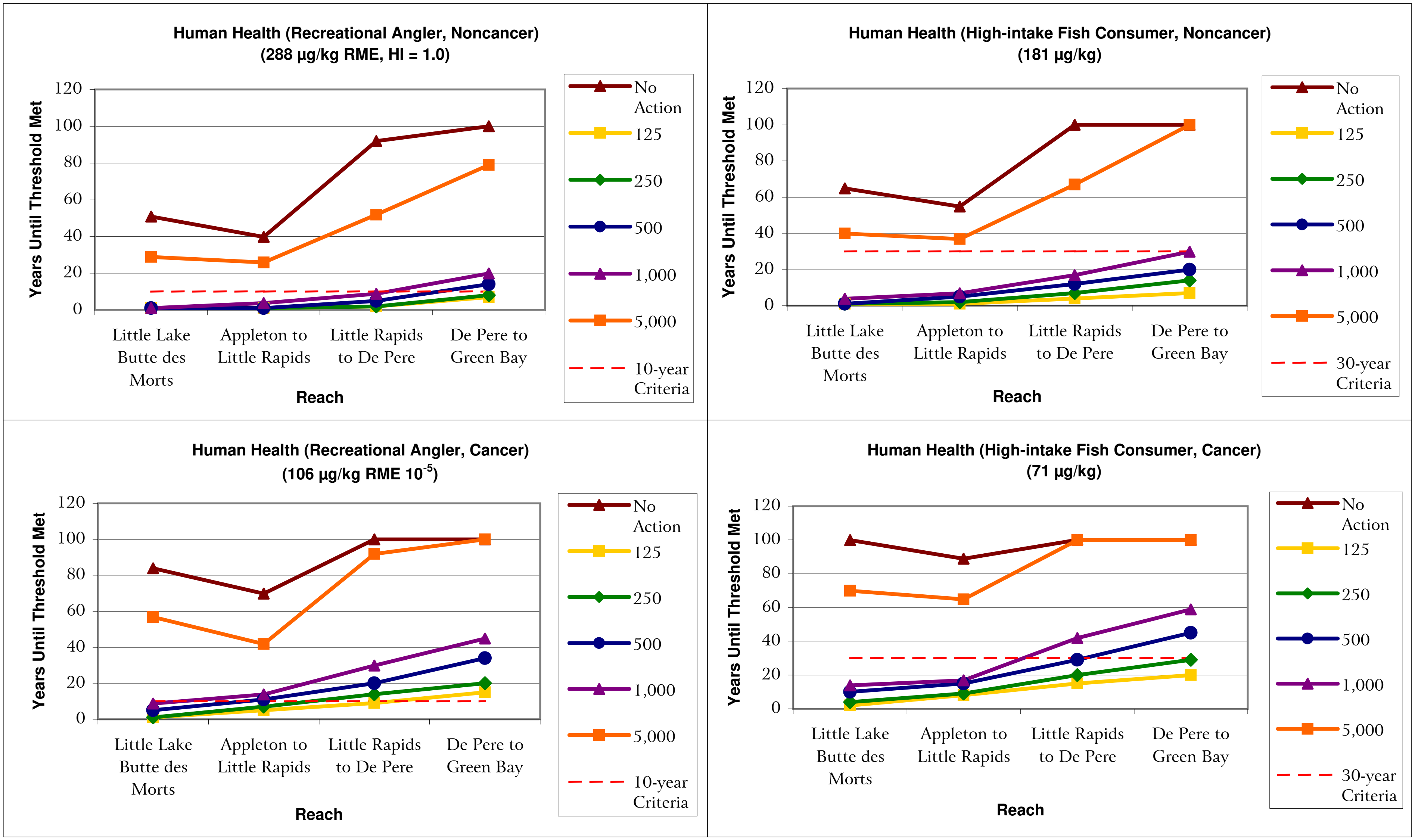


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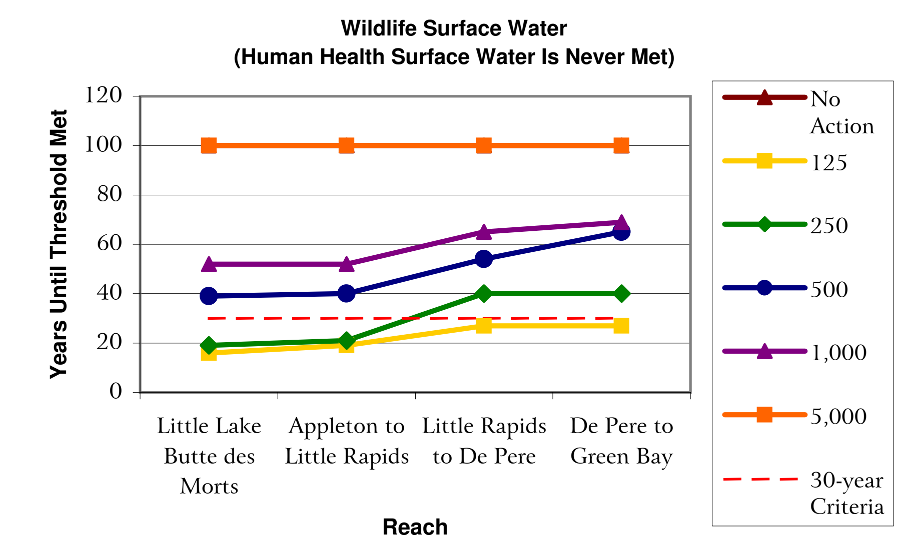
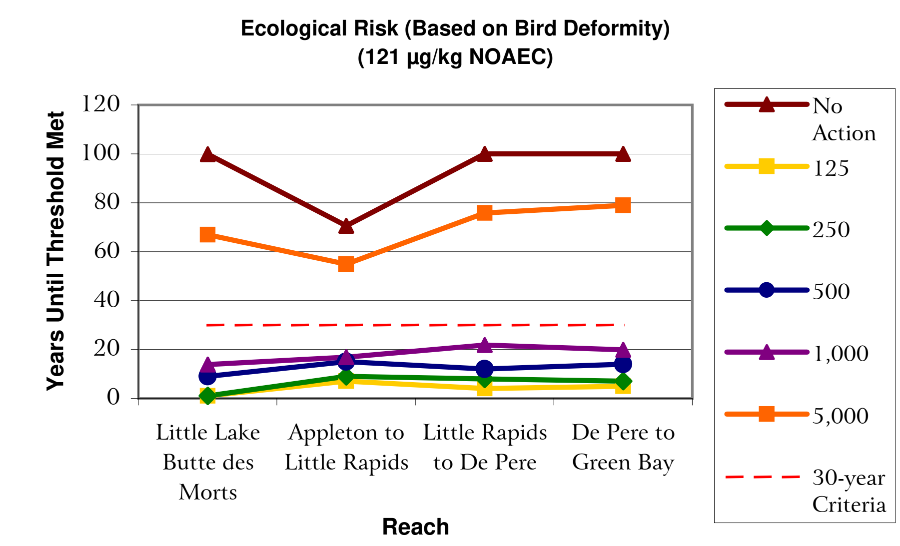
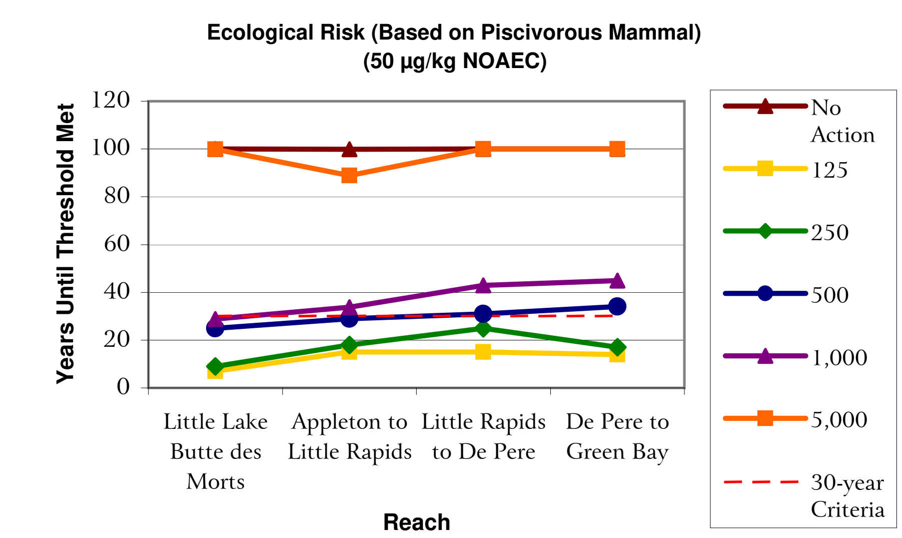
Figure 10-13 Comparison of Protection - All Reaches







RAO 4 not evaluated in Fox River reaches.

Figure 10-14 Total PCB Sediment Loading for All Remedial Action Levels - De Pere to Green Bay Reach

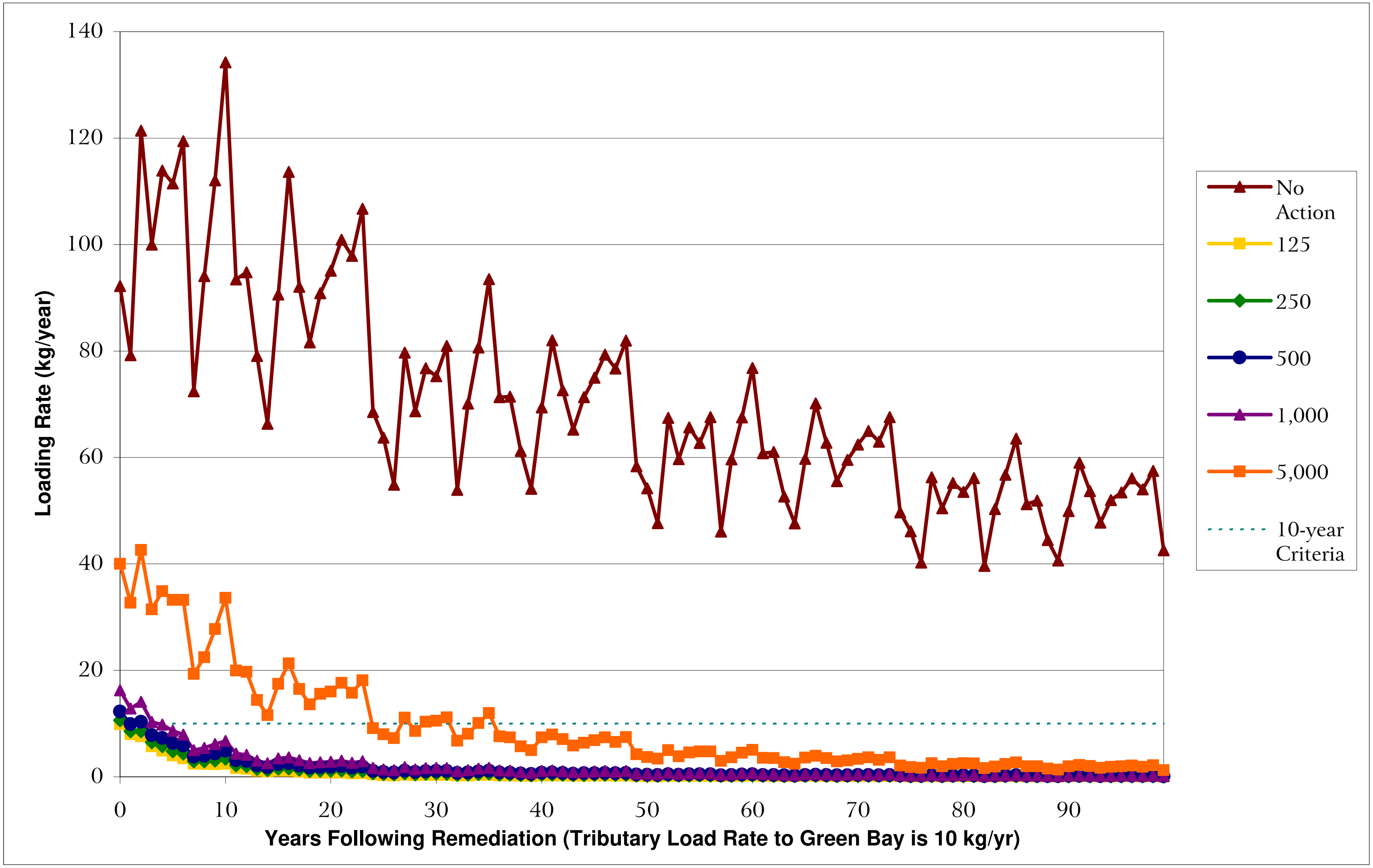


Table 10-1 Comparative Evaluation Measures

Issue	Quantitative Measure	Comment
Time Post-remediation Necessary to Achieve Fish Tissue Concentrations Resulting in Negligible Risk to Human Receptors	Number of years necessary to achieve the “human health - recreational fish consumer RME, HI is 1.0” for noncancer, walleye, whole fish consumption.	As discussed in Section 8, none of the remedial alternatives identified in the FS provide for immediate 100 percent relief for all human and ecological receptors in the river and bay. A key assumption in this alternative analysis is that sediment transport and burial over time would achieve further reductions in PCB mass and thus concomitant reductions in risk. At some time in the future, natural recovery processes would result in restoration of the river and bay to be fully protective for all uses and all receptors. Thus, the time to achieve such risk reduction is considered an objective measure of the efficacy of an alternative. Targeted time frame of 10 years following remediation.
	Number of years necessary to achieve the “human health - recreational fish consumer RME” for 10^{-5} cancer risk level, walleye, whole fish consumption.	As discussed in Section 8, the number of years required to reach protective levels were projected for 100 years from a calibration period of 6 years. There is no precision associated with these projections; however, they do provide reasonable expectations of trends between alternatives. Targeted time frame of 10 years following remediation.
	Number of years necessary to achieve the “human health - high-intake fish consumer RME” for 10^{-5} cancer risk level, walleye, whole fish consumption.	The targeted time frame to remove fish consumption advisories for high-intake fish consumers is 30 years following remediation.
	Number of years necessary to achieve the “human health - high-intake fish consumer RME, HI is 1.0” for noncancer walleye whole fish consumption	The targeted time frame to remove fish consumption advisories for high-intake fish consumers is 30 years following remediation.

Table 10-1 Comparative Evaluation Measures (Continued)

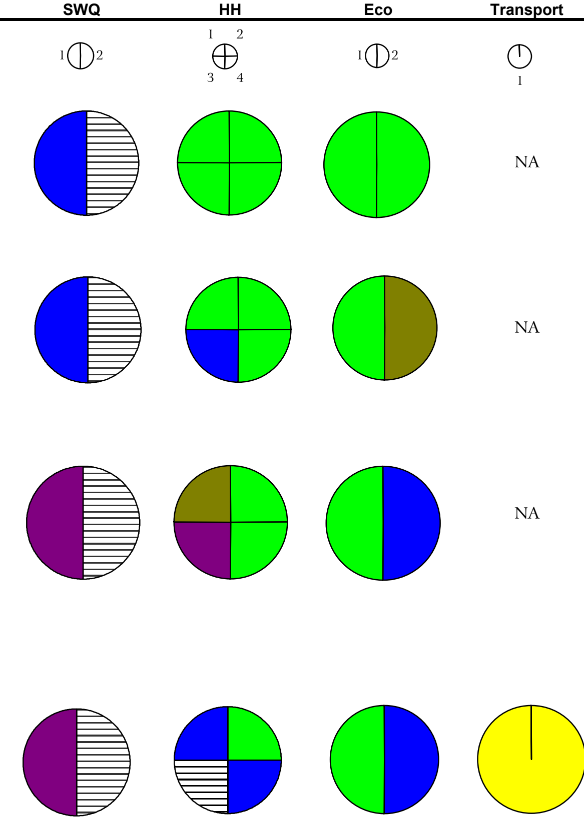
Issue	Quantitative Measure	Comment
Time Post-remediation Necessary to Achieve Fish Tissue Concentrations Resulting in Negligible Risk to Ecological Receptors	Number of years necessary to achieve the "ecological health - carnivorous bird deformity NOAEC" based on carp, whole fish consumption.	For the purposes of this FS, the targeted time frame to achieve ecological protectiveness is 30 years following remediation (or implementation of monitored natural recovery). The ecological thresholds are more stringent than the human health thresholds.
	Number of years necessary to achieve the "ecological health - piscivorous mammal NOAEC" based on carp, whole fish consumption.	For the purposes of this FS, the targeted time frame to achieve ecological protectiveness is 30 years following remediation (or implementation of monitored natural recovery). This ecological threshold is the most stringent threshold carried forward in the FS for comparative purposes.
Time to Meet Surface Water Quality Protective of Human and Ecological Receptors Based on Sediment PCB Concentrations	Number of years necessary to achieve surface water quality criteria - human health drinking water (0.0003 ng/L) and wildlife (0.12 ng/L).	The targeted time frame to achieve, to the extent practicable, is 30 years following remediation (assuming 10 years of remediation for a total of 40 years).
Time Post-remediation Necessary to Achieve PCB Loads from the Lower Fox River to Green Bay that Are Equivalent to the Sum of PCB Loads from Green Bay Tributaries	Number of years necessary to meet Green Bay tributary loads of 10 kg/yr PCBs.	The targeted time frame to reduce PCB loads to Green Bay and achieve source control is 30 years following remediation. For the monitored natural recovery alternative, the expectation is 40 years.

Table 10-1 Comparative Evaluation Measures (Continued)

Issue	Quantitative Measure	Comment
Time to Implement Cleanup Alternative	The estimated number of years for implementation of each alternative.	Significant disruptions to the community are expected to occur during implementation of the alternatives. The disruption may be caused by a number of factors, including: noise, environmental releases (air emissions and sediment resuspension), diminution of recreational use of the river, presence of heavy equipment, truck traffic, etc. The expected disruption of local communities is expected to be similar for all alternatives during the construction period. The alternatives do, however, vary considerably with respect to the expected time for completion of construction activities. For these reasons, the expected time of construction is considered an objective measure of the level of disruption to local communities.
Mass of PCBs Removed	Mass of PCBs removed from the river (kg).	The mass of PCBs removed from the river as a result of remediation is considered an objective measure of the permanence of the remedial option as it relates to environmental conditions within the river.
Cost	Estimated total alternative cost ($M).	The total cost provides a direct measure of the estimated funds to implement a remedial alternative. Total costs include capital costs, indirect costs, and annual operation and maintenance costs. For cost breakdown information, please see Table 10-2. For detailed cost estimates, please see Appendix H.
Incremental Cost to Reduce Years to Reach Protective Levels	Incremental cost (in $M/yr).	This measure represents the incremental cost of reducing the years to achieve protective levels to recreational anglers based on cancer risk by 1 year, and is considered a measure of the cost-to-benefit ratio of the alternatives. It is calculated as: $\left[\frac{Alternative\ Cost - Natural\ Attenuation\ Cost}{Natural\ Attenuation\ Years - Alternative\ Years}\right]$.

Table 10-2 Summary of Remedial Costs and Risk Reduction for Lower Fox River Remedial Alternatives

Lower Fox River Reaches	Remediation Alternative	PCB Action Level (ppb) 125	250	500	1,000	5,000	Maximum Action Level that Meets Risk Reduction Criteria Related to Project RAOs: RAO 1 SWQ	RAO 2 HH	RAO 3 Eco	RAO 4 Transport
Little Lake Butte des Morts	Impacted Volume (cy)	1,689,173	1,322,818	1,023,621	784,192	281,689				
	PCB Mass (kg)	1,838	1,814	1,782	1,715	1,329				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900				
	C1: Dredge, Off-site Disp. (Pass. Dewater)	$231,500	$185,600	$147,800	$116,700	$48,500				NA
	C2: Dredge, Off-site Disp. (Mech. Dewater)	$126,200	$102,500	$82,800	$66,200	$28,300				
	D: Dredge to CDF, Off-site TSCA Disp.	$116,000	$110,300	$105,100	$68,000	$54,500				
	E: Dredge and Thermal Treatment	$117,200	$96,000	$78,500	$63,600	$29,300				
	F: Cap and Dredge to CDF	$145,200	$138,600	$99,300	$90,500	$66,200				
Appleton to Little Rapids	Impacted Volume (cy)	182,450	80,611	56,998	46,178	20,148				
	PCB Mass (kg)	106	99	95	92	67				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900				NA
	C: Dredge, Off-site Disp.	$38,300	$25,000	$21,700	$20,100	$16,500				
	E: Dredge and Thermal Treatment	$26,200	$19,700	$17,900	$17,100	$15,200				
Little Rapids to De Pere	Impacted Volume (cy)	1,483,156	1,171,585	776,791	586,788	186,348				
	PCB Mass (kg)	1,210	1,192	1,157	1,111	798				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900				
	C1: Dredge to NR 500 Facility (Pass. Dewater)	$224,200	$180,700	$124,200	$95,100	$38,100				
	C2A: Dredge to Comb. Dewater/Disp. Facility	$72,300	$63,200	$51,400	$43,900	$32,400				NA
	C2B: Dredge to Sep. Dewater/Disp. Facilities	$179,800	$152,800	$118,300	$99,900	$65,300				
	C3: Dredge to NR 500 Facility (Mech. Dewater)	$161,700	$130,800	$90,300	$69,100	$28,400				
	D: Dredge to CDF, Off-site TSCA Disp.	$72,300	$66,800	$58,400	$52,500	$44,400				
	E: Dredge and Thermal Treatment	$142,700	$123,800	$99,500	$86,200	$61,900				
	F: Cap and Dredge to CDF	$143,700	$114,300	$87,800	$62,900	$34,700				
De Pere to Green Bay	Impacted Volume (cy)	6,868,500	6,449,065	6,169,458	5,879,529	4,517,391				
	TSCA Volume (cy)	240,778	240,778	240,778	240,778	240,778				
	PCB Mass (kg)	26,620	26,581	26,528	26,433	24,950				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	$9,900	$9,900	$9,900	$9,900	$9,900				
	C1: Dredge to NR 500 Facility (Pass. Dewater)	$769,100	$723,100	$692,300	$660,600	$511,100				
	C2A: Dredge to Comb. Dewater/Disp. Facility	$196,000	$186,900	$180,400	$173,500	$138,700				
	C2B: Dredge to Sep. Dewater/Disp. Facilities	$564,500	$534,100	$513,500	$491,800	$388,000				
	C3: Dredge to NR 500 Facility (Mech. Dewater)	$595,200	$561,000	$537,800	$513,500	$397,200				
	D: Dredge to CDF, Off-site TSCA Disp.	$611,800	$566,400	$536,200	$505,100	$360,700				
	E: Dredge and Thermal Treatment	$404,500	$384,000	$370,000	$355,100	$283,300				
	F: Cap and Dredge to CDF	$432,600	$403,900	$381,900	$357,100	$234,400				



Notes:

20% contingency costs not included.

Threshold criteria used to evaluate risk reduction:

RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.

RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.

RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.

RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.

NA - Not applicable.

Action Level (ppb) that Consistently Meets Criteria after 10 or 30 Years of Recovery after Remediation Completion

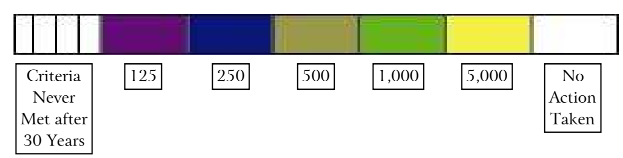
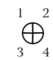
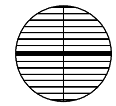
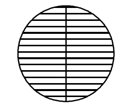
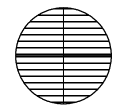
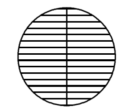
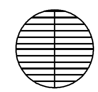
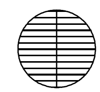
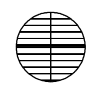
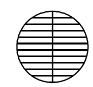


Table 10-3 Summary of Remedial Costs and Risk Reduction for Green Bay Remedial Alternatives

Green Bay Zone	Remediation Alternative	Action Level (ppb)					Maximum Action Level that Meets Risk Reduction Criteria Related to Project RAOs			
		125	250	500	1,000	5,000	RAO 1 SWQ	RAO 2 HH	RAO 3 Eco	RAO 4 Transport
										
Green Bay Zone 2	Impacted Volume (cy)	NE	NE	29,748,004	29,322,254	4,070,170				
	PCB Mass (kg)	NE	NE	29,896	29,768	6,113				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	NA	NA	$9,900	$9,900	$9,900	NE			NA
	C: Dredge, Off-site Disp.	NA	NA	NA	NA	$507,200				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$824,700	$814,100	$166,500				
	G: Dredge to CAD	NA	NA	$707,400	$697,800	$124,000				
Green Bay Zone 3A	Impacted Volume (cy)	NE	NE	16,328,102	14,410	NE				
	PCB Mass (kg)	NE	NE	2,156	2	NE				
	Remedial Cost (in 1,000s $)									
	A/B: No Action	NA	NA	$9,900	$9,900	NA	NE			NA
	C: Dredge, Off-site Disp.	NA	NA	NA	$11,000	NA				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$474,300	NA	NA				
	G: Dredge to CAD	NA	NA	$389,100	NA	NA				
Green Bay Zone 3B	Impacted Volume (cy)	NE	NE	43,625,096	NE	NE				
	PCB Mass (kg)	NE	NE	4,818	NE	NE				
	Remedial Cost (in 1,000s $)						NE			NA
	A/B: No Action	NA	NA	$9,900	NA	NA				
	D: Dredge to CDF, Off-site TSCA Disp.	NA	NA	$1,155,100	NA	NA				
	G: Dredge to CAD	NA	NA	$1,010,900	NA	NA				
Green Bay Zone 4	Impacted Volume (cy)	NE	NE	0	NE	NE				
	PCB Mass (kg)	NE	NE	0	NE	NE				
	Remedial Cost (in 1,000s $)						NE			NA
	A/B: No Action	NA	NA	$9,900	NA	NA				

Notes:

20% contingency costs not included.
Threshold criteria used to evaluate risk reduction:
RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.
RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.
RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.
RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.
NA - Not applicable.
NE - Not evaluated.

Action Level (ppb) that Consistently Meets Criteria after 10 or 30 Years of Recovery after Remediation Completion

Criteria Never Met after 30 Years | 125 | 250 | 500 | 1,000 | 5,000 | No Action Taken

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Appendix A

Summary of Previous Remedial Action Objectives

Summary of Previous RAOs

Document 1

The first document, *Polychlorinated Biphenyl (PCB) Contaminated Sediment in the Lower Fox River: Modeling Analysis of Selective Sediment Remediation* (WDNR - Bureau of Watershed Management, February 1997), provides the following goals (referred to as endpoints) for the management of impacted sediments:

- Meet existing PCB water quality standards
  - 0.01 ng/L (warm water fisheries)
  - 0.003 ng/L (Great Lakes)
  - 0.12 ng/L (wildlife)

[Note: The concentrations reported above reflect present surface water quality criteria, which are not the same as those originally stated in the referenced document.]

- Reduce mass transport of PCBs from Lower Fox River to Green Bay
- Reduce fish tissue concentrations to levels protective of:
  - Human health
  - Fish-consuming birds and mammals

Document 2

The second document, *Feasibility Study Report for Deposits POG and N on the Fox River* (Graef, Anhalt, Schloemer & Assoc. Inc., April 1997), provides the following RAOs:

- General Lower Fox River and Watershed
  - Reduce the mass and volume of PCB- and mercury-contaminated sediments before the sediments are transported downstream of the De Pere dam or enter Green Bay
  - Reduce or eliminate off-site transport of PCBs and other contaminants from deposits POG and N
  - Eliminate POG and N as continued input/source of contaminants to the system

- Human Health Protection

  - Reduce exposure to humans (via direct ingestion, dermal contact with sediments or from consumption of fish and waterfowl) to mercury and PCBs in sediments transported from deposits N and POG

  - Reduce the exposure of humans to PCBs and mercury bioaccumulated in fish and waterfowl from sediments of deposits N and POG.

- Ecological Protection of Top Receptors (Eagles and Mink)

  - Reduce or eliminate bioavailability of PCBs and mercury present in sediments at POG and N to eliminate biotransfers in the food chain (aquatic and terrestrial) and bioaccumulation in top receptors that cause hazard quotients above 1 and/or acute and chronic toxicity

- Chemical Specific ARARs

  - Reduce exceedances of chemical-specific ARARs/TBCs in water, sediment, fish, and waterfowl in the Lower Fox River resulting from exposure and transport of chemicals originating from Deposits N and POG

Document 3

The third document, *Remedial Investigation/Feasibility Study: Little Lake Butte des Morts Sediment Deposit A* (Blasland, Bouck & Lee, Inc., July 1993), provides the following RAOs:

- Human Health Protection

  - Prevent the ingestion of fish containing PCB concentration in excess of FDA limit (2 ppm)

  - Reduce PCB availability from Deposit A to levels resulting in the reduction of PCB concentrations in fish to levels that are acceptable for ingestion.

- Environmental Protection

  - Reduce bioavailability of Deposit A PCBs to prevent acute or chronic toxicity to aquatic and terrestrial organisms

- Chemical-Specific ARARs

  ▸ Minimize the potential for exceeding Ambient Water Quality Criteria (AWQC) in Little Lake Butte des Morts

Document 4

The fourth document, *Draft Feasibility Study Report for Sheboygan Harbor and River Superfund Site* (Blasland, Bouck & Lee, Inc., April 1998), lists items provided by the EPA to be included as RAOs for the Sheboygan River and Harbor Site. These items were synthesized into four Primary/comprehensive RAOs provided in the FS.

- Provide further protection of human health and the environment from potential adverse effects of PCBs attributable to the Site.
- Mitigate potential PCB sources to the River/Harbor system, and reduce PCB transport within the River system.
- Remove and dispose of Confined Treatment Facility (CTF)/Sediment Management Facility (SMF) sediments.
- Minimize potential human health and environmental risks that may be associated with remedial activities, to the extent practical.

Document 5

The fifth document, *Manistique River and Harbor Engineering Evaluation/Cost Analysis* (Blasland, Bouck & Lee, Inc., April 1994), provides the following RAOs:

- Reduce PCB concentrations in fish and water in the Manistique River and Harbor to levels that would not present an unacceptable human-health or ecological risk and allow elimination of existing fish consumption advisories.
- Maintain the harbor as a navigable waterway for commercial shipping, fishing boats, and recreational watercraft. In general, restore the river and harbor areas for use by deeper draft vessels.
- Minimize the need for future remedial action in the area following completion of a non-time critical action.
- Implement actions which would best contribute to the efficient performance of any future remedial action(s) in the area.
- Achieve compliance consistent with federal and state ARARs for the Site.

- Comply with risk-based objectives defined by TERRA, Inc., as part of the risk assessment.

- Reduce, as much as practicable, the release of PCBs associated with particles and dissolved in the water to Lake Michigan.

Appendix B

Sediment Technologies Memorandum

Sediment Technologies Memorandum for the Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

♦ **The RETEC Group, Inc.**

RETEC Project No.: WISCN-14414

December 2002

Executive Summary

Dredging of PCB-impacted sediment has received national and regional attention regarding its viability as an effective remedial alternative. To address these concerns and evaluate dredging as a potential remedial alternative for the Lower Fox River and Green Bay project, an independent review of 20 environmental dredging case studies was conducted. The objective of this review was to relate the effectiveness of dredging with achievement of short-term target goals (immediately after dredging) and long-term remedial objectives (e.g., reduced fish tissue concentrations) for each project.

Projects selected for detailed review were retained from a screening process involving an initial list of over 60 sediment remediation projects. The screening process included several requirements necessary for selection: the remedy is complete, and post-verification samples were collected; the chemicals of concern in site sediments were above protection levels to human health or the environment; at least 2,500 cubic yards of sediment were removed; and primary documentation is available. The 20 projects retained for detailed review include a geographic cross-section of sites from the west coast (five sites); midwest (seven sites); east coast/south (five sites); and international projects (three sites), all implemented in the past 12 years.

Review methods began with acquiring primary sources of information, interviewing site managers, and assembling monitoring results. Review parameters included types of equipment used, site characterizations, sediment cleanup goals, water quality impacts during dredging, monitoring conducted to verify achievement of goals, and project outcome. The lessons learned from this review can be directly applied to the Lower Fox River and Green Bay feasibility evaluations. Many of these findings and recommendations are consistent with the findings of the National Research Council in their recently released review document titled *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC, 2001). The key conclusions and lessons learned from this review of dredging case study projects are summarized below.

Achievement of Short-term Target Goals. Short-term target goals are also referred to as performance-based criteria. Achievement of performance-based criteria was evaluated on the expectations defined by the projects themselves and the dredging goals defined for the contractor. Chemical-based performance criteria were used in only 10 out of 20 projects. Other removal criteria included mass removal, depth, horizon, and evaluation. The two projects that did not achieve performance goals lacked adequate site characterizations and engineered designs. Dredging can obtain target goals such as percent mass removal or removal down to a target elevation, depth, sediment horizon, or concentration (18 out of 20 projects) provided that the appropriate remedial technologies and expectations have been selected for the site conditions. Dredging of soft sediments can effectively remove PCB-contaminated sediments with minimal resuspension and downstream transport of contaminants and minimal impacts to air quality. Dredging may not be an effective tool for sediment remediation in areas with large quantities of wood and buried debris (sometimes removed with an excavator prior to dredging), cobbles covering the river/lake bottom, steep slopes, or restricted access. An adequate site characterization (e.g., identifying the presence of wood debris, bedrock, slopes, buried concrete and rubble) can significantly influence the outcome and cost of dredging activities, and assist with the selection of an appropriate technology. Selection of experienced contractors coupled with good communication with the surrounding community can also influence the schedule, progress and costs of dredging activities.

For most of the projects, over 80% of the mass was removed and the average surface sediment concentrations were lower than pre-existing conditions. However, some projects noted post-dredge maximum concentrations that were the similar to the maximum pre-dredge surface concentrations. Many of the projects had elevated but localized concentrations in the water column, surface sediments ,and caged fish tissues during dredging, but these concentrations were significantly reduced after time in all media if adequate source control was in-place.

Achievement of Long-term Remedial Objectives. The measurement tools used to define long-term success are removal of fish consumption advisories, return of a site to beneficial use, or delisting of regulatory status. By these definitions, dredging has effectively reduced the risk to human and environmental health in six out of 20 projects reviewed. For several other projects (seven out of 20 projects) the initial long-term monitoring results suggest a decreasing trend towards improved environmental health (primarily assessed by fish tissue concentrations), however, more time is required to determine the significance of the observed downward trend. For the remaining seven sites reviewed, the long-term trends were inconclusive, either by inherent variability of the data or lack of a well-defined monitoring plan capable of detecting a trend. Variability in temporal site conditions, sampling protocols, and systematic sampling efforts are likely contributors to the variability observed between sampling events. In many cases, insufficient time has passed since completion of the dredging effort to verify the achievement of protection, or the site has not achieved source control immediately outside of the project area.

Projects Reviewed. The projects included in this detailed and independent review of contaminated sediment dredging projects were Bayou Bonfouca, LA; Black River, OH; Collingwood Harbor, Canada; Ford Outfall, MI; Lower Fox River Deposit N and SMU 56/57, WI; GM Foundry, NY; Grasse River, NY; Lake Jarnsjön, Sweden; Manistique River, MI; Marathon Battery, NY; Minamata Bay, Japan; New Bedford Harbor, MA; Port of Portland, OR; Port of Vancouver, WA; Puget Sound Naval Shipyard, WA; Sheboygan River, WI; Sitcum Waterway, WA; Waukegan Harbor, IL; and West Eagle Harbor, WA.

Recommendations. A summary of recommendations for the potential application of dredging as a remedial tool include:

- Develop clear target goals (e.g., source removal, no restrictions on fish consumption, time frame) to be used for selecting the appropriate dredging technology (if selected) and expectations;

- Obtain an adequate knowledge of site conditions and limitations before designing and selecting the final remedial technology;

- Determine acceptable levels of risk during implementation based on the knowledge of site conditions. There will always be some risk.

- Measure "achievement" by both the intended performance of the project and long-term risk reduction.

- Use a mass balance approach to determine potential contaminant transport during dredging and the extent of potential risk; and

- Develop an appropriate long-term monitoring plan designed to verify project success.

In addition, multiple metrics are needed to verify the implementability and effectiveness of dredging. A containment system and subsequent net transport of sediments off-site or residual surface sediment concentrations are valuable indicators but should only be one of many metrics used to evaluate short-term project success. Post-dredge fish tissue sampling (or other biota) can be valuable indicators of system health but careful and consistent methodologies should be developed to accurately quantify risk reduction.

Acknowledgments

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Other reviewers that contributed to the content and interpretation of specific case studies included: Bob Paulson, Ed Lynch and Bill Fitzpatrick of Wisconsin DNR and Mike crystal of Sevenson Environmental (Lower Fox River demonstration projects); Murray Brooksbank of Environment Canada (Collingwood Harbour project); Dick Gilmur of the Port of Tacoma (Sitcum Waterway project); James Hahnenberg of USEPA (Manistique Harbor); Mary Logan of USEPA (Grasse River project); and A. R. Winklhofer of USEPA (Black River project). Many thanks to other USEPA and state project managers; NOAA representatives (i.e., Todd Goeks and Jo Linse); USFWS (i.e., David P. Allen); project site managers; and other interested parties for improving the quality of this review by providing primary documentation of sediment remediation and monitoring activities.

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List of Attachments - Case Studies of Sediment Dredging Projects

List of Attachments - Case Studies of Sediment Dredging Projects

List of Acronyms

ACOE	United States Army Corps of Engineers
AET	Apparent Effects Threshold
AOC	Administrative Order by Consent
AOC	area of concern
ARARs	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments Program
ASRI	Alternative Specific Remedial Investigation
AVS	acid volatile sulfide
AWQS	Ambient Water Quality Standards
BAF	Bioaccumulation factor
BBL	Blasland Bouck and Lee Engineers
BBSS	Bayou Bonfouca Superfund Site
CAA	Clean Air Act
CAB	cable arm bucket
CAD	confined aquatic disposal
CB/NT	Commencement Bay/Nearshore Tideflat
CBOS	Center for Bio-Organic Studies
CCG	Canadian Coast Guard
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Register
CGLRM	Council of Great Lakes Research Managers
COC	chemical of concern
COI	constituent of interest
CRD	Columbia River Datum
CSL	Cleanup Screening Level
CTF	confined treatment facility
CWA	Clean Water Act
DEQ	Department of Environmental Quality
DGPS	Differential Global Positioning System
DMMU	dredged material management unit
DOFO	Department of Fisheries and Oceans
DOT	Department of Transportation
DWZ	dangerous waste zone
Ecology	Washington State Department of Ecology
EDC	Eastern Drainage Channel
EE/CA	Engineering Evaluation/Cost Analysis
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EROD	ethoxynesorusin-o-deethylase
ESD	Explanation of Significant Differences
ESE	External Source Evaluation
EWQC	Ecology Water Quality Certification

List of Acronyms

FMC	Ford Motor Company
GLHS	Great Lakes Harbor Sediments
GLNPO	Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Act
HAET	High Apparent Effects Threshold
HCB	hexachlorobutadiene
HDPE	high-density polyethylene
HPAH	high-molecular weight polyaromatic hydrocarbon
HPC	heavily polluted classification
IJC	International Joint Commission
IMP	Interim Monitoring Program
JTU	Jackson turbidity units
LDEQ	Louisiana Department of Environmental Quality
LDHH	Louisiana Department of Health and Hospitals
LEL	Lowest Effects Level
LOPH	Louisiana Office of Public Health
LSI	Liver Somatic Index
MCUL	Minimum Cleanup Level
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MLLW	mean lower low water
MTCA	Model Toxics Control Act
NCGP	non-consumption for general population
NCP	National Contingency Plan
NCSP	non-consumption for sub-population
NGVD	National Geodetic Vertical Datum
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority/Priorities List
NRDA	National Resource Damage Assessment
NSRAP	National Site Remedial Action Plan
NTCRA	Non-Time-Critical Removal Action
NTU	turbidity units
NWPA	Navigable Waters Protection Act
NYDEC	New York State Department of Environmental Conservation
OMC	Outboard Marine Company
OMEE	Ontario Ministry of Environment and Energy
OMMP	Operations Maintenance and Monitoring Plan
OMOE	Ontario Ministry of the Environment and Energy
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
ppb	parts per billion
ppm	parts per million

List of Acronyms

ppt	parts per trillion
PS	Pilot Study
PSDDA	Puget Sound Dredge Disposal Analysis
PSEP	Puget Sound Estuary Program
PSMG	Provincial Sediment Management Guidelines
PSNS	Puget Sound Naval Shipyard
PSR	Pilot Study Report
PUC	polyurethane columns
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RA	removal action
RAO	remedial action objective
RAP	Remedial Action Plan
RARA	Removal Action Recommendation and Action Memorandum
RCRA	Resource Conservation and Recovery Act
RGP	restricted, general population
RI/FS	Remedial Action/Feasibility Study
ROD	Record of Decision
RSP	restricted, sub-population
RTP	Remediation Technologies Program
SAB	Science Advisory Board
SAP	Sampling and Analysis Plan
SACM	Superfund Accelerated Cleanup Model
SCU	sediment containment unit
SedPac	Sediment Priority Action Committee
SEDTEC	Sediment Technologies, Environment Canada
SMF	sediment management facility
SMS	Sediment Management Standards
SMU	sediment management unit
SMWG	Sediment Management Work Group
SQOs	sediment quality objectives
SQS	Sediment Quality Standards
SRA	sediment removal area
SWD	surface water discharge
TDS	total dissolved solids
TOC	total organic carbon
TSCA	Toxic Substances Control Act
TSCS	Target Sediment Cleanup Standards
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration

List of Acronyms

VOC	volatile organic carbon
WDFHPA	Washington Department of Fisheries Hydraulic Project Approval
WDNR	Wisconsin Department of Natural Resources
WHOU	West Eagle Harbor Operable Unit
WQB	Water Quality Board
WQC	Water Quality Certification
WQMD	Water Quality Monitoring of Discharge
WSDNR	Washington State Department of Natural Resources
WWTP	wastewater treatment plant

1 Introduction

This document provides a review of case studies relating to the use of dredging as an excavation method for the removal of contaminated sediments. The objective of this review was to evaluate information regarding the effectiveness of environmental dredging as a potential remedial action for the sediment-bound polychlorinated biphenyls (PCBs) in the Lower Fox River and Green Bay. The information presented in this paper will be evaluated during the development of remedial alternatives for the Lower Fox River and Green Bay Feasibility Study, along with additional site-specific information generated for the Lower Fox River and Green Bay.

Source: EPA
Clamshell Dredge on Barge

The effectiveness of dredging as a tool for sediment remediation has recently been questioned by some groups (BBL, 1999; Lower Fox River Group, 1998 and 1999; Ortiz et al., 1998). Citing a limited number of cases, critics of dredging suggest that dredging has limited exposure reduction benefits, and may increase rather than decrease contaminant exposure. However, the underlying reasons for apparent short-term deficiencies (e.g., poor dredging design, contractor quality control) are not taken into consideration in these discussions, and the long-term positive effects of removal actions at other contaminated sediment sites are ignored. The purpose of this document was to independently review primary sources of information and present a summary of the effectiveness of dredging based upon a review of sediment project case studies.

This focused report examines 20 sediment dredging projects to assess both the short- and long-term effectiveness of dredging as a remedial alternative. Each case study discusses the type of equipment used, the sediment cleanup goals, water quality impacts during dredging, and monitoring of physical, chemical, and biological parameters for determining short-term effectiveness. Short-term effectiveness is defined as achievement of goals based on project expectations, not on expectations the reviewer may impose on the project. When available, the evaluation of long-term effectiveness towards the ultimate goals of habitat quality, reduced exposure to biota, protection of human health, rescinding of fish consumption advisories, and reduced bioaccumulation up the food chain are also discussed.

1.1 Background

Many of our nation's rivers, bays, and estuaries have been adversely impacted by historical point source and non-point source activities. Most of these impaired systems have been linked to maritime harbors and industrialized rivers and waterways (Fairey et al., 1998; NRC, 1997; Long et al., 1996; Swartz et al., 1989). Contaminated sediments may contain metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAH), or more recalcitrant chemicals such as PCBs, dioxins, or pesticides that sorb to fine-grained particles and settle into and on the sediment floor of the water body. While typically these contaminant zones range from only a few inches to a few feet in thickness, these contaminated sediments cover wide areas and have the potential to affect human health and the environment.

Management of these contaminated sediments is complicated, as impacts to human health, the environment, and local or national economies must be considered in selecting strategies that balance environmental concerns with economic practicalities. How big is the problem? Under the Water Resources Development Act passed by Congress in 1992, the U.S. Environmental Protection Agency (EPA) undertook the National Sediment Inventory, and identified that as much as 10 percent of the sediment underlying the nation's surface waters was sufficiently contaminated to pose risks to humans and wildlife who eat fish (EPA, 1997 and 1998). This encompasses over 1,700 water body segments as potential areas of concern (AOC) nationwide (Demars et al., 1995). Within the Great Lakes area alone, the United States and Canada identified 43 AOCs where contaminants in sediments are elevated to the point where the beneficial uses of water (drinking, swimming, fishing, and boating) are significantly impaired. In addition, the National Research Council estimated that there are approximately 14 to 28 million cubic yards of contaminated sediments from navigation projects that must be managed annually (NRC, 1997).

Management of contaminated sediments has been the subject of multiple review documents (NRC, 2001; NRC, 1997; Demars, 1997; Cleland, 2000 for Scenic Hudson; Sediment Management Work Group, 1999; Sediment Priority Action Committee, 1997; SEDTEC, 1997; DOD, 1994; EPA, 1994a and 1994b; Averett et al., 1990). In the recently published document titled *A Risk Management Strategy for PCB-Contaminated Sediments* by the National Research Council (NRC, 2001), the review committee supported the conclusion that exposure to PCBs in sediment may pose long-term risks to public health and the ecosystem, and that risk management should be the paramount consideration. Risk management should be site-specific and consider all available technologies (NRC, 2001). While there are numerous methods developed for the remediation of contaminated sediments, there are six generally accepted response actions that can be applied (EPA, 1994b):

- Natural attenuation (no action),
- Monitored natural recovery,
- Containment in place,
- Treatment in place,
- Excavation and containment, and
- Excavation and treatment.

Of those alternatives, this case study review focuses specifically on removal or excavation of subaqueous sediments (i.e., dredging by wet-excavation) (Averett, 1997). Results of the review will be applied to the Lower Fox River/Green Bay Remedial Investigation and Feasibility Study (RI/FS) to help the project team evaluate feasible remedial alternatives for the Lower Fox River and Green Bay. The other response actions listed above (natural attenuation, containment or treatment options) are explored in the feasibility study.

Excellent reviews of dredging technologies can be found in the ARCS Program *Remediation Guidance Document* (EPA, 1994b), *Removal of Contaminated Sediments: Equipment and Recent Field Studies* (Herbich, 1997) and in Environment Canada's Contaminated Sediment Removal Program (SEDTEC, 1997). The types of dredges suitable for work in the Lower Fox River are discussed in Section 7 of the Feasibility Study.

In general there are two types of subaqueous excavation that are germane to the discussions in this document: mechanical and hydraulic dredging. Mechanical dredges apply mechanical force to dislodge and remove sediment. A mechanical dredge consists of a suspended or articulated bucket lowered to the bottom that "bites" the dredge material and raises it to the surface. The dredged material is then deposited in a haul barge, or other contained conveyance, for transport and re-handling to final disposition. Hydraulic dredges applying mechanical agitation (such as with a cutterhead augers or high-pressure water jets) to dislodge sediment. The loosened slurry is essentially then "vacuumed" into the intake pipe by the dredge pump and transported over long distances through a dredge discharge pipeline.

Dredging as a remedial alternative is included in the evaluation of alternatives for the Lower Fox River and Green Bay. Critics of dredging have argued that while it may be feasible to dredge, effectiveness of dredging is limited by:


Christina River Dredging
Source: Sevenson

- Inability of dredging to remove all constituents from the sediment bed;
- Constituents left behind could be available to the food web in higher concentrations;
- Constituents of concern could be resuspended and subsequently released into the water body, to be deposited outside the dredge area or carried downstream;
- Dredging is too expensive when compared to other alternatives, and
- Removal of the sediment bed destroys existing habitat (BBL, 1999).

Critics of dredging in essence argue that the inability to remove all constituents of interest results in exposing or re-distributing contaminants at higher concentrations than existed at the surface prior to implementing the removal action. This argument assumes that the highest concentrations tend to be located at depth (2 to 3 feet below the sediment surface) and are naturally attenuating or are being buried by cleaner sediments. Based on this premise, the argument is that the action is counter-productive, and that the risks to aquatic receptors, or birds or humans that eat fish from that system, are exposed to higher levels of contaminants than would otherwise be encountered since the highest concentrations are at depth. On this basis, some have argued that dredging should not be considered as a remedial alternative for the Lower Fox River.

1.2 Purpose

The focus of this report is to review major environmental dredging projects for the purposes of evaluating:

- Achievement of proposed short-term performance-based target cleanup goals;

- Achievement or progress towards proposed long-term remedial objectives;
- Adequacy of site characterizations and engineering design components appropriate for the site;
- Effects on downstream and off-site transport of contaminated sediment during removal;
- Adequacy of monitoring to be able to assess goals, and;
- Determine if dredging is viable remedial alternative.

Each of these evaluations are discussed in Section 4.

1.3 Application to the Lower Fox River/Green Bay Project

An estimated 90,720 kilograms (kg) (200,000 pounds) of PCBs were released into the Lower Fox River between 1954 and the present (ThermoRetec, 1999). PCBs in the Lower Fox River pose a potential threat to human health and ecological receptors due to their tendency to sorb to sediments, persist in the environment, and bioaccumulate in aquatic organisms. General fish consumption advisories are currently in effect for 13 species of fish located within the project area from Little Lake Butte des Morts (upstream of the De Pere dam) and out into Green Bay. Fish consumption advisories have been in place since the 1970s.

Mouth of Lower Fox River to Green Bay
Source: WDNR

The intent of this technical memorandum is to apply the concepts, applications, and lessons learned from 20 contaminated sediment remediation projects towards the screening and development of the Lower Fox River/Green Bay remedial alternatives. Specifically, results of this paper will be used to evaluate the dredging alternative with respect to three criteria: technical implementability, effectiveness and cost (EPA, 1988). The lessons learned regarding site conditions, problems encountered, elements of the initial site characterization and engineering design, along with the ability to verify achievement of target goals from the monitoring programs will be directly applied to the Lower Fox River/Green Bay feasibility evaluations.

2 Project Selection and Review Methods

2.1 Project Selection

The process of selecting contaminated sediment dredging projects for review entailed a tiered screening of projects based on current status of the remedy, extent of monitoring programs, and type of dredging. Selection of case studies were determined *a priori* to provide as unbiased of a foundation for review as possible. The initial screening process involved accessing a full-breadth of readily available information on over 60 dredging projects (Table 1).

2.1.1 Initial Screening

Specific and general resources for the initial screening included:

- EPA regional websites, fact sheets, and publications;
- Dredging-related websites and journal articles;
- Proceedings from dredging conferences;
- Assessment and Remediation of Contaminated Sediments (ARCS) Program, EPA's Great Lakes National Program Office (GLNPO) publications;
- Sediment Priority Action Committee (SedPac) and International Joint Commission (IJC) publications;
- White papers published by research groups;
- Sediment Management Workgroup (SMWG) Publications;
- *Contaminated Sediments in Ports and Waterways Cleanup Strategies and Technologies* (NRC, 1997,);
- Conference Proceedings from the National Symposium on Contaminated Sediments (NRC, 1998);
- Western Dredging Association newsletters;
- Hudson Watch website (http:\\www.hudsonwatch.com) or (http:\\www.hudsonvoice.com);
- U.S. Army Corps of Engineers publications;
- Contacting dredging design engineers;

- Environment Canada's SEDTEC publication; and
- Personal experience.

SMU 56/57 Stockpile
Source: EPA

Dredging projects retained after this initial data-gathering phase had to meet the following criteria (to be applicable to the Lower Fox River/Green Bay project): 1) the purpose of the remedy was environmental dredging (as opposed to maintenance or navigational dredging); 2) the remedy was already implemented and not in the planning stages; 3) the contaminants of concern were PCBs, or other persistent chemicals such as PAHs or metals that tend to accumulate in site sediments; and 4) the remedy was a wet excavation project (standing water over the sediments and accessed by barge). A combination of technologies in which dredging was at least one of the implemented methods was also acceptable.

2.1.2 Secondary Screening

Dredging projects retained after the secondary screening process had to meet the minimum following requirements:

- Contaminated sediment with concentrations exceeding site-specific chemical levels determined to be protective of human health and the environment;
- Dredged in 1988 or later, to benefit from improved monitoring techniques and requirements;
- At least 2,500 cubic yards of sediment were removed;
- Verification monitoring after cessation of dredging operations; and
- Access to primary documentation.

Projects meeting the secondary criteria were selected for detailed review (Table 1).

The year of 1988 was selected as cutoff for review since the EPA guidance document for conducting remedial investigation/ feasibility studies (RI/FS) was published in 1988, providing a framework for consistency, methods of evaluating success, and defining short-term and long-term goals (EPA, 1988). Projects conducted outside of the U. S. were selected primarily on the amount of primary documentation available for review. The volume of 2,500 cubic yards was selected to help focus efforts towards full-scale remediation projects as opposed to pilot studies. Some pilot studies were selected (greater than 2,500 cubic yards) if the volumes were large or if an intensive amount of monitoring was conducted around the pilot study. Many of the projects reviewed with less than 2,500 cubic yards were collected for laboratory and treatability testing with no intention of mass removal. The purpose of these small-scale projects was generally not to test the effectiveness of environmental dredging. Adequate baseline sampling and post-project verification sampling had to be included as elements of the project in order to verify achievement of project goals. Sediment remediation projects considered are summarized in Table 1.

2.2 Focus of Review

For each case study selected, the specific focus was to acquire and review primary references, including data results from sampling activities and documents stating the project objectives (usually defined in the Record of Decision). Primary references/resources likely included, but were not limited to the following documents (Table 2):

- Records of Decision (RODs);
- Project bid requests and specifications;
- Contractor project design submittals;
- Initial site investigation reports;
- Fish consumption advisories;
- Remedial design/remedial action work plans;
- Project completion reports;
- U.S. EPA Fact Sheets;
- Enforcement action memos;
- Sampling and analysis plans for verification sampling;
- Water and sediment quality monitoring reports; and
- Operation, maintenance and monitoring plans (OMMPs).

To fill in data gaps after the initial review of acquired primary resources, secondary references were also pursued, when appropriate, including journal articles, conference presentations, EPA summary fact sheets, Internet websites, and communications with site project managers. These documents were reviewed to assess dredging methodologies, monitoring results, problems encountered, lessons learned, and verification of achievement of target goals and long-term objectives.

2.3 Project Review Parameters

A total of 20 contaminated-sediment dredging projects were reviewed. Each case study was organized into the headings described below (see Attachment 1 for the complete writeups). The review parameters and types of information presented in each section are defined below. A brief summary of results and findings are discussed in Section 3. A checklist briefly describing the types of information reviewed is presented in Table 2.

2.3.1 Statement of the Problem

The "statement of the problem" briefly summarizes the nature and extent of the problem and impacted resources. The reason why remedial activities were conducted including the purpose, time frame, and intent of the dredging activities were are also mentioned. This section also defines the lead regulatory agency.

Round Cutter Head Dredge
Source: Terra et Aqua

2.3.2 Site Description

This section describes the physical environment of each site, including location; receiving water bodies; water body type; site access; average water depth; substrate type and thickness; surrounding property use; and industrial sources.

2.3.3 Site Investigation

This section describes the initial site investigations leading up to a site ranking or regulatory listing; and subsequent site investigations, risk assessments, and/or pilot studies leading up to remedial activities. It describes the regulatory framework of the decision-making process, identification of problem areas, and identification of guidelines for cleanup. The primary contaminants of concern of the site are identified including: the vertical and horizontal extent of contamination, constituents of concern (COCs), maximum concentrations detected at the site, and impaired resources. A summary of investigation studies, and the regulatory framework are also defined.

2.3.4 Performance-Based Target Goals and Project Objectives

This section describes the short-term target goals and the long-term remedial action objectives (RAOs) for each project. The target goals are defined as the performance-based criteria used to define completion of the dredging project and compensation costs to contractors. Performance-based target goals were usually related to removal of sediment down to a measurable physical criteria such as: the residual chemical concentration, depth or elevation, or percent of contaminant mass removal. The performance-based criteria were based on site-specific expectations defined by each project. The RAOs are defined as the intended long-term benefits hoped to gain as a result of the dredging activity. Long-term objectives were usually related to risk reduction to humans and the environment. The remedial action implemented for each site was based on knowledge that contaminated sediments posed some unacceptable level of risk to the aquatic system, determined from baseline site investigations.

2.3.5 Project Design

This section summarizes the overall remedy for the project and how it was designed. It describes how the role of engineering and design played into the project planning and implementation and includes a review of bid package characteristics including type of payment, adaptive management strategies, quality assurance/quality control (QA/QC) requirements, and qualifications-based or low-bid selection criteria. Fate and transport modeling and bench-scale tests to predict effects of dredging activities on adjacent resources are also defined. The quality of design components and pre-planning strategy efforts used to maximize the likelihood of achieving target goals are described to the best extent possible from available resources.

Dewatering Activities
Source: Bill Fitzpatrick, WDNR

2.3.6 Remedial Actions

This section describes the dredging equipment, dewatering and treatment process, and disposal methods implemented for each project. Descriptions also include problems encountered, project limitations, the duration and schedule of removal action (number of hours per day and days per week), production rates, description of equipment used, and problems encountered. Site limitations that affected dredging production rates are also described. Limitations ranged from physical characteristics (water depth, restricted access, ice, currents) to policy decisions (shutdown during fish spawning windows, public outreach, special permits).

2.3.7 Environmental Monitoring Program

This section summarizes the monitoring program for each project including physical, chemical, and biological elements. Physical elements may include bathymetry, acoustic, lead-line, and sub-bottom profiling surveys. Chemical elements may include water column, sediment surface, sediment core, or air surveys. Biological elements may include sediment or water column toxicity testing, tissue analysis of plants, invertebrates, caged fish, resident fish, and benthic community structure analyses. Questions asked during the review included, but were not limited to:

- What parameters were measured during dredging activities and how were exceedances handled?
- What was the extent of baseline environmental data and were background concentrations known?
- Was the monitoring program modified to compensate for problems encountered?
- Was long-term monitoring designed into the remedial plan and if so, how many years were actually implemented?

2.3.8 Performance Evaluation

Core Sampling
Source: ThermoRetec

This section summarizes the degree to which each project met the stated performance-based target goals and long-term remediation objectives. During this review the questions asked included, but were not limited to:

- Was the project intended to be a full remediation project with 100 percent removal of contaminated sediment above a threshold criteria, or was it a focused removal project that considered site-specific conditions and limitations?
- What was the mass and volume of contaminants?
- What were the project expectations, and were acceptable levels of risk during implementation defined?
- Was overdredge allowed or designed into the program to ensure compliance with target goals?

- Were performance specifications modified during dredging activities to compensate for problems encountered?

- Was residual capping designed into the program to reduce exposure from contaminated sediment remaining in place, or as an afterthought because the target chemical criteria could not be achieved after several attempts?

- What was the residual risk after dredging?

- Were there concentration reductions in surface sediment (surface weighted average) or at depth?

- Were there reductions in surface water concentrations?

- Were the dredge design depths achieved and were post-verification samples collected?

- Can pre-dredging trends be established? If not, what trends could be generally expected?

- Were fish consumption advisories reduced or removed after project completion?

- Were other management-type actions implemented on the project (i.e., site delisting) based on observed results?

Sediment from Box Core
Source: ThermoRetec

This section also discusses how the design specifications may have influenced the outcome of the project, and the lessons learned for each project.

2.3.9 Costs

This section summarizes both the total dredging and disposal costs, when available, and calculates a cost per cubic yard. When cost breakdowns were not available, total remediation costs are presented. However, this review focuses primarily on effectiveness of dredging at meeting project expectations, not necessarily cost-effectiveness.

2.3.10 Contacts

This section provides the names of regulatory project managers to contact for more information. When available, the lead design engineer, regulatory agency, and general contractor are also listed.

2.3.11 References

This section cites the primary references used to extract pertinent information. It also includes secondary references including websites, fact sheets, and personal communications when appropriate.

3 Results and Findings

3.1 Statement of the Problem Findings

All of the projects reviewed were under regulatory action to conduct environmental remediation (pilot or full-scale) of the site from observed impacts to human health and the environment ranging from fish consumption advisories to fish deformities and sediment toxicity. The distribution of the major contaminants of concern (out of 20 projects) included: PCBs (10 sites), PAHs (four sites), and heavy metals (six sites) (Table 3).

All of the projects reviewed have had fish consumption advisories posted in their project area (Table 4).

3.2 Site Description Findings

The projects reviewed were grouped into five major water body types: riverine (9), lake (3), marine (4), estuarine (2), and coves/marshes (2). Average water depths ranged from intertidal (substrate exposed at low tide) up to 65-foot water depths with an average depth of approximately 15 feet.

Lower Fox River
Source: Great Lakes United

Physical constraints commonly encountered at many of these sites included winter storm and ice conditions, strong currents, tidal swings, hard bottom substrate (difficult to anchor silt curtains and difficult to implement overdredge), passing ships disturbing the silt curtains, access to sites from private land owners, shallow water depths, access under docks and pier structures, boating and fish spawning seasons (required downtime), and significant debris, wood, cables, and boulders buried in the substrate.

The stratigraphy in most of the riverine and lacustrine systems was a layer of silt/sand (less than 10 feet thick) over very dense, almost impenetrable glacial till (called hardpan) or bedrock layers. The stratigraphy in most of the marine systems was a layer of soft silt over medium dense sand (easy to penetrate), while the estuarine and marshes generally had thick soft silt/sand layers.

3.3 Site Investigation Results

The primary chemicals of concern driving the remedial cleanup projects were either PCBs, PAHs, or heavy metals. All of these analytes were found to accumulate in site sediments and served as a source of bioaccumulation and toxicity to benthic and aquatic organisms. The majority of contaminants were detected in the upper 3 feet of most systems with a few sites extending down to 5- and 6-foot depths below the mudline sediment surface.

3.4 Target Goals and Project Objectives Findings

The short-term performance-based target goals among the projects reviewed were generally grouped into four categories based on the type of metrics used to verify achievement and the purpose of the removal effort:

1. Mass removal of contaminated sediment for source control, prevention of downstream transport, or enhancement of natural recovery (three projects) (Grasse River, Port of Portland, and Collingwood Harbour);

2. Risk-based chemical criteria designed to be protective of human health and the environment (10 projects) (Marathon Battery, Port of Vancouver, GM Foundry, Lake Jarnsjön, Manistique, Minamata Bay, New Bedford Harbor, Sitcum Waterway and West Eagle Harbor and Waukegan Harbor); and

3. Physical criteria such as depth, elevation or horizon (seven projects) (depth: Bayou Bonfouca, Black River, Fox River Deposit N and SMU 56/57; elevation: Puget Sound Naval Shipyard (PSNS) and Sheboygan Harbor, and horizon: Ford Outfall).

Only 50% of the projects reviewed used chemical criteria as performance-based target goals. Elevated chemical concentrations were obviously driving the need for removal action, but other site-specific criteria were used as project expectations for the contractor (i.e., elevation). Residual surface sediment concentrations are presented in Table 5. The volume/mass of sediment removed for each project is presented in Table 6. These criteria serve as general categories recognizing that metrics from one category may have been used to develop target goals for another metric. For example, the New Bedford Harbor project established a concentration of 4,000 ppm as a target goal, however, elements of mass removal were considered as well since the concentration level was developed from a PCB mass/sediment volume curve.

Clamshell Bucket Dredge
Source: EPA

For many pilot demonstration projects or shoreline redevelopment projects, the target goals were often driven by elevation, depth or bedrock/hardpan requirements (Table 6). At these sites, contamination was correlated to sediment lithologies, and dredging to a physical design goal such as depth was assumed to be protective of the environment. For many projects an overdredge depth ranging from 0.5 to 1.0 ft below the maximum anticipated depth of impacted sediments was built into the remedial design (discussed below). Primary measurement methods for determining compliance with target goals were post-verification surface sediment grab/core samples.

The long-term RAOs could be categorized into three groups:

1. To protect human health (nine projects);

2. To protect the environment (six projects);

3. To provide physical source control and minimize downstream transport (five projects).

Many of the projects did not explicitly define long-term RAOs because they were either pilot studies, were only concerned with mass removal of sediments for source control, or assumed if chemical criteria were met, then long-term objectives would be met as well. For example, in Puget Sound the Washington State Sediment Management Standards are designed to be protective of benthic and aquatic communities through Apparent Effects Thresholds (AETs). While there is not a direct measurable correlation between contaminant concentration and exposure, if chemical concentrations measured at a site are below the AET values then the site is determined to be protective of the benthic community.

3.5 Project Design Findings

A summary of the project designs and implemented remedies for each project are presented in Table 6.

3.5.1 Overdredge

Seven projects designed "overdredge" into the project plans. Four of these sites were located in the Pacific Northwest (Sitcum Waterway, West Eagle Harbor, Port of Vancouver, Puget Sound Naval Shipyard), while others included Lake Jarnsjön, Lower Fox River SMU 56/57 and New Bedford Harbor. The term "overdredge" refers to additional 0.5- to 1.0 ft lift of sediment removed from underneath the maximum known extent of contamination to ensure removal of all contaminated sediments. This technique can only be applied to site locations where contaminated material does not rest directly on top of an impenetrable layer such as hardpan or bedrock. In addition, the cost of dredging additional material can be costly and must be well managed and coordinated with the dredge contractor to manage costs. In cases where overdredge could occur, target goals were achieved.

Hydraulic Horizontal Auger Dredge
Source: D.C. Roukema, J. Driebergen, and A.G. Fase

A controversial exception to this finding is the SMU 56/57 demonstration project. Although a 0.5 ft overdredge was designed into the 1999 remedy, the target elevation was not achieved in most areas and the verification sampling had elevated PCB levels. However, a detailed review of the data by subunits revealed that the target elevation goals could be achieved. Contractors returned to the site in August 2000 to remove remaining sediment down to the targeted elevation. In New Bedford Harbor, the dredge design included an over-dredge allowance of 0.5 to 1.0 ft, but actual dredging depth exceeded the design depth to meet the targeted cleanup level. For the Sitcum Waterway project, an additional two feet of overdredge was added to the project beyond the vertical extent of impacted sediment for navigational needs.

3.5.2 Bench-Scale Tests/Modeling/Physical Testing

Bench-scale testing is generally conducted prior to implementing a dredging program to predict sediment performance during the dredging, pumping and dewatering process. Bench-scale treatability and physical testing is used to refine the selection of appropriate equipment sizes for removal and dewatering efforts. Based on the data reviewed, only about 50 percent of the dredging projects conducted laboratory testing to refine the project designs.

Transport modeling is generally conducted prior to implementing a dredging program to predict sediment resuspension and downstream transport effects during dredging. Many projects rely on literature values to predict off-site transport for the purposes of permitting, selecting environmental controls (i.e., silt curtains), and determining compliance boundaries. A few projects conducted site-specific modeling efforts to predict the magnitude of off-site contaminant transport. For example, the Sitcum Waterway project used computer models (EFQual and Plumes) to determine the dilution zone distances from the point of dredging and the appropriate compliance boundaries for water quality monitoring during dredging (silt curtains were not used).

The recently published sediment management report by the National Research Council (NRC, 2001) emphasized the need for better pre-remedy assessments of the processes governing the fate of PCBs, the impact of co-contaminants, and pilot scale testing. A full understanding of the hydrogeologic setting and the risk reduction potential of the management options are important predictors of effectiveness (NRC, 2001).

3.5.3 Site Characterization

All of the projects reviewed conducted subsurface sediment profiling to determine the horizontal and vertical extent of contamination and to evaluate the physical properties of sediments requiring remediation. Some of the projects used acoustic profiling equipment to determine additional physical characteristics of the site (i.e., refusal, bedrock, buried debris, density). Buried material such as boulders, concrete, bricks, scrap metal, discarded wood and lumber, or pier remnants often discovered at sediment sites can greatly impact the cost and schedule of a dredging project if not anticipated. Correlation of a contaminant with a particular stratigraphic unit, physical substructure, or sediment color can help the dredging contractor manage their activities more effectively.

For example, the Collingwood Harbour project used the presence of a bluish hue color in the excavated material as an indicator that the underlying, clean clay layer was being dredged. This "early indicator" helped guide and improve the efficiency of the dredging effort. The pilot dredging project at Collingwood Harbour encountered numerous delays by large-size debris present from historical shipbuilding activities. Lessons learned from the demonstration project were considered when selecting the final dredging equipment. This resulted in significantly less frequent delays during the full-scale remediation project. In both the GM Foundry and Grasse River projects, large boulders and debris identified in the physical surveys were removed using an excavator bucket prior to initiation of hydraulic dredging activities. Unanticipated physical characteristics of the site sediment and bedrock influence the production rate and schedule of dredging activities. At the Manistique River/Harbor site, unanticipated rock and wood debris encountered during dredging contributed substantially to delays and cost increases and required a change in technologies. For the GM Foundry project, excavation of contaminated soft sediments down to "hardpan" material resulted in clogging of pumping equipment from the clayey or gravelly structure of the underlying clean substrate.

For the Bayou Bonfouca and Sheboygan River projects, contaminated sediment volumes encountered during dredging were significantly larger (up to three times more) than estimated sediment volumes requiring removal specified in the project ROD or design plans based on RI/FS sediment investigations. These findings support the argument that inherent limitations exist in sediment coring and poling activities when refusal is encountered.

A repeating theme for many projects is the necessity for a comprehensive understanding of the physical characteristics of site sediments. A clear understanding of site conditions can help formulate an appropriate dredging plan. For the dredging projects in Lake Jarnsjön and Marathon Battery, the dredging equipment was switched from hydraulic methods to clamshell buckets when coarse sand and gravel were encountered in selected areas. For sites where the side-slopes are known to be unstable and difficult to access, the remediation footprint can be designed around these limitations as was implemented in the Ford Outfall, Port of Vancouver, and Port of Portland.

3.5.4 Capping of Residuals

Three of the projects placed sand caps on residual sediments to isolate remaining sediments from risk and exposure to aquatic organisms. For the Sheboygan River, sand caps were purposely placed at several hotspots as part of the demonstration pilot project to assess the efficacy of placement based on site conditions. In the case of West Eagle Harbor, both thick and thin caps were designed into project plans. The thick cap was placed to isolate contaminants and reduce risk of exposure while the thin cap was placed to enhance natural recovery and return the sediment concentrations to below toxic thresholds within 10 years after remedial activities. In the case of GM Foundry, a sand cap was unanticipated and placed on one of six dredge quadrants after several attempts failed to remove residual contaminants. After the year 2000 dredging activities at Fox River SMU 56/57 a sand cap was placed over the entire dredge footprint, although not required by regulatory agencies, to isolate and prevent further downstream transport of residual impacted sediments.

Stockpiling Dewatered Sediment
Source: Bill Fitzpatrick, WDNR

3.6 Remedial Action Findings

3.6.1 Types of Dredging Technologies

The types of dredging technologies utilized at these sites can be grouped into five general categories: mechanical clamshell buckets with barge/scow (seven projects), a hydraulic cutterhead dredge with pipeline to shore (six projects), a hydraulic horizontal auger dredge with pipeline to shore (five projects), a hydraulic suction dredge without a cutter (one project), and other technologies such as the Pneuma airlift pump (one project). A few projects switched technologies during implementation after encountering site difficulties (usually debris and wood) (Lake Jarnsjön, Marathon Battery, Manistique). To access underpier and shoreline areas, several projects also implemented airlift vacuum pumps, backhoes, or diver-assisted smaller hydraulic pumps for difficult areas (Port of Portland, Manistique, Sitcum Waterway). A summary of dredging technologies used for the projects is presented in Table 7.

3.6.2 Containment Systems

Containment systems utilized during dredging to minimize downstream transport of suspended sediments included silt curtains (12 projects), sheetpile walls (three projects), oil booms (three projects), and no containment (two projects) (Table 8). In the case of GM Foundry, a silt curtain was initially installed, but did not work well in the strong river currents and wind. The silt curtain was removed and a sheetpile wall system devised. Additional information is needed to assess whether the silt curtain was not appropriate for the site or whether the design and installation were poorly implemented. In the case of New Bedford Harbor, silt curtains were initially installed, but later removed because of disturbance from tidal and weather conditions. Downstream transport was monitored by changes in chemical mass transport and bioassays using surface sediment chemistry. In the case of Bayou Bonfouca a combination of barrier systems was used, silt curtains and oil booms were installed around dredging activities, and a sheetpile wall installed along the shoreline banks for stabilization.

Bucket Dredge
Source: SAIC

On the other hand, experience at the Deposit N demonstration project has shown that the barrier containment system was redundant and unnecessary given the low resuspension of sediment by the environmental dredge. Extensive water column monitoring during the first phase of work showed little elevation of turbidity from the dredging operations, no significant difference between the inside and outside barrier samples, and therefore no apparent threat to the river water column. Based on the monitoring results, the second phase of the dredging proceeded without the barrier containment system with comparable results. No water quality exceedances were observed.

For the two projects that did not install containment systems (both in Puget Sound) an authorized, site-specific, chronic dilution zone was established around the dredging activities based on modeling results. The surface water compliance monitoring stations were established along the edge of the dilution zone and dredging activities were carefully monitored to minimize sediment transport. No significant exceedances were observed. In general, no significant water quality exceedances were noted in any of the projects reviewed, and no modifications to the dredge operations were noted based on water quality results (Table 8).

Monitoring Device
Source: SAIC

The significance and consequences of off-site loss of contaminants during environmental dredging have not been universally defined in the literature. For most projects, containment systems are installed either to: 1) prevent off-site exceedances of acute or chronic risk-based criteria, or 2) prevent mass transport of contaminants downstream. Monitoring requirements are determined by permit-based criteria which defines a particular regulatory decision on the allowable amounts of off-site concentrations (contaminant levels or surrogate parameter such as turbidity or suspended solids). The decision to install a barrier system should consider the purpose of the water quality permit balanced with the cost to install and maintain a containment system. The water quality permits should be based on site-specific risk management and judgement values that depend upon the valued endpoints of the project and site conditions. Overall, the effectiveness of a containment system and subsequent net transport of contaminants off-site should be only one metric with which to evaluate project success.

3.6.3 Problems Encountered

Common problems encountered during active dredging and processing can be grouped into seven general categories: 1) debris or unanticipated changes in physical material characteristics, 2) disturbance of containment systems, 3) difficulty dredging the underlying hardpan layer, 4) access to restricted areas (underpiers and side slopes) and sloughing of side slopes, 5) lower percent solids than anticipated in the dredge slurry and filter press cake, 6) public opposition to selected activities, and 7) seasonal restrictions to dredging activities (boating, fish spawning, ice during winter). Most of these problems are discussed in various discussions of Section 4 and detailed in each of the Appendix A case studies.

Physical Conditions. Problems encountered with debris, hardpan, side slopes and difficult access are discussed in Section 4.1. Problems encountered with containment systems and site characterizations are discussed in Section 4.3.

Low Percent Solids. The percent solids in the filter press cake of Lake Jarnsjön sediments was lower than expected. To meet the 35 percent solids content for disposal, the mechanically-dewatered sediment had to be remixed with sand and dewatered again to meet the landfill requirements. For the Lower Fox River SMU

56/57 project, the average percent solids in the dredge slurry during the year 2000 dredging activities was about 4.4 percent (40 percent lower than anticipated solids content). However, after mechanical dewatering, the dredged material was between 50 and 60 percent solids. For Waukegan Harbor, the sediment placed in the on-site nearshore containment cell required over two years to reach the target 90 percent consolidation despite dewatering and application of sand and coagulant efforts to "thicken" the material.

Barge Overflow
Source: SAIC

Public Opposition. Strong opposition to planned redevelopment activities or dredging and dewatering processes can influence the final design parameters for a sediment remediation project. For the New Bedford Harbor project, the surrounding community was opposed to incineration of contaminated sediments for fear of exposure to air emissions. As a result, contaminated sediments were placed in a nearshore confined disposal facility (CDF). For the West Eagle Harbor project, proposed shoreline redevelopment activities included the expansion of the Washington State ferry system facility which would result in the displacement of a local boatyard and haul-out facility for local boaters. The local community residents appealed the loss of their local boatyard. As a result, EPA amended the ROD, specified which off-site disposal, allowing construction of a nearshore CDF which would give the ferry system the additional space they needed and allow the adjacent boatyard to remain in-place.

Seasonal Restrictions. Almost all of the projects reviewed had seasonal limitations and permit restrictions associated with dredging operations. Many of these site-specific restrictions limited dredging operations to only six months of the year. Fish spawning restrictions often applied for three to five months a year to protect aquatic life. Boating season restrictions (when dredging activities could not limit passage of ships or recreational boats) were often in place during the summer months in many river and lake systems. Onset of winter conditions (ice, cold temperatures), especially in the Great Lakes region, limited dredging equipment operations to warmer months. The frozen surface ice limited the mobility of equipment and the cold temperatures compromised the effectiveness of equipment. Some projects, such as Lower Fox River SMU 56/57 and Manistique projects, struggled to meet the project target goals before onset of winter conditions, often requiring demobilization before site activities had been completed.

3.7 Environmental Monitoring Program Results

A summary of the monitoring program elements and the results associated with each testing media are summarized at the end of each case study located in Attachment 1. Additional monitoring program designs for other case study projects are included for reference in Attachment 2. The monitoring programs utilized for the 20 case study projects are summarized in Tables 9 through 12. The most common monitoring parameters utilized at the dredging sites were sediment, water quality and fish tissue sampling (discussed below). However, the purpose of the sampling events were often different depending upon the phase of the remedy effort. Using the phase of the remedy effort as a guide, the monitoring program elements were easily divided into four groups:

- Baseline;
- Implementation during dredging (short-term);
- Post verification (short-term); and
- Long-term.

A summary of the results and types of monitoring used for each group is discussed below and presented in Tables 9, 10, 11, and 12.

Aerial photograph of River Mouth, Green Bay and Renard Island CDF
Source: B. Paulson, WNDR

Baseline monitoring was conducted to establish a level of comparison. Short-term monitoring during implementation was performed to ensure compliance with water quality requirements and minimize downstream transport of contaminants during dredging. Verification monitoring was conducted immediately after completion of dredging to ensure the actions were implemented as designed. Long-term monitoring was conducted to verify achievement and performance of the remedy.

The measurement methods used to verify achievement of short-term target goals and long-term objectives were dependent on the nature of the goal/objective. For example, all projects with chemical criteria target goals used post-project sediment samples to verify compliance. Projects with physical goals used bathymetry and mass reduction of contaminants to verify compliance. However, in some cases (Ford Outfall, Black

River, Lower Fox River - SMU 56/57 and Deposit N, Sheboygan River) where the target goal was to depth or horizon, verification sampling was conducted as a secondary measure to ensure that the site characterization adequately predicted hotspot depths and to use residual concentrations as baseline measures for future monitoring.

3.7.1 Baseline Monitoring

The results of the baseline monitoring review are summarized in Table 9. Physical, chemical, and biological data collected for baseline events generally included bathymetry, sediment, surface water chemistry, and fish tissue, respectively. Physical monitoring included bathymetry in 17 of 20 projects and surface water quality (e.g. turbidity, pH) in four projects. Sediment was analyzed for chemistry prior to dredging in each of the 20 projects reviewed. Analysis was on surficial sediment in six projects, cores in nine projects, and both in two projects. The sample collection technique was not specified in the three remaining projects. Surface water chemistry was analyzed in nine projects and baseline air monitoring was conducted in four projects.

Vibracore Sampling
Source: ThermoRetec

The most predominant biological monitoring was tissue analysis of fish and shellfish in six out of 20 studies. In one study where fish tissue analysis was conducted, vegetation, benthic algae, phytoplankton, and zooplankton tissues were also analyzed for COCs. Invertebrate toxicity and benthic abundance were also commonly measured during baseline monitoring.

Sediment samples were collected using cores at a much higher frequency than surficial samples in baseline monitoring when compared to other monitoring periods. This was due to the desire to measure concentrations of contaminants in sediment at various depth horizons. Sediment sampling in other monitoring periods were often only concerned with surface sediment concentrations. This observation did not apply to projects in which a cap was applied after dredging and sediment sampling was conducted to evaluate transport of contaminants through the cap.

3.7.2 Implementation During Dredging Monitoring

The results of the implementation during dredging monitoring review are summarized in Table 10. Physical, chemical, and biological data collected for implementation monitoring generally included bathymetry, surface water chemistry, and caged fish/mussel tissue, respectively. In some cases, surface sediment samples were also collected between dredging passes to determine compliance with concentration-based cleanup goals. However, for the purposes of this study, these surface sediments samples used to describe current conditions after immediate dredging passes are described in the post-monitoring section.

Physical monitoring focused on surface water quality, which was measured in 16 of the 20 projects. Seven monitoring programs measured bathymetry during dredging to monitor progress. Surface water was the most commonly analyzed chemical parameter, being measured in 11 of the 20 projects. Air monitoring was also commonly measured, occurring in nine of 20 sites. Analysis of sediment chemistry was only noted in four projects during dredging (two surface, one core, and one not specified).

Hydraulic Auger Dredge
Source: EPA

Fish and shellfish tissue were the most common biological parameters analyzed (five of 20 projects). The shellfish studies generally utilized cased mussels at fixed locations. Although case studies sensitive indicators of sediment transport and uptake they are subject to significant confounding factors (such as passing vessel) that traffic render the results questionable (e.g., Lower Fox River SMU 56/57). Physiological parameters were monitored in fish at two projects, but no fish/shellfish toxicity tests were completed in any project. Invertebrate toxicity was measured in one project, however, no benthic abundance was conducted in any projects.

The focus of monitoring conducted during dredging was on the control of contaminant transport, rather than cleanup goals. This is illustrated by the predominant inclusion of surface water quality, surface water chemistry, air monitoring, and fish and shellfish tissue analyses in the monitoring program. Other than bathymetry, which was commonly used to measure progress of dredging, no monitoring parameter was included in more than three monitoring programs. Physiological responses in fish were measured in two monitoring programs as an inexpensive method to evaluate toxic effects. While only included in the Black River and Lake Jarnsjön monitoring programs, physiological responses were successfully used to determine project effects on receptors.

Programs which included other parameters, (e.g. sediment cores and invertebrate toxicity) did not apply the data to aid project evaluation or adjustments to design.

3.7.3 Post-dredging Monitoring

The results of the post-dredging monitoring review are summarized in Table 11. Physical monitoring included bathymetry in 14 of the 20 projects and surface water quality in two projects. Chemical analysis of sediment was conducted in 17 projects. Surficial sediment samples were preferred in post-dredge monitoring, being collected in 11 projects, while cores were collected at three projects, and the sampling method was not specified in three others. Surface water chemistry was only measured in four projects, and no air monitoring was conducted in any of the post-dredge monitoring programs. Biological monitoring included fish/shellfish tissue (five of 20) and benthic abundance and invertebrate toxicity (three of 20). Fish/shellfish were evaluated for physiological responses in two projects, although no toxicity testing was conducted on fish or shellfish in any project.


Deposit N Sand Drop Box
Source: Bill Fitzpatrick, WDNR

Either sediment chemistry or bathymetry was noted as a part of the post-dredge monitoring in each of the projects, except in Manistique River where monitoring data is not yet available. Monitoring of bathymetry and sediment chemistry are logical and direct methods to measure achievement of dredge depth and chemical sediment criteria. Although not used as commonly, fish tissue data also served to measure attainment of project goals in dredging projects.

3.7.4 Long-term Monitoring

The results of the long-term monitoring review are summarized in Table 12. Long-term monitoring was limited to chemical and biological analyses; no physical monitoring was noted in any of the projects. Commonly monitored parameters included sediment chemistry and biological tissue analyses. Sediment chemistry was analyzed on surficial samples in six projects, cores in two projects, and was not specified in one project. Biological analyses included tissue chemistry of fish and/or shellfish (seven projects) and plant, bird, and algae tissue (one project) and benthic abundance (five projects). No chemical air monitoring was conducted and surface water was only monitored at one project.

The extent of long-term monitoring and the parameters measured were considerably different compared to other monitoring periods. Compliance with long-term objectives is shown to be primarily measured through sediment chemistry, fish tissue, and benthic abundance. It is not surprising that emphasis is placed on fish tissue during long-term monitoring considering depuration rates for contaminants in fish require three to seven years, depending on the species (Thomann and Connolly, 1984).

3.8 Performance Evaluation Results

The performance evaluations for each project are discussed in Section 4.

3.9 Costs

Total remedial implementation management, monitoring and disposal costs ranged from approximately \$0.5 to \$44 million. Three out of 20 projects did not have costs available for review. The total costs per cubic yard ranged from \$6 to \$1,842 (Table 13). The dredging component alone ranged from approximately \$6.20 per cubic yard to \$507 per cubic yard (N = 11, other data not available). The dredging costs per cubic yard generally decreased as the volume of sediment to be removed increased (regardless of removal method). However, the total remediation project costs were variable and did not correlate to sediment volumes. This variability can be explained by site-specific differences in management plans, disposal options, site restrictions, monitoring, and redevelopment decisions.

3.10 Contacts

The EPA (or equivalent) was the lead agency on 17 of the 20 projects reviewed. The remaining three projects were conducted under state lead.

Turbidity meter M-2.

Deposit N Water Quality Monitoring
Source: Bill Fitzpatrick, WDNR

4 Data Analysis and Verification of Goals

Measures of success depends on the question being asked, and as such, there can be no single measure of success for all of these projects. Success is measured on a site-specific basis and for the purposes of this report, success is defined as the degree to which the remediation activity achieved the short-term target cleanup goals and long-term remedial action objectives (RAOs). Achievement of short-term performance-based target goals were determined by comparing the results to the site-specific expectations defined by the project. Achievement of both target goals and long-term risk reduction is limited by the ability to verify the achievement and is solely dependent on a well-developed monitoring plan. The verification of achievement should also recognize dredging design factors, implementation difficulties, presence/absence of a decision-making framework, and the monitoring program design when evaluating each project. Each of these elements will be discussed separately below as they relate to the contaminated sediment dredging projects reviewed:

- Achievement of short-term performance-based target goals;
- Degree of progress towards long-term project objectives, as they relate to risk reduction;
- Application of a dredging design components; and
- Adequate design of monitoring methods used to verify achievement of goals.

4.1 Achievement of Short-Term Target Goals

4.1.1 Summary of Projects Reviewed

As previously summarized in Section 2, the performance-based target goals were grouped into four categories: 1) removal to a chemical criteria; 2) volume or mass removal; 3) removal to a physical horizon; 4) removal to an elevation; and 5) removal to a vertical depth below the sediment surface. Sites with no stated goals or assumed to be mass removal projects were generally pilot studies, focused time-critical removal actions, or combined with other objectives in mind. Removal of sediments to a chemical criteria were generally based on site-specific, risk-based models or regionally-developed sediment quality thresholds such as used in Puget Sound and Canada. Cleanups to a chemical criteria were designed to be protective of human health and the environment. Removal of sediments to a depth, horizon, or design elevation were also intended to be protective of the environment through previous site characterizations and knowledge of the distribution of

Box Core Sediment Sampler
Source: EPA Great Lakes National Program Office

contaminants. However, other physical performance-based criteria were used by design instead of a chemical concentration. Post-verification sampling of the residual sediments were used to determine residual chemical concentrations after remedy completion. In most cases, when other criteria were used for the contractors besides chemical concentration, the COCs were contained in the surficial/near-surficial soft, silty to silty sand sediment deposits overlying denser sand deposits or bedrock/ hardpan. Excavation to these identifiable and quantifiable horizons added a second tier of quality control to the dredging activities. The distribution of the target goal types and their relative percent success are summarized below:

Distribution of Performance Goal Types and Achievement

Short-Term Target Goal	Number of Projects	Number of Projects Achieving Performance-Based Criteria
Chemical Criteria	10	8
Mass Removal	3	3
Horizon (bedrock)	2	2
Elevation	2	2*
Vertical Depth	3	3
Total	**20**	**18**

* SMU 56/57 did not reach target elevation during year 1999 dredge activities, but did reach the target elevation in year 2000.

Residual surface sediment concentrations for each project are listed in Table 5, and the volume/mass of sediment removed is presented in Table 12.

4.1.2 Evaluation of Effectiveness and Implementability

Of the 20 case study projects reviewed, 18 projects met their stated target goals. The two projects that did not meet their stated target goals were GM Foundry and Manistique Harbor/River. The Lower Fox River SMU 56/57 project did not meet the target elevation during year 1999 dredge activities, but returned to the site in year 2000 and completed the sediment removal to project specifications. A fourth project, the Ford Outfall site, met 80 percent of its target goal and therefore was lumped into the "achieved goals" group.

Sampling
Source: ThermoRetec

The target goal of the Ford Outfall project was to remove soft overlying silt down to hardpan (glacially overridden silt/sand/ gravel, called till); however, verification sampling required residual sediments to measure less than 10 ppm PCBs. Verification sampling measured below 10 ppm in 11 of the 14 dredge cells (80 percent successful). In the case of GM Foundry, great care was taken to implement a successful project with extensive design elements, pilot testing, and modeling; however, post-project residual PCB concentrations were higher than the target chemical criteria. In the case of Manistique, PCB concentrations were also higher than the chemical criteria. For both projects, development of unrealistic target goals, lack of adequate understanding of site conditions, and the need for additional engineering design components, were likely contributors to dredging projects not achieving target goals.

In the case of the Lower Fox River SMU 56/57 demonstration project in year 1999, the initial contractor did not meet the target elevation criteria in 49 of the 53 dredge subunits, not because of limitations in dredging equipment, but because of the need to demobilize before onset of winter. A final cleanup pass was implemented in four subunits to assess dredging effectiveness and the ability to achieve target elevation goals at the site. In the four areas dredged to the design depth, the verification samples measured low concentrations of PCBs (below the anticipated goal of 1 ppm although not a specified design criteria). In areas where a final cleanup pass was not conducted to the design elevation, residual surface sediment concentrations higher than the chemical criteria (up to 280 ppm PCBs) were left exposed. However, in August 2000, a new dredge contractor returned to the site and continued removing impacted sediments. Sediments were successfully removed to the target elevation and confirmation samples were below the target criteria of 10 ppm PCBs (avg. = 2.2 ppm). In summary, the target goal is achievable based on well-planned implementation of dredging techniques.

Based on the review of primary reports and interviews with site managers, the most likely explanations for not achieving target goals included the following physical constraints: the unforeseen extent of wood and other debris (e.g., rock or construction materials) limiting the access to sediment removal, presence of an impenetrable base layer (hardpan, bedrock) preventing removal of residual sediments resting on it, and recontamination of the dredge area from external sources (passing ships, sloughing side slopes, transport from other sediment sources). Each of these physical constraints is discussed below.

Presence of Rock, Wood and Other Debris. Dredging technologies had trouble effectively removing material located between rocks and debris. Often these materials clogged the dredging/dewatering equipment thereby slowing down production rates. Adequate characterization of site conditions were needed to develop realistic target goals and to select the most appropriate removal technology. Ford Outfall and Manistique both encountered cobbles, rocks, and debris which compromised the ability to remove contaminated sediments and limited the production/capacity of selected equipment to handle the site conditions. In the case of Manistique, some of these obstacles were not adequately characterized prior to mobilization for dredging, and thus were not anticipated. Therefore the appropriate technology and target goals for Manistique were not assigned. On the other hand, both the Grasse River and GM Foundry projects anticipated significant amounts of rocks and cobbles at the site and mobilized excavation equipment to specifically remove larger material before dredging equipment was mobilized, alleviating much of the burden during dredging.

Presence of Bedrock and Impenetrable Base Layers. In cases where overdredging was feasible, (Sitcum Waterway, Wyckoff/West Eagle Harbor, and Lake Jarnsjön) where the absence of hardpan or bedrock enabled the dredge to penetrate below the contaminated sediments, removal of all contaminated material was likely ensured (assuming source control). However, most of the river systems reviewed (Lower Fox River Deposit N, Manistique, Ford Outfall, GM Foundry) were not able to overdredge since the soft sediments generally rested on bedrock/hardpan. In the case of Lower Fox River Deposit N, the project was designed with this limitation in mind and sediments were dredged to within 3 inches of hardpan, recognizing that residual contaminants would be left in place. Although these sediments were newly exposed at the surface, a significant portion of the PCB mass was removed and the areal surface coverage of sediments exposed at the surface was significantly reduced. Built into the

Assembling Slurry Pipeline
Source: ThermoRetec

remedial design was the expectation that the residual PCBs would attenuate through burial by the natural river sediments load. Thus, the cost of the project was contained at approximately $4.3 million, saving the project time and resources to excavate the thin layer of sediment resting on top of the bedrock by incorporating an element of natural attenuation. This project met its short-term target goal of achieving a vertical depth below mudline (as opposed to a chemical criteria).

In summary, dredging equipment is limited at effectively removing excavate residual sediments resting on bedrock, but this limitation is often coupled with site conditions such as the percent solids of *in-situ* material and how easily the material is resuspended and resettled, along with the ability to control downstream transport of suspended material. However, overdredging is feasible when bedrock/hardpan is not present, and where site conditions allow overdredging, target cleanup goals can usually be achieved.

Recontamination and Source Control. Beyond the obvious potential for recontamination of dredge areas located within larger areas of concern, localized sources of recontamination included sloughing from side slopes, resettling of suspended solids from dredging activities, and river currents/passing ships disturbing the sediment bottom and transporting bedload sediments into the dredge area. In the case of the Ford Outfall removal project, the dredge prism extended below the navigation channel creating unstable side slopes that sloughed into the excavation underneath the silt curtain. At the Wyckoff/West Eagle Harbor site, the newly exposed intertidal sediments were sloughing from tidal action and required armoring to stabilize the slopes. At the GM Foundry site, the verification samples may have been collected from underlying glacial till that contained contaminated material when most of the overlying soft silts were removed.

4.1.3 Reduction of Surface Sediment Concentrations

A total of 17 out of 20 projects successfully reduced the maximum detected concentrations in surface sediments by 69 to 99.9 percent (Table 5). Three projects with post-verification concentrations similar to the baseline concentrations were the Black River, Puget Sound Naval Shipyard (PSNS) and Lower Fox River SMU 56/57 (1999) sites. For the Black River, however, the long-term remedial action objective of reduced fish liver neoplasm deformities was achieved. For the PSNS and 1999 SMU 56/57 projects, the majority of the dredge prism of contaminated sediments was removed; however, a small portion was left in place because of policy and field decisions, and not because of dredging equipment limitations. As a result of these projects knowingly deciding to stop dredging before removing an entire deposits, sediments with elevated concentrations of contaminants were newly exposed. In the cases of Bayou Bonfouca and Collingwood Harbour, post-verification sample results were not available for review, but it was assumed that the target goals were achieved since the long-term goal of protecting human health was realized when the fish consumption advisories were lifted (Table 4).

4.1.4 Limitations of Target Goals

Critics of dredging (BBL, 1999) cite that although dredging projects have successfully reduced the volume and mass of contaminated sediments, these are not relevant measures of success, since by definition, each project achieved mass removal. They cite that only evidence of reduced chemical concentrations and reduced risk to the environment are viable measures of achievement. Furthermore, researchers argue that if reductions of risk are actually measured (e.g., lower bioaccumulation in fish, lower surface sediment concentrations), that the source of the effect cannot be quantitatively distinguished between different remedies such as source control, natural attenuation, dredging, or other isolation of contaminants. Other naturally-occurring site conditions may be confounding the interpretation of dredging effectiveness.

Silt Curtain
Source: ThermoRetec

How can we distinguish between the effects of source control or natural attenuation on the system and the effects of an implemented dredging program? Well-designed monitoring programs that are consistently implemented would help determine the natural variability of the system and be able to distinguish between a full-scale removal effort and natural attenuation. The relationship and direct exposure pathways between surface sediment concentrations and water column concentrations to bioaccumulation in aquatic organisms are well established; however, adequate post-project monitoring programs and sufficient time are required to observe long-term trends over time.

Finally, surficial concentrations only reflect a single “snapshot” in time and may not reflect longer term exposures. Dynamic and episodic deposition and scour patterns need to be evaluated when determining residual risk. If deeper sediments with higher concentrations remain in-place, then the confidence in which these sediments will remain buried versus resuspend from physical disturbance events (i.e., storm events, ice scour, prop wash) is not always well defined.

4.2 Achievement of Long-term Project Objectives

4.2.1 Summary of Projects Reviewed

Long-term RAOs were grouped into three major categories: 1) protection of human health, 2) protection of the environment, and 3) physical removal of the contaminant mass for source control, with an implied intention of protecting the environment. The third category also includes pilot studies that generally do not have well-defined long-term objectives beyond mass removal. The distribution of the RAOs stated for each project are summarized below and in Table 14:

Distribution of Remedial Action Objectives and Status of Achievement

RAO	No. of Projects	Achieved (1)	Progress Towards (2)	Variable Results (3)
Protect Human Health	9	▸ Bayou Bonfouca ▸ Black River ▸ Minamata Bay	▸ GM Foundry ▸ Ford Outfall, Waukegan	▸ Marathon Battery ▸ Grasse River ▸ Manistique
Protect Environment	6	▸ Collingwood ▸ Lake Jarnsjön ▸ Sitcum Waterway	▸ Wyckoff/WEH	▸ New Bedford Harbor
Physical/Source Control	5	▸ None	▸ Port of Portland ▸ Port of Vancouver ▸ Sheboygan,	▸ New Bedford Harbor ▸ PSNS ▸ Fox River Deposit N ▸ Fox River SMU 56/57
Total	**20**	**6**	**7**	**7**

Notes:

(1) Fish consumption advisories have been removed, or site restored to functional use, or the sites were delisted from regulatory status.

(2) Some evidence of decreasing concentration in sediment and biota tissue, but no decision-making action taken based on results.

(3) No discernable trends observed.

Protection of human health in this context implies reduction of risk through dermal contact and fish consumption. Measurement endpoints used to assess protection of human health were usually surface sediment chemistry (isolation/removal of contaminants) and removal of fish consumption advisories. Protection of the environment in this context implies a reduction of risk to invertebrates, fish, birds, and mammals through sublethal and lethal toxicity, reproduction, bioaccumulation, and consumption. Measurement endpoints used to assess the protection of the environment included water column and benthic toxicity testing, benthic community structure (although hardly ever assessed for compliance because of inherent variability), and fish tumors and lesions.

Measurement endpoints used to assess the protection of the physical environment (minimized downstream transport of contaminants and isolation) were surface sediment chemistry, removal of contaminant, mass/volume, and downstream resident fish tissue sampling. Removal of contaminant mass is assumed to reduce the risk of downstream transport by eliminating the sediment source.

Lack of long-term objectives generally apply to pilot studies where the information gained would be applied to a larger scale remedy, and doesn't necessarily imply a "lack of planning" or that the project goals were not achieved. Basically, it means these projects cannot be evaluated solely by the metric of measurable risk reduction because there was no intent for long-term objectives to be measured (e.g., Sheboygan River) nor was risk reduction necessarily a major goal of the project. These projects sometimes do measurably reduce risk, but instead are intended to provide source control and to gather information on the ability to implement tested technologies.

4.2.2 Evaluation of Effectiveness and Implementability

Of the case study projects reviewed, six met their stated long-term project objectives (Bayou Bonfouca, Black River, Minamata Bay, Lake Jarnsjön, Sitcum Waterway, and Collingwood Harbour). In the first three cases, the fish consumption advisories have been rescinded from the project area (Table 4). Both Collingwood Harbour and Sitcum Waterway were delisted from regulatory status. Although a change in the regulatory status of the Lake Jarnsjön project was not specified, the project achieved its stated goals of reduced PCB levels in biota. For Waukegan Harbor, the fish tissue concentrations in carp fillets showed a significant downward trend from pre-dredge conditions, but the data was considered by some reviewers to be inconclusive because of small sample sizes and large variability. Despite this variability, the fish consumption advisory for Upper Waukegan Harbor was rescinded. (However, recent 1999 fish data for Waukegan Harbor may require re-evaluation of advisory status; the chemical criteria selected for clean up may not have been protective enough.)

The fish consumption advisories were lifted from dredging projects completed between 1990 and 1995, and none of the projects completed during and after 1995 have had consumption advisories lifted. In addition, the two projects completed in 1993, Sitcum Waterway and Collingwood Harbour, have had regulatory closure for the sites. Since depuration rates for PCBs and other contaminants in fish tissue requires three to seven years (depending upon the species), projects completed after 1995 will likely require additional monitoring to observe consistent downward trends in fish tissue concentrations (assuming source control or mass reduction) (Thomann and Connolly, 1984).

4.2.3 Limitations of Long-term Remedial Objectives

Critics of dredging often state that dredging is often unable to remove all constituents from the sediment bed and that dredging destroys existing habitat. They state that dredging has limited effectiveness in reducing the amount of biologically available PCBs (in the surface sediments) and the contaminants of concern could be resuspended and released to a waterway during dredging only to be redeposited outside of the dredge area and carried downstream. Constituents left behind could be available to the food web at higher concentrations than if the dredge area was left to natural attenuation.

Research studies to assess the quality of long-term monitoring plans (NRC, 1990) found numerous limitations in the data sets including:

- Limited availability of long-term fish data monitoring results;
- Lack of comprehensive post-closure monitoring reports and documentation;
- Detailed descriptions of fish collection data are often missing (age, size, sex, season, weight, fillet vs. whole body, lipid-based corrections, collection location,

resident or caged, suspended in water column on substrate);

- Inability to distinguish between dredging effectiveness, source control, and recontamination; and

- Although reduction of PCBs in fish is a meaningful measure of risk reduction, inherent variability exists in the measurements. It is difficult to filter out confounding factors and determine the relationship between fish tissue concentrations (fish deformations) and reduction of sediment concentrations from dredging activities.

These limitations confounded the monitoring efforts and their ability to verify achievement of long-term remedial objectives.

4.3 Evaluation of Engineering and Design Components

4.3.1 Summary of Projects Reviewed

Design components of each remediation project were evaluated to determine the level and extent of pre-planning and site characterization prior to mobilization to a site. Site conditions and design factors that influenced the outcome of each project are summarized in Table 15. Some of the design components evaluated and considered to be useful for maximizing the likelihood of success included (EPA, 1994; Averett, 1995):

- An experienced dredging design consultant;

- Early identification of required approvals/permits, and ability to comply with them;

- Adequate baseline monitoring to verify achievement;

- Verification sampling before demobilization from site;

- A silt curtain/barrier to prevent downstream migration;

- A performance-based contract allowing contractor flexibility to meet objectives;

- Source control in place or at least considered;

- Long-term monitoring in place or considered;

- Physical constraints anticipated;
- Predictive modeling of contaminant releases;
- Adequate physical characterization of impacted sediments including design level informational studies;
- Remedy not limited by treatment or disposal constraints;
- Contingency plan for evaluating exceedances during dredging;
- Selection of equipment compatible with site conditions and the constraints of the project; and
- Realistic target goals for the site conditions and overall objectives.

Although design components were evaluated while reviewing project documents (Table 2), each case study had a unique set of variables, site conditions, and regulatory framework which made it difficult to categorize or group the results. However, a common theme resurfaced on many projects which included: 1) installation and maintenance of containment systems and realizing their limitations, 2) performance-based contracts to help ensure compliance with environmental monitoring and criteria, and 3) a complete understanding of site conditions to minimize unforeseen problems in the field and to select the most appropriate removal technology.

4.3.2 Evaluation of Effectiveness and Implementability

Containment Systems. A total of 15 out of 20 projects observed no significant exceedances of water quality (turbidity and total suspended solids [TSS]) during dredging activities (except from storm events and passing ships). One project (Sheboygan River) observed some turbidity and water quality exceedances in downstream samples. For the remaining four projects, data was not available for review. The Grasse River project had turbidity exceedances during the initial boulder removal activities, but water quality measurements further downstream were in compliance. Three projects (Sitcum Waterway, Port of Portland, Wyckoff West Eagle Harbor, and Port of Vancouver) did not install barrier systems around dredging activities. Compliance monitoring boundaries were established at the dilution zone boundaries and no exceedances were observed at these points. No exceedances were measured in any of the water quality samples collected for chemistry, it seems turbidity was a more sensitive indicator of sediment transport. However, the significance of turbidity measurements should by reviewed based on to possible lack of correlation between turbidity and the chemical concentration of surface water. Caged fish samples were also sensitive indicators of resuspension showing elevated concentrations of contaminants during dredging activities in all projects used. However, the data had limited decision-making value and did not help determine net sediment transport rates or masses.

Air Quality. At least nine projects monitored air quality during dredging and dewatering operations. Samples were collected immediately around the operations and compared to ambient air quality samples collected further offsite. No major exceedances above safe human health levels defined for the project were observed. In general, no management action or remedy modifications were implemented based on measured air quality concentrations.

Performance-based Contracts. A time and materials contract may allow for large cost overruns without accountability by contractors to help achieve the project goals. The New Bedford Harbor project was a fixed price for hotspot removal that also included water treatment and incineration. Projects including Lower Fox River Deposit N, Sitcum Waterway, and Wyckoff/West Eagle Harbor, the contractor was aware of the project objectives, given flexibility to meet these objectives, and held accountable through performance-based contracting.

Disposal Site Liner Fabric
Source: ThermoRetec

Understanding of Site Conditions. Physical conditions of the site, physical properties of the sediment (obtained from testing and include grain size, specific gravity, percent solids, Atterberg limits, and WET testing methods), and the extent of contaminated sediments need to be adequately characterized to maximize the likelihood of success. At the GM Foundry site, although the soft sediments containing most of the contaminant mass were removed, the verification samples had elevated concentrations above cleanup criteria. One commonly perceived explanation for the elevated samples was that the underlying glacial till layer (below the dredge design depth) had absorbed the PCB contaminant thereby confounding possible verification of sediment removal to the target cleanup goal. At the Manistique site, sediment core refusal to a hardpan layer was inappropriately confused with the buried slab wood and debris, when the actual stratigraphic horizon with clean material occurred much deeper in the profile at the bedrock interface. Most of the projects reviewed, however, conducted detailed bench-scale tests, laboratory physical testing and/or pilot studies (Sitcum Waterway, Lake Jarnsjön, Wyckoff/West Eagle Harbor, New Bedford Harbor, Collingwood Harbour, Bayou Bonfouca) which contributed to the observed success of achieving target goals for these projects.

4.3.3 Limitations of Design Components

Selection of specialty dredges designed for minimizing sediment resuspension or for maximizing performance does not guarantee superior results. The key to effective operations not only includes the selection of appropriate equipment, but also the use of highly skilled dredge operators that understand the constraints of the project and are managed by performance-based criteria and compliance monitoring (EPA, 1994).

Critics of dredging cite that dredging is too costly for removing well-distributed moderately contaminated sediments over a large area. A common criticism is that mass removal of contaminated sediment is not an important objective; only reduction of risk to human health and the environment is important (BBL, 1999). However, mass removal often serves as a method of source control to prevent further downstream migration and dispersion of contaminated sediments. Mass removal can serve to reduce risk by depleting the environmental reservoir of contaminants thereby accelerating the dilution of remaining contaminants. Mass removal may also change the depositional patterns of a sediment site by shifting from steady-state model to an area of deposition or accretion. By removing a volume of contaminated sediment, these newly vacated areas can capture suspended sediment particles leading to deposition and accelerated burial of residual contamination not potentially captured by the mass removal dredging efforts.

The intended purpose of the remedy and associated costs are policy decisions and not decisions that impact the use of dredging as a tool for source control and long-term benefit.

4.4 Evaluation of the Monitoring Programs

4.4.1 Summary of Projects Reviewed

Monitoring programs were developed to verify achievement of target goals, to verify improvement of valued resources, to determine the effectiveness of remedial activities, and to determine if adequate source control was achieved for the project area. Most of these elements were mentioned in earlier sections of this document and are briefly summarized here. The types of measurement endpoints used in the monitoring programs to verify achievement of target goals and recovery of impaired resources (long-term goals) were summarized into eight categories:

Measurement/Assessment Endpoints

Measurement Endpoint for Assessing Impairment (SedPac, 1999)	Used for Assessing Short-term Target Goals (N = 20)	Used for Assessing Long-term Objectives (N = 20)
Sediment Chemistry	20	3
Water Column Chemistry	2	1
Caged Tissue - Fish, Invertebrates	6	2
Resident Tissue - Fish, Invertebrates	6	6
Fish Deformities	1	1
Benthic Community Structure	2	2
Water and Sediment Toxicity	3	3
Sediment Traps	1	0

4.4.2 Evaluation of Effectiveness and Implementability

Monitoring programs were used to evaluate project success and attainment of project objectives and goals as well as to gather information useful in project design and in process modifications. Projects often used bathymetry measurements, sediment chemistry, and fish tissue data to determine project success. Successful projects were often improved through the development of monitoring programs which throughly measured baseline physical and chemical site characteristics, developed consistent monitoring parameters, and considered short-term and long-term goals and objectives at all stages of the monitoring program. Those programs which did not develop consistent monitoring through selection of target species, sample type, or sample collection method, had difficulties developing trends and were viewed with scrutiny.

Evaluation of Baseline Conditions. The most commonly cited factor contributing to the failure of attaining project goals was inadequate characterization of baseline conditions. Physical characteristics of the sediment and subsurface conditions including presence of buried rock, boulders, dense sand, and/or gravel were noted as a primary factor limiting the removal of sediment in the Grasse River, Lake Jarnsjön, Marathon Battery, and Port of Vancouver projects. Many of these characteristics were not revealed during pre-dredge monitoring studies. The presence of wood debris mistaken for bedrock inhibited sediment removal and contributed to miscalculations of contaminant distribution in the Manistique River and Harbor project. The failure to identify actual conditions led to significant increases to the volume removed and project cost. The extent of baseline contaminant distribution, however, was corrected during the Bayou Bonfouca dredging project, allowing the scope of work to be expanded prior to commencement of remedial activities.

Monitoring Program Development. Project success was usually evaluated through monitoring efforts designed specifically for the project goals. For example, bathymetry measurements were commonly used to evaluate success of projects to achieve the design depth, while sediment chemistry was measured to gauge success in achieving COC concentration criteria. Use of consistent monitoring parameters was necessary to evaluate the positive or negative effects of dredging. This is of particular importance in biological monitoring due to the variability of factors such as species, tissue type (whole body, fillet, etc.), and source of samples (caged vs. resident).

Monitoring was fairly consistent in most projects, although variability between pre and post remediation did exist. For example, the GM Foundry and Lake Jarnsjön projects consistently monitored fish with regard to analytical method, species, and timing throughout both projects resulting in data which was temporally comparable. In the Grasse River project, caged fish were consistently monitored the dredging program for measuring the effects of dredging. Resident fish, however, were only collected after completion of dredging and could not be used to gauge the effectiveness of dredging. In the case of Bayou Bonfouca, crab tissue samples were collected during the baseline event, but fish tissue samples were collected during the post-project sampling and therefore not comparable.

In the case of Ford Outfall and GM Foundry, no post-project resident fish were collected, and tissue monitoring started 1 to 2 years into the long-term monitoring plans. Tissues sampled in the Marathon Battery project varied considerably between monitoring periods. During baseline monitoring, macroinvertebrates, and plant tissues were analyzed for cadmium, however, post-dredge analyses included benthic algae, plant, and bird tissues. Of the six tissues analyzed, only two were comparable, making the evaluation of dredging difficult. Although five projects used benthic community structure to assess impairment of resources, only two projects used this method for measuring beneficial reuse of habitat (Collingwood Harbour and Marathon Battery).

Evaluation of Post-Remediation Conditions. Many projects did not conduct any post-verification sampling, but began a long-term monitoring program three to four years after project completion.

Lake Kettelmeer Disposal Site
Source: Terra et Aqua

Monitoring programs need to consider the long-term objectives of a project prior to collection of baseline data so that results are comparable and dredging effects can be quantified. Changes in background exposure conditions over time also need to be taken into account when evaluating the success of remedial actions, or when evaluating natural decline in fish tissue concentrations without active intervention by dredging. In the New Bedford Harbor project, the long-term monitoring program was clearly outlined early in the project. Parameters measured and sampling methods followed the procedures set forth for baseline and post-dredge monitoring.

4.4.3 Limitations of Monitoring Programs

Monitoring programs need to adequately characterize the baseline conditions prior to remediation, develop consistent monitoring parameters, and formulate expectations prior to implementation. Most of the monitoring programs reviewed included sediment chemistry sampling and fish tissue sampling to determine compliance with project objectives. However, the frequency of sampling, the species selected over time, and the purpose of sampling are often unclear and inconsistent. Monitoring programs should be reasonable based on baseline data, and be designed to answer the question asked. The success of dredging projects and the applicability of the data used to evaluate success are largely determined by the monitoring program.

4.5 Lessons Learned

Common lessons learned from this review of case studies and summarized from other studies (SMWG, 1999; SPAC, 1999; BBL, 1999; IJC, NRC, 1997; Cushing, 1999; Cura et al., 1998) are summarized on Table 15 and include:

- The availability and quality of final post-project reports was limited.

- The role of sediment surface area on total load of PCBs into surface water (a primary route of exposure to fish and invertebrates) is very important (Ortiz et al., 1998). Removal of small hotspots may not significantly reduce the concentrations observed in surface water since low PCB contaminants may be contributing the bulk of PCB loads into surface water; however, mass removal to prevent downstream transport of contaminated material and dispersion of hotspots into widely distributed concentrations may be appropriate. The purpose of the remedy and the questions being asked must be carefully defined.

- Wastewater effluent requirements tend to be very restrictive. Contaminants returned to the site via treated wastewater are insignificant relative to existing site conditions, site risk, and contaminant mass.

- Defining the remedial goal as a surface-weighted average concentration over a moderate size area may be a useful way to evaluate dredging effectiveness.

- Dredging technologies typically cannot remove 100 percent of soft sediments down to bedrock or other impenetrable layers. At least 80 percent removal of the material can be expected, and some sediment residuals resting on bedrock should be expected. The amount of material left behind and the estimated percent concentration should be considered when designing a remedial program. Acceptable levels of short-term risk should be determined during the design phase.

- Experiences in the projects reviewed indicate that dredging-induced resuspension is typically not a significant source of off-site contamination. Dewatering-induced particulate matter is typically not a significant source of off-site air quality impacts.

- Barrier systems designed to contain suspended sediment worked very well with few water quality exceedances. Modifications were made efficiently to resolve problems encountered. Caged fish monitoring during dredging usually showed elevated levels of contaminants and therefore may be better, more sensitive, water quality monitors.

- Barrier systems may not always be necessary. Extensive monitoring on the two Lower Fox River pilot projects showed no significant resuspension during dredging activities. The extensive barrier system used on the Deposit N project was deleted from the contract and dredge permit about half-way through the project based on river monitoring.

- In river systems, the target goal of 1 ppm PCBs chemical criteria for post-verification surface sediment samples at discrete locations may not be achievable at all sites, depending upon source control and site conditions.

- Dredging has implementability limitations under site conditions with wood, cobbles and debris, impenetrable hardpan, sloughing from side slopes, shallow water, and difficult access (under piers).

Dredge utilized at Deposit N.

Dredge
Source: Foth and Van Dyke

- Redundancy of critical equipment is a key factor in maintaining project schedules, achieving project goals and cost requirements. For example, the recent SMU 56/57 dredging project in the Lower Fox River had two “backup” dredges on standby which were frequently used during routine equipment breakdowns. Without sufficient spare equipment, breakdowns inevitably slow project progress and impede project goals.

- For hydraulic dredging projects, where feasible, installation of upland physical markers (e.g., sheet piles, concrete blocks) can serve as easy “low tech” survey markers for dredge location control and possibly serve as tie-down points for hydraulic cables.

- Good on-site project management cannot be overemphasized. Essential aspects include good communication between team members, adaptive management to resolve unforeseen site conditions, and proactive planning to modify project expectations at every stage of the operation. Obvious (but sometimes overlooked) activities should include daily progress meetings amongst team members and comprehensive monitoring of dredging operations. Monitoring should include daily tracking of specific targets such as: slurry solids, cubic yards removed, gallons of water treated, mass of contaminated material disposed, dewatering production, discharge water quality, bathymetric elevations, and sediment sampling results (if available). Improvements to the dredging operation need to be continually evaluated on an on-going basis.

- Surface sediment concentrations measurements are valuable and effective methods for determining achievement of target goals; however, this achievement should be coupled with reduction in the surface area of remaining contaminated sediments to ensure achievement of risk reduction and exposure pathways.

5 Conclusions and Recommendations

Based upon the in-depth review of 20 case study environmental dredging projects, several lessons were repeatedly observed in most of these projects. These lessons can be summarized into five key findings discussed below, many of which are similar to the recommendations put forth by the National Research Council in their recent review of similar dredging projects (NRC, 2001).

5.1 Risk Reduction Versus Source Removal

In order to evaluate the objective of reducing fish tissue concentrations and protecting human consumption of fish (typically a major risk driver), then it is necessary to examine the mass of contaminant material removed, the surface-weighted concentration of remaining material bioavailable to the food web, and reduction of the ongoing potential for sediment resuspension from storm events and scouring. These three factors will determine the extent of source control and magnitude of residual risk for a contaminated sediment deposit. Levels of risk reduction is a decision-making process. In some cases the maximum detected concentrations were the similar to the maximum pre-dredge surface concentrations; although a significant portion of the mass was removed. Many of the projects had elevated concentrations in the water column, surface sediments and caged fish tissues during dredging, although these releases were a fraction of the losses that would occur annually, assuming no removal would take place. In almost all projects, the concentrations measured in the post-project verification and the long-term monitoring samples were significantly reduced in all media if adequate source control was in place.

Cutterhead Dredge
Source: SAIC

Projects designed for risk reduction by mass removal typically have incorporated site-specific and technology-specific limitations of dredging into the design. The projects focused on depletion of the environmental reservoir of contaminants, reduction of off-site contaminant loading, protection from potential disruption by storm events, and encouragement of depositional process at the site to reduce the net residual contaminant concentrations over time. Lowered surface sediment concentration will reduce biological and water column exposure and therefore reduce risk.

A few key findings to consider when developing a dredging program includes:

- Mass removal is a beneficial process of source control which likely leads to long-term risk reduction.

- Individual samples for chemical concentrations in residual surface sediments should be one of several considerations relative to risk reduction. The percent reduction in surface concentrations over the entire deposit/footprint in both the short-term and long-term should be considered.

5.2 Sediment Transport Downstream During Dredging

Excessive downstream transport of contaminants during dredging is an argument cited by some as a major limitation of dredging as a viable remedial alternative. It is undoubtedly true that dredging does cause some short-term resuspension of sediments into the water column and that some of these sediments are transported downstream. However, the prevailing question is whether this mass loading is significant when compared to the entire contaminant mass, the entire contaminant load from non-point sources, and the long-term protection of the environment from episodic storm events that mobilize large quantities of normally acquiescent deposits. The allowable mass-based loading criteria that can be acceptably transported downstream without adverse risk to the environment can be difficult to quantify. These measures should not be based on a single metric unit, but instead should be risk-based values based on site-specific modeling efforts.

Monitoring. The purpose of water quality monitoring during dredging is to determine if sediments are being transported downstream in excess of criteria (e.g., turbidity) and to possibly quantify the amount of contaminant mass transported downstream. Over 60 percent of the projects reviewed monitored surface water quality during dredging using chemical concentration in addition to turbidity/TSS. The remaining projects monitored only TSS after developing baseline correlation studies with chemical concentrations. However, studies of the Lower Fox River Deposit N and Grasse River projects determined that TSS and turbidity did not completely characterize releases and did not correlate well with PCB mass as sediment properties changed. Although the number of particles suspended in the water column may not significantly change during dredging, the concentration of PCB molecules attached to each grain particle tend to increase during dredging. However, these measurements are expected to be good indicators of more significant releases from dredging operations.

Mass Loading. The New Bedford Harbor and Lower Fox River demonstration projects were the only projects reviewed that monitored surface water quality and transport in terms of mass loading. Results of the New Bedford Harbor dredging project showed that the calculated net total of PCB mass loading was only 24 percent of the total allowable mass transport during dredging (240 kg) to maintain an average downstream contaminant concentration that did not exceed 1 ppm PCB in surface sediment concentrations. The Lower Fox River Deposit N Demonstration Project estimated a net loss of 2.2 kg PCB during dredging operations, less than 0.01 percent of the total PCB mass found in Deposit N.

In summary, sediment remediation projects should consider the purpose and variables of interest when developing a monitoring plan. For example, if the primary variable of interest is contaminant transport, then surface water quality should be measured in terms of overall mass loading during the duration of the dredging program and steer away from discrete chemical criteria. If the primary variable of interest is acute protection of aquatic life, then short-term measures of dissolved oxygen, temperature, turbidity, oil sheens that may have immediate and adverse impacts to the environment should be monitored.

A few key findings and recommendations to consider when developing a sediment remediation dredging project include:

- Dredging can be conducted without significant contaminant mass loading further downstream when compared to the overall mass of contaminant removed from the site;

- Containment systems were generally effective in over 90 percent of the projects reviewed based on TSS except for a very few short-term exceedances associated with passing ships or episodic storm events;

- Caged mussel and fish tissue analyses conducted during dredging almost always show elevated concentrations when compared to background levels;

- Passing ships, disturbed containment systems, and storm events can act as confounding factors when trying to interpret chemical and biological monitoring data;

- Turbidity and TSS do not completely characterize surface water chemical quality. The concentration of contaminant may increase per grain particle during dredging. However, turbidity and TSS measurements can be valuable indicators of "significant" contaminant releases during dredging;

- For assessing contaminant transport, monitoring plans should measure net mass transport of contaminants.

5.3 Cost-effective Management

Many regulatory and private interest groups are searching for answers to the same questions of how to cost-effectively manage contaminated sediments while ensuring protection of human health and the environment over the long term (Peterson et al., 1999; Hahnenberg, 1999; Krantzberg et al.; Zarull et al, 1999; SMWG, 1999; SPAC, 1997). A few key findings and recommendations to consider when implementing a remedial dredging program include:

- Greater emphasis should be placed on post-project monitoring of effectiveness of sediment remediation and restoration of uses (SedPac, 1999).

- Higher priority should be placed on monitoring of ecological effects and beneficial use restoration at remediation sites (SedPac, 1999).

- Dredging as a remedial tool depends not only upon an adequate site characterization and a clear understanding of impairments and risks, it also depends on policy decisions developed for the purpose of dredging rather than the effectiveness of the remedial tool.

- Projects typically benefit from performance-based contracts with flexibility for implementation by contractor. Contracts should require a scientific demonstration of the particular dredging technology and clearly establish performance and payment criteria. Retain an engineering design firm that has experience designing remedial dredging programs (Taylor, 1998).

- Permit requirements will greatly affect project costs. Overly stringent permit requirements will increase dredging and disposal costs, set unrealistic expectations for the contractor and project team, and may have no significant contribution towards managing residual risk. Examples of permit requirements that have affected costs include: low wastewater effluent requirements redundant or unnecessary environmental controls (in-water barriers, double-walled pipes), and excessive monitoring requirements.

- Dredging costs can be reasonable if appropriately designed and generally decrease (cost per cubic yard) with increasing volumes. The disposal method and costs are also important to cost-effective management.

5.4 Understanding Site Conditions

A repeating theme for most projects reviewed is the need for a comprehensive understanding of a site's physical characteristics to formulate an appropriate dredging plan. This step is often underestimated and it is not until equipment has been mobilized to a site and unforeseen site conditions are encountered that the need for more baseline data is realized. Unforeseen site conditions encountered on many projects have ranged from buried cobbles and debris that prevent sediment removal, to unstable side slopes that slough into recently dredged areas, and the vertical extent of contamination extends deeper than originally believed, and varying grain sizes and clay content clog dredging equipment and exceed the design capacity of the dewatering system. Many of these unforeseen but preventable conditions have significantly increased remediation project costs and duration and decreased dredging productivity.

Adverse site conditions is an argument cited by some critics as a major limitation that dredging is not a viable remedial alternative. It has also been argued that dredging equipment currently used for full-scale sediment remediation projects cannot solve site condition problems, and therefore dredging is not a practicable solution. However, this can be addressed by ensuring that design engineers have an adequate understanding of site conditions prior to implementing a remedial action. Information that has been overlooked on some projects generally relate to site history and site conditions (e.g., human-generated debris) sometimes causing remediation to take longer and cost more than expected or budgeted. Therefore, in order to properly evaluate the efficiency of past projects, one has to determine whether the site conditions and limitations were adequately quantified in order to select the best and most appropriate technology, and select reasonable and attainable target goals that will provide long-term protection of human health and the environment. Undoubtedly some site conditions will hinder the performance of some dredging technologies, but these issues are decision-making criteria that balance the inherent limitations of dredging equipment with cost to implement the strategy and the long-term benefit associated with source control efforts.

In summary, a few key findings and recommendations to consider when developing a sediment remediation dredging project include:

- The goals of the project need to be clearly defined and balanced with the limitations of dredging equipment. Dredging projects should consider not only performance-based chemical criteria but also mass reduction of contaminants. This would save significant amounts of money trying to remove residual concentrations of contaminant material resting on bedrock, or other impenetrable layers when a significant amount of the mass and risk has already been removed.

- Sediment coring and bathymetry surveys do not always adequately define the vertical extent of contamination, especially if refusal (especially gravel or debris) is encountered at mid-depth. Site history can sometimes provide valuable information regarding human-generated debris and should be reviewed during the site characterization.

- The grain size and physical characteristics of underlying clean material (and not just the COI sediment) need to be considered when selecting appropriate dredging and dewatering equipment, since the material is often inadvertently or intentionally excavated as well.

5.5 Elements of Project Design

A few key findings and recommendations to consider when developing a remedial dredging program include:

Liner Installation for Disposal Site
Source: ThermoRetec

- Projects need well-defined measurement methods and well-defined target goals. The long-term goals for most remediation programs are loosely defined as "reduction of risk" and protection of human health and the environment. Clear objectives regarding how these goals will be evaluated should be determined during project design. Endpoint measures may include metrics such as: surface-weighted sediment concentration averages, discrete maximum exceedances for any individual measure, restoration or return of a given aquatic population, or removal of fish consumption advisories in a given period of time.

- Methods for post-verification surface sediment sampling should be specified and should be representative of aerial surface conditions. Specify the minimum residual thickness required to collect a sample and if residual sediment located between rocks and in crevasses is relevant. The goal should be to minimize sample bias by collecting sediment from localized hot spots.

- Target goals should be realistic based on site conditions and technologies without compromising the long-term objectives. The risk-based cleanup criteria values need to be implementable and protective of human health and the environment.

- Dredging can be an effective tool for achieving target goals depending upon the question being asked. When the goal is mass removal of sediment or source control to prevent downstream transport of contaminants, dredging is effective. When the goal is removal to a chemical criteria, then dredging can be partially to fully effective if source control measures are in place when needed. When the goal is risk reduction, dredging can achieve progress towards risk reduction for protection of human health and the environment.

5.6 Develop Long-term Monitoring Plans

A common theme encountered on many of the projects reviewed was the lack of comprehensive monitoring programs sufficient to verify long-term project success. Quantitative evaluations of the degree of success in meeting project objectives require well designed and implemented monitoring programs. Appropriate metrics must be identified and data collected with sufficient spatial and temporal dimensions to adequately characterize the variables of interest.

6 Limitations of This Review

Great blue heron on the bank of the Lower Fox River.

Source: D. Breneman

Data presented in this memorandum has been reviewed to the best of ThermoRetec's and WDNR's abilities given the data available for review. Primary source documents, files, and reports were queried from many different sources and no information was intentionally omitted from this review. Interpretations may change/modify as each additional piece of information is revealed and as additional monitoring is conducted over time.

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Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Allied Paper/Portage Creek/Kalamazoo River, Michigan	Dry excavation in progress.	Dry excavation
Baird & McGuire, Massachusetts	1,500 cy wet excavated from banks in 1995.	Small volume (<3,000 cy)
Bayou Bonfouca, Louisiana	Mechanical dredging of 169,000 cy from 1993 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Black River, Ohio	Mechanical dredging of 99,700 cy from 1989 to 1990.	Over 2,500 cy dredged after 1988 with verification monitoring
Cherry Farm, New York	Hydraulic dredging of 50,000 cy in 1998.	No chemical post-monitoring
Collingwood Harbour, Ontario	Hydraulic dreding of 3,896 cy in 1992 and 1993.	Over 2,500 cy dredged after 1988 with verification monitoring
Convair Lagoon, California	Capping completed in mid-1998.	No sediment removal
Duwamish Waterway, Washington	Hydraulic dredging of 255-gallon PCB spill.	Prior to 1988
Ellicott Creek, Columbus McKinnon, New York	Auger dredged 2,349 cy in 1995 to landfill.	No post-monitoring; small volume (<3,000 cy)
Ford Outfall/River Raisin, Michigan	Mechanical dredging of 28,500 cy in 1997.	Over 2,500 cy dredged after 1988 with verification monitoring
Formosa Plastics, Texas	Hydraulic dredging of 7,000 cy in 1992 (ethylene dichloride spill).	PCBs not present
Lower Fox River Deposit N, Wisconsin	Hydraulic dredging of 8,175 cy from 1997 to 1999. Pilot Study	Over 2,500 cy dredged after 1988; relevant to the Fox River
Lower Fox River SMU 56/57, Wisconsin	Hydraulic dredging of 31,000 cy in 1999.	Over 2,500 cy dredged after 1988; relevant to the Fox River
Gill Creek DuPont, New York	Dry excavation of 7,000–8,000 cy in 1992.	Dry excavation; no verification sampling
Gill Creek Olin, New York	Dry excavation of 6,850 cy in 1998.	Dry excavation
GM Foundry/St. Lawrence River, New York	Hydraulic dredging of 27,000 cy in 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Gould, East Doane Lake, Oregon	Hydraulic dredging of 11,000 cy in 1998.	A lake system; PCBs not present
Grasse, River, New York	Hydraulic dredging of 3,500 cy in 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Hamilton Harbour, Ontario	Two mechanical dredging operations of 330 cy and 200 cy in 1996.	Small volume (<3,000 cy)
Hooker (102nd Street), New York	Dry excavation of 28,500 cy in 1996 and 1997.	Dry excavation
Housatonic River, Massachusetts	Dry excavation of 4,900 cy in 1997.	Dry excavation
Hudson River, New York	Small PCB hotspots removed in 1998 totaling 1,075 cy.	Mostly capped; small volume (<3,000 cy)
James River, Virginia	Natural recovery remedy selected.	No dredging action
Lake Jarnsjon, Sweden	Hydraulic dredging of 196,000 cy from 1993 to 1994.	Over 2,500 cy dredged after 1988 with verification monitoring
Lavaca Bay, Texas	Mass removal of 400,000 cy with mercury in 1998 from intertidal areas.	Difficult to access documentation
Lipari Landfill, New Jersey	Wet and dry excavation of 163,000 cy from 1994 to 1996.	Primarily dry excavation

Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Loring Air Force Base, Maine	Wet and dry excavation of 164,000 cy soil and sediment in 1997 and 1998.	A ditch system; no post-monitoring
Love Canal, New York	Dry excavation of 31,000 cy in 1989.	Dry excavation
Lower Rouge River, Double Eagle Steel, Michigan	Dredged 34,500 cy of zinc-contaminated sediment in 1997.	Prior to 1988
LTV Steel, Indiana	Hydraulic dredging of 109,000 cy with PAHs and oil from 1994 to 1996.	PCBs not present; difficult to access documentation
Mallinckrodt Baker (J.T. Baker), New Jersey	Dry excavation of 3,500–4,000 cy in 1993.	Dry excavation
Manistique River and Harbor, Michigan	Hydraulic dredging of 120,000 cy from 1995 to 1999.	Over 2,500 cy dredged after 1988 with verification monitoring; relevant to the Fox River
Marathon Battery, New York	Hydraulic and mechanical dredging of 100,200 cy form 1993 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Menominee River, Michigan	Dredging not conducted at time of review.	No action yet
Minamata Bay, Japan	Hydraulic dredging of 1,025,000 cy from 1983 to 1987.	Over 2,500 cy dredged with verification monitoring
National Zinc, Oklahoma	Dry excavation of 6,000 cy in 1998.	Dry excavation
Natural Gas Compressor Station, Mississippi	Dry excavation of 75,000 cy in 1996 and 1997.	Dry excavation
New Bedford Harbor, Massachusetts	Hydraulic dredging of 14,000 cy in from 1994 to 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Newbergh Lake and Upper Rogue River, Michigan	Mechanical and hydraulic dredging of 1,800 cy in 1997 from a small stream and dry excavation of 588,000 cy from lake in 1998.	A small system; small volume (<3,000 cy)
North Avenue Dam/Milwakee River, Michigan	Dredged 8,000 cy in 1997.	No post-monitoring
North Hollywood Dump, Tennessee	Hydraulic dredging of 40,000 cy for pesticides/metals in 1995/96, relocated to isolated oxbow and capped.	PCBs not present
Ottawa River, Ohio	Dry excavation of 8,039 cy in 1998.	Dry excavation
Pioneer Lake, Ohio	Hydraulic dredging of 2,100 cy with VOCs and PAHs in 1996 and 4,500 cy in 1997.	A lake system; PCBs not present
Port of Portland T4 Pencil Pitch, Oregon	Mechanical dredging of 35,000 cy from 1994 ot 1995.	Over 2,500 cy dredged after 1988 with verification monitoring
Port of Vancouver Copper Spill, Washington	Hydraulic dredging of 5,000 cy in 1990.	Over 2,500 cy dredged after 1988 with verification monitoring
Portland General Electric, Oregon	Removal of 14 cy.	Small volume (<3,000 cy)
Puget Sound Naval Shipyard Pier D, Washington	Mechanical dreding of 105,000 cy in 1994.	Over 2,500 cy dredged after 1988 with verification monitoring
Queensbury NMPC Site, New York	Dry excavation of 4500–5,000 cy in 1996.	Dry excavation
Ruck Pond, Wisconsin	Dry excavation of 7,730 cy in 1994.	Dry excavation
Sangamo - Weston, South Carolina	Natural recovery remedy selected.	No dredging action

Table 1 Dredging Projects Considered for Review

Contaminated Sediment Remediation Project	Summary of Activities	Reason Not Selected or Selected
Sheboygan River and Harbor, Wisconsin	Mechanical dreding of 3,800 cy from 1989 to 1991.	Over 2,500 cy dredged after 1988 with verification monitoring; relevant to the Fox River
Shiawassee River, Michigan	Mechanical dredging of 1,805 cy of sediment in 1982; pilot study.	Prior to 1988; small volume (<3,000 cy); additional dredging planned
Sitcum Waterway Commencement Bay, Washington	Hydraulic and mechanical dredging of 425,000 cy in 1993.	Over 2,500 cy dredged after 1988 with verification monitoring
Tennessee Products, Tennessee	Dry excavation of 13,222 cy in 1997.	Dry excavation
Thunder Bay, Canada	Capping chosen as remedial action in 1999.	Project to use capping
Town Branch Creek, Kentucky	Dry excavation of 17,000 cy sediment.	Dry excavation
Triana/Tennessee River, Alabama	Dewatering and capping of sediment.	No dredging action
United Heckathorn, California	Mechanical dredging of 108,000 cy with DDT and dieldrin in 1996.	PCBs not present; difficult to access documentation
Waukegan Harbor, Illinois	Hydraulic dredging of 38,300 cy from 1991 to 1992.	Large volume; PCBs; relevant to the Fox River
Welland River, Ontario	Hydraulic dredging of 13,000 cy with industrial mill scale in 1995.	PCBs not present; very little primary documentation
Willamette River, Oregon	Hydraulic dredging of 100 cy.	Small volume (<3,000 cy)
Willow Run Creek, Michigan	Dry excavation of 310,000 cy sediment in 1998.	Dry excavation
Wycoff/West Eagle Harbor Operable Unit, Washington	Mechanical dredging of 6,000 cy in 1997.	Over 2,500 cy dredged after 1988 with verification monitoring

Note:

Shaded projects were retained for detailed review.

Table 2 Project Checklist

Project Name:
Project Location:

Reviewed by:
Checked by:

Parameter	✓	Text Answer	Parameter	✓	Text Answer
Project Overview					
Minor water body Major receiving water body Water body type Major COCs Average water depth Access (good/poor) Wet or dry dredging Concentrations			Duration of dredging Date action completed Volume of material dredged Depth of contamination Schematic figure Size of site Combined with other RAs Substrate type		
Permits/Conditions/Regulatory Program					
Regulatory program Regulating body Date ROD issued Operational constraints			Federal permits State permits Local permits Permit restrictions		
Project Design Factors					
General dredge type Specific dredge type Dredge expert used in planning Contractor bid package Type of payment Contractor selection criteria Contractor plans and specs Problems encountered			Dewatering required (equip.) Effluent treatment required (equip.) Silt curtain/barrier required Hours of operation (hours, days) Daily dredge volume (t. solids) Daily water volume (liters/gals) Percent solids Overdredge planned		
Material Treatment and Disposal					
General disposal alternative Specific disposal alternative Beneficial use (yes/no) Permit restrictions Operational constraints Material transport type Landfill location/capacity Landfill monitoring			Hours of operation/day Volume received (liters/gals) Solids produced (meters/cys) Chem. analysis of treatment material Water treatment - size/capacity/filters Water treatment - vol. sand/charcoal Frequency of filter replacement		
Baseline Monitoring			*Condition/Progress Monitoring*		
Physical Chemical Biological			Physical Chemical Biological Duration Distance from operation Modifications Distance from operation Exceedances handled Health and safety concerns		
Post-dredge Monitoring					
Physical Chemical Biological # of years planned # of years actual					

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Bayou Bonfouca Slidell, Louisiana	PAHs	Lake Pontchartrain	Contaminated sediment found from 2.6 to 17 ft thick along 4,000-ft-long stretch of the bayou. Very shallow with standing water.	Designated as a Superfund site from former wood treating facility. Observed impact to fish; posted fish consumption advisories, but partially rescinded in 1998.
Black River Northwest Ohio	PAHs	southern Lake Erie	Freshwater tributary to southern Lake Erie.	Designated as a Great Lakes area of concern (AOC) from former steel facility, and effluent waste. Observed impact in aquatic organisms. Fish consumption advisories rescinded in 1997.
Collingwood Harbour Ontario, Canada	copper	Lake Huron	Dredge area is 2.45 acres surrounded by wetlands and shipyards. Shallow water and soft silts (2 ft thick) over clay then bedrock.	Soft surface sediments exceeded Ontario's chemical guidelines for protection of sediment quality. Moderately contaminated, but no open-water disposal.
Ford Outfall/River Raisin Monroe, Michigan	PCBs	River Raisin to Lake Erie	The hotspot around Ford Outfall is located within the larger River Raisin AOC. It is moderately sloped down to the main navigation channel with very soft silt (2 ft thick) over stiff clay (9 ft thick) over hardpan.	Designated as a Great Lakes AOC from motor plant industrial discharges. Observed impact to sediments and biota; posted fish consumption advisories. Emergency Superfund removal for source control of hotspot.
GM Foundry/St. Lawrence River Massena, New York	PCBs	St. Lawrence River	Entire study area includes 62,000 cy of sediments from the St. Lawrence River, Raquette River, and Turtle Cove. This focused St. Lawrence River project dredged approx. 13,800 cy (11 acres) located on a shallow shelf of the St. Lawrence River consisting of soft silt/sand over hardpan. Remediation of the Raquette River and Turtle Cove are planned.	Designated as a Superfund site from industrial discharges. Observed impacts to sediment and biota; posted fish consumption advisories.
Grasse River Massena, New York (pilot)	PCBs	St. Lawrence River	Entire study area (AOC) encompasses an 8.5-mile stretch of river. The pilot dredge project was a hotspot approx. 1 acre in size, in 2 to 14 ft of water within a larger study area. Substrate consists of soft sediment with loose cobbles over hardpan.	Designated as voluntary cleanup by ALCOA under Superfund from aluminum plant discharges. Sediments determined as unacceptable risk to environment. Posted fish consumption advisories.
Lake Jarnsjon Sweden	PCBs	Eman River to Baltic Sea	Entire study area (and dredge area) is a shallow 63-acre lake located along the Eman River (5- to 8-ft depth). Contamination was found across the lake in soft sediments up to 6 ft thick.	The lake was designated as a continuing source of contamination to the river sediments from historic paper mills and other industries by the Swedish EPA. Sediments were an unacceptable risk to aquatic organisms.

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Lower Fox River Deposit N Kimberly, Wisconsin	PCBs	Fox River to Green Bay	The hotspot deposit is contained with the larger 39-mile Fox River AOC. Dredge area is 3 acres size, avg. 8-ft water depth, and 3-ft-thick soft sediments over bedrock.	Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Lower Fox River SMU 56/57 Wisconsin	PCBs	Fox River to Green Bay	The demonstration project is contained within the larger 39-mile Fox River AOC. Dredge area is 9 acres in size, avg. water depth 2 to 14 ft, and avg. 10 ft soft sediment over clay.	Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Manistique River Manistique, Michigan	PCBs	Lake Michigan	Entire study area extends 1.7 miles of river and a 97-acre harbor. Dredge area was a 15-acre hotspot in the harbor and several nearshore areas of the river in water depths of 15 to 20 ft.	Designated as a Superfund site from paper mills and other industrial discharges. Observed impact to fish; posted fish consumption advisories.
Marathon Battery Massena, New York (Areas I and III)	cadmium	Hudson River	Entire study area includes 340 acres of marshes and tidal flats, and over 200 acres of coves designated in 3 operable units. Areas are very shallow (5-ft depth) and tidally-influenced. Substrate is soft clay(1 ft thick) over clayey hardpan.	Designated as a Superfund site from battery manufacturing discharges. Observed impact to sediments and biota; posted fish consumption advisories.
Minamata Bay Kyushu, Japan	mercury	Yatsushiso Sea	The project reached dredging of 1,025,000 cy. Of contaminated sediment from 373 acres of a marine bay. A 143-acre reclamation area of isolated dredged material and an additional 950,000 cy of contaminated sediment. Dredge depth was up to 7 ft and water depths were up to 50 ft.	The bay posed serious risk to human health through ingestion of fish and shellfish. Contamination resulted in permanent health effects in several thousand people, the death of over 100 people, and eventual fish consumption restriction.
New Bedford Harbor Bristol County, Massachusetts	PCBs	Buzzards Bay	Entire study area includes 17, 950 acres of Acushnet River, upper and lower harbor, and Buzzards Bay sediments. The dredge area was a 5-acre hotspot removal project in the upper harbor. Substrate consists of soft sandy silt up to 4 ft thick.	Designated as a Superfund site from electronics manufacturing discharges. Observed impacts to sediments and biota; posted fish consumption advisories.
Port of Portland T4 Pencil Pitch Portland, Oregon	PAHs	Willamette River to Columbia River	Terminal 4 is an active port facility along the shorelines of the Willamette River. Area is acquiescent with limited disturbance from currents. Dredge area was in Slip 3 and underpier areas, with pencil pitch contained within the upper 15 cm.	Designated for cleanup as source control from off-loading spills of pencil pitch (coal tar) from vessels. Observed sediment concentrations and toxicity above state standards. Entire river is an AOC and currently under investigation; posted fish consumption advisories.

Table 3 Site Description and Statement of the Problem for Selected Projects

Project	Major Contam.	Receiving Water Body	Site Description	Statement of Problem
Port of Vancouver Copper Spill Vancouver, Washington	copper	Columbia River	Dredge area covers 0.8 acre along the shore slopes of the river in 5 to 40 ft of water. Substrate consists of slightly silty sand with contamination contained in the upper 18 cm.	Designated for cleanup as source control from copper spill associated with off-loading activities. Observed sediment concentrations and toxicity above state standards. Posted fish consumption advisories for lower river.
Puget Sound Naval Shipyard Pier D Bremerton, Washington	PAHs	Sinclair Inlet to Puget Sound	Dredge project area is approx. 7.2 acres to 9-ft depth below mudline in 43 ft of water. Substrate consists of soft silt and sand over dense sand (no hardpan). Area is tidally-influenced with weak tidal currents.	Project area designated for cleanup under MTCA and CERCLA from shipyard construction activities. Selected sediments within the operable unit needed immediate removal to expand vessel draft depths; however, sediment concentrations and toxicity measured above state standards.
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	PCBs	Lake Michigan	Entire study area includes 13 miles of upper, lower, and middle river sections and the harbor. Dredge area encompassed 18 small hotspots in the upper river section with avg. water depth of 2 to 4 ft.	Designated as a Superfund site from die-casting and other activities. Observed impacts to sediments and biota; posted fish consumption advisories.
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	arsenic	Commencement Bay to Puget Sound	Project area is 52 acres with an avg. water depth of 25 ft. Substrate consists of soft silty sand with renewed deposition from Puyallup River. Area is tidally-influenced.	Designated a problem area within the Commencement Bay/Nearshore Tideflat Superfund Site from multiple sources. Observed impact to sediments and biota; posted fish consumption advisories. Remedy was a partial cleanup and navigational dredging project.
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	PCBs	Lake Michigan	The harbor is approx. 37 acres with avg. water depths of 14 to 25 ft. The harbor is lined by A 20-ft sheetpile wall. Substrate consists of soft silt (7 ft thick) over sand (4 ft thick) over hardpan.	Designated as a Great Lakes AOC from die-casting discharges. Observed impact to sediments , biota, and community structure. Fish consumption advisories rescinded in 1996.
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	mercury	Puget Sound	Entire study area is a marine embayment of 3 operable units totaling 500 acres and avg. water depths of 10 to 20 ft. Dredge area for OU-3 included tidally-influenced soft silt to gravelly sand with buried timber piles (minimal currents). OU-2 was capped.	Designated as a Superfund site from historical shipbuilding and wood treating activities. Observed impacts to sediment and biota; posted fish consumption advisories.

Table 4 Summary of Fish Advisories for Case Study Projects

Project	Status	Advisory Number	Extent	Pollutant	Number of Species/ Population	Issued By	Date Rescinded
Bayou Bonfouca, Louisiana	Rescinded	170	(7 mi) [040907]	Creosote	all fish: NCGP	State	12/10/1998
Black River, Ohio	Active	781	31st St. Bridge, Sheffield to Lake Erie	PCBs (Total)	brown bullhead, common carp, freshwater drum: RGP	State	NA
	Rescinded	781	31st St. Bridge, Sheffield to Lake Erie	PAHs	all fish: NCGP	State	6/30/1997
Collingwood Harbour, Ontario	Active	11856	Collingwood Harbour- harbor area only	Mercury	smallmouth bass, white sucker: UC	Province	NA
					yellow perch, walleye: UC, RGP		
Ford Outfall, Raisin River, Michigan	Active	279	Below Monroe Dam	PCBs (Total)	common carp: NCSP, NCGP	State	NA
					white bass: RGP, RSP, NCGP, NCSP		
GM Foundry, St. Lawrence River, New York	Active	748	Entire River	PCBs (Total), Mirex, Dioxins	all fish: NCSP	State	NA
					American eel, brown trout, channel catfish, Chinook salmon, common carp, lake trout: NCGP		
					brown trout, Coho salmon, rainbow trout, white perch: RGP		
		11833	St. Lawrence River from East of Iroquois to Cornwall	Mercury	American eel, black crappie, black perch, brown bullhead, northern pike, rock bass, smallmouth bass, walleye, white perch, yellow perch, yellow sucker: UC	Province	NA
					American eel, northern pike, rock bass, smallmouth bass, walleye: RGP		
					smallmouth bass: NCGP		
				PCBs (Total), Dioxins	carp: UC, RGP		
		11834	St. Lawrence River from East of Cornwall to Quebec Border	Mercury	brown bullhead, pumpkinseed sunfish, redhorse, rock bass, yellow perch: UC	Province	NA
					northern pike, smallmouth bass, walleye, white sucker: UC, RGP		
				PCBs (Total)	channel catfish: NCGP, NCSP, RGP		
Grasse River, New York	Active	2108	Mouth to Massena Power Canal (St. Lawrence County)	PCBs (Total)	all fish: NCSP, NCGP	State	NA
Green River, Wisconsin	Rescinded	915	Great Lake	PCBs	carp: NCGP	State	no date given
Hudson River, New York	Rescinded	3513	Niagara Mohawk Boat Launch down to Sherman Island Dam	PCBs	all fish: NCGP, NCSP, RGP	State	1/1/1998
Lake Michigan, Michigan	Rescinded	218	Little Bay de Loc- including Tributaries	PCBs	salmon, smelt, trout, yellow perch: RGP	Federal	4/1/1998
					brown trout: NCGP		
Lower Fox River, Deposit N, Wisconsin	Active	882	From mouth at Green Bay up to De Pere Dam	PCBs (Total)	12 species: RGP, RSP, NCGP, NCSP	State	NA

Table 4 Summary of Fish Advisories for Case Study Projects

Project	Status	Advisory Number	Extent	Pollutant	Number of Species/ Population	Issued By	Date Rescinded
Manistique River, Michigan	Active	219	Schoolcraft Co. Upstream of dam at Manistique	Mercury	northern pike: RGP, RSP	State	NA
		248	Schoolcraft Co. downstream from M-94/Old U.S. 2	PCBs (Total)	common carp: NCGP, NCSP, RSP	State	
Marathon Battery, New York	Active	3519	Bridge at Catskill South to and including upper bay of New York Harbor	PCBs (Total)	14 species: RGP all fish: NCSP shellfish: NCGP	State	NA
				Cadmium	shellfish: RGP, NCGP		
Menominee River, Michigan	Rescinded	3347	Below first dam	PCBs	bass, pike, salmon, trout, walleye: NCGP	State	1/1/1998
Milwaukee River, Wisconsin	Rescinded	892	Estuary to Estabrook Falls	PCBs	catfish: NCGP	State	no date given
Minamata Bay, Japan	Rescinded	NA	All Minamata Bay	Mercury	all fish shellfish	Ministry of Health and Welfare	10/1/1997
New Bedford Harbor, Massachusetts	Active	4948	NA	PCBs (Total)	shellfish: NCGP all bottomfish, American eel, flounder, scup, tautog: NCGP, NCSP	State	NA
		4949	NA	PCBs (Total)	shellfish: NCSP, NCGP	State	NA
Ohio River, Ohio	Rescinded	2015	All waters	PCBs	bass, carp: NCGP	State	6/30/1997
Old North Harbor, Waukegan, Illinois	Rescinded	2150	NA	PCBs, Chlordane	alewise, carp: NCGP	State	12/31/1996
Bremerton Shipyard, Pier D, Sinclair Inlet, Washington	Active	4243	Port Washington narrows west to Gorst	PAHs Metals	all bottomfish, rockfish, shellfish: NCGP	Local Health Dept.	NA
Port of Portland, Terminal 4, Oregon	Active	4573	Willamette River to Eugene	Mercury	largemouth bass, smallmouth bass, squawfish: RGP, RSP	State	NA
Port of Vancouver, Lower Columbia River, Washington	Active	4570	Length of the lower Columbia River from Bonneville Dam to the Pacific Ocean	PCBs (Total), DDT, Dioxins	common carp, largescale sucker, peamouth chub: RSP, RGP	State	NA
Sheboygan River and Harbor, Wisconsin	Active	890	From the dam at Sheboygan Falls to the mouth	PCBs (Total)	12 species: RSP, RGP, NCGP, NCSP	State	NA
Sitcum Waterway/Milwaukee Fill, Commencement Bay, Washington	Active	4246	Industrially developed waterways at South end	PCBs (Total) Tetrachloro-ethylene	all bottomfish, shellfish: NCGP	Local Health	NA
Thunder Bay River, Michigan	Rescinded	1297	Upstream to first dam	PCBs	carp: NCSP	State	1/1/1998
Thunder Bay, Lake Huron, Michigan	Rescinded	4354	Thunder Bay	PCBs	walleye: RGP	Federal	4/1/1998
Waukegan Harbor, Outboard Marine, Illinois	Active	105	977,000 acres	Chlordane	lake trout: NCGP	State	NA
				PCBs (Total)	catfish, common carp, lake trout: NCGP brown trout, Chinook salmon, Coho salmon, lake trout: RGP		
	Rescinded	105	977,000 acres	PCBs (Total)	brown trout, Chinook salmon: NCGP brown trout, Chinook salmon, Coho salmon, lake trout: NCSP	State	12/31/1996
Wyckoff/West Eagle Harbor, Washington	Active	3339	Bainbridge Island	PAHs Mercury	shellfish, all bottomfish: NCGP	State	NA

Notes:

Data obtained from the Listing of Fish and Wildlife Advisories Website: http://www.fish.rti.org/scripts/esrimp.dll?name=Listing&Cmd=Map. Last updated December 31, 1998. Query of database in April 2000.

Lower Fox River data obtained from Wisconsin Department of Natural Resources Website. Last queried May 2000

NA - Not applicable.

NCGP - No consumption, general population.

NCSP - No consumption, subpopulation.

RGP - Restricted, general population.

RSP - Restricted, subpopulation.

Table 5 Cleanup/Target Goals and Residual Chemical Concentrations In Surface Sediments

Project	Major Cont.	Approx. Dredge Depth (ft)	Detected Concentration in Surface Sediments Max (ppm)	Detected Concentration in Surface Sediments Avg. (ppm)	Cleanup Target Goal	Residual Concentration in Surface Sediment Post-Dredging Max (ppm)	Residual Concentration in Surface Sediment Post-Dredging Avg. (ppm)	% Reduction of Max.	% Reduction of Avg.	Factors Influencing Outcome
Bayou Bonfouca, Louisiana (wet wt)	PAHs	3–17	60,000	—	depth verify = 1,300 ppm	47	achieved target depth	100%	—	Unknown
Black River, Ohio	PAHs	—	8.8	—	horizon	9.8	—	-11%	—	Long-term goals achieved in reduction of fish liver deformities.
Collingwood Harbour, Canada	copper	1.6	61	—	100% mass verify = tox	NA	NA		—	Chemical results not available, but claim significant reduction.
Ford Outfall/River Raisin, Michigan	PCBs	6	42,167	—	horizon verify = 10 ppm	20	~5	100%	—	80% of dredge cells met criteria.
GM Foundry, New York (pilot)	PCBs	—	5,700		1 ppm	27	—	100%	—	83% of dredge cells met criteria; cap placed over residuals.
Grasse River, New York	PCBs	2.5	11,000	1109	30% mass	260	75	98%	93%	Boulders prevented removal of residuals.
Lake Jarnsjon, Sweden	PCBs	5	30	5	0.5 ppm	0.85	0.06	97%	99%	Included overdredge material.
LowerFox River Deposit N, Wisconsin	PCBs	3	186	—	to depth	43	—	77%	—	Divers collected verification samples from cracks/crevices from lack of sediment.
LowerFox River SMU 56/57, Wisconsin	PCBs	10	710	—	elevation	17 (28)	—	94%	—	Demobilized from site before reaching design depth.
Manistique River, Michigan	PCBs	—	4,200	—	10 ppm	1300	—	69%	—	Repeated dredging to remove residuals on bedrock.
Marathon Battery, New York (Area I)	cadmium	1	171,000	27,799	100 ppm (Area I)	90	12	100%	100%	Background = 10 ppm.
Marathon Battery, New York (Area III)	cadmium	1	2,700	179	10 ppm (Area III)	50	14	98%	92%	Background = 10 ppm.
Minamata Bay, Japan	mercury	0-7	7,600	—	25 ppm	90	9.6	99%	—	Real-time bathymetry measurements
New Bedford Harbor, Massachusetts	PCBs	3.5	100,000	—	4,000 ppm	2,068	124	98%	—	Sampled the upper 2 cm.
Port of Portland Terminal 4, Oregon	PAHs	1	230,000; or 23%	—	mass 0.5% (wt)	0.0004	—	100%	100%	
Port of Vancouver, Washington	copper	2	70,000	—	depth verify = 1,300 ppm	5,240	1,200	93%	—	0.5 ft of overdredge.
PSNS Pier D, Washington	PAHs	8		—	elevation	NA	achieved target elevation		—	Combined navigational dredging; 1 ft overdredge.
Sheboygan River, Wisconsin (pilot)	PCBs	2	4,500	—	mass verify = 686 ppm	295	—	93%	—	Pilot cap placed over residuals.
Sitcum Waterway, Washington	arsenic	5	291	—	depth	0	achieved target depth	100%	—	Removed additional material for navigational depth; overdredge.
Waukegan Harbor/Outboard, Illinois (Upper Harbor)	PCBs	7	460	—	50 ppm	8.9	6.4	98%	—	Slip 3 sediments (<500 ppm) were left in-place (CAD site); maximum concentration was 16,400.
Wyckoff/West Eagle Harbor, Washington	mercury	3	32	—	5 ppm Hg	4	achieved target criteria	88%	—	Design plan called for capping of non-dredged areas; 1 ft overdredge.

Table 6 Contaminated Sediment Dredge Removal Volumes and Mass

Project	Major Cont.	Total Cont. in Prism Volume (cy)	Total Cont. in Prism Mass (kg)	Proposed Volume (cy)	Proposed Mass (kg)	Actual Removal Volume (cy)	Actual Removal Mass (kg)	Remaining in Scoped Area Volume (cy)	Remaining in Scoped Area Mass (kg)	% Reduction Volume	% Reduction Mass	Factors Influencing Outcome
Bayou Bonfouca, Louisiana	PAHs	—	—	150,000	—	169,000	—	residual	—	113%	—	Unknown.
Black River, Ohio	PAHs	—	—	49,000	—	49,000	—	residual	—	100%	—	Unknown.
Collingwood Harbour, Canada	metals, PCBs	—	—	3,896	—	3,896	—	residual	—	100%	—	Dredged to underlying silt layer (clean).
Ford Outfall/River Raisin, Michigan	PCBs	—	—	28,000	—	28,000	—	residual	—	100%	—	Dredged to bedrock/hardpan.
GM Foundry, New York (pilot)	PCBs	—	—	13,800	—	27,000	—	residual capped	—	196%	—	Elevated residuals in Quadrant 3 on bedrock.
Grasse River, New York (pilot)	PCBs	—	—	3,500	—	2,600	—	550	—	74%	—	Boulders prevented removal of residuals.
Lake Jarnsjon, Sweden	PCBs	157,000	397	157,000	397	196,000	394	residual	2.9	125%	99%	Included overdredge material.
lower Fox River Deposit N, Wisconsin	PCBs	11,000	59	8,175	11	8,175	—	residual	—	100%	82%	Dredged to within 3 in of bedrock.
Lower Fox River SMU 56/57, Wisconsin	PCBs	80,000	—	80,000	—	31,346	—	49,000	—	39%	—	Demobilized from site before reaching design depth.
Manistique River, Michigan	PCBs	—	14,000	120,000	—	>120,000	—	residual	—	100%	—	Repeated dredging to remove residuals on bedrock.
Marathon Battery, New York	cadmium	100,200	50,000	86,000	—	100,200	—	residual	—	117%	—	Inaccurate initial estimate; dredge design depth of 1 ft.
Minamata Bay, Japan	mercury	—	—	1,025,000?		1,025,000?	—	residual	—	100%	—	Unknown.
New Bedford Harbor, Massachusetts (Hotspot)	PCBs	—	—	10,000	`	14,000	—	residual	—	140%	50%	Hotspot removal
Port of Portland Terminal 4, Oregon	PAHs, pencil pitch	35,000	10,654	35,000	10,654	35,000	—	residual	1,614	100%	85%	Difficult access under piers and riprap slopes.
Port of Vancouver, Washington	copper	1,900	—	1,900	—	1,900	—	unknown	—	100%	—	0.5 ft overdredge.
PSNS Pier D, Washington (pilot)	PAHs, PCBs	53,400	—	105,000	45%	105,000	—	residual	—	100%	—	Removed additional material for navigational depth; 1 ft overdredge.
Sheboygan River, Wisconsin (pilot)	PCBs	—	—	3,800	—	3,800	—	residual	—	100%	—	Few expectations.
Sitcum Waterway, Washington	metals, PAHs	127,500	—	425,000	—	425,000	—	residual	—	100%	—	Removed additional material for navigational depth; overdredge.
Waukegan Harbor/Outboard, Illinois	PCBs	—	300,000	38,300	136,000	38,300	136,000	residual	900	100%	96%	Sediments within Slip 3 CAD site (<500 ppm) were left in-place.
Wyckoff/West Eagle Harbor, Washington	mercury	9,200	—	3,650	—	3,650	—	capped	—	100%	—	1 ft overdredge.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Bayou Bonfouca Slidell, Louisiana	PAHs	169,000	Mechanical by crane	Wet excavation using a mechanical custom-designed crane-mounted clamshell bucket on a barge. Material was pipelined to a holding pond then to an on-site incineration system. Leftover ash was placed in an on-site landfill. Full-scale remediation of the 4,000-ft-long project area.	Sheetpile walls surrounding the areas were left in-place to minimize disturbance of sediments and house foundations.
Black River Northwest Ohio	PAHs	49,700	Mechanical	Wet excavation using a mechanical clamshell bucket and hydraulic cutterhead dredge. Material was placed in an on-site CDF and capped. Full-scale remediation of study area.	Switched to a cutterhead dredge when bucket could not close from presence of debris.
Collingwood Harbour Ontario, Canada	copper	3,896	Hydraulic Pneuma pump	Wet excavation using a hydraulic Pneuma airlift pump. Material was pipelined to an onshore CDF. Dredged the contaminated surficial soft silt overlying a blue clay layer. Full-scale remediation of project area after an initial pilot study was conducted.	Large debris would plug the Pneuma pump cylinder.
Ford Outfall/River Raisin Monroe, Michigan	PCBs	28,500	Mechanical	Wet excavation using mechanical closed clamshell buckets with a barge and scow. Material was treated and transported to an on-site CDF. This was a focused removal project of hotspot sediments near the Ford Outfall. Cleanup criteria designed to be protective of biota. Remedy of the River Raisin is planned.	Passing cargo vessel generated prop wash and disturbed silt curtains. Sediment resuspension/settling on top of hardpan.
GM Foundry/St. Lawrence River Massena, New York	PCBs	27,000	Hydraulic horizontal auger	Wet excavation using a hydraulic horizontal auger dredge (dry excavation of nearshore areas). Boulders and debris were excavated before dredging. Material was pipelined to a settling basin and stored temporarily. Treated material will be sent to an on/off-site CDF depending upon the levels. Turtle Cove was not dredged; possible continued source. Full-scale remediation project of the St. Lawrence AOC. Remediation of Raquette River and Turtle Cove discussed in 1999 ROD. Capped residuals.	River currents required switch from silt curtains to sheetpile walls. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove.
Grasse River Massena, New York (pilot)	PCBs	3,175	Hydraulic horizontal auger	Wet excavation using a hydraulic horizontal auger dredge (dry excavation around ALCOA outfall). Boulders were excavated prior to dredging. Material was dewatered and transferred to an upland landfill. Voluntary dredge cleanup project of hotspot area around outfall by ALCOA (25% of total mass).	550 cy of sediment left in-place because of boulders and cobbles. Silt curtain switched from screws to bottom weights.
Lake Jarnsjon Sweden	PCBs	157,000	Hydraulic horizontal auger [1]	Wet excavation using a hydraulic auger dredge and mechanical bucket for denser material. Material was dewatered and placed in nearby landfill. Full-scale remediation of lake sediments.	Pockets of dense sand and gravel required switch of dredge equipment.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Fox River Deposit N Kimberly, Wisconsin (pilot)	PCBs	8,175	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge. Material pipelined to an on-site treatment area. Dewatered material transported to off-site landfills. A pilot demonstration project to assist selection of remedial technologies for Lower Fox River project.	Winter shutdown conditions.
Fox River SMU 56/57 Wisconsin (pilot)	PCBs	31,346	Hydraulic horizontal auger	Wet excavation using hydraulic cutterhead and horizontal auger dredge. Material was dewatered and placed in off-site landfill. Was a demonstration project to gather information for Lower Fox River project.	Winter shutdown conditions.
Manistique River Manistique, Michigan	PCBs	120,000	Hydraulic cutterhead [1]	Wet excavation using hydraulic cutterhead dredges customized for the project. Material was pipelined to on-site treatment and settling tanks, then transported to off-site landfills. Full-scale remediation to 95% mass removal of sediments above chemical criteria.	Many site conditions compromised implementation: buried slab-wood and debris, winter weather and wind, and excavation to bedrock.
Marathon Battery Massena, New York (Areas I and III)	cadmium	100,200	Hydraulic horizontal auger [1]	Wet excavation of coves and ponds using a hydraulic horizontal auger and mechanical clamshell dredges (dry excavation of marshes). Material was placed in on-site settling basin, fixated then transported to off-site landfills. Full-scale remediation to 95% mass removal of sediment above chemical criteria.	Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.
Minamata Bay Japan	mercury	1,025,000	Hydraulic suction	Wet excavation using a hydraulic dredge (no cutterhead). Material pipelined to near shore containment facility which isolated additional contaminated sediment. Full-scale remediation to 100% mass removal of sediment above chemical criteria.	None specified.
New Bedford Harbor Bristol County, Massachusetts (Hotspot)	PCBs	14,000	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge. Material pipelined 1 mile to a temporary CDF. Only a partial mass removal project of upstream sediments (45%) to control ongoing sources and prevent downstream transport during storm events. Modeled for the most benefit for the least cost. Remediation of lower harbor and Buzzards Bay planned.	Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains. Dredging operations/ strategy were adjusted in response to monitoring.
Port of Portland T4 Pencil Pitch Portland, Oregon	PAHs	35,000	Mechanical [1]	Wet excavation using shrouded clamshell bucket and bottom-dump scows. Nearshore areas excavated with airlift pump. Material transported to an in-water CDF. Capping not considered. Full-scale remediation to 100% mass removal of spilled pencil pitch (coal tar).	Difficult to access and dredge underpier and riprapped areas.

Table 7 Summary of Project Designs and Remedial Actions

Project	Major Contam.	Removed Volume (cy)	Dredge Method	Project Design and Implemented Remedy	Problems Encountered
Port of Vancouver Copper Spill Vancouver, Washington	copper	5,000	Hydraulic cutterhead	Wet excavation using a hydraulic cutterhead dredge, with diver assistance in underpier areas. Material pipelined to on-site settling pond then transported to disposal sites located on port property. Full-scale remediation project of 100% mass removal to eliminate source (spilled copper).	The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind.
Puget Sound Naval Shipyard Pier D Bremerton, Washington	PAHs	105,000	Mechanical	Wet excavation using clamshell buckets and dump scows. Material transported to either open-water disposal or off-site landfill. Only a partial cleanup of larger study area implemented by need to increase navigational depths near berths.	None specified.
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	PCBs	3,800	Mechanical	Wet excavation of 18 hotspots using clamshell buckets and land-based backhoes. Material placed in on-site CTF, some hotspots capped. A pilot study with main objective to assist future selection of full-scale remedial alternatives. Mass removal of hotspot sediments above 686 ppm PCBs. Also placed a pilot cap.	Winter shutdown and strong currents. Very shallow areas required backhoes. Permission to access areas from shoreline residents.
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	arsenic	425,000	Hydraulic cutterhead [1]	Wet excavation using hydraulic cutterhead dredges and clamshell buckets for specialized areas. Material placed in an on-site, nearshore CDF used to expand port facilities. Full-scale remediation of waterway combined with a navigational dredge project caused by rapid sedimentation.	Significant debris on underpier armored slopes. Tide swings required horizontal and vertical control maintenance.
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	PCBs	38,300	Hydraulic cutterhead	Wet excavation using hydraulic cutterhead dredge. Material <500 ppm placed directly in nearshore CDF located over the area of highest contamination (Slip 3) minimizing volume requiring excavation. Material >500 ppm stabilized then returned to containment cell. Full-scale remediation of upper harbor.	Activities halted during boating season. CDF required 2 years to consolidate before closure.
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	mercury	3,650	Mechanical	Wet excavation using clamshell buckets and backhoes for underpier areas. Dredged material barged to on-site CDF used to expand ferry terminal facilities. Capped remaining sediments below state cleanup criteria, but still exposure risk. Cap used to enhance natural recovery. Full-scale remediation of OU-3.	Tide swings sloughed exposed sediment, armored areas for protection.

Note:

[1] Used clamshell, backhoe or diver-assisted methods for difficult areas.

Table 8 Containment Barrier System and Water Quality Monitoring Results

Project	Barrier System	Water Quality Monitoring Results
Bayou Bonfouca, Louisiana	silt curtains and oil booms, sheetpile for banks	Not specified.
Black River, Ohio	oil booms	Not specified.
Collingwood Harbour, Canada	unknown	Water quality turbidity criteria met during dredging.
Ford Outfall/River Raisin, Michigan	silt curtains (disturbed from passing ship)	No major exceedances of water quality (turbidity).
GM Foundry/St. Lawrence River, New York	silt curtains then switched to sheetpile wall	After modification to sheetpile wall, minimal turbidity exceedances which corresponded to a storm event. No PCB chemical exceedances.
Grasse River, New York (pilot)	silt curtains	Turbidity exceeded during boulder removal, but not 2,300 ft downstream. No PCB chemical exceedances. Caged fish had elevated PCBs during dredging.
Lake Jarnsjon, Sweden	silt curtains	No significant exceedances of water quality (turbidity).
Fox River Deposit N, Wisconsin	HDPE plastic barrier	No exceedances of water quality (turbidity).
Fox River SMU 56/57, Wisconsin	silt curtains	No exceedances of water quality (turbidity).
Manistique River, Michigan	silt curtains and oil booms, sheetpile walls for certain areas	Unknown water quality results. Caged fish had higher than background concentrations but no statistical differences between during and baseline conditions.
Marathon Battery, New York	silt curtains, earthen berm for dry excavation	Unknown.
Minamata Bay, Japan	none	No major exceedances of water quality
New Bedford Harbor, Massachusetts	silt curtains, but removed; surface booms and shroud on dredge	PCB mass transport was monitored. Unknown if turbidity was monitored, however, water column acute toxicity had minimal exceedances compared to reference. Deployed mussels were within seasonal variability.
Port of Portland T4 Pencil Pitch, Oregon	unsure if silt curtain was installed	Turbidity was within normal range of variability for the river. No exceedances of pencil pitch chemical criteria.
Port of Vancouver Copper Spill, Washington	none	No copper chemical exceedances detected at midpoint or downstream boundary of dilution zone.
PSNS Pier D, Washington	oil booms	Water quality samples were collected but results were not available for review.
Sheboygan River, Wisconsin (pilot)	silt curtains (occasionally toppled from currents)	Some turbidity and chemical water quality exceedances observed downstream. Caged fish had higher concentrations during dredging.
Sitcum Waterway, Washington	none	No significant exceedances of water quality (turbidity) measured 300 ft from dredge.
Waukegan Harbor/Outboard, Illinois (Upper Harbor)	silt curtains, sheetpile wall around CDF	No water quality exceedances measured during dredging (turbidity).
Wyckoff/West Eagle Harbor, Washington (OU-3)	silt curtains	Turbidity exceedances were within compliance criteria (less than 20% exceedances at 200-ft mixing zone boundary).

Table 9 Baseline Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca, Louisiana			◆		◆	◆	◆						
Black River, Ohio				◆								◆	
Collingwood Harbour, Ontario	◆		◆	◆				◆	◆				
Ford Outfall/River Raisin, Michigan	◆				◆		◆			◆			
Fox River Deposit N, Wisconsin	◆	◆		◆						◆			
Fox River SMU 56/57, Wisconsin	◆		◆		◆					◆			
GM Foundry/St. Lawrence River, New York	◆			◆[1]			◆			◆			
Grasse River, New York	◆		◆		◆		◆	◆		◆			
Lake Jarnsjon, Sweden	◆	◆	◆		◆					◆		◆	
Manistique River, Michigan	◆		◆[4]		◆					◆			◆[2]
Marathon Battery, New York				◆						◆			◆[3]
Minamata Bay, Japan	◆		◆	◆[1]						◆			
New Bedford Harbor, Massachusetts	◆			◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch, Oregon	◆	◆		◆	◆				◆		◆		
Port of Vancouver Copper Spill, Washington	◆			◆	◆			◆	◆				
Puget Sound Naval Shipyard Pier D, Washington	◆				◆				◆	◆			
Sheboygan River and Harbor, Wisconsin	◆		◆		◆					◆			
Sitcum Waterway Commencement Bay, Washington	◆	◆	◆		◆					◆			
Waukegan Harbor/Outboard Marine, Illinois	◆			◆					◆	◆			
Wycoff/West Eagle Harbor Operable Unit, Washington	◆		◆	◆[1]				◆					
Total	17	4	10	11	11	1	4	5	6	14	1	2	2

Notes:

[1] Sampling method was not specified as surface or core.
[2] Chemical analysis of material collected in sediment traps.
[3] Biological analysis of vegetation, benthic algae, phtoplankton, and zooplankton tissues.
[4] Available from published sources.

Table 10 Environmental Monitoring Program Measurements During Implementation

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana							◆						
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada		◆											
Ford Outfall/River Raisin - Monroe, Michigan		◆	◆				◆						
Fox River Deposit N - Kimberly, Wisconsin		◆					◆						
Fox River SMU 56/57 - Wisconsin		◆	◆				◆						
GM Foundry/St. Lawrence River - Massena, New York		◆	◆				◆						
Grasse River - Massena, New York	◆	◆	◆				◆			◆			
Lake Jarnsjon - Sweden		◆	◆				◆					◆	
Manistique River - Manistique, Michigan	◆	◆	◆	◆	◆					◆			◆[1]
Marathon Battery - Cold Springs, New York													
Minamata Bay - Minamata City, Japan	◆	◆	◆							◆			
New Bedford Harbor - Bristol County, Massachusetts							◆		◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon	◆	◆	◆	◆									
Port of Vancouver Copper Spill - Vancouver, Washington		◆	◆	◆[2]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington		◆											
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin		◆	◆							◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington	◆	◆	◆										
Waukegan Harbor/Outboard Marine - Waukegan, Illinois	◆	◆					◆						
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington	◆	◆	◆										
Total	7	16	12	4	1	0	9	0	1	5	0	2	1

Notes:

[1] Chemical analysis of material collected in sediment traps.

[2] Sampling method was not specified as surface or core.

Table 11 Post-dredging Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana	◆												
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada	◆			◆				◆	◆				
Ford Outfall/River Raisin - Monroe, Michigan	◆			◆									
Fox River Deposit N - Kimberly, Wisconsin	◆			◆									
Fox River SMU 56/57 - Wisconsin	◆		◆		◆								
GM Foundry/St. Lawrence River - Massena, New York	◆			◆[1]									
Grasse River - Massena, New York	◆	◆	◆		◆					◆			
Lake Jarnsjon - Sweden		◆	◆		◆	◆				◆		◆	
Manistique River - Manistique, Michigan [2]													
Marathon Battery - Cold Springs, New York				◆[3]									
Minamata Bay - Minamata City, Japan	◆			◆[3]						◆			
New Bedford Harbor - Bristol County, Massachusetts	◆			◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon	◆			◆									
Port of Vancouver Copper Spill - Vancouver, Washington	◆			◆[3]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington	◆			◆									
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin			◆	◆						◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington	◆			◆				◆	◆				
Waukegan Harbor/Outboard Marine - Waukegan, Illinois													
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington	◆			◆									
Total	14	2	4	14	3	1	0	3	3	5	0	2	0

Notes:

1 Surface sediment samples collected by hand-augered coring.

2 Post-dredging monitoring data is not yet available.

3 Sampling method was not specified as surface or core.

Table 12 Long-term Environmental Monitoring Program Measurements

Dredging Project	Physical		Chemical					Biological					Other
	Bathymetry	Surface Water	Surface Water	Surface Sediment	Sediment Cores	Ground Water	Air	Benthic Abundance	Invertebrate Toxicity	Fish/Shellfish Tissue	Fish/Shellfish Toxicity	Fish/Shellfish Physiological Responses	Additional Monitoring
Bayou Bonfouca - Slidell, Louisiana			◆		◆					◆			
Black River - Northwest Ohio				◆								◆	
Collingwood Harbour - Ontario, Canada								◆					
Ford Outfall/River Raisin - Monroe, Michigan					◆					◆			
Fox River Deposit N - Kimberly, Wisconsin [1]													
Fox River SMU 56/57 - Wisconsin [1]													
GM Foundry/St. Lawrence River - Massena, New York										◆			
Grasse River - Massena, New York								◆					
Lake Jarnsjon - Sweden [2]													
Manistique River - Manistique, Michigan [3]													
Marathon Battery - Cold Springs, New York				◆				◆					◆[6]
Minamata Bay - Minamata City, Japan										◆			
New Bedford Harbor - Bristol County, Massachusetts				◆				◆	◆	◆			
Port of Portland T4 Pencil Pitch - Portland, Oregon													
Port of Vancouver Copper Spill - Vancouver, Washington				◆[5]									
Puget Sound Naval Shipyard Pier D - Bremerton, Washington				◆									
Sheboygan River and Harbor - Sheboygan Falls, Wisconsin [4]										◆			
Sitcum Waterway Commencement Bay/Nearshore Tideflat - Tacoma, Washington				◆									
Waukegan Harbor/Outboard Marine - Waukegan, Illinois				◆					◆	◆			
Wycoff/West Eagle Harbor Operable Unit - Bainbridge Island, Washington								◆					
Total	0	0	1	7	2	0	0	5	2	7	0	1	1

Notes:

1 No long-term monitoring program has not been developed at this time.
2 No long-term monitoring data was available for review.
3 The long-term monitoring program was not yet available at the time of this review.
4 Additional long-term monitoring will be included along with full-scale remediation.
5 Sampling method was not specified as surface or core.
6 Biological analysis of vegetation, benthic algae, and bird tissues.

Table 13 Summary of Dredging and Disposal Costs

Project	Dredging			Treatment and Disposal Method	Additional Expenses	Total Cost[1]	
	Volume Removed (cy)	Cost per CY	Method			Cost per CY	Total Cost
Bayou Bonfouca Slidell, Louisiana	169,000	$125	Mechanical	Incineration and on-site landfill		$680	$21.1million
Black River Northwest Ohio	49,000	$25	Mechanical	CDF		$83	$5 million
Collingwood Harbour Ontario, Canada	3,896	$34	Hydraulic	CDF		$154 (CAN)	$0.6 million (CAN)
Ford Outfall/River Raisin Monroe, Michigan	28,000	—	Mechanical	On-site landfill		$220	$6 million
Fox River Deposit N Kimberly, Wisconsin (pilot)	27,000	—	Hydraulic cutterhead	Off-site landfill		$525	$4.3 million
Fox River SMU 56/57 Wisconsin (pilot)	2,600	$27	Hydraulic cutterhead	Off-site landfill		$286	$9 million
GM Foundry/St. Lawrence River Massena, New York	196,000	$230	Hydraulic horizontal auger	On-site storage and cap	Placement of cap	$370	$10 million
Grasse River Massena, New York (pilot)	8,175	$450	Hydraulic horizontal auger	Off-site landfill and cap		$1,534	$4.9 million
Lake Jarnsjon Sweden	31,346	—	Mechanical, Hydraulic horizontal auger	Off-site landfill		$40	$6.4 million
Manistique River Manistique, Michigan	>120,000	—	Hydraulic cutterhead	Off-site landfill		$300	$36 million
Marathon Battery Massena, New York (Areas I and III)	100,200	—	Hydraulic horizontal auger	Off-site landfill		$142	$11 million
Minamata Bay Japan	1,025,000?	$40	Hydraulic with suction	Nearshore CDF	New harbor construction	$487	$50 million
New Bedford Harbor Bristol County, Massachusetts (Upper Harbor)	14,000	$124	Hydraulic cutterhead	CDF	Wastewater treatment	$1,430	$20.1 million
Port of Portland T4 Pencil Pitch Portland, Oregon	35,000	$6.20	Mechanical	CAD		NA	NA
Port of Vancouver Copper Spill Vancouver, Washington	1,900	—	Hydraulic cutterhead	On-site landfill		$526	$1 million
Puget Sound Naval Shipyard Pier D Bremerton, Washington	105,000	—	Mechanical	Open-water and CDF		NA	NA
Sheboygan River and Harbor Sheboygan Falls, Wisconsin (pilot)	3,800	$450	Mechanical	On-site LTF		$1,842	$7 million
Sitcum Waterway Commencement Bay/Nearshore Tideflats Tacoma, Washington	425,000	$1.50–$25	Hydraulic cutterhead	Nearshore CDF	Habitat	$6.20	$17.5 million
Waukegan Harbor/Outboard Marine Waukegan, Illinois (Upper Harbor)	38,300	—	Hydraulic cutterhead	Thermal desorption and nearshore CDF		$552	$21 million
Wyckoff/West Eagle Harbor Operable Unit Bainbridge Island, Washington (OU-3)	3,650	—	Mechanical	Nearshore CDF	Habitat	$630	$3.8 million

Note:

[1] Total cost included dredging, disposal, treatment, project planning, and monitoring.

Table 14 Dredging Project Expectations and Outcomes

Project	Dredged Volume (cy)	Year Dredging Completed	Short-term Performance-Based Goal [1]			Long-term Objective [1]				Comments
			Defined Target Goal	Target Achieved	RAO Category	Defined Remedial Action Objective	Achieved	Progress Towards	Variable Results	
Bayou Bonfouca, Louisiana	169,000	1995	chemical	yes	HH	reduce PAH contact (HH)	yes			Advisories rescinded
Black River, Ohio	60,000	1990	horizon	yes	HH	reduce toxicity to biota	yes			Advisories rescinded
Collingwood Harbor, Canada	3,896	1992	mass	NA	E	reduce toxicity to biota	yes			Site redeveloped
Ford Outfall/ River Raisin, Michigan	28,500	1997	horizon	80%, yes	E	reduce PCBs in fish		yes		
Fox River Deposit N, Wisconsin	8,125	1999	depth	yes	M	mass removal			ND	Demonstration project
Fox River SMU 56/57, Wisconsin	50,000	2000	elevation	yes	M	mass removal			ND	Demonstration project
GM Foundry, Massena, New York	27,000	1996	chemical	no	HH	reduce PCBs in fish		yes		
Grasse River, New York - pilot	2,600	1995	mass	yes	M	mass removal			variable	
Lake Jarnsjon, Sweden	196,000	1994	chemical	yes	HH	reduce PCBs in biota	yes			Objectives met
Manistique River, Michigan	72,000	1999	chemical	no	HH	reduce PCBs in fish			variable	
Marathon Battery, New York	100,200	1995	chemical	yes	HH	reduce bio impacts			variable	
Minamata Bay, Japan	1,025,000	1987	chemical	yes	HH	reduce toxicity to HH (HH)	yes			Advisories rescinded
New Bedford Harbor, Massachusetts	14,000	1995	chemical	yes, but 4,000 ppm	HH	reduce PCBs in fish			variable	
Port of Portland Terminal 4, Oregon	35,000	1995	mass	yes	E	reduce toxicity to biota		yes		
Port of Vancouver Copper Spill, Washington	1,900	1990	depth	yes	E	remove all Cu seds		yes		
Pier D, Bremerton Shipyard, Washington	105,000	1995	elevation	yes	M	none			variable	
Sheboygan River, Wisconsin -pilot	3,800	1991	mass	yes	M	mass removal		yes		
Sitcum Waterway, Washington	425,000	1994	depth	yes	E	remove all contaminated sediments	yes			Site delisted
Waukegan Harbor/Outboard Marine, Illinois	38,300	1994	chemical	NV, depth	HH	reduce PCBs in fish		yes		Advisories rescinded, but status unsure
Wykcoff/West Eagle Harbor, Washington	3,650	1997	chemical	yes	E	reduce toxicity to biota		yes		

Notes:

[1] Remedial expectations were defined by the projects themselves.
E - Ecological Health
HH - Human Health
M - Mass
NV - No value available for review.

Table 15 Lessons Learned for Case Studies

Project	Factors Influencing Outcome	Lessons Learned
Bayou Bonfouca, Louisiana	Sheetpile walls surrounding the areas were left in-place to minimize disturbance of sediments and house foundations.	The incineration costs were hugely expensive and the majority of the $55 million costs (dredging was $125/cy). Adequate sediment investigation accurately defined volume of contaminated material and site conditions prior to remediation.
Black River, Ohio	Dredged to hard bottom. Switched to a cutterhead dredge when bucket could not close from presence of debris.	Although PAH concentrations post-project were similar to baseline levels (after plant closure) the incidence of fish liver tumors were <1% after dredging compared to 32% prior to dredging (but after plant closure). Fish consumption advisories lifted.
Collingwood Harbour, Canada	Large debris would plug the Pneuma pump cylinder.	A pilot study was useful in predicting dredging effectiveness. Site was delisted.
Ford Outfall/River Raisin, Michigan (hotspot removal)	Passing cargo vessel disturbed silt curtains. Mechanical Cable Arm dredged below depth of navigational channel resulting in side slope sloughing. Sediment resuspension/settling on top of hardpan.	Dredged to hardpan/bedrock. 80% of dredge cells met chemical criteria. Need to look at design depths relative to surrounding elevations and the potential for sloughing/recontamination of dredge area.
GM Foundry/St. Lawrence River, New York	River currents required switch from silt curtains to sheetpile walls. The silt curtain was poorly designed for river conditions, may have been implementable with different design. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove. Dredged to hardpan.	Despite multiple attempts, elevated concentrations remained in Quadrant 3 requiring a sediment cap. PCB contaminant in the underlying glacial till was suspected. Other quadrants (5 of 6) averaged 5 ppm PCBs post-project (10-fold reduction) but did not achieve target goal of 1 ppm PCBs.
Grasse River, New York (pilot)	550 cy of sediment left in-place because of boulders and cobbles. The extent of these materials was not anticipated. Silt curtain switched from screws to bottom weights.	Horizontal auger did not work well with cobbles. Caged fish located along/outside the perimeter of contaminant system showed elevated PCBs during dredging, but significantly reduced immediately post-project.
Lake Jarnsjon, Sweden	Pockets of dense sand and gravel required switch of dredge equipment (from auger to bucket). Higher sand content required addition of more water for the suction dredge (lower % solids). Designed 0.5 ft of overdredge.	
Lower Fox River Deposit N, Wisconsin	Target goal was to dredge down to within 3 in of bedrock.	Development of realistic target goals helped maximize achievement of risk reduction for a reasonable cost. Plastic HDPE plastic barrier unnecessary to river water quality.
Lower Fox River SMU 56/57, Wisconsin	Demobilized from site before reaching target depth from onset of winter conditions. Actual sediment removal rates were one-third of targeted goal.	Elevated surface sediment verification samples were the result of incomplete dredging (did not reach target depth below PCB hotspot).
Manistique River, Michigan	Many site conditions compromised implementation: buried slab wood and debris, winter weather and wind, and excavation to bedrock.	Repeated dredging to removal residuals on bedrock.

Table 15 Lessons Learned for Case Studies

Project	Factors Influencing Outcome	Lessons Learned
Marathon Battery, New York (Areas I and III)	Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.	Discrete samples exceeded chemical criteria, however, the average concentrations met target goals. Background concentrations were 10 ppm.
Minamata Bay, Japan	Real-time bathymetry measurements during dredging used to gauge completion of dredging to design depth.	Surface sediment criteria easily achieved, however, fish tissue criteria were not met until six years later.
New Bedford Harbor, Massachusetts	Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains. Sampled the upper 2 cm for verification.	Designed as a mass removal project for source control (remove sediments >4,000 ppm PCBs) to prevent downstream transport. Target goal selected based on cost/benefit analysis. Target goal easily achieved. Observed daily low tides and project shutdown in winter (ice). Community opposed incineration. Many monitoring adjusts to comply with criteria, especially air emissions for DNAPL.
Port of Portland T4 Pencil Pitch, Oregon	Difficult to access and dredge underpier and riprapped areas. Combined with navigational dredge project. Designed 1 ft of overdredge.	Even with overdredge designed into project, exceeded chemical criteria in most cells, likely because of contaminated non-dredged areas.
Port of Vancouver Copper Spill, Washington	The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind. Designed 0.5 ft overdredge. No silt curtains installed because of deep water.	The post-project concentration averaged among all dredge cells met the 1.300 ppm copper chemical criteria although some discrete dredge cell measurements exceeded 1,300 ppm.
PSNS Pier D, Washington	Designed 1 ft of overdredge.	Combined navigational and source control dredging project. Chemical criteria was not met in numerous dredge cells, suspect recontamination from areas not dredged but in the AOC.
Sheboygan River, Wisconsin (pilot)	Winter shutdown and strong currents. Very shallow areas required backhoes. Strong currents toppled the silt curtains. Access restrictions from shoreline residents. A pilot cap was placed over residuals in hotspot areas (designed into project).	Sediment probing techniques used to assess sediment thickness underestimated actual volumes of material requiring removal. Dredge equipment was versatile and mobile.
Sitcum Waterway, Washington	Tide swings required horizontal and vertical control maintenance. Combined with a navigational project. Designed 1 ft overdredge.	Underpier areas had significant debris, cables, concrete, and boulders which proved difficult to access and dredge effectively.
Waukegan Harbor/ Outboard, Illinois (Upper Harbor)	Activities halted during boating season. Slip 3 sediments (<500 ppm) were left in-place (CAD site). CDF required 2 years to consolidate before closure.	Additional baseline sediment data needed (right before sampling) for comparison to post-project samples. Fish tissue samples collected yearly but few samples and variability is high.
Wyckoff/West Eagle Harbor, Washington (OU-3)	Design plan called for capping of non-dredged areas for enhanced natural recovery. Designed 1 ft overdredge. Tide swings sloughed exposed sediment, armored areas for protection.	Compliance with state sediment management standards chemical criteria is assumed to be protective of the benthic community based on AET tests.

Attachment 1

Detailed Case Studies

- Dredged 1993-1995
- PAHs
- 169,000 cubic yards
- $125 per cy dredging ($680 per cy total)

1 Statement of the Problem

Historic releases of creosote resulted in polyaromatic hydrocarbon (PAH) contamination at the Bayou Bonfouca site with 60,000 ppm (wet) maximum PAH concentration measured. The contamination presented human risk pathways through recreational exposure and fish consumption. The site was categorized as a public health hazard due to extensive soil, sediment, biota, surface water, and groundwater contamination. A written advisory and warning signs were posted against swimming and consumption of fish and shellfish by the Louisiana Department of Health and Hospitals and the Louisiana Department of Environmental Quality (LDEQ) for a 7-mile length of the bayou. Hotspots were dredged from November 1993 to July 1995. The lead agency for the project was Environmental Protection Agency (EPA) Region 6.

2 Site Description

The Bayou Bonfouca Superfund Site is an abandoned creosote wood treating facility located in Slidell, Louisiana, approximately 25 miles northeast of New Orleans. The dredging area is located along 4,000 linear feet of the bayou with a channel width of 250 feet. The bayou is lacustrine in nature consisting of shallow standing water and saturated soils. The nominal water depth of the bayou is 10 feet. The receiving water body is Lake Pontchartrain, located approximately 7 miles south of the site.

3 Site Investigation

Aerial of Bayou Bonfouca
Source: U.S. EPA Region 6

The site investigation included sediment, soil, groundwater, surface water, and air sampling to determine the horizontal and vertical extent of creosote contamination. EPA established the remedial action level for sediment removal at 1,300 ppm total PAHs. Because the remedial action took place before establishment of ecological risk, this level was established based on human risk criteria. Project oversight was provided by EPA Region 6 under Superfund (CERCLA) and the State of Louisiana. The ROD was signed March 31, 1987. The ROD stated an estimate of 46,500 cubic yards of sediment was to be removed along a 2,000-foot length of the bayou (EPA, 1987).

Sediment explorations were performed on three occasions to determine the extent of contamination and bank stability. The explorations were conducted from June 9 to June 27, 1988, December 1 to December 17, 1988, and May to June, 1990. In 55 sediment samples collected from within the bayou, PAH concentration ranged from below the method detection limit to over 60,000 ppm (wet weight) (CH_2M Hill, 1990). Results of the 1988 and 1989 investigations showed a significant increase in the extent of contamination presented in the ROD. The dredge area was therefore expanded to include all areas of the bayou with greater than 1,300 ppm PAHs. The increase corresponded to an estimated volume of 150,000 cubic yards of sediment along a 4,000-foot length of the bayou. Elevated sediment contamination ranged from 2.6 to 17 feet in depth. An *Explanation of Significant Differences* report was released February 5, 1990 explaining the updated scope of the remedial action (Layton, 1990). Contamination levels above 1,300 ppm for total PAHs were also found in sediments located outside of the bayou including three of the four borings in the Eastern Drainage Channel, and one boring located in the Western Creek (see Figure 1) (CH_2M Hill, 1990). Because two borings located downstream in the Western Creek did not exceed contamination criteria, it was assumed that the creosote released was not of sufficient volume to flow into the bayou.

Evidence of creosote contamination was confirmed in upland soil waste piles and in two of the three groundwater aquifers of the site. The surficial (ground surface to -9 NGVD) and shallow artesian aquifers (-12 to -28 feet NGVD) had creosote contamination. No contamination was detected in the deep artesian aquifer that began at a depth of -34 feet NGVD and was at least 10 feet thick. Surface water samples from the bayou were collected and analyzed during the second remedial investigation and design investigation. PAH contamination ranged from 160 to 628 ppb in the bayou surface water (CH_2M Hill, 1990).

Based on remedial and design investigations, a comparison of alternatives was conducted to evaluate each of nine identified alternatives (CDM & F.P. Corp., 1989). Specific criteria considered in the evaluation included:

- Odor potential of remedial activities,
- Need for source control,
- Riverbank stability,
- Constructability,
- Need for long-term monitoring,
- Life expectancy of the remedial facilities, and
- Time required for remediation.

The use of mechanical dredging and on-site incineration was determined to be the most appropriate alternative for protection of human health and the environment. Dredging and on-site incineration remained the preferred alternative in the *Explanation of Significant Differences*, although the addition of a protective cap was included in the remedial action for all dredged areas. Long-term monitoring of the cap would be required. Incineration provided the greatest degree of risk minimization of sediment toxicity. Institutional considerations for the selected alternative included deed restrictions for on-site ash and soil disposal.

4 Target Goals and Project Objectives

The project was designed to remove hotspot PAH contamination in excess of 1,300 ppm. The 1,300 ppm PAH action level for sediments was imposed for sediment removal based on direct contact exposure and potential for ingestion of carcinogens in groundwater, surface soils, and in the food chain (EPA, 1997). This level was found to present lifetime increased cancer risk of less than 1×10^{-4} (EPA, 1987). The action levels conformed to the acceptable health risk criteria contained in the National Contingency Plan. Minimal volumes of residual contaminants were left behind due to the need to ensure stable excavations, but capped to minimize exposure.

5 Project Design

Pre-planning and Bid Documents. Data not available for review.

Summary of Remedial Action Plan. The remedial project design involved mechanical dredging with use of silt curtains and adsorbent booms to minimize silt and contaminant transport. Dredging without dewatering of the bayou was determined to be the best approach because of the depth of excavation required (up to 17 feet). Sheetpile walls were used to ensure stable conditions in deep excavation areas. After dredging, a protective layer of sand and gravel was installed to isolate and contain small areas of residual contamination and contamination below the criteria level. Sediments were to be dewatered on site and treated water discharged into the bayou. Dewatered sediment was to be treated by incineration then landfilled and capped on site (GE/AEM/BBL, 1999; Tetra Tech).

Dredging design accounted for minimal residual contamination remaining after excavation. As stated in the 1987 ROD, "Any excavation on slopes greater than what is considered safe could results in the undermining of trees along the bayou resulting in the possible loss of property and harm to the environment." Therefore, the design accounted for limited residual PAH contaminated sediments over 1,300 ppm to remain in some areas. Sheetpile walls were to be used in unstable excavation areas with significant volumes of contaminated sediment to allow sediment removal.

A protective layer was included in the 1990 *Explanation of Significant Differences* for protection of human health by minimizing contact with remaining contamination. The cap would also provide a stable substrate for restoration of aquatic life. The application of a protective layer was added in the 1990 update, "After dredging, the contaminated portion of the bayou will be backfilled with clean materials to reduce the chances of contact with any residual materials."

Short-term environmental considerations included the possibility of odor, noise, and bank stability problems during dredging, and dust control during capping. Air impacts were one possible long-term impact that was minimized with an emission control system. Disturbances to the bayou generally resulted in intense and relatively far-reaching creosote odor. An attempt to minimize sediment disturbance was therefore attempted in the proposed remedies. Preference for dredging to take place only during daylight hours was stated in the remedial planning activities document.

Residual upland soils containing greater that 100 mg/kg PAHs and less than 1,000 mg/kg were collected and landfilled on site. Those with concentration of greater than 1,000 mg/kg PAHs were incinerated. Soils less than 100 mg/kg were left in place (Klink & Obert).

Incinerator specification for destruction and removal efficiency was established at 99.99 percent for all constituents of concern by RCRA incinerator regulations (40 CFR Part 264, Subpart O). All ash had to be less than 10 mg/kg before on-site landfilling.

Limitations and Permits. None specified.

6 Remedial Actions

6.1 Dredging

Computer Controlled Dredging
Source: U.S. EPA Region 6

The project involved removal of PAH contaminated sediments and soils derived from creosote. Approximately 169,000 cubic yards of sediment and 10,000 cubic yards of soils were excavated and treated by incineration. A crane-mounted clamshell dredge was used to excavate sediments to a barge. Dredging took place at a nominal depth of 10 feet (maximum depth of 17 feet) along a 4,000-foot length of the bayou. The nominal width of the dredge area was 250 feet.

Schedule and Duration. The completion of remedial action was scheduled for December 1996. The actual dredging activities were begun in November 1993 and completed in July 1995, approximately 18 months ahead of schedule. The total project time was 21 months, 15 months of which was active dredging. The daily schedule was 9 hours per day, 5 days per week.

Equipment. Mechanical dredging was completed using a custom-designed, crane-mounted clamshell on a barge. Dredging operations took place within silt curtains and absorbent booms. Sheetpile walls were installed on both sides of the bayou in some locations to provide bank stabilization.

Total Volume Removed and Production Rates. A total of 169,000 cubic yards of sediments were removed at a rate of 520 cubic yards per day based on days of active dredging.

Site-specific Difficulties. The initial project design specified driving sheetpile walls on either side on the bayou prior to dredging to ensure stability. The design called for removal of the sheetpile walls after backfilling was complete. Problems with liquefying of sediments, and damage to foundations of adjacent houses resulted from driving the sheetpile walls. For this reason, the sheetpile walls were left in-place (Duane Wilson of LDEQ, 2000. Personal communication.).

6.2 Dewatering and Water Treatment Operations

Process water from dewatering operations was treated by clarification, bioreactor, granular-activated carbon system. A total of 171 million gallons of water were treated at a rate of 500 gallons per minute.

Water Quality Monitoring of Discharge. The effluent water was discharged into the bayou. A discharge criteria of less than 20 parts per billion of individual PAHs was established.

Groundwater Treatment. Groundwater treatment began in June 1991 and succeeded in reducing the volume of contamination and prevented further migration. Approximately 9 million gallons of contaminated groundwater were extracted and treated by August 1999 resulting in recovery of 26,000 gallons of creosote oil. Treated water was discharged into the bayou. Additional recovery and monitoring wells are being installed to address the creosote plumes found in the shallow artesian aquifer. EPA will continue long-term remedial action until July 2001, at which time the State of Louisiana will take over the long-term remedial action for the next 20 years.

6.3 Storage and Disposal

Sediments were transported to a holding pond by a 24-inch diameter floating pipeline. Sediment was then transported to an on-site incineration system consisting of feed system (filter press dewatering and blending), rotary kiln, secondary combustion chamber, and gas cleaning system. Following thermal treatment, incinerator ash was placed in an on-site landfill along with marginally contaminated upland material. An engineered cap constructed of high-density polyethylene geotextile material, Claymax, and native clay was then installed over the landfill (EPA, On-site Incineration).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, sediment sampling, invertebrate tissue, and fish tissue sampling (Table 1).

7.1 Baseline

Physical. Field and laboratory tests were conducted to determine the necessary slope to maintain stable conditions upon excavation.

Chemical. Chemical air monitoring was reported in the Pilot Study Report. The ambient air monitoring characterized air quality conditions on site prior to remediation efforts. The air monitoring detected naphthalene in concentrations of 5 to 11 ppb in two of five sample stations.

Two phases of off-site sediment sampling were conducted in Bayou Bonfouca, and upstream areas located in the Western Creek and the Eastern Drainage Channel. Sediment sampling consisted of a total of 63 cores. The streambed of Bayou Bonfouca was cored in 55 locations ranging from approximately 300 feet upstream of the confluence of Western Creek and the Bayou, to approximately 4,000 feet downstream of the confluence of the Eastern Drainage Channel and the Bayou. Eight additional cores were drilled, four in the Western Creek and four in the Eastern Drainage channel (CH_2M Hill, 1990).

Extensive creosote contamination existed along approximately 4,000 feet of the bayou sediments. In 1981, pentachlorophenol (PCP) was detected in two sediment samples located downstream of the site at the boat landing. The low levels that were detected of PCP did not pose a health threat.

Biological. LDEQ posted an advisory against fish/shellfish consumption and swimming along a 7-mile length of Bayou Bonfouca on November 24, 1987. In 1981, the Center for Bio-Organic Studies at the University of New Orleans collected plankton, blue crabs, and clams from the bayou for metals and PAH testing (Louisiana Office of Public Health, 1994). Analyses of the bayou waters did not detect PAHs. Biota sampled had total PAH concentrations of 210 parts per million (μg/g) in plankton; 170 μg/g in crabs; and up to 0.6 μg of benzo(a)pyrene per gram of wet tissue in the clams (8).

Three blue crabs were sampled in three different locations in Bayou Bonfouca: 1) 0.35 mile south of the turning basin, 2) 0.6 mile south of the turning basin, and 3) Bayou Bonfouca adjacent to Southern Shipyards (south of the site). The three blue crabs that were sampled had very low levels of PAH contamination, which did not pose a health threat. However, the blue crabs did contain elevated levels of mercury and lead (9). Mercury concentrations in the crabs ranged from 20 to 250 ppb while lead concentrations ranged from 560 to 16,400 ppb. These metals have not been associated with the study area.

7.2 Implementation During Dredging

Physical. No physical progress data were available for review.

Chemical. Continuous air monitoring was conducted by LDEQ during dredging to protect workers and community residents. Data were collected at three monitoring stations for volatile, semivolatile, and particulate readings. Air monitoring was designed to warn workers if federal health guidelines were exceeded and dredging would cease.

Biological. No biological progress data were available for review.

7.3 Post

Physical. The Corps of Engineers conducted post-remedial bathymetry surveys to determine the elevations following dredging and placement of the protective layer.

Chemical. No post-construction data were available for review.

Biological. No post-construction data were available for review.

7.4 Long Term

Data were collected as a part of the state annual monitoring program on September 16, 1997 for sediment, water, and fish testing. Sediments were analyzed for PCBs (3 samples) and semivolatiles (10 samples). Semivolatiles in sediment were detected at a maximum concentration of 47.7 ppm (di-n-butylphthalate). The highest detected PAH compound was fluoranthene at a concentration of 34.9 ppm. Water samples (10) were below the detection limit for semivolatiles. (Louisiana DEQ, 1998).

Fish were collected for analysis of arsenic, lead, PCBs, and semivolatiles. Fish collected included largemouth bass (15 samples), red ear sunfish (7 samples), freshwater drum (5 samples), white bass (1 sample), and channel catfish (5 samples). Maximum concentrations were 0.1 and 0.006 ppm for arsenic and lead, respectively (both in largemouth bass). PAHs were not detected above the quantitation limit in fish, although phthalates were detected in the semivolatile analysis. The maximum phthalate concentration was 37.6 ppm bis (2-ethylhexyl) phthalate (wetweight). However the majority of fish results were below detection limits for PCBs, encouraging the initiation of removing the fish consumption advisory (Louisiana DEQ, 1996 and 1998). PCBs were also analyzed in the fish and sediments samples; however, detected concentrations were in the ppb range.

Table 1 Summary of Monitoring Results

Testing Parameters	PAH Concentration (ppm)			
	Baseline 1988–1993	During Nov 1993 – July 1995	Post 1995	Long-term 1996 - 1997
Bathymetry	Yes	Unk	Unk	Unk
Sediment Cores	0 to 60,000 ppm wet	Unk	NA	34.9 ppm (fluoranthene)
Surface Water	0.160 to 0.628	Unk	NA	Non-detect
Air Monitoring	None	Conducted	None	None
Tissue	210 μg/g plankton (ppm) 170 μg/g crabs (ppm)	NA	NA	Non-detect fish

Unk - Unknown
NA - Not available for review

8 Performance Evaluation

The site was categorized as a public health hazard due to extensive soil, sediment, biota, surface water, and groundwater contamination (Louisiana, 1994). A written advisory and warning signs were posted against swimming and consumption of fish and shellfish by the Louisiana Department of Health and Hospitals and the Louisiana Department of Environmental Quality (LDEQ) for a 7-mile length of the bayou in 1987. The non-consumption for general population (NCGP) fish advisory for all fish species with creosote pollutant was rescinded on December 10, 1998 (EPA, 2000). As stated by EPA, "the bayou has been restored for aquatic life, and approved for human residential and recreational use including installation of a public boat launch" (EPA, 1999).

8.1 Meet Target Objectives

No post-remedial sediment data were reviewed to determine attainment of target goals. However, the project is widely viewed as successful since the long-term remedial action objective, defined as the protection of human health and the environment was achieved through removal of the fish consumption advisory in 1998. The remedial action was successful in treating over 169,000 cubic yards of contaminated sediment and approximately 9 million gallons of site groundwater.

8.2 Design Components

The remedial action design was based on extensive sampling of sediment, groundwater, and surface water. Nine alternatives were evaluated for specific criteria to determine the most appropriate remedy. Mechanical dredging and on-site incineration were selected.

8.3 Lessons Learned

Sediment investigation determined the volume of sediment in excess of cleanup action levels was approximately three times greater than specified in the 1987 ROD. The investigation allowed the scope of work to be expanded and the Explanation of Significant Differences to be issued prior to commencement of remedial activities.

9 Costs

The project cost was estimated at $55 million in the 1987 ROD and updated to $100 million in the 1990 *Explanation of Significant Differences*. The total remediation cost was approximately $115 million ($680 per cubic yard). The cost of dredging was $21.1 million ($125 per cubic yard).

10 Project Contact

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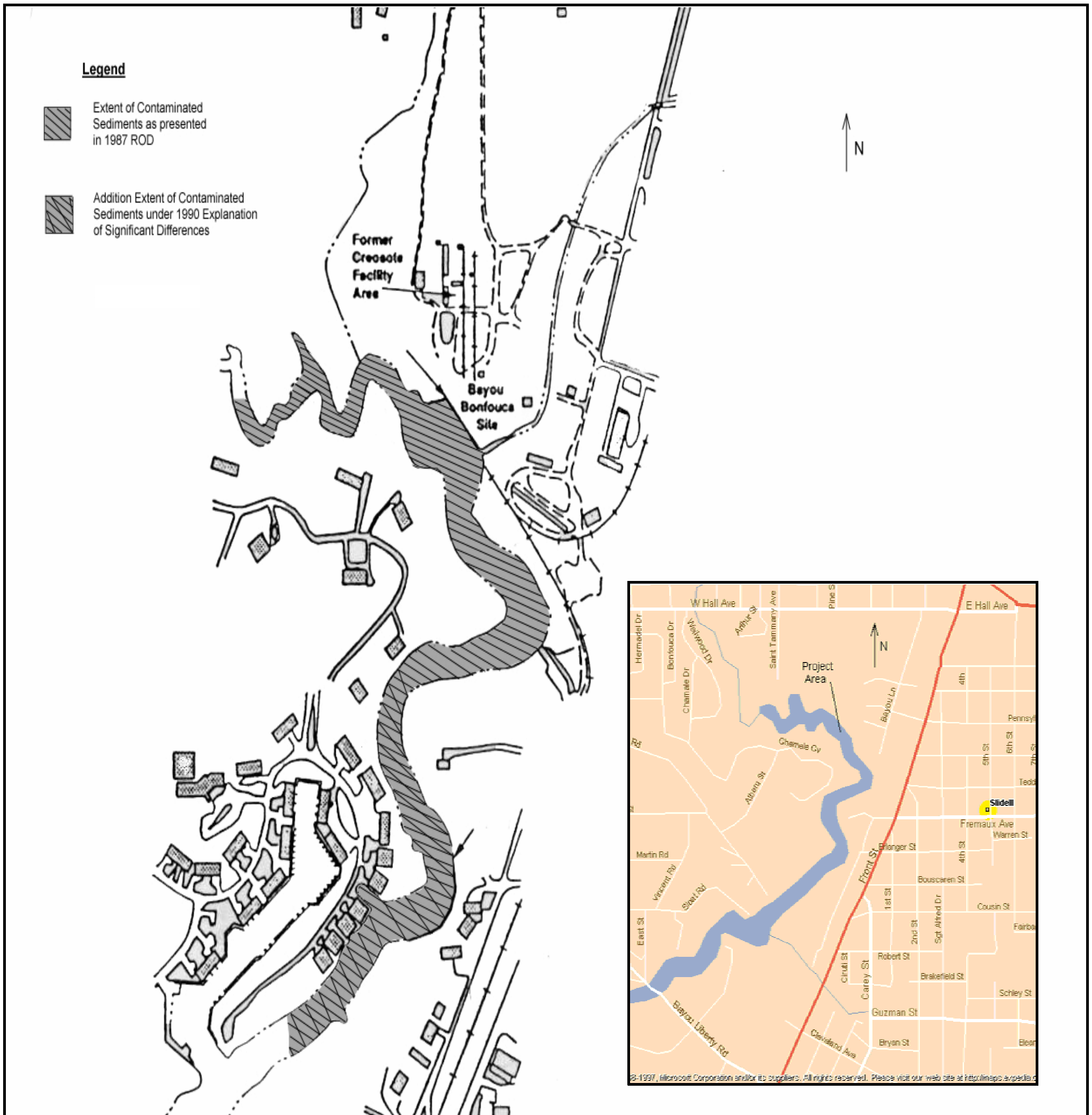
Figure 1 Remedial Dredge Plan - Bayou Bonfouca



Source: CH2M Hill Remedial Design Approach and Design Investigations

1 Statement of the Problem

- Dredged 1989–1990
- PAH
- 60,000 cubic yards
- $83 per cy total

The Black River, Ohio was the site of a remedial dredging project in 1989 mandated by the Environmental Protection Agency (EPA) to remove high concentrations of contaminants, specifically polynuclear aromatic hydrocarbons (PAH). The nature and extent of the contaminated sediment, accumulated from continual industrial discharge, and the ensuing threat to ecological receptors, prompted the EPA to order the dredging project (Lesko *et al.*, 1996; Baumann and Harshbarger, 1998). The lead agency for this project was EPA Region 5.

2 Site Description

The Black River flows northwesterly through Ohio, draining into southern Lake Erie, the Great Lakes, at Lorain Harbor (Figure 1). This freshwater tributary is situated between the Huron River (to the west) and the Cuyahoga River (to the east), which also drain into Lake Erie. There are several major industrial facilities along the river.

3 Site Investigation

The International Joint Commission (IJC) for the Great Lakes defined the Black River as an Area of Concern (AOC) based upon the high level of contamination that has resulted from industrial discharge (Smith *et al.*, 1994). The primary industry along the lower Black River is USX-Kobe (formerly US Steel), with several other large industrial and municipal facilities located further upstream. Of the various industries that discharge waste to the river, the EPA considered the USX-Kobe coke facility to be the major contributor, discharging over 1 million gallons of industrial waste per day, until its closure in 1983. Effluent from this coke facility was considered to be the major source of high concentrations of PAH contaminants in the Black River (IJC, 1999). Although PAH concentrations in Black River sediment declined after the coke facility closed in 1983, levels remained of concern with regard to the health of brown bullhead catfish and other resident aquatic organisms.

Aerial of Black River
Source: U.S. EPA Region 5

In 1985, the EPA issued a Consent Decree to USX-Kobe mandating the removal of 38,000 cubic meters (or about 50,000 cubic yards) of PAH-contaminated sediment from the main stem of the Black River in the vicinity of the former coke facility (EPA, 1999). Remedial dredging activities were conducted between 1989 and 1990 using a mechanical clamshell dredge, and removed all sediments above 390 ppm PAHs. The remediation project was mandated to remove the high levels of PAHs from the river system to ultimately reduce the incidence of fish abnormalities, such as liver and lip cancers and neoplasms, in resident brown bullhead populations. PAH concentrations in sediment and the incidence of liver cancers and tumors were measured and compared over a period of several years in an attempt to evaluate the effects of PAH contamination in the system, and the effectiveness of the sediment remedial dredging project.

4 Target Goals and Project Objectives

The primary cleanup goal was to remove all PAH-contaminated sediment in the main stem of the Black River near the former USX-Kobe coke facility to "hard bottom," or to the underlying shale bedrock. Specifically, the 1985 EPA Consent Decree mandated the removal of 38,000 cubic meters (49,700 cubic yards) of PAH-contaminated sediment. In removing contaminated sediment, it was anticipated that this remediation project would eliminate the high incidence of liver tumors and cancer in resident brown bullhead fish populations.

5 Project Design

USX-Kobe was required to comply with EPA's 1985 Consent Decree, which was initially issued to deal with violations of the Clean Air Act, but included the supplementary requirement of dredging the PAH-contaminated sediment. Once issued, the parties involved were not able to immediately agree upon a disposal site and, thus, dredging did not commence until 1989 (Baumann, 1998).

Black River Dredge
Source: U.S. EPA Region 5

Pre-planning and Bid Documents. None are available for review.

Summary of Remedial Action Plan. The remedial action entailed wet excavation of site sediments using a mechanical clamshell bucket and a hydraulic cutterhead dredge (for areas with debris since the bucket could not close) to "hard bottom" or bedrock. Excavated sediment was placed in an upland, on-site, lined containment cell landfill then subsequently capped.

Limitations and Permits. Required permits included the Clean Water Act for NPDES, Section 404, dredge and fill, and Section 401, water quality certification. Disposal of the dredged sediment had to comply with RCRA requirements (IJC, 1999). Dredging operations ceased during the fish spawning season, May through July.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities commenced in the fall of 1989 and were completed in December 1990, at a cost of $1.5 million. Dredging hours of operation increased from one shift 5 to 6 days per week, to 7 days per week, then up to 24 hours per day through project completion on December 13, 1990 (GE, 1998).

Equipment. A watertight clamshell dredge was used during the dredging operations to reduce the loss of sediment to the water column. An oil boom was erected to prevent the potential spread of oil during operations. Upon removal, the dredged sediment was moved from the dredge barge into a lined containment cell on site of the steel facility, dewatered, capped in-place, and monitored. A contingency plan was defined in the event of a spill.

Total Volume Removed and Production Rates. The Consent Decree required removal of 49,700 cubic yards of contaminated sediment; however, 60,000 cubic yards were actually removed from two hotspots in the Black River.

Site-Specific Difficulties. None specified in review documents.

6.2 Dewatering and Water Treatment Operations

Once in the lined containment cell, the dredged sediment was allowed to dewater. The decanted water was then treated.

6.3 Storage and Disposal

Disposal of the dredged sediment, which exceeded the EPA's Heavily Polluted Classification for Great Lakes Harbor Sediments, was required to be placed in a confined disposal facility (CDF). After dewatering on site of the USX-Kobe facility, the sediment was capped in-place, and monitored following closure. Such careful disposal procedures were followed to prevent potential groundwater contamination, which would have violated EPA's RCRA requirements for cap closure. Leachate generated at the closed CDF is treated and discharged to the Black River through an outfall limited by the company's National Pollutant Discharge Elimination System (NPDES) permits.

7 Environmental Monitoring Program

Monitoring in the Black River was conducted over a period of several years to evaluate physical and chemical characteristics (i.e., PAH concentrations in sediment) and to evaluate biological characteristics (i.e., the incidence of liver cancer and neoplasms and the detection of PAH metabolites in liver and bile in brown bullhead populations).[1] Monitoring

[1] Fish tissues are not directly analyzed for PAH concentrations because organisms rapidly metabolize and excrete PAHs.

provided insight regarding the extent of contamination, the effects of contaminants on receptors, and the ultimate result of remedial dredging activities. Refer to Table 1 and Figure 2 for comparison of monitoring results before dredging, during dredging, and after dredging.

7.1 Baseline

Baseline conditions refer to the physical, chemical, and biological characteristics of the Black River between 1980 and 1989, prior to dredging operations. The USX-Kobe coke facility, which discharged high levels of PAHs (and certain metals) into the river, was in operation until 1983, at which point the facility closed and discharge of process-generated wastewater ceased. The company had high phenol and ammonia levels in its type 002 outfall (groundwater runoff) for a number of years after the coke plant closed.

Chemical. 1980 and 1981, during coke facility operations, sediment sampled in the Black River at the outfall of the USX-Kobe coke plant detected a total of 1,096 ppm of PAHs (dry weight), including the carcinogen benzo(a)pyrene at a concentration of 20 to 40 ppm (Table 1). There were also elevated levels of certain metals (e.g., cadmium measured at 30 ppm), pesticides, and oils and grease (Baumann, 1998; Baumann and Harshbarger, 1998; IJC, 1999).

Following the permanent closure of the USX-Kobe coke facility in 1983, PAH concentrations in Black River sediments declined due to the reduction of waste discharge, supplemented by natural sedimentation that buried the contaminated sediments. The PAH concentration measured in sediments was between 4.3 and 8.8 ppm (about two orders of magnitude less than concentrations during coke plant operations) (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1).

Biological. PAH profiles in the resident brown bullhead catfish (*Ameiurus nebulosus*) in 1980 and 1981 (metabolites detected in bile) corresponded to the high PAH concentrations in the sediment, confirming exposure. Additionally, the prevalence of liver cancer in brown bullhead populations ranged from 22 to 39 percent, and the frequency of all liver neoplasms (including non-cancerous tumors) was detected at 56 to 60 percent (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1; Figure 2). Incidence of liver neoplasms correlated positively with age (Folmar, *et al.*, 1995).

When PAH concentrations in the sediments declined following the facility closure, the frequency of liver cancer in brown bullheads declined to approximately 10 percent, and the frequency of all liver neoplasms decreased to between 21 and 32 percent (Baumann, 1998; Baumann and Harshbarger, 1998) (Table 1; Figure 2). Bioavailability of PAHs appears to have been reduced after the 1983 coke facility closing by natural sedimentation that covered PAH deposits (and by the export of PAHs out of the system), as evidenced by the reported decline in brown bullhead liver cancers.

7.2 Implementation During Dredging

Sediment and fish samples were collected from the Black River during dredging in 1989 and 1990; however, the data were not available for review.

7.3 Post

Sediment and fish samples were collected from the Black River during and immediately following the dredging operations that occurred in 1989 and 1990.


Haul Truck
Source: U.S. EPA Region 5

Chemical. In 1992, 2 years following dredging, PAH concentrations in the sediments had increased slightly to 16.6 ppm (Baumann and Harshbarger, 1998) (Table 1). Possible explanations for the observed increase include exposure to elevated levels of contaminant sediment from temporary resuspension and redistribution of sediments during dredging activities (despite all efforts to minimize disturbance), flow induced scour and redistribution of contamination, and other causes.

Biological. In 1992, the total percentage of brown bullhead with liver neoplasms also increased. The incidence of all neoplasms rose from 21 to 32 percent to between 56 and 58 percent) immediately following dredging. The same positive correlation was seen between age and tumor frequency rates (Baumann and Harshbarger, 1998; Folmar *et al.*, 1995) (Table 1; Figure 2). This increase in tumor incidence to levels as high as those during coke facility operations suggests an increased exposure of fish to PAHs in sediments that became naturally buried then temporarily resuspended and redistributed in the water column during dredging operations.

7.4 Long-term Monitoring

After dredging activities were completed and the PAH-contaminated sediments were removed, the PAH concentrations measured in the sediments and the incidence of neoplasms detected in brown bullheads both declined dramatically.

Physical/Chemical. After the sediment remediation project was completed, the total concentration of PAHs in Black River sediment declined from the 1980 levels (1,096 ppm) to 9.8 ppm in 1994, similar to concentrations found in the late 1980s after natural sedimentation occurred (Baumann and Harshbarger, 1998) (Table 1). Although PAH concentrations in the sediments were similar to those measured in the early 1980s, the subsequent decline in biological effects was much more dramatic following the remedial dredging project. (Moloney, M.E., 1993).

Biological. A dramatic decline in the prevalence of liver cancer and neoplasms occurred in the first class of fish not present in the river during dredging (i.e., spawned after the dredging operations were complete). Fish liver neoplasm rates in age 3 fish declined to nearly 0 percent in 1994, with no incidence of cancer and the greatest increase in the percentage of completely normal livers (Baumann and Harshbarger, 1998) (Table 1; Figure 2). Any PAH exposure caused by dredging, therefore, was apparently restricted to the time frame of the activity itself, with the end result reaching the remediation goal of dramatically reduced PAH concentrations in sediment and the elimination of liver cancer and neoplasms in brown bullheads.

Table 1 Summary of Monitoring Results

Testing Parameters	Baseline 1 Operational Coke Plant 1980–1982	Baseline 2 Post-facility Close 1983–1989	During Dredging 1990–1992	Post/Long-term 1993–1994
Physical/Chemical PAH Concentrations in Sediment	1,096 ppm	4.3 to 8.8 ppm	16.6 ppm	9.8 ppm
Biological Liver Neoplasms in Brown Bullheads	56 to 60%	21 to 32%	46 to 58%	<1%

8 Performance Evaluation

8.1 Meet Target Objectives

Overall, this dredging project successfully met the target goals of removing the PAH-contaminated sediment to "hard bottom." Incidence of liver cancer increased in brown bullheads collected 2 and 3 years following dredging. This increase was associated with PAH redistribution during dredging. Liver cancer incidence decreased and normal tissue incidence increased 3 and 4 years post-dredging. Therefore, the long-term project objective of reducing the incidence of fish liver tumors was also met.

Data collected between 1980 and 1994 on the Black River support the hypothesis that high levels of PAHs in sediment cause such abnormalities as liver cancer and neoplasms in resident benthic brown bullhead catfish. When PAH concentrations were high in sediment (during coke facility operations and during dredging activities), the incidence of liver cancer and neoplasms was high. When the coke facility closed, eliminating the source of PAHs to the river and allowing natural sedimentation to effectively cover the PAH-contaminated sediments, rates of fish liver neoplasms decreased. It appears that remedial dredging activities briefly caused an increase in PAH concentrations in sediment, and thus higher incidences of neoplasms, by temporarily resuspending buried contaminated sediments.

After contaminated sediment was dredged, PAH concentrations declined substantially and, subsequently, fish that spawned after completion of the dredging project showed no incidence of liver neoplasms and a dramatic increase in normal liver tissue. The decline in PAH concentrations in sediment, and the ensuing elimination of liver cancer in resident brown bullheads, as well as the most dramatic decline in liver neoplasms in general to the lowest levels measured since coke facility operations, provides evidence of the ultimate efficacy of dredging as a remedial measure for PAH-contaminated sediment at this site.

The state fish consumption advisory for "no consumption - general population" was rescinded on January 1, 1998 for all PAH-contaminated fish (EPA, 2000).

8.2 Design Components

None were available for review.

8.3 Lessons Learned

Adaptive management allowing the contractor to switch dredge types in the middle of the project when site conditions proved difficult (debris), helped maximize performance of this remediation project.

9 Costs

The estimated total cost for dredging, disposal and monitoring was reportedly $5 million ($83 per cubic yard) (GE, 1998). Dredging costs were estimated at $1.5 million. ($25 per cubic yard)

10 Project Contact

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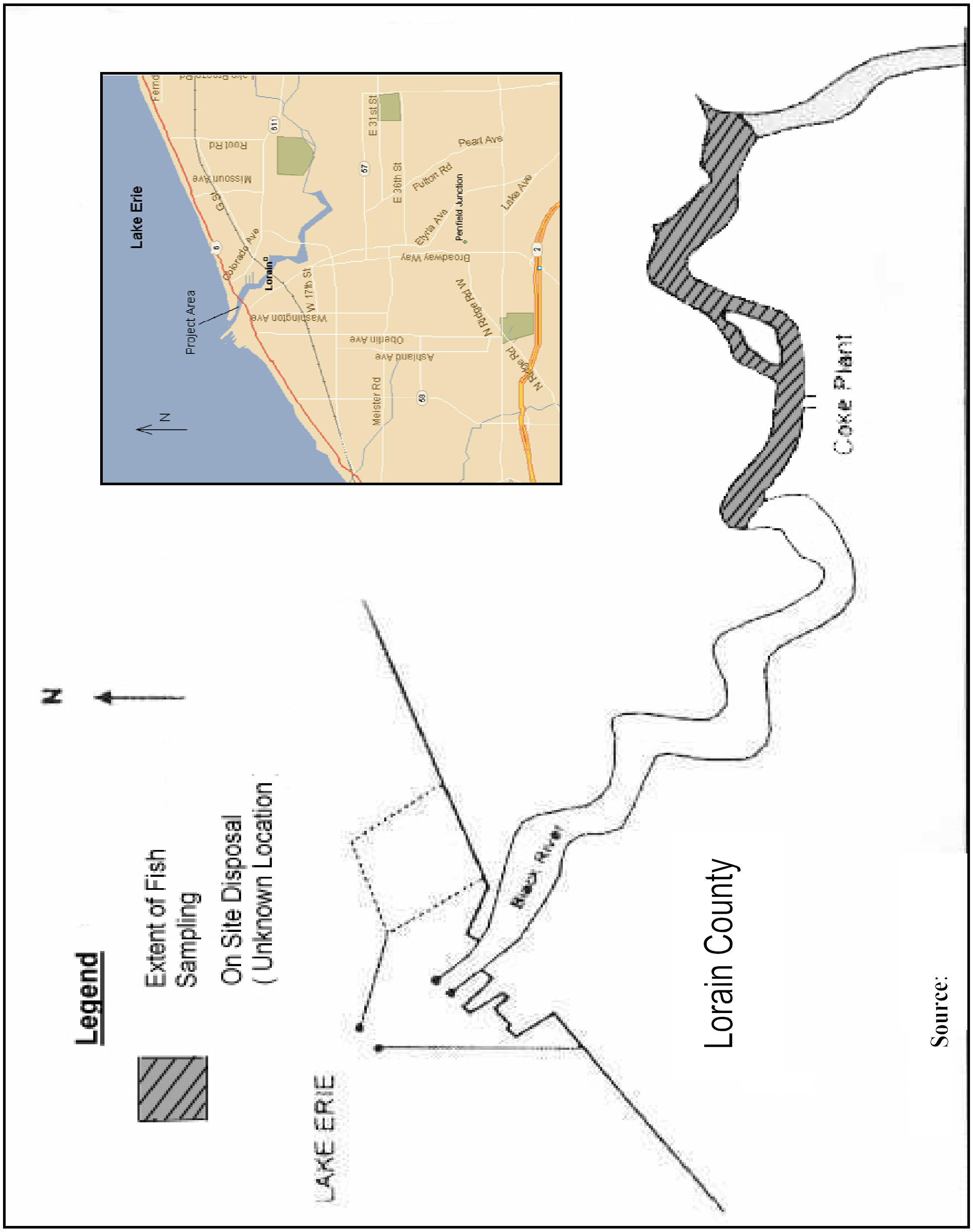
Figure 1 Remedial Dredge Plan - Black River



- Dredged 1993
- Metals
- 3,896 cubic yards
- $154 per cubic yard

1 Statement of the Problem

Sediment in Collingwood Harbour was contaminated with metals from historical shipbuilding activities. Navigational dredging was performed in the harbor in 1986 and a remedial demonstration dredging project was performed in 1992. After the pilot project, the cleanup action consisted of dredging a 2.45-acre area in 1993. Cleanup sediment removal was implemented in order to rehabilitate degraded benthos, remove chronic toxicity and lift restrictions on navigational dredging. The lead agency for coordinating remedial actions was the Ontario Ministry of Environment. Environment Canada and Public Works Canada were lead agencies for the dredging activity.

2 Site Description

Collingwood Harbour is located on the south shore of Nottawasaga Bay in the southern extension of Lake Huron's Georgian Bay in Ontario, Canada (Figure 1). The harbor is approximately 200 acres in area. The harbor is relatively shallow with maximum water depth of 21 feet (at datum). Sediments consisted of soft silt that overlaid a clay layer and bedrock. The harbor is surrounded by a wetland complex, wastewater treatment plant outfall, marina, grain terminal, former shipyards, and the town of Collingwood (population 16,000) (Gamble, 1998).

3 Site Investigation

Navigational dredging was conducted in Collingwood Harbour in 1986. Contaminant levels of chromium, copper, lead, zinc, and PCBs were found in excess of the LEL established by the Provincial Sediment Management Guidelines and subsequently led to restrictions on open-water disposal of dredged sediment. Similar maximum PCB and metals concentrations were observed in a 1987 investigation. A summary of maximum contaminant concentrations before and after the navigational dredging are given in Table 1.

A sediment sampling survey was performed in April 1992 to determine the nature and extent of contamination for designing of the cleanup dredging plan. Contaminants in excess of the LEL cleanup criteria level included chromium, copper, lead, and zinc as shown in Table 1 (SEDTEC, 1993). PCB concentrations were below the detection limit in all samples collected in the 1992 investigation. The contaminated silt sediments were

Aerial of Collingwood Harbor
Source: Environment Canada

present at thicknesses of 0.7 to 1.6 feet (IJC, Case Study). The sediment investigation concluded that contamination was contained within the soft silt layer and the underlying clay layer was deposited before industrial activity and was not contaminated. Results of the investigation indicated that an area of 2.45 acres required removal to meet biological requirements for healthy benthos and removal of chronic toxicity. (Figure 1)

Contaminants of Concern. The major contaminants of concern were trace metals including chromium, copper, lead and zinc. Maximum concentrations detected in a 1992 sediment sampling investigation were 31 ppm chromium, 61 ppm copper, 150 ppm lead, and 180 ppm zinc (Sedtec, 1993). However, conflicting values from a 1993 investigation found maximum concentrations of 300 ppm copper, 1000 ppm lead, and 4000 ppm zinc (Brooksbank 2000). All maximum concentrations from both investigations were above the LEL cleanup criteria. A summary of chemical cleanup criteria is provided below (OMOE, 1993).

Contaminant	LEL (ppm oc)	SEL (ppm oc)
Chromium	26	110
Copper	16	110
Lead	31	250
Zinc	120	820

4 Target Goals and Project Objectives

The principal goal of remedial activities was to remove sediment toxic to benthic organisms. One hundred percent removal of sediments causing toxicity was the target objective of the dredging action. Concentrations of metals, trace or organic contaminants and nutrients in surface sediments within the harbor turning basin had to meet Ontario Ministry of Environment sediment guidelines (IJC, 1999).

5 Project Design

Pre-planning and Bid Documents. A demonstration of contaminated sediment removal was conducted in 1992 using the Pneuma airlift pumping system. The demonstration involved removal of 1,800 cubic meters of marginally contaminated sediment from the west boat slip and the eastern dry dock. The percent solids of the dredged sediment slurry ranged from 15 to 30 percent (Environment Canada, 1998). Results of the demonstration project were used to design the 1993 remedial dredging plan.

Several contractors submitted competitive bids for the 1993 cleanup action dredging project. The selected contractor was the lowest proposal cost received for the cleanup.

Summary of Remedial Action Plan. Sediment was removed in the 1992 demonstration and the 1993 cleanup by a barge-mounted hydraulic dredge set up with guide cables that extended across the harbor channel. The dredge was advanced 13 to 16 feet per minute using a winch system. Dredged sediment was pumped through a 6-inch pipeline to a newly constructed confined disposal facility (CDF) located approximately 3,300 feet from the dredge area (C.B. Fairn, 1993).

Limitations and Permits. Regulatory approvals were required before proceeding with remedial activities. Approval to dredge in a navigable waterway under section 5(2) of the Navigable Waters Protection Act, RSC 1985, Chapter N-22 was granted by the Canadian Coast Guard and the Department of Transportation. The Department of Fisheries and Oceans gave approval under Section 33 of the Fisheries Act (SEDTEC, 1993).

6 Remedial Actions

6.1 Dredging

The dredging area was located in the inner section of the Collingwood Harbour adjacent to the east dock wall and immediately north of the east dry dock slip in the southern portion of the harbor (Figure 1). The water depth in this area ranged from 10 to 18 feet increasing toward the center of the channel.

Schedule and Duration. Dredging operation was conducted from November 24 to December 8, 1993, 6 days a week, 10 hours a day. The duration of active dredging was 66 hours. A total of 53 hours was spent on downtime activities, which included mobilization, demobilization, dredge relocation, and maintenance. The dredging crew consisted of five workers including a superintendent, dredge foreman, dredge operator, compressor operator, and laborer/boat operator.

Equipment. Hydraulic dredging was conducted using a Pneuma pump unit 150/30 including pump body, distributor, vertical inlet shovels, hoses, lowering and raising frame. The dredge was suspended from a 25-ton Crawler crane mounted on a floating flat barge (45 feet by 28 feet by 5 feet) equipped with steel spuds, anchors, four winches, generator, and lights. Dredged sediment was transported to the shore by a floating discharge pipeline where it connected to a 6-inch-diameter PVC pipeline. The PVC pipeline transported the dredged sediment approximately 3,300 feet to a CDF (C.B. Fairn, 1993).

The Pneuma pump uses static water head and compressed air inside special cylinders in a manner similar to a piston pump. The head creates a vacuum and sediment slurry is suctioned into the pump and attached pipeline (hydrostatic pump principle). Small debris (such as cobbles, bottles, tin cans) did not effect operation but larger items, however, (plate steel, timber) required removal through access ports before continuing operations.

Total Volume Removed and Production Rates. An estimated total volume of 3,896 cubic yards of sediment was removed from a 2.45-acre area. The resulting production rate was 59 cubic yards per hour. Percent solids of the dredge slurry was approximately 30 percent. Three passes were made over each section of the dredged area with overlap to ensure no areas were missed.

Site-specific Difficulties. Significant down times for Pneuma Pump cylinder cleanup were necessary during the 1992 demonstration project due to plugging by medium- and large-sized debris from historical shipbuilding activities (Environment Canada, 1998). Some minor delays were experienced due to debris encountered during the 1993 cleanup dredging. The frequency of such delays were significantly less than in the demonstration project.

Soundings indicated that contaminated silt sediment remained after two passes of the dredge. A third pass of the dredge was therefore conducted. A bluish hue observed during the third pass indicated that the underlying clay was being dredged, and all contaminated silt and sediment was presumably removed.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediments were pumped via a 6-inch PVC pipeline to a CDF. Dewatering of the slurry was accomplished via passive dewatering in a CDF. Carriage water was separated from dredge solids through gravity settling, evaporation, and infiltration through the CDF sidewalls and bottom. Walls of the CDF were constructed with cobble, sand, and filter fabric (Brooksbank, 2000).

Water Quality Monitoring of Discharge. No water treatment of discharge was conducted. No monitoring data were available for review (unknown if collected).

6.3 Storage and Disposal

Evaporated sediment was capped with clean material in the CDF.

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, water quality sampling during dredging, sediment sampling, toxicity testing, and benthic community assessment (Table 1).

7.1 Baseline

Physical. A detailed pre-dredge survey of the dredging site was conducted on April 22, 1993 using an echo sounder to establish bathymetry of the harbor bottom and to determine the thickness of contaminated sediments to be dredged. Because only silt sediments were considered contaminated, this determination could be made using physical data. The soft silty sediment ranged from 0.7 to 1.6 feet in thickness and overlaid a native clay layer (C.B. Fairn, 1993).

Water quality monitoring conducted prior to dredging was used to establish ambient levels for turbidity, total suspended solids (TSS), temperature, and pH on October 26, 27, and November 3, 1992. Water samples were collected at two depths: 1 meter below the surface and 1 meter above the sediment surface. Ambient conditions were determined as 5 NTU turbidity and 5 mg/L TSS in both surface and bottom samples (SEDTEC, 1993).

Chemical. Chemical analysis conducted in 1992 and 1993 measured sediment contamination in excess of the LEL for chromium, copper, lead, and zinc (Table 1).

Biological. Benthic abundance/community structure analysis and sediment toxicity tests were conducted in 1992 and 1993 throughout the harbor (and outside) to determine baseline conditions. Oligochaetes were found to be abundant in areas of low-level toxicity in the benthic community structure analysis. Sediment toxicity tests provided evidence that sediment was the cause of toxic impact, rather than the water column or other factors. Chronic low-level toxicity was present in the shipyard slips and in an area northwest of the slips. No growth inhibition was demonstrated in sediment bioassays conducted in 1993 on areas outside of the dredge area.

7.2 Implementation During Dredging

Physical. Water quality monitoring was conducted during dredging for turbidity, total suspended solids (TSS), temperature, and pH at a frequency of two to eight times per day. The acceptance criteria for turbidity was established at an increase of less than 30 percent over ambient levels. The levels for turbidity averaged 6 NTU 1 meter from the surface and 8 NTU 1 meter from the bottom at a distance of 25 meters from the dredge. The acceptance criteria for TSS was established at an increase of less than 25 mg/L over ambient levels. Average TSS results were 5 mg/L at the surface and 10 mg/L at the bottom at a distance of 25 meters from the dredge with ambient levels of 5 mg/L at the surface and bottom. Acceptance criteria for turbidity and TSS (based on average levels) were met during dredging.

7.3 Post

Physical. A sounding survey of the dredged area was conducted using an echo sounder to determine depths of excavation and volume of dredged sediment. The average depth of excavation was 1.0 foot.

Chemical. Chemical analysis of post-dredging sediments was stated to demonstrate a sharp decline in metals concentrations; however, the sediment chemical data have not been received for review at this time (IJC, 1999).

Biological. As stated in the Collingwood Harbour RAP, State 3 Document, "in locations where the LEL is marginally exceeded, concentrations are comparable to background values, or biological responses, in terms of community composition and bioassay endpoints, are not statistically different from reference values."

7.4 Long Term

Routine monitoring will be conducted to determine the rate of benthos recolonization; however, monitoring data are not available to date. A status survey is scheduled for year 2000.

Table 1 Summary of Monitoring Results

Contaminant	Concentration (in ppm dry-weight)			
	Pre-baseline 1992 (after navigation dredging)	During 1992	Post-1993	Long Term
Bathymetry (echosounder)	Soft sediment 0.7 to 1.6 ft thick	Unknown	Avg. depth of dredge = 1 ft	—
Surface Sediment	Chromium - 31 ppm max Copper - 61 ppm max Lead - 150 ppm max Zinc - 180 ppm max PCBs - 160 ppm max (SedTech, 1993)	Unknown	NA, but stated as "decreased"	—
	Copper - 300 ppm max Lead - 1000 ppm max Zinc - 4000 ppm max (Brooksbank, 2000)			
Surface Water Column	TSS, temperature, pH, turbidity	TSS, temperature, pH, turbidity; criteria met	None	—
Sediment Toxicity Tests	Sediment is cause of toxicity	None	Not statistically different from reference	—
Benthic Community	Oligochaetes abundant	None	Not statistically different from reference	Planned

8 Performance Evaluation

Collingwood Harbour was delisted as an Area of Concern in November 1994. The project was successful in reducing ecological risk. The project also demonstrated successful use of an innovative technology, the Pneuma pump, during remediation.

Since completion of remedial activities, additional fish and wildlife habitat rehabilitation and restoration activities have taken place in the harbor. The community has been involved with the Greening of Collingwood program and the Environment Network of Collingwood to continue environmental restoration work and environmental education begun by the Collingwood Harbour Public Advisory Committee and the Remedial Action Plan Team.

8.1 Meet Target Objectives

Sediments that demonstrated toxicity to benthic organisms have been removed from the harbor.

8.2 Design Components

A sediment removal demonstration was conducted in the fall of 1992, prior to the full-scale remedial cleanup. The demonstration evaluated the Pneuma airlift pumping system during the removal of 5,200 cy of sediment. Results of the demonstration proved useful in selected an appropriate dredge technology and determining sediment characteristics before the cleanup dredging.

Adequate baseline chemical characterization helped equate visual characteristics (blue hue of the clay material) as general confirmation of dredge success during the 1993 cleanup dredging without waiting for post-verification sampling.

Environmental quality monitoring was conducted for chemical and biological condition of sediment prior to and after dredging activities. Water quality monitoring was conducted during dredging to ensure sediment dispersion was minimized.

8.3 Lessons Learned

A pilot study was useful in predicting effectiveness of dredging and foreseeing potential problems and parameters. Public involvement through education and restoration activities also contributed to the success of the project. Contaminated sediment can be successfully removed using environmental dredging technologies. Beneficial use, measured via biological and chemical testing, can be restored in an industrial harbor.

9 Costs

The cost of the 1992 demonstration and 1993 cleanup dredging (9,548 cubic yards) was $635,000 with a unit cost of $67 per cubic yard.

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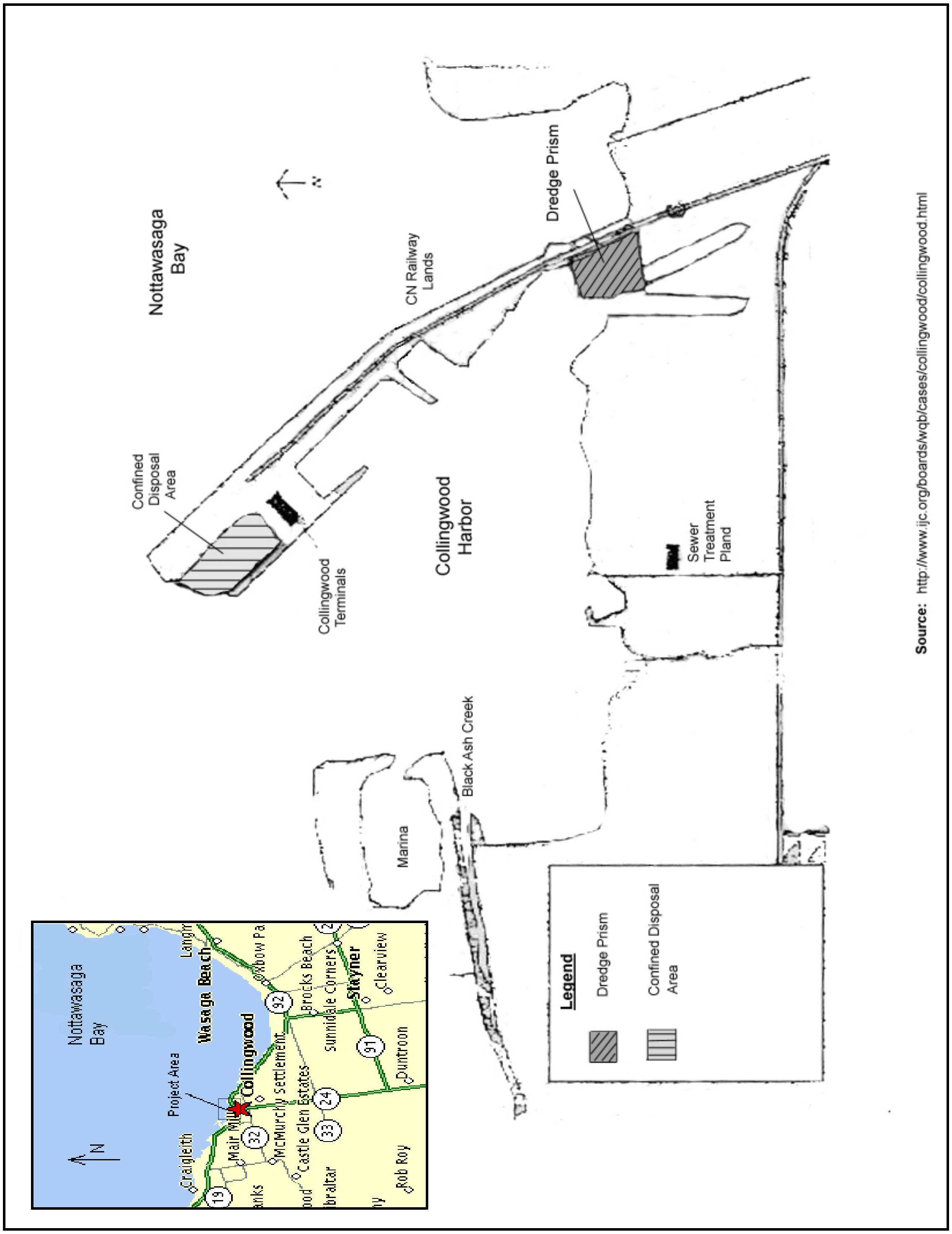
Figure 1 Remedial Dredge Plan - Collingwood Harbour



Source: http://www.ijc.org/boards/wqb/cases/collingwood/collingwood.html

1 Statement of the Problem

- Dredged 1997
- PCBs
- 27,000 cubic yards
- $220 per cubic yard

The Ford Motor Company dredged approximately 27,000 cubic yards (20,520 cubic meters) of PCB-contaminated sediment in 1997 from a "hotspot" located near their 48-inch discharge outfall adjacent to the shipping channel of the River Raisin. The EPA-selected remedy was to dredge the hotspot sediments to below the risk-based chemical criteria of 10 ppm polychlorinated biphenyls (PCBs). Contaminated sediment was stabilized with Portland cement and disposed of in a Toxic Substances Control Act (TSCA) landfill located on site. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The entire River Raisin Area of Concern (AOC) is a 2.6-mile section of the lower River Raisin located near the city of Monroe, Michigan, in the southeastern portion of the state (Figure 1). It extends from the Winchester Bridge (Dam #6) downstream to the receiving water body of Monroe Harbor and Lake Erie extending 0.5 mile out from shore. The Ford outfall site is located within the AOC. Although the site is located in the industrial center of Monroe on Ford Motor Company property, the adjacent terrain is relatively flat with a large portion composed of wetlands, woods, and Sterling State Park. The Ford outfall project site consists of the sewer system at the Ford plant and the River Raisin sediments in the proximity to the closed 48-inch and 36-inch outfalls at the plant (outfalls closed since 1972). The sediment removal area is located in proximity to the closed 48-inch discharge pipe, in an embayment adjacent to the River Raisin just downstream of the turning basin.

View of River Raisin

The river has an annual mean discharge of 728 cubic feet per second. Water depth ranges from 4 to 6 feet nearshore, sloping to 18 feet on the side slopes, then 30 feet in the navigation channel. River sediments consist of soft silty clay surface deposits with no cohesion (up to 2 feet thick) over soft to stiff organic silty clay (up to 9 feet thick) over hard glacial till (Metcalf and Eddy, 1994).

According to the U.S. Environmental Protection Agency (EPA), the Ford Monroe Stamping Plant manufactured automotive parts at the site starting in 1949 and discharged wastewater directly into the River Raisin via outfalls until the 1970s. In 1972, the old outfalls were closed and new ones constructed further downstream. The majority of wastewater was generated by cleaning, painting and plating processes containing PCBs.

3 Site Investigation

Both EPA and the Michigan Department of Environmental Quality (MDEQ) detected elevated PCB concentrations in samples collected from wastewater, fish, and sediment surrounding the wastewater discharge pipes between 1973 and 1992. After a Michigan State University Research team detected high concentrations of PCBs in sediments near the former Ford outfall pipe in 1991, the EPA issued an Administrative Order of Consent (AOC) to the Ford Motor Company (EPA, 1993). With EPA oversight, Ford conducted a remedial investigation to define the lateral and vertical extent of PCB contamination in this area known as the "hotspot." In 1993, sediment samples collected near the 48-inch outfall ranged from 1.5 to 29,000 ppm PCBs, and samples collected near the 36-inch outfall ranged from 5.8 to 180 ppm PCBs. Samples collected 300 feet downstream of the 48-inch outfall measured up to 120 ppm PCBs (EPA, 1995). In 1995, EPA conducted sediment sampling to determine if any hotspots were present in the river in addition to the hotspot located near the Ford outfall discharge pipe. Chemicals detected in these surface sediment samples included: PCBs, dioxins, furans, chromium, nickel and zinc. In 1997, MDEQ conducted additional sampling to further define the extent of sediment contamination at certain locations. Based on PCB contamination and perceived impact to fish and wildlife habitat, a Remedial Action Plan was issued by the Michigan Department of Natural Resources (MDNR) in 1987 for the River Raisin Area of Concern.

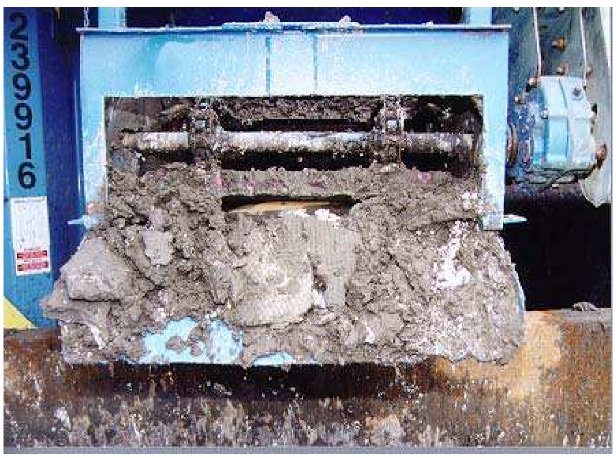
The Ford Outfall Site was identified for a Superfund Emergency Removal Action under the direction of EPA Region V using the Superfund Accelerated Cleanup Model (SACM). A final remedy plan was selected in August 1996. The SACM was intended to provide EPA with greater flexibility to clean up NPL-caliber sites with more efficiency. In 1998, after the 1997 remediation effort, MDEQ conducted sediment sampling to determine the success and extent of the PCB cleanup, and to determine if contamination was present further upstream.

Contaminants of Concern. The major contaminant of concern driving the cleanup actions was PCBs. The highest PCB concentrations were detected in sediment samples collected near the outfall pipe in 1991 measuring 42,167 ppm PCBs. Baseline sediment samples collected in 1995 measured maximum concentrations of 52 ppm and 140 ppm PCBs immediately downstream and 2 miles further downstream of the hotspot area, respectively. PCB-contaminated contaminants of concern included dioxins and trace metals measured in concentrations above the Ontario Ministry of Environment and Energy (OMEE) potential severe effects levels.

4 Target Goals and Project Objectives

The remedial project goals were to remove all contaminated sediment from a hotspot located near the outlet of the Ford plant's wastewater discharge pipe. The proposed hotspot measured 600 feet long to 200 feet wide and totaled 28,000 cubic yards of sediment. The target goals were twofold: 1) to dredge all sediment down to hardpan from within the dredge prism, and 2) monitor residuals for compliance with 10 ppm PCB cleanup criteria based on EPA risk-based cleanup criteria designed to be protective of fish and wildlife. Post-verification sediment sampling was used to measure dredging success. As stated in the AOC, the target goals were "respondent shall dredge and dewater all sediment that contains PCBs above 50 ppm"; however, this chemical criteria was changed to 10 ppm PCB based on EPA's streamlined risk assessment.

Long-term Project Objectives. Following redeposition from nearby areas, EPA expected residual hotspot concentrations to range between 10 and 30 ppm PCBs. These concentrations were considered protective of the larger fish exposure zone of the River Raisin AOC. As stated in the 1995 AOC, the long-term remedial action objective (RAO) was to reduce PCB concentrations in fish and to protect human health:



Filter Cake
Source: WDNR

> "A proposal to remove sediments down to the clay layer within the defined removal area was reviewed and recommended by the Sediments Group (EPA) to be accepted based on the estimates showing PCB levels left behind would likely reduce PCB contamination in biota to acceptable levels for human consumption." (EPA, 1995)

The amended 1997 removal decision document stated the long-term RAO was to:

> "Reduce potential threat to human health and the environment by reducing the mass of chemical constituents in the river sediment, sewer material, and soil at the site available for bioaccumulation via ingestion of contaminated fish." (EPA, 1997)

5 Project Design

Pre-planning and Bid Documents. The remedial design activities included environmental physical, chemical, and biological studies, physical characterizations, and subsurface sediment sampling to refine the horizontal and vertical extent of contamination. The AOC required an engineering evaluation/cost analysis (EE/CA) plan, a statement of work, a monitoring program, corrective action plan, contingency plans, performance standards, a completion of removal action report, pre-construction inspections, and a field sampling and analysis plan (SAP) and quality assurance project plan (QAPP). An EE/CA for the Ford Outfall Site was conducted in 1994 by Metcalf and Eddy that outlined the remedial alternatives, stated how each RAO would be performed to maximize success, operational steps to minimize resuspension of sediment, compliance with ARARs, sediment handling, and monitoring plans. The EE/CA recommended using the cable arm bucket based on site conditions (Metcalf and Eddy, 1994).

EPA contracted the U.S. Army Corps of Engineers (ACOE) to conduct oversight of the remediation effort. A district oversight work plan was approved to be used by the ACOE in conjunction with the bid documents and other contractors submittals to assure the PRPs performance was in compliance with the ROD.

Summary of Remedial Action Plan. In 1996, EPA selected a final remedy plan for the Ford outfall hotspot that included: dredging of contaminated sediment exceeding 10 ppm PCBs using a mechanical closed-bucket clamshell dredge, containing sediment resuspension with a silt curtain, transfer sediment to treatment area by barge and scow, solidifying/stabilizing the sediment with Portland cement, uploading and hauling of treated sediment to a TSCA-approved on-site disposal facility (sediment containment unit), monitoring air quality during dredging, establishing baseline conditions before dredging, and conducting post-verification sediment sampling. The remedy also called for additional upland plant and sewer investigations (IJC, 1999; EPA, 1998).

Limitations and Permits. None specified. However, all aspects of the water and sediment treatment system were tested prior to beginning full-scale remedial activities.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities operated from mid-July through the end of September 1997 (55 actual dredging/ redredging days out of 88 calendar days). Hours of operation were 8 hours per day, 5 days per week.

Equipment. A derrick barge equipped with a 6-cubic-yard environmental cable arm clamshell bucket with a vibrator and a 4-cubic-yard conventional clamshell bucket (when warranted) were used to dredge sediments from a 2.6-acre hotspot around the 48-inch outfall. A silt curtain was installed with anchor weights and “no wake” buoys. The clamshell bucket dumped dredged sediment into an 800-cubic-yard-capacity three-compartment scow barge, then wet sediments were transferred into sealed tandem dump trucks by an overhead crane and slim-profile cable arm bucket. Bobcat loaders, front-end loaders and excavators were used to transport sediments from different upland areas. A silt screen made of geotextile fabric was placed around dredging operations from the water surface own to a few feet above mudline to minimize sediment transport downstream. The curtain was installed with anchor weights and “no wake” buoys.

Total Volume Removed and Production Rates. Approximately 27,000 cubic yards of contaminated sediment (34,724 tons) was removed and treated from the Ford outfall hotspot in 1997.

Site-specific Difficulties. In August 1997, a 634-foot-long cargo vessel generated prop wash while turning around in the burning basin causing damage to the silt curtain. The silt curtain required repair before resuming activities. Resuspension caused sediment to remain in the center of the river despite numerous dredging attempts to remove all sediment down to native material. According to MDEQ, possible explanations for dredging difficulties included: 1) operator carelessness, and 2) cargo ships passing through the dredging area disturbing the water column.

6.2 Dewatering and Water Treatment Operations

Wastewater from the scow was pumped into a holding tank before processing at the on-site wastewater treatment facility (WWTP) equipped with sand filters. Treated water was released back to the River Raisin after passing water quality testing of PCBs. As of 1997, the wastewater treatment plant remained on site to continue treatment of leachate water pumped from the sump area of the sediment containment unit (SCU) (ACOE, 1998).

Air Monitoring Equipment
Source: B. Paulson, WDNR

6.3 Storage and Disposal

Wet sediments were temporarily stockpiled on land-based pads. An excavator transported sediment into a shaker/screen then conveyored to a pugmill power screen, which fed directly into a pugmill hopper. The pugmill homogenized the PCB-contaminated sediment with reagent. Treated sediments were stockpiled for curing then disposed of in a 3-acre TSCA cell that was built on the property of the Ford Monroe Plant. The TSCA cell was located within a larger 32-acre on-site landfill. The sediment containment unit (or TSCA cell) was covered with a geotextile cap and leachate will continue to be collected and treated on site through the WWTP.

7 Environmental Monitoring Program

The environmental monitoring program included baseline sediment sampling, air and surface water quality sampling during dredging, and post-verification sediment sampling. Bioaccumulation studies in caged and resident fish were also conducted after the 1997 dredging. Verification of monitoring success was based on sediment sampling chemical criteria. The monitoring program also included a corrective action plan, a contingency plan, and field SAP and QAPP.

7.1 Baseline

Physical. According to the EE/CA, "hydrography surveys will be performed prior to sediment removal to locate the river bottom and the underlying clay layer."

Chemical. In 1995, EPA collected 22 sediment cores from the River Raisin AOC to depths of 2 to 6 feet below mudline to determine if any additional hotspots (beyond Ford Outfall) were present in the larger AOC. In May/June 1997 (a few months before remediation of the Ford Outfall hotspot), MDEQ collected 27 sediment cores to refine the extent of PCB contamination in the River Raisin AOC identified in the 1995 study. Samples collected from both the 1995 and 1997 study were analyzed for a multiple classes of analytes in addition to PCB Aroclors; however, none of these samples were collected within the Ford Outfall hotspot area. The downstream sediment sample collected closest to the hotspot area measured 52 mg/kg PCB Aroclor 1242 in the surface interval while the average downstream concentration for all samples was 14.9 mg/kg PCB Aroclor 1242 in 1995. The maximum detected concentration in the upstream samples was 9.0 mg/kg PCB Aroclor 1242 with an approximate average of 1.0 mg/kg PCB 1242. The 1997 samples are not discussed because the detection limits were an order of magnitude higher than the 1995 samples and comparable to neither the 1995 nor 1998 data (MDEQ, 1999).

Air monitoring for PCB particulates was conducted at three ambient stations placed upwind and downwind from the exclusion zone. Five 24-hour samples taken at 6-day intervals were collected prior to the removal action for determining background concentrations.

Biological. Caged fish monitoring was conducted in 1988 and 1991 by MDEQ. Details of the sampling events were not available for review.

7.2 Implementation During Dredging

Physical. A turbidity monitoring program was established to monitor potential resuspension of sediments during dredging. Turbidity in the water column was measured twice per day at one upstream and one downstream location of the sediment removal area (SRA) at two vertical depths (mid-depth and just above mudline). Water column samples were also analyzed for PCBs, but discontinued because the action levels to trigger additional monitoring were not exceeded. There were reportedly no major violations of the compliance parameters and no adjustments to the dredging plan were made based on compliance measurements.

Chemical. As specified in the remedy, air and water column monitoring was to be conducted during dredging, but no details were available for review. No biological testing was performed during dredging.

As stated at the hudsonwatch website, “as soon as re-dredging in a dredge-cell was completed, re-sampling of the cell floor and/or sideslopes was performed for confirmation. In a few dredge cells, re-dredging and re-sampling were performed several times. Post-verification surface ponar grab samples were collected from the dredged area, and confirmatory sample results from all 14 dredge-cells indicated the AOC target cleanup goal of 50 ppm PCBs was met. Confirmation sideslope sample results also indicated that the U.S. EPA target cleanup goal of 10 ppm was met (specifically the sideslopes).”

"The redredging effort went essentially to bedrock. Often the remaining sediment being dredged consisted of a 2- to 6-inch layer of highly liquid sediment. The redredging effort was assisted by diver inspections."

Water quality monitoring for turbidity was conducted twice daily upstream and downstream of the dredging activities (collected mid-depth).

Air monitoring for PCB particulates consisted of daily collection of 24-hour composite samples over a 2-week period, then every third working day, from three ambient stations. No significant exceedances of the 0.01 $\mu g/m^3$ PCB action level were reported. Action levels were determined by readings above the Threshold Limit Value (TLV) set by the American Conference of Governmental Industrial Hygienists (ACOE, 1998).

A wastewater treatment plant was used at the site for water treatment during the project. Analytical results indicated that effluent met discharge requirements for the project before discharge to the River Raisin (ACOE, 1998).

7.3 Post

Physical. Final pole soundings were conducted in all areas after redredging. According to the ACOE on-site representative, sediment was dredged to the design depths and dimensions indicated on the remediation drawings (ACOE, 1998).

Chemical. After completion of redredging (September 26, 1997), a verification sediment sample for lab analysis was collected near the center of each of the 14 dredge-cells that constituted the 2.6-acre target area. Surface grab samples were collected using a ponar sampler and compared to the 10 ppm target cleanup level. In seven of 14 cells, insufficient sediment remained for sample collection. In four of 14 cells, the final sample was less than 10 ppm PCBs (0.5 to 7 ppm range). In three of 14 cells, the final sample was greater than 10 ppm (12 to 20 ppm range).

In 1998, MDEQ collected sediment samples from 20 stations to determine post-dredge conditions. Two surface sediment samples (0 to 6 inches and 0 to 18 inches) were collected from within the dredged hotspot area with measured concentrations of 64 mg/kg and 110 mg/kg PCB Aroclor 1242. The sediment samples located downstream of the hotspot removal area ranged from non-detect to 32 mg/kg PCB Aroclor 1242 with an average of 6 mg/kg. The 1998 average downstream concentration of PCB Aroclor 1242 is 2.5 times lower than the average 1995 sediment concentration. All other Aroclors were non-detect (MDEQ, 1999).

Biological. Habitat or benthic abundance was not monitored in the River Raisin immediately after dredging.

7.4 Long Term

Post-monitoring activities are ongoing by MDEQ and include sediment cores, caged fish bioaccumulation studies, and resident fish tissue analysis for PCB concentrations (MDEQ, 1998a and 1998b; GE/AEM/BBL, 1999). Caged fish were placed at three locations in the Raisin River in 1998 to evaluate results of the removal project. Cages were placed at the Grand Trunk Railroad Bridge (upstream), downstream of the turning basin (near dredging site), and at the mouth of the river. Total PCB concentrations in tissue were highest at the mouth (0.01 to 0.67 ppm). Concentrations were significantly different ($p < 0.05$) between sites (MDEQ, 1998).

Table 1 Summary of Monitoring Results

Test Parameters	Monitoring (maximum concentration of PCB Aroclor 1242 in ppm)				
	Baseline 1988	Baseline 1991/1993	Pre-dredge 1995	Post-dredge 1997	1998
Physical				met design depth	
Surface Sediment (maximum)		29,000 ppm		20 ppm (all below 50 ppm)	110 ppm (average 10 ppm)
Fish Tissue (net uptake) [1]	4.06	1.07			0.6678

Note:

[1] Net contaminant uptake in caged fish from mouth of river (MDEQ, 1998).

8 Performance Evaluation

8.1 Meet Target Objectives

The target goal of mass removal of contaminated sediment down to the clay horizon (native) with verification sampling to 10 ppm PCBs was achieved in 80 percent of the dredge cells. Progress towards risk reduction of PCBs to human health and the environment was observed by a 263-fold reduction in maximum PCB concentrations from baseline conditions and a 0.6-fold reduction in fish tissue concentrations. Design elevation was achieved based on physical and chemical monitoring data. The post-verification sediment sample chemical concentrations were below the compliance criteria, therefore the remedial dredging objectives were met.

As stated in the Hudsonwatch website, "Confirmatory sample collection activities in many dredge-cells were revealing that sediment remained, even through prior dredging to refusal had occurred. A review of information from dredging, sampling, and the dive inspection of the silt curtain, identified the following suspected sources of remaining sediment:

- Sediment deposited due to passage of unauthorized lake freighter;

- Recent sediment deposition following resuspension during dredging;

- Sloughing of sediment outside of the dredge prism along the base of the silt curtain into the dredge area; and

- Sloughing of sediment along the slope from the nearshore shelf to the deeper dredged channel" (GE/AEM/BBL, 1999).

As stated in a letter from Mike Collins of the EPA to the Ford Motor Company, "Based on agency oversight, final reports, and inspection reports, I concluded that the Ford Motor Company has completed the following work required by the AOC..." (EPA, 1999). However, Roger Jones of MDEQ collected two samples on September 22, 1998 that exceeded the target goal of 50 ppm PCBs. MDEQ believes the extent of remaining contaminated sediment should be quantified.

8.2 Design Components

During preliminary negotiations, EPA did not consider other options besides dredging as a remedial alternative. They were interested in source control and minimizing downstream transport of PCB hotspots further downstream and into Lake Michigan. With this in mind, the project engineers considered different dredging technologies, site conditions, limitations, and existing data. However, based on the 1997 post-project sediment sampling (N = 14) where results ranged from 0 to 20 mg/kg PCBs, when compared to the 1998 sampling event (N = 2) where results were 64 and 110 mg/kg PCBs, it appears that: 1) source control has not been achieved, or 2) ridges and furrows exist within the former hotspot with patchy concentration distributions. It is likely that source control was not achieved, since resuspension, redeposition, sloughing of sideslopes, and potential upstream sources of PCBs were anticipated. This dredging project may have proceeded in haste (to show significant progress within the Superfund framework) without adequate consideration of site conditions in the project design. However, the target goal was to remove all hotspot sediments down to native horizon, which was achieved and implementable within the framework of the larger AOC (River Raisin).

8.3 Lessons Learned

After initial dredging to refusal, confirmation sediment samples revealed thin layers of sediment remained on the bedrock resulting in several additional passes with dredge equipment. Other sources of sediment deposition included: passage of an unauthorized lake freighter, resuspension during dredging, and sloughing of material from adjacent sideslopes.

As dredging activities approached the hardpan layer, dredged material consisted of a mixture of sediment, rock and hard clay. These harder materials clogged the treatment system and slowed the treatment process. A comprehensive understanding of site conditions and sediment properties is necessary to adequately design a dewatering and treatment system capable of handling the dredged material.

Communication with surrounding industries, interest groups, and nearby residents is essential to completing a successful dredging project within the vicinity of multiple land uses. The unauthorized passage of a lake freighter that utilized the turning basin immediately upstream of the dredging activities and passed over the silt curtain, thereby disturbing the silt curtain, may have been avoided through public awareness and coordination with local industries.

9 Costs

The total cost for dredging, treatment and disposal on site was projected to be $5.17 million and the actual cost was approximately $6 million ($220 per cubic yard). Estimated cost for out-of-state disposal at a TSCA landfill was $15.29 million (not implemented).

10 Project Contact

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Lead Agency: U.S. EPA
Design Engineer: Metcalf and Eddy
General Contractor: Sevenson Environmental Services
Dredge Contractor: Luedtke Engineering Company
Oversight: ACOE and MDEQ

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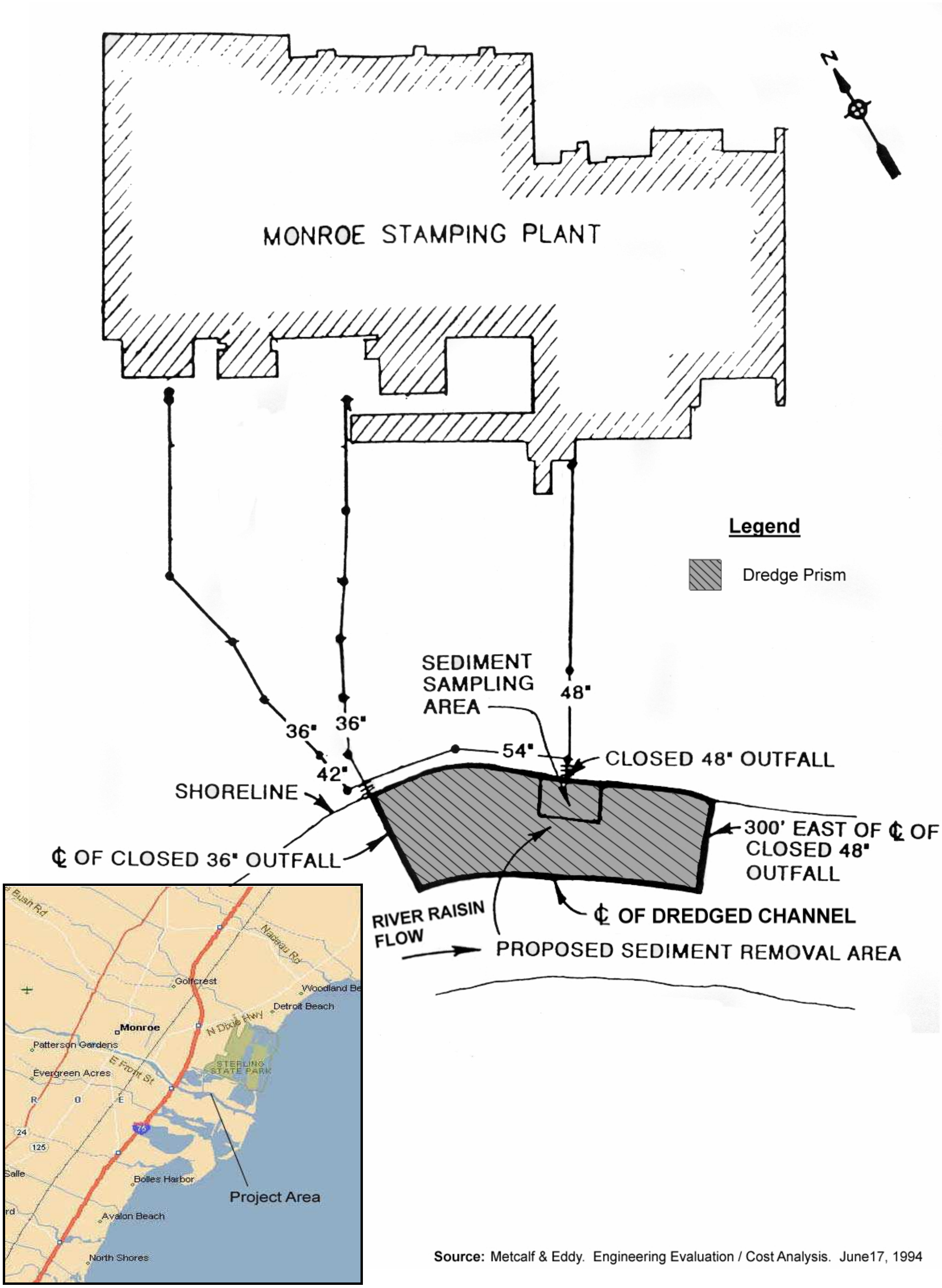
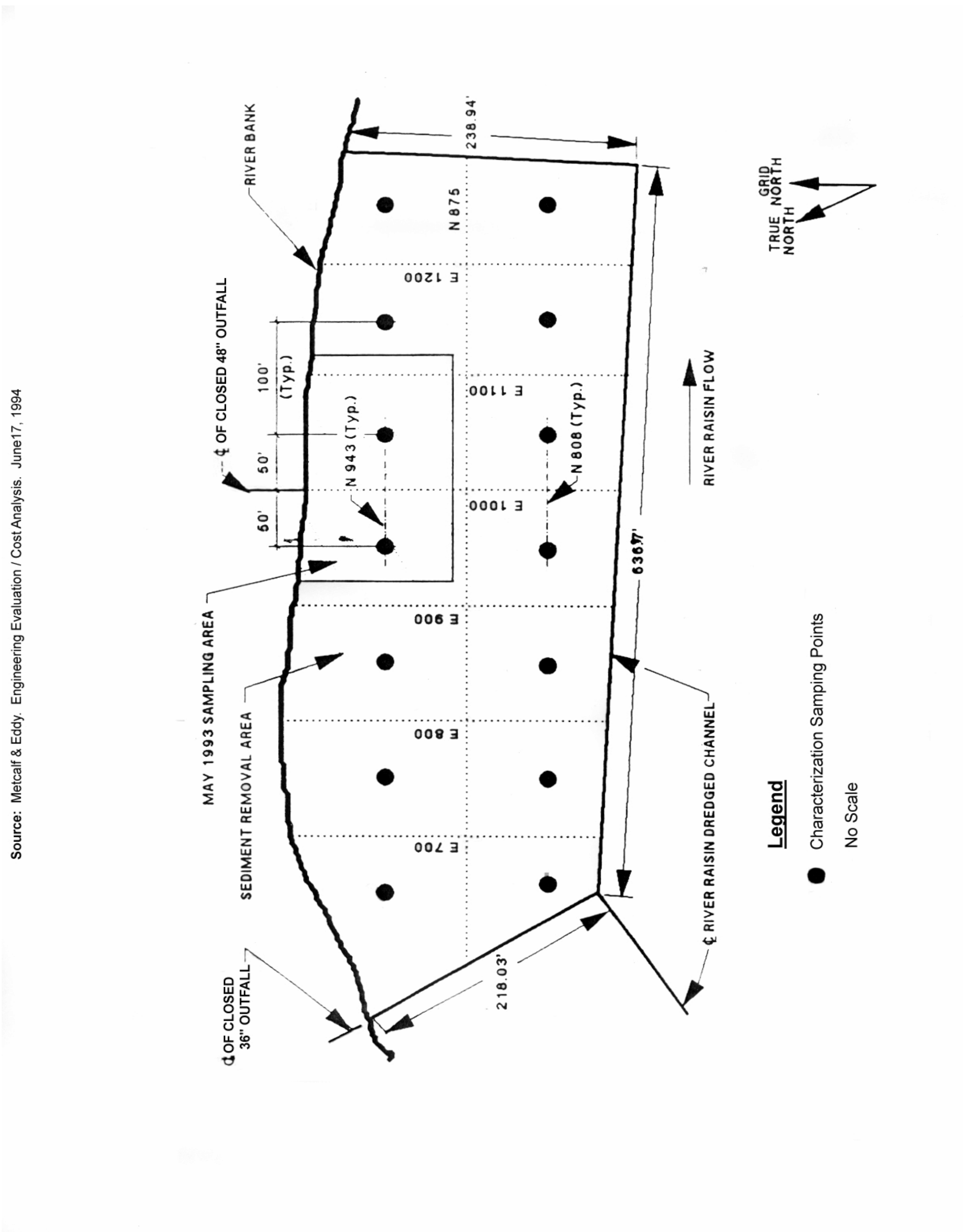
Figure 1 Ford Outfall Dredge Prism



Source: Metcalf & Eddy. Engineering Evaluation / Cost Analysis. June17, 1994

Figure 2 Ford Outfall Dredge Prism/Sampling Locations



1 Statement of the Problem

- Dredged 1998–1999
- PCBs
- 8,175 cubic yards
- $525 per cy total

Deposit N, located in the Lower Fox River near Kimberly, Wisconsin was contaminated with polychlorinated biphenyls (PCBs) from multiple industries and paper mill facilities. Maximum concentrations detected in surface sediment samples were 186 mg/kg dry-weight PCBs. Deposit N, along with other deposits in the Lower Fox River, resulted in fish consumption advisories for the Fox River. This priority deposit, approximately 3 acres in size and 11,000 cubic yards in volume, was identified by Wisconsin Department of Natural Resources (WDNR) for a pilot demonstration removal project for the larger Fox River RI/FS project. The selected remedy was 100 percent removal of contaminated sediment to a design depth of 3 to 6 inches above bedrock using a hydraulic cutterhead dredge. Remedial activities were conducted in 1998 and 1999. As a pilot study, the target goal of the dredging project was to achieve mass removal of PCB-contaminated sediment down to the design elevation and to assess the protectiveness of environmental dredging in removing PCB contamination. The project objective was to use the information gained to assess appropriate remedial technologies, effectiveness and implementation of the selected technology and costs for a large-scale remedy of the Lower Fox River.

2 Site Description

Deposit N is part of the Lower Fox River/Green Bay remedial investigation/ feasibility study (RI/FS) project located in Wisconsin on the western shores of Lake Michigan. The Lower Fox River extends 39 miles from Lake Winnebago to Green Bay, Wisconsin, draining 2,445 square miles. Twelve dams impound the once navigable river as it drops approximately 158 feet in elevation from the lake down to the De Pere dam. The Deposit N project area is approximately 3 acres in size, 0.25 mile wide, and 11,000 cubic yards in volume. The surrounding area is a mixture of paper mill industries, residential, and undeveloped land. Water depths at the location are generally 8 feet deep and the average sediment thickness prior to removal was 2 to 3 feet. The mean annual Fox River discharge recorded in 1994 was 4,252 cubic meters per second (120 cubic feet per second). Site sediments were generally soft, silty clay in the western lobe and sandy in the eastern lobe averaging 2 to 3 feet thick over fractured bedrock with scattered boulders near the shorelines (ThermoRetec, 2000).

3 Site Investigation

In 1995, an RI/FS investigation characterized Deposit N as an elongated point bar deposit just offshore in Inter Lake Papers Company Site (SAIC, 1996 and 1997). A final Record of Decision (ROD) for remedial action will be addressed after release of the river and bay-wide RI/FS data reports. The lead agency is WDNR with financial support from the U.S. Environmental Protection Agency (EPA).

Contaminants of Concern. The primary contaminant of concern was PCBs from the production of carbonless copy paper by the paper mill industries located along the shoreline of the Fox River. Other contaminants include mercury and heavy metals. PCBs were measured as high as 186 ppm and mercury was measured up to 4.7 ppm. Contaminated sediment was contained primarily in the soft silts (0 to 3 feet thick) overlying fractured bedrock.

4 Target Goals and Project Objectives

The target goals of the pilot study were to achieve sediment removal by hydraulic dredging down to a design depth of 3 to 6 inches above bedrock. No target chemical cleanup criteria was required in the project specifications since detectable PCB concentrations were expected from residual sediment resting on the hard fractured bedrock after dredging activities. The thin residual layer was considered during the design phase to gain the highest removal efficiency for the cost. Without the ability to overdredge and remove residual sediments, the target goal of sediment mass removal within the dredge prism was a viable design. No long-term project objectives were specified except to aid in the future refinement of remedial alternatives for the Lower Fox River project.

5 Project Design

In late 1997, the pilot study was initiated on behalf of WDNR and EPA.

Dredge and Silt Curtain
Source: B. Fitzpatrick, WDNR

Pre-planning and Bid Documents. Extensive physical and chemical laboratory testing was conducted to simulate dredging and filling activities and to predict the fate and transport of site chemicals. Tests included: sediment dewatering bench tests, water treatment, filter press, stabilization bench tests, whole effluent toxicity tests and TSS/turbidity correlation tests (Foth and van Dyke, 2001). The pre-design project work provided the foundation for the construction performance specifications for Deposit N. A design engineer prepared and issued competitive bid specifications and bid documents. The contracting strategy centered on a performance-based contract that contained specific performance criteria, but allowed the contractor flexibility to modify remedial strategies while maintaining performance standards. The lowest qualified bidder was awarded the contract. A project quality assurance project plan (QAPP) was developed by the contractor that provided the field and laboratory quality objectives for monitoring work, and defined sampling procedures, equipment, and corrective action responsibilities.

Pre-removal activities also included acquiring state and federal permits, access agreements, and an environmental assessment. Permits included: a Wisconsin Chapter 30 permit for dredging, an ACOE nationwide permit for dredging and barrier construction in federal waters, a WPDES permit for effluent discharge back to the river and solid waste disposal plan modification approval for TSCA-level waste disposed to approved Wisconsin state solid waste landfills (approved by EPA) (Foth and Van Dyke, 2001).

Summary of Remedial Action Plan. Overall, the remedial action entailed construction of a special containment system around the deposit to prevent transport of resuspended sediments, wet excavation of subtidal sediments using a hydraulic cutterhead dredge, treatment of extracted sediment slurry with sieve screens, hydrocyclones, and filter presses, stabilization of sediments with polymer, and off-site disposal of material to an upland landfill. Water separated during the sediment treatment process was discharged back to the river after chemical testing (Foth and Van Dyke, 2000).

Limitations and Permits. Dredging activities ceased during the winter months because of ice and freezing weather conditions.

6 Remedial Action

6.1 Dredging

Schedule and Duration. Equipment was mobilized to the site in October 1998 and work continued until December 31, 1998 (holiday off) when operations ceased for the winter from sub-zero weather conditions. Dredging operations resumed the following summer from August 20, 1999 to October 14, 1999. Dredging operations occurred for 104 days. Operation hours were 24 hours per day during the 1998 activities and 10 hours per day during the 1999 dredging activities. Dredging time averaged an aggregate of 3 to 5 hours per day (Foth and Van Dyke, 1999, 2000 and 2001; ThermoRetec, 2000).

Hydraulic Cutterhead Dredge
Source: B. Fitzpatrick, WDNR

Equipment. Sediment removal was conducted using an 8-inch Moray/Utra hydraulic cutterhead dredge with a swinging ladder configuration, rotating, variable speed cutter, and an intake/suction line. The slurry material was pumped from the dredge to the onshore treatment facility through an 8-inch-diameter, double-walled (1998 only), high-density polyethylene (HDPE) pipeline (Foth and Van Dyke, 2000). Percent solids of dredge slurry ranged between 0.4 and 6 percent with an average of 2 percent based on 1998 data (ThermoRetec, 2000). Sediment resuspension and transport

Dewatered Filter Cake
Source: B. Fitzpatrick, WDNR

was minimized by placement of a perimeter turbidity containment barrier consisting of 80-mil HDPE anchored to the bottom, weighted to the bottom with rail lengths placed in manufactured pockets and suspended at the water surface with 12-inch-diameter floats. In addition to the perimeter barrier, two other barriers were also installed: a deflection barrier and a silt curtain. During the 1999 operations, the perimeter curtain was not deployed; only the silt curtain and deflection barrier were used during the 1999 dredging work.

The summary report stated "for final dredging cleanup work close to the bedrock, the dredge was modified by extending the suction pipe mouth inside the cutterhead and reducing the area of the mouth opening by 15 percent to increase vacuum pressure." With additional funds and time leftover after meeting project design requirements, additional supplemental dredging was conducted in the western lobe to remove additional soft sediments resting on bedrock (Foth and Van Dyke, 2000).

Total Volume Removed and Production Rates. A total of 8,190 cubic yards of sediment were removed (6,470 tons of dewatered sediment and removal of 112 pounds of PCBs from the Fox River). The estimated dredge prism volume was approximately 11,000 cubic yards, but the target volume was 7,060 cubic yards to allow for the residual volume left on the riverbed as specified in the removal contract. A small area adjacent to the shore was not dredged due to the presence of coal and large boulders resting on the riverbed. Of the volume removed by the project, 7,160 cubic yards was removed from Deposit N and 1,030 cubic yards was removed from Deposit O.

Following the removal to specifications at Deposit N and the supplemental dredging of the western lobe, the contractor was authorized to perform additional sediment removal of an adjacent deposit called Deposit O. Additional work at Deposit O was approved to take advantage of the mobilized equipment and existing permits for the work. Approximately 1,030 cubic yards of low level PCB contaminated sediment was removed from Deposit O over a three-week period. Approximately 1 pound of PCBs were removed in the sediment from Deposit O.

Site-specific Difficulties. None that impacted the overall success of the project. The presence of shallow bedrock was a known factor that was anticipated in the project design and as expected did slow production. To collect post-verification samples, divers had to look in cracks/crevices of the fractured bedrock and underneath boulders to find adequate sample volume for testing.

6.2 Dewatering and Water Treatment Operations

Extracted sediment slurry from the barge was screened through a 0.375-inch shaker screen to remove debris and gravel fractions. Remaining slurry was pumped into a settling tank then pumped into two hydrocyclones to remove the sand fraction (greater than #200 sieve). The remaining material was conditioned with a polymer in mixing tanks to increase percent solids, and pumped into two 200-cubic-foot filter presses for compression at 200 pounds per square inch (psi). Project specification requirements for 50% solids in the dewatered sediment were achieved by the treatment process (Foth and Van Dyke, 2001). The compressed solid material was stockpiled and tested for PCBs, mercury, and percent solids. Water separated during filter presses was treated through solid sand filtration and liquid-phase carbon adsorption prior to testing and discharge back to the Fox River.

Water Quality Monitoring of Discharge. Prior to discharge back to Fox River, water was tested for PCBs, TSS, ammonia, mercury, priority pollutants, and whole effluent toxicity testing. The discharge pipe was configured to satisfy a Wisconsin Pollutant Discharge Elimination System (WPDES) zone of discharge requirement. Monitoring demonstrated no exceedances of WPDES permit requirements.

6.3 Storage and Disposal

Dewatered sediment and debris were loaded into haul trucks using a front-end loader. Based on the PCB concentrations of dried sediment relative to TSCA standards, the material was transported to either Winnebago County Landfill (PCBs less than 50 ppm) located 28 miles from the site, or the Wayne Disposal Landfill in Bellevue, Michigan (PCBs greater than 50 ppm). During 1999, all dredged sediments were transported to the Winnebago County Landfill.

7 Environmental Monitoring Program

The environmental monitoring program included surface sediment sampling, water quality monitoring during dredging, and post-verification surface sediment sampling (FRRAT, 2000) (Table 1).

7.1 Baseline

Physical. Bathymetric surveys were conducted during the RI/FS investigations to determine sediment stratigraphy, topography, and soft sediment thickness. Surveys were also conducted prior to mobilization to the site to determine compliance criteria for dredging activities. Turbidity meters were placed at six locations to monitor water quality during dredging operations and establish baseline turbidity conditions

Chemical. Both prior to and shortly after dredging in both the west and east lobes of the deposit, surface sediment samples were collected by divers to provide data on PCB mass removal. Although PCB target concentrations were not required in the project specifications, the average pre-dredge PCB sediment concentration in Deposit N was 11.7 ppm, with a maximum of 85.4 ppm and approximately 82 percent of the PCB mass was removed. A plot of PCB mass at Deposit N over a defined area (PCB pounds per square yard) showed considerable reduction in available mass of PCBs to the aquatic environment.

Biological. Caged fish studies were conducted in October and November 1997 for PCB Aroclors. Numerous resident fish tissue bioaccumulation studies have occurred between 1988 and 1996 including the 1989/1990 Green Bay mass Balance Study, the WDNR fish contaminant advisory study, the USGS water quality assessment program, the 1996 RI/FS WDNR fish tissue data collection, the 1996 BBL fish tissue data set, and the NRDA 1996 fish tissue collection study by the USFWS. Results of these studies are currently being folded into an ecological and human health risk assessment in support of remedial alternatives for the RI/FS Lower Fox River project. Nine species of fish (carp, walleye, yellow, perch, alewife, common shiner, emerald shiner, gizzard shad, golden shiner, and rainbow smelt) were analyzed for total PCBs, PCB congeners, and other constituents of concern and are included in various food web models developed for each river reach.

7.2 Implementation During Dredging

Physical. Turbidity meters were placed at six locations to monitor water quality during dredging operations and establish baseline conditions. Turbidity results in the vicinity of operations showed a range averaging less than 2 to 4 NTUs above the background upstream stations and showed that on average, dredging produced little change to river turbidity.

Chemical. No sediment sampling was specified. Air quality monitoring was conducted during the 1998 activities with four real-time, particulate monitors surrounding the land-based treatment operations. Air sample results complied with site standards.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. A bathymetric survey was conducted to document the final topography of the project area using similar methods described in the progress section.

Chemical. Post-verification sediment sampling was conducted immediately after dredging before equipment was demobilized. The average PCB sediment concentration in Deposit N was 7.5 ppm, with a maximum of 43 ppm. After the supplemental dredging effort to try and remove the residual layer of soft sediment resting on bedrock (before demobilization, but not required in the project plans), sample collection was difficult at many stations since bedrock was exposed. Divers had difficulty collecting adequate sample volume and had to look in cracks/crevices and underneath boulders to find sediment. The maximum PCB concentration detected was 130 ppm.

Biological. No biological testing was conducted after dredging.

7.4 Long-Term

Long-term monitoring of the dredging activities at Deposit N will be developed as part of the overall remedial design program for the Lower Fox River and Green Bay project. A long-term monitoring plan for Deposit N has not been developed yet.

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration (in ppm)		
	Baseline 1988–1997	During Dredging 1998–1999	Post 1999
Bathymetry	Conducted	None	Met target depth 3 in above bedrock (west) 6 in above bedrock (east)
Surface Sediment	Avg = 11.7 ppm Max. = 85.4 ppm 1994 max. = 186 ppm PCB mass = 130 lbs (60 kg)	None	Avg. = 7.5 ppm Max. = 43 and 130 ppm PCB mass = 24 lbs (11 kg)
Treated Water Effluent	None	No exceedances of WPDES parameters	None
Water Column [2]	Detectable PCB concentrations up and downstream	Daily during dredging, 20–28 NTU Non-detects up and downstream	None
Air Quality	Yes	Daily at treatment site; no exceedances	None
Caged Fish [1] N=9	Collected upstream, downstream, and on deposit	None	None

(1) Caged fish data collected in 1997 only.

(2) FRRAT, 2000; B. Paulson, 2000.

8 Performance Evaluation

8.1 Meet Target Objectives

The pilot dredging project met the depth and volume target goals specified in the design specifications. The target goal was to remove all sediment (7,065 cubic yards) with the dredge prism to within 3 to 6 inches of the hard bedrock. The actual depth achieved in some areas was to less than 3 inches of bedrock and the actual volume removed was 7,149 cubic yards. Overall, 82 percent of the PCB mass (49 kg) was removed from Deposit N. Post-verification sediment samples from the dredge prism measured elevated PCB concentrations; however, a chemical compliance criteria was not a specified target goal for this project. Long-term project objectives were defined as engineering and design components that will assist in the selection of the final remedial design. Long-term objectives were not evaluated in this review.

8.2 Design Components

Several design components including performance-based dredging contract, adaptive dredging management and flexibility enabling the contractor to specialize their approaches, bench-scale tests to determine sediment properties prior to dredging, allowing a thin layer of soft sediments to remain on top of the bedrock, and positive communication and outreach to the public community, all likely contributed to the success of this remedial pilot project.

8.3 Lessons Learned

Cost management. Dredging costs were controlled in the planning stages by reviewing site conditions, current dredging technologies, and bench-scale tests, and then pooling these results into a cost/benefit analysis. Dredging efforts and costs were managed by defining realistic project goals (i.e., significant reduction in PCB mass at the surface exposed to the aquatic environment). If PCB concentrations in surface sediments were the primary method for determining dredging success (as opposed to mass reduction), then contractors would have been compelled to spend significant time, money, and effort to vacuum up residual sediments resting on bedrock that often prove too difficult to isolate and remove.

Verification sampling. In addition, when residual sediments were successfully removed to bare bedrock, it was difficult to acquire a sediment verification sample. In response to the difficulty of obtaining post dredge samples, divers were allowed to deviate from the original sampling plan and QAPP by moving off predetermined sampling stations to search the cracks and crevices for adequate sample volume thereby adding "bias" to the surface-weighted residual concentrations. It retrospect, verification sampling methods that stayed with the original sampling plan would have avoided some of the sample collection bias and probably yielded lower overall post project PCB results.

Mass balance approach. The Fox River Remediation Team (FRRAT, 2000), evaluated the effectiveness of environmental dredging at Deposit N using multiple mass balance approaches (deposit mass balance, process mass balance, river transport) with the following results:

Process	PCB Concentration [1]		
	Median μg/g	**Load (kg)**	**% of slurry**
(Initial) Dredge Slurry	192 μg/l	17	NA
Press Cake	19	16.5	16.5/17
Sand Pile	5	0.55	0.55/17
Debris Pile	1.2	0.21	0.21/17
Filter Bags	37.5	0.005	0.005/17
Sand/Carbon	0.95	0.09	0.09/17
Effluent	4.5 μg/l	0.0002	0.0002/17
Estimated Net Loss Downstream	2.2 kg out of dredge area		
Estimated Upstream Loading into Area	0.8 kg PCBs		

[1] FRRAT, 2000. Measured between Nov 26, 1998 - Dec 30, 1998.

Conclusions and recommendations presented in the Deposit N project reports that will be useful during development of remedial alternatives for the Lower Fox River/Green Bay project included:

- Turbidity monitoring was not an accurate measurement of downstream PCB transport during dredging. Low suspended solids concentrations did not correlate well with PCB concentrations in the water column. Monitoring required actual measures of PCB levels in the water column and a mass balance study of PCB residuals to obtain accurate measurements of net transport (Fox River Remediation Advisory Team, 2000). The mass balance study estimated that the resulting press cake material contained 96 percent of the PCBs removed from the deposit and that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river. The mass balance model did not measure an overall increase in mass of particles transported downstream during dredging (TSS), however, the PCBs transported on the particles did increase (increased net load of 2.2 kg PCB during the active dredging period).

- Due to the presence of a hard bedrock substrate located beneath the soft sediments, the target goal of the demonstration project was to remove contaminated sediment down to a design depth of 7.5 to 15 cm (3 to 6 inches) above bedrock. Approximately 5,475 m^3 (7,160 cy) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (F&VD, 2000). Overall, 82 percent of the PCB mass was removed from Deposit N and approximately 31 kg (68 pounds) of PCB remained in the sediments that were not accessible to dredging activities. (F&VD, 2000).

- The Deposit N pilot dredging project met the depth and volume target goals specified in the project plans (dredge to within 3 inches of bedrock). Over 82 percent of the PCB mass was removed from Deposit N. The post-dredge average residual PCB concentration was 7.5 ppm (40 percent reduction from 11.7 ppm avg). Sediment removal to bedrock (from 3 inches to bedrock) was time-consuming and inefficient with very low percent solids content in the dredge slurry.

- Standard water treatment technologies were capable of meeting effluent requirements.

- The silt curtains at Deposit N were occasionally disturbed by passing ships and required immediate repair. Elevated PCB levels were measured in the water column downstream of dredging during this occasions. However, overall the silt curtains were effective barriers minimizing downstream transport of PCBs to a net load of 2.2 kg during dredging operations (<2 percent of the 142 kg mass in the entire deposit).

9 Costs

The dredging, monitoring, treatment, disposal, public outreach, and extra 1999 mobilization costs for this pilot study were approximately $4.3 million ($525 per cubic yard). This disposal costs totaled $654,000 and the specific unit cost in the construction contract for dredging was $20.70 per cubic yard. A post project analysis of the project costs noted that Deposit N as the first of the PCB cleanup projects on the Fox River, had incurred significant a typical project costs that are not likely representative of what a similar future project of this scale would cost (Foth & Van Dyke, 2000). The report noted that expenses for a public visitor area and outreach ($150,000), redundant in-river environmental controls (e.g., $500,000 plastic containment system used in 1998) that one would likely avoid in a more routine project results in an estimated cost for a future sized project of about $250 per cubic yard. Foth & Van Dyke also estimated that a larger 100,000 cubic yard project at a similar site could be expected to be performed for $200 per cubic yard under the type of conditions encountered at Deposit N.

10 Project Contact

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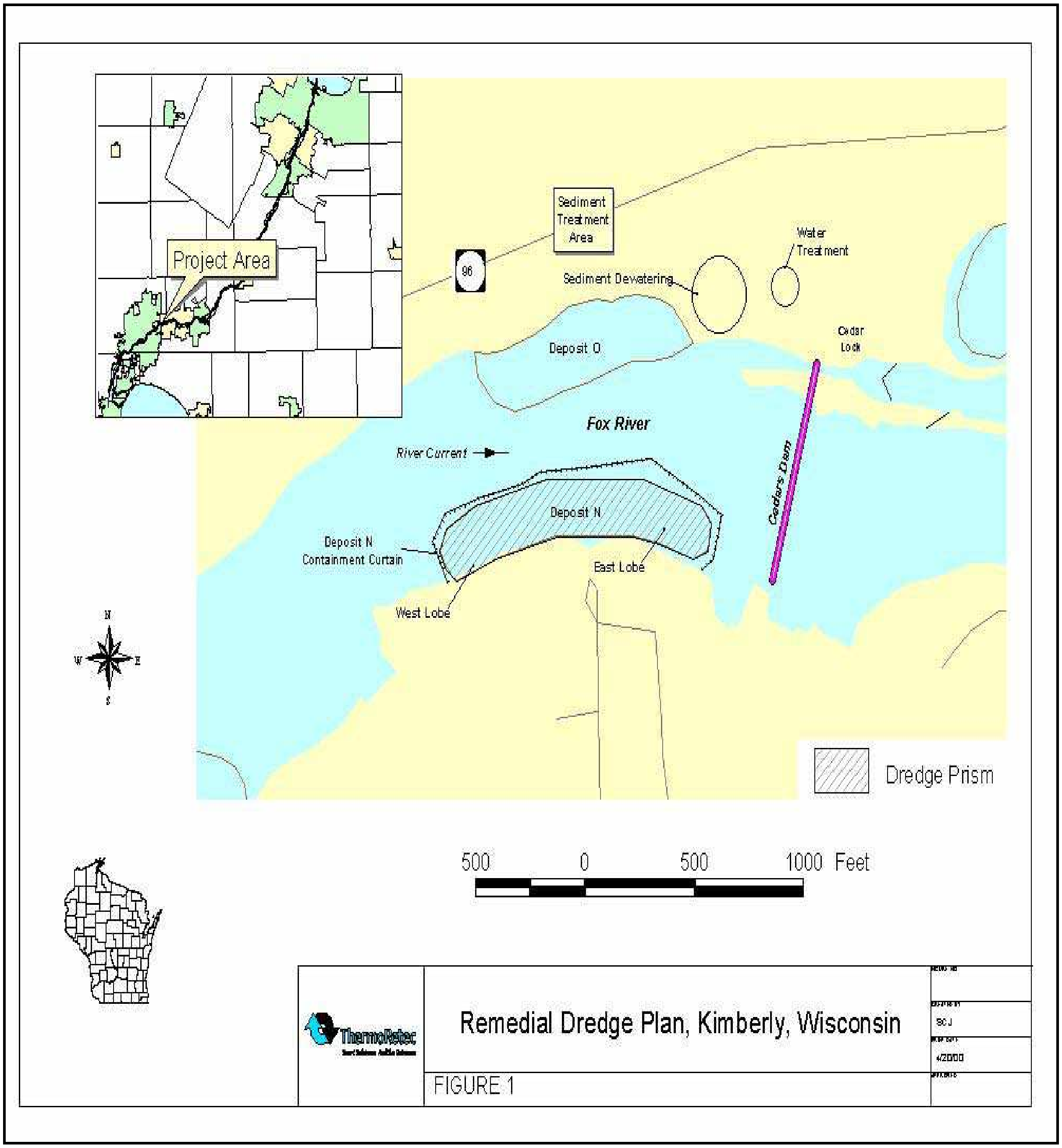
Figure 1 Remedial Dredge Plan - Lower Fox River Deposit N



1 Statement of the Problem

- Dredged 1999 & 2000
- PCBs
- 31,346 cubic yards 1999
- 50,316 cubic yards 2000
- $286 to $296 per cy

The Fox River Sediment Management Unit (SMU) 56/57 Demonstration Project Site is located in the Lower Fox River in Green Bay, Wisconsin. Sediment polychlorinated biphenyl (PCB) contamination is present from multiple industries and paper mill facilities. PCB concentrations up to 710 ppm have been detected in sediment. The selected remedy was removal of approximately 80,000 cubic yards sediment to a design elevation of 565 feet (Mean Sea Level, NGVD29) in 1999. This was expected to remove all sediment with PCB concentrations greater than or equal to 1 ppm. However, the dredge prism was only partially removed by December 1999, when the equipment was demobilized. Additional sediment was removed in August, 2000 to a targeted volume.

2 Site Description

The Fox River SMU 56/57 Demonstration Project Site is located in a 7-mile stretch of the Fox River from below the De Pere dam to the mouth of Green Bay. SMU 56/57 is approximately 9 acres in area and is located in the City of Green Bay on the west shore of the river in an area adjacent to the Fort James turning basin and shipping dock (ThermoRetec, 1999a and 1999b).

View of Fort James Corporation
Source: WDNR

Continuous soft sediment deposits present in the river bottom ranged from 1 to 16 feet in thickness (average 10 feet). Soft sediments are primarily soft organic silt overlying firmer native clay. The water depth in the project area ranged from 2 feet at the shoreline to 14 feet at the outer edge. Normal flow velocity ranges from +2.5 feet per second (fps) to -2.5 fps. Flow reversal occurs in the river during periods of strong and prolonged winds from the northeast. Flow velocity measurements collected from within the project area on 1 day ranged from 0 to 0.6 fps.

3 Site Investigation

In a 1995 investigation conducted by the Wisconsin Department of Natural Resources (WDNR) and U.S. Environmental Protection Agency (EPA), approximately 100 cores were collected at various depth intervals and analyzed for PCBs and other constituents. Results of the investigation were used with other data as input variables into a water and fish quality model that established a total of 115 sediment management units (SMUs) for the lower reach of the river below the De Pere dam. SMU 56 and 57 were contaminated with the highest concentrations of PCBs found to date, with a maximum concentration of 400 ppm measured at a depth interval of 3 to 5 feet. The maximum surface (0 - 10 cm) concentration was 99 ppm.

On January 31, 1997, the State of Wisconsin and the Fox River Group (a consortium of seven paper mill companies) entered into a state agreement for a sediment restoration project in the SMU 56/57 demonstration project area. In November 1997, WDNR and EPA took 32 cores in the SMU 56/57 focus area. PCB concentrations of the sediment ranged between non-detect and 710 ppm with the highest concentrations present in the top 2 to 5 feet. Sediment with PCB concentrations of at least 1 ppm were present at thicknesses of 2 to 16 feet with an average of approximately 10 feet (Montgomery Watson, 2000).

Contaminants of Concern. The primary contaminant of concern was PCBs from wastewater discharges to the river during the manufacture and recycling of carbonless copy paper. Although concentrations and mass removal of mercury were also discussed, it was not identified as the focus of the hotspot removal project.

4 Target Goals and Project Objectives

1999 Removal Activities

The project was intended to remove hotspot sediment from SMU 56/57 and to generate as much information as possible towards the design of larger-scale remediation project for the lower Fox River. The target goal was to dredge sediments to a design elevation of 565 feet (Mean Sea Level, NGVD29). Selection of this target elevation assumed that sediments with concentrations of PCBs greater than or equal to 1 ppm would be removed from the dredge prism. The dredge footprint called for removal of approximately 80,000 cubic yards of sediment (Paulson, 2000).

Silt Curtain and Dredge
Source: WDNR

2000 Removal Activities

The project goals were to complete the removal of contaminated sediment from SMU 56/57 to a pre-determined maximum *in situ* sediment volume of 50,000 cubic yards. The target goal was to continually dredge hotspot sediments until the surficial sediment PCB concentration was less than 1 ppm or the designated volume was met (maximum concentration of 10 ppm), whichever came first. The volumetric extent of dredging was pre-determined by 1) the need to preserve stable side slopes, 2) avoid leaving elevated PCB concentrations above 1 ppm in surface sediments, and 3) not exceed the remaining capacity in Fort James Green Bay Landfill Cell 12A (WDNR, 2000 Statement of Work). The SOW also called for surface sediment concentrations to be less than 10 ppm in 90% of the subunits and the maximum concentration in a subunit to be less than 25 ppm. Target dredge elevations were used to achieve project goals. A 6-inch clean sand cap would be placed over remaining surface sediments with average PCB concentrations in a subunit between 1 and 10 ppm (Fort James et al., 2001).

5 Project Design

Investigation and design for the demonstration project was conducted between September 1997 and May 1998. Procurement and permitting began in June 1998 and was completed in June 1999.

Pre-planning and Bid Documents. Three separate requests for bids were prepared for dredging, water treatment, and dewatering with performance-based specifications. Performance-based specifications allowed use of contractor expertise and available equipment, and provided flexibility. The project planning was completed using a public review process (Montgomery Watson, 1999a, b, and c).

Summary of Remedial Action Plan. Overall, the remedial action entailed installation of a silt curtain, hydraulic dredging of sediment in 53 dredge cells within the dredge prism, and transport of sediment slurry to an onshore treatment process area on Shell Oil's Property (agreed access). The sediment slurry was fed into equalization (settling) basins. Water was treated with dual-media filters and granular activated carbon prior to discharge to the river. Sediments were dewatered and disposed at an off-site landfill. The SMU 56/57 focus was divided into 53 subunits measuring approximately 100 feet by 100 feet each and the initial target elevation for the entire area was 565 feet elevation with a 6-inch overdredge (actual elevation 564.5 feet).

Limitations and Permits. Dredging activities were designed to be protective of intake access and boat slip access for continued operations of the paper mill. Major permits and approvals required for the remedial activities included an Environmental Assessment, WDNR Dredging Permit, U.S. Army Corps of Engineers Dredging Permit, and WPDES Permit (Four Seasons Environmental, 1999a, b, and c).

In 1999, the onset of winter resulted in freezing water in pipelines and process equipment and formation of river ice. Due to time constraints, the dredge design elevation was raised to 567 feet in the northern half of the dredge area. The design elevation was raised again to 568 feet in subunits 2 and 23. A cleanup pass initially planned for all areas was only conducted only in a 30-foot by 30-foot area in the center of 4 dredge cells. The target goal of the cleanup pass was 6 inches below the 565-foot elevation. No limitations were noted during the 2000 dredge activities.

6 Remedial Action

6.1 Dredging

1999 Removal Activities

Schedule and Duration. Construction of the Fort James landfill PCB disposal cell was performed between middle June and late August 1999. The construction phase of the sediment removal lasted from July to late August 1999, and included mobilization of dredging, water treatment, and dewatering systems and personnel. Dredging was conducted between August 30 and December 15, 1999.

Dredging was discontinued on December 15, 1999 due to the onset of winter conditions. Project demobilization took place between December 15, 1999 and January 19, 2000. Additional activities, including general site cleanup and removal of equipment and dredged material, was scheduled to take place during spring 2000. Dredging was conducted during 96 of 108 calendar days of the project, averaging 4.3 hours per day. The total dredging time of the project was 464.5 hours. The dredging crew consisted of a dredge operator, a laborer stationed onshore, and a laborer at the equalization basin (Montgomery Watson, 2000)

Equipment. A 1,700-foot silt curtain was installed around the entire dredge area prior to commencement of dredging. The silt curtain skirt was a black, woven polypropylene, monofilament geotextile fabric with a 40–50 U.S. Standard sieve equivalent opening size and a percent open area of 15 percent. The silt curtain was anchored with "Manta Ray" anchors and concrete weights. Closed cell foam flotation was used to hold the curtain at the water surface.

A hydraulic dredge with a 12-inch pump and round cutterhead was used initially, beginning on August 30, 1999. After approximately one week of dredging, the dredge was replaced with an IMS 4010 Versi horizontal auger dredge in an attempt to increase solids of the dredge slurry. The IMS 4010 dredge operated in conjunction with an inline booster pump to transport the slurry to the equalization basins. On September 10, the dredge was replaced with an IMS 5012 Versi horizontal auger dredge with a 12-inch pump and a larger booster pump, and on September 22–23, a wider cutterhead (9 feet) was placed on the 5012 dredge. A number of dredge passes were necessary to achieve target elevations. Dredge passes were made by advancing the dredge along cables.

Dredge slurry was transported to equalization basins through a 2,800 linear-foot pipeline. The pipeline consisted of a single-walled 12-inch-diameter high-density polyethylene (HDPE) slurry pipe within the silt curtain. For the 1,860-foot portion of the hydraulic pipeline outside of the silt curtain, the 12-inch-diameter slurry pipe was double-walled within a 16-inch containment pipe (Montgomery Watson, 2000).

Total Volume Removed and Production Rates. Dredging was conducted in 96 of the 108 calendar days of the project, resulting in the removal of a total of 31,346 cubic yards of sediment. The average hourly dredging rate (60 cubic yards per hour) and the average daily dredging rate (294 cubic yards per day) were less than the project goals (200 cubic yards per hour and 900 cubic yards per day). The average percent solids of the dredge slurry was 4.4 percent. A goal of 7.5 percent solids was established prior to dredging. Dredging resulted in the removal of 1,326 pounds of PCBs from the Fox River (Montgomery Watson, 2000).

Site-specific Difficulties. Dredge equipment was changed on multiple occasions in an attempt to increase the solids content of the dredge slurry. Onset of winter conditions required demobilization before completion of dredging effort.

2000 Removal Activities

Schedule and Duration. The construction phase of the sediment removal lasted from July to late August 2000, and included mobilization of dredging, water treatment, and dewatering systems and personnel. Dredging and sand cap placement were conducted between August 23 and November 8, 2000. An aggressive schedule allowed the project to be completed two weeks ahead of schedule and before the onset of cold weather (Fort James et al., 2001).

Equipment. A new, deeper silt curtain was placed around the entire dredge area and anchored through a series of sheet piles, screw anchors, and chains. Inside the perimeter curtain, three additional temporary silt curtains were used to separate the dredge footprint into four areas. Once an area was dredged, it was separated from the rest of the site to avoid re-contamination.

Three hydraulic dredges were available on-site to remove sediment from the dredge prism. All dredges were horizontal auger style, equipped with submersible pumps. The pumps transported dredge slurry (excavated sediment mixed with water) through a pipe system to a booster pumping station which, in turn, pumped the slurry to the land-based dewatering facility. Multiple dredges helped to ensure continuous dredging throughout the construction period, although only one dredge was used at any given time.

The onshore dewatering facility operated on a site adjacent to the Fort James mill. The sediment was separated from the water and trucked off to a waste disposal landfill, owned and operated by Fort James, located near Austin Straubel International Airport in Ashwaubenon.

Total Volume Removed and Production Rates. Dredging averaged 24 hours per day throughout the project, removing a total of 50,316 cubic yards of sediment. The average daily dredging rate was 833 cubic yards per day. The highest production day was October 20, 2000, removing 1,599 cubic yards of material. The average percent solids of the dredge slurry was 8.4 percent with a range from 3.5% to 14.4%. Dredging resulted in the removal of 670 pounds of PCBs from the Fox River during the year 2000. Combining the amount of PCBs removed during 1999 and 2000 yield a total of 2,111 pounds of PCBs removed from the Fox River (Fort James et al., 2001).

Placement of Sand Cap. After completion of dredging, a 6-inch layer of clean sand was placed over the dredge footprint covering approximately 7.4 acres (although not required in areas with surface concentrations less than 1 ppm PCBs). Thicker sand layers were placed in side slope areas. Sand placement was conducted by Buffalo Divers of New York using clam bucket located on a barge from September 23 to November 8, 2000. The sand was deployed in a radial pattern around each barge set-up location. A total of 13,500 cy of cover sand was placed with an average thickness of 8 inches (Fort James et al., 2001).

Site-specific Difficulties. The required dredging production rate was not met early in the project because of dredge downtime and filter cake pressing capacity. The contractor brought another dredge to the site and replaced the smallest press (94 cu ft) with two larger presses (22 cu ft each) (Fort James et al., 2001), which increased the daily dredge production rates to performance expectations (max rate of 1,599 cy per day).

6.2 Dewatering and Water Treatment Operations

1999 Removal Activities

Dewatering of sediment was conducted using recessed chamber filter presses to allow effective handling and disposal of sediment. The average percent solids of the filter cake was 53.1 percent based on laboratory analysis. The dewatering system was operated 24 hours per day, seven days per week by a crew of six to seven people working each 12-hour shift.

Process water generated for the treatment system were primarily from the equalization basin supernatant and press filtrate. Treatment consisted of adding polymer for total suspended solids (TSS) reduction and acid for pH reduction followed by flocculation and settling, filtration through two dual-media (sand/gravel) filters, and polishing through a granular activated carbon vessel. Treated water was discharged back to the river. Water treatment operations were conducted 24 hours per day, seven days per week except for breakdowns. The water treatment staff consisted of two people per 12-hour shift. Operation of the water treatment system was ended three days after completion of dredging (Montgomery Watson, 2000).

Water Quality Monitoring of Discharge. Effluent from the water treatment system was analyzed for a number of parameters prior to discharge. Concentrations of PCBs, mercury, and oil and grease were below the WPDES limit in all samples. The TSS WPDES daily limit (WDNR, 1999) was exceeded eight times during the project. BOD results exceeded the weekly average limit of 2 mg/L in all except for three samples. The results of effluent analytical testing are summarized in Table 1 (Montgomery Watson, 2000).

2000 Removal Activities

The dredge and booster pumps transported the slurry from the river to a shore-based vibrating shaker screen set on a V-bottom tank. The shaker screen was used to remove debris, stones, and vegetation from the dredge slurry. The dredge slurry was further circulated in the V-bottom tank and pumped through hydrocyclones to remove a portion of the sand. The dredge slurry then flowed into a 20,000-gallon agitated pump tank that transferred slurry to agitated mix tanks where polymer was added. These tanks fed the mechanical presses (Fort James et al., 2001).

Plate and frame mechanical presses dewatered the sediment to meet the specifications of 50% solids with a compressive strength of 0.4 tons per square foot. Average percent solids of slurry entering the mechanical presses was approximately 7.3%. Dried sediment was discharged to a conveyor system (press drop), which transported the dewatered sediment to the work area storage pad. The average percent solids of the filter cake was 59% with 11.0 ppm PCBs based on laboratory analysis. The dewatering system operated 24 hours per day, seven days per week working 12-hour shifts (Fort James et al., 2001).

Dewatered and stabilized sediments were to be separated into batches of 20,000 cubic yards or less, sampled for PCBs, and tested for free liquids (RCRA paint filter test) and other relevant geotechnical characteristics as needed. The average concentration of PCBs was 11 ppm and the concentration of PCBs ranged from 0.48 ppm to 32 ppm. Batches were transported to and disposed of in Cell 12A of the Fort James Green Bay Landfill.

The water treatment system processed up to 2,400 gallons per minute, and consisted of an untreated water surge tank, cloth bag filters, sand filters, carbon absorption system, and a final set of cloth bag filters. The treated water was sampled prior to discharge. Effluent flow rates were measured through a magnetic flow meter, and the water was discharged into the Fox River. Water treatment operations were conducted 24 hours per day, seven days per week. Approximately 66,329,000 gallons of water were treated and returned to the Fox River (Fort James et al., 2001).

Water Quality Monitoring of Discharge. Effluent from the water treatment system was obtained and analyzed as directed by the On-Scene Coordinator and the WDNR On-Scene Representative. On October 13, 2000, with USEPA and WDNR approval, the frequency of testing effluent for PCBs and mercury was changed from twice weekly to once a week. This change was based on the data, which showed that the previous six weeks of monitoring resulted in no detects of these parameters in the effluent. Over 66 million gallons of treated water was discharged back the river (WDNR, 2000b).

Table 1 Water Treatment Effluent Test Results (Fort James et .al., 2001)

Parameter	Units	Average	Minimum	Maximum	WPDES Limit
PCBs	μg/L	0.02	0	0.37	1.2
Mercury	ng/L	16.5	0	101.8	1,700
TSS	mgL	7.3	0	280	10
Oil & Grease	mg/L	3.4	0	8.3	10
pH	su	7.5	6.0	10.8	6–9
Turbidity	NTU	1.2	0	22	—
BOD_5	mg/L	11.5	0	27	2.0
Ammonia-N	mg/L	16.7	1.6	49	—
Dioxins	Pg/L	0	0	0	—

6.3 Storage and Disposal

1999 Removal Activities

Dewatered sediment was transported by truck to an off-site landfill. Tri-axle and semi trucks were loaded with cake material using a front-end loader. A total of 1,240 loads of dewatered sediment and project wastes were taken to the Fort James landfill between September 9, 1999, and January 17, 2000. The total sediment mass disposed to date has been 26,927 wet tons. Additional dredged sediment remaining in the equalization basins was to be removed in spring 2000 (Montgomery Watson, 2000). Approximately 1,441 pounds of PCBs were removed.

2000 Removal Activities

Dewatered sediment was transported by truck to an off-site landfill, owned and operated by Fort James near Austin Straubel International Airport in Ashwaubenon. A total of 2,484 loads of dewatered sediment and project wastes were taken to the Fort James landfill(Cell 12A) between August 2000, and November, 2000. Dewatered sediment had an average solids content of approximately 59%. The total dewatered sediment material disposed during the project was 51,613 dry tons (Fort James et al., 2001) with 670 pounds of PCBs removed.

7 Environmental Monitoring Program

The environmental monitoring program included analysis of sediment cores at various depths (including surface intervals), bathymetry measurements, water and air quality measurements, and caged and resident fish bioaccumulation data (Table 2).

7.1 Baseline

1999 Removal Activities

Physical. The Corps of Engineers performed a baseline bathymetric survey on August 23,1999 using single-beam sonar on range lines spaced at 50-foot intervals. Sediment cores were collected by Blasland Bouck & Lee (BBL) for physical characterization on August 19 to 21, 1999.

Chemical. As discussed in the site investigation section, WDNR and EPA took 32 cores in the SMU 56/57 focus area in November 1997. PCB concentrations of the sediment ranged between non-detect and 710 ppm with the highest concentrations present in the top 2 to 5 feet. Sediment with PCB concentrations of at least 1 ppm were present at thicknesses of 2 to 16 feet with an average of approximately 10 feet. Additional cores were collected from 40 locations on August 19 to 21, 1999 by BBL to provide additional analytical characterization of sediment for comparison with post-dredge sampling. The maximum concentration was 650 ppm at a depth of 4 to 5 feet (Paulson, 2000).

Aerial View of Silt Curtain and Dredge
Source: B. Paulson, WDNR

Baseline surface water data were collected, but were not available for review.

Biological. Caged fish studies were conducted in October and November 1997 for PCB Aroclors. Numerous resident fish tissue bioaccumulation studies have occurred between 1988 and 1996 including the 1989/1990 Green Bay Mass Balance Study, the WDNR fish contaminant advisory study, the USGS water quality assessment program, the 1996 RI/FS WDNR fish tissue data collection, the 1996 BBL fish tissue data set, and the NRDA 1996 fish tissue collection study by USFWS. Results of these studies are currently being folded into an ecological and human health risk assessment in support of remedial alternatives for the RI/FS Lower Fox River project. Nine species of fish (carp, walleye, yellow perch, alewife, common shiner, emerald shiners, gizzard shad, golden shiner, and rainbow smelt) were analyzed for total PCBs, PCB congeners, and other constituents of concern and are included in various food web models developed for each river reach.

2000 Removal Activities

Physical. A pre-dredge bathymetry survey was completed by Baird and Associates on August 14, 2000 as sloughing and siltation in the area may have occurred after completion of the 1999 Demonstration Project. Based on this survey approximately 49,600 cubic yards of sediment needed removal to obtain an average residual sediment concentration of 1 ppm PCBs. This volume would include redredging of some 1999 dredge units.

Six additional geotechnical borings were collected to further define grain size, degree of consolidation and other geotechnical characteristics within the disturbed side slopes of adjacent cells.

Chemical. No additional chemical testing was undertaken prior to dredging.

Biological. No additional biological testing was undertaken prior to dredging.

7.2 Implementation During Dredging

Environmental quality monitoring conducted during the dredging activities included river and velocity monitoring, water and air quality monitoring, bathymetric surveys, dredge slurry and dewatered filter cake sampling, water treatment monitoring (discussed above) and sediment confirmation sampling.

1999 Removal Activities
Physical. Turbidity measurements were taken at 15-minute intervals, 24 hours per day at two locations inside of the silt curtain and four locations outside of the silt curtains. Average monthly turbidity ranged from 16 to 49 NTU inside the silt curtain and 11 to 46 NTU outside of the silt curtain. Average turbidity measurements outside of the silt curtain were not appreciably different between upstream and downstream locations. The average turbidity inside the silt curtain was slightly higher than outside the silt curtain (range 3 NTUs lower inside to 11 NTUs higher inside). The downstream "trigger" level was never exceeded during dredging.

Optical surveys were performed by sightings along a baseline of wooden hubs along the shoreline to check for potential slope instability caused by dredging. No lateral movement was detected, and only slight vertical movement was measured during the dredging period.

Chemical. No sediment chemical data were collected from the 53 dredge cells, or subunits, during dredging. Surface water data were collected during dredging, but was not available for review. Extensive air monitoring data were collected from 25 onsite stations and several offsite locations up to 1.25 miles from the site. Samples were collected as 24-hour and 72-hour composites for total PCBs and aroclors from the landfill area, the dredging area, and systematic offsite distances away from activities. Air samples were locally elevated onsite but achieve background levels at a distance of 1250 meters (24 hour) and 750 meters (72 hour). No samples exceeding the health risk level of 100 ng/m^3. Total possible loss of PCBs via volatilization was 10.7 lb PCBs (0.8% of PCBs removed) at an emission rate of 0.01 to 0.1 lbs per day during dredging and dewatering activities (WDNR, 2000).

Biological. Not collected during dredging.

2000 Removal Activities

Physical. Dewatered and stabilized sediments, in batches of 20,000 cubic yards or less, were sampled for relevant geotechnical characteristics. Turbidity measurements were taken in the river at one station upstream (M1), at the water intake, and two stations (M2 & M3) 10 feet and 50 feet downstream, respectively, of the work. When turbidity measured at M2 or M3 was twice the turbidity measurement of M1, downstream water column samples were to be colleted and analyzed for PCBs. Sampling frequency decreased from twice daily to once per day, to every other day with USEPA approval as no elevated turbidity readings were reported.

Chemical. No sediment samples were from the dredge cells, or subunits, during dredging. Dewatered and stabilized sediments were sampled for PCBs and tested for free liquids (RCRA paint filter test). In accordance with the approved monitoring plan, river water quality testing for PCBs was not performed since there were no exceedances of turbidity as a result of dredging.

Biological. Not collected during dredging.

7.3 Post

1999 Removal Activities

For clarification, each of the dredging subunits was 100 ft by 100 ft. The SMU 56/57 area was divided into 53 units, but only 19 subunits were within the dredge area. Only four of these subunits received a final cleanup pass. The cleanup pass that attempted to reach the final elevation (565 ft) plus 1/2 foot of overdredge in these four subunits, focused only in the center portion of the 100 ft by 100 ft square. This area was approximately 30 ft by 30 ft. The cleanup pass did not remove 100% of the material in these four subunits.

Physical. A post-dredge acoustical bathymetric survey was conducted by Superior Special Services. The final elevation in areas that did not receive the final cleanup dredge pass contained sediment ranging from 1 to 7.5 feet thick above the final design elevation (Paulson, 2000). The final target elevation was achieved in four areas measuring approximately 30 feet by 30 feet.

Chemical. A summary of achievements included:

- Only 13 of 19 subunits had post-dredge verification core samples collected (the other five subunits had less than 1 foot of sediment removed and therefore were not sampled).

- Only one of 19 subunits achieved the target depth. The average post-dredge sediment concentration of this subunit was less than 1 ppm PCBs.

- Only three of the 19 subunits were below 1 ppm PCBs (average concentration). These three subunits were included in the four final "cleanup pass" subunits attempting 100 percent mass removal of contaminated sediments down to target depth (75 percent success in cleanup areas).

A post-dredge core was collected from each subunit in which the sediment elevation changed by more than 1 foot (13 locations). The maximum PCB concentration measured was 330 ppm at a depth interval from 0.3 to 1.0 foot. In areas where a cleanup pass was not performed, post-verification sediment concentrations at the surface increased considerably from baseline concentrations. The post-dredge surface sediment concentrations ranged from 32 to 280 ppm, with corresponding baseline concentrations of 2 to 5 ppm. In three of four areas where a cleanup pass was performed surface PCB concentrations declined from pre-dredge concentrations. The final concentrations ranged from non-detect to 2.0 ppm. Duplicate surface samples collected from the fourth area measured 4.5 and 17 ppm PCBs compared to a pre-dredge concentration of 2.7 ppm (Montgomery Watson, 2000).

Post-dredging surface water data were collected, but was not available for review.

Biological. None collected as part of this demonstration project.

2000 Removal Activities
Physical. Post-dredge top-of-sediment surveys were performed using sonar surveys for each of the four completed sections to confirm that target elevations had been achieved. In areas were the dense, native river bottom (clay) was encountered above the target elevations, dredging was considered complete. All sonar surveys were supplemented with Foth & Van Dyke poling surveys conducted on the non-side slopes of each section.

Chemical. Surficial sediments (upper 4 inches) were collected from each subunit and analyzed for PCBs. One to five samples were collected from each 100 ft by 100 ft grid cell. Concentrations ranged from "no detect" to 9.5 ppm and averaged 2.2 ppm (Fort James et al., 2001). The *in situ* percent solids of surface sediments ranged from 33% to 68%. After verification sampling, all dredged areas were covered with 6-inches of sand (even though the AOC stated that surface sediments below 1 ppm PCBs need not be contained). Surface grab samples were used to verify placement of sand, and hand-push cores (2-inch CAB liners) were used to verify the thickness of the sand cap.

All effluent PCB results were non-detect values below established discharge limits. All effluent BOD results were below the daily maximum target concentration of 30 mg/L. Effluent pH values were all within target concentrations during the project. There were three low-level detects of mercury in the effluent, but all levels were well below the project target concentration of 1.7 ppb.

Biological. None collected as part of this project.

7.4 Long-Term

Long-term monitoring of the post- dredge conditions and recovery at SMU 56/57 will be developed as part of the overall remedial design program for the Lower Fox River and Green Bay project.

Table 2 Summary of Monitoring Results

Testing Parameter	Total PCB Concentration (in mg/kg)				
	Baseline 1989–1999	During Dredging Aug. - Dec. 1999	Post Dec. 1999	During Dredging Aug. - Nov. 2000	Post Dec. 2000
Bathymetry	Collected	Shoreline stability	Met target depth in four 30-ft × 30-ft areas; ranged from 1 to 7.5 ft above target depth in rest of study area	NC	Collected
Sediment Cores from Subunits 25, 26, 27 & 28 (1) (2) (5)	Surface = 2.3 to 3.1 Max = 330 ppm	NC	Surface= 0.01 to 4.5 ppm Max = 49 ppm	NC	NC
Sediment Cores All other Subunits (1) (2)	Surface= 0.35 to 5.3 1999 Max = 650 ppm 1997 Max = 710 ppm	NC	Surface= 32 to 280 ppm Max = 330 ppm	NC	Surface= ND to 9.5 ppm (avg = 2.2 ppm) before capping
Water Quality	NA	NA	NA	NA	NA
Caged Fish Data (3)	Non-detect to 310 μg/kg PCB Aroclors	Detectable	NA	NC	NC
Air Quality	Unk	Non-detect to very low levels 0.7-79.7 ng/m^2 total PCBs	Unk	NC	NC

(1) The surface interval is approximately 0 to 0.3 ft. depth. The maximum depth for sediment cores was about 14 ft. for baseline and about 4 ft. for post sampling.
(2) The max. concentrations are the highest values detected in core.
(3) Caged fish data collected in 1997, also had the suspended inside and outside silt curtain during dredging.
(5) Subunits received final cleanup pass to design depth.
NC = Not collected
ND = Non detect
NA = Not available
Unk = Unknown

8 Performance Evaluation

8.1 Meet Target Objectives

1999 Removal Activities

The target goal of removing contaminated sediment down to a target elevation of 565 feet with verification samples compared to a 1 ppm PCB goal was partially achieved. Due to time and weather constraints, the target elevation was raised 2 feet (to 567 feet) in the northern half of the dredge area in mid-November 1999. The design elevation was raised again to 568 feet in subunits 2 and 23 (a total of 53 subunits) at the end of November 1999, when it became evident that contractors could not complete the proposed plan before cost overruns accrued and before the onset of ice conditions. The final elevation in the southern 565-foot target area ranged between 562 and 568 feet. The final elevation in the northern area ranged between 567 and 572 feet. A cleanup pass initially planned for all areas was only conducted in four 30-foot by 30-foot areas. The target goal of the cleanup pass was 6 inches below the 565-foot target elevation. Only 31,346 cubic yards of the estimated 80,000 cubic yards of sediment slated for removal were actually removed.

Post-dredge PCB concentrations in surface samples were considerably higher than pre-dredge surface concentrations where a cleanup pass was not performed. The results are not unexpected because dredging was not completed to the design depth in most areas. However, the post-dredge results were less than the maximum concentrations detected in pre-dredge core samples, indicating that a significant mass for contaminated sediment was successfully removed.

Water quality and air quality monitoring during the removal operations determined that the majority of PCB mass (>95%) could be entrained in the treatment process and disposed as filter cake. Less than 1% was released as air emissions and only 5% was released downstream in the river.

2000 Removal Activities

The target goals for the 2000 removal project were generally met. The target elevations were achieved and all discrete sediment samples were below the 10 ppm PCBs (maximum allowable concentration) within the pre-determined removal volume of 50,000 cy. The project objectives called for the removal of 50,000 cubic yards of contaminated sediment from SMU 56/57, assuming that remaining surface sediments would have PCB concentrations less than 1 ppm PCBs. Approximately 41% of the post-dredge verification samples were below 1 ppm PCBs (80% were below 3 ppm PCBs) with an average of 2.2 ppm PCBs. It was expected that some residual surface sediment concentrations may be above 1 ppm PCBs.

Areas with PCB concentrations of less than 1 ppm were considered to be completed, requiring no further work. Areas with PCB concentrations between 1 and 10 ppm were to be covered with at least a six-inch layer of clean sand. Fort James Corporation chose to cover the entire dredged area with sand to further reduce exposure to PCBs. Sand covering most of the 6.5 acre dredge area ranged from 6 to 14 inches thick, averaging 8 inches.

This helped to cover any exposed PCBs left in the surface sediment and in the side slopes along the edges of the dredged area. All the clean- up objectives were met for this project. Confirmation samples taken from the site ranged from non-detect to 9.5 ppm prior to capping.

Monitoring of water quality, effluent, and filter cake conducted during dredging operations confirmed that dredging operations did not cause significant sediment resuspension or releases during removal operations. No significant exceedances were observed.

8.2 Design Components

Performance-based specifications were used to select the contractor for each component of the demonstration project. A public review process was included in the project design. The contractors quickly identified deficiencies in the dredging performance and brought in additional equipment to improve daily production rates.
The filter presses successfully dewatered the dredged sediment to an average solids content of approximately 59%, eliminating the need for further solidification prior to disposal.

8.3 Lessons Learned

1999 Removal Activities
Actual sediment removal rates achieved in the demonstration project were less than one-third of the projected goal. Less than 40 percent of the sediment was removed before the onset of winter forced the stop of remedial activities. Elevated PCB concentrations in surface sediments were the result of incomplete dredging. Partial dredging of the contaminated sediment prism resulted in newly exposed surface sediments with PCB concentrations higher than expected if the entire hotspot had been successfully removed. In the four subunits where the target elevation was achieved, residual PCB concentrations were less than 1 ppm in three of the four subareas. These elevated post-dredge concentrations and elevations do not imply that horizontal auger dredges are not effective tools for removing contaminated sediment.

Results of the PCB water column analysis and mass balance study conducted by USGS (Stever, 2000; USGS, 2000), showed that approximately 95% of the PCB mass contained in the dredged material was entrained in the dewatering and treatment process, and only 5% (24 kg) was lost downstream. A summary of the mass balance includes:

PCB Mass Balance Table (Stever, 2000 of USGS) September 1 - December 15, 1999			
Process	**Rate**	**Total Mass (kg)**	**% of Dredged Material**
Total mass of SMU 56/57 deposit	-	2,086 - 2,722 (80,000 cy)	
Total dredged material	-	654 (1441 lb)	100%
Effluent back to river	82 - 676 µg/l	0.14 kg	0.015%
Dewatered sediments			95%
Transported downstream during dredging	226 gm/day	24 kg	5%
Volatilized		2.6 kg	0.4%
Annual load from the LFR to Green Bay	186 kg/year	20.9 kg	

Conclusions and recommendations presented in the SMU 56/57 project reports that will be useful during development of remedial alternatives for the Lower Fox River/Green Bay project included:

- The SMU 56/57 pilot dredging project did not meet the depth and volume target goals specified in the project plans (dredge to 565 feet elevation). Only 18 to 24% percent of the PCB mass was removed from SMU 56/57. The contractors demobilized from the site before completion to target elevation because of unexpected site conditions and onset of winter conditions. In areas where the contractor did not achieve the target depths, surface sediment concentrations were similar to pre-dredge conditions or higher. However, in areas where the target depth was achieved, the post-dredge surface sediment concentrations were below the 1 ppm PCB comparison criteria in most areas.

- The horizontal auger produced a sediment slurry with 4.5 percent solids, much lower than the design specifications. Another method of hydraulic dredging may increase the percent solids content and lower the overall production costs.

- Debris was encountered at SMU 56/57 during dredging, which hindered progress and production rates. The dredge needed shorter cables, better positioning, and more overlapping transects to remove residual sediment ridges.

- Post-dredge average residual PCB concentration at SMU 56/57 was 7.5 ppm (40 percent reduction from 11.7 ppm avg).

- Partial cleanup left significantly higher PCB concentrations in some surface sediments where the target elevation was not achieved.

- Dredging activities should be completed before onset of winter conditions. Winter conditions adversely affected project costs and performance.

2000 Removal Activities
Sediment removal rates met project objectives and goals illustrating that horizontal auger dredges are effective tools for removing contaminated sediment. A key component of implementing a dredging project is selection of a qualified contractor with experience and good equipment. Good communication between parties and realistic expectations are also important variables to consider when implementing an aggressive construction schedule to ensure that project goals would be met before the onset of winter conditions. The apparent differences between the success of the 1999 and 2000 removal activities conducted at the same site with the same sediments, reemphasizes the influence of pre-planning, communication, expectation, and qualified contractors on the success of a project.

9 Costs

1999 Removal Activities
The total cost of the project was approximately $8.97 million including construction, dredging, treatment, disposal, and operational monitoring and construction management ($286 per cubic yard). The cost of the dredging component was approximately $27 per cubic yard. There was a $2 million difference between contract terms and payment versus penalties (Montgomery Watson, 2000). Disposal costs were not part of the contract since sediment was disposed on-site, however, estimated costs for off-site disposal were included in the total project costs for future planning purposes.

56/57 Upland Landfill
Source: B. Paulson, WDNR

2000 Removal Activities
The total direct cost of the project was $8.18 million, yielding a cost of $159 per cubic yard of *in situ* sediment (Fort James, et al., 2001). Direct costs included site improvement ($0.4 M); dredging, dewatering and treatment ($5.5 M); estimated disposal to dedicated onsite landfill ($1.1 M at $21/ton); operation of landfill ($0.1 M), and project management ($1 M). Additional project costs that were required to implement this project included rental of the former Shell Terminal Property for dewatering ($0.4 M), value of Cell 12A disposal cell ($5.9 M), and Fort James project team ($0.4 M). Therefore, the total project cost required to implement this project was approximately $14.9 million ($296 per cubic yard).

10 Project Contact

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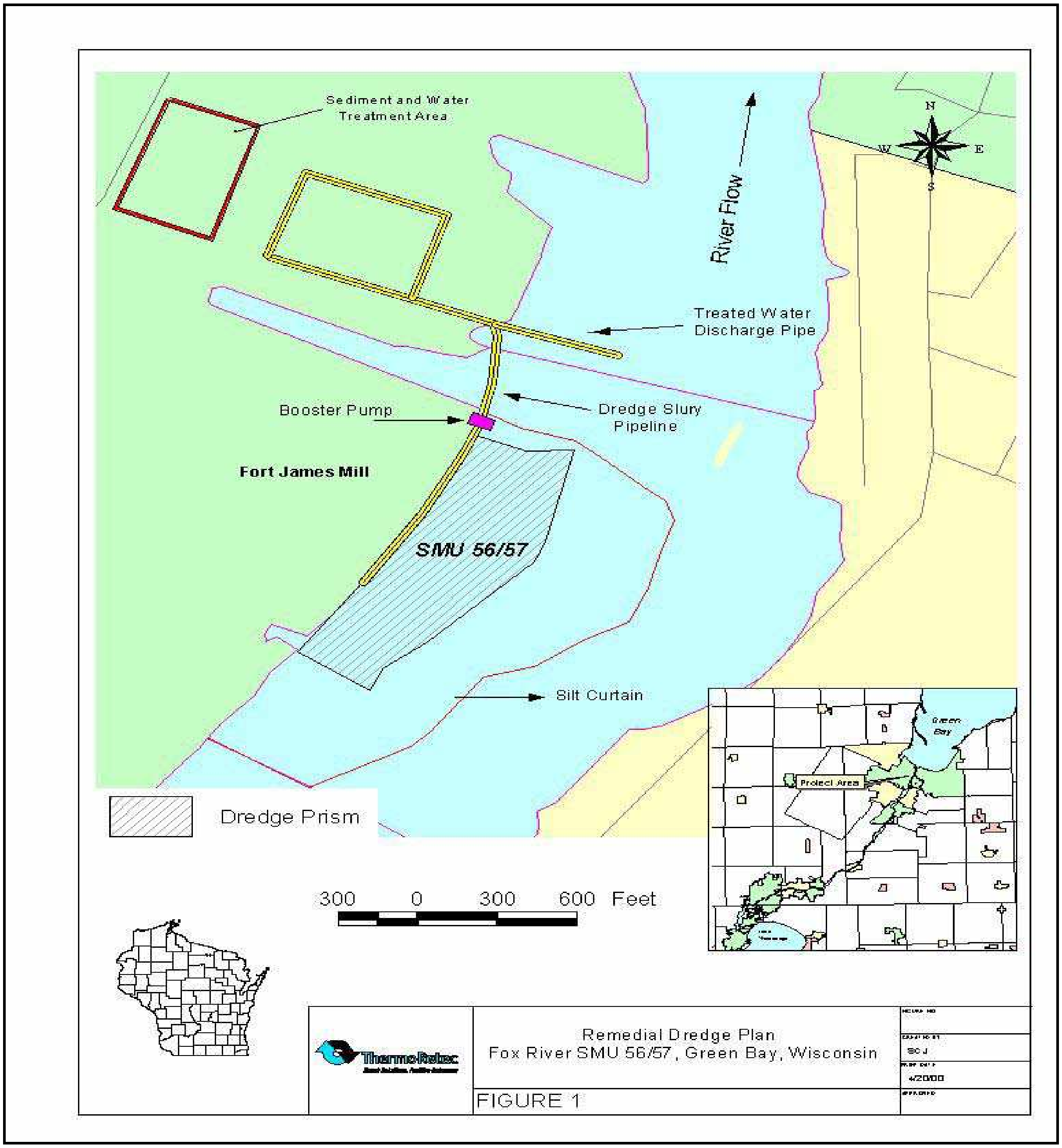
Figure 1 Remedial Dredge Plan - Fox River SMU 56/57



1 Statement of the Problem

- Dredged in 1995
- PCBs
- 27,000 cubic yards
- $680 per cy total

The General Motors (GM)/St. Lawrence River site generated an estimated 30,000 cubic yards of PCB-contaminated sludges from hydraulic oil used for aluminum casting from 1959 to 1973. PCB-contaminated sediments measuring up to 5,700 ppm polychlorinated biphenyls (PCBs) were present in the St. Lawrence River, the Raquette River, and Turtle Cove near the GM Foundry Plant (Figure 1). Over 11 fish consumption advisories were posted for the entire river.

The site was added to the National Priorities List (NPL) in 1984. Records of Decision (RODs) were issued in 1990 and 1992. The RODs were modified in the 1999 ROD to address changes in the treatment and disposal plans. The scope of remedial activities included excavation of sediment with PCB concentrations greater than 1 ppm, and on-site (<10 ppm) and off-site (>10 ppm) disposal. Dredging took place in the St. Lawrence River in 1995, removing 27,000 cubic yards of in situ contaminated sediment from an 11-acre nearshore site adjacent to the GM facility. The target concentration of 1 ppm PCBs was not reached. Average PCB concentration ranged from 3 to 27 ppm in six sampling areas. Concentrations significantly greater than the target goal remained in one 1.72-acre area and resulted in the addition of a protective cap to the remedial design (EPA, 1998). Contaminated sediment in the Raquette River and Turtle Cove are addressed in a 1999 ROD. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 2 under Superfund.

2 Site Description

The site is located in the St. Lawrence River adjacent to the GM Foundry facility in Massena, New York. The river and adjacent lands provide habitat for a number of New York State-listed endangered, threatened, and special concern fish species and nesting for a variety of waterbirds and shorebirds.

Aerial view of GM Foundry
Source: St. Regis Mohawk Tribe

The portion of the river addressed in the remedial activities consists of a shallow bay shelf that extends approximately 250 feet into the river. The shelf sediments are primarily fine-grained clay, silt, and sand with high levels of organic matter. Dense glacial till underlies the sediment. Areas containing large rocks and boulders were also present.

Water velocity in the main channel of the river ranges from 2.75 to 4.42 feet per second. Lower velocities were observed on the shelf where remedial activities took place. The regulated flow ranges between 258,000 and 289,000 cubic feet per second in the St. Lawrence River.

3 Site Investigation

The GM Foundry site was proposed for the NPL on September 1, 1983. The final NPL listing date was September 1, 1984. PCB contamination existed in sediments of the St. Lawrence River, the Raquette River, and Turtle Cove and in other areas of the site including an industrial landfill, the east disposal site, and site groundwater and surface water. The 1990 and 1992 RODs (EPA, 1990; EPA, 1992) examined six alternatives for treatment of contaminated materials including biological destruction, chemical destruction, chemical extraction, incineration, and thermal extraction, and solidification. The 1990 ROD estimated removal of 62,000 cubic yards of sediment from the St. Lawrence River, the Raquette River, and Turtle Cove. Maximum PCB concentrations measured in the sediment of the St. Lawrence River, the Raquette River, and Turtle Cove were 5,700, 390, and 48 ppm, respectively. The actual dredging was conducted only in the St. Lawrence River and included the removal of 27,000 cubic yards of material. Sediment removal from the Raquette River and Turtle Cove are addressed in an amended March 1999 ROD (EPA, 1999).

4 Target Goals and Project Objectives

Criteria for removal of sediment from the St. Lawrence River was based on requirements of the Toxic Substances Control Act (TSCA), a baseline human health risk assessment conducted by EPA, and an ecological risk assessment conducted by the New York State Department of Environmental Conservation (NYSDEC) and the St. Regis Mohawk Tribe. Removal of sediment with PCB contamination in excess of 1 ppm was established as the target objective for the remedial action to protect human health and the environment. As stated in the 1990 ROD, "The 1 ppm PCB cleanup in the St. Lawrence and Raquette Rivers was based on interim federal and State sediment quality criteria guidance as well as on EPA's risk assessment."

5 Project Design

Pre-planning and Bid Documents. A horizontal auger dredge was selected after an assessment of five different dredging techniques based on sediment removal efficiency and sediment suspension.

Summary of Remedial Action Plan. The remedial action plan consisted of the installation of a sediment containment system, removal of sediment from six established quadrants in the study area, and on-site dewatering and water treatment. A sediment cap was added to the remedial action within Quadrant 3 after dredging was completed due to high residual PCB concentrations (Figure 1).

The initial containment system consisted of double barrier silt curtains placed at the perimeter of the dredge area. The silt curtain containment system was installed in 1994, but was determined to be unacceptable due to installation difficulties and swift river currents (Cushing, 1999). In 1995, GM changed contractors and a revised containment system was designed (GE/AEM/BBL, 1984). The revised design consisted of interlocking sheetpile walls that were driven to an average depth of 6 feet into the river bottom. The tops of some individual sheets were driven below the water surface to reduce stress during storm events by allowing water flow to pass through the containment area.

Mechanical removal of debris and rock was conducted prior to dredging using a barge-mounted backhoe. The barge was anchored with spuds located on each side of the barge. Larger material was rinsed of residual fines by agitating the bucket in the water column, then transported for storage in a sediment stockpile located south of the dredge area (Figure 1). Mechanical excavation of sediment located in shallow areas near the shoreline was conducted after dewatering using a Portadam System. The Portadam is a portable dam structure composed of upright steel frames that support an impermeable liner.

Waste Pile Sampling
Source: B. Paulson, WDNR

Hydraulic dredging was conducted using an 8-foot horizontal auger dredge winched along a cable guide. Areas with PCB concentrations in excess of 500 ppm were dredged first and confirmed with sediment sampling. Dredging resumed, removing sediments within the 1 to 500 ppm range. Sediments in excess of the 1 ppm PCB were dredged after the removal. Residual PCB concentrations in Quadrant 3 remained elevated after several dredging and sampling events. Alternative dredging methods were therefore implemented in Quadrant 3 with limited success. The alternative methods included a vacuum head dredge fitted with a metal shroud, and mechanical removal of sediment with the barge-mounted backhoe (BBL, 1996b). A sediment cap (75,000 square feet) was placed over Quadrant 3 residuals to isolate contaminated sediments.

Limitations and Permits. No remediation has occurred in Turtle Cove due to difficulties with access to the property (Fox River Group, 1999). Remediation of Turtle Cove and the Raquette River are addressed in a 1999 ROD.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. An ineffective silt curtain containment system was installed and removed in 1994. Remedial activities were reinitiated and conducted from March 29, 1995 to January 9, 1996. The sheetpile containment system was installed between May 8, 1995 and July 21, 1995, after the silt curtains were removed. Hydraulic dredging was conducted between June 29, 1995 and November 6, 1995. The initial schedule called for dredging eight to 10 hours per day, six days a week with dewatering and water treatment operation 24 hours per day. Due to additional available capacity at the water treatment plant, the dredging schedule was increased to 24 hours per day between September 11 and October 16, 1995. The sediment cap was installed in Quadrant 3 between November 9 and December 7, 1995.

Equipment. Equipment utilized in the installation of the containment system included a 30-foot by 90-foot barge, tug boat, material barge, 100-ton crane, and a vibratory hammer. The sheetpile wall consisted of American Institute of Steel Construction designated AZ-13 interlocking sheets and W 16 × 89 or HP 14 × 89 piles. Mechanical debris removal was conducted using a barge-mounted backhoe anchored with spuds with assistance from divers.

Hydraulic dredging was conducted using an 8-foot horizontal auger head moved by winching along a cable guide anchored at the shore and the sheetpile wall. The dredge advanced approximately 2 to 4 feet per minute and cut a depth of 3 to 12 inches on each pass. After a series of passes (typically four to six) the dredge was moved laterally 7 feet, allowing a 1-foot overlap, and dredging resumed.

Dredging in St. Lawrence
Source: K. Martin

Total Volume Removed and Production Rates. A total of 27,000 cubic yards of contaminated material was removed from the St. Lawrence River, which included 3,000 cubic yards of rocks and 13,800 cubic yards of residual filter cake requiring disposal (Crystal, 2001 personal communication). Production rates are not available for review.

Site-specific Difficulties. The sediment containment system in the initial 1994 project consisted of a double barrier of silt curtains placed along the perimeter of the dredge area. However, the silt curtains did not work well and in 1995, GM changed contractors and a revised sheetpile containment system was designed. Modifications were made to the sheetpile containment system during dredging due to turbidity measurements in excess of action levels between July 10 and August 14, 1995 (outside the system). Modifications included installation of filter fabric, installation of short steel sheets over low sheetpiles, and mechanical raising of low sheetpiles (ones driven further into sediment).

The changes proved to be effective in reducing turbidity outside of the containment system. Quadrant 3 had elevated PCB concentrations above cleanup criteria after several dredging attempts utilizing different techniques, therefore a sediment cap was placed over the residuals (surface area of 75,000 square feet). Reasons for the exceedances were summarized in the project completion report (BBL, 1996b).

> "...The solids content within the dredge slurry had dropped considerably, apparently due to exposure of the underlying till. Further removal work was technically impractical, given that all methods of sediment removal had been used in this area, sediment probing indicated only a thin layer of remaining sediment, mechanical removal activities were removing more underlying materials than modern sediment, sampling results were not significantly improving with each sampling round, and there were only a limited number of work days remaining before the winter season. Therefore a sediment cap for Quadrant 3 was designed...and approved by the USEPA."

Shoreline booster pumps were commonly clogged with rocks and debris so an intermediate 0.25-inch shaker screen was added between the hydraulic dredge and booster pump (BBL, 1996b).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediment was pumped (with shoreline booster pumps) via a pipeline through on-site tandem vibrating 0.25-inch and #10 screens and into an equalization basin (approximately 350 to 1,000 feet distance). An additional 0.25-inch shaker screen was installed between the hydraulic dredge and booster pump due to problems with blockages in the pipeline formed by debris and large rocks.

Sediments were mixed with lime and dewatered using three recessed filter presses. Dewatered sediment was separated into two stockpiles based on pre-dredge PCB concentrations. Stockpile cell #1 received sediment with greater then 500 ppm PCBs and stockpile cell #2 received sediment less than 500 ppm PCBs. Large debris and rocks were stockpiled in cell #3.

Water pumped from the equalization basin and generated from dewatering was pumped to the water treatment plant. The treatment plant consisted of an oil-water separator, clarifier, mixed media filters, cartridge filters, and carbon filters. Treated water was held in a finished water tank until composite samples were collected. Treated water meeting water quality criteria was discharged to the St. Lawrence River.

Water Quality Monitoring of Discharge. A total of 43,285,316 gallons of water were treated between July 7 and November 21, 1995. Discharge criteria for treated water were 10 mg/L total suspended soilds (TSS), 15 mg/L oil and grease, and nondetectable concentrations of PCBs. Criteria for individual PCB Aroclors was set at 0.065 μg/L. If any or all PCB Aroclors were greater than the target detection limit but less than 0.3

μg/L, an evaluation of the pretreatment units was conducted to ensure optimum performance. If any or all PCB Aroclors exceeded 0.3 μg/L, the discharge of treated water was halted or recycled to the basin until corrective action had taken place and plant performance could be demonstrated (BBL, 1995).

Composite samples were collected daily from the finished water tank. A total of 91 samples were collected for PCBs, oil and grease, and TSS. PCBs were in excess of the detection limit, but less than 0.3 μg/L in 16 of the samples. PCB concentrations in excess of 0.3 μg/L were measured in three samples on July 8, July 11, and October 26, 1995. Discharge of treated effluent to the St. Lawrence River was immediately halted and recycled to the equalization basin until corrective actions were implemented and discharge criteria were met. High flow and resultant short retention times were responsible for exceeding discharge criteria on July 8 and July 11. The corrective action included reducing flow and the addition of 20,000 pounds of activated carbon to the treatment system. Conversion of the carbon filter system from a series to parallel alignment was responsible for exceeding criteria on October 26. The problem was corrected by returning the carbon filter system to a series alignment.

Except for three oil and grease samples not analyzed due to a shortage of sample preservative, all oil and grease results were less than the detection limit. TSS results were in excess of 10 mg/L in 14 of the 91 samples with a maximum concentration of 87 mg/L. When TSS criteria was exceeded, the pretreatment units were analyzed and subsequent corrective actions were reviewed and approved by GM and the on-site EPA representative.

6.3 Storage and Disposal

Dewatered sediments were stockpiled on site until 1999 awaiting a decision for final disposal. In a release dated March 25, 1999 (EPA, 2000a) the EPA stated, "sediments have been stored on the site pending the resolution of the strong public opposition to a Post-Decision Proposed Plan released by EPA in 1995 that called for the on-site treatment of PCB-contaminated materials below 500 ppm. EPA withdrew that plan this past summer and replaced it with another plan, which formed the basis of this modification. Materials with PCB concentrations of 1 to 10 ppm will be contained on the site in the East Disposal Area, which will be covered with an engineered cap. Materials with PCB concentrations above 10 ppm will be disposed of at licensed out-of-state facilities."

A second EPA statement dated June 10, 1999 (EPA, 2000b) explained details of the final disposal. "The U.S. Environmental Protection Agency (EPA) announced today that 23,000 cubic yards of contaminated sediments and soil will be removed this summer from the General Motors (GM) Superfund site in Massena, New York for disposal at a licensed facility in Utah. The total includes 13,000 cubic yards of contaminated sediments dredged from the St. Lawrence River and stored on the site since 1995, and 10,000 cubic yards of contaminated sludge from the active wastewater treatment plant on the GM property."

7 Environmental Monitoring Program

Monitoring parameters included in the dredging action included bathymetric surveys, chemical PCB analysis of sediment and the water column, and air monitoring. The monitoring and maintenance plan included measurements of PCB bioaccumulation in spottail shiner samples, and inspection and maintenance of the protective cap. Juvenile spottail shiners were chosen as the target species due to the presence of previously collected data in the St. Lawrence River; they have a limited home range and a typical life span of 3 years (BBL, 1996a).

7.1 Baseline

Physical. A pre-dredging bathymetric survey was conducted to document mudline elevations. Depths were measured along 50-foot transects located perpendicular to the shore.

Chemical. Sediment PCB concentrations measured from non-detect to 5,700 ppm with a median value of 74 ppm in investigations conducted during the remedial investigation.

Baseline air monitoring was conducted for PCBs between May 23 and June 20, 1995, prior to dredging. Samples were collected from Turtle Cove and from the future site of the sediment stockpiles. The results measured PCBs in two of 17 samples collected at the Marina location at concentrations of 0.2 $\mu g/m^3$. All other results for the Marina location and all 14 samples from the sediment stockpile locations were non-detect.

Biological. Annual PCB bioaccumulation was measured in spottail shiners from the St. Lawrence River prior to dredging from 1986 to 1992 and in 1994. Lipid normalized PCB concentrations ranged from 4 to 2,917 ppm (BBL, 1999). The results are summarized in Table 1 along with post-dredging results.

7.2 Implementation During Dredging

Physical. Turbidity was measured in water samples collected throughout the remedial activities. The criteria for turbidity outside of the containment system was established at 28 NTU. During installation of the sheetpile wall, measurements ranged from 0 to 13 NTU. From July 10 to August 14, 1995, the turbidity criteria was exceeded in 18 of 923 measurements with results ranging from 31 to 127 NTU. Modifications were made to the containment system including installation of filter fabric, installation of short steel sheets over low sheetpiles and mechanical raising of low sheetpiles. In the period (August 17 to December 5, 1995) following the modifications, only one turbidity measurement in excess of the 28 NTU criteria was measured (49 NTU). This sample corresponded with a storm event and high waves on October 14, 1995.

Chemical. Water column samples were collected from one location outside of the containment system and analyzed for PAHs and PCBs. A total of 38 samples was collected over 19 days and analyzed for PAHs.

Results were non-detect and PAH sampling was discontinued July 15, 1995. A total of 146 samples collected over 73 days was analyzed for PCBs. Only one sample, collected during mechanical removal activities, exceeded the 2 μg/L action level (BBL, 1996b). A sheetpile wall was subsequently installed resulting in no exceedances of performance criteria.

Air monitoring samples for PCBs were collected between June 21 and December 15, 1995 from a location adjacent to the sediment stockpiles and Turtle Cove. A total of 50 of the 98 samples collected from the sediment stockpile area exceeded the 0.1 $\mu g/m^3$ action level. Samples exceeding criteria ranged from 0.11 to 4.7 $\mu g/m^3$ PCBs. A total of 24 of the 82 samples collected from the marina exceeded the criteria concentration, ranging from 0.11 to 0.55 $\mu g/m^3$. Air monitoring samples for particulate dust were also collected throughout the project. Measurements exceeded the 150 $\mu g/m^3$ criteria in samples collected in 21 of 142 days. Watering of gravel roads and/or work areas was immediately implemented as a dust control measure after exceeding the dust criteria.

Biological. Biological monitoring was not conducted during the remedial activities.

7.3 Post

Physical. A post-dredge bathymetric survey and sediment probing were conducted immediately following dredging to determine the topography of the riverbed and depth of remaining sediment. The volume of sediment removed during dredging was calculated to be 13,800 cubic yards based on comparison of the initial and final bathymetric surveys.

Chemical. Residual PCB concentrations in river sediments were measured following each of the multiple removal attempts conducted in each of six quadrants. Average residual PCB concentrations in quadrants 1, 2, 4, 5, and 6 ranged between 2.5 and 3.9 ppm. Residual PCB concentrations in Quadrant 3 measured less than 100 ppm with an average residual PCB concentration of 27 ppm after eight rounds of dredging and sampling. The U.S. Army Corps of Engineers (ACOE) representative (observing site activities) requested the collection of a single sample at the western end of Quadrant 3 prior to installation of a sediment cap. The sample was collected November 8, 1995 and measured 6,281 ppm PCBs (BBL, 1996b).

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration (in ppm)			
	Baseline ≈1986 - 1995	During Dredging March 1995 - Jan 1996	Post November 1995	Long Term 1997 - 2001
Bathymetry	Yes	None	Removal of 13,800 cy	None
Sediment Core	Non-detect to 5,700 ppm with median of 74	To check progress	Average range 2.5 to 2.9 in five quadrants; average 27 ppm in one quadrant	None
Water Quality	None	Turbidity: 0 to 127 NTU: 19 exceedances, N >1,000 PCBs: one exceedance, N = 146	None	None
Biological - Resident Fish	Lipid-normalized PCB concentrations ranged from 4 to 2,917 ppm in spottail shiners	None	None	Average Lipid-normalized PCB concentrations = 22 ppm (1997) = 79 ppm (1998) = 27 ppm (1999) in spottail shiners (composite)
Air Quality	Non-detect to 0.2 $\mu g/m^3$ (N = 31)	Range from non-detect to 4.7 $\mu g/m^3$, 74 of 180 samples exceeded 0.1 $\mu g/m^3$ criteria	None	None

Table 2 Summary of Sediment PCB Concentrations

Location	PCB Sediment Concentration (in ppm)					
	Baseline			Post		
	Minimum	Maximum	Median	Minimum	Maximum	Average
	non-detect	5,700	74			
Quadrant #1				0.079	8.22	2.6
Quadrant #2				0.076	7.9	3.8
Quadrant #3				0.57	91.0	27.0
Quadrant #4				0.16	5.52	2.7
Quadrant #5				0.073	8.41	3.9
Quadrant #6				0.036	6.35	2.5

Biological. Following completion of dredging activities, fish tissue samples were not collected for another 1.6 years and are discussed in the long-term monitoring section. Since dupuration rate of PCBs in fish tissue often takes three to seven years depending on the species, this is not inappropriate. Sampling is expected to continue annually for five years.

7.4 Long Term

Annual PCB bioaccumulation measurements began in 1997 for the St. Lawrence River 5-year long-term monitoring plan (OMMP). Fish tissue samples for whole body and lipids were collected using spottail shiner if available, or else emerald shiner and longnose dace (BBL, 1999). Table 3 represents fish tissue data from pre- and post-dredging activities. Average lipid-normalized concentrations dropped from 620 ppm pre-project to 50 ppm PCBs after dredging.

In 1999, the fourth year of sediment cap inspections and third year of resident biota sampling was conducted in accordance with the OMMP. The integrity of the stone armor cap for all areas inspected appeared to be undisturbed and in good condition (following minor restoration with new armor materials after minor disturbance observed in previous yearly inspections). Resident spottail shiner fish were collected and analyzed as whole-body young-of-year composites for PCBs and percent lipid. Wet-weight total PCB concentrations ranged from 0.79 to 6.8 mg/kg PCBs (average = 2.4) and lipid-normalized concentrations ranged from 8.4 to 75 mg/kg lipid PCB (average = 27) (BBL, 2000). The mean total concentration in 1999 is lower than in 1998, and similar to levels in 1997. Collectively, the data appear to indicate a general downward trend in spottail shiner PCB concentration since the late 1980s.

Table 3 Resident Juvenile Spottail Shiner PCB Tissue Data (BBL, 1999 and 2000)

	Collection Date	Number of Samples	Lipids (%)	Average Total PCB (ppm wet-weight)	Average Lipid-Normalized PCBs (ppm)[2]	
Pre-dredge	1986 (Aug.)	9	1.41	1.22	87	Avg. = 620
	1987 (Sept.)	7	1.44	1.26	89	
	1988 (Sept.)	7	1.97	21.5	1,202	
	1989 (Sept.)	5	4.58	22.6	489	
	1990 (Sept.)	7	1.40	1.54	105	
	1991 (Sept.)	7	4.26	3.06	69	
	1992 (Aug.)	2	1.33	35.3	2,917	
	1994 (Sept.)	5	2.42	0.09	4	
Post-dredge	1997 (Oct.) LT[1]	7	5.58	1.20	22	Avg. = 64
	1998 (Oct.) LT[1]	7	4.54	3.59	79	
	1999 (Oct.) LT[1]	7		2.4	27	

Notes:

1 Each sample is a 15-fish whole-body composite.

2 The average PCB lipids for pre-dredge samples is 620 ppm and 50 ppm for post.

8 Performance Evaluation

8.1 Meet Target Goals and Objectives

Sediment removal was not successful in achieving the target PCB concentration of 1 ppm. Average residual PCB contamination ranged between 2.5 and 3.9 ppm in quadrants 1, 2, 4, 5, and 6. Residual contamination in Quadrant 3 averaged 27 ppm after eight rounds of dredging and sampling. A sediment cap was therefore designed and installed over Quadrant 3. The cap consisted of a 6-inch sand and activated carbon layer and a 6-inch armor stone layer.

Although the target goal of 1 ppm PCBs was not achieved, the project made progress relative to achieving human health and ecological endpoints by reduction of PCB concentration and mass. The average sediment PCB concentration dropped from 74 (median) to 27 ppm (before capping) with post-project average concentration of 7.1 ppm for all quadrants (10-fold reduction).

The average fish tissue concentrations dropped from 620 to 64 ppm PCBs since remedy completion (lipid normalized) (10-fold reduction). Additional long-term fish tissue monitoring samples should be, and will be, collected to verify this observed downward trend. Based on tissue results from 8 years of baseline data, the results can be highly variable.

Variability in certain years of the data may be due to several factors, including different fish lengths, sizes, species mobility, sample sizes, and sampling locations.

Sediments in Turtle Cove containing PCBs at concentrations up to 48 ppm were not included in the remedial dredging program and may continue to serve as a source of PCBs to fish.

8.2 Design Components

The horizontal auger dredge was selected after an assessment of five different dredging techniques based on sediment removal efficiency and sediment suspension.

Because residual contamination in Quadrant 3 averaged 27 ppm (above the 1 ppm cleanup criteria), a sediment cap was designed and installed over Quadrant 3. The cap design consisted of a 6-inch sand and activated carbon layer, a 6-inch gravel bedding layer, and a 6-inch armor stone layer. In 1999, the armored cap appeared intact with minimal disturbance. No routine maintenance was required; however, additional armor material was added in 1998 to restore minor nearshore areas.

8.3 Lessons Learned

The target removal criteria established for dredging was not achieved in any of the six quadrants of the removal action. Possible reasons for not meeting compliance criteria may include inadequate site characterizations, selection of removal methods, and selection of unrealistic cleanup criteria. However, significant reductions in fish tissue concentrations (12-fold) and surface sediment concentrations (10-fold) were observed. Although cleanup criteria of 1 ppm was not achieved, progress was made towards risk reduction.

Other lessons learned included:

- Silt curtains did not work well in fast-moving rivers.

- Installation of sheetpile walls need careful consideration. If the tops were placed above waterline, they were subject to disturbance, but placement below waterline resulted in turbidity exceedances outside the containment system.

- The cleanup criteria of 1 ppm PCBs was likely not a realistic target goal for post-verification sampling efforts based on site conditions and dredging method selected (horizontal auger). An average of 12 to 21 subsamples were collected in each of the six quadrants and less than 40 percent of the subsamples measured less than 1 ppm PCBs dry-weight. However, none of the discrete samples exceeded 10 ppm PCBs (except in Quadrant 3).

- The number of dredge passes varied by area, averaging approximately 15 dredge passes across all areas with certain areas exceeding 30 dredge passes (BBL, 1996b). A vacuum head was placed on the end of the auger and every attempt was made to remove residual sediment resting on top of glacial till. A lot of effort was expended for residuals with little return under these site conditions.

9 Costs

The cost of the 1995 dredging of 27,000 cubic yards of in situ sediment was approximately $7 million based on a firm fixed-price contract. A total of 13,800 cubic yards of filter cake required disposal. This figure did not include cost of the sediment cap or disposal. The cost including the sediment cap was approximately $10 million. Based on these values, dredge and cap costs were $680 per cubic yard.

10 Project Contact

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Design Engineer: BBL
Contractors: Sevenson Environmental Services

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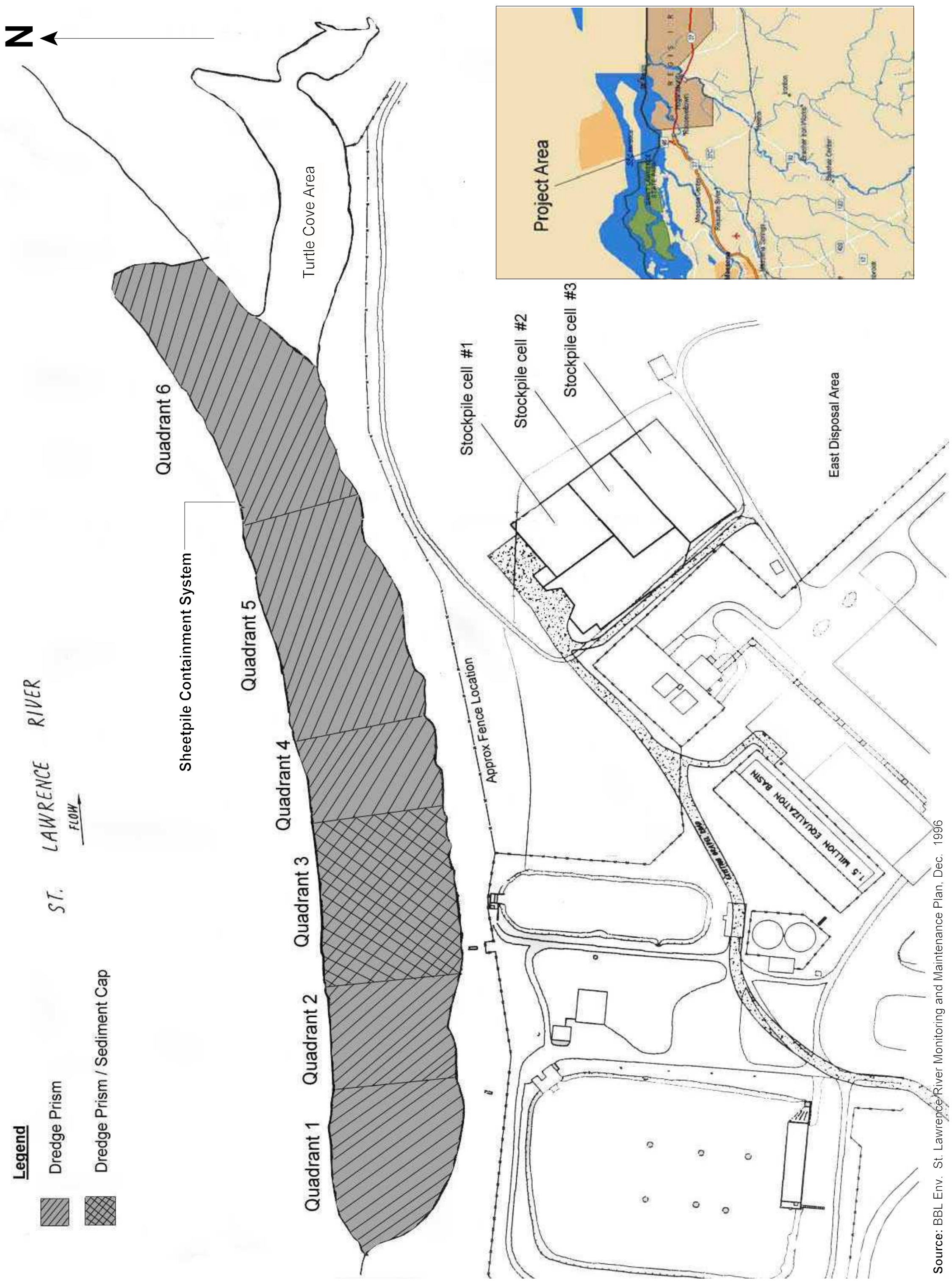
Figure 1   Remedial Dredge Plan - GM Foundry/St. Lawrence River



- Dredged 1995 (pilot)
- PCBs
- 3,800 cubic yards
- $450 per cy for dredging

1 Statement of the Problem

PCB contamination was present in Grasse River sediments at concentrations up to 11,000 mg/kg. Approximately 2,600 cubic yards of sediment were dredged in 1995 as a pilot study to gain site-specific information/experience and to remove highly contaminated sediment from a major hotspot. A *Draft Analysis of Alternatives* was completed in December 1999 to address future remediation of the site. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 2.

2 Site Description

The Grasse River area of concern, located in Massena, New York, is an 8.5-mile stretch extending upstream from the confluence with the St. Lawrence Seaway. The river bottom consists of glacial till containing large boulders, cobbles, and rock overlain with a soft sediment layer containing loose gravel and cobbles. The water level in the project area ranges from 2 to 3 feet near shore to a maximum depth of approximately 14 feet. The width of the river channel is approximately 400 feet. The dredging area was approximately 1 acre in size and measured approximately 100 feet wide by 500 feet long.

3 Site Investigation

A grid sediment sampling investigation, conducted in September 1993, found PCBs at concentrations up to 11,000 mg/kg. PCBs were the contaminant of interest at the Grasse River site and are primarily derived from historic discharges of the ALCOA aluminum product production plant. Contamination was present in sediment up to depths of 1 to 2.5 feet.

Hydraulic Horizontal Auger Dredge
Source: D.C. Roukema, J. Driebergen, and A.G. Fase

A Non-Time-Critical Removal Action (NTCRA) was proposed by ALCOA as a voluntary cleanup of Grasse River sediment located adjacent to the ALCOA Outfall No. 001. Final approval of the NTCRA, which included dredging, mechanical dewatering, and disposal in the ALCOA Secure Landfill, was granted by EPA in May 1995 under Superfund. To date, the site is not on the National Priorities List (NPL) nor has a Record of Decision (ROD) been issued (EPA, 2000).

4 Target Goals and Project Objectives

A 1993 EPA baseline risk assessment concluded the study area presented unacceptable risk due to ingestion of fish, ingestion of and dermal contact with sediment, and dermal contact with surface water (GE/AEM/BBL, 1995). The pilot remedial action was intended to remove only highly contaminated sediment from a 1-acre hotspot within the 8.5-mile study area. This entailed proposed removal of approximately 3,550 cubic yards of contaminated sediment from a dredge prism in the immediate vicinity of ALCOA Massena Facility permitted Outfall No. 001. By removing 3,550 cubic yards, it was expected that 25 to 30 percent of the total polychlorinated biphenyl (PCB) mass from the entire study area would be removed. No target contaminant concentration criteria was established for the pilot removal.

5 Project Design

Pre-planning and Bid Documents. An engineering evaluation/cost analysis (EE/CA) was conducted to analyze removal action alternatives for the NTCRA. The EE/CA also defined the objectives of the study including volume and contaminant mass removal. A monitoring plan was instituted to determine the effects of remedial activities and to apply these findings to future designs. Underwater geophysical and diver surveys conducted in September 1993 and July and November 1994 provided information for the removal of boulders from the project area to assist in dredging.

Summary of Remedial Action Plan. The NTCRA was conducted as a voluntary action by ALCOA with oversight provided by EPA Region 2. In chronological order, remedial design included a helical screw-anchored silt curtain containment system, boulder removal, and dredging with a horizontal auger dredge. Dredged sediments were then dewatered, filter pressed, and transferred to a permanent upland landfill facility. Environmental monitoring was conducted prior to, during, and after dredging activities by an independent quality assurance contractor. During installation of the silt curtain, concrete blocks were used as anchoring devices due to the inability to drive helical screws into the river bottom.

In the immediate outfall area (Area B), an additional 200 cubic yards of sediment was removed by dry excavation from a dewatered area of the outfall. Dewatering of Area B was accomplished using a diversion pipe, a sheetpile wall, and submersible pumps. Manual removal of sediment was performed using two suction lines attached to an augerhead dredge pump manifold. The Area B dry excavation is not discussed further in this case study.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial action took place from June 19, 1995 to October 3, 1995 (110 days). Boulder removal took place from July 17, 1995 to August 9, 1995. Dredging was conducted from August 9, 1995 to September 6, 1995. The work schedule for the project was eight to 10 hours per day and five days per week.

Equipment. A silt curtain was installed surrounding the dredge area to contain sediments suspended during dredging. Redesign of the silt curtain anchoring system was necessary due to the inability to drive helical screw anchors into the river substrate. Helical screws were therefore replaced with large concrete blocks to anchor the silt curtains. Prior to dredging activities, boulders, cobble, and debris identified in an underwater physical survey were removed from the dredging area. A Caterpillar 320L long-stick excavator with a riprap and rock removal bucket was used for removal (OHM, 1995).

Boulder removal resulted in significant suspension of sediment and failure of PCB and total suspended solids (TSS) water quality monitoring criteria. Initially, boulders were manually pressure washed within the bucket immediately after being lifted from the river. Modifications were made to wash the boulders beneath the waterline by agitating the loaded bucket. This allowed boulder removal to proceed with fewer elevations in TSS/PCB concentrations.

Sediment removal was conducted using a horizontal auger dredge operated with low-speed, high-torque hydraulic motors. During dredging, cobbles and rocks greater than 4 inches in diameter were removed from the dredge using a grappler. Consecutive dredge traverses were overlapped 12 to 24 inches to ensure all areas were covered.

Total Volume Removed and Production Rates. A total of 3,550 cubic yards of sediment were slated for removal. Although two dredge passes were made in some areas, approximately 550 cubic yards of sediment remained after dredging. The total sediment removed for this project was 3,175 cubic yards resulting in a removal efficiency of 85 percent. A summary of the dredged material includes:

- Boulders removed prior to dredging - 390 cubic yards,
- Sediment removed (average of two measurements) - 2,585 cubic yards,
- Dry excavation from Area B - 200 cubic yards,
- Sediment left in-place - 550 cubic yards, therefore
- Total = 3,725 cubic yards.

Sediment remained in-place due to accessability issues with the dredge resulting mainly from the presence of boulder and cobble material. The volume removed was calculated from production was 2,526 cubic yards and volume removed calculated from geophysical investigation was 2,643 cubic yards. These figures did not include the removed boulders. The solids content of dredged material ranged from 2 to 5 percent. The average daily pumping rate was 720,000 gallons.

Site-specific Difficulties. The proposed silt curtain anchoring system was replaced with large concrete blocks due to inability to drive helical screws into the river bottom.

Although 390 cubic yards of boulders and cobbles were removed from the site prior to dredging, additional boulders and cobbles were discovered during dredging and were left in-place. The presence of this material and the hard and dense conditions of the river bottom (glacial till) inhibited the efficient operation of the horizontal auger, resulting in reduced sediment removal efficiency. Sediment remained in the dredge prism at thicknesses between 0 and 14 inches (average of 4 inches).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Sediments were dewatered using four 100-cubic-foot recessed chamber filter press units. The water treatment system consisted of sand filters, dual bag filters, and dual cells of liquid-phase granular activated carbon (OHM, 1995). The water treatment system operated 24 hours a day from August 9, 1995 until September 19, 1995 (42 days) treating a total of 11,667,211 gallons. Treated water was discharged back to the Grasse River.

Water Quality Monitoring of Discharge. A discharge water grab sample was collected and analyzed daily for PCBs, TSS, total dissolved solids (TDS), polyaromatic hydrocarbons (PAHs), and fluoride. PCBs in excess of the discharge criteria (detection limit) were detected in two samples collected August 12 and August 18 at concentrations of 0.911 and 0.309 μg/L, respectively. PCB concentrations entering the granular activated carbon unit ranged from 6.5 to 8.3 μg/L (BBL, 1995).

6.3 Storage and Disposal

Following screening and dewatering, the filter cake, sand, and gravel residuals were disposed of in the ALCOA on-site secure landfill along with boulders and cobbles. A total of 169 cubic yards of gravel, 1,215 cubic yards of sand, 1,142 cubic yards of filter cake, and 390 cubic yards of boulder and cobble material were disposed in the landfill.

7 Environmental Monitoring Program

Physical, chemical, and biological monitoring was conducted prior to, during, and following dredging operations. The results of the monitoring program were presented in the NTCRA documentation report (BBL, 1995) and are summarized in Tables 1 and 2.

7.1 Baseline

Physical. Underwater geophysical surveys were conducted using magnetometry, side-scan sonar, and ground-penetrating radar to determine sediment stratigraphy and bathymetry in September 1993. Supplementary physical data were provided by diver surveys conducted in July and November of 1994.

Chemical. A gridded sediment sampling program was conducted within the hotspot excavation area in September 1993, with PCB results ranging between non-detect and 11,000 mg/kg. The average PCB concentration was 1,109 mg/kg. The average PCB concentration in the top one foot of sediments (bioavailable zone) was 518 mg/kg.

Site-wide water column PCB analysis of filtered and unfiltered samples were conducted at 13 fixed transect locations between July 1993 and May 1994. PCB concentrations were less than the practical quantitation limits for all samples (0.5 and 0.7 μg/L, depending on the Aroclor). Results were less than the method detection limits (0.05 and 0.07 μg/L, depending on the Aroclor) in 92 percent of samples.

Baseline air monitoring for particulate- and vapor-phase PCBs was conducted on July 13 and 15, 1995. PCBs were not detected in any samples.

Biological. PCB bioaccumulation was tested in caged and resident fish at two locations upstream and two locations downstream of the removal area. Results of caged fish studies conducted between October and November 1993 detected PCBs in all sampling locations with higher concentrations in locations downstream of the outfall (Figure 1 and Table 2).

Ambient Air Monitoring
Source: B. Paulson, WDNR

Resident fish from locations including background, upper, middle, and lower stretches of the river, and the mouth of the river were tested for PCB bioaccumulation in 1991 and September and October 1993. A total of 58 smallmouth bass, 72 bullhead, and 12 spottail shiner samples were analyzed in the 1993 sampling. PCBs were detected in all samples. Although actual analytical data were not reviewed, the NTCRA Documentation Report stated that results did not show strong spatial trends and that there was no statistical difference in PCB concentrations between the 1991 and 1993 studies.

A benthic community assessment was conducted between August and November 1993 measuring the presence, abundance, and diversity of the macroinvertebrate benthic community. Samples from seven transects were taken at each of two sites (background and downstream of the remedial site). Based on the results, one downstream community transect was impaired.

7.2 Implementation During Dredging

Physical. The water column was monitored for TSS, TOC, DOC, temperature, pH, conductivity, and turbidity during dredging operations. Due to difficulties in removal, an average of 4 inches of sediment was left behind. This correlates to approximately 550 cubic yards. Weak correlation was observed between turbidity, TSS, and PCB concentration. Sediments were probed after each dredge pass to determine completeness of dredging to the base soft sediment in the dredge prism. A second dredge pass was required in some areas that did not meet the progress survey requirements.

Chemical. Filtered and unfiltered PCB concentrations were measured daily in the water column during boulder removal and dredging. Samples were collected from two upstream locations and three locations immediately outside of the containment system. Concentrations ranged from non-detect to 13.3 μg/L at the perimeter locations. The 2 μg/L water quality criteria was surpassed on July 20, 21, 25, 26, 28, August 1, and 9 during boulder removal and August 10, 11, 12, 15, 16, and 17 during sediment removal. In the events exceeding criteria, additional sampling was conducted at a point 2,300 feet downstream. PCB concentrations in these samples ranged between non-detect and 1.38 μg/L. Because the concentration never exceeded 2 μg/L at this sampling point, the corrective action procedure was never implemented.

Filtered and unfiltered water column PCB samples were also collected from 13 fixed transect locations spanning a 4.5-mile length of the river during boulder removal and dredging. Two rounds of samples were collected daily throughout removal operations (July 17 through September 6, 1995). The results showed no detectable concentrations of PCBs during boulder removal. PCBs were detected during dredging in four of the transect samples at concentrations up to 1.1 μg/L. No PCBs were detected in any of the filtered samples.

Air monitoring was conducted daily from July 13, 1995 to September 6, 1995 for particulate- and vapor-phase PCBs. No PCBs were detected.

Biological. PCB bioaccumulation was tested using caged fish studies in the same four locations used in the 1993 baseline monitoring (Figure 1). PCB concentrations were significantly increased in upstream and downstream samples. See the post-monitoring section for concentrations and comparisons.

7.3 Post

Physical. A bathymetric survey was conducted to document the final topography of the river following dredging. A physical description of remaining sediments was also conducted. The water column was monitored for TSS, TOC, DOC, temperature, pH, conductivity, and turbidity.

Chemical. Two rounds of water column testing for PCBs (filtered and unfiltered) were conducted site-wide at the 13 transect locations. One sample had detected concentrations of PCBs in the first round of sampling at 0.7 μg/L. No PCBs were detected in the second round of sampling.

Sediment sampling within the excavation area was conducted two days after dredging on September 8, 1995, to document residual PCB concentrations. Results of sediment sampling for pre- and post-dredge sampling are given in Table 1. In the bioavailable zone, post dredge PCB sediment concentrations decreased 88 percent when compared with pre-dredge 1993 maximum concentrations and decreased 86 percent when compared to 1993 average concentrations, with measured concentrations varying from non-detect to 2,200 ppm in surface sediments (ALCOA, 1999) prior to dredging.

Table 1 Pre- and Post-Dredge Sediment Sampling Results

Sampling Events	PCB Concentrations (in ppm)		
	Pre-dredge (1993)	Post-dredge (1995)	Percent Decrease (1993–1995)
All Sample Depths			
Minimum	non-detect	1.1	—
Maximum	11,000	260	99.9%
Average	1,109	75	93%
Bioavailable Zone (top foot)			
Minimum	non-detect	1.1	—
Maximum	2,200	260	88%
Average	518	75	86%

Biological. PCB bioaccumulation was tested on caged fish samples collected October 17, 1995 and November 7, 1995 from the four locations used in baseline and progress monitoring (Figure 1). Monitoring showed an increase in PCB concentrations measured in cage fish during dredging and at least one month following dredging (Table 2). PCB bioaccumulation increases were higher in downstream locations than upstream locations; however, the PCB concentrations in the upstream samples were also higher than respective baseline conditions.

Post-dredge PCB bioaccumulation samples of resident brown bullhead, smallmouth bass, and spottail shiner were collected between October 11 and October 18, 1995. PCBs were detected in resident fish from all sampling locations. Samples were collected from the same locations as the 1991 and 1993 pre-dredge sampling events. Although actual analytical data were not reviewed for baseline samples, the NTCRA Documentation Report concluded that statistically significant increases from baseline 1993 samples were shown only in spottail shiner samples from the upper stretch of the river. No significant increases were demonstrated in smallmouth bass or brown bullhead samples compared to pre-dredge samples. Results of 1995 post-dredging fillet samples for smallmouth bass and brown bullhead are presented in Table 2. While significantly elevated concentrations of PCBs were shown in downstream samples relative to the background (upstream) samples, no significant difference was shown between the three downstream regions of the river, below the dredging area.

7.4 Long Term

A benthic community assessment was scheduled to be completed in the summer of 1996. Data were not available for review and is not included in this case study.

Table 2 Caged/Resident Fish PCB Bioaccumulation in Fillet Samples (mg PCBs/kg lipid)

Testing Parameter	Stage	Baseline (Oct/Nov 1993)	During (Aug/Sept 1995)	Post (Oct/Nov 1995)
Caged Fish [1, 2]	Cage #1 (upstream, nearshore)	9.7	129	60.5
	Cage #2 (upstream, farshore)	5.2	76.2	20.4
	Cage #3 (downstream, nearshore)	110	2,736	388
	Cage #4 (downstream, farshore)	24.7	667	152
	Average Downstream Relative to Upstream	**8.0 ×**	**15 ×**	**7.0 ×**
Resident Fish [3] (Bass)	Background Stretch (upstream, above dam)	NA	NA	3.9
	Upper Stretch (downstream)	NA	NA	1,134
	Middle Stretch (downstream)	NA	NA	943
	Lower Stretch (downstream)	NA	NA	1,043
	Mouth of River	NA	NA	NA
Resident Fish [3] (Bullhead)	Background Stretch (upstream, above dam)	NA	NA	3.0
	Upper Stretch (downstream)	NA	NA	607
	Middle Stretch (downstream)	NA	NA	756
	Lower Stretch (downstream)	NA	NA	465
	Mouth of River	**NA**	**NA**	**NA**

Notes:

[1] Results presented are from 3-week sampling events.
[2] All cages were located along the perimeter of the containment system and below the dam.
[3] PCBs were detected during baseline, but apparently no significant temporal or spatial trends were observed.
NA - Data not available for review.

8 Performance Evaluation

8.1 Meet Target Objectives

Short-term Target Goals. Only 84 percent of the proposed 3,550 cubic yards of contaminated soft sediment was removed from the hotspot because of impediments from rocks and boulders and underlying glacial till. The competent glacial till acted as refusal to dredge penetration. The 8-foot horizontal augerhead could not remove all sediment under these conditions. Although the total mass of PCBs at the site was not available for review, measurements based on site-wide and hotspot sediment sampling determined that approximately 27 percent of the total PCB mass for the entire site was removed by the hotspot dredging. This was within the project goal of 25 to 30 percent mass PCB removal. Although no chemical criteria was established, the average PCB concentration in sediment decreased from 1,105 to 75 ppm (93 percent) from pre- to post-dredge samples. The dredging project was partially successful meeting the volumetric cleanup goals and was completely successful meeting the mass reduction criteria.

Long-term Remedial Objectives. Elevated concentrations (15 times above background) were measured in caged fish during dredging activities. The 1995 post-dredge results collected one and two months after dredging demonstrated a marked decline in the average PCB concentration when compared to measurements collected during dredging, but not a significant improvement from baseline conditions. These sample results were likely influenced by residual dredging disturbance. Caged fish locations were located outside, but within 150 feet of the perimeter containment system (Figure 1). Overall, one data point showed a slight reduction in downstream tissue concentrations, relative to the reference site, when pre-dredge conditions (eight times reference) to post-dredge (seven times reference) sample results. Subsequent caged fish studies were proposed for 1996 and 1997; however, data were not available for review. Data are inconclusive

Although the largest hotspot of PCB contamination was removed from the Grasse River, resident fish show continued exposure to residual PCB-contaminated sediments remaining in the area of concern (73 percent mass remaining after hotspot dredging).

8.2 Design Components

Geophysical and diver surveys were conducted to determine site conditions as an aid for boulder removal prior to dredging. The surveys failed to supply necessary information regarding the nature of subsurface sediment and the presence of subsurface boulders. Not enough pre-planning project data were collected and the project designers did not properly respond to the information they had.

8.3 Lessons Learned

The selection of the horizontal augerhead dredge was based primarily on the ability to operate with minimal suspension of sediment. The dredge was not capable of achieving the desired sediment removal efficiency due to insufficient project planning. Contingency plans and potential modifications to project target goals should have been considered if difficult substrate conditions were anticipated.

9 Costs

The total project cost was $4.87 million, resulting in a unit cost of $1,534 per cubic yard (for 3,175 cubic yards). The cost breakdown for various aspects of the action was $675,000 for design and design support, $2,895,000 for construction, $425,000 for transportation and disposal, $575,000 for monitoring and documentation, and $300,000 for management. The costs do not include agency oversight or preparation of the EE/CA (BBL, 1995).

10 Project Contact

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11 References

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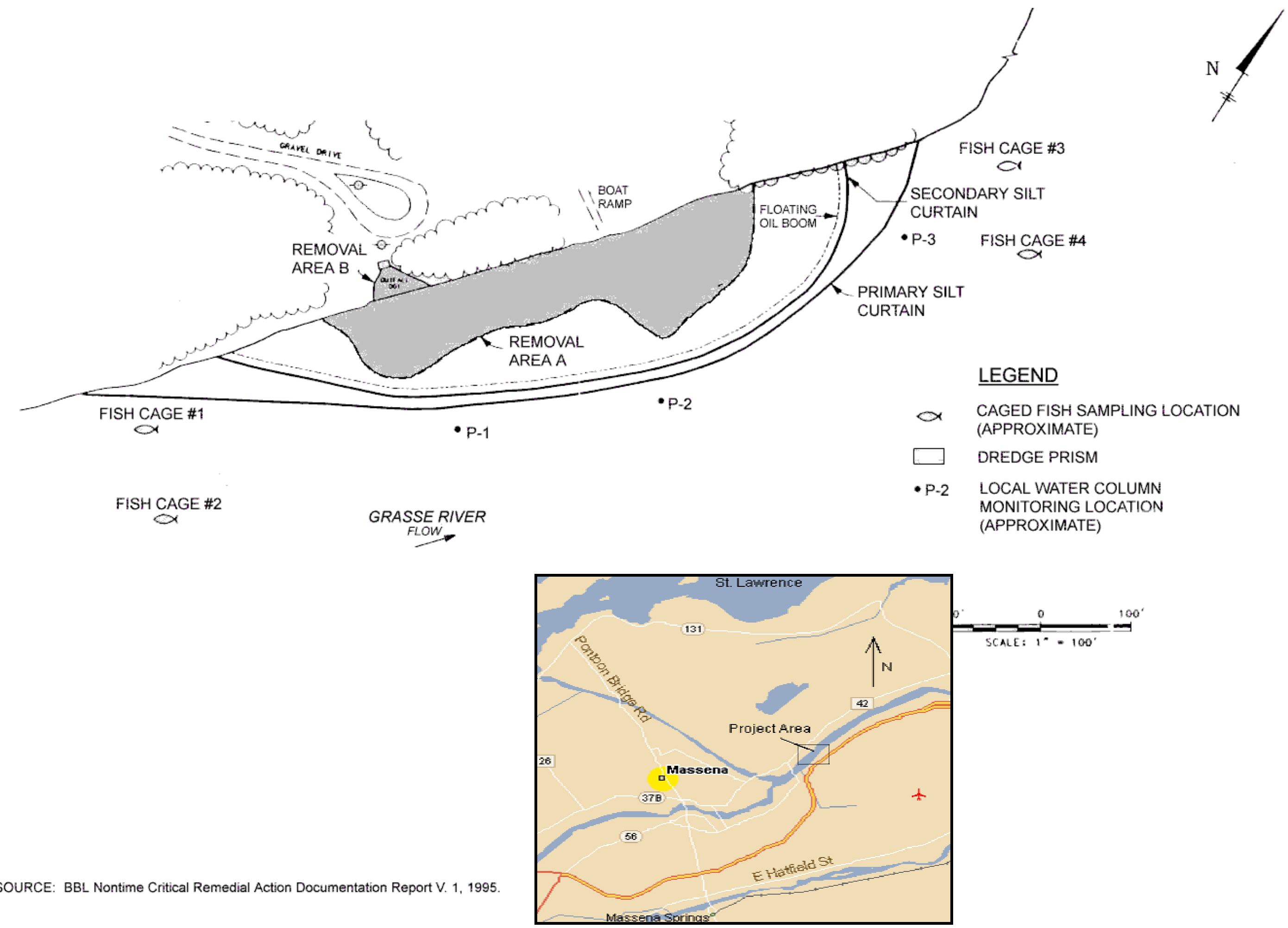
OHM, 1995. Final Implementation Plan for the Grasse River Study Area Non-Time-Critical Removal Action, Massena, New York. OHM Remediation Services Corp., Massena, New York. April 21.

Figure 1 Remedial Dredge Plan - Grasse River



SOURCE: BBL Nontime Critical Remedial Action Documentation Report V. 1, 1995.

1 Statement of the Problem

- Dredged 1993/1994
- PCBs
- 157,000 cubic yards
- $40 per cubic yard

At the Lake Jarnsjön site on the Eman River in Sweden, the primary constituents of concern were polychlorinated biphenyls (PCBs) with a maximum detected concentration of 30.7 mg/kg dry-weight (average 5.0 mg/kg). The cleanup remedy was to dredge from 0.4 to 1.6 meters of sediments from the lake bottom and dispose of the dewatered contaminated material in a nearby landfill. Dredging took place during the fall of 1993 and the summer of 1994. The lead agency for this project was the Swedish Environmental Protection Agency (EPA).

2 Site Description

Lake Jarnsjön is a 62-acre lake located 72 miles upstream from the mouth of the Eman River in Sweden (Figure 1). Eman River is the largest watercourse in southeastern Sweden and it discharges waters into the Baltic Sea. Lake Jarnsjön is a shallow lake, with typical depths ranging from 1.8 to 2.8 meters (5 to 8 feet depth), with a maximum depth of approximately 4.5 meters (13.5 feet). The flow rate through the lake ranges from less than a few meters per second to over 100 meters per second, creating a rapid exchange rate of water volume in the lake. Lake sediments are characterized as very soft organic sediments, mixed with mineral silty sediments and scattered sand pockets (Elander and Hammar, 1998).

3 Site Investigation

In the 1980s, elevated PCBs were found in the mouth of the Eman River. Large quantities of PCBs were found in paper fibers that had accumulated in Lake Jarnsjön. The lake was pinpointed as the primary source of ongoing contaminant discharges into the river system. The PCB-contaminated sediments were contained in a layer that covered the entire 62-acre lake bottom. The thickness of this contaminated layer varied from less than 0.4 meter to as great as 2 meters of contaminated sediments. The most highly contaminated sediments were primarily located in the eastern part of the lake, with the lesser contaminated sediments located in the remainder of the lake.

View of River Eman
Source: Emåprojektet website
www.emaprojecktet.h.se/

PCBs were the primary constituent of concern in the Lake Jarnsjön remediation project, with approximately 400 kilograms present in the lake. Elevated concentrations of metals were also found at the site; however, they were not specifically addressed in this cleanup. Historical discharges have been documented upstream from Lake Jarnsjön, including waste from paper mills (PCBs, metals), a battery factory (metals) and an accumulator factory (metals). However, the primary responsible party, a paper mill using recycled self-copying paper as raw material, caused the most extensive damage (Bremle and Larsson, 1998, Fox River Group, 1999, Gullbring *et al.*, 1998).

Remediation at Lake Jarnsjön was governed by the Swedish EPA and was part of the Swedish National Site Remedial Action Plan. The Swedish EPA was in charge of project planning and the local municipality was responsible for remedial action. A formal decision to undertake cleanup was made in 1992 (Gullbring *et al.*, 1998).

4 Target Goals and Project Objectives

The primary objective to the dredging project at Lake Jarnsjön was to protect human health and the environment. This would be done by removing contaminated sediments without harming the ecosystem. This project was a full-scale remediation project to be used as a national pilot cleanup, demonstrating that dredging was an ecologically and economically feasible cleanup option in Sweden. This project would expand knowledge about the cleanup of contaminated sediments and the decreasing PCB exposure in lakes and downstream areas.

5 Project Design

Pre-planning. Based on a pre-dredging Feasibility Study, a few options for remediation were explored. One option included capping the entire lake bottom with a clean material. This option did not seem feasible due to the already shallow nature of the water body. A second option included diversion of the Eman River via a new channel. This option was very expensive and would destroy nearby habitat. A third option, and the one chosen for implementation, was to hydraulically dredge the lake within a barrier of geotextile screens, mechanically dewater the contaminated sediments, and to dispose of them in a nearby landfill (Bremle, 1997, Bremle *et al.*, in press).

The Swedish EPA was in charge of planning remediation activities, and the local municipalities implemented the dredge plan and monitoring. A time schedule and cost estimate was agreed upon and was continually revised as the project progressed. The cost estimate was based upon unit costs and quantities (time and materials method) and performance-based environmental dredging criteria. The entirety of the cleanup was carried out within the agreed time frame and cost estimate.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging was scheduled from May to November of 1993, and during the summer of 1994. These months were chosen for the low water discharge at this time of year.

Equipment. A hydraulic dredge with an auger head was used to dredge Lake Jarnsjön. The dredge was specially designed with an advanced positioning system to work with high precision and in turn reduce the amount of suspended sediments. In areas of denser, more coarse sediments, a bucket dredge was utilized. Geotextile screens (silt curtains) were used in the highly contaminated eastern portion of the lake to reduce spread of suspended solids. The screens were kept in place in the eastern portion of the lake until August of 1994 and were not utilized in the western portion of the lake.

Total Volume Removed and Production Rates. During 1993, the highly contaminated eastern area of the lake was dredged. One to four layers of sediments were removed in 0.4-meter-thick dredge lifts to a depth of 1.6 meters in some locations (approximately one-third of the lake surface area). Geotextile screens were used to localize turbidity and confine suspended solids to the eastern portion of the lake (Figure 1). In 1994, in the lesser contaminated western area of the lake was dredged. Only one layer of sediments was removed in a 0.4-meter-thick dredge lift. The geotextile curtain was removed during dredging of this western area due to low percent solids suspended during dredging. By the completion of the project in 1994, 157,000 cubic yards of contaminated sediments were removed. An additional 39,000 cubic yards of sediment were removed as "overdredge" material, pushing the total sediments removed to 196,000 cubic yards. Within this dredge volume, a total of 394 kg PCBs were removed from the lake. This equated to approximately 99 percent of total PCBs in the lake. Of the approximate 2.9 kg PCBs which remained in the lake after dredging, nearly all the contaminants were located near the lake shores, in areas which were not included in the remediation plan (Bremle and Larsson, 1998; Gullbring *et al.*, 1998).

Site-specific Difficulties. The auger dredge used for cleanup was specifically designed for the soft sediments of the lake. However, in the southern area of the lake, sediments were dominated by dense sand and gravel, and could not be cut by the dredger. In some instances these sediments had to be removed with a bucket dredge. In other instances, the sandy layers could be dredged by suction auger, but required the addition of more water to the sediments, consequently increasing the load at the dewatering plant (Elander and Hammar, 1998).

In order to reduce the risk to aquatic life in the lake, dredging was halted during the winter months, from December to April.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Mechanical dewatering was carried out on the dredged sediments from Lake Jarnsjön. In consideration of landfill stability, the dry solids requirement for dewatering was 35 percent. The dry sediment was disposed of in a landfill. One difficulty with this requirement was that with the filter presses used for dewatering, as they could not achieve 35 percent solids with the quantity of fine-grain fraction of sediments from the lake. Instead, the fine fraction had to be remixed with sand and then dewatered again. Water was treated by flocculation chemicals to settle suspended solids and PCBs before the water was returned to the lake (Gullbring *et al.*, 1998).

Water Quality Monitoring of Discharge. After dewatering, water returned to Lake Jarnsjön was not allowed to exceed more than 50 mg/L suspended matter. This equated to approximately 2 kg of PCBs being allowed to return to the lake during the dredge project (Bremle *et al.*, 1995).

6.3 Storage and Disposal

After dewatering, the residuals were deposited in a nearby landfill. The highest contaminated sediments were placed at the bottom of the landfill, on top of a geotextile liner and with the more contaminated sediments on the bottom. These different layers of contamination were separated by a geotextile screen so that in the future, it would be easier to remove specific sediments if better remedial technologies became available. The landfill was covered with a 1.2-meter layer of uncontaminated sand and gravel, and then the entire landfill was covered with uncontaminated soil and restored to pastureland (Gullbring *et al.*, 1998).

7 Environmental Monitoring Program

The monitoring program included water column sampling, surface sediment sampling, air monitoring, and caged and netted fish tissue analysis (Bremle, 1997; Bremle and Ewald, 1995; Bremle *et al.*, 1995; Bremle *et al.*, 1998; Bremle and Larsson, manuscript 11; Bremle and Larsson, in press-a; Bremle and Larsson, in press-b; Engwall, *et al.*, 1998, Forlin and Norrgren, 1998; Gullbring *et al.*, 1998).

7.1 Baseline

Physical. Turbidity and total suspended solids (TSS) were measured prior to dredging. TSS were measured both upstream and downstream of the lake.

Bathymetry surveys were also conducted in the summer and autumn of 1991.

Chemical. In 1990, the lake was divided into 12 operable units and studied for sediment PCB values. In each unit, five to nine cores were collected by core sampler from 0 to 0.4 meter depth. All cores were collected with a core sampler, composited within each unit, and analyzed for a composited average value for the area. The overall average PCB values ranged from 0.4 to 30.7 mg/kg dry-weight, with an average of 5.0 mg/kg.

PCB concentrations in water were measured in Lake Jarnsjön during the summer and autumn of 1991 at five locations (two upstream, one in the lake, and two downstream). The methodology for collection included pumping approximately 100 liters of river water through polyurethane columns (PUCs) at a flow rate of 10 ml per minute. Samples were frozen until analysis. The average value of PCBs in the waters of and around Lake Jarnsjön in 1991 was 8.6 ng/L, with PCB values declining with distance from the upstream paper mill source.

Biological. Netted fish studies were conducted in 1991 to look at PCB concentrations in adult fish. Perch were caught by netting at five locations, as close to the water sampling stations as possible. At each location, five male and five female one-year-old perch were caught. Whole fish were weighed, pulverized, and frozen for PCB analysis. The average value of PCBs in the fish in Lake Jarnsjön in 1991 was 34 mg/kg.

A 1991 caged fish study, using perch and trout, determined a baseline value at various locations upstream, in and downstream from Lake Jarnsjön. Liver Somatic Index (LSI), ethoxyresorufin-O-deethylase (EROD) activity, plasma parameters, and histopathological characteristics were all analyzed. The results for 1991 showed no significant differences between different locations.

7.2 Implementation During Dredging

Physical. Turbidity and TSS were measured on a regular basis during dredging as a control instrument for dredging activities. TSS were measured both upstream and downstream of the lake, in the discharge and dewatering zone, and within the protective dredging screens. At each location, two samples were taken per each shift by the contractor. Additionally, weekly monitoring was conducted immediately above the lake, 10 kilometers below the lake, and 80 kilometers below the lake. Results showed that the dredge equipment worked well and the overflow was less than 0.5 percent. Turbidity measurements were taken to daily to supplement TSS data.

Chemical. PCB concentrations in water were measured weekly from 1993 to 1995. The range of PCB values during the period of 1993 to 1995 was 1.7 to 30.2 nanograms per liter (ng/L), with an average of 7.8 mg/L. No significant changes were observed during dredging when compared to baseline water column concentrations.

PCBs were measured for air quality during dredging and disposal in the landfill. Eleven stations were located between 5 and 1,000 kilometers from the disposal site and at one reference station located 12 kilometers from the disposal facility. For each sample, 1,000 cubic meters of air was pumped through PUC columns at a flow rate of 40 liters per minute. Samples were frozen until analysis. Although air quality was elevated from background at 2.5 ng per cubic meter during dredge activities, it was still within an acceptable range of national average metropolitan background volumes in Sweden. After remediation was completed, PCB air quality returned to normal background levels.

Biological. In 1993 and 1994, caged fish studies were repeated upstream, downstream and in Lake Jarnsjön. The results showed reduction in the LSI value, elevation in EROD activity, similar histopathological lesions, and reduced plasma electrolytes as compared to the 1991 data.

7.3 Post

Physical. TSS was measured at 10-week intervals from the end of dredging until 1996. Sampling locations included two stations upstream of the lake, one station at the outlet of the lake, and two stations downstream of the lake. The results were not presented in the given documentation.

Chemical. In 1996, 54 areas were studied for sediment PCB concentrations in Lake Jarnsjön. In each area, five surface cores were collected from 0 to 0.2 meters depth. All cores were collected with a core sampler, composited at each location, and analyzed to give an average value for each area. The average PCB concentrations ranged from 0.01 to 0.85 mg/kg dry-weight, with an overall average of 0.06 mg/kg. This was a 97 percent decrease in maximum concentration and 99 percent decrease in the average from the 1991 results.

PCB values in water continued to be measured weekly from May 1995 to 1996 at locations in and below the lake. The range of PCB concentrations during the period of 1995 to 1996 was 0.4 to 8.2 ng/L, with an average of 2.7 ng/L. This was a 30 percent decrease from the 1991 data.

In the PCB sediment and water studies monitored for two years after completion of dredging, contaminant concentrations decreased over time from values recorded prior to and during dredging. Besides the overall decrease in PCB values, a seasonal variation was noted. The highest PCB values were recorded during the lowest discharge months (i.e., summer) and the lowest PCB values were recorded during the highest discharge months (i.e., winter). This effect has been contributed to a dilution factor, with high discharges diluting PCB values during the winter months and emphasizing values in the summer (Bremle *et al.*, manuscript 3).

Eight groundwater wells and six drinking water wells within the vicinity of the disposal site were tested for PCBs through 1997. The median PCB concentration was found to be 0.5 ng/L in the groundwater and drinking water over time.

Biological. Following the methods of the 1991 netted fish study, perch were caught in 1996 by netting at four locations, as close to the water sampling stations as possible. At each location, five male and five female one-year-old perch were caught. Whole fish were weighed, pulverized, and frozen until analysis. The average value of PCBs in the fish in Lake Jarnsjön in 1996 was 16 mg/kg. This was a nearly 53 percent decrease from the 1991 results.

In 1996, caged fish studies were repeated. Compared to results from the previous years, the LSI was reduced, but the EROD was elevated. The decrease in the LSI was probably due to reduction of available food supplies or changes in metabolism before and during dredging causing depletion in energy reserves. Conversely, the EROD activity is one of the most sensitive biomarkers and results showed that in 1996, even with the decrease in PCBs in sediments and water, caged fish continued to indicate effects from PCB exposure.

7.4 Long Term

No long-term studies were documented in the reports.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (average PCB values in mg/kg dry-weight)			
	Baseline (1990/1991)	Progress (1993/1994)	Post (1996)	Percent Change (1991–1996)
PCBs in Sediment	5.0 mg/kg (max = 50 mg/kg)	—	0.06 mg/kg (max = 0.85 mg/kg)	99% reduction
PCBs in Water	8.6 ng/L	7.8 ng/L	2.7 ng/L	30% reduction
Netted Fish [1]	34 mg/kg	—	16 mg/kg	53% reduction
Caged Fish [2]	no differences between sites	NA	NA	
Air Quality	—	2.5 ng/L	—	
Groundwater	—	—	0.5 ng/L	
EROD (caged fish)	NA	Values not available; elevated levels	Values not available; reduction noted	
LSI (caged fish)	NA	Values not available; reduced levels	Values not available; reduction noted	

Notes:

[2] Caged fish collected in 1991; data not available.

[1] Netted fish co-located with surface water sampling stations, concentrations based on extractable fat.

NA - Data not available for review.

8 Performance Evaluation

8.1 Meet Target Goals and Project Objectives

Although not specified as a target goal, remedial dredging at Lake Jarnsjön was able to remove 99 percent of PCB contaminated sediment from the site. From data collected during the two years post-dredging, results show a decline in PCBs in the sediments, lake water, and in fish. As the remedial action primary objective of the cleanup was to protect human health and the environment, it can be concluded that Lake Jarnsjön succeed in its project objectives. In supplement to these findings, one of the review authors noted that changes in background exposure over time need to be taken into account when evaluating the success of remedial actions.

From the results of this cleanup, Lake Jarnsjön can be considered a successful remedial action project, fulfilling the secondary objective of the cleanup: to expand knowledge and provide an example for future Swedish cleanup actions.

8.2 Design Components

Little was documented about the design components of the Lake Jarnsjön cleanup. One success in the planning of the project is that the project was financed as a "time and materials" method of remediation rather than a "lump sum" method. This allowed for a more thorough cleanup process.

8.3 Lessons Learned

A better understanding of bottom sediments may have prepared dredge planners for more technologically-suited dredge equipment. Dense, coarse-grained sediment challenged the dredging equipment (equipment selected for the fine-grained material) resulting in some project delays and increased costs. These delays and extra costs may have been avoided if properly anticipated.

9 Costs

The estimated costs for planning the remediation at Lake Jarnsjön from spring of 1990 through the detailed planning phase in 1992 was approximately $770,000 US. Total remediation costs are estimated to be approximately $6.4 million US. This equates to an approximate cost of $40 per cubic yard.

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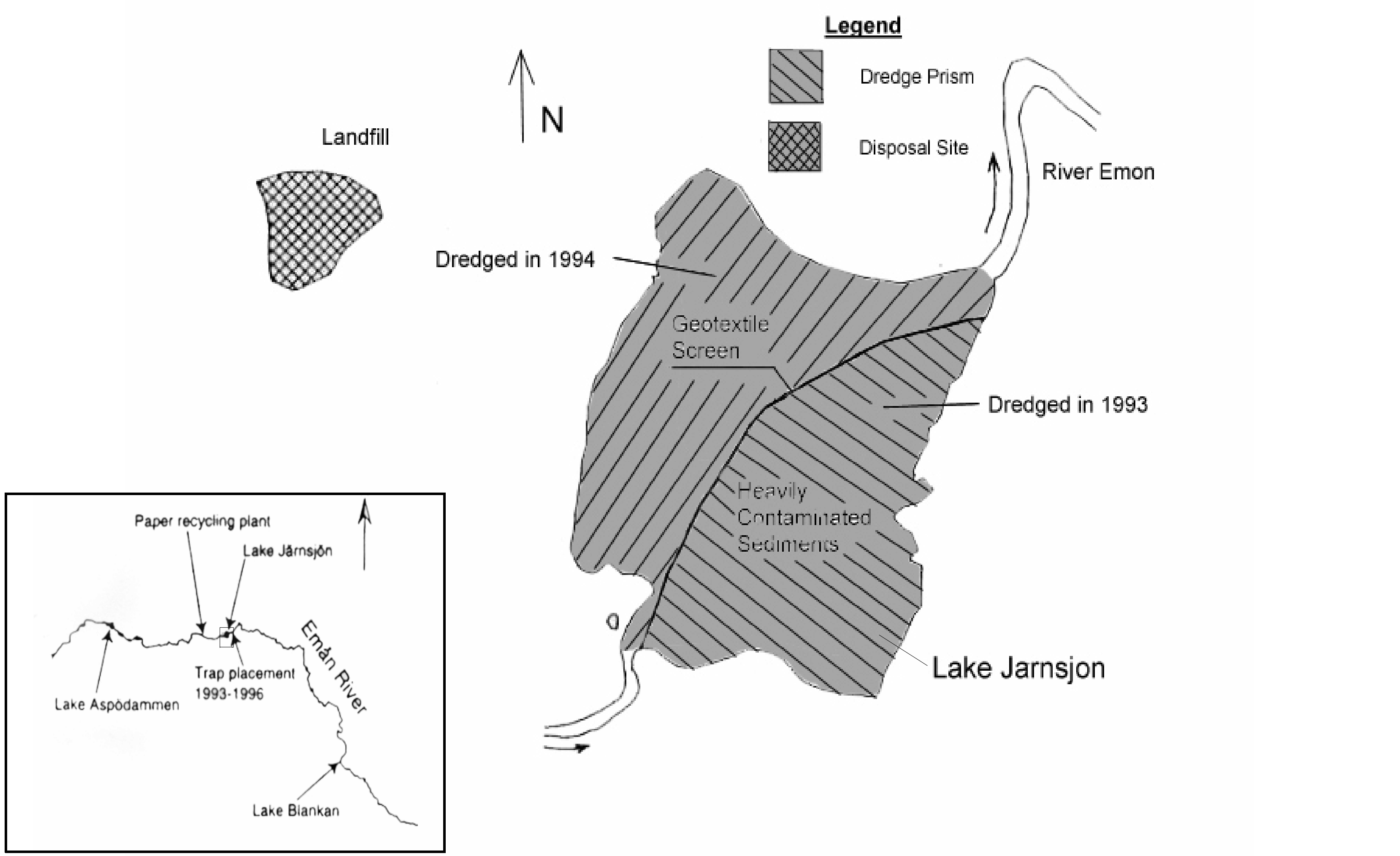
Figure 1 Remedial Dredge Plan - Lake Jarnsjön



Source: Elander and Hammer, 1998. *Ambio. (Aug)*

- Dredged 1995-2000
- PCBs
- 120,000 cubic yards
- $300 per cubic yard

1 Statement of the Problem

At Manistique River and Harbor superfund site in Michigan, the primary constituents of concern were polychlorinated biphenyls (PCBs). The cleanup remedy was dredging of three hotspots within the river and harbor. The cleanup goal was 95 percent removal of sediments contaminated with greater than 10 ppm PCBs (Blasland, 1999). Dredging began in 1995 and PRPs executed a buy-out in 1996 (Blasland, 1999). The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Manistique River and Harbor is located in the city of Manistique, on the southern shores of Michigan's Upper Peninsula. The project area is bounded to the east and west by the banks of the Manistique River, to the north by the Manistique Dam, and to the south by the outer boundaries of Manistique Harbor in Lake Michigan. Average water depth within the harbor is 18 to 20 feet, with average river depth ranging from 15 to 20 feet. The harbor is subject to sieche and storm-induced weather from Lake Michigan, especially in the winter months. The average sedimentation rate throughout the site is approximately 1.5 inches per year. The area of concern extends 1.7 miles downstream from the Manistique Dam, and includes both riverine and harbor sediments. The site is primarily used for recreational boating and fishing within the harbor, and for industrial and commercial use within the river.

3 Site Investigation

The Manistique site is composed of several nearshore and backwater hotspots, as well as an approximately 15-acre hotspot within the 97-acre harbor. PCBs are the primary constituents of concern, with approximately 14,000 pounds present in the river and harbor sediments (Blasland, 1999; EPA, 1995a; EPA, 1995b). Historical discharges have been documented upstream from Manistique Harbor, including waste from sawmills, a paper mill, industrial plants, a wastewater treatment plant, and navigation for shipping lumber. Wastes include paper, wood, and various industrial chemicals, with large quantities of sawdust and wood chips remaining in waters through time (Blasland, 1999; Garbaciak and Averett, 1999; GE/AEM/BBL, 1993).

Manistique Dredging
Source: B. Paulson, WDNR

In June 1995, an action memo was signed authorizing time-critical dredging removal of PCB-contaminated sediments at Area B. In October 1995, an action memo was signed authorizing capping of Areas C and D. After successful demonstration of dredging in Area B during the summer 1995, EPA Region V proposed dredging Areas C and D to the local public and PRPs. In December 1995, the public and PRPs supported the modification from capping to dredging and a revised action memo was signed on September 10, 1996.

In 1996, EPA issued a Removal Action Recommendation and Action Memorandum in lieu of a ROD, and the site is regulated by CERCLA (Interagency Review Team, 1995). Applicable or relevant and appropriate requirements (ARARs) complied with included: TSCA, CWA, Fish and Wildlife Coordination Act, Endangered Species Act, State of Michigan ARARs, Environmental Response Action, Water Resource Act, Great Lakes Submerged Lands Act, Soil Erosion and Sedimentation Control Act, Solid Waste Management Act, Air Pollution Act, Goemaere-Anderson Wetland Act, Inland Lakes and Streams Act, and Shoreline Protection and Management Act (Interagency Review Team, 1995; Hahnenberg, 2000).

Target sediment cleanup standards (TSCSs) were generated by calculating fish target levels and a bioaccumulation model (BASF) biota to a sediment accumulation factor. From this model a TSCS was established for PCBs at an accumulation level of 10 mg/kg (Interagency Review Team, 1995). In addition to establishing a protective action level, health advisory signs and fish advisories on carp were put into effect for local residents.

4 Target Goals and Project Objectives

The primary objective of the dredging project at Manistique was the long-term protection of Lake Michigan. A secondary objective was to reduce health risks to humans and wildlife consuming fish from the Manistique River and Harbor. By using the 10 mg/kg action level determined by the BASF model, the goal of the Manistique dredging was to remove all PCBs above this action level, based on a 95 percent removal of contaminated sediments (Interagency Review Team, 1995).

5 Project Design

Pre-planning and Bid Documents. EPA's position on sediment removal at Manistique has changed over the span of this project. When dredging was being planned in 1994, erosion-prone areas were to be dredged to the 10 mg/kg PCB action level. Other locations having 10 to 50 mg/kg PCBs were to be capped. In 1995, an interagency review team concluded that dredging alone has a much longer-term performance record than capping and therefore all sediments above the 10 mg/kg action level were to be dredged (Interagency Review Team, 1995). The capping remedy was removed altogether from the cleanup plan.

Superior Special Services was the primary contractor for the Manistique dredging project. Environmental Quality Management provided oversight contracting. Costs were calculated on a "time and materials" method and performance-based criteria. No dredge design engineering was done; however, the contractor was given adaptive management flexibility. Three hotspots were targeted for dredging: a dead-end lagoonal hotspot (Area

B), a nearshore river hotspot (Area C), and a 15-acre hotspot in Manistique Harbor (Area D). Once hotspots were removed, the entire target area was anticipated to meet target PCB concentrations.

Summary of the Remedial Action Plan. The remedial project design at Manistique River and Harbor was a full-scale dredging project for the long-term protection of Lake Michigan. The operation included mechanical dredging, on-site treatment, and off-site disposal. A sheetpile cutoff wall, silt curtains and a floating boom were installed midway through the dredging to limit spread of contaminants.

Limitations and Permits. Because EPA was managing this dredging project, there were no specific permits required for cleanup. However, the site did need to comply with Surface Water Discharge restrictions, and later, the U.S. Army Corps of Engineers Dredging Permit Process. Dredging was limited to the non-winter months, from approximately April to October, and was dependent on weather conditions and partial freezing of water bodies.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The Manistique dredge plan was implemented in 1995 and is continuing into 2000. Dredging is being completed in 2000. Dredging occurred during three months in 1995, six months in 1996 and 1997, five months in 1998, and has just been completed for the 1999 year. In 1997, a temporary HDPE cover, originally placed in 1993 over contaminated sediments in Area C, was removed prior to dredging.

Equipment. Dredging was completed by several sizes of hydraulic dredges, depending upon site conditions. Equipment included a custom hydraulic dredge with twin suction pumps and a modified head (some diver assistance), a diver-assisted hydraulic dredge with hose/pump, a diver-assisted vacuum removal hydraulic auger dredge, and a hydraulic cutterhead dredge with a 10-inch hoseline, pump and twin suction pumps added later. Site conditions dictated which equipment was best suited for removal operations (i.e., the slab-wood encountered at depth required diver assistance for removal). The variety in dredge equipment used over the years was based on knowledge gained the previous years and adopting adaptive management to improve dredge performance. To limit the spread of contaminants, a plastic sheetpile steel cutoff wall, with silt curtains and floating booms, was installed midway through the dredging removal portion of the Area B project. A plastic sheetpile was constructed instead of steel wall to alleviate concerns about fracturing the bedrock and disturbing bridge pilings.

Total Volume Removed and Production Rates. The total volume removed from Areas B, C, and D at the end of 1998 was estimated at 120,000 cubic yards of contaminated sediments, based on the proposed *in-situ* dredge prism (Zweibel, 2000). It was difficult to estimate the total *in-situ* volume removed through 1999 due to the necessity of redredging areas to remove residual contaminated material. However, the *ex-situ* volumes removed in 1998 were estimated to be 22,000 cubic yards and in 1999 were estimated to be 25,000 cubic yards (Hahnenberg, 2000). This difficulty of comparing *in-situ* and *ex-situ* dredge volumes accounts for the discrepancy between reports of dredged sediments and final volumes disposed.

Manistique Dredging
Source: EPA

Through the course of the project and weather permitting, the dredging schedule of seven days per week, and six hours per day was typically achieved.

Site-specific Difficulties. On-site constraints included slowdowns due to wood and debris in the dredging areas, wind-driven waves causing extensive downtime, dredge production rates exceeding land-based handling and water treatment capacity, and rough weather causing shutdowns due to disruption of barge spuds. As well, it was impossible to overdredge due to contamination extending down to bedrock. Thus 100 percent removal of contaminated sediments was not possible by an overdredging technique, and areas had to be redredged multiple times, over multiple years. The EPA plans to use a diver-assisted vacuum removal in the spring of 2000 to remove residuals which have settled on the bedrock (Hahnenberg, 2000).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Prior to 1997, dredge material was pumped directly to an onshore treatment facility. Beginning in 1997, dredge material was pumped onto a barge and then transported to the onshore treatment facility. Following the removal of dredged material, sediment was sieved through a coarse screen, a vibrating screen, and then a rotary screen to remove large material. Remaining sediments were then sent to a FRAC tank for gravity settling. In 1996, hydrocyclones were added and material was then directed into four settling basins and a belt filter press. All waste and water treatment was done on-site (Blasland, 1999).

Water was treated through a dual-media filter (sand and coal), and then passed through activated carbon. All treated water met the 0.5 ppb PCB criteria and was then returned to Manistique Harbor.

6.3 Storage and Disposal

The majority of contaminated sediments dredged at the Manistique site have been disposed of in off-site landfills. In 1995, sediments containing less than 50 ppm PCBs (97 percent of sediments) were sent to a RCRA Subtitle D landfill (non-TSCA). Those sediments above 50 ppm (3 percent) were sent to an in-state TSCA landfill. From 1996, approximately 70 percent of sediments (less than 50 ppm) were sent to in-state commercial Subtitle D landfills, and approximately 30 percent (greater than 50 ppm) were sent to an in-state TSCA landfill (EPA, 1999).

7 Environmental Monitoring Program

The environmental monitoring program included bathymetric surveys, side-scan sonar surveys, sediment cores, caged fish tissue analysis, and sediment traps (BBL, 1998).

7.1 Baseline

Physical. Prior to dredging, bathymetry was collected by U.S. Army Corps of Engineers. Data were collected via sediment cores in 1993, 1997, and 1998, and caged fish studies in 1995 and 1998. Bathymetric and side-scan sonar bottom surveys were also conducted in 1998 to develop a picture of bottom sediments as dredging progressed.

In 1993, EPA installed a temporary sediment cap in the Manistique River (approximately 100' x 240') in water depths between 5 and 25 feet deep. The mat fabric was a 40-mil, high-density polyethylene (HDPE) plastic liner, anchored around the perimeter with concrete traffic-style barricades and attached to the mat by braided steel cables. The temporary cover was placed in an upstream area (between turning basin and Route 2 overpass) over sediments exceeding 124 ppm PCBs. A 1994 underwater diver inspection of the sediment cap revealed recent sedimentation up to six inches thick on the mat. The divers noted several areas where the fabric mat was deformed, stretched taut, or had lifted off the bottom from venting gas bubbles (Lopata, 1994). Sediment samples collected over the plastic cap contained <10 mg/kg PCBs in all 10 samples (and below 1 mg/kg in nine samples).

Chemical. Sediment cores collected in 1993 were used to assess PCB distribution in Manistique Harbor sediments.

Biological. A caged fish study was conducted in 1995 to provide a pre-dredge baseline. Four fish cages were deployed within the Harbor area and fish were analyzed for PCBs and TOC. The results from the sediment cores and the caged fish study were later paired to calculate a site-specific estimate of bioaccumulation factor (BASF), which was then used to establish the TSCS and the 10 mg/kg PCB action level.

7.2 Implementation During Dredging

Physical. In tracking mudline elevation at the Manistique site, bathymetric monitoring was done using standard bathymetric survey techniques. Side-scan sonar was also used to characterize the Harbor bottom and to determine if dredging has increased potential for exposure to PCBs by creating additional bottom topography. Both the bathymetric and the side-scan sonar surveys were conducted in 1998, after dredging had been completed for the season. Other ancillary data were collected at that time to provide on-site environmental conditions, and included available flow, meteorological, and lake level data for the sampling period.

Chemical. Chemical monitoring at Manistique included downstream water quality samples (1997 and 1998), sediment cores (1997 and 1998), and sediment trap studies (1998). Sediment PCB concentrations were reported on a dry-weight basis and all fish PCB concentrations were reported on a wet-weight basis.

During dredging, water quality was monitored by turbidity monitoring. When spikes were observed in the turbidity monitoring, water samples were collected and analyzed. Locations for water quality monitoring included samples taken immediately downstream from the dredge area, approximately 100 to 150 feet downstream from the dredge area, and within the dredge area.

Sediment cores were collected by divers at five locations in Area B and 24 locations in the Harbor (the same locations for both the 1997 and 1998 studies). At each location, cores were driven to refusal, depth was measured, cores were segmented and analyzed for PCB and TOC. In Area B, two of five cores exceeded the target limit of 10 mg/kg PCBs. In the Harbor (Area D), 50 percent of the sample cores exceeded the target limit (Blasland, 1999).

Four sediment traps were deployed by divers downstream of each dredge prism and at the downward most extreme of project area. Each trap contained 16 Lexan tubes to collect settling particulate matter. The sediment traps were deployed during the winter months, when dredging was not in progress and after silt curtains had been removed for the season. All samples were analyzed for PCBs and TOC. Most sample results had PCB concentrations below 2 ppm, with the exception of three samples which ranged from 9 ppm to 84 ppm. These samples exceeding criteria of 10 ppm were from locations immediately below Area B and below the entire dredge area (Blasland, 1999).

Biological. In 1998, caged fish were deployed and suspended at three locations downstream of dredging activities in Area B and the harbor, and in one location upstream of dredging (used for background). Each cage was stocked with 30 juvenile fish, deployed by divers, and checked midpoint in each exposure period for mortality and proper positioning within the water column. After completion of the exposure period, whole fish composites were analyzed for PCB and lipid analysis. Results of this study showed that PCB levels remained higher than background levels, however there was no statistically significant difference between the 1995 data and the 1998 data (Blasland, 1999).

7.3 Post

Since dredging activities at the Manistique site lasted from 1995 to present, post-monitoring for the entire project has not yet taken place. However, progress monitoring occurred every year at the end of each dredging season (approximately October). Post-verification sampling was done after each dredging season, and if exceedances were found, the area was marked for redredging. Eventually, post-dredge sampling data should be replaced with the data collected during year 2000.

As of 1998, cleanup in Area B was labeled as complete. Thirty-five cores were collected and analyzed for PCB concentrations. Twenty-six of the

30 samples showed no detectible PCB concentrations. Overall, sampling showed a 40-fold reduction compared to pre-dredge concentrations (Blasland and Lee, 1998; Blasland, 1999; Hahnenberg, 1998).

7.4 Long Term

As of March 30, 1999, a long-term monitoring plan for the Manistique site has not yet been developed. According to the EPA, one should be in place by the finish of the dredging project in 1999.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (ppm PCBs)		
	Baseline 1993/1995	**Progress 1995–1999**	**Post 1999/2000**
Bathymetry	collected	collected	NA
Side-scan Sonar	not collected	collected	NA
Sediment Cores	non-detect to 90 ppm (1993)	0.34 ppm to 65 ppm (1997) 0.14 ppm to 4,200 ppm (1998 - Area D)	non-detect to 1,300 ppm (1998 - Area B)
Caged Fish	0.25 ppm to 10 ppm (1995)	non-detect to 28 ppm (1998)	NA
Sediment Traps	not collected	<2 ppm to 84 ppm (1998)	NA
Water Quality (surface water samples)	NA triggered by TSS		

NA = not available for review

8 Performance Evaluation

8.1 Meet Target Objectives

The target goal for the Manistique cleanup was to remove 95 percent of sediments contaminated with 10 ppm or greater PCB concentrations. As the project is still being completed, a final evaluation is not yet possible for all three dredge areas. Dredging in Area B was completed in 1998 and shows the volume goal removal of all contaminated sediments above 10 ppm PCBs was met. However, it has not been possible to verify that the target volume of 95 percent mass removal was met in Area B.

8.2 Design Components

Implementation of the dredging project was compromised by an incomplete site characterization prior to starting dredging activities. Design components were constructed from sediment cores that supposedly hit refusal when the cores actually hit buried wood and debris, and not bedrock. The dredging equipment was selected based on this premise. The difficulty of dredging wood, sawdust, rock, and gravel, was not fully considered when estimating the cleanup effort. Due to site conditions, most dredged areas were not initially cleaned up to meet target objectives and subsequently needed to be redredged, sometimes multiple times. Overdredging was not an option because contamination extended down to bedrock.

In addition, volumes were miscalculated prior to dredging. This occurred when some cores were driven into slab wood rather than to bedrock (Zweibel, 2000). From these incorrect depth estimates, a more conservative contaminated sediment volume was estimated than was later discovered. To create a further discrepancy between original volume estimates and actual volume of contaminated sediments, it was originally assumed that the bulk of contamination was limited to the sawdust and wood chip waste in the river and harbor. It was later discovered, in the midst of the dredging project, that the sediments were equally contaminated and also needed to be removed. These greater actual dredge volumes increased both the time and money required to reach cleanup goals.

One positive component to the dredge program was the flexibility given to the dredge contractors. Because the clean-up was controlled by an "environmental dredging" mind-set, the dredge program was periodically revised and more efficient techniques and equipment were adapted into the cleanup plan over time.

8.3 Lessons Learned

In conclusion, a better understanding of site conditions, as well as a more thought-out dredge plan, would have allowed for a timelier and less costly site cleanup.

9 Costs

Through the end of 1999, a total of $36 million has been spent on dredge and disposal activities at the Manistique site ($300 per cubic yard). Approximately $3.9 million was spent in 1995, approximately $3.8 million was spent in 1996, and approximately $7.8 million was spent in 1997. Approximately $9.5 million was spent in 1998, and an additional $11 million was spent in 1999 (Hahnenberg, 2000).

10 Project Contact

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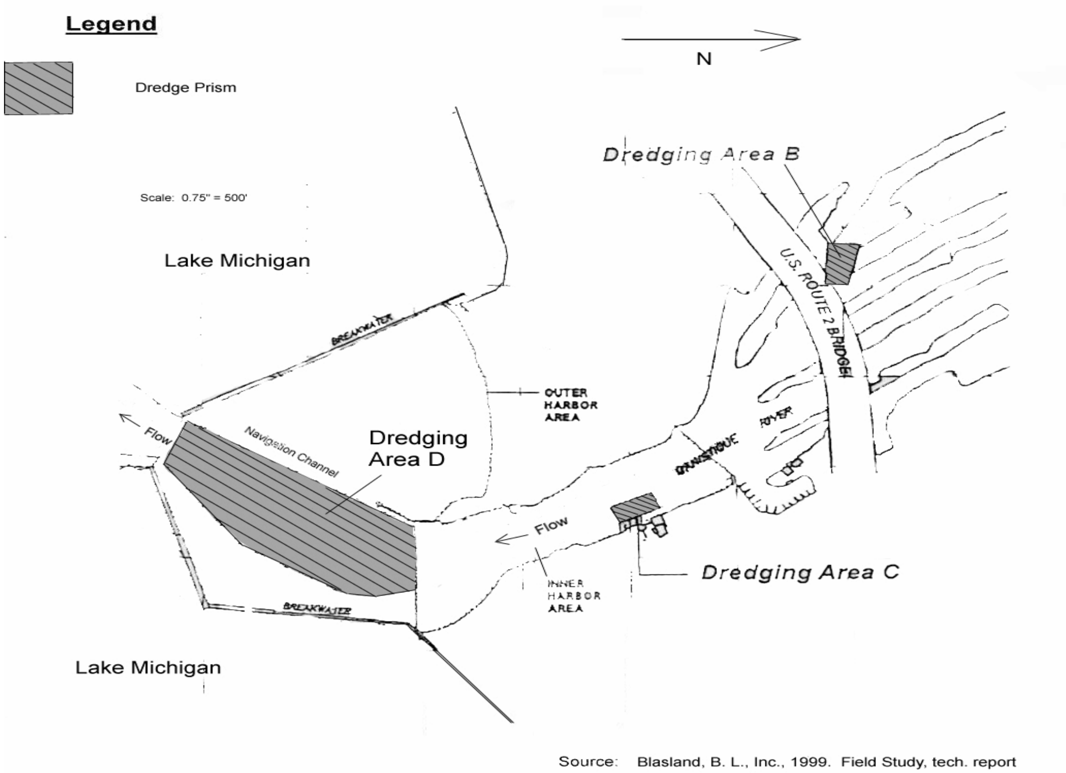
NOTE: Following several opportunities for EPA Region 5 to review the draft version of the Sediment Technology Memo and individual case studies, EPA requested the following statement be added to the Manistique discussion: "U.S. EPA Region 5 Superfund Emergency Response Branch has not reviewed nor approved information in this report. Preliminary production estimates indicate that a total of 178,708 cubic yards of contaminated sediments, containing 27,444 pounds of PCBs have been removed from the site. Once the final QA/QC evaluations have been completed, results will be included in the Administrative Record, and considered in any pending cleanup determination for the Lower Fox River and Green Bay Site."

Figure 1 Remedial Dredge Plan - Manistique River and Harbor



1 Statement of the Problem

- Dredged 1993-1995
- Metals
- 100,200 cubic yards
- $142 per cubic yard

The Marathon Battery Superfund site was contaminated with metals, primarily cadmium and nickel, from wastewater discharges of manufacturing nickel-cadmium batteries with maximum detected concentrations of 171,000 ppm and 156,000 ppm, respectively. Established target sediment cleanup standards for human and ecological protection were revised over time to focus on a depth removal of one foot with no final concentration level objective. Remedial methods consisted of dredging, dewatering and fixation on site, followed by transportation to an off-site sanitary landfill. The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 2.

2 Site Description

The Marathon Battery Superfund site is located on the Hudson River near the city of Cold Springs, New York (Figure 1). The site includes a former nickel-cadmium battery plant (in operation from 1952 to 1979), the city of Cold Springs pier, and a series of backwater areas known as Foundry Cove and Constitution Marsh. Foundry Cove consists of East and West Foundry Coves. East Foundry Cove consists of approximately 20 hectares, of which 5 hectares is marsh and 15 hectares tidal flat and cove. Constitution Marsh is connected to Foundry Cove by a channel system with a 117-hectare Audubon Society sanctuary to the south. The residential and business district of Cold Springs is located to the north.

Marathon Battery
Source: EPA

Water depths in the vicinity of the Cold Springs pier range from 0 to about 18 feet. The water circulation between Foundry Cove and the Hudson River is influenced by a tide of 3 to 4.5 feet, exposing a large portion of the East Foundry Cove at low tide. Shallow water depths in the Cove facilitate aquatic plant growth in 30 percent of the cove bottom. Loose unconsolidated sediments of silty clay 1 foot or less in thickness overlay a hard impermeable clay-like material. Shallow groundwater flows toward Foundry Cove and the Hudson River.

3 Site Investigation

Prior to 1965, the battery plant's wastewater system discharged directly into the Hudson River at the Cold Springs pier through the municipal sewer system. During periods of overflow or system shutdown, the wastewater was discharged directly into East Foundry Cove. A new sewage treatment plant designed in 1965 could not handle the battery plant's industrial discharge, therefore, plant operators began channeling the wastewater into East Foundry Cove. In 1966, the state of New York ordered Marathon Battery to cease discharge and clean up the contamination. Parts of the cove were dredged between September 1972 and July 1973. After completion, the dewatered dredge spoils were deposited in a clay-lined underground vault on the plant property and then sealed with asphalt and fenced. Post-dredging monitoring continued to detect elevated levels of cadmium and nickel concentrations in the Cove's sediments, flora, and fauna.

In October 1981, EPA listed the Marathon Battery Company site on the National Priorities List (NPL). EPA and the State of New York signed a cooperative agreement to undertake a remedial investigation and feasibility study (RI/FS) for the site. The site is composed of three study areas which consist of Area I, Area II, and Area III. Each area was designated under separate Record of Decisions (RODs) established in 1986, 1988, and 1989, respectively. Area II consisted of the former battery facility and did not involve dredging; Areas I and III did include dredging components.

Area I, designated in the 1986 ROD, encompassed the East Foundry Cove Marsh and Constitution Marsh. Area III, designated in the 1989 ROD, included dredge sediments from East Foundry Cove and the Cold Springs pier area. Each ROD proposed a long-term remedy of dredging the contaminated sediments, chemically binding them, removing them from site for disposal, restoring the marsh, and long-term monitoring along with public participation. The major contaminants of concern were metals (cadmium and nickel). The maximum concentration detected in site sediments were 171,000 ppm cadmium and 156,000 ppm nickel (EPA, 1986). The extent of contamination was 340 acres of backwater marshes and sheltered cove, 200 acres of open cove, and a small cove in the Lower Hudson River (near Cold Springs pier).

4 Target Goals and Project Objectives

The primary cleanup target goal for Area I focused on dredging of sediments greater than 100 ppm cadmium (EPA, 1986). Area III focused on a 95 percent mass removal of cadmium with a target goal of 10 ppm (EPA, 1989). To achieve this target, the necessary removal depth was determined to be 1 foot. A risk-based approach was used to define the target criteria. A "no action" criteria was established for other metals since it was assumed that any remedial action would mitigate these metals as well. The long-term remedial action objective was the restoration of marsh vegetation. The stated objective was to alleviate the environmental and potential human health effects stemming from excessive levels of heavy metals contamination, and to prevent further migration of these highly contaminated sediments to Foundry Cove, the Hudson River, and Constitution Marsh.

5 Project Design

A phased evaluation process was used to determine feasible remedial technologies due to the complex environmental, technical, regulatory, and health issues associated with this site. Based upon consideration of the requirements of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), EPA, and NYSDEC (New York State Department of Environmental Conservation) a remedial alternative was selected. The remedial action plan included dredging of the contaminated sediments as specified in the target objectives. It was estimated that 30,000 cubic yards of sediment would be dredged from Area I and 56,000 cubic yards of sediment dredged from Area III. Dredged sediments would then be thickened and treated by chemical fixation on site. Chemical fixation technologies were verified using bench-scale testing (EPA, 1989). Treated sediments would then be transported for off-site disposal. Area I included restoration of the original contours by installing a bentomat layer with the placement of a 1-foot-thick layer of cover soil. After reconstruction, a restoration project would then be implemented to include replanting of various wetland and upland plant species. Both Area I and Area III were then subject to continued long-term monitoring of contaminant concentrations (EPA, 1994; EPA, 1995; EPA, 1999).

The selected remedy complied with all action and location-specific ARARs (applicable or relevant and appropriate requirements). Specifically, ARARs included the Clean Water Act Section 401, federal and New York State water quality criteria and mixing zone requirements under the National Pollutant Discharge Elimination System (NPDES) permit program, National Historic Preservation Act (NHPA), and Resource Conservation and Recovery Act (RCRA) facility location requirements, and New York State non-hazardous soil waste requirements. In addition, appropriate actions were taken to comply with the following environmental statutes and executive orders: Endangered Species Act, NHPA, Coastal Zone Management Act, Executive Order 11990 (Wetlands Protection), and Executive Order 11988 (Floodplain Management).

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial actions began in August 1993 and were completed in April 1995 for a duration of 21 months, including restoration activities. Detailed duration of dredging activities was not available for review.

Equipment. Remedial methods applied were hydraulic and mechanical dredging for coves and ponds, and dry excavation for marshes. Due to rocks, a custom-built horizontal auger dredge was used during dredging along with a barge-mounted clamshell to complete the cove in the Lower Hudson River (GE/AEM/BBL, 1999). Silt curtains were utilized to contain resuspended sediments and minimize short-term environmental impacts. Remediation of the East Foundry Cove Marsh was accomplished via specialized marsh excavation vehicles with extra-wide tires and low-pressure tracked excavators. Water-filled containment structures were used to hydraulically isolate the marsh during remediation. These were replaced in sections by earthen berms due to failure of the hydraulic containment structures.

Total Volume Removed and Production Rates. The total volume of sediment removed was 100,200 cubic yards. The distribution of sediment dredged from Area I and Area III were: East Foundry Cove Marsh, 23,000 cubic yards; East Foundry Cove, 53,200 cubic yards; East Foundry Pond, 14,400 cubic yards; and Cold Springs pier, 9,600 cubic yards (GE/AEM/BBL, 1999).

Site-Specific Difficulties. Replaced hydraulic water-filled containment structures with earthen berms after failures.

6.2 Dewatering and Water Treatment Operations

Decant water from the on-site gravity settling basin was pumped to sand trickling filters, then treated with a polymer in a return settling basin. Treated water was tested to make sure it met EPA and New York State water quality standards before being discharged into the East Foundry Cove.

6.3 Storage and Disposal

Dredged sediments were allowed to settle out on site in settling basins and then chemically fixated in a pug mill using Maectite (GE/AEM/BBL, 1999). After curing and TCLP testing, the fixated material was transported in 1,979 railcars to City Management Landfill in Michigan and to Chemical Waste Management's hazardous waste landfill in Model City, New York.

7 Environmental Monitoring Program

In May 1984, NYSDEC initiated the Area I RI/FS covered by the cooperative agreement in May 1984. The RI/FS for Area III was prepared by EPA. Surface and subsurface soils, sediments, and surface water were sampled during the RI. Additionally, fish were sampled and bioassays were performed using contaminated sediment. All media were found to be contaminated to various degrees. Cadmium contaminants were of greater concern than nickel and cobalt because cadmium is more toxic and concentrations were generally of the same magnitude between metals of concern. East Foundry Cove Marsh was contaminated to the greatest extent. Monitoring provided insights to the extent of contamination, the effects of contaminants on receptors, and the result of remedial dredging actions. Refer to Table 1 for comparison of baseline, post, and long-term monitoring results.

7.1 Baseline

Baseline results are presented from the RODs for Area I (1986) and Area III (1989).

Physical. Data not available for review.

Chemical. The Area I RI determined the highest levels of contamination occurred in the East Foundry Cove Marsh sediments as high as 171,000 ppm cadmium, with a mean of 27,799 ppm. Contamination in the surrounding channels to Constitution Marsh decreased by four orders of magnitude as distances increased. Distribution of cadmium in the remainder of East Foundry Cove appeared to be dictated by flooding tidal patterns, ebbing tidal patterns, the 1972–1973 dredging effort, and the presence of aquatic vegetation. Background cadmium concentrations in the Hudson River Estuary was shown to have a mean concentration of 10 ppm.

The RI found that cadmium contamination in Area III ranged from 0.28 ppm to 2,700 ppm with a mean of 179.25 ppm cadmium for all depths in the East Foundry Cove. In the Hudson River at the Cold Spring pier, cadmium contamination ranged from 1.2 ppm to 1,030 ppm with a mean of 12.6 ppm cadmium for all depths. Only six samples showed levels above 20 ppm. The major portion of contamination was found in the upper layer of sediment (0 to 10 cm). West Foundry Cove had a cadmium contamination range of 1.1 ppm to 569 ppm with a mean of 43.9 ppm cadmium for all depths. Contamination in West Foundry Cove appeared to be evenly dispersed vertically and acted as a depositional area.

Biological. Cadmium contamination present in the biota in the Foundry Cove area was a clear indication of the environmental threat posed at the site. Baseline monitoring showed the majority of trophic groups sampled had elevated tissue burdens of cadmium (EPA, 1986). Most biological sampling was centered around Area I.

At Area I, in the East Foundry Cove Marsh, the wetland vegetation showed a mean cadmium concentration in the roots of 500 ppb. Vegetation serves an important role in the trophic pathways of the marsh ecosystem. Benthic algae sampled in the area measured a mean cadmium concentration of 506 ppb. Cadmium concentrations in Foundry Cove phytoplankton measured a mean of 245 ppt and zooplankton measured a mean of 342 ppt. A widespread problem at the site showed cadmium contamination of the macroinvertebrates (blue crab) at a mean concentration of 19.4 ppt. Cadmium concentrations in the liver of the *Morone americana* (white perch) were measured as high as 47 ppt. However, due to the mobility of fish it could not be concluded that contamination was the result of exposure to Foundry Cove. A bioaccumulation study was conducted and revealed that significant body tissue uptake of cadmium occurs even under a limited duration of exposure.

Fish samples were collected at four locations in Area III. All fish analyzed measured cadmium concentrations below detection limit results; however, interference from matrix effects prohibited the laboratory from attaining a detection limit lower than 1.0 ppm.

7.2 Implementation During Dredging

Implementation Monitoring was not conducted at the Marathon Battery Site.

7.3 Post

Post-monitoring results are presented for the completion of the remedial action in the spring of 1995 (Advanced Geoservices, 1997a; Advanced Geoservices, 1997b).

Physical. Data not available for review.

Chemical. Post-monitoring results for Area I in the East Foundry Cove Marsh had a mean residual sediment concentration of 11.8 ppm, a 99.6% decrease from average pre-dredge considerations (Table 1). Monitoring samples in the East Foundry Cove Marsh were collected within the cover soil placed as part of the Marsh restoration.

The monitoring results for Area III also measured a decrease in sediment cadmium concentrations. Post-project monitoring in the East Foundry Cove had cadmium concentrations that ranged from 0.74 ppm to 81.2 ppm, with a mean value of 10.9 ppm. The Cold Springs pier area had cadmium concentrations ranging from 2.5 ppm to 35.7 ppm, with a mean value of 15.0 ppm. Results in the East Foundry Pond had cadmium concentrations ranging from 1.0 ppm to 37.1 ppm, with a mean value of 8.4 ppm.

Biological. Biological monitoring was scheduled to take place in the summer of 1996 to be included in the long-term monitoring results.

7.4 Long Term

The long-term monitoring results refer to sampling conducted after all dredging actions were completed in order to assess the success of remediating the Marathon Battery site. Results presented are from the June 1996 sampling event 1 year following dredging and are included in the sampling event report issued June 1997 (Advanced Geoservices, 1997a).

Long-term monitoring results were inconsistent with post-remediation concentrations and variations may be attributed to the method of sample collection. Post-remediation sampling utilized a hand auger to retrieve a representative 6-inch sample of the bottom sediments. The sampling dredge did not penetrate the full 6 inches within the firm bottom and thus retrieved a disproportionate amount of surface material. An alternative sediment sampling procedure using a hand auger was issued in the February 21, 1996 Supplemental Long-term Monitoring Plan. This procedure was and will continue to be used to collect subsequent samples.

Physical. Data not available for review.

Chemical. Area I long-term monitoring in the East Foundry Cove Marsh was conducted by sampling within the cover soil placed as part of the marsh restoration. Sediment cadmium concentrations measured a range of non-detect to 0.475 ppm with a mean value of 0.203 ppm. This indicated an increase from post-monitoring. The source of the increase was not believed to be leaching of the underlying marsh soils, but rather a result of cyclic flooding of the marsh during high tide deposits from East Foundry Cove. Long-term monitoring sediment cadmium results for Area III were generally consistent with post-monitoring cadmium concentrations.

Biological. Biological sampling was conducted during the late summer and fall of 1996. Vegetation samples collected from the East Foundry Cove Marsh had a mean cadmium concentration of 0.08 ppm. Benthic invertebrate samples consisted of a mixture of oligochaete worms and chironomid midge larvae. The cadmium concentration of the algae sample collected from East Foundry Cove was 0.78 ppm. Long-term sampling also included sampling for whole body swallows and marsh wrens. Cadmium concentrations for whole body swallows measured a range of 0.1 ppm to 0.42 ppm with a mean of 0.24 ppm. Sampling of whole body marsh wrens measured a range of 0.13 ppm to 0.31 ppm with a mean of 0.2 ppm cadmium.

The ROD for the Marathon Battery Remediation Site required the performance of long-term monitoring for a period of 30 years after completion of the remedial action. Future sampling results will become available as sampling event reports and annual reports are prepared. Re-vegetation of the East Foundry Cove Marsh will also be monitored on a regular basis with replanting and/or other techniques used for sparsely vegetated areas.

Table 1 Summary of Monitoring Results

Monitoring	Testing Parameters - Max/Mean Cadmium Concentration (ppm)				
	Baseline 1989	Post 1995	Long Term 1996	Percent Decrease 1989–1996	Long Term 1997
Area I					
Sediment	171,000 (Avg = 27,799)	0.38 to 90 (Avg = 11.8)	NC	99.9% (Avg = 99.6%)	
Cover soil	NC	ND	ND to 0.485 (Avg = 0.203)	52.9%	
Benthic Algae	0.51	NC	0.78		
Zooplankton	342,000	NC	NC		
Phytoplankton	245,000	NC	NC		
Macroinvertebrates	19,400	NC	NC		
Plant	0.50	NC	0.08	84%	
Birds (whole body)					
Swallow	NC	NC	0.24		
Marsh Wren	NC	NC	0.20		
Area III					
Sediment	2,700 (Avg = 179.3)	81.2 (Avg = 10.9)	3.2 to 50.6	98% (Avg = 92%)	0.39 to 104 (Avg = 20)
Fish	<1.0	NC	NC		
Background (sediment)	10 ppm	10 ppm	10 ppm		

Note:
NC represents no data collected.
ND represents non-detect.

8 Performance Evaluation

8.1 Meet Target Objectives

Dredging of cadmium contaminated sediments at the Marathon Battery site has succeeded in meeting performance-based target remediation goals. Cadmium concentrations in Area I sediments were remediated below the 100 ppm target criteria with an average reduction of 99.9 percent: however, concentrations were higher than background. Area III remediation actions also meet the target objective of 95 percent cadmium removal with an average reduction of 94 percent. However, the average post-sediment concentration was 10.9 ppm cadmium, slightly above the 10 ppm action level. Post-dredge as well as long-term monitoring confirm attainment of the target remediation goals.

Long-term monitoring for marsh restoration is inconclusive at this time. Re-vegetation has been slowed due to inclement weather and predation.

8.2 Design Components

Extensive pre-design consulting and planning was implemented prior to dredging actions. This included site history and conditions, bench-scale tests, monitoring, risk assessment, and modeling. Unforeseen conditions at the site did pose difficulties when dredging. Tidal conditions slowed dredging when limited water depths occasionally grounded the hydraulic dredge used in the confined inshore areas. Areas with coarse sand, gravel, and rock in deeper areas of the Hudson River reduced the effectiveness of the hydraulic dredge and required clamshell dredging. Clogging of screens by organic materials in the initial dewatering operations caused a redesign in the process.

8.3 Lessons Learned

Understanding initial site conditions will aid in developing a dredge design and may reduce difficulties encountered such as tidal cycles and sediment profile. It is important to establish a baseline monitoring program that will enable future monitoring to be consistent for comparison. This will aid in determining the success of the remediation action. Overall, contaminated sediment can be successfully removed using environmental dredging technologies.

9 Costs

Dredging at the Marathon Battery site was estimated to cost between $9 and $11 million for the East Foundry Cove and Pond and for the cove at Cold Spring Pier ($110 to $142 per cubic yard).

10 Project Contact

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General Contractor: Sevenson Environmental Services

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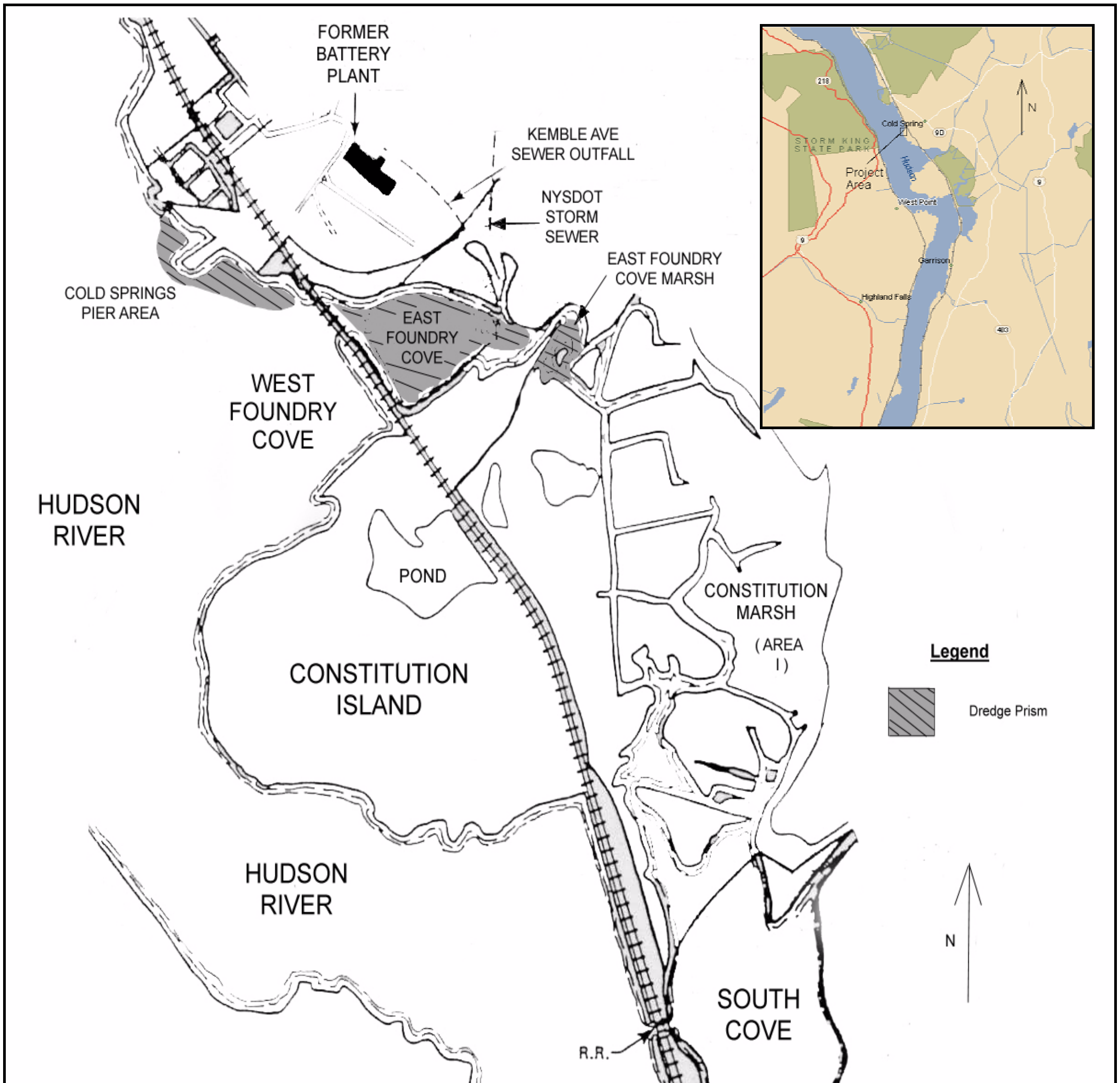
Figure 1 Remedial Dredge Plan - Marathon Battery



Source: Record of Decision, 1989 (Area III).

- Dredged 1983-1987
- Mercury
- 1,025,000 cubic yards
- $40 per cubic yard

1 Statement of the Problem

Mercury contamination in Minamata Bay and the Agano River was the result of discharges from the manufacture of acetaldehyde by the Chisso Corporation between 1932 and 1968 (History of Minamata Disease, 1998). Discharges of mercury to Minamata bay were estimated to be in excess of 70 to 150 tons. Ingestion of mercury-contaminated fish caused Minamata disease; a poisoning disease of the central nervous system. The first Minamata disease patient was reported initially as suffering from nervous symptoms of an unknown cause in 1956. It took 12 years to reach the official conclusion that mercury was the cause of the disease. While the reported effects varied from source to source, Minamata disease resulted in permanent health effects in several thousand people and the death of over 100 people (Kudo et. al, 1998). Typical symptoms included sensory and auditory disturbances, ataxia, dysarthria, constriction of the visual field, and tremor.

2 Site Description

Minamata Bay is a small marine inlet located on the southwestern coast of Japan on Kyushu Island (Figure 1). The coast is sparsely populated, with steep hills and dense vegetation. Although historically an isolated fishing village, the protected harbor supported the development of a valuable commercial fishing industry. The only inflow of fresh water to the Bay is a creek with an average flow rate of 130 gallons per second, primarily fed by the Chisso Corporation. The harbor is up to 50 feet in depth and is protected by Koiji-Shima Island. Up to 20 percent of the Bay water can be exchanged twice a day by the tide with the outlying Yatsushiro Sea (Kudo and Miyahara, 1987).

3 Site Investigation

The Chisso Corporation began production of acetaldehyde in 1932 using mercury as a catalyst. Wastewater was discharged directly to Minamata Bay. The presence of mercury in fish tissue had been documented in Minamata Bay since 1961. The Chisso Corporation installed a closed circulatory wastewater system in 1965 and discontinued production of acetaldehyde in May 1968. Mercury was officially recognized as the constituent responsible for Minamata disease in a report released by the Japanese government in September 1968. The report cited the Chisso Corporation Minamata factory as the source of mercury contamination in Minamata Bay.

Aerial of Minamata Bay
Source: www.pitt.edu.lecture

Early investigations of mercury concentrations in sediment, shellfish, and human tissue were performed in 1959 and 1960. Sediment concentrations were as high as 2010 mg/kg (wet weight). Marine life displayed high concentrations of mercury ranging from 11.4 to 39.0 mg/kg in *Hormomya nutabilis* (a littoral mussel), 5.61 mg/kg in oysters, 35.7 mg/kg in crabs, and 14.9 mg/kg in *Scidena schlegelii* (Harada, 1995). Tissues of human patients who died from Minamata disease measured mercury concentrations ranging from 22.0 to 70.5 ppm in livers, 2.6 mg/kg to 24.8 mg/kg in brains, and 21.2 to 140.0 mg/kg in kidneys. Analysis of hair samples obtained from patients ranged from 2.46 mg/kg to 705 mg/kg.

Surface sediment samples were collected in 1975 to define the vertical and horizontal extent of contamination. Contamination in excess of 25 mg/kg was present in approximately 490 acres of Minamata Bay at sediment depths up to 6.6 feet. Concentrations were greatest at the creek which served as the Chisso Corporation discharge location and deceased with distance from the discharge point. Maximum concentrations in the vicinity of the discharge location were in excess of 600 mg/kg.

Additional investigations have been conducted to measure changes in mercury concentrations in the Yatsushiro Sea, which lies directly outside of Minamata Bay (Kudo and Miyahara, 1984; Kudo et. al, 1998). Mercury was transported by natural processes to the Yatsushiro Sea. Surficial sediment sampling (up to 4 cm) has been conducted at 24 stations annually since 1975. Mercury concentrations generally increased between 1975 and 1984. After 1984, decreases in mercury concentration were measured in the Yatsushiro Sea and were likely attributed to the initiation of dredging in Minamata Bay in June 1983. Mercury concentrations in Yatsushiro Sea surface sediments ranged between 0.027 mg/kg and 15.9 mg/kg (Kudo et. al, 1998).

4 Target Goals and Project Objectives

The goal of the Minamata Bay Dredging and Reclaiming Project, sponsored by the national and prefectural governments and Chisso Corporation, was to rapidly and safely dispose of the mercury contaminated sediment. The target concentration for mercury in fish tissue was established at 0.4 mg/kg in 1973 based on human health risk assessments using normal consumption of seafood. The sediment cleanup criterion was established in 1973 by the Provisional Standard for Removal of Mercury Contaminated Bottom Sediment at a concentration of 25 mg/kg. Criteria considered in the development of this standard included protection of marine life, mercury content in seafood, mercury accumulation in food chains, leaching of mercury from bottom sediments, and diffusion and mixing of mercury in water (Ishikawa and Ikegaki, 1980).

5 Project Design

Pre-planning and Bid Documents. The Kumamoto prefectural government commissioned Kumamoto University to perform a study of viable treatment methods for bottom sediment of Minamata Bay. A committee of scholars, and officials from the Ministry of Transport, the Environment Agency, the Fisheries Agency, the Kumamoto prefectural government, and other government agencies was formed in 1974 to develop the remediation plan (Ishikawa and Ikegaki, 1980).

Summary of Remedial Action Plan. October 1977 marked the commencement of remediation in Minamata Bay with the installation of 12,000-foot fish containment net surrounding the Bay. A 720-foot break in the net was provided to allow access of passenger and cargo ships to Minamata Port. Acoustic devices were set on the sea bottom to prevent passage of fish through the opening. A temporary cofferdam was installed at the north end of Koijishima Island to create quiescent conditions thereby minimizing transport of contaminants outside of the remediation area.

The remediation project consisted of a combination of reclamation and dredging. Areas in the vicinity of the discharge location with mercury concentrations in excess of 100 ppm were reclaimed through the construction of two containment cells. Contaminated sediments in the remaining harbor areas with mercury concentrations in excess of 25 ppm were dredged.

The containment cells were formed through the assembly of multiple cylindrical cells with steel piles. The cells were placed with a vibratory hammer and then filled with sand. The cells stood side-by-side and were linked together with arc-shaped combined piles to form a watertight containment wall. A total of 950,000 cubic yards of mercury contaminated sediment were isolated through creation of the containment cells. An additional 1,025,000 cubic yards were removed from the Bay by dredging and placed in the containment cells. Dredging continued until 1987. The reclamation area created 143 acres of land and received its final cover in 1990.

Limitations and Permits. Due to limited capacity for sediment disposal, the dredge depth was minimized through real-time monitoring of dredge depth and three dimensional computer programs displaying actual and target bottom topography. However, the intended design depth for overdredge material was not available from documents reviewed.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging was conducted between June 1983 and December 1987. Confirmation samples were collected following dredging and the results provided to the Supervisory Committee. The Supervisory Committee officially confirmed that all sediment with mercury exceeding the maximum limit had been removed in February 1988.

Equipment. Four ships, each fitted with a dredge, were dispatched to the work area. Hydraulic dredging was conducted using suction heads without cutters. Dredged sediment was transported by an individual pipeline from each vessel to the reclamation area.

Total Volume Removed and Production Rates. A total of 1,025,000 cubic yards of mercury contaminated sediment were dredged from an area of 373 acres.

Site-specific Difficulties. No site-specific difficulties for the dredging project were noted in the review. However, the occurrence of a 200-year rainfall event which occurred in 1982 resulted in 11.4 inches of rainfall in three hours and the deposit of nearly one million tons of clean sediment in Minamata Bay and the Yatsushiro Sea (Kudo et. al, 1998).

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. The sediment slurry was allowed to settle under quiescent conditions in the containment cell. A treatment plant was operated 24 hours a day to treat overlying water. The treatment system consisted of polymer coagulation/sedimentation and filtration.

Water Quality Monitoring of Discharge. Water discharged from the water treatment plant was analyzed for turbidity and total mercury. After developing a correlation between turbidity and mercury concentration, turbidity was continuously monitored before final discharge as a quick screening tool. The Japanese Standard Effluent Concentration used as the mercury discharge limit was 0.005 mg/L. Treated water which did not meet this standard was returned to the containment cell. Following treatment, water which met criteria was discharged to Minamata Bay.

6.3 Storage and Disposal

Dredged sediment was piped into a newly constructed nearshore containment cell located in the project area. Physical stabilization and soil capping were utilized to isolate contaminated sediment in the reclamation area. Following gravity settling and dewatering, reclaimed sediment had a high proportion of fine particles and contained large quantities of interstitial water. The soft sediment was stabilized with application of a 2.6-foot thick layer of volcanic ash earth to produce suitable physical conditions for soil capping (Hosokawa, 1993). Following stabilization, the sediment was capped with clean soil and leveled. The cap was completed in March 1990, three years after initial placement. The thickness of the final cap was not specified.

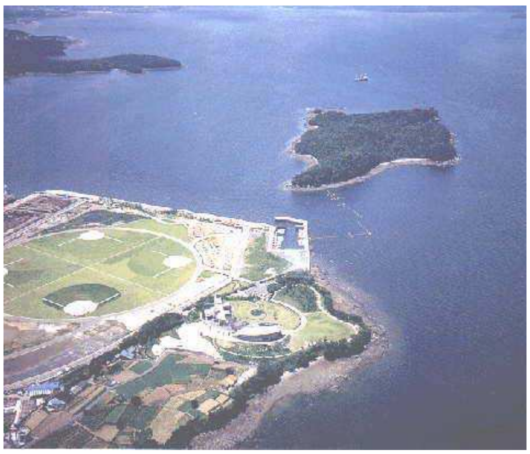
7 Environmental Monitoring Program

7.1 Baseline

Physical. Bathymetry and physical characteristics of the sediment were documented prior to remediation. Bathymetry information was utilized to prepare three-dimensional programs to aid in achieving the desired dredge depth.

Chemical. Baseline distribution of mercury in the bottom sediment and water were measured to assist the project planning effort in 1975. Sediment mercury concentrations collected on a 200 meter grid system were used to define the horizontal and vertical extent of the dredging project. Maximum pre-dredge mercury concentrations exceeded 600 mg/kg in surface sediments.

Biological. Monitoring of mercury concentrations in resident fish tissue collected from Minamata Bay area began in 1961. Fish tissue concentrations generally decreased in time from 1961 to 1974 from over 16.5 mg/kg to less than 1.0 mg/kg (Environmental Health Department, 1997). However, mercury levels in fish rose to their maximum between 1978 and 1981 (Zarull, et. al, 1999) during placement of the net. The data from this period were excluded from the Environmental Health Department data presentation (1997) and were therefore not available for review.



Land Reclaimed from Minamata Bay
Source: www.fsinet.or.jp/~soshisha/10tisiki/10_3_e.htm

7.2 Implementation During Dredging

Physical. Continuous monitoring was conducted during dredging for turbidity measurement and bottom configuration detection. Monitoring devices mounted beside the mouth of the dredged included a continuous-type turbidometer, a submerged television camera, and four echo sounders. With the help of a microcomputer, an operator monitored the dredge cut and bottom sediment topography before and after dredging, suction head position, swing speed and swing direction, and dredged volume of sediment and solid concentration. Real-time adjustments to the dredging depth were made by comparing the assigned dredging program to the actual dredge depth on the monitoring screen.

Chemical. Water quality was monitored for total mercury, pH, chemical oxygen demand (COD), dissolved oxygen, cyanide, and lead at four locations just inside of the fish containment net. Total mercury was measured three times a day, pH, COD, and dissolved oxygen were measured once a day, and cyanide and lead were measured once a week. Mercury concentrations remained below criteria at the monitoring locations during dredging (Hosokawa, 1993).

Biological. Biological monitoring consisted of mercury measurements in resident fish tissue collected inside and outside of the fish containment nets, and in cultivated fish deployed inside the nets. Resident fish were collected from three stations outside of the containment nets four times a year and one station inside the containment nets once a month. Cultivated fish were collected every 10 days and consisted of 10 individuals each of porgy and croaker. Mercury concentrations in fish within the project area continued to exceed the 0.4 mg/kg criteria until 1994, over six years after the completion of dredging. The numerical data from this period were excluded from the Environmental Health Department data presentation (1997) and were therefore not available for review. Fish collected outside of the project area did not exceed the 0.4 mg/kg criteria (Hosokawa, 1993).

7.3 Post

Physical. As discussed in the implementation during dredging section, bottom topography was monitored from the mouth of the dredge during and immediately following dredging. Dredge depth ranged from approximately 3.3 to 6.6 feet in the inner bay to 0.0 to 0.4 feet in the off-shore areas.

Chemical. Post-dredge surficial sediment samples were collected over a grid system established at 200-meter intervals over the project area. Samples were collected at each of the grid-line intersections. The mean mercury concentration was of the four grid points surrounding each location was calculated and compared to the mercury criteria (25 mg/kg). Sampling locations were co-located with baseline sampling locations and the method of data averaging was established prior to sampling. Mean concentrations were calculated at 59 locations and ranged from 0.91 mg/kg to 8.99 mg/kg. The overall mean post-dredge mercury concentration was 4.60 mg/kg. This data were reported in February 1988. Table 1 shows a summary of pre- and post-dredge sediment mercury concentrations.

Biological. Although the data were not available for review, fish tissue mercury concentrations were in excess of the 0.4 mg/kg criteria in samples collected following dredging.

7.4 Long-term

Physical. No long-term physical monitoring was noted in the review.

Chemical. No long-term physical monitoring was noted in the review.

Biological. In the three-year period from 1994 to 1997, mercury concentrations remained below the 0.4 mg/kg criteria in fish and shellfish. Although data were not available for the period prior to 1994, mercury concentrations were above the 0.4 mg/kg criteria demonstrating that a significant lag time was necessary after dredging to achieve the target mercury body burdens. After 1997, monitoring of fish and shellfish continued at a frequency of twice a year for at least three additional years.

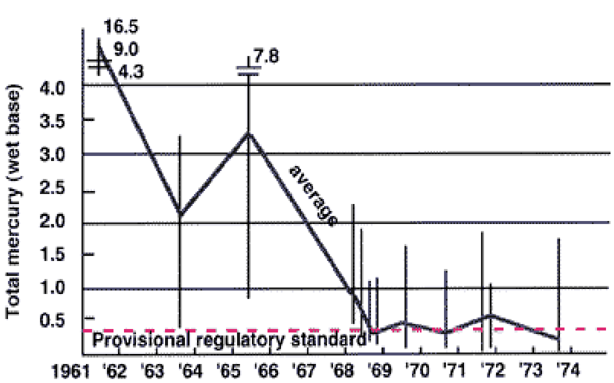
Table 1 Pre- and Post-Dredge Sampling Results

Sampling Events	Mercury Concentrations (in mg/kg)				
	Pre-dredge (1975)	Implementation During Dredging (1983-1987)	Post-dredge (1988)	Long-term (1994-1997)	Percent Decrease (1993-1995)
Surface Sediment					
Minimum	25 mg/kg	NA	0.91 mg/kg	NA	96.4 %
Maximum	> 600 mg/kg		8.99 mg/kg		> 98.5 %
Average	NE		4.60 mg/kg		NE
Surface Water	NA	Below Criteria (<0.0005 mg/kg)	NA	NA	NE
Biological Tissue					
Fish	<1.0 to >16.5 mg/kg	> 0.4 mg/kg in project area <0.4 mg/kg outside project area	> 0.4 mg/kg	< 0.4 mg/kg	NE
Shellfish	Mussel 11.4 to 39.0 mg/kg Oyster 5.61 mg/kg Crab 35.7 mg/kg *Scidena schlegelii* 14.9 mg/kg		> 0.4 mg/kg	< 0.4 mg/kg	NE
Human	Liver 22.0 to 70.5 ppm 2.6 Brain 2.6 to 24.8 mg/kg Kidney 21.2 to 140.0 mg/kg Hair 2.46 mg/kg to 705 mg/kg	NA	NA	NA	NE

NE - The average could not be evaluated due to lack of detailed data.
NA - Not analyzed

8 Performance Evaluation

8.1 Meet Target Objectives



Minamata Bay Fish Levels
Source: www.pitt.edu.

Short-term Target Goals. The target surface sediment mercury concentration of 25 mg/kg was met at each of the 59 sampling locations. The average surficial sediment concentration was 4.6 mg/kg and the maximum concentration was 8.99 mg/kg.

Long-term Remedial Objectives. Mercury concentrations in fish declined below the 0.4 mg/kg target level in 1994. Dividing nets were removed and fishing restrictions were lifted in 1997.

8.2 Design Components

The remediation design was completed by a committee of scholars, and officials from the Ministry of Transport, the Environment Agency, the Fisheries Agency, the Kumamoto prefectural government, and other government agencies. The large scale remedial action benefitted greatly from pre-planning and extensive investigative efforts. Extensive baseline sampling and bathymetry measurements were used to produce three dimensional computer models of the proposed dredge prism.

8.3 Lessons Learned

The Chisso Corporation and the Kumamoto prefectural government have received extensive criticism due to the extreme health effects caused by Minamata disease and the length of time required to document its cause.

As stated in the design components section above, the horizontal and vertical extent of contamination and site conditions were well documented prior to mobilization. Adequate characterization and good communication during implementation were components of the successful project. Echo sounders attached at the mouth of the dredge were used to generate real-time displays of the dredging progress ensuring complete removal of target depths.

Contaminated sediment was determined to be the primary exposure pathway of observed mercury concentrations in fish and human tissue. Source control of sediment was a viable pathway to risk reduction and long-term protection of human health and the environment.

9 Costs

The total cost of the dredging project was approximately $40 million to $42 million U.S. dollars (Zarull, et. al, 1999) or approximately $40 per cubic yard. The total project cost including reclamation and the creation of a modern harbor was estimated at $500 million (Kudo et. al, 1998).

10 Project Contact

No project contact was available.

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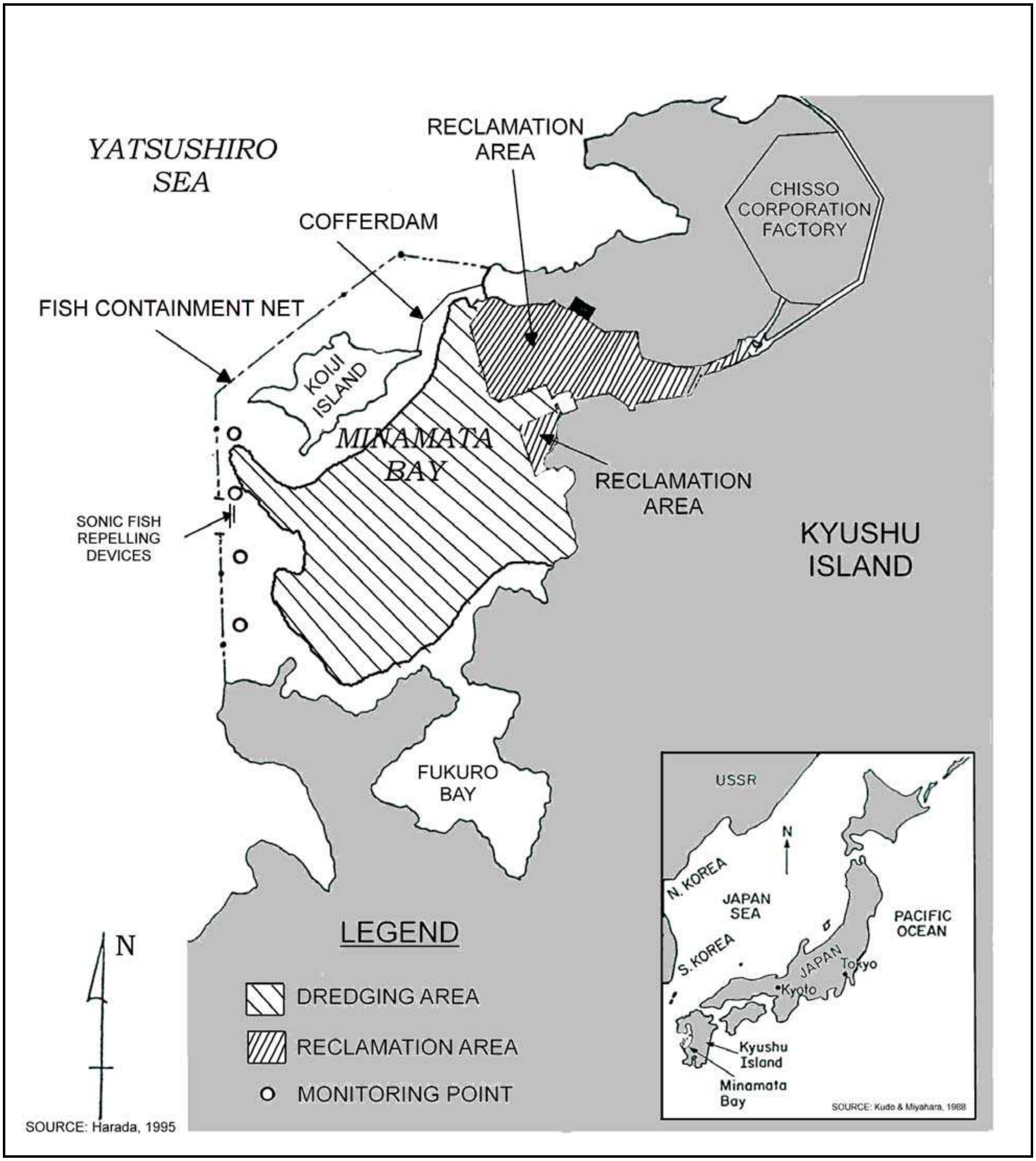
Figure 1 Remedial Dredge Plan



1 Statement of the Problem

- Dredged 1994–1995
- PCBs
- 14,000 cubic yards
- $1,430 per cubic yard

Polychlorinated biphenyl (PCB) contamination was present in New Bedford Harbor sediments at concentrations over 100,000 parts per million (ppm). A hotspot remedial dredging action was conducted in 1994/1995 to remove sediments containing over 4,000 ppm PCBs to reduce a source of migrating contamination, remove a significant mass of PCB contamination, and protect public health and marine life by preventing contact. A pre-design field test (PDFT) was conducted in August 2000 to demonstrate and record performance data for use in developing a full-scale remediation plan. Further remedial activities are planned for remaining contamination and are presently in the design stage. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 1.

2 Site Description

The New Bedford Harbor Superfund Site is located in Bristol County, Massachusetts. The site extends from the Acushnet River estuary south through New Bedford Harbor and into Buzzards Bay. The entire Superfund site includes four areas: mouth of Acushnet River including the hotspots, upper New Bedford Harbor, lower New Bedford Harbor, and approximately 17,000 acres of Buzzards Bay. This area of Buzzards Bay is closed to lobster fishing because of PCB contamination. This case study addresses the removal of six hotspots of contamination limited to the Acushnet River and upper New Bedford Harbor and the PDFT in a 100- by 550-foot area in the upper New Bedford Harbor. The collective area encompassed by the hotspots was approximately 5 acres with water depths ranging from 1 to 6 feet. The remediation area is within a shallow tidally-influenced estuary. Sediments consisted of fine sandy silt with some clay.

View of New Bedford Harbor
Source: City of New Bedford Harbor Development Commission

3 Site Investigation

The primary sources of contamination were two electronic component manufacturers, which used PCBs in the production of capacitors. Evidence of PCB contamination in sediments and seafood was first discovered through EPA region-wide sampling programs conducted during the mid-1970s. The site was placed on the Superfund National Priority List (NPL) in September 1983. The Record of Decision (ROD) for hotspot dredging was issued in April 1990 with oversight by EPA Region 1 (EPA, 1990). The ROD for the upper and lower harbor, including the remaining contamination in the hotspots (<4,000 ppm) was issued on September 25, 1998.

PCBs are the principle contaminant of concern, although high concentrations of cadmium, chromium, copper, and lead were also present. PCB contamination was found at levels as high as 100,000 ppm in some areas. Contamination was principally found in the top 2.0 feet of sediment, but extended to depths of 3.9 feet in several areas.

The entire Superfund site includes four areas: mouth of the river and the upper harbor (OU-1) and the lower New Bedford Harbor extending out to Buzzards Bay (OU-2). The ROD for this second operable unit was issued on September 25, 1998 and is currently in the design stage (EPA, 1998). The entire project study area and their respective selected remedies were summarized in the 1998 ROD (listed from upstream to downstream):

Area of Concern	Size	Cleanup Level
Acushnet River	16.5 acres	10 ppm PCBs
Upper Harbor	187 acres	10 ppm PCBs
Lower Harbor	750 acres	50 ppm PCBs
Buzzards Bay	17,000 acres	1 to 25 ppm PCBs intertidal areas
Total	**17,953.5 acres**	

The highest PCB concentrations were detected in the upper harbor sediments and were considered to be a continued source of contamination to the lower segments of the harbor and bay. The hotspot dredging project occurred mostly in the upper harbor in the shallow tidal estuarine area where the Acushnet River merges with the harbor.

4 Target Goals and Project Objectives

The principle objective of the hotspot removal project in the upper harbor and adjacent sections of the Acushnet River was to remove sediments contaminated with PCBs in excess of 4,000 ppm for source control. The 4,000 ppm criteria was derived from an optimum point by removing the greatest percentage of PCB mass for the least volume of sediment. The hotspot excavation was estimated to contain 45 percent of the total mass of PCBs for the entire site. A second objective for the remediation was to avoid the need for additional remediation in the lower harbor as a result of the dredging program by minimizing contaminant transport. This was evaluated through environmental monitoring.

The goal of the PDFT was to evaluate new technology, including the use of a water recirculation system, with regard to site-specific cleanup levels and to compare these values with previous estimates. Performance data was demonstrated and recorded that included dredge production, accuracy, slurry solids concentration, and air and water quality impacts. Estimates of PCB removal efficiency and dredge production would be used in developing a full-scale remediation plan. Additional objectives were to evaluate the effectiveness of applying contaminant dispersants and flocculents within the CDF to reduce PCB losses to air, to evaluate mechanical dewatering methods, and to evaluate the use of granular activated carbon (BAC) to treat wastewater.

5 Project Design

Pre-planning and Bid Documents. The EPA employed the U.S. Army Corps of Engineers to perform an engineering feasibility study (EFS) of dredging and disposal alternatives (EPA, 1987) which included field data collection, literature reviews, bench-scale studies (Allen & Fowler, 1989), and analytical and numerical modeling (Francinques *et al.*, 1988). Five alternatives were evaluated prior to selection of dredging and on-site incineration (Allen & Ikalainen). A confined disposal facility (CDF) was used in place of on-site incineration due to public opposition. The EFS was conducted from August 1985 to September 1988 and consisted of several tasks: 1) preparation of maps of water depth and mudline elevations, 2) sediment characterization of contamination extent and physical properties, 3) physical characterization of soils and groundwater elevations, 4) lab and field tests predicting sediment/contamination released by dredging, relationship of flow and suspension/settling, estuarine and hydrodynamic and transport model for sediment, 5) testing of dewatering/treatment parameters including settling, solidification/ stabilization, flocculation/clarification, necessity of effluent water treatment, and 6) a study of the most effective dredges. A pilot dredging study was conducted to evaluate three recommended dredges and dredging practices (Otis & Andreliunas, 1987). The pilot study also included chemical, physical, and biological monitoring (Otis & Averett, Holmes, 1987).

Prior to the hotspot removal project, a pilot study removed two sediment cells containing 300 cubic yards (cy) each for implementability assessments. The hotspot removal was awarded as a fixed price contract that also included water treatment and incineration.

Summary of Remedial Action Plan. Dredging operations were designed for hydraulic dredging using the Ellicott 370 12-inch cutterhead dredge within silt curtains. No other sediment removal alternatives were used in the hotspot operable unit. Sediment was to be dewatered and incinerated, however, due to public opposition, sediment was stored in a CDF. Sediment was transported from the dredge to the CDF through a floating pipeline. Process water from dewatering operations was treated in an on-site wastewater treatment plant and discharged to the Achshnet River.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial dredging action took place from April 26, 1994 to September 5, 1995. Work was scheduled for five days a week, although dredging was only conducted on a total of 261 of the available days. Due to shallow water conditions at the site, dredging activities took place only during high tides at water depths of 1 to 6 feet. Dredge operation was limited to 4 to 6 hours per day due to tides and limited capacity of the wastewater treatment plant. Work was discontinued from December 1994 through March 1995, because of ice formation in the Acushnet River.

Equipment. Hydraulic dredging of sediments was performed using an Ellicott 370 12-inch cutterhead dredge. High suction rates and slow auger rotation were used to control dispersion of sediments after exceeding air monitoring criteria during the first three days of dredging. Silt curtains were initially used during dredging for containment of sediment dispersed by dredging. Agitation of silt curtains by reversing tidal currents resulted in the disturbance of sediment and subsequent release of PCB oil. Use of silt curtains was therefore discontinued.

Total Volume Removed and Production Rates. A total of 14,000 cubic yards of sediments were removed from an area of approximately five acres at a production rate of approximately 13 cubic yards per hour. The solids content of dredged material was approximately 5 percent (ThermoRetec, 2000). A likely reason for the low solids content was that the dredge was used to vacuum oil released during dredging from the water surface. Removal to target contamination levels was confirmed with post-dredge sampling. A total of 15 final composite samples were analyzed over the 5-acre area for PCBs. Results ranged from 67 to 2,068 ppm and a median value of 707 ppm. One of six hotspot areas (Area B) was not dredged due to its proximity to submerged high-voltage power lines.

Site-specific Difficulties. The presence of submerged high-voltage power lines prohibited dredging in one of the six hotspot areas. Use of silt curtains was discontinued because the weights contacted the surface bottom during the lower part of the tidal cycle (4 ft tidal range) and released PCB oils). Dredging difficulties included the tides, shallow water depths, and high PCB concentrations in sediments.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. Dredged sediments were transported up to one mile distant via a floating pipeline to a CDF located along the New Bedford shoreline for storage and water treatment. Dewatering and water treatment consisted of an equalization tank, alum flocculation tanks, a secondary clarifier, automatic sand backwash filter, ultra fine polishing filters, activation by hydrogen peroxide and PCB destruction by ultraviolet light (application of an innovative technology). Treated water was discharged to the Acushnet River.

Water Quality Monitoring of Discharge. Effluent was analyzed for PCBs, cadmium, chromium, copper, and lead. Discharge requirements were developed during the design phase and were defined in a permit based on degradation of the Acushnet River and quantitation limits. The PCB monthly discharge level of 0.6 ppb was consistently met. Requirements for metals were consistently met with the exception of copper which was exceeded in May 1994 (11.4 ppb) and lead in December 1994 (8.9 ppb) and January 1995 (4.9 ppb).

6.3 Storage and Disposal

The April 1990 ROD called for on-site incineration of contaminated sediment. EPA terminated the incineration component of the project due to vehement and congressionally-supported public opposition. Contaminated sediments were temporarily stored in an interim shoreline CDF approximately one mile from the dredge area for five years. The hydraulically dredged sediments were pumped directly into the CDF via a floating pipeline. EPA issued a proposed plan in August 1998 to dewater and dispose of sediments in an off-site landfill.

7 Pre-Design Field Test Actions

7.1 Dredging

Schedule and Duration. Trial dredging took place over 4 days (August 10 through 13, 2000) during which the dredge system underwent modifications to prepare for test dredging, which was performed over the course of 5 days (August 14 through 18, 2000).

Equipment. A hybrid environmental mechanical/hydraulic excavator dredge was used to enable accurate dredging of the contaminated sediment, to minimize the amount of water added during the slurry pumping process by recycling water decanted from the slurry effluent, and to minimize the potential for adverse environmental impacts. A horizontal profiling grab bucket (HPG) is able to mechanically excavate thin layers of material with a high degree of accuracy causing minimal spill and turbidity. A crane monitoring system (CMS) with an onboard electronic sensor system and slurry processing unit (SPU) that delivers high percent solids concentrations by introducing controlled amounts of recycled water from the CDF to mechanically dredged material were both part of the innovative techniques utilized for the PDFT.

Total Volume Removed and Production Rates. Dredging was performed to obtain representative production rates over a range of conditions, including varying depths, bank height, and chemical and physical conditions. The representative average production rate for the excavator was 80 cubic yards per hour (cy/hr) in areas with bank height ranging between 1.7 and 2.0 ft. It is estimated that a production rate of 95 cy/hr could be achieved on a full-scale project in deeper areas of the upper harbor if the system is optimized. In shallower areas, where working of the tides would increase the number of barge movements and reduce the overall dredging efficiency, the dredge production would be anticipated to be similar to the use of a smaller dredge (35 to 50 cy/hr).

The solids content of dredged material ranged from 13.3 to 16.3 percent solids by weight. These concentrations were achieved in dredge areas having *in-situ* sediments with average solids concentrations of 32 to 43 percent solids by weight (40 to 50 percent solids by volume).

Dredging accuracy of the test dredge equipment demonstrated that a mechanical bucket, operated from an excavator with rigid connections and a state-of-the-art monitoring and positioning system, could achieve a plus or minus (±) 4-inch vertical dredging accuracy based on comparison of the PDFT post-dredge survey with the target depths. An accuracy evaluation showed that 95 percent of the test area was dredged to within 6 inches of the target depth and 90 percent of the test area was dredged to within 4 inches. The average sediment PCB concentration (upper 1 foot) was reduced from 857 to 29 ppm over the dredged area. The PCB mass remaining after dredging appeared to reside entirely in a thin surface veneer and was attributed to recontamination of the dredged area rather than incomplete removal.

Site-specific Difficulties. SPU production was found to limit dredge production, due primarily to problems with debris clogging. Attempts were made during the PDFT to remedy clogging problems by adding water jets in the suction line, welding baffle walls in the hopper, and other operational measures.

7.2 Dewatering and Water Treatment Operations

Dewatering, Treatment, and Disposal. A pilot-scale wastewater treatment system was used to treat the wastewater generated during the PDFT. Over 1 million gallons of wastewater was treated with unit processes that included chemical addition and settling, ultra-fine sand filtration (0.45-micrometer nominal), granular activated carbon absorption, ultraviolet/oxidation, and sludge dewatering with a plate-and-frame filter press. Contaminants contained in the wastewater are strongly associated with the suspended particles. The seawater with which the dredged sediment was combined to create the slurry contains colloidal particles that cannot be removed by flocculation, clarification, and filtration alone. The concentration of PCBs and copper associated with the colloidal particles is sufficient that wastewater could exceed the discharge limits unless tertiary treatment in the form of activated carbon is performed.

Water Quality Monitoring of Discharge. Effluent was analyzed for PCBs, cadmium, chromium, copper, and lead. Activated carbon was successful in reducing the concentration of PCBs to below the discharge limit of 0.065 micrograms per liter (μg/L) per Aroclor and the concentration of total and dissolved metals, most notably copper.

8 Environmental Monitoring Program

Baseline, progress, post-dredging, and long-term monitoring for physical, chemical, and biological parameters were included in remediation activities. The full-scale baseline monitoring was conducted in 1993. Additional full-scale monitoring events have taken place in 1995 following the hotspot remedial action and in 1999.

The long-term monitoring program has been proposed for 30 years with full-scale sampling events every 3 to 5 years or before and after major remedial activities. Mussel bioaccumulation will be conducted twice a year. A wetland assessment will be conducted every 10 years.

8.1 Baseline

Baseline sampling was performed in 1993 prior to dredging (EPA, 1996). Sampling stations were established just downstream of dredging activities, approximately 1 mile downstream (NBH-2) and approximately 2.5 miles downstream (NBH-4) as shown on Figure 1. This figure shows the CDFs for the entire operable unit that is currently in design, it does not show the hotspot CDF. A reference station was established and designated NBH-5. Sampling stations NBH-2, NBH-4, and NBH-5 were used throughout the bioaccumulation studies to obtain correlating data. Sediment analysis was conducted on grab samples of the top 2 centimeters (cm).

Physical. Physical analysis was conducted on sediments for grain size, total organic carbon (TOC), and acid volatile sulfide (AVS). Site bathymetry was determined using cross-sectional multi-point sampling arrays.

Chemical. Surface sediment samples (2 cm) tested for PCBs in the upper New Bedford Harbor averaged 94 ppm at 24 sampling locations. A maximum concentration of 431 ppm was detected in the upper harbor.

Biological. Bioaccumulation of PCBs from the water column was tested in *Mytilis edulis* and *Fundulus heteroclitus*. Baseline bioaccumulation concentrations in *Mytilis edulis* ranged from 613 to 15,012 nanograms per gram (ng/g). Results are shown in the post-monitoring section. Benthic infaunal invertebrates in sediments (7 cm) were tested for species richness, EMAP index of benthic community condition, and community structure. The average number of species per station was 20 ± species while the outer harbor measured 72 ± 21 species. Sediment toxicity tests were conducted on *Ampelisca abdita* with an average of 55 percent survival in the upper harbor.

8.2 Implementation During Dredging

Progress monitoring was conducted during dredging from April 1994 to September 1995 for the pilot project (EPA, 1997) and during dredging activities in August 2000 (Foster Wheeler, 2001).

Physical. In the hotspot remedial dredging action, as part of the dredging contract, bathymetric measurements were taken to confirm sediment removal to design depths. Dredge cuts were 0.5 ft per pass with a follow-up clean-up pass.

Chemical – Hotspot Remedial Action. Total suspended solids (TSS) and PCB concentrations were monitored in the water column during dredging activities to determine if remedial actions had a significant effect on net downstream transport of PCBs. Samples were intensively collected from five horizontal locations and multiple depths during flooding and ebbing tidal cycles (EPA, 1997). The criteria for maximum cumulative transport was the level of PCBs over background concentrations that would increase the lower harbor sediment PCB concentration by more than 1 ppm. The corresponding total PCB mass was calculated to be 240 kg over the entire dredging period (240 kg/ 260 days). The total mass of PCB transported was 57 kg which was 24 percent of the net sediment transport allowed.

A total 4,041 PCB air monitoring samples were collected during dredging and CDF placement activities and compared to three different action levels (notification, operational, and stop work). A total of 10 samples exceeded the stop work action level of 1,000 nanograms per cubic meter (ng/m^3). Only one of these samples was located within the dredging area (of 2,469 samples taken), the other nine being sampled at the CDF. A total of 49 samples exceeded the action level of 500 ng/m^3 (18 of 2,469 dredge area). A total of 1,063 exceeded the notification action level of 50 ng/m^3 (661 of 2,469 in dredge area). Effluent water quality met discharge requirements on all occasions for all parameters, except for copper exceedances on 3 separate days.

Chemical – Pre-Dredge Field Test. TSS and PCB concentrations were monitored in the water column during dredging activities to determine if remedial actions had a significant effect on net downstream transport of PCBs. Samples were intensively collected from four horizontal locations and multiple depths during flooding and ebbing tidal cycles. (Foster Wheeler, 2001). Field-measured turbidity and PCBs showed some spikes in the vicinity of the dredge, but generally returned to background levels within 500 ft down current of the dredge.

PCB air monitoring samples were collected from nine different potential sources of PCB emissions in a flux changer, and ambient air sampling around the CDF and harbor were collected. Calculations based on surface area inside the silt curtains were approximately 100 milligrams per day (mg/day). Emission rates calculated from raw sediment and from sediment with a thin water cover at the CDF ranged from 666 to 4,090 ng/m^2-min with an average of approximately 2,500 ng/m^2-min. Based on headspace readings from the grizzly and hopper on the dredge, a hopper volume of 72 cubic meters (m^3) and an air exchange rate of one hopper volume every 15 minutes, the emission rate would be approximately 20 μg/min or 0.03 gram of PCBs per 24-hour day (Foster Wheeler, 2001). Emission flux measurements from the mudflat areas ranged from 63 to

600 ng/m^2-min, less than those measured from sediments and sediment-water mixtures at the CDF. The use of surfactants, Dawn and Biosolve, to control the sheen at the CDF does not appear to be effective for controlling PCB emissions.

Biological. PCB bioaccumulation testing in the water column was conducted during dredging using caged mussels, *Mytilis edulis*. Mussels were deployed in mesh bags one-meter above the bottom at three sites for a period of 28 days (NBH-2, NBH-4, and NBH-5). Stations NBH-2 and NBH-4 are located approximately 1 and 2.5 miles downstream, respectively (Figure 1). Caged mussels were also used for baseline and post-remediation monitoring. The available results are shown in the monitoring data table. At stations NBH-2 and NBH-5 (reference site) no increase in PCB bioaccumulation was observed. A significant increase was observed during dredging at station NBH-4. Stations NBH-2 and NBH-4 are located approximately 1 and 2.5 miles downstream, respectively (see Figure 1).

Acute toxicity determinations of the water column were conducted using *Arbacia punctulata*, *Mysidopsis bahia*, and *Champia parvula*. Toxicity criteria for mortality was established to be greater than 50 percent of background for the remedial activities. In 86 *Arbacia punctulatasperm* cell tests, acute toxicity was consistently less than 10 percent than background conditions (NBH-5). In seven acute toxicity tests of *Mysidopsis bahia* 100 percent mortality was observed at one time point at station NBH-2 in the December 12, 1994 sample. Samples at stations closer to dredging operations did not show toxicity on this date. In 85 *C. parvula* sampling points, 50 percent mortality was exceeded in one instance on September 7, 1994 at the reference site (NBH-5). Dredging operation stations did not exceed criteria on this date. Sub-lethal effects attributable to the dredging were measured in *C. parvula* reproduction in two of 72 valid tests. EPA concluded that no acute toxicity effects measured during dredging were attributable to dredging operations (EPA, 1997).

8.3 Post

Following hotspot dredging, physical, chemical, and biological testing were conducted following the same protocols described in the baseline monitoring.

Physical. Data not available for review.

Chemical. Confirmation monitoring in the hotspot was done by collecting 9 to 25 surface sediment (0-2 cm) samples in each dredge unit (approximately 0.25 acre). The samples from each dredge unit were composited into one sample for analysis. If the composite sample concentration was >4000 ppm PCB, then the unit was re-dredged.

Post-dredge verification sampling of sediments in the hotspot areas for PCBs confirmed sediments in excess of 4,000 ppm PCB had been removed. A total of 15 composite samples were collected in 1995 from the 5 acres of hotspot areas. PCB results ranged from 67 to 2,068 ppm with a median value of 707 ppm.

The October 1995, sampling showed localized increases in surface PCB concentrations in the upper harbor after completion of dredging. In the lower harbor, 27 percent of the surface sediments of stations showed an increase, while 67 percent decreased. The outer harbor concentrations remained virtually unchanged (Bergen, et al., 1998). Post-dredging bathymetry was determined using cross-sectional multi-point sampling arrays.

Biological. PCB bioaccumulation results of a composite, post-operational 1995–1997 study of *Mytilis edulis* in the water column are shown in Table 1. As in the progress monitoring, no increase in PCB concentration was observed at stations NBH-2 and NBH-5, while a significant increase was observed at station NBH-4. However, it is unlikely that this increase was attributable to the hotspot remediation, otherwise, higher concentrations would be expected at NBH-2, located closer to the remediation area (EPA, 1997).

8.4 Long Term

Since the 1995 post-remedial sampling, one set of monitoring data has been collected. This sampling took place in 1999, although data are not presently available. Long-term monitoring followed the sampling protocols established in the 1993 baseline sampling.

For New Bedford Harbor, the primary goal of long-term monitoring is to "assess the effectiveness of remediation by quantifying spatial and temporal biological and chemical changes in different environmental compartments." The primary measurement endpoints are water quality standards (biomonitoring) and FDA standards for PCB levels in seafood (EPA, 1996). As of 1997, four rounds of long-term caged mussel bioaccumulation studies have been conducted (twice per year). No statistically significant increase has been observed for NBH-2 and NBH-5. An increase was observed at station NBH-4 but is unlikely attributable to hotspot remediation since no increase was observed at NBH-2.

Table 1 Summary of Monitoring Results

Testing Parameter		Average PCB Concentration			
		Baseline [1] 1987–1993	Progress [2] April 1994–Sept. 1995	Post [3] 1995–1997	Long Term 1999
Bathymetry Station		Yes	Yes	Design depth achieved	—
Surface Sediment (ppm)		Avg = 94 (N = 24)	—	67 to 2,068 (N = 15)	—
Subsurface Sediment (ppm)		100,000 = max	—	—	—
Water Quality Monitoring		Yes	Net transport of PCB mass below allowable criteria	—	—
Air Monitoring		None	(N = 4,041) minimal exceedances (<1%)	—	—
Water Column Acute Toxicity (ng/g dry)	NBH-2 [4]	None	Minimal exceedances compared to reference	—	—
	NBH-4 [5]				
	NBH-5 [6]				
Caged Mussel Water Column Bioaccumulation (ng/g dry)	NBH-2 [4]	15,012 ±4368	15,052 ±4719	14,639 ±3715	NA
	NBH-4 [5]	3,814 ±892	4,250 ±890	6,315 ±711	NA
	NBH-5 [6]	613 ±187	403 ±73	371 ±204	NA
Sediment Toxicity		Avg. = 55% survival	None	—	NA
Benthic Community		Avg = 20 ±7 species per station	—	—	NA

Notes:

1 Average of nine sampling events between July 1987 and December 1993.
2 Average of 14 sampling events between May 1994 and September 1995.
3 Average of four sampling events between October 1995 and May 1997.
4 Station located 1 mile downstream.
5 Station located 2.5 miles downstream.
6 Reference station.

Results are dry-weight corrected.
NA - Not available for review.
Data generated from EPA, October 1997 Report

9 Performance Evaluation

9.1 Meet Target Objectives

Hotspot Removal. The principal objective of the 1995 hotspot removal was to remove all sediments with PCB concentrations in excess of 4,000 ppm. Post-verification sampling included 15 samples from composites of regularly spaced 2 cm surface samples collected as each dredge unit was completed (5 acres). Results verified that the target removal goal to 4,000 ppm PCBs was met. Post-remedial PCB concentrations ranged from 67 to 2,068 ppm with a median value of 707 ppm. This source removal effort supported the second objective to minimize potential future downstream transport of PCBs to the lower harbor from physical disturbances (i.e., scour, storm events) as predicted from USACE studies in the late 1980s.

During implementation, the goal was to minimize increased PCB transport from dredging activities (above baseline bedload values). Air quality results during dredging had minimal exceedances. Downstream surface sediment concentrations in the outer harbor remained unchanged (some localized increases and decreases observed in lower harbor, closer to the dredge area). Total PCB mass transport downstream during dredged measured 57 kg, which equaled 24 percent of the net transport allowed.

EPA considered the hotspot removal project successful because of the quantity of PCB mass removed and the minimal amount of PCB transport and biological impact during and after dredging (EPA, 1997). Minimal environmental effect on New Bedford Harbor and Buzzards Bay from the dredging operation was based on:

- Acceptable water quality monitoring results,
- Acceptable air monitoring data results,
- Mussel bioaccumulation studies were not statistically significant during dredging,
- Minimal net transport of PCBs, well below the necessary level calculated to be protective of the lower harbor,
- No acute toxicity effects attributable to dredging, and
- Post-dredge mussel bioaccumulation studies were not statistically different close to the dredge area (did increase further downstream however, discussed below).

Specific criteria were not stated in the long-term monitoring plan for the long-term objectives toward protection of human health and the environment. Measurement criteria to be used for long-term monitoring include bioaccumulation studies, sediment toxicity, and benthic community assessments. As of 1997, four rounds of caged mussel bioaccumulation studies have been completed with significant increase in neither the NBH-2 nor NBH-5 sample. An increase was observed at the NBH-4 station located 2.5 miles further downstream, however this increase was not statistically significant from pre-dredge conditions. A comparison of pre- and post-concentrations measured in the reference sample NBH-5 observed a 60 percent decrease in levels indicating a large temporal variability in sample collection and measurement efforts. Possible explanations for this variability include: potential scour and exposure from PCB sediments in non-dredged areas, variable sedimentation rates in the harbor, variable uptake rates, and storm events. Specific criteria were not stated for long-term objectives toward protection of human health and the environment.

Pre-Design Field Test. In the PDFT, a state-of-the-art hybrid mechanical/hydraulic dredging system demonstrated dredge performance values exceeding those that have previously been achieved at the New Bedford Harbor site in the areas of dredge production, accuracy, and slurry solids concentrations. Both the sediment removal data and PCB data acquired indicate that the dredging technology used for the PDFT is very efficient and has a high probability of achieving sediment PCB cleanup goals established for upper New Bedford Harbor. Furthermore, given the data set collected during this study, the question of residual contamination due to sloughing or migration should be able to be addressed logistically by modifying certain dredging procedures during a full-scale remediation. For full-scale remediation activities, dredging production in water deeper than 4 ft and between 2 and 4 ft are estimated by be 95 and 35 cy/hr, respectively. Vertical dredging accuracy to the design depths is recommended to be estimated at ±4 ft and horizontal accuracy is 1.5 ft. Average solids concentration of the dredge slurry is 10 to 20 percent solids by weight.

Water column monitoring revealed only a very limited impact on the water column from the actual dredging in terms of both PCBs and suspended solids. The detected elevations of these parameters were within the range of fluctuations found in the harbor with changing environmental conditions. This limited impact was attributed to the bucket design and the method of operation. Results of the wastewater treatment pilot study showed that granular activated carbon, when used with clarification and filtration, can remove PCB concentrations to below the site-specific discharge limit of 0.065 mg/L per Aroclor.

9.2 Design Components

Although this was a small hotspot removal project relative to planned additional dredging presently being designed, extensive pre-design consulting and planning was implemented prior to dredging activities. Design components included:

- Field data collection,
- Literature reviews,
- Bench-scale studies,
- Analytical and numerical modeling, and
- A pilot dredging study.

9.3 Lessons Learned

Although the target goal of 4,000 ppm PCBs was met (concluding a successful dredging project), this level is unlikely protective of human health and the environment based on other risk-based cleanup levels reviewed; however, the project was never intended to be a protective remedy. The intent was a cost-effective five acre mass removal of highly contaminated sediments (dredging $124 per cubic yard). Approximately 955 acres of contaminated sediment (55 percent of mass) still remain. The hotspot remediation was an interim action to prevent mass transport of PCBs further downstream and to prevent an expensive cleanup of widely distributed low-level PCB-impact sediments. Additional long-term monitoring is needed to confirm the reduction of these sediments as a continued source of PCBs. Monitoring results so far indicate no significant change observed in water column bioaccumulation results.

Incineration was initially chosen as the disposal alternative, although congressionally-supported public opposition reversed this decision. This illustrates the need to consider the public's input early in the project design.

The site conditions caused problems with the effectiveness of silt curtains due to disturbance of sediment and release of oil. It is important to consider the nature of contaminant and site-specific factors such as tides and wind. Because PCBs were found in oil form, release of PCBs to the air occurred when oil rose to the surface.

10 Costs

The total project cost, including dredging, CDF construction, and the wastewater treatment plant was $20.1 million ($1,430 per cubic yard). The total dredging cost was $1.74 million ($124 per cubic yard).

11 Project Contact

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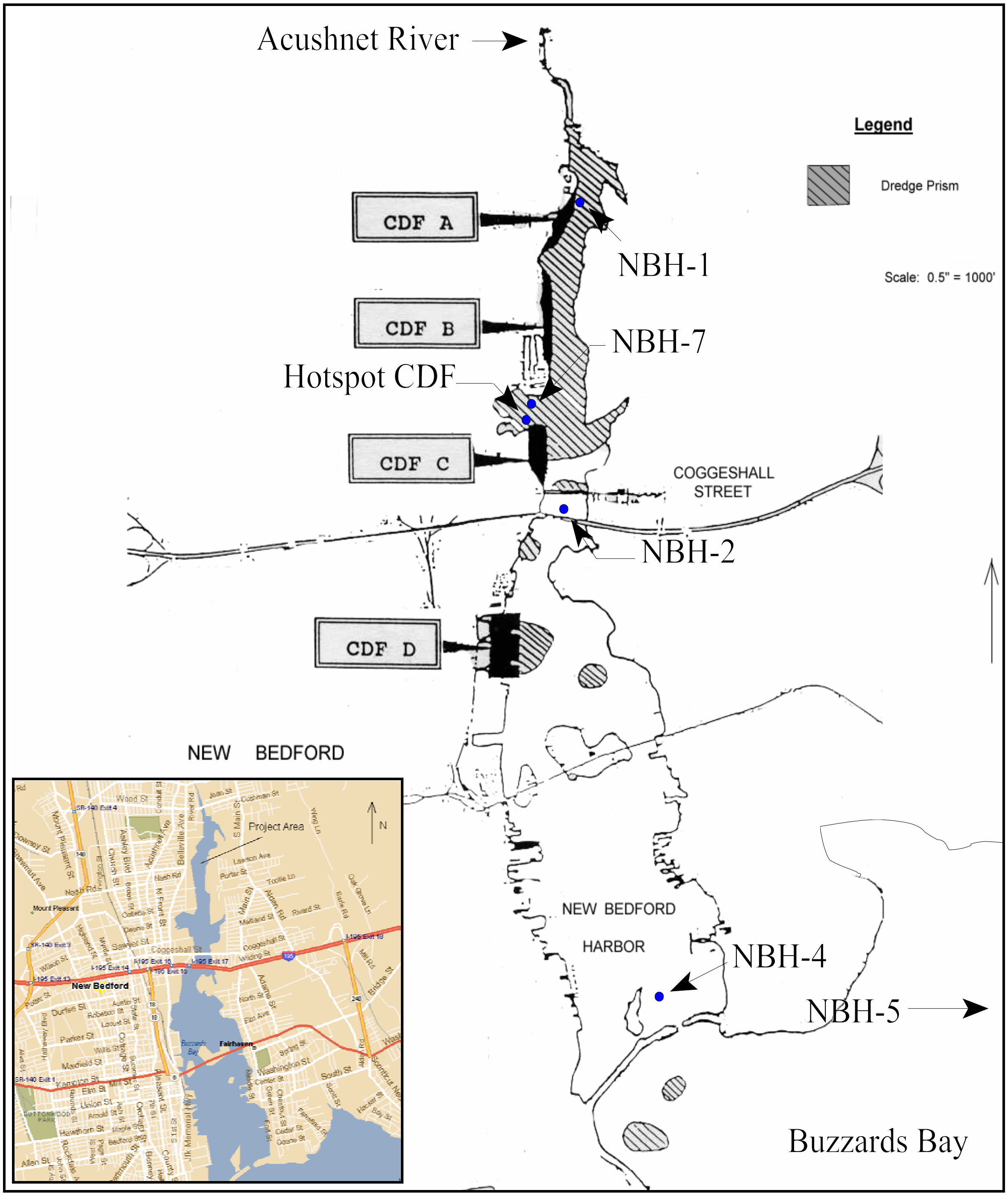
Figure 1 Remedial Dredge Plan - New Bedford Harbor



1 Statement of the Problem

- Dredged 1994
- Pencil Pitch
- 35,000 cubic yards
- $6.20 per cubic yard

Surface sediments were contaminated with pencil pitch (similar to coal tar) from offloading barge activities at the Port of Portland's Terminal 4, Slip 3, Berth 411 facility. Approximately 35,000 cubic yards of pencil pitch-contaminated sediments were mechanically dredged from in-water and underpier areas to achieve a 0.5 percent concentration (by weight). Remediation of spilled pencil pitch of Slip 3 at Terminal 4 was completed in December 1994 through January 1995, in accord with the Consent Decree ordered by the U.S. Environmental Protection Agency (EPA) and state of Oregon. The lead agency for the project was EPA Region 10 under the Clean Water Act.

2 Site Description

The Port of Portland operates Terminal 4, which is located along the Willamette River in Portland, Oregon, approximately 5.2 miles upstream from the confluence with the Columbia River. Terminal 4 is a multi-use, deep-draft cargo facility with 13 berths. Berth 411 has historically been a dry bulk facility used for offloading pencil pitch (coal tar), a cinder-like material used in the manufacture of diverse items including aluminum, electrodes and clay pigeons. Transported as finger-sized pellets, pencil pitch has been imported through the facility since the 1970s.

Aerial of Willamette River and Terminal 4
Source: Port of Portland

Adjacent to the Willamette River, Slip 3 at Terminal 4 is not directly subjected to the currents of the river. The slip experiences sedimentation of fine-grained materials as a result of the slower circulation in the slip relative to the river. The water depths in the slip vary from -45 feet Columbia River Datum (CRD) at the entrance of the slip to -36 feet CRD at the head of the slip.

3 Site Investigation

Initial sampling to determine the extent of pencil pitch in Terminal 4 sediments was conducted in December 1988 consisting of grab and sediment core samples. Those samples were analyzed for physical and chemical characteristics. In early 1989, chronic and acute bioassays were performed using crushed pellets from a new pencil pitch shipment. Depth of pencil pitch contamination was in the upper 10 to 15 cm within Slip 3 near Berth 411 with no acute toxicity detected. Since Terminal 4 was not CERCLA site, a record of decision was not applicable. The site was remediated under Consent Order RE: USA versus Port of Portland, No. CV 93-267 RE (D.OR) Terminal 4 Consent Decree.

Contaminants of Concern. The major contaminants of concern were primarily polynuclear aromatic hydrocarbons (PAHs) and some trace metals (lead, copper and zinc) with a maximum detected concentration of 33 percent total PAHs (330,000 ppm TPAHs). PAHs were listed as toxic pollutants under Section 307 of Clean Water Act (CWA) and 40 CFR 401.15.

4 Target Goals and Project Objectives

The project was performed under consent decree to remediate spills of pelletized pencil pitch (coal tar) at the Port of Portland's Terminal 4, Slip 3, based on chemical concentration. No acute toxicity was found related to the spilled pellets although the consent decree stated that PAHs may cause adverse health effects under certain circumstances. The consent decree specified that pencil pitch levels were to be remediated to 0.5 percent (by weight) as defined through infrared scanning spectroscopy (IR scanning). Consent Decree, page 6, stated:

> "For purposes of this Consent Decree, removal and disposal shall be considered to be complete when pencil pitch levels are at or below one-half of one percent dry weight of the sediments remaining in the slip as determined by sampling and testing."

The site was to be remediated within four years of the Consent Order. The Consent Decree specified either an upland or aquatic confined disposal area. Even though the consent decree did not specify remediation levels for trace metals and PAHs, the dredging plan addressed the remediation of the entire sediment matrix.

5 Project Design

The Port of Portland developed a dredge plan called Dredging, Transportation and Disposal Plan that described the proposed remediation effort for permitting purposes as well as for construction purposes. It formed the scope of work for the contractor's work and integrated the controls of the Consent Decree. The objective of the operation was to remove contaminated sediments by mechanical dredge, load them into bottom-dump scows, and dispose of them at a confined disposal area. Removal of the pencil pitch was specifically designated by the Consent Decree; capping was not an option.

The dredging contract was awarded to M. Cutter, who was given flexibility to modify operations to meet the project goals. However, since dredging operations were successful as proposed, modifications to the plan were not necessary. Insufficient information was available to know whether the contract was competitively bid or awarded based on low-bid or qualifications-based.

The Port, with EPA's assistance and consult selected a confined in-water disposal area at Hardtack Island, part of the Ross Island Lagoon mining and disposal operation operated by Ross Island Sand & Gravel. The disposal area is located approximately 9 miles upriver from Terminal 4 (EPA, 1993).

Operational Constraints. The remediation plan required dredging of riprapped banks located under the docks of Terminal 4. Sediments overlaying the riprap were inaccessible with a bucket dredge. These sediments were "swept" with a hand-operated airlift pump into the middle of the slip and then dredged as usual.

Permits/Restrictions. Project permit conditions stipulated the use of a closed bucket mechanical dredging system. An exception was made for materials along the riprap under the dock face that were inaccessible to a mechanical dredge. The Consent Decree and permit also contained requirements for water quality monitoring to meet State Section 401 requirements and the placement of a silt curtain across the entrance to Slip 3. Remedial dredging was carried out under federal Nationwide Permit 38 and State Removal/Fill Permit #RF8820.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The contractor mobilized to the site on December 17 and 18, 1994 and dredged from December 19 to January 7, 1995, taking only Christmas Day off (19 days). Dredging activities operated for two consecutive eight-hour shifts and then took one eight-hour shift for maintenance.

Equipment. An enclosed, or "shrouded" bucket was selected by the contractor for the clamshell dredge. The clamshell bucket placed dredged material from open-water areas into bottom-dump barges. A silt curtain was placed across the entrance to Slip 3. Nearshore sediments overlaying the riprap were inaccessible with a bucket dredge so these sediments were "swept" with a hand-operated airlift pump into the middle of the slip and then dredged as usual.

Total Volume Removed and Production Rates. Approximately 35,000 cubic yards of sediment was removed by a clamshell bucket and loaded into bottom-dump barges.

6.2 Dewatering and Water Treatment Operations

Mechanically-dredged material was transported in bottom-dump barges to an aquatic confined disposal area. Water treatment was not an issue, and water quality monitoring was not needed.

6.3 Storage and Disposal

The Port of Portland selected a confined aquatic site as its disposal area. The selection of an aquatic confined site was consistent with the

Environmental Protection Agency's preference for confined in-water disposal. Short-term or interim storage of the material was not necessary. The material was carried in dump scows approximately 9 miles upriver to the aquatic disposal area at Hardtack Island operated by Ross Island Sand & Gravel. The Dredging Plan stipulated that the dredged sediment from Slip 3 would be covered with 1 foot of clean cap material within one month of placement (ACOE, 1994).

The CDF operated in conjunction with a sand and gravel mining operation by private party with long-term submerged lands lease with the State of Oregon. The disposed material, both clean and contaminated was used to replace materials harvested from the island site by Ross Island Sand & Gravel.

7 Environmental Monitoring Program

The environmental monitoring program included bathymetry, sediment chemistry and bioaccumulation tests, water column monitoring and toxicity tests (State of Oregon, 1995; Hartman Associates, 1995).

7.1 Baseline

Initial baseline data collection and characterization occurred in December 1988 when the Port of Portland carried out synoptic studies of the horizontal and vertical distribution of pencil pitch at Slip 3.

Physical. Hydrographic surveys of all Port terminals were conducted on a regular basis by the Port of Portland to determine dredging needs. Slip 3 was surveyed during routine reconnaissance surveys near the time of the original pencil pitch distribution studies in late 1988. However, bathymetric surveys were not referenced in original characterization studies. Sediment grain size was also measured from the samples taken in December 1988.

Chemical. Chemical characterization had two primary purposes:

- Quantify the amount of pencil pitch in the sediment; and
- Quantify the presence/absence of PAHs, trace metals, pesticides and PCBs.

Preliminary laboratory testing was conducted to determine whether and how pencil pitch was distinguishable from the sediments themselves. Results of the laboratory studies indicated that pencil pitch had very low solubility in water, and the concentration of pencil pitch could be detected and roughly estimated in sediment by extraction with freon and IR scanning.

The horizontal extent of pencil pitch in the sediments was determined by collecting 28 surface samples to a depth of 10 cm and determining the physical and chemical properties (grain size, organics). The presence or absence of pencil pitch was established by estimating its concentration by volume (g/cc) using IR scanning. Samples were additionally analyzed for PAHs, trace metals, pesticides and PCBs. Sediment core samples were also taken at six stations to estimate vertical distribution of contamination.

The IR scan of Terminal 4 sediment samples measured concentrations of pencil pitch ranging from a high of 33 percent to less than 1 percent a short distance away. Results indicated the pencil pitch residue was confined to the upper 10 to 15 cm of surface sediments. Results of PAH testing demonstrated PAHs outside the area known for pencil pitch concentration. Their connection to coal tar contamination was inconclusive so a correlation between pencil pitch and PAHs could not be determined.

Background water quality sampling was performed on December 17 and 18, 1994. Data included ambient water quality profiles for field positions and laboratory analysis of total suspended solids (TSS), and turbidity.

Biological. Water column toxicity tests, sediment toxicity tests and bioaccumulation studies were conducted in 1988 to determine acute and chronic toxicity to aquatic organisms (invertebrates and fish). Tests were designed under "worst-case" conditions. The water toxicity tests included elutriate tests to examine the flux or bioavailability of PAHs between pencil pitch and the water column. The potential for bioaccumulation was evaluated by determining body burden after 20-day exposure. Creating the "worst-case" scenario with pencil pitch for bioassays was problematic; grinding the pellets changed the pencil pitch's physical form so that *in-situ* conditions could not be replicated and correlations made with confidence.

Chronic and acute toxicity testing resulted in the following:

1. The elutriate was not acutely lethal to the freshwater cladoceran *Daphnia magna*. However, sublethal toxicity was evident in the 100 percent elutriate, but not at 30 percent.

2. Pencil pitch in powdered form was toxic to the freshwater amphipod *Hyalella azteca* at all levels (0.4, 4, and 40 percent by weight).

3. Limited bioaccumulation of five PAH compounds occurred in coho salmon exposed to 4 percent pencil pitch powder in sediment. The tests were terminated after 12 days due to high mortality.

7.2 Implementation During Dredging

Physical. Hydrographic surveys were conducted for purposes of dredging contractor payment.

Chemical. The State Water Quality Permit required initial characterization of the ambient conditions of the construction, disposal, control and reference sites prior to startup. Previous monitoring near the site demonstrated high variability in turbidity and TSS since the site is along an active navigation channel and downstream of shipyard operations. Sampling location requirements included:

- One reference site (upriver and out of project influence),
- Stations in the construction site within the silt curtain, and
- A control site outside the silt curtain.

The Port's final sampling locations included an upstream reference point, a downstream control point, a point in the mixing zone of the dredging area, and disposal site point. Real-time data were reported from three depth locations in the water column: surface at approximately 2 to 3 feet below the water surface; the mid-depth; and the bottom, approximately 3 to 6 feet off the river's bottom. Daily reporting of water quality during both dredging and disposal was required by the water quality permit. TSS samples were collected only when the mean turbidity value was greater than 10 NTU above the mean background value. Water quality requirements included:

- *Turbidity (Jackson Turbidity Units, JTU):* No more than a 10 percent cumulative increase in natural stream turbidities as measured relative to a control point.

- *Dissolved Oxygen:* Maintained above 8.0 mg/L outside the silt curtain.

- *Pencil Pitch:* Monitored in the water column to ensure that the resuspension of particulate pencil pitch was not entering the waterway. Pencil pitch measurement was specified as *in-situ* colorimetric analysis, as an alternative to IR scanning. Since IR scanning required two weeks of laboratory time, the method was not responsive to ongoing construction operations.

Measurements indicated that natural variability in river conditions for turbidity was highly variable (10 to 55 NTU) at the Terminal 4 sampling stations and that natural events such as propeller wash and storm events raised turbidity levels more than dredging. Dissolved oxygen remained stable to the background measurement except during storm events when it dropped.

Water quality samples were also analyzed for pencil pitch at all locations with results reported within 24 hours using *in-situ* colorimetric analyses. With a reporting limit of 0.001 percent, and a method detection limit of 0.00025 percent, no pencil pitch was detected.

Sediment samples were collected during dredging to confirm contractor progress and provide information on sediment chemistry. Sediment samples were analyzed for pencil pitch, trace metals, PAHs, and grain size. Sampling dates were December 27, 1994, and January 5, 1995. Analytical results from some areas exceeded the target cleanup goals and required redredging. Redredging and resampling was conducted before equipment was demobilized.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. Post-dredging surveys were conducted and additional dredging was performed based on those survey results.

Chemical. Over 30 post-dredge sediment samples were collected on January 7 and 26, 1995 after redredging of areas and resampling. The chemical analyses by IR scanning indicated that the pencil pitch levels had been reduced to below the specified 0.5 percent (by weight) in all of the dredged areas. Additionally, the concentrations of trace metals and PAHs showed a substantial reduction in concentrations relative to the pre-dredge levels.

Biological. None required or performed.

7.4 Long Term

No long-term monitoring of the dredging site appears to have been required. A monitoring program for the disposal area was instigated in 1999 due to other concerns in the Willamette River and at the disposal area.

Table 1 Summary of Monitoring Results

Testing Parameter		Concentration			
		Baseline 1988/1994	During 1994/1995	Post 1995	Long Term
Bathymetry		Yes	Yes	Yes	
Surface Sediment (0 to 10 cm)		(N = 28) 1 to 33% pencil pitch	Some exceedances; redredged	(N = 30) <0.5% pencil pitch, PAHs, and metals decreased	None required
Water Column Toxicity Tests	*Daphnia magna*	Not lethal, but sub-lethal >30%	None	None	None required
	Hyalella azteca	Lethal at all test levels	None	None	None required
Surface Water Quality		TSS/turbidity	10 to 55 NTU pencil pitch = no exceedances DO stable	—	None required
Sediment Bioaccumulation		Limited bioaccumulation (inconclusive)	None	—	—

8 Performance Evaluation

The project was considered a success since the terms of the consent order were fulfilled. Chemical analyses of sediment samples indicated that the concentrations of pencil pitch remaining in the sediments after dredging was below the cleanup target goal of 0.5 percent limit (by weight) in all areas of the dredge prism. Even though the consent order did not specify a reduction level for PAHs, post-project sampling showed that concentrations of trace metals and PAHs in the sediments were substantially reduced. Water chemistry samples collected during dredging also indicated no measurable release of pencil pitch from the dredging operations.

9 Costs

The pencil pitch remediation effort cost approximately $212,000 to dredge 35,000 cubic yards ($6.20 per cubic yard). This cost did not include disposal or capping efforts (Haynes, 2000).

10 Project Contact

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11 References

ACOE, 1994. Portland District, U.S. Department of the Army Nationwide Permit 38 Pre-Discharge Notification, Application No. 94-549.

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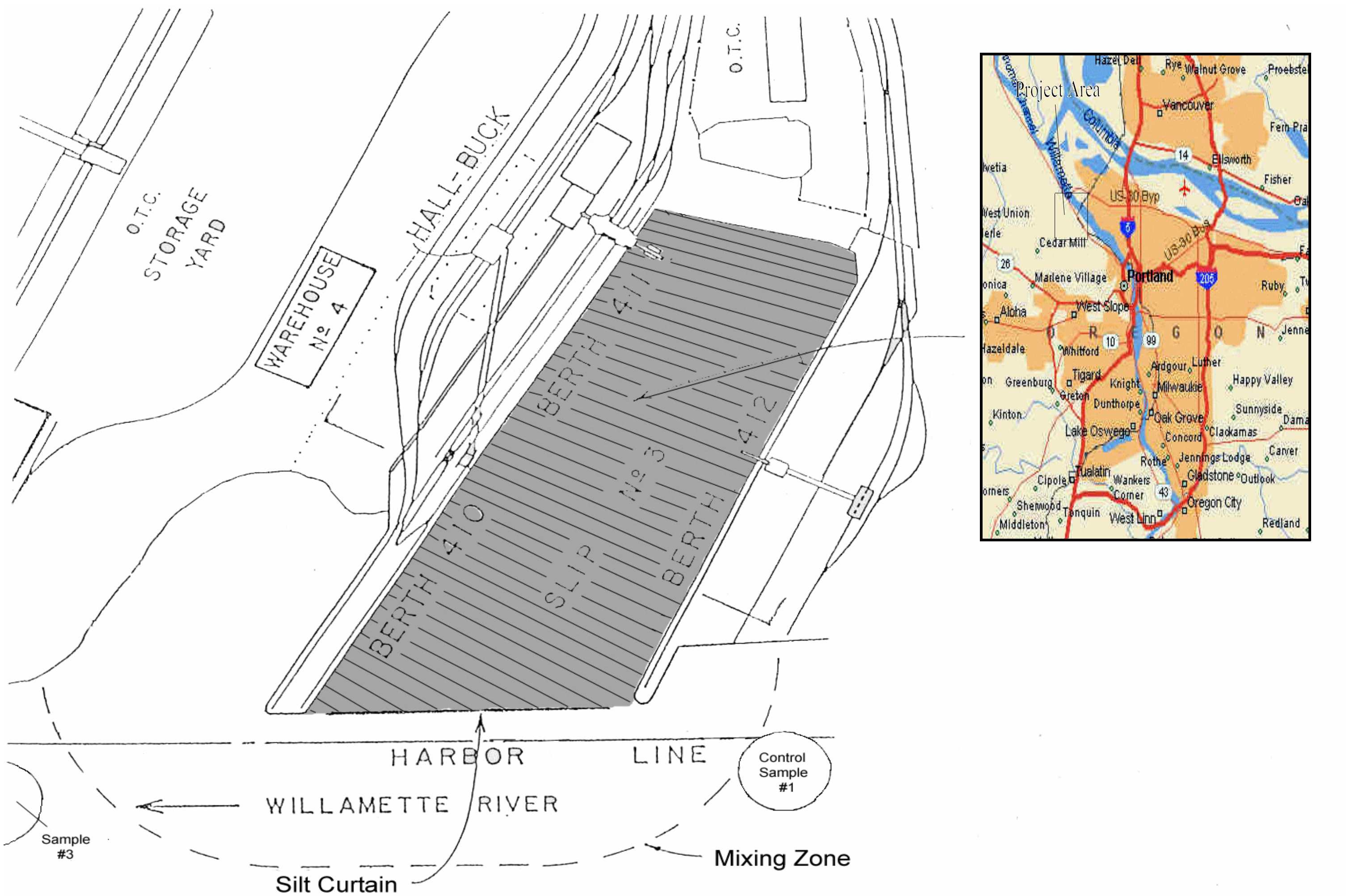
State of Oregon, 1995. Material Removal/Fill Permit No. 8820 for the Port of Portland. Oregon Division of State Lands. August 29.

Figure 1 Remedial Dredge Plan - Port of Portland T4 Pencil Pitch



Source: Portland District, U.S. Department of the Army Nationwide Permit 38 Pre-Discharge Notification, Application No. 94549

PORT OF VANCOUVER COPPER SPILL - VANCOUVER, WASHINGTON

1 Statement of the Problem

- Dredged 1990
- Copper
- 1,900 cubic yards
- $526 per cubic yard

Approximately 1,900 cubic yards of sediment were contaminated with copper concentrate exceeding state standards from bulk loading activities along Berth 7 at the Port of Vancouver. The maximum detected concentration in surface sediments was approximately 68,000 ppm copper. The state required removal of sediment from in-water and under dock areas to less than 1,300 ppm copper concentration in surface sediments. Sediments were hydraulically dredged to a depth of 1.5 feet in July and August 1990 with baseline, progress, and post-monitoring performed for chemical exceedances. The lead agency for this project was the Washington State Department of Ecology (Ecology).

2 Site Description

The Port of Vancouver's Berth 7 (bulk loading facility) is located on the Columbia River at River Mile Post 104.5 near Vancouver, Washington. With a 40-foot-deep navigation channel, the Columbia River represents a major shipping corridor used by deep-draft vessels and barges. The currents in the Columbia River vary throughout the year, but an average current is on the order of a few feet per second. Also, the currents differ across the project site, being slower in the shallower water than the main channel.

Aerial Port of Vancouver
Source: EPA

The site sediments were contaminated with copper concentrate from material spilling from ship loading conveyors prior to 1987. The water depths affected by high levels of copper concentrate range from -5 feet Columbia River Datum (CRD) to deeper than -40 feet CRD. The river sediments at the project site consist primarily of poorly graded medium to fine sands with about 10 percent of fines (silt and clay fraction). Since the copper concentrate was fine grained, the percent of fines served as an indicator to the amount of concentrate present. The sediments with the highest copper concentrations had approximately 25 percent fines. Based on Ecology data and U.S. Army Corps of Engineers (ACOE) database information, the average background copper concentration in Columbia River sediments was approximately 24 to 25 ppm copper.

3 Site Investigation

Since 1982, the Port of Vancouver has operated an ore concentrate transfer facility at its dockfront site, using conveyors to transfer copper concentrate into deep-draft ships for export. Prior to 1987, a section of the ship loading conveyor system lacked protection against spillage loss into the Columbia River. Sediment sampling conducted in 1988 indicated that copper concentrations in the sediments below the loading dock exceeded 68,000 ppm, classifying the sediments as dangerous waste under Ecology regulations. The initial field sampling and laboratory analyses were conducted in 1988 with additional data collected in 1989. Sediment samples were collected and analyzed to determine the copper concentrations, acute bioassay toxicity, and benthic macroinvertebrate abundance. Pursuant to the Model Toxics Control Act (MTCA), Ecology issued a Remedial Action Order (No. DE-90-5189) to the Port of Vancouver for contaminated sediments. Ecology set the cleanup criteria at 1,300 ppm copper since testing indicated that this concentration did not exceed the lower limit of toxic effects for copper concentrate.

Contaminants of Concern. The contaminant of interest was copper concentrate. The highest copper concentrations were centered below the dock at Berth 7, as shown on Figure 1, with lower concentrations surrounding the dock area. Based on sediment sampling, the extent of copper contamination appeared to extend from the surface down to a depth of 18 inches. The maximum copper concentrations at the project site were around 70,000 ppm, located in a central deposit underneath the upstream dock face.

4 Target Goals and Project Objectives

Ecology established a cleanup level of 1,300 ppm (mg/kg) for copper concentration. The remedial objective was 100 percent removal of contaminated sediment exceeding 1,300 ppm copper surrounding Berth 7. Defined by previous sampling investigations, the target depth for dredging was 2 feet (with 6 inches of overdredge included). This target depth was assumed to meet the required 100 percent mass removal objective.

Although the chemical cleanup criteria was established by Ecology, the port interpreted the target objective as the overall average sediment concentration had to be below 1,300 ppm copper, while Ecology intended every sediment sample to be below 1,300 ppm copper (each grid sample).

5 Project Design

The remedy planned to dredge approximately 1,900 cubic yards of material to a target removal depth of 1.5 feet. Due to the high copper concentrations, the sediments underneath the bulk loading dock at Berth 7 and adjacent areas along the upstream dock face (Figure 1) were designated a dangerous waste under Revised Code of Washington (RCW) 173.303 Washington State regulations. Termed Area A, the Dangerous Waste Zone contained approximately 310 cubic yards of material (Port of Vancouver, 1990). Area B comprised the remainder of the dredge prism (1,600 cubic yards) with the sediments containing copper concentrations in excess of 1,300 ppm (but well below Area A concentrations), but still requiring remediation. The dredge prism was subdivided into a grid with cells measuring 40 feet by 40 feet to assist project management. Dredging was the only activity considered feasible for the site. While natural recovery would have decreased the high levels of copper concentrate due to sediment transport, the amount of time required was unacceptable to the agencies. Given the site’s proximity to a navigation channel, capping was not a preferred alternative. Dredging was not required to maintain navigational depths. Dredged material was pumped to upland disposal sites located on the Port of Vancouver's property for permanent storage or treatment depending upon chemical concentration (Ogden Beeman, 1989 and 1991).

Operational Constraints. No information available.

Permits/Restrictions. Permits for this project included the USACE Section 10/404 and Washington Department of Fisheries Hydraulic Project Approval.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The primary dredging work occurred from July 17 through August 16, 1990. Dredging was permitted to occur 24 hours a day.

Equipment. A small cutterhead pipeline dredge performed the initial dredging for the entire prism, dredging the Dangerous Waste Zone (Area A) first and then completing Area B. For the area underneath the dock, diver-operated redredging was necessary since the pipeline dredge was unable to reduce the copper concentrations below the threshold level in some locations.

Total Volume Removed and Production Rates. Information not available.

Site-Specific Difficulties. Sediments beneath the loading dock proved difficult to access with dredging equipment due to the limited horizontal and vertical clearances. The loading dock consisted of a concrete pier supported by 35 to 40 steel piles with a row of 8 to 10 steel fender piles along the face of the dock. The pilings underneath the dock were closely spaced with a vertical clearance less than 20 feet. In addition, steep, unstable gravel slopes under the dock made successful remediation difficult. The contractor changed methods to better access underpier areas, with limited success (see monitoring section).

One other factor involved the heavier weight of the copper concentrate relative to the river sands. Follow-up sampling indicated that during dredging, a fraction of the heavier copper particles were not entrained by the hydraulic dredge, but rather resuspended and redeposited on the bottom as confirmed by verification sampling.

6.2 Dewatering and Water Treatment Operations

Two dewatering/disposal sites were used, depending upon the characterization of the dredged material. The dredged material containing dangerous wastes from Area A was discharged to Disposal Site I, a lined, diked sedimentation pond on the Port's property, to allow the solids to settle out of suspension. Dredged material from Area B was deposited in an upland disposal site on Port property termed Disposal Site II. The disposal site was located on a paved lot equipped with surface drains that connected to the Port's stormwater treatment facility. Settling basins were used to treat the large volumes of return flow created by hydraulic dredging with the discharge water returned to the river per authorization from Ecology.

If the return water from either disposal site contained copper concentrations that exceeded the Ambient Water Quality Standards chemical criteria, then the return water was treated in the Port's stormwater treatment facility and discharged to the City of Vancouver's Westside Treatment Plant. No problems occurred with surface water since all water samples collected were non-detect for copper.

6.3 Storage and Disposal

Disposal of the dredged material depended upon the concentration of copper in the sediments. For the dredged sediments with high levels of copper (from Area A), the materials were piped to Disposal Site I, a temporary dangerous waste disposal site located on Port of Vancouver property. The port planned to recycle the dredged solids through the ore process system to recover the copper concentrate. For the sediments with significantly lower copper concentrations (from Area B), recovery of the ore was not cost effective and the materials were piped to Disposal Site II, an upland site located on port property (Port of Vancouver, 1990).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, water column sampling and sediment sampling for compliance with chemical criteria. Baseline toxicity testing and benthic abundance studies were also conducted (Table 1) (Century West, 1989 and 1990).

7.1 Baseline

Physical. A pre-dredge survey was performed within two weeks of the start of dredging and served as the contract basis for the work.

Chemical. The initial field sampling and laboratory analyses were conducted in 1988 by Century West Engineering with additional data collected in 1989. Sediment samples were collected by surface grabs and core samples and analyzed to determine the copper concentrations present.

Biological. Based on the results of acute static bioassay tests and benthic macroinvertebrate studies, Ecology designated a portion of the dredged materials, contained in Area A, to be Dangerous Waste.

7.2 Implementation During Dredging

Physical. No surveying was performed during the dredging operation.

Chemical. As a condition of the permits, water quality sampling was performed three times during the first week of dredging to monitor turbidity and dissolved copper concentrations. For the initial dredging in the Dangerous Waste Zone (Area A), samples were collected on the first day of dredging, July 17, 1990, and also later on July 19, 1990. For Area B, one round of samples was gathered on the first day of dredging, July 27, 1990. Samples were gathered downcurrent of the dredging at both the midpoint of the dilution zone (225 feet from the dredge) and at the dilution zone boundary (450 feet from the dredge). Within the water column, samples were collected near the surface, mid-depth, and 3 to 5 feet above the river bottom.

Ecology established an upper concentration limit of 12 ppb of copper at the edge of the dilution zone (450 feet downcurrent from the dredge). Based on the results of the sampling analyses, no detectable concentrations of dissolved copper occurred at the midpoint or downstream boundary of the dilution zone.

One sediment sample was collected from each of the 35 grid cells (Figure 2) in the dredge prism and analyzed to determine the level of copper concentrate that remained in the bottom sediments. The sediment samples were gathered from Area A on August 3, 1990 following the completion of the dredging of the Dangerous Waste Zone with the samples for Area B gathered on August 16, 1990.

Sampling results indicated that cells 4, 10, 11, 17, 18 and 25 contained copper concentrate levels that exceeded the 1,300 ppm threshold (six out of 35 cells). Using a diver-articulated dredge, cells 4, 11, and 10 were redredged, in that order, with the cutterhead hydraulic dredge used in cells 17, 18 and 25. Cells 10 and 11 were redredged again with the cutterhead due to a ridge of gravels and cobbles raising concerns about diver safety.

Biological. No biological testing was performed during dredging.

7.3 Post

Physical. Post-dredge surveys were conducted within three working days following the completion of dredging.

Chemical. The redredging effort during August 1990 for the remaining hotspots also proved unsuccessful at removing enough copper concentrate to drop the level below 1,300 ppm of copper for three grids (Table 2). Post-dredge sediment sampling revealed that three cells in the dredge prism grid (numbers 10, 11 and 25) still had copper concentrations in excess of 1,300 ppm. Cells 10 and 11 were located underneath the dock on a slope that varied from 1V:4H to about 1V:2H. In cells 10 and 11, the sediments consisted of a shallow (1 foot) layer of sandy sediment mixed with gravel, underlain by a layer of cobbles and rock. Cell 25 was located in the channel of the Columbia River with water depths of -40 feet to -44 feet CRD and sandy bottom sediments. The combination of water depth and river currents at Cell 25 proved problematic for the dredge given the weight of the heavier copper particles relative to the sandy bottom.

Overall, the average copper concentration after dredging was 622 ppm for all of the grid cells (both Areas A and B), which was lower than the perceived agency objective of 1,300 ppm for copper. However, according to Ecology, the cleanup criteria required that each grid sample be below 1,300 ppm copper.

Biological. No biological testing was performed after dredging.

7.4 Long-Term

Additional sediment sampling was performed in April 1991 to determine the current copper concentrations at the time. While sampling showed that residual copper concentrations had diminished, the sediment sampling also revealed that four cells contained copper concentrations in excess of 1,300 ppm, specifically cells 10, 11, 25 and 26, as shown in Figure 3.

Table 1 Summary of Monitoring Results

Testing Parameter	Copper Concentration (ppm)			
	Baseline 1988–1990	**During Dredging July/August 1990**	**Post-Dredging August 1990 (3 days after)**	**Long Term April 1991**
Bathymetry	Yes	None	Yes	
Surface Sediment Grabs	ND to 68,000	None	(N = 35) ND to >1,300 (Avg = 622)	ND to >1,300
Sediment Cores	NA	None	None	
Water Column	None	No exceedances	None	
Sediment Toxicity Tests	NA	None	None	
Benthic Macroinvertebrate Community	NA	None	None	

Notes:

NA - Data not available for review.
ND - Non-detect.
None - Not tested.

Table 2 Summary of Post-Dredge Copper Concentrations

Grid Cell Number (35 total)	Sediment Copper Concentration (ppm)	
	August 1990 (days after redredging)	April 1991
10	4,790	2,020
11	4,610	2,030
25	3,430	5,240/4,280 (duplicate)
26	906	1,570
All Other Cells	<1,300	<1,300

Cell 26 was located downstream and adjacent to cell 25 with natural downstream sediment transport credited for the increase in the copper concentrate level.

Given the location of cells 10 and 11 underneath the dock, limited options existed to allow dredge equipment access to the area, with diver-controlled apparatus being the most viable alternative. However, the unstable nature of the slope, combined with the presence of gravels, cobbles and rocks posed a serious threat to diver safety. In cells 25 and 26, the river's velocity and water depths hampered the ability of the dredge to reclaim the copper concentrate.

8 Performance Evaluation

Dredging successfully reduced the overall average copper concentration to well below the agency objective of 1,300 ppm from the area around the Berth 7 bulk loading facility at the Port of Vancouver. However, isolated spots with concentrations of copper concentrate exceeding 1,300 ppm remained underneath the dock and in the river channel, despite repeated dredging attempts.

For discrete samples, the dredge prism was divided into 35 discrete cells within the dredge footprint (grid) and surface sediment samples were collected from each cell after dredging. Out of 35 samples, only three samples exceeded the compliance criteria of 1,300 ppm copper after repeated dredging attempts (88 percent success). Dredging was difficult in these three areas (two underpier, one open channel) because of unstable cobbles and gravel ridges under the piers and strong currents in the open channel.

Overall, the dredging did not fulfill the agency objective of remediating the entire prism to copper concentrations below 1,300 ppm. The difficulties encountered in dredging were primarily related to two factors:

1. The gravels and cobbles under the dock were covered by a foot of sand and were not detected during sampling due to the difficulty in obtaining sediment cores in sands. The

threat to diver safety introduced by the ridge of gravels and cobbles eliminated using diver-operated equipment while the restricted access hampered the operation of mechanical equipment.

2. The difficulty experienced by the dredge in removing the copper concentrate due to its heavier weight was not anticipated.

9 Costs

Project costs for dredging and disposal were approximately $1 million ($526 per cubic yard) for 1,900 cubic yards of contaminated sediment.

10 Project Contact

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11 References

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Figure 1 Remedial Dredge Plan - Port of Vancouver Copper Spill

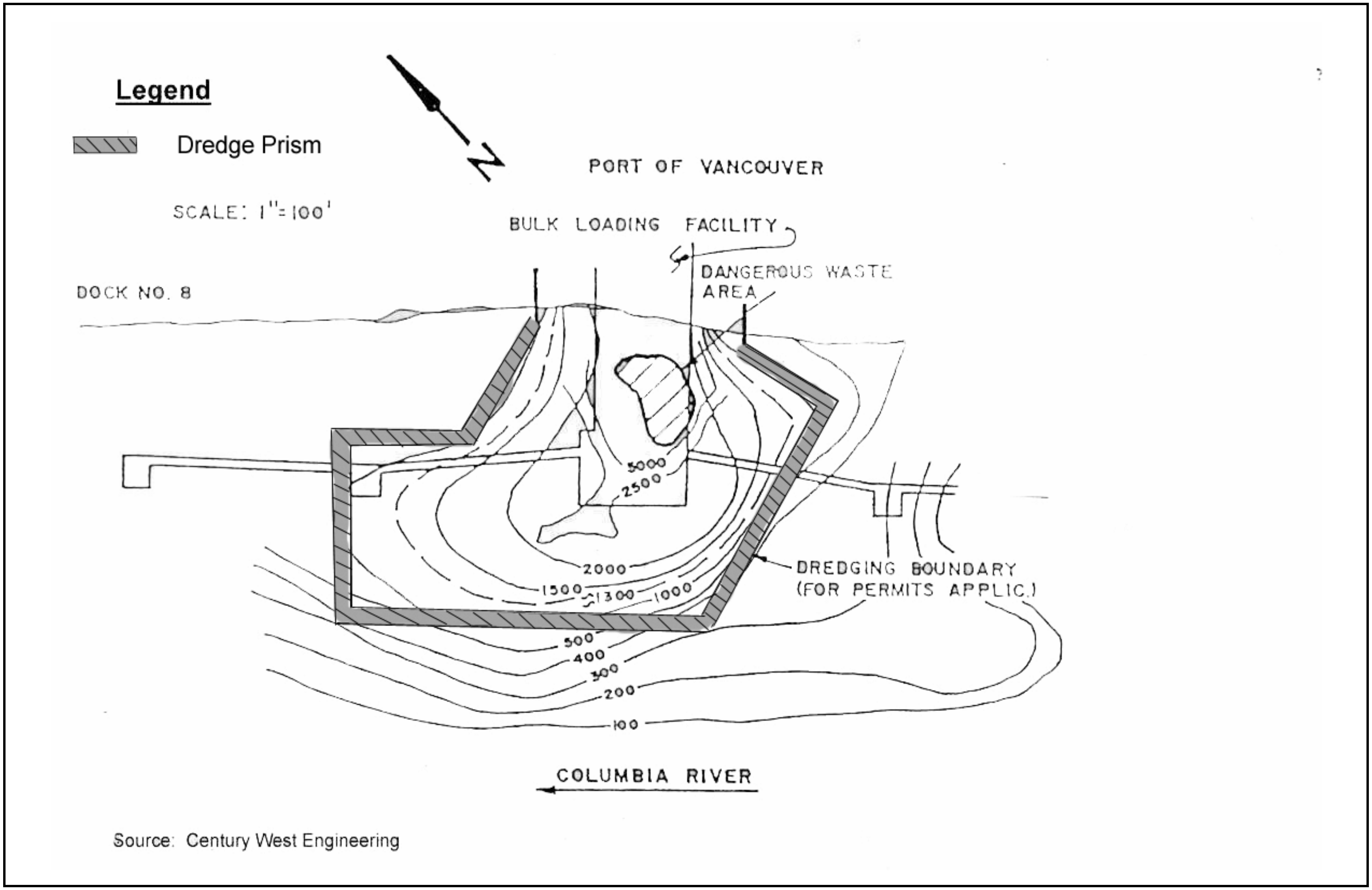
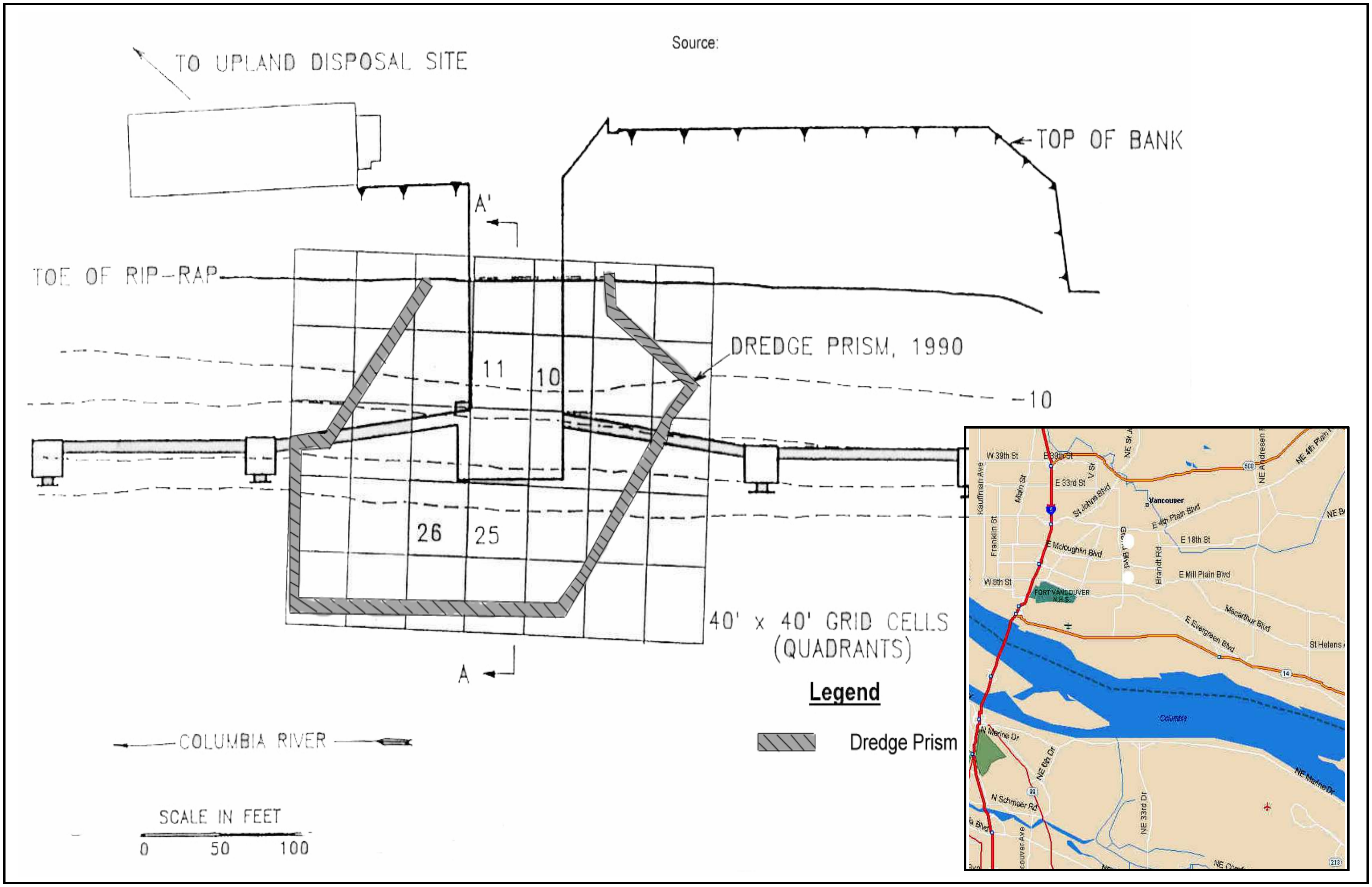


Figure 2 Remedial Dredge Grid Plan - Port of Vancouver Copper Spill



PUGET SOUND NAVAL SHIPYARD PIER D - BREMERTON, WASHINGTON

1 Statement of the Problem

- Dredged 1994-1995
- PCBs, PAHs, metals
- 53,400 cubic yards
- Costs not available

The primary purpose of the dredging project was to deepen the berths along Pier D to accommodate larger Navy vessels at the Puget Sound Naval Shipyard. However, the sediments in the vicinity of the pier were contaminated with a variety of metals and chemicals from shipyard operations since the late 1800s. Dredging provided the necessary navigational improvements with contaminated sediments within the dredging prism removed and relocated to an upland disposal site. Pier D is contained within Operable Unit B, which is currently being evaluated under CERCLA for additional remediation. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10 with the assistance from the Washington State Department of Ecology (Ecology).

2 Site Description

The Puget Sound Naval Shipyard is located on the northern shoreline of Sinclair Inlet in Bremerton, Washington (Figure 1). Established in 1891 as a naval station, Puget Sound Naval Shipyard built new ships during World War I, primarily repaired battle damage to ships during World War II, and modernized carriers after World War II. Currently, the shipyard repairs submarines and is a nuclear-capable repair facility. The largest and most diverse shipyard on the West Coast, the Puget Sound Naval Shipyard has the capability to alter, repair, construct, deactivate, overhaul and drydock the Navy's ships in addition to serving as the home port for nuclear cruisers and fast combat support ships (U.S. Army Corps of Engineers [ACOE]). Over time, the shipyard operations have resulted in the contamination of sediments with metals, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and other chemicals.

View of Puget Sound Naval Shipyard Pier D
Source: EPA

Sinclair Inlet is a slender estuary that connects to the main part of Puget Sound through Rich Passage. With a maximum depth of 65 feet, Sinclair Inlet is 3.4 miles long and has a maximum width of 1.4 miles. The wind-generated waves in Sinclair Inlet range from 0.5 to 2.5 feet in height with weak tidal currents producing maximum water velocities of 0.2 to 0.3 knots. Typically, the water movement is slow enough to allow fine-grained sediments to settle out of suspension and deposit within the inlet. As Washington State Shoreline of Statewide Significance, Sinclair Inlet is classified as a Class A water body, indicating that it is considered fishable and swimmable. Substrate consists of a 2- to 4-foot-thick layer of soft, black silt and fine sand (mud) overlying a more dense, gray silty sand. Proposed dredge depth ranged between 4 and 13 feet below mudline with an average depth of 9.3 feet (ProTech, 1994).

3 Site Investigation

Under the Model Toxics Control Act (MTCA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Navy is conducting a Remedial Investigation/Feasibility Study (RI/FS) on Operable Unit B, which includes the sediments at Pier D. Due to past fill practices, the site is classified as a hazardous waste site under the MTCA. Ecology's Toxic Cleanup Program and the EPA Region 10 Federal Facilities Superfund Section were the regulatory agencies during the design of the RI/FS. A CERCLA ROD for Operable Unit B has not been issued at this time. Other RODs for the Puget Sound Naval Shipyard Complex include EPA/541/R-97/046 for Operable Unit 1 and EPA/541/R-97/047 for Operable Unit 4. The Final Supplemental Environmental Impact Statement (FSEIS) for the Pier D dredging was prepared with coordination of the EPA Region 10, the ACOE Seattle District, Ecology, the City of Bremerton, Washington and the Suquamish Tribe (August 1994).

Contaminants of Concern. Sediment samples tested according to 1994 Puget Sound Dredged Disposal Analysis (PSDDA) criteria revealed elevated concentrations of metals, PAHs, PCBs, bis(2-ethylhexyl)phthalate, and DDT. The depth and extent of contamination at the Puget Sound Naval Shipyard extend beyond the dredging prism at Pier D. The contaminated area, termed Operable Unit B, encompasses a portion of the industrial core at the Puget Sound Naval Shipyard and the offshore sediments. It also contains the Pier D dredging footprint.

4 Target Goals and Project Objectives

The project goals were to maintain and expand navigational water depths. The scope of dredging was to enlarge the mooring basins on each side of Pier D to accommodate the Navy's largest vessels. The goal was to provide safe navigation depths and mooring for ACOE-type transport ships on the east and west sides of Pier D and for an aircraft carrier on the west side of Pier D. Water depths around Pier D were to be increased from -42 feet mean low-low water (MLLW) to -44.4 feet MLLW at the ACOE-6 berthing and to -49.4 feet MLLW at the deep-draft berth.

5 Project Design

The FSEIS anticipated dredging a total of 105,000 cubic yards of material, which included 1-foot of over-depth dredging. The materials to be dredged were mainly fine-grained silts and sands with more than 70 percent fine material. The sediments were similar to other sediments dredged from quiescent Puget Sound bays and harbors.

The dredging prism was divided into Dredged Material Management Units (DMMUs), following PSDDA guidelines, as shown in Figure 3.

The DMMUs were broken down into surface (a layer of the top 4 feet) and subsurface (a layer of material below 4 feet). The dredging footprint contained 63,100 cubic yards in the surface DMMUs and 42,000 cubic yards in the subsurface DMMUs. Based on chemical and biological tests, the PSDDA agencies (the ACOE EPA, Ecology, and Washington State Department of Natural Resources) designated each DMMU as either suitable or unsuitable for open-water disposal.

Of the 17 surface DMMUs, only six were suitable for in-water disposal: S1, S10, S11, S13, S15 and S17, with the rest of the surface DMMUs designated for upland disposal. Of the five subsurface DMMUs, three (C1, C3 and C4) were suitable for in-water disposal with C2 and C5 sent to upland disposal.

The FSEIS expected 51,700 cubic yards of material to be clean and approved for in-water disposal at the PSDDA Elliott Bay site near Seattle. Since the FSEIS considered the remaining 53,400 cubic yards as contaminated, the material was unsuitable for open-water disposal and designated for confined upland disposal. Where possible, the dredging of contaminated materials occurred first in an attempt to prevent contamination of clean material.

Operational Constraints. None specified.

Permits/Restrictions. Permits for this project included: the ACOE Section 10/404 and Washington Department of Fisheries Hydraulic Project Approval for dredging, an Environmental Impact Study for the EPA, and a Water Quality Certification from Ecology (Seattle District; Ecology, 1994).

Restrictions on dredging operations included limiting dredging to daylight hours and halting in-water disposal during periods of Treaty Indian fishing at the disposal site. In addition, booms were to be placed around the dredging area to contain oil or other floating material due to the dredging.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Dredging operations began on the east side of Pier D from October to mid-December, 1994. The west side of Pier D was dredged from late December 1994 through mid-March 1995. The dredging schedule proposed a five-day work week with a single work shift per day. RCI Environmental, Inc. performed the dredging operations.

Equipment. For both the upland and open-water disposal methods, dredging was performed using a 6.5-cubic-yard flat rehandler clamshell bucket mounted on a derrick barge. A dump scow and tug were used to deposit the clean dredge spoils at the in-water Elliott Bay site while flat-deck barges transported the contaminated materials from the dredge to the upland holding area.

Total Volume Removed and Production Rates. The predicted production rates were 1,200 cubic yards per shift for contaminated materials and 2,000 cubic yards per day for clean materials (U.S. Navy, 1994).

Site-specific Difficulties. None specified.

6.2 Dewatering and Water Treatment Operations

Partial dewatering of the contaminated dredge materials occurred during a series of steps. Initially, water at the surface of the loaded barge was decanted back into Sinclair Inlet, provided water quality requirements were met. In addition, 21,000-gallon storage tanks were proposed to provide additional settling of suspended sediments prior to discharging the runoff from the transfer site into Sinclair Inlet. Surface water that collected in the back of the trucks en-route to the landfill was decanted into the landfill's leachate collection and treatment system.

Additionally, if the dredged material did not meet the landfill's final disposal requirements for water content, additional dewatering was proposed by processing the spoils through a pug mill mixer and adding pozzolan-portland cement. During the hydration of the portland cement, water is removed, and the final product is a mixture of sediment and concrete.

6.3 Storage and Disposal

After dredging, the contaminated materials were transported by flat scow to the upland holding area. At the holding area, a clamshell bucket moved the dredged material from the barge to the paved transfer site. Rubber-tired loaders managed the dredged material stockpile and loaded the trucks for transport to the landfill.

After the contaminated sediments were removed, adjacent clean sediments were dredged and placed on a dump scow for transport to the in-water PSDDA 415-acre disposal site located in Elliott Bay Seattle, WA. A bottom-dump barge was used to transport the clean material to the Elliott Bay disposal site, and the barge was inside the 600-foot radius dump target zone, the hull of the barge was opened, and the clean material released into the water.

Contaminated material unsuitable for open-water disposal was (53,400 cubic yards) designated for confined upland disposal. The contaminated dredged material was offloaded to trucks at an onshore staging area and disposed at an approved upland sediment disposal area. Ten miles south of the site on State Highway 304, the Olympic View (Kitsap County) Sanitary Landfill was the designated disposal site with transportation of the material accomplished by using trucks with trailers. If the local landfill was eliminated as an option, railcar containers were proposed for distant upland disposal at sites including commercial landfills at Roosevelt, Washington and Arlington, Oregon, about 280 miles from Puget Sound Naval Shipyard.

7 Environmental Monitoring Program

7.1 Baseline

Physical. Prior to dredging, the dredging prism was surveyed to establish volumes of material to be removed.

Chemical. Following PSDDA guidelines, chemical analyses were performed on the sediment core samples taken from each DMMU in 1993. Chemicals detected at levels above the 1994 PSDDA screening levels included the following for various DMMUs: antimony (Sb), cadmium (Cd), copper (Cu), lead (Pb), mercury (Hg), zinc (Zn), DDT, PCB, fluoranthene, hexachlorobutdiene (HCB), indeno(1,2,3,cd)pyrene (IP), pyrene (P), total HPAH (TP), and bis(2-ethylhexyl)phthalate (BP). Not all of the contaminants were present in each of the DMMUs slated for upland disposal. In addition, the shipyard is still operating and serves as a possible ongoing source of contamination.

The first round of sediment sampling occurred in 1991 with the samples delineated using the 1992 PSDDA suitability criteria. In response to the amount of time that had elapsed during the planning stage, additional sediment samples were gathered in 1993 to reflect the current bottom conditions and submitted in January 1994. The PSDDA suitability criteria were updated in April 1994 and used to characterize the second round of sediment samples for the shipyard.

Biological. Due to concerns about timing and exceeding bioassay holding times, the Navy chose to perform bioassay tests concurrently with the chemical analyses. Tests performed for the 22 DMMUs included amphipod, sediment larval, Neanthes biomass, saline microtox, and bioaccumulation testing. Mortality and growth results had 50 percent failure of PSDDA screening criteria.

Based on the results of the chemical and biological testing, only six of the 17 surface DMMUs were suitable for in-water disposal, with the rest of the surface DMMUs designated for upland disposal.

7.2 Implementation During Dredging

Physical. A daily project log was maintained during the dredging that included the dredging location, volumes and disposal in addition to noting any incidences of state water quality standards being exceeded.

Chemical. Daily water quality testing of the discharge from the transfer site was performed during the first week of operations to measure turbidity, dissolved oxygen and pH.

Biological. No biological testing was performed during dredging.

7.3 Post

Physical. Following the completion of each DMMU, a final record survey of the DMMU was conducted to ensure that the specifications for the proposed footprint were achieved.

Chemical. Post-dredging samples were collected to determine the environmental effects of dredging as a condition of the Ecology Water Quality Certification. In accordance with the Puget Sound Estuary Program protocols, Beak Consultants, Inc. collected sediment samples at 10 stations, five on each side of the pier, located along the center of the dredging prism at 200-foot intervals. Beak Consultants sampled the east side of the pier on December 17, 1994 and the west side on March 7, 1995, gathering the samples within one week after completion of dredging. Surface sediment samples were collected from the top 2 centimeters and analyzed for the Washington State Sediment Management Standards (SMS) suite of chemicals and the PSDDA chemicals of concern. The SMS chemical analysis related the concentrations to two chemical criteria: the lower Sediment Quality Standards (SQS), the chemical concentration that allows for minor adverse biological effects, and the more stringent Cleanup Screening Level (CSL) (Beak, 1995).

Of the 10 stations, six stations had metal concentrations above the CSL, and one station exceeded the SQS. Of the 10 stations, three stations had PCB concentrations above the CSL and six stations exceeded the SQS.

In general, the concentrations of chemicals in the surface sediments were similar between the pre- and post-dredging sampling with some metal concentrations measured at slightly lower concentrations after dredging. Since the sediment samples represented only the top 2 centimeters of sediment, it would appear that resuspension during dredging or natural sediment transport mechanisms were responsible for covering the dredging prism with material from the surrounding operable unit still requiring sediment remediation.

Biological. Using SMS requirements, the Navy could elect to perform bioassay testing concurrently with the chemical analyses.

7.4 Long Term

Long-term sampling and monitoring requirements were included in the permits, recognizing the possibility that they could be superceded by the decisions included in the CERCLA ROD for Operable Unit B.

One year after the initial sampling, the same 10 locations would be resampled with testing performed on the top 2 centimeters of each sample. The results of the chemical analyses would determine if a need existed for additional sampling or testing. The sampling would occur on an annual basis, unless superceded by Ecology approving a sampling and testing plan under CERCLA and/or MTCA. The need for biological sampling, such as bioassays or benthic abundance, depended upon the results of the chemical analyses of the sediment samples.

Table 1 Summary of Monitoring Results

Testing Parameter	PCB Concentration in mg/kg (ppm)			
	Baseline 1993	**Progress 1994**	**Post 1994/1995**	**Long Term**
Bathymetry	Yes	Unknown	Achieved design depth	
Sediment Samples	4.9 PCBs	NC	(N = 10) 0 to 2 cm depth max = 104 mg/kg overall, similar to baseline conditions Avg = 32 mg/kg	
Sediment Toxicity	50% failure of PSDDA criteria; exceedances of screening criteria	NC	NC	
Bioaccumulation Potential	AF = 1.9 Significant uptake of Aroclor 1254 in clams compared to reference [1]	NC	NC	
Water Quality	NC	Turbidity D.O. pH	NC	

Note:

[1] Concentration below FDA guideline of 2.0 mg/kg for PCBs, but designated as high risk from reference.

NA - Not available for review.

NC - Not collected.

8 Performance Evaluation

The dredging successfully enlarged the mooring basins on both sides of Pier D, enabling the shipyard to accommodate larger Navy vessels. The removal of contaminated sediments was a byproduct of the deepening with additional remediation necessary to address contamination still remaining in Operable Unit B.

9 Costs

Not available for review.

10 Project Contact

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11 References

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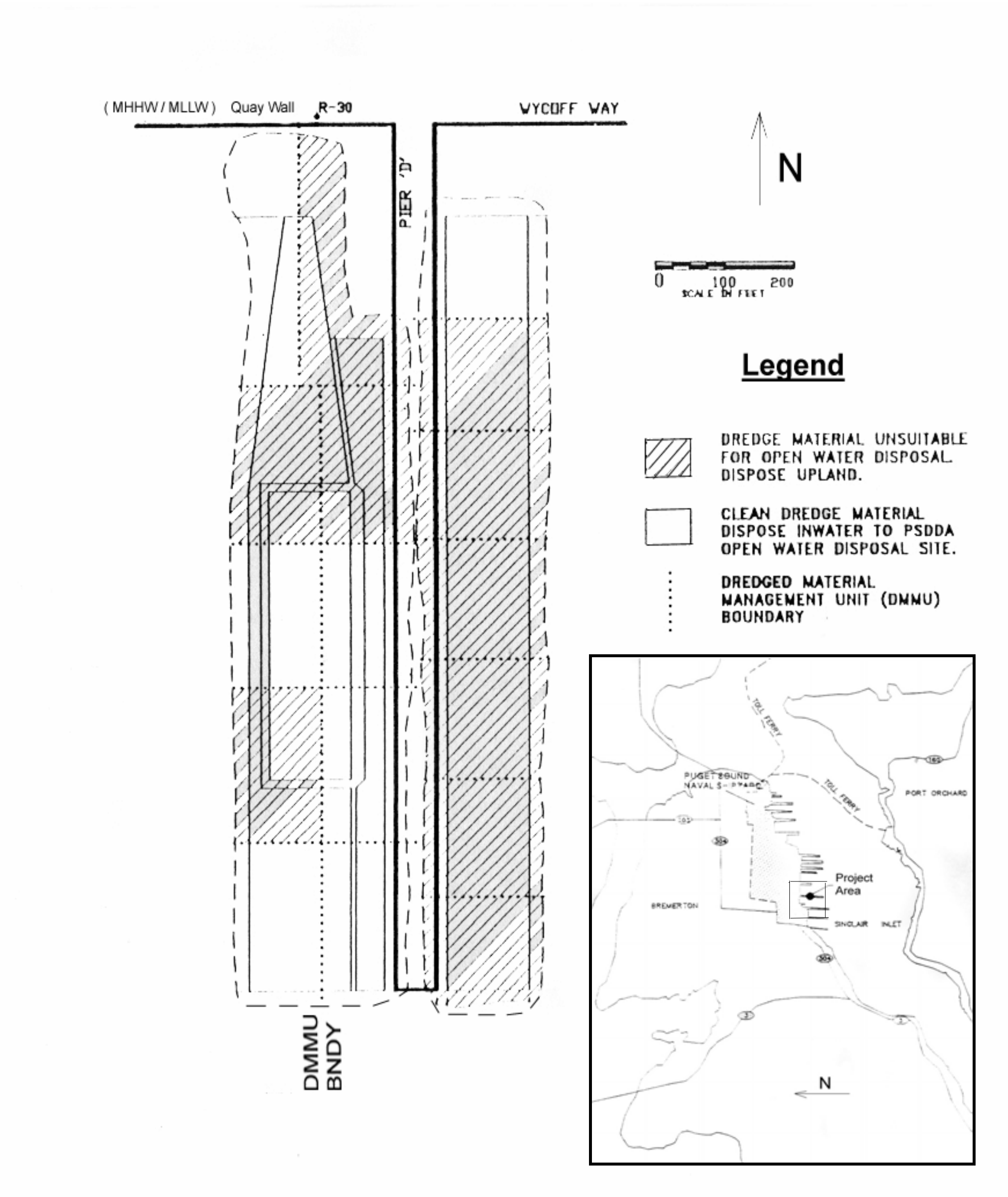
U.S. Navy, 1994. Naval Shipyard Puget Sound Pier D Dredging Final Supplemental Environmental Impact Statement: Puget Sound Naval Shipyard, Bremerton, Washington. August.

Figure 1 Remedial Dredge Plan - Puget Sound Naval Shipyard Pier D



Source: U.S. Navy, Naval Shipyard Puget Sound Pier D Dredging Final Supplemental Enviironmental Impact Statement, August 1994.

SHEBOYGAN RIVER AND HARBOR - SHEBOYGAN FALLS, WISCONSIN

1 Statement of the Problem

- Dredged 1989-1991
- PCBs
- 3,800 cubic yards
- $450 per cubic yard

The Sheboygan River and Harbor in Wisconsin were contaminated with polychlorinated biphenyls (PCBs) and metals from historical industrial sources (BBL, 1990). The maximum detected concentration was 4,500 ppm PCBs. The target objectives of the 1989–1991 Alternative Specific Remedial Investigation (ASRI) pilot study (pilot study) were to dredge 10 hotspot areas within the upper river, and to analyze aspects of contaminants and remediation techniques for future cleanup and treatment alternatives. The unofficial cleanup goal was the removal of sediments contaminated with greater than 686 ppm PCBs (BBL, 1995). The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Sheboygan River and Harbor cleanup site is located in the cities of Sheboygan and Sheboygan Falls, Wisconsin. Flowing from west to east, the Sheboygan River discharges into Sheboygan Harbor, which in turn discharges into Lake Michigan. The site is composed of approximately 13 miles of riverine and harbor sediments, on the western shore of Lake Michigan. For cleanup purposes, the river and harbor were divided into three sections, the Upper River (this study), the Middle River, and the Lower River and Inner/ Outer Harbor areas.

Sheboygan Falls
Source: G. R. Frysinger

The Upper River section is a 3.2-mile stretch, located 7 miles upriver from Sheboygan Harbor and approximately 0.5 miles downstream of the Sheboygan Falls Dam. The riverbed is composed primarily of rocks and cobbles, and sand with scattered pockets of soft sediment. Soft sediment is estimated to comprise 15 percent of the sediment surface area and hard sediment the remainder of the area. The average width is 120 feet and the average water depth is 2 to 4 feet. This section was chosen for the pilot dredging and capping project and is included in the selected remedy of the U.S. EPA Record of Decision released in May 2000.

The Middle River section runs approximately 7 miles upriver from Sheboygan Harbor. It is a rapid flow section of the river, with bottom composed of rocks, gravel, and sand with intermittent soft sediment deposits estimated at 15 percent of the sediment surface area. The average width is 100 feet and the average depth is 0.5 to 2 feet. This section was not chosen for dredging or capping activities in the pilot study but is included in the selected remedy of the U.S. EPA Record of Decision.

The Lower River and Inner/Outer Harbor section is a 2- to 3-mile stretch from the mouth of the Sheboygan River out into the Harbor. This area has deeper, slower moving water than the other river areas, and has more continuous sedimentation, especially within the Harbor area. Average water depths in the river and Inner Harbor are 6 to 12 feet, deepening to 23 feet in the Outer Harbor area. The Inner and Outer Harbor have been designated as a navigation channel. This section was also not chosen for dredging or capping during the pilot study, but is included in the selected remedy of the U.S. EPA Record of Decision.

3 Site Investigation

Historically, Sheboygan River and Harbor were used for recreational and commercial activities, including boating, fishing, and shipping (BBL, 1995). The Wisconsin Department of Natural Resources (WDNR) also used the area for a salmonid stocking program (BBL, 1995). In 1956, the U.S. Army Corps of Engineers (ACOE) began dredging and monitoring the harbor for a navigational channel. However, the dredging was halted in the 1970s when a series of fish and sediment sampling events identified high concentrations of metals in the harbor. In the 1970s, a dike removal project was implemented at the Tecumseh property due to WDNR's discovery of PCBs in fish in the 1970s. In 1986, Sheboygan River and Harbor was added to the Superfund National Priorities List (NPL) (GE/AEM/BBL, 1986). No ROD has been issued to date, but the lead agency is the U.S. Environmental Protection Agency (EPA).

A remedial investigation/feasibility study (RI/FS) was conducted in 1987–1988 by BBL, on behalf of the only participating PRP, Tecumseh Corp. A baseline investigation revealed that sediment contamination existed in the Upper River, the Lower River and Inner Harbor, and in floodplains off the river. In this study, they identified metals and PCBs as the primary contaminants of concern (BBL, 1990).

Contaminants of Concern. Contaminants of concern included PCBs and metals, with the largest PCB mass located in the Lower River and Harbor; however, the largest concentrations are located in the Upper River. In baseline data, concentrations of PCB contamination ranged from less than 0.065 ppm to 4,500 ppm. Four PRPs were named from multiple sources, with Tecumseh Products Company's die casting facility being the most likely source for the Upper River PCB contamination. In 1988, a site-specific endangerment assessment was performed to evaluate long-term effects of contamination to human health and the environment (BBL, 1990). From this study, three effects were noted:

- Long-term dermal exposure to PCB contaminated sediments,
- Long-term ingestion to certain fish species over FDA limit (2 ppm), and
- Long-term ingestion of waterfowl in concentrations over 4 ppm.

Based on the observed exposures and effects, EPA decreed removal of contaminated sediments in the Upper River for the ASRI pilot study. Following the preliminary dredging and capping in 1989 through 1991 (discussed here), a full feasibility study (FS) was submitted in 1998.

Thirty fish advisories were in effect over the course of the pilot study. Fish under advisory included bass, carp, suckers, catfish, crappie, pike, salmon, trout, and walleye. All resident fish were designated as "do not eat" to the general population.

In May 2000, a Record of Decision was released by the EPA outlining specifications for the remedial actions of the Upper River, Middle River, Lower River, Inner Harbor, floodplain soils, and potential groundwater contamination at the Tecumseh property.

4 Target Goals and Project Objectives

The objectives of the ASRI pilot study were more general with no stated cleanup targets. They included further delineation of contaminated sediments, transport of contaminants (PCBs and metals), investigation of applicable remedial technologies, and removal of hotspot sediments from the Upper River, as requested by EPA. This study also aimed at monitoring in-river construction activity, construction and testing of a pilot confined treatment facility (CTF), conducting biodegradation studies, and conducting bench-scale treatability studies (BBL, 1995).

However, the physical target for removal during the pilot study was mass removal of hotspot sediments containing greater than 686 ppm PCB concentrations. This number was based upon dermal contact risk. The estimated target volume for removal was approximately 2,600 cubic yards of sediment. Objectives of dredging included complying with EPA's request for sediment removal, evaluation of removal technique effectiveness, and evaluation of short- and long-term remedial alternatives. No long-term remedial objectives were specified, but could be implied as reduced dermal contact risk.

The EPA's Record of Decision remedial objective is to achieve a soft sediment PCB-contaminated surface weighted average concentration (SWAC) of 0.5 ppm in each section of the river: the Upper River, Middle River, and Lower River and Inner Harbor. Over time, the entire river will reach an average PCB sediment concentration of 0.5 ppm and fish consumption advisories will be phased out.

The Upper River remedy requires a re-characterization and removing approximately 20,774 cubic yards of PCB-contaminated sediment to achieve a soft sediment surface weighted average concentration (SWAC) of 0.5 ppm. The areas capped in the ASRI/removal action activities will be removed and sediment samples will be taken once every five years after dredging to document natural processes.

The Middle River sediments shall be re-characterized because high flow events may have significantly disturbed and redistributed soft sediment. Sediment will be removed, if necessary, to achieve a soft sediment SWAC of 0.5 ppm in the Middle River. Data from the FS indicate that an estimated 12,500 cubic yards of sediment must be removed. PCB contaminated soft sediment shall be removed if its PCB concentrations exceed 26 ppm.

Despite limited 1997 NOAA data collected from the Lower River indicating PCB concentrations in surface sediment have dropped off significantly from the time sediment was obtained from the RI/FS, high flow events and boating traffic likely changed the profile of these soft sediments from year to year. Therefore, the Lower River sediments shall also be re-characterized to determine if removal of contaminated sediments is warranted. From the RI/FS report, EPA estimates that 127,000 cubic yards of sediment must be removed. The top two feet of the sediment surface shall be removed from areas of the Lower River with contaminated sediment concentrations higher than 26 ppm.

The Record of Decision requires the Inner Harbor to be characterized prior to any dredging, and that a bathymetry analysis be done to identify contaminated areas susceptible to scour. These areas as well as areas of PCB-contaminated sediment exceeding 26 ppm will be removed from the Inner Harbor and backfilled/covered with clean sediment. Annual bathymetric surveys of the Lower River and Inner Harbor will be conducted to assess sediment profile changes and determine if buried PCB-contaminated sediment is being exposed and vulnerable to scour and boat effects. EPA estimates that 53,000 cubic yards of sediment will need to be removed to achieve a SWAC of 0.5 ppm in the Lower River and Inner Harbor surface sediments.

The Record of Decision also requires the removal of floodplain soil containing PCB concentrations greater than 10 ppm and the investigation and mitigation of potential groundwater contamination and possible continuing sources at the Tecumseh plant.

5 Project Design

Hydrodynamic modeling was performed prior to implementing the study to estimate the possible extent and role of natural processes in the burial of sediments within the Inner Harbor. Based upon baseline probing and PCB data from sediment cores in all sections of the project cleanup site, areas targeted for sediment removal included hotspots in the Upper River area. Components of the hotspot removal (pilot study) included dredging of individual 18 hotspots in the Upper River section (Figure 1). Each hotspot was individually curtained off with a silt curtain barrier, and dredged materials were disposed of in a CTF.

Other components of the study included extent and transport of contaminants, determination of the degree and rate of dechlorination of contaminants in CTFs versus *in-situ* burial of contaminated sediments, and capping/armoring of undredged and dredged sediments. Physical and chemical observations recorded during the pilot study would help design the overall remedial action plan. Observation components included volume and dredge techniques, contaminant transport and removal, and various benchmark treatability studies such as sediment dewatering, sediment/ash leachability, armoring, PCB remedial technologies, sediment settleability, and geotechnical tests on river and harbor sediments.

In-situ capping was also completed as part of the pilot study. As a contingency for exceeding chemical criteria and as a study for technical remediation alternatives, nine discrete sections of the site totaling 1,200 square yards were capped/armored to prevent further contaminant releases and support further degradation of PCB contaminated sediment (BBL, 1995). Four hotspot deposits were capped after exceeding chemical criteria in post-dredge monitoring (after four sweeps by dredge equipment). Five additional deposits were capped as part of a non-dredged technical study. Each pilot cap included: a base layer of 150-mil geotextile fabric, a 1-foot-thick layer of coarse material to settle the fabric, a second layer of geotextile, gabions around the corners for anchoring, and additional coarse material to fill in the voids and gaps (minimum of 1 foot thick).

Limitations and Permits. A winter shutdown, dependent on weather conditions, limited operations and typically lasted from November or December to April each year. Permit requirements are unknown.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The pilot study and remediation was conducted from November 1989 to November 1991. After dredging has been completed as ordered by the Record of Decision, a 30 year monitoring program will be implemented to monitor sediment and fish tissue concentrations in the Upper River, Middle River, and Lower River to ensure that over time the entire river will reach an average PCB sediment concentration of 0.5 ppm or less, and that over time fish consumption advisories will be phased out.

Bucket Dredge
Source:

Equipment. Dredging equipment used during sediment removal of areas targeted in the pilot study included sealed clamshell buckets and land-based backhoes. Mechanical dredging equipment was deployed for wet excavation from barges or along the shoreline of hotspot areas. Backhoes were used in areas inaccessible to the clamshell bucket. Double-layer silt curtains, composed of geomembrane lined with a geotextile, were hung from booms and anchored to the river bottom.

Total Volume Removed. The total *in-situ* volume removed in the Upper River during the pilot study and an additional 1991 EPA Removal Action was 3,800 cubic yards (GE/AEM/BBL, 1986). This volume of dredge material exceeded the original estimated volume by an additional 1,200 cubic yards. Some possibilities for this overestimate included sediment "bulking" during removal, excess removal of the buffer zone to obtain an acceptable PCB concentration, or inadequate site assessment.

Site-specific Difficulties. Although the pilot study dredging was completed within the proposed two-year time frame, a few site-specific difficulties reduced productivity at the site. Freezing weather and ice buildup lowered production rates and increased production costs during December of 1989. Shallow water created access difficulties for barge passage. High water and strong currents caused overtopping of silt curtains and reduced their effectiveness. Site access was sometimes limited along shorelines due to private land ownership issues, creating additional barge haul distances and times.

6.2 Dewatering and Water Treatment Operations

Water treatment was required in the CTF, but details were not available for review. Any dredged sediment as ordered by the Record of Decision will be dewatered and stabilized.

6.3 Storage and Disposal

All dredged materials were disposed of in a CTF and storage tanks located on Tecumseh property. Once the capacity of the CTF had been reached (late 1990), sediments were then disposed of in a contained holding tank, a Sediment Management Facility (SMF), also located on Tecumseh property (EPA, 1998). The Record of Decision requires any dredged sediment to be dewatered, stabilized, and disposed of in either a WDNR-approved in-state landfill or out-of-state hazardous waste landfill, depending on PCB concentration.

7 Environmental Monitoring Program

The monitoring program included bathymetry, evaluation of physical conditions, sediment cores, caged and netted fish studies, and water column monitoring during dredging (Table 1).

7.1 Baseline

Physical. Prior to any dredging activities at the Sheboygan site, sediment probing and sediment coring were performed to determine the vertical and horizontal extent of PCBs in the sediment. Sediment probing involved probing river sediments with a rod at regular intervals along the banks and across the mid-section of the river. Soft areas that could be penetrated by the rod were considered soft sediments. These areas were noted on an areal photograph, assigned a reference number, and labeled as to their length, width, average sediment depth, average water depth, and any other physical observations.

Chemical. Fifty-three sediment cores were collected in 1989 by boat or by wading in the Upper River. Cores were driven until refusal with a steel core driver, using reasonable human force. A vacuum pump was used to increase core retention in the coring device. Cores were then segmented into 6-inch sections for the top foot, and 1-foot sections for the remainder of the core, and then analyzed for PCB concentrations. Using both the probing and the coring results, 46 potential areas of concern were identified in the 3.2-mile stretch of the Upper River. Thirteen areas were above the 686 ppm project target for PCBs and were slated for dredging and capping at EPA's request. Five additional areas were approved for capping only (BBL, 1995).

Sheboygan Harbor
Source: SAIC

Water quality monitoring was conducted prior to dredging to establish baseline conditions.

Biological. Caged fish studies were conducted in 1989, 1990, 1992, and 1994. However, due to laboratory error, there are no acceptable baseline results.

In addition to the caged fish studies, netted fish monitoring was conducted in 1989 on specific species of fish to provide information on human health risks posed by PCB contamination. To determine baseline conditions, 80 salmon, 25 steelhead, nine smallmouth bass, and 25 carp were collected for tissue PCB analysis. Adult fish were caught using electrofishing techniques, in accordance with the WDNR Field Procedures Manual.

7.2 Implementation During Dredging

Physical. No bathymetry data were collected during the progress monitoring period of the pilot study. Surface water quality was monitored as described below.

Chemical. Daily and weekly water column monitoring was conducted during the course of the dredging and capping. Daily water column samples were collected and analyzed for total suspended solids (TSS) and turbidity. A correlation between TSS and turbidity was found during 1989 activity and, as a result, only turbidity was monitored in 1990 and 1991. Water samples were taken within the silt curtain and downstream and upstream of the work areas to assess the effectiveness of the silt curtains. Additionally, weekly water samples were collected outside and downstream of silt curtains to monitor PCB transport during dredging. Results indicated that the silt curtains contained substantial amounts of suspended material. Weekly PCB results showed some transport of PCBs during activities at the sites. Additionally, higher PCBs were noted in dredge areas than in the capping-only areas.

Biological. Caged fish studies were conducted in 1989 and 1990. During both years, cages containing approximately 250 juvenile fathead minnows were suspended at six locations in the Upper River area. Cages were held in place by anchor and floats. Fish were analyzed at seven-day, 21-day, 42-day, and 56-day intervals. Results indicated that fish caged downstream of the Upper River site had higher PCB values than fish caged upstream above the Tecumseh facility. The results also showed higher PCB values in the 1989 study than in the 1990 study (BBL, 1995).

Additional adult fish monitoring was done in 1990, following the same procedures as the previous year. No significant differences were observed between the Sheboygan River fish.

7.3 Post

Physical. No physical data were collected during the post-monitoring period of the pilot study.

Chemical. Post-dredging water column monitoring was performed within the curtained area, following completion of dredging and capping. Exceedances of PCBs were found within the curtained areas, and were higher in areas of dredging and capping than in areas of capping only (BBL, 1995).

Before the silt curtains were removed, surface sediment samples (0 to 3 inches) were collected from each hotspot and at 30-foot intervals along the length of the curtained area. A minimum of two samples were taken from each hotspot area. Samples were composited and analyzed for PCBs. At the end of the pilot study, only four areas had exceeded the goal of greater than 686 ppm PCBs, and it was agreed by EPA that these areas would be capped along with the five previously determined capping areas. In the other 14 dredged areas, PCB values ranged from 0.3 to 38.7 ppm and cleanup standards were reached after dredging. In post-monitoring, water column data and fish monitoring studies showed a decrease in PCBs at the Upper River area of Sheboygan River and Harbor site.

Biological. Post-dredging caged fish studies were conducted in 1991, 1992, and another was done in 1994 under the Interim Monitoring Program (IMP). The same methodology was followed as in the original study. Post-monitoring results showed a decrease in fish tissue PCB concentrations in subsequent years following dredging and capping (BBL, 1995).

Adult fish monitoring of ambient species was done in 1991, 1992, and 1993 (carp only), following the same procedures as the previous years. The steelhead showed no significant difference compared to control fish. The salmon had lower or equal concentrations of PCBs as the control fish. The bass and carp showed no overall trends (BBL, 1995).

7.4 Long Term

Long-term monitoring of the pilot study results will be rolled into the proposed remediation plan for final cleanup at the entire site. An Interim Monitoring Program (IMP) was set up to monitor post-dredging caged fish PCB values from 1994 through 1996; however, only the 1994 results are available, showing a general decreasing trend of PCB values over time.

Table 1 Summary of Monitoring Results

Testing Parameters	Monitoring Periods (ppm PCBs)						
	Baseline 1989	Progress 1989–1991	Post 1991	Post 1992	Long Term 1994	Long Term 1996	Long Term 1998
Sediment Cores	0.065 to 4,500 (N = 53)	None	0.3 to 38.7 (dredge only) 7.7 to 295 (designated for capping)	None	None	—	ND to 840 (in dredge prism) ND to 0.9 (outside dredge prism)
Caged Fish [1]	None (rejected data)	ND to 270 [3]	ND to 283	ND to 91	ND to 109	4.4 mg/kg (N = 18) [4]	11.5 mg/kg (N = 24) [4]
Netted Adult Fish [2]	NA	NA (no significant differences from control)	NA (no significant differences from control)	0.4 to 200 (no significant differences from control)	1993 carp only; no trends		
Water Column Monitoring (ppb)	None	0 to 0.47 (outside silt curtain)	0.5 to 8.3 (inside silt curtain)	ND	None		

Notes:

1 Juvenile fathead minnows at four duration intervals.
2 Netted fish included: salmon, steelhead, smallmouth bass, and carp by electrofishing.
3 Downstream fish had higher concentrations.
4 Rochester Park white sucker resident fish.

8 Performance Evaluation

8.1 Meet Target Objectives

The only specific cleanup target criteria specified during the pilot study at Sheboygan River and Harbor was the removal of three isolated hotspot areas (greater than 686 ppm) by EPA Administrative Order by Consent for Removal Action. The scope of the project was expanded to include a 15 additional hotspot areas (T = 18), each surrounded by clean sediments. The dredging required between two and four sweeps by the removal equipment to remove all delineated sediment, the end result was the total mass removal of these areas. Although no long-term remedial action objectives were explicitly stated for this pilot study, the Remedial Action Objective (RAO) can be inferred as: 1) reduced dermal contact risk, and 2) protection of human health by reducing PCB concentrations in fish.

Short-term Target Goals. Based on the target goals of the pilot study, the Sheboygan River dredging project met the chemical criteria and mass removal target goal in 14 of the 18 hotspot areas (80 percent success). The four areas exceeding the target criteria were capped and post-verification sediment sampling collected after dredge and cap activities met chemical criteria (100 percent isolation of chemical contaminants in dredged areas). We did not verify why the four remaining areas could not meet the target criteria after several dredging attempts; however, site access and shallow water depths are the most likely reasons based on site conditions.

This project was successful in reducing PCBs in hotspot areas, resulting in an 80 percent success of 18 hotspot areas. However, we did not verify why four hotspot areas could not meet target criteria after several dredging attempts. This was were possibly attributable to debris and access restrictions.

Long-term remedial action objectives were not explicitly stated, but can be inferred as: 1) reduced dermal contact risk, and 2) protection of human health by reducing PCB bioaccumulation in fish. Based on post-remediation surface sediment concentrations, dermal contact risk has been reduced. The fish tissue data are inconclusive; however, a decreasing trend of PCB concentrations in caged fish is observed in post-dredge samples. More long-term monitoring data are required to clearly define these preliminary trends and evaluate long-term RAOs.

Long-term Remedial Objectives. Based on the post-remediation surface sediment concentrations, dermal contact risk was successfully reduced. The fish tissue data are inconclusive; however, a decreasing trend of PCB concentrations in caged fish is observed in post-dredge samples. No significant differences were observed in resident fish between baseline and post-dredge sampling events. More long-term monitoring data are required to clearly define these preliminary trends and to evaluate long-term RAOs.

According to a 1999 External Source Evaluation (BBL, 1999), it is unlikely that long-term protection of human health and the environmental will be achieved until adequate source control is in place. This study was implemented after elevated PCB fish tissue concentrations were measured in resident white sucker fish collected from Rochester Park in 1996 and 1998. Results of the study (BBL, 1999) stated:

> "A review of chromatograms for the various soil samples (collected from the Tecumseh property) indicate a PCB compositional pattern similar to that of the unweathered pattern observed in the 1998 white suckers. This evidence suggests that

> the plant site is acting as the external PCB source to the River, and likely is the cause of the recent increase of PCBs and change in the PCB pattern observed in the resident fish."
>
> "Based on these results, the Tecumseh facility contains sufficient PCB concentrations and plausible migration pathways to have caused the noted increase in the 1998 resident fish PCB tissue concentrations. In addition, the PCB chromatogram pattern found in the facility soils, as well as the nearshore sediments, all are similar to those in the 1998 resident fish in Rochester Park (unweathered pattern). Thus, it may be concluded that the Tecumseh facility is the major external source of PCB to the River."

8.2 Design Components

Several dredging technologies were considered. Design engineers selected mechanical dredging to limit carriage water, avoid pipeline logistics and avoid wastewater expenses. A backhoe was used in shallow selected areas; however, the clamshell equipment proved to be more efficient during dredging than the backhoe. This was due to higher amounts of sediment being disturbed and suspended while using the backhoe. It was also noted that deployment of silt curtains also caused suspension of contaminated sediments.

8.3 Lessons Learned

The pilot study and sediment removal plan were mainly used as an avenue to better assess future dredging techniques and remediation technologies for future site cleanup in Sheboygan River and Harbor. In all, a more thorough understanding of the site was gained. It was found that techniques for estimating contaminated sediment volumes (sediment probing and coring) were efficient; however, they underestimated actual volumes of material removed and were not considered accurate. Methods utilized in dredging were found to be versatile, relatively easy to mobilize, and did not require significant equipment for dewatering and water treatment. The study found that short-term effects on water quality could not be eliminated by use of silt curtains, however, they did assist in controlling movement of contaminants away from the dredge area.

9 Costs

The total cost of the design, construction, remediation, sampling, and monitoring of the Sheboygan River and Harbor pilot study was $7 million ($1,842/cy). The specific dredging cost was approximately $450 per cubic yard. This $450 per cubic yard cost included dredging and installation/removal of silt curtains, but did not include costs of transportation, stabilization, mobilization/demobilization, and disposal of removed materials (GE/AEM/BBL, 1986).

The EPA estimates that the total cost of the remedial action outlined in the Record of Decision is more than $47 million with additional expenses for operational and maintenance costs.

10 Project Contact

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Lead Agency: U.S. Environmental Protection Agency
Design Engineer/Contractor: BBL
Contractors: McMullen & Pitz, E&K Services (now Superior Services)

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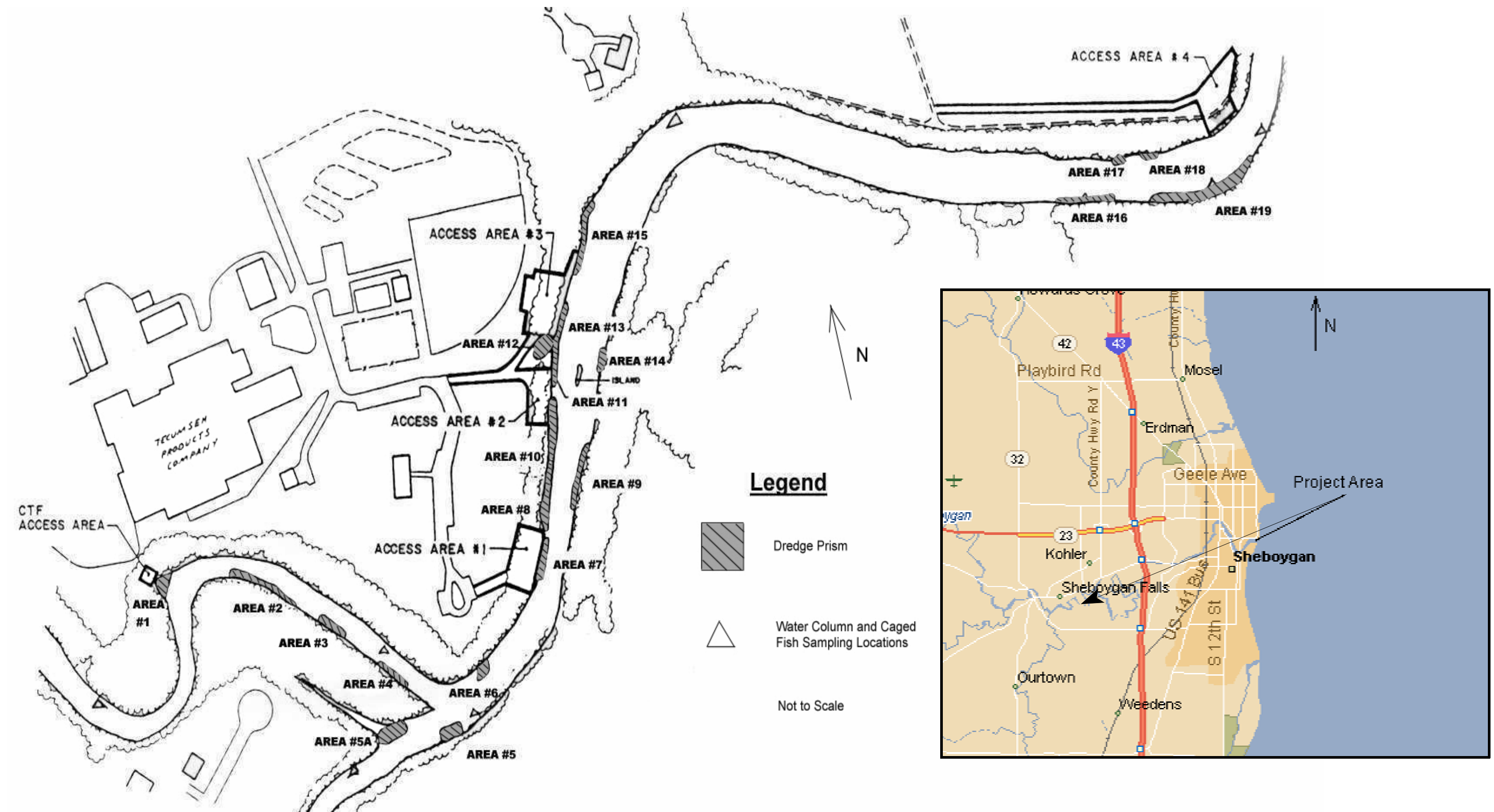
Figure 1   Remedial Dredge Plan - Sheboygan River and Harbor



Source: Blasland, B. L., Inc., 1995. Remedial Investigation Report

SITCUM WATERWAY COMMENCEMENT BAY/NEARSHORE TIDEFLAT - TACOMA, WASHINGTON

- Dredged 1993
- Metals and PAHs
- 127,500 cubic yards
- $6.20 per cubic yard

1 Statement of the Problem

The Sitcum Waterway Superfund Site was contaminated with metals and polynuclear aromatic hydrocarbons (PAHs) from off-loading container and bulk ore activities. The maximum concentrations measured in site samples were 89 ppm PAHs, 2,720 ppm zinc, and 241 ppm arsenic. The selected remedy was 100 percent mass removal of contaminated sediments with additional removal of clean material to maintain navigational depths (plus 2 feet overdredge). Sediment disposal occurred in a nearshore CDF in the adjacent Milwaukee Waterway. The remediation effort was a combined developmental and cleanup project, and dredging was completed in 1994. The lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10.

2 Site Description

The Sitcum Waterway is one of eight problem areas of the Commencement Bay Nearshore Tideflat (CB/NT) Superfund Site located in Tacoma, Washington (EPA Site ID# WAD980726368). The waterway is 3,000 feet long by 750 feet wide (52 acres) and operates as an active port terminal with adjacent industrial facilities. The waterway is a tidally-influenced, nearshore marine environment with an average water depth of 25 feet. The substrate consists primarily of silty sand and receives continued sediment deposition and shoaling from the nearby Puyallup River (EPA, 1999).

3 Site Investigation

EPA conducted a remedial investigation/feasibility study (RI/FS) of Commencement Bay, including the Sitcum Waterway, between 1984 and 1988. The Record of Decision (ROD) was issued in 1989. The ROD determined that natural recovery would not sufficiently reduce contaminated concentrations in the Sitcum Waterway within 10 years, so active sediment remediation was required. EPA suggested the Port of Tacoma combine the Sitcum Waterway contaminated sediment cleanup project with the navigational requirements and development objectives for expanding port facilities in the Milwaukee Waterway. The ROD set forth specific Sediment Quality Objectives (SQOs) for the Sitcum Waterway which served as performance and compliance criteria for the remediation efforts.

Sitcum Waterway (on the left)

Contaminants of Concern. The major contaminants of concern were metals and PAHs. The highest metal concentrations detected in site samples were 291 mg/kg arsenic, 2,580 mg/kg lead, 2,720 mg/kg zinc and 1.8 mg/kg mercury. The highest total high molecular weight polyaromatic hydrocarbon (HPAH) concentrations were measured in the upper 2 feet at 89,300 μg/kg (Hart Crowser, 1992).

4 Target Goals and Project Objectives

The primary cleanup goal was to dredge all contaminated sediment plus 2 feet of additional overdredge. The two additional feet was the navigational target elevation and ensured that all contaminated material would be removed. However, only 30 percent of the dredged material proved to be contaminated. Remediation success was determined by evaluating post-construction sediment chemical quality. No long-term remedial action objectives were specified, but were implied as maintaining navigational channel depths (Port of Tacoma, 1992).

5 Project Design

Pre-planning and Bid Documents. The remedial design activities included additional environmental, physical, chemical, and biological studies, physical characterizations by diver and video surveys, subsurface sediment sampling to refine the horizontal and vertical extent of contamination, bioassay toxicity tests, benthic infauna abundance enumeration, evaluation of contaminant mobility (elutriate, column leaching, and column settling tests), habitat assessment, and fate and transport modeling.

Aerial of Sitcum Waterway and Milwaukee Fill to the Left of Puyallup River
Source: CECW

Extensive physical and chemical laboratory testing was conducted simulating dredge and fill activities to predict the fate and transport of site chemicals. Computer models (EFQual and Plumes) were used to determine the dilution zone distances and appropriate compliance boundaries (330 feet). A dredging design consultant prepared and issued competitive bid specifications and bid documents. The selected contractor produced a pre-mobilization work plan outlining the dredging, CDF construction, and sediment disposal activities, including a quality control plan. The bid documents allowed contractor flexibility in selecting the most appropriate dredging equipment to be used for the project. Use of barriers such as silt curtains were also left up to the contractor. An independent quality assurance contractor was responsible for conducting environmental monitoring (Manson, 1993a and 1993b; Hart Crowser, 1993).

Water quality during dredging was predicted from modified elutriate tests and computer models (Plumes and EFQual) to determine the dilution requirements and dilution zone distances from the dredging zone and effluent discharge point (Spadaro *et al.*, 1993).

Summary of Remedial Action Plan. In 1992, EPA selected the nearshore fill option as the preferred remedial alternative. The selected remedy dredged and placed about 428,000 cubic yards of Sitcum Waterway sediment behind a berm in the abandoned Milwaukee Waterway via pipeline and diffuser. The Sitcum sediments were capped with clean sediments from the Blair Waterway. After a multi-year settling period, the fill was capped with asphalt and transformed into container storage space. Monitoring wells were constructed around the perimeter of the nearshore fill (and one in the berm) to verify groundwater quality. The remedy also included a 21-acre habitat mitigation area at the mouth of the Milwaukee Waterway using leftover sediment from the Blair Waterway (GE/AEM/BBL, 1999; Gilmor, 1992).

Limitations and Permits. Dredging operations ceased during the fish spawning window from March 25 through June 15.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial dredging activities operated from October 23, 1993 through September 1994 (excluding fish spawning window from March 25 through June 15, 1994). Operation schedule was six days per week, 24 hours per day, and eight hours per shift.

Equipment. A variety of dredging equipment was used depending upon site conditions, volume, and access. A small 8-inch hydraulic dredge (estimated production of 480 cubic yards per day) was used for underpiers and a large 26-inch cutterhead suction dredge with variable-speed engines (estimated production rate of 15,200 cubic yards per day) was used for the open waterway. The small 8-inch dredge had its ladder and cutterhead removed, and essentially replaced with a double-pipe leading to a 36-foot-wide draghead-type unit at the front of the dredge. Fluidizing jets surrounded the draghead and the draghead and jets were surrounded by a rubber skirt to prevent the jet water from escaping the suction and spreading contaminated sediments.

Two mechanical clamshell dredges (8- and 15-cubic-yard buckets) were also used for the open waterway with a combined production rate of 10,000 cubic yards per day. Other equipment included an 8- and 26-inch pipeline to the CDF, a disposal diffuser barge, boosters to assist with pumping, dump scows, and a small clamshell bucket (5 cubic yards).

Total Volume Removed and Production Rates. A total of 425,000 cubic yards of sediments from the Sitcum Waterway and 2.4 million cubic yards of clean sediments from the Blair Waterway were moved to the abandoned Milwaukee Waterway. The capacity of the

Milwaukee Waterway was very limited. Consequently, the contractor needed to stay within the dredging prism to minimize material volumes. The contractor recognized the limited disposal capacity of the nearshore CDF. Fathometers and GPS were continually used at the site of dredging and dredge depths were verified daily. The fill elevation inside the CDF was monitored hourly.

Site-specific Difficulties. The small underpier dredge was designed to clean the slopes and hard-to-reach areas under the docks. Actual operations encountered extreme debris along the armored slopes, including chunks of concrete, cables, tires and other uneven projections. These materials made it difficult to maintain the dredge's suction face close to the slope and thereby difficult to clean these areas thoroughly.

Another difficulty was attributable to the marked and dynamic tidal fluctuations during a 24-hour dredging day. Although fathometers and GPS were in constant use, the lever man was required to pay constant attention to reading the tide gauges because of the limits on disposal capacity.

6.2 Dewatering and Water Treatment Operations

The solids and water slurry mixture was pumped directly to the bermed CDF in the Milwaukee Waterway. Dredged sediment was dewatered by gravity settling and decanted water was discharged into the bay via an effluent discharge pipe during placement. No water treatment methods were used.

6.3 Storage and Disposal

The dredged sediment, 30 percent of which exceeded the Commencement Bay SQOs, was disposed of in a nearshore, newly-constructed CDF located in the adjacent Milwaukee Waterway. The Milwaukee Waterway was 3,200 feet long by 450 feet wide, ranging from 0- to 40-foot depths. The CDF filled 73 percent of the waterway (24 acres) with dredge material from the Sitcum placed near the bottom and covered with clean material from the Blair Waterway. After a multi-year period of settling, the CDF was capped with asphalt to expand the shipping container port facilities. Groundwater monitoring wells were placed around the perimeter of the CDF and one in the berm for long-term monitoring of water quality.

7 Environmental Monitoring Program

The objective of the Operations, Maintenance, and Monitoring Plan (OMMP) was to determine the effectiveness of contaminated sediment removal (dredging), confirm natural recovery in designated areas, evaluate the success of the remedy, evaluate effectiveness of confinement structure, evaluate the success of habitat enhancement and fisheries mitigation, and confirm the attainment of cleanup objectives. Elements of the monitoring program included bathymetry, sediment chemistry, and surface water column sampling during dredging. Success of the remediation project was determined by post-construction sediment quality.

7.1 Baseline

Physical. Pre-dredge surveys of mudline conditions included underpier side-scan sonar surveys, diver and lead-line spot checks, and bathymetry surveys on 220-foot range lines at 100-foot intervals. Electronic tide gauges and Del Norte DGPS were used for vertical elevation control.

Chemical. Ambient water quality measurements were made before dredging to determine background concentrations and performance standards for dredging. Compliance requirements were set for the point of dredging (330 feet from the activity) and the point of effluent discharge, based on elutriate sampling and modeling. The point of compliance, located downstream of dredging activity, was measured three times per day at three vertical depths. Another sampling location was established at the midpoint between the dredging area and 330 feet downstream as an early indicator of potential exceedances. Parameters included: dissolved oxygen, turbidity, temperature, metals, and PAHs.

Biological. Biological testing included a 1992 *in-situ* 90-day caged mussel study for a NRDA assessment (Port of Tacoma, 1992). The study measured the uptake of contaminants at nine locations in the Sitcum Waterway co-located with the sediment chemistry locations. The results indicated greater than 50 percent mortality in the Penn Cove mussels; however, a NOAA technical response report commented that the study was unusable because of technical design and implementation deficiencies. Other habitat data were not available for review.

7.2 Implementation During Dredging

Physical. Bathymetry surveys were conducted before dredging and at the end of each dredging unit (or every 3 days, whichever came first) to establish the depth and extent of dredging for costing. Conditional surveys also included daily progress surveys to verify appropriate dredge depths. Dredging of specific areas was completed and verified prior to moving to a new dredge area. Survey equipment included sonar sounding devices, electronic tide gauges, tide boards, and GPS.

Chemical. The water column was monitored at the compliance boundary at the edge of the mixing zone (330 feet) and at the water quality midpoint (165 feet). Samples from each station were collected at three discrete depths (upper meter, mid-depth, and bottom 2 meters). Parameters monitored included pH, temperature, turbidity, TSS, dissolved oxygen, and metals. The exceedance criteria for water quality monitoring of dredging activities were:

- Failure of temperature, pH, or DO compliance criteria in 20 percent or more of samples during a single monitoring round; or

- Exceedance of lab-confirmed performance criterion at compliance boundary during two successive monitoring rounds.

Corrective actions were specified in the work plan as "at the discretion of the Port and EPA" if water quality exceeded the criteria. The federal Clean Water Act served as the ARARs for water quality compliance under 1989 EPA Water Quality Acute Criteria Section 304. The water quality monitoring schedule would start as intensive (two per shift) triggered by exceedances, modifications, or startup, then routine (one per day), then limited (one per week) for the duration of dredging. The percentage of water column samples collected at the mixing zone boundary exceeding the compliance criteria were less than 20 percent (recorded in the preliminary reports) and, therefore, were within the performance design criteria. There were reportedly no major violations of the compliance parameters and no adjustments to the dredging plan were made based on compliance measurements.

No air, sediment, or biological tissue monitoring was conducted during sediment dredging activities.

7.3 Post

Physical. Same as progress survey.

Chemical. Success of remediation effort was determined by post-construction sediment chemical quality. Surface (0 to 1 foot) sediment samples were collected at 24 locations and analyzed for PAHs, metals, BEP, PCBs, TS, and TOC. Five discrete samples exceeded the SQOs (one to three analytes each) with enrichment ratios ranging from 1.04 to 2.09. This means that maximum concentrations are one to two times higher than protective thresholds. The 95 percent upper confidence limit (UCL) of the mean sediment concentration for each analyte was less than the SQO with the exception of arsenic at one location (59 mg/kg and ER = 1.03). This area was redredged and supplemental verification samples were below the SQOs. Overall, the post-verification sampling met the compliance criteria in the open-water Phase 1 areas (underpier areas are Phase 2) (Hart Crowser, 1994a and 1994b).

Biological. Habitat was not monitored in the Sitcum Waterway after dredging, however, the newly constructed nearshore habitat constructed along the outer edges of the Milwaukee fill site was monitored for substrate type, benthic abundance, acute toxicity, and caged mussel studies.

7.4 Long Term

Under the long-term OMMP plan, the exposed side slopes and underpier areas were monitored for sediment recontamination at nine locations in 1998. Mercury exceeded the SQOs at four locations and PAHs exceeded the SQOs at one location. These locations had similar sediment quality at the post-construction sediment quality except mercury and five PAHs were not detected in the post-dredging verification survey. Recontamination was likely from continued source input from recent sediment deposition or off-loading activities (Port of Tacoma, 1994).

The open-water areas were characterized during a 1998 PSDDA maintenance dredging evaluation for shoaled areas, and satisfied the OMMP long-term monitoring requirements. The PSDDA prism included 144,000 cubic yards of sediment ranging from 5- to 10-foot thickness. None of the samples exceeded the PSDDA screening levels or the SQOs (Hart Crowser 1998a and 1998b; EPA, 1998).

Table 1 Summary of Monitoring Results

Testing Parameter	Concentrations (ppm)			
	Baseline 1988 RI/FS, 1992	During 1993–1994	Post 1994	Long Term 1995–Present
Bathymetry	Yes	Yes	Not required	—
Surface Water Quality	Yes, to determine baseline (Aug 1993)	No violations	Not required	—
Groundwater	8 Rounds	No Violations	Data collected, not reviewed	—
Sediment Cores	Max PAHs = 89 Arsenic = 291 Zinc = 2,720 Mercury = 1.8	None	(N = 24 0 to 1 foot) All met criteria	1998—Navigational maintenance dredge met chemical disposal criteria

Notes:
Unknown - Results not available.
NA - Data not available for review.

8 Performance Evaluation

The goal of 100 percent mass removal of contaminated sediment to the design elevation was achieved based on physical and chemical monitoring data. The post-verification sediment sample chemical concentrations were below the compliance criteria; therefore, the remedial dredging objectives were met.

9 Costs

The total cost for dredging, fill construction and monitoring, and habitat mitigation was $17.5 million with an average cost of $6.20 per cubic yard. The hydraulic dredging and placement cost of Sitcum sediments from the navigational channel was $1.50 per cubic yard. The mechanical dredging and placement cost of sediment from the underpier and side slope areas was $25 per cubic yard.

10 Project Contact

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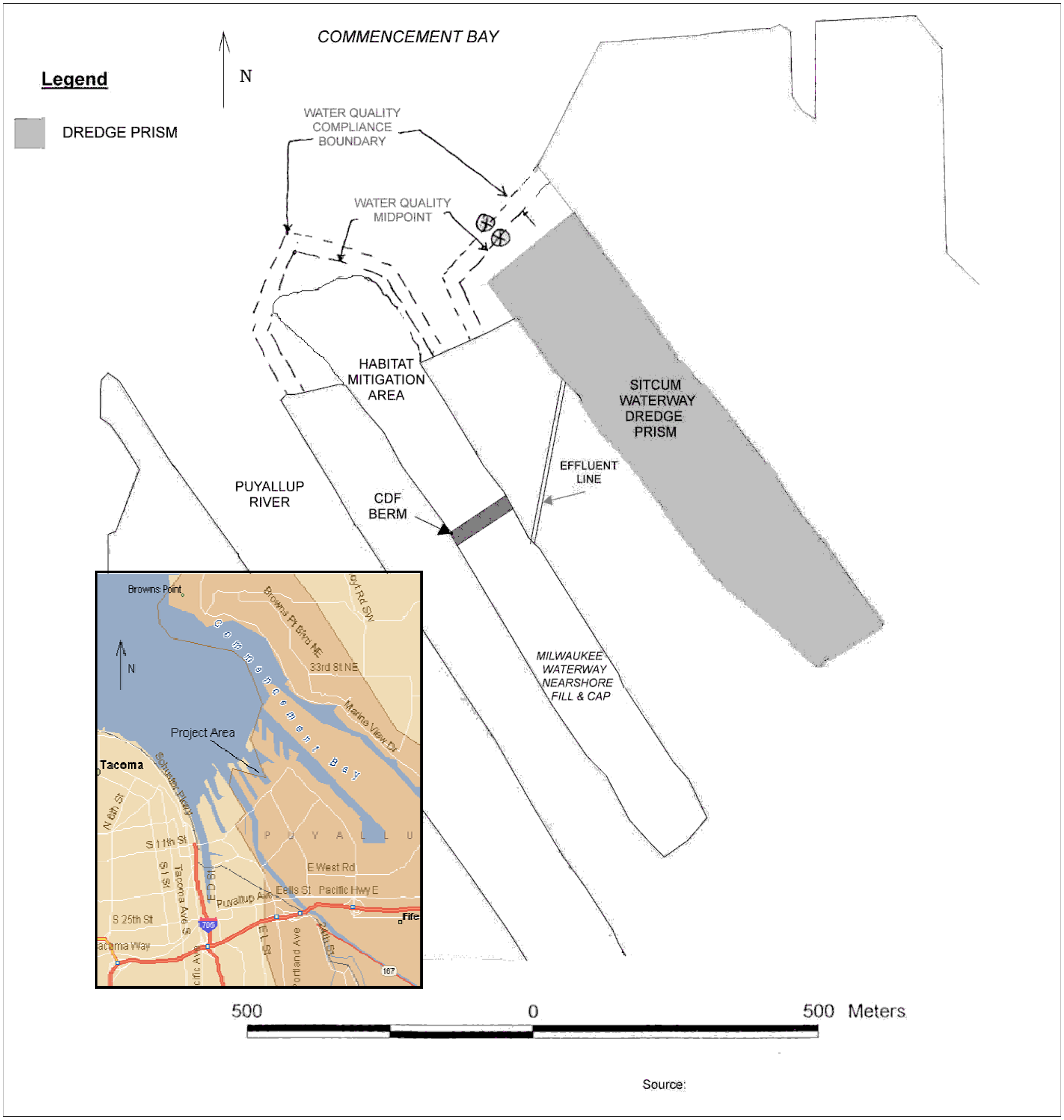
Figure 1 Remedial Dredge Plan - Sitcum Waterway Commencement Bay/Nearshore Tideflat



WAUKEGAN HARBOR/OUTBOARD MARINE - WAUKEGAN, ILLINOIS

1 Statement of the Problem

- Dredged 1991-1992
- PCBs
- 38,300 cubic yards
- $552 per cubic yard

Hydraulic fluid containing polychlorinated biphenyls (PCBs) was used in the die cast works of the Outboard Marine Company (OMC) marine products manufacturing plant from 1961 to 1972. This fluid was discharged to Slip 3 of the harbor and a number of upland areas. An estimated 300,000 pounds of PCBs were released to Waukegan Harbor and 700,00 pounds to the OMC property (EPA, 1999b).

Contamination resulted in beneficial use impairments, including benthos degradation, restrictions on dredging activities, beach closings, and degradation of phytoplankton and zooplankton populations. Remedial action pursuant to an ROD signed in 1984 (EPA, 1984) was halted due to litigation between EPA and OMC. A Consent Decree implementing an OMC cleanup proposal was accepted by EPA in 1989 (EPA, 1989).

Dredging of PCB-contaminated sediment in Waukegan Harbor was completed in 1992. Sediment in Slip 3 with PCB contamination ranging between 500 and 500,000 ppm was dredged and thermally extracted on site. Contaminated sediment ranging from 50 to 500 ppm was dredged from the Upper Harbor and placed in a containment cell formed in Slip 3 (Figure 1). The lead agency for the project was U.S. Environmental Protection Agency (EPA) Region 5.

2 Site Description

The Waukegan Harbor Area of Concern (AOC) is located in Lake County, Illinois, on the west shore of Lake Michigan. The harbor receives drainage from Waukegan River basin and subsequently discharges to Lake Michigan. The present shape of the harbor reflects the industrial activities at the site including filling of the natural inlet and wetlands.

Waukegan Harbor
Source: EPA

Waukegan Harbor is approximately 37 acres in area. The water depth in the upper harbor ranges from 14 to 25 feet (IJC, 1999). Sediments consist of 1- to 7-foot-thick layer of soft organic silt overlying a 4-foot layer of sand and a 50- to 100-foot layer of glacial till. A 20- to 25-foot steel sheetpile wall surrounds the harbor.

3 Site Investigation

A 1972 benthic survey of the Waukegan Old North Harbor found that pollution-tolerant forms of benthic life predominated at each station sampled. Sediment sampling conducted by EPA in May 1976 (six stations) found sediment PCB concentrations ranged from 1.8 to 36 ppm in the Lower Harbor (five samples), and 216 ppm in the Upper Harbor (one sample). Further investigation was conducted in June 1976 in the Upper Harbor and Slip 3. PCB concentrations ranged from 74 to 301 ppm in the Upper Harbor (four samples) and from 3,900 to 10,300 ppm in Slip 3 (two samples). The 10,300 ppm result was the average of replicate samples with concentrations of 4,200 and 16,400 ppm. Investigations conducted by EPA in 1976 also revealed PCB concentrations in resident fish species were in excess of the U.S. Food and Drug Administration action level of 2.0 ppm. Surface sediment sampling conducted in July 1977 exhibited PCB concentrations from 350 to 3,600 ppm in Slip 3 (three samples), 36 to 460 ppm in the Upper Harbor (five samples), and 0.8 to 26 ppm in the Lower Harbor (eight samples). In 1981, EPA made a formal recommendation against consumption of fish from Waukegan Harbor. The site was proposed for the National Priorities List on October 8, 1981 and was placed on the list on September 18, 1983.

In 1983, EPA approved a $100,000 feasibility study to identify alternatives for remedial action at the site (EPA, 1983). A ROD signed in 1984 proposed on-site containment and off-site disposal of upland contaminated soil and dredged sediment as the preferred alternative. All remedial actions were suspended in 1985 due to litigation between OMC and EPA regarding access to OMC property. In 1986, OMC signed a Consent Decree under which the remedial actions established in the ROD remained unchanged with the exception of the addition of on-site treatment for highly contaminated soil and sediment. The addition of the treatment step was required due to re-authorization of Superfund during litigation. The final Consent Decree and ROD specifying the remedial activities was signed March 31, 1989 (EPA, 1989; EPA, 1999a). Remedial activities were conducted with PRP lead with oversight by EPA Region 5.

4 Target Goals and Project Objectives

Results of a 1981 modeling study conducted by HydroQual, Inc., showed that residual PCB concentrations of 10 to 100 ppm would result in negligible PCB influx to Lake Michigan. EPA established a target sediment cleanup goal of 50 ppm based on the results of this study (Herbich, 1995). EPA calculations showed that removal of sediment to a concentration of 50 ppm would result in removal of 96 percent of the PCB mass in the Upper Harbor. Long-term remedial action objectives for the project were described as protection of human health and the environment.

5 Project Design

Summary of Remedial Action Plan. The remedial action included both on-site containment and on-site treatment of upland contaminated soil and dredged sediment. The remedy included construction of a permanent containment cell through isolation of Slip 3 with a double sheetpile cutoff wall. A new slip was constructed on the east side of the Upper Harbor to replace Slip 3.

The dredging plan entailed (EPA, 1999a):

- Slip 3 sediment (greater than 500 ppm PCBs) that was highly contaminated was dredged, treated on-site by thermal desorption, and returned to the Slip 3 containment cell (6,300 cubic yards).
- Slip 3 sediment (moderately contaminated 50 to 500 ppm) was left in-place.
- Upper Harbor sediment (50 to 500 ppm) was dredged and placed directly in the containment cell without treatment.
- All sediments less than 50 ppm PCBs were to be left in-place.

It assumed that sediments in the Upper Harbor did not exceed 500 ppm.

Sediment from the Upper Harbor was dredged and placed directly in the Slip 3 containment cell without stabilization. The 6,300 cubic yards of highly contaminated sediment (greater than 500 ppm PCBs) dredged from Slip 3 were treated on site by thermal desorption and returned to the Slip 3 containment cell. A short-term water treatment facility was constructed for treatment of water generated during remedial activities. A smaller permanent water treatment system was constructed for the treatment of water extracted from the containment cells. Water was removed from the containment cells using extraction wells to maintain an inward hydraulic gradient and prevent PCB migration. Upon reaching 90 percent consolidation, the containment cells were capped with a high-density polyethylene liner and a soil cover. Monitoring wells were constructed around the perimeter of the containment cells to verify groundwater quality.

Limitations and Permits. No dredging was permitted in the Upper Harbor during boating season which lasted from April 30 to October 30. Dredging was therefore conducted during the winter season.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. Remedial activities were conducted between 1990 and 1994. Actual dredging took place in late 1991 and early 1992. Slip 3 was dredged during a two-week period in December 1991 and the Upper Harbor was dredged over a period of eight weeks from January 3 to February 25, 1992. On May 17, 1994, after two years and five months of settling, 90 percent consolidation of sediment was achieved in the containment cell and was subsequently capped. Continued treatment of containment cell water was initially proposed until 1999, although treatment is presently anticipated to continue for an extended period of time.

Waukegan Harbor
Source: Waukegan Harbor Citizens' Advisory Group website
http://nsn.ns/silus.org/wkkhome/iepa

Equipment. Hydraulic dredging removed sediment from both Slip 3 and the Upper Harbor using cutterhead dredges. Slip 3 was dredged using an 8-inch cutterhead and the Upper Harbor was dredged with a 10-inch cutterhead. Bottom anchored silt curtains were installed for containment of dispersed sediment at the lower (southern) boundary of the Upper Harbor and at the entrance to the newly constructed slip.

Total Volume Removed and Production Rates. Approximately 6,300 cubic yards of sediment in excess of 500 ppm PCBs were dredged from Slip 3, treated on site by thermal desorption, and placed in the Slip 3 containment cell. Approximately 32,000 cubic yards of contaminated sediment with PCB concentrations ranging between 50 and 500 ppm were dredged from the Upper Harbor and placed directly in the containment cell (EPA, 1998b).

Site-specific Difficulties. Sediment placed into the Slip 3 containment cell required over two years to reach the target 90 percent consolidation, although dewatering and applications of sand and coagulant were implemented.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. A total of 95 million gallons of water associated with dredging were treated by sand filtration in the temporary water treatment system. The water treatment system consisted of four filters with a combined capacity of 1,000 gpm. Water produced by recovery wells installed to promote sediment consolidation and maintain an inward water gradient was treated by the permanent water treatment system. The water treatment system consisted of sand filtration and carbon adsorption. Treated water was discharged to a nearby storm drain which flowed to the Upper Harbor.

Water Quality Monitoring of Discharge. The water discharge limit for treated dredge water was 15 ppb PCBs. Discharge criteria for treated water from the containment cell was 5 ppb PCBs. Water discharge criteria were consistently achieved for dredge water discharge.

6.3 Storage and Disposal

A requirement for treatment of a portion of the contaminated material on site was included in the 1989 Consent Decree and ROD. Although a treatment technology was not specified, a PCB treatment efficiency goal of 97 percent was included. Slip 3 sediment with PCB concentrations greater than 500 ppm were treated on site using the SoilTech mobile Anaerobic Thermal Processor (ATP) extraction system. Contaminated material from the OMC site with PCB concentrations greater than 10,000 ppm were also treated with the ATP system. The ATP was a thermal desorption treatment which included a feed system, a rotary kiln thermal desorber, a vapor recovery system, a flue gas treatment system, and a tailings handling system. Extracted PCBs were transported to an off-site facility for high-temperature combustion in accordance with the U.S. Toxic Substances Control Act (TSCA). No soils or sediments that exceeded 50 mg/kg PCBs remained on site except those within the containment cells.

The ATP system operated from January 22, 1992 until June 23, 1992 and treated 12,700 tons of PCB-contaminated soil (from upland remediation) and sediment, including the 6,300 cubic yards of sediment dredged from Slip 3. The ATP system met the PCB treatment efficiency goal with an average PCB removal efficiency of 99.98 percent. PCB concentrations in the treated soil ranged from 0.4 to 8.9 ppm. The 99.9999 percent DRE stack emission requirement for PCBs was not met during the proof-of-process period (January 23 until March 5, 1992). The system was shut down from March 5 to May 30 while SoilTech made modifications to the system. All stack gas emission requirements were met for the remainder of operation (EPA, 1995).

The containment cell received 6,300 cubic yards of sediment dredged from Slip 3 and 32,000 cubic yards of dredged sediment from the Upper Harbor. The 6,300 cubic yards of sediment dredged from Slip 3 was treated by thermal desorption prior to placement in the containment cell. Water was removed from the containment cells using extraction wells to maintain an inward hydraulic gradient and prevent PCB migration. On May 17, 1994, after two years and five months of settling, 90 percent consolidation of sediment was achieved. The containment cell was capped with a high-density polyethylene liner and a soil cover. Monitoring wells were constructed around the perimeter of the cell to verify groundwater quality (GE/AEM/BBL, 1998).

7 Environmental Monitoring Program

The monitoring program included bathymetry surveys, waste quality sampling during dredging, sediment sampling, sediment toxicity testing, and fish tissue analyses (IJC, 1999; EPA, 1998a and 1998b; Fox River Group, 1999).

7.1 Baseline

Physical. Physical investigations showed that sediment consisted of one to seven feet of soft organic silt overlying four feet of sand. Glacial till underlies the sand from 50 to over 100 feet thick. PCB contamination was present only in the soft organic silt layer.

Chemical. Prior to remediation, generalized PCB sediment concentrations were stated between 10 to 50 ppm in the Lower Harbor, 50 to 500 ppm in the Upper Harbor, and 500 to 500,000 ppm in Slip 3 (Figure 1), based on the results of sampling investigations conducted by EPA in 1976 and 1977. Actual ranges of PCB concentrations for each area are shown in Table 1.

Biological. Toxicity testing of baseline sediment samples demonstrated significant reduction in survival and growth of *Hyalella azteca* after 29 days exposure to Waukegan Harbor sediments (EPA, 1998a).

Whole carp PCB tissue analysis of samples taken in 1978 (one sample) and 1979 (three samples) had average PCB concentrations of 26.5 and 21.7 ppm, respectively. Carp fillet samples collected in 1983 (three samples) and 1991 (one sample) had PCB concentrations of 9.2 and 19.0 ppm, respectively. A summary of carp tissue analysis is presented in Table 2.

7.2 Implementation During Dredging

Physical. A fathometer depth sounder was used to determine when the design depth of dredging had been reached. Upon reaching this depth, sediment samples were collected to ensure that organic silt had been removed. The criteria for dredging success was when at least 50 percent (by weight) of the material collected was retained by a No. 200 sieve or 4 inches or less depth sample was recovered.

Turbidity criteria was established to be less than 50 NTU outside of the silt curtains. Samples were collected daily at depths of 10 and 20 feet outside of the silt curtain and 500 feet south of the curtain in the Lower Harbor. All turbidity readings were less than 17 NTU and within the criteria limits.

Chemical. No PCB sediment verification samples were collected following dredging. Physical data were used to determine the extent and completion of dredging.

Air monitoring data were collected on personnel and at the perimeter of the remedial activities. The criteria for personnel was below the TLV-PEL of 1 mg/m^3. The highest concentration during sampling was 0.008 mg/m^3 and all samples were non-detect during dredging. The perimeter criteria of 2.31 $\mu g/m^3$ was not exceeded during remedial activities.

Biological. No biological data were available from the period during dredging.

7.3 Post

Physical. No physical data were available from the period immediately following dredging. Physical data collected during dredging were used to determine completeness of excavation.

Chemical. No chemical sediment verification sampling was conducted to document residual PCB concentrations. Physical data collected during dredging were used to determine completeness of excavation.

Biological. No biological data were available from the period immediately following dredging. However, long-term monitoring was initiated after 1993 and included sediment sampling, sediment toxicity testing, and fish tissue analyses.

7.4 Long Term

Long-term monitoring included sediment sampling, sediment toxicity testing, and fish tissue analyses. Sediment samples were collected and analyzed for PCBs from 18 locations in Waukegan Harbor between April 17 and 19, 1996. Results ranged from 3 to 8.9 ppm in eight samples collected in the Upper Harbor (dredged between January 3 to February 25, 1992) with an average concentration of 6.4 ppm. The Lower Harbor concentrations ranged between 0.87 and 6.3 ppm with an average of 4.5 ppm. The average concentration of all samples was 5.4 ppm. No samples were collected from the containment cell (previously Slip 3).

Although not a consideration in the success of remedial dredging, metals and PAHs were also present in sediment samples. Concentrations ranged from 11 to 120 ppm arsenic, 2 to 30 ppm cadmium, 46 to 228 ppm copper, 0.12 to 0.50 mercury, and 12 to 188 ppm lead. The maximum individual PAH concentration was 4.25 ppm phenanthrene.

Table 1 Summary of Sediment Monitoring Results

Location	Sampling Date	Number of Samples	Minimum Concentration (ppm)	Maximum Concentration (ppm)
Slip 3	June 1976 (pre-dredge)	2	3,900	10,300
	July 1977 (pre-dredge)	3	350	3,600
Upper Harbor	June 1976 (pre-dredge)	4	74	301
	July 1977 (pre-dredge)	5	36	460
	April 1996 (post-dredge)	8	3	8.9
Lower Harbor (not within dredged area)	May 1976 (pre-dredge)	6	1.8	216
	July 1977 (pre-dredge)	8	0.8	26
	April 1996 (post-dredge)	10	0.87	6.3

Sediment toxicity was evaluated in 20 samples between April 17 and 19, 1996. Toxicity testing included a 42-day whole-sediment toxicity test of the amphipod *Hyalella azteca* for survival, growth, and reproduction, a 28-day whole-sediment bioaccumulation test of the oligochaete *Lumbriculus variegatus*, and bacteria sediment toxicity tests which measured luminescent light emission.

Survival of amphipods was significantly reduced in six of the 20 samples and growth was significantly reduced in all samples relative to a prepared control. Reproduction toxicity was shown in only two of the amphipod samples. Bioaccumulation data in oligochaetes were not included in the report due to high detection limits which made the bioaccumulation analysis between sampling locations impossible. Bacterial luminescence testing showed toxicity in one organic sediment extract and approximately 50 percent of the sediment samples. Lethal and sub-lethal toxicity in sediment samples was attributed to metals, PAHs, and PCBs (EPA, 1998a).

A significant decrease in PCB bioaccumulation was demonstrated in post-dredging whole carp and carp fillets although only limited data are available (IJC, 1999). Results of PCB tissue analysis of whole carp and carp fillet are summarized in Table 2.

Table 2 Summary of Whole Carp and Carp Fillet Monitoring Results

Sample Year (number of samples)	Average PCB Concentration in Carp, Whole (mg/kg) [1]	Average PCB Concentration in Carp Fillet (mg/kg) [1]
1978 (1) Pre-dredging	26.5	NA
1979 (3)	21.7	NA
1983 (3)	NA	9.2
1991 (1)	NA	19.0
1992 (0)	NA - Samples not collected during dredging	NA - Samples not collected during dredging
1993 (6) Post-dredging	NA	2.6
1994 (1)	NA	3.45
1995 (1) (3)	1.3	1.9
1996 (3)	NA	4.2
1997 (5)	NA	5.0
1998 (3)	NA	6.8

Note:
NA - No samples analyzed.

8 Performance Evaluation

Physical data collected during dredging were used to verify sediment removal to 50 ppm PCBs. No chemical sediment analysis was conducted until April 1996. While evidence from this sediment sampling investigation seems to demonstrate successful removal of PCBs to a concentration below 50 ppm, biological testing results have shown that toxicity is present. Residual PCBs, and the presence of metals and PAHs are possible explanations for these findings.

8.1 Meet Target Objectives

Physical data, including depth and physical sediment characteristics, were used as verification that excavation was complete to a target PCB concentration of 50 ppm. No chemical sediment analysis was conducted to verify this claim. Sediment PCB concentrations were measured in April 1996, over four years after the completion of dredging. Results of the 1996 sediment investigation showed that PCB concentrations in the Upper Harbor dredging area ranged between 3 and 8.9 ppm with an average concentration of 6.4 ppm. Maximum concentrations in 1996 represented a 97 percent decrease and 98 percent decrease over pre-project conditions in the Lower and Upper Harbor, respectively. Using the data in Table 2 and comparing the average pre- and post-project fish tissue results, data show that concentrations have decreased 94 percent and 72 percent in whole carp and carp fillets, respectively. EPA lifted a partial ban on the consumption of fish from Waukegan Harbor in 1997 (EPA, 1999c; Fox River Group, 1999).

8.2 Design Components

The project was relatively simple in scope, dealing with the removal of one contaminant of interest by a single PRP. No special design components were noted in the review of the remedial action.

8.3 Lessons Learned

Litigation between EPA and OMC and the resulting delays to the remedial action illustrate the need for cooperation in the development and implementation of cleanup activities. Lack of post-dredging chemical sediment data and the limited number of fish tissue samples make determination of success difficult to determine and somewhat subjective.

9 Costs

The total cost of the entire remedial action was approximately $21 million ($552 per cubic yard).

10 Project Contact

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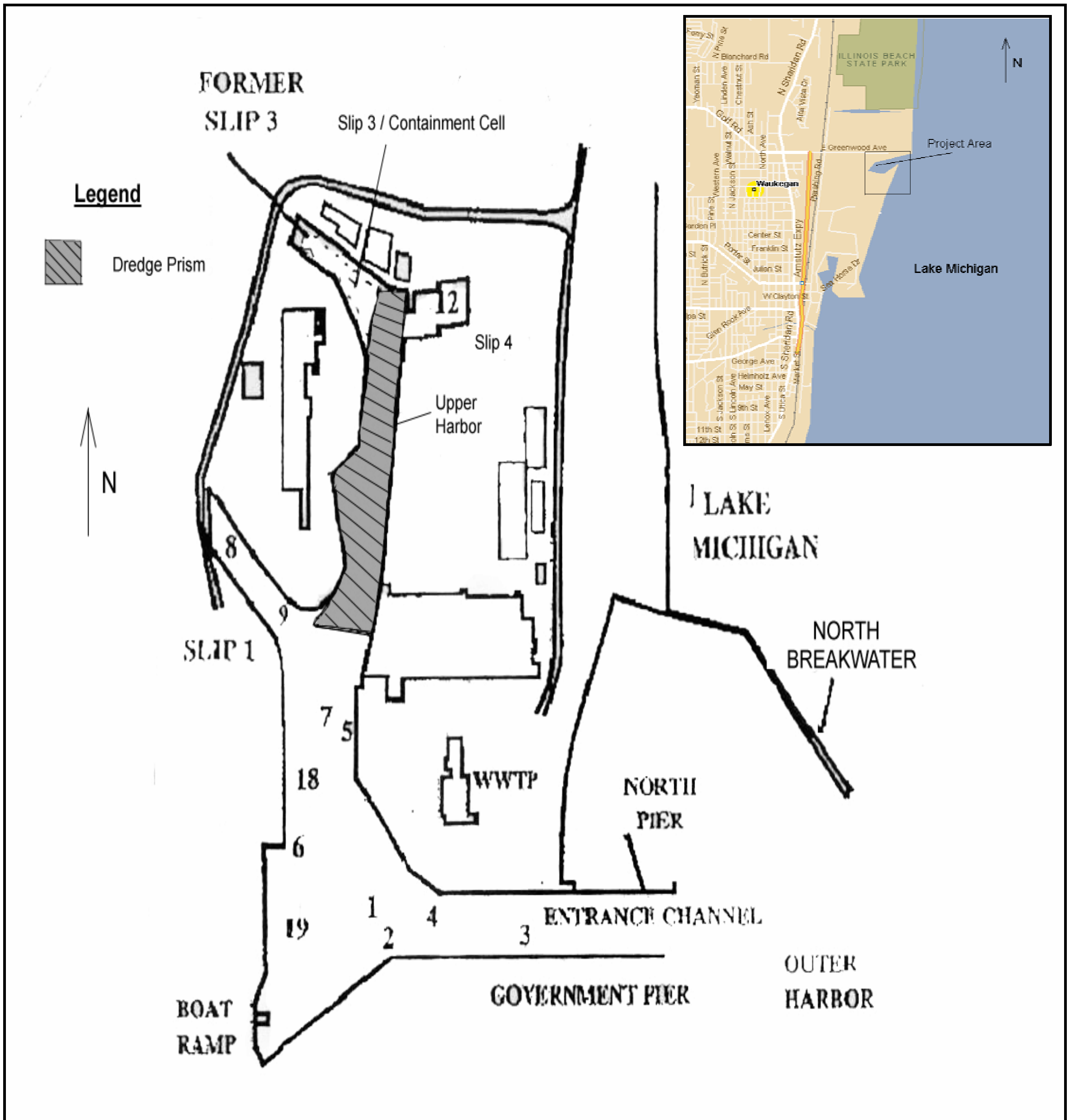
Figure 1 Remedial Dredge Plan - Waukegan Harbor/Outboard Marine



Souce: EPA Evaluation of Toxicity and Bioaccumulation, 1998.

WYCKOFF/WEST EAGLE HARBOR OPERABLE UNIT - BAINBRIDGE ISLAND, WASHINGTON

1 Statement of the Problem

- Dredged 1997
- Mercury and PAHs
- 6,000 cubic yards
- $630 per cubic yard

West Eagle Harbor Superfund site was contaminated with mercury and polynuclear aromatic hydrocarbons (PAHs) from former shipyard and wood treating facilities. Maximum concentrations detected in 1995 surface sediment samples were 32 mg/kg dry-weight mercury and 148 ppm dry-weight total high molecular weight PAHs (HPAHs). The selected remedy was protective of state sediment management standards chemical criteria and included several components: dredging, thick capping, thin capping, and construction of a nearshore confined disposal facility (CDF). Remedial activities were conducted in 1997 and the lead agency for this project was U.S. Environmental Protection Agency (EPA) Region 10.

2 Site Description

The West Eagle Harbor Operable Unit (OU-3) is part of the Wyckoff/Eagle Harbor Superfund Site located on the east side of Bainbridge Island in Central Puget Sound, Washington. The West Harbor OU is one of three operable units within the Superfund site and includes a former shipyard, intertidal and subtidal sediments, and upland sources of contamination. The project area is an intertidal marine embayment of 202 hectares (500 acres) with minimal current, wave action, and sedimentation except for prop wash disturbance from an adjacent ferry terminal. The Eagle Harbor shoreline is mostly residential except for a commercial area around the town center which includes restaurants, shops, a small marina, and public park. Shoreline industry includes a boatyard, ferry terminal and maintenance facility, and former wood treating facility. Site sediments range from gravelly sands to sandy silts with buried timber piles and sandblast grit. Average water depths range from 10 to 20 feet (GE, 1999).

West Eagle Harbor
Source: EPA

3 Site Investigation

The Wyckoff/Eagle Harbor site was proposed for the NPL in 1985, following concerns about hydrocarbon accumulation and potential human health and environmental hazards from initial NOAA and EPA sampling data. A seafood health advisory was posted in 1985 recommending against the harvest and consumption of fish and shellfish in Eagle Harbor. In 1987, EPA initiated an RI/FS which included harbor-wide oceanographic, sediment, shellfish, and fish data studies over a 3-year period. In September 1992, a Record of Decision (ROD) for remedial action was finalized for the West Harbor OU, and amended in December 1995 to include a nearshore CDF alternative. Remedial alternatives for the East Harbor OU (OU-1) and the Wyckoff facility (OU-2) were addressed under separate EPA actions.

Contaminants of Concern. The primary contaminants of concern were mercury from application, use, and removal of bottom paints and antifoulants at the former shipyard during the 1940s and 1950s, and polyaromatic hydrocarbons (PAHs) from the former wood treatment facility. Most of the sediments in the WHOU were characterized by relatively low levels of contaminated sediment over large areas in the upper 3 feet except for a few hotspots. The maximum concentrations measured were 32 mg/kg dry weight mercury and 148,100 μg/kg dry weight total HPAHs in samples collected from the 1995 pre-remedial design sampling effort. The Washington State Sediment Management Standards (SMS) were selected as primary applicable or relevant and appropriate requirements (ARARs) for the project compliance criteria.

4 Target Goals and Project Objectives

As stated in the ROD, "sediments within the top 10 cm must meet the minimum cleanup level (MCUL) chemical criteria within 10 years after active remediation is completed, unless an extension is approved (EPA, 1992 and 1995a and b). In areas where natural recovery is predicted based on accepted mathematical modeling, sediment must meet the MCUL criteria within 10 years of source control." In order to define areas requiring specific types of remediation, the overall cleanup objective developed under the SMS program was supplemented by three EPA chemical criteria objectives: 1) 5 mg/kg dry weight mercury as a means of source control, 2) 1,200 μg/kg dry weight HPAH for intertidal sediments for protection of human health, and 3) 2.1 mg/kg dry weight mercury for protection of biological toxicity. The sediment concentration of 2.1 mg/kg is more than three times the MCUL and is the High Apparent Effects Threshold (HAET) for mercury.

5 Project Design

As stated in the ROD and 1995 ROD amendment, the selected remedy used a combination of alternatives to meet the project objectives (EPA, 1992 and 1995a and b):

- Construct a 1-acre nearshore CDF around nearly half of the targeted sediment (leaving it *in situ)*, filling the rest with excavated sediment and increasing the upland ferry terminal capacity by 20 percent;

- Excavate mercury sediment hotspots (greater than 5 mg/kg) and dispose of sediments in nearshore CDF (estimate 13,000 cubic yards);

- Construct a 1-meter cap over surface sediments with greater than 2.1 to less than 5 mg/kg mercury;

- Place a thin-layer cap (6 inches) over surface sediments with greater than 0.59 (MCUL) to less than 2.1 mg/kg mercury; and
- No action for remaining sediments below the MCUL.

Construction of Nearshore Fill CDF
Source: U.S. EPA

Pre-planning and Bid Documents. Extensive physical and chemical laboratory testing was conducted to simulate dredging and filling activities and to predict the fate and transport of site chemicals. A design engineer prepared and issued competitive bid specifications and bid documents. The selected contractor (Wilder Construction) produced a pre-mobilization work plan outlining the dredging, CDF construction, and sediment disposal activities, including a quality control plan. The bid documents allowed contractor flexibility in selecting the most appropriate dredging equipment to be used for the project. Use of barriers such as silt curtains were also left up to the contractor. An independent quality assurance contractor was responsible for conducting environmental monitoring. Unit price and payment changes were considered if any item changed ±25 percent from expected costs. Some subtasks were lump sums. The contractor would be reimbursed for actual production costs for surplus processed material produced by the contractor (Hart Crowser, 1996a and b, 1997a and 1997b).

Summary of Remedial Action Plan. Overall, the remedial action entailed wet excavation of subtidal sediments, dry excavation of intertidal sediments at low tide, stabilizing sediments exceeding TCLP analysis and transporting hazardous wastes to a RCRA landfill, capping, and enhanced natural recovery. The majority of contaminant sediments were placed in a nearshore confined disposal facility via pipelines and barges. Dredging operations were designed with 1 foot of overdredge to ensure removal of target sediments. The CDF was constructed on site with berm walls, and a low-permeability, geomembrane textile liner to help maintain saturated, saline conditions. After a brief settling period, the CDF was capped with clean fill and asphalt. The short-term dredging impacts were somewhat reduced under the CDF alternative since most of the hotspot sediments within the CDF footprint did not require excavation; only the sediments underneath the berm were excavated. Sediments remaining in-place outside of the berm were capped or left for natural recovery. Sediment was dewatered by gravity settling in the CDF lagoon and supernatant water was discharged back to Eagle Harbor (Wilder, 1997).

Limitations and Permits. Permits were not available for review; however, the remedy did call for mitigation of intertidal habitat loss by construction of Shel-Chelb estuary located near southwest corner of Bainbridge Island.

6 Remedial Actions

6.1 Dredging

Schedule and Duration. The remedial action mobilized in April 1997 and was completed in October 1997 (210 days). The number of hours per day and days per week were not specified.

Equipment. Prior to dredging activities, piers, timber piles, railroad spurs, boulders, and other structures identified during previous surveys were removed from the dredging area. Open-water sediment removal was conducted using a roundnose, 5-cubic-yard clamshell bucket. Dredged material from subtidal areas was transported to the CDF via flat-deck barges moored alongside the clamshell bucket. Sediment resuspension was minimized by reducing the rate of retrieval of the full bucket, and placing a silt curtain around the perimeter of the open-water dredging operation. Intertidal sediments were excavated at low tide using a land-based small track excavator, a Bobcat loader, and a 330 track excavator. The 330 excavator transferred material to a Cat 966 loader for transport and temporary upland stockpiling. Open-water capping utilized the same clamshell bucket and underpier capping utilized a centrifugal pump mounted on a flat-deck barge.

Total Volume Removed and Production Rates. A total of 3,650 cubic yards of sediment were removed (1,350 cubic yards by mechanical dredging, 1,650 cubic yards by wet excavation, 650 cubic yards at low tide by dry excavation). A thick cap was placed on 0.5 to 0.7 acres with 7,400 tons of quarry material. A thin cap was placed on 6 acres with 22,600 tons of quarry material to enhance natural recovery. The solids content of dredged material ranged from 2 to 5 percent. The average daily effluent pumping rate was 720,000 gallons.

Site-specific Difficulties. None that impacted the overall success of the project. Tide swings of 12 feet caused sloughing of newly excavated intertidal sediments from underpiers. Contractor backfilled excavated areas with clean gravel to prevent sloughing.

6.2 Dewatering and Water Treatment Operations

Dewatering, Treatment and Disposal. The solids and water slurry water and sediment generated during dredging were gravity dewatered in the CDF lagoon. Supernatant water was discharged directly to Eagle Harbor maintaining specific turbidity and mixing limits. No other method of water treatment was used.

Water Quality Monitoring of Discharge. The gravity settling time was modified to meet water quality discharge criteria as necessary. Water quality was monitored in the CDF lagoon and at the CDF discharge pipe. Parameters included turbidity, temperature, DO, and mercury. CDF supernatant was sampled prior to discharge at 2-foot depth vertical depth intervals down to the maximum depth of proposed drawdown.

6.3 Storage and Disposal

Dredged sediments were disposed of in a nearshore CDF (2,350 cubic yards) following gravity dewatering. The CDF was constructed on 0.9 acre of intertidal land by dredging hotspot sediments located beneath the berm footprint and stockpiling for eventual return to the CDF after completion. Sediments contained within the footprint of the CDF and below the design depth were not disturbed. The CDF was lined with a low-permeability, geomembrane textile fabric to minimize dewatering after closure. Dredged material was filled to 10 feet MLLW elevation. After dewatering and settlement, clean fill was placed up to 15 feet MLLW and topped with an asphalt cap. Settlement plates were installed in the CDF and monitored twice per week for settlement (accuracy 0.01 foot). Remaining sediments were temporarily stockpiled upland and disposed of at an off-site commercial landfill (650 cubic yards).

7 Environmental Monitoring Program

The environmental monitoring program included bathymetry surveys, water column sampling during dredging sediment samples, sediment toxicity tests, and benthic community assessment (Table 1). The ROD stated "physical, chemical, and biological monitoring after cleanup will continue as long as necessary. Assume 30 years for costing purposes." CERCLA requires that EPA review the remedy for signs of contamination for at least five years if contaminants are left in-place (EPA, 1995a and b).

7.1 Baseline

Physical. Underwater geophysical surveys were conducted using bathymetry and video surveys to determine sediment stratigraphy and topography.

Chemical. Ambient water quality samples were collected within two weeks prior to start of dredging activities to determine compliance concentrations. Water samples were collected at five stations approximately 600 feet from water quality monitoring stations on a two-point depth profile (upper 1 meter and bottom 2 meters). Pre-dredge sediment samples were collected in selected areas immediately before dredging to better define the extent of contamination that required removal.

No baseline air monitoring was conducted for sediment remediation activities.

Biological. A benthic community assessment was conducted between August and November 1993 measuring the presence, abundance, and diversity of the macroinvertebrate benthic community. Samples from seven transects were taken at each of two sites (background and downstream of the remedial site). The results showed one impaired community in the downstream transects.

7.2 Implementation During Dredging

Physical. Bathymetry surveys were conducted before dredging and at the end of each dredging unit (or every 3 days whichever came first), to establish the depth and extent of dredging. Survey equipment included sonar sounding devices, electronic tide gauges, tide boards, and GPS. Sounding line station intervals were 20 feet apart and extended 50 feet beyond the project boundary. An independent contractor, de Maximis, verified the dredge's horizontal position and digging depth during remedial activities (de Maximis, 1998).

Chemical. The water column was monitored at five locations downstream of the 200-foot mixing zone radius around the clamshell dredging activities. Each station was sampled at three depths (top, middle, bottom). Parameters monitored included pH, temperature, turbidity, TSS, dissolved oxygen, total lead, and total mercury. In addition, water samples were collected in the middle of the turbidity plume (if observed) not for compliance, but to assess overall performance. The exceedance criteria for water quality monitoring of dredging activities were:

- Failure of temperature, pH, or DO compliance criteria in 20 percent or more of samples during a single monitoring round; or

- Exceedance of lab-confirmed performance criterion at compliance boundary during two successive monitoring rounds.

Per the work plan, if water quality exceeded the criteria, then modifications such as slowing the dredge rate were employed. At the first sign of significant oil sheen or distress/dying fish, then dredging operations would cease. The water quality monitoring schedule would start as intensive (two per shift) for two days or after an exceedance, then routine (one per day) for five days, then limited (one per week) for the duration of dredging. The percentage of water column samples collected at the mixing zone boundary exceeding the compliance criteria were less than 20 percent (recorded in the preliminary reports) and, therefore, were within the performance design criteria.

No sediment sampling was specified. No air monitoring was conducted during sediment dredging activities.

Biological. No biological testing was conducted during dredging.

7.3 Post

Physical. Bathymetric survey was conducted to document the final topography and extent of dredging and capping of the project area using similar methods described in the progress section.

Chemical. Post-verification sediment sampling was conducted immediately after dredging before equipment was demobilized (Pentec, 1997). Surface sediment samples were collected using a van Veen grab sampler at 50-foot grid intervals in the dredge prism and at 50-foot spacing along the perimeter. A detailed contingency plan was in-place to determine exceedances and subsequent actions. A chemical exceedance for sediments was determined by three criteria:

- The areal-weighted average concentration must be less than 5 mg/kg mercury;
- Less than 20 percent of individual samples can exceed 5 mg/kg mercury; and
- No individual sample can exceed 10 mg/kg (ER ratio of 2).

If a sediment exceedance was determined, then two additional verification samples were collected at 5-foot distances from the highest exceedance. If these samples exceeded the criteria, then the area was re-dredged to a uniform depth of 1 foot in a 50-foot-wide grid. The area would be re-sampled for verification of compliance. The post-verification sampling also determined where a thick cap was needed in the dredge area. Compliance criteria for dredge prism DU-2 were met and the maximum mercury concentration detected after DU-2 dredging was 8.7 mg/kg. Collection of water, air, and tissue samples was not specified. Post-verification sampling was based on chemical compliance of sediment. According to Ken Marcy of U.S. EPA, all post-verification sediment sampling met compliance criteria (Paccar, 1996).

Biological. No data available for review.

7.4 Long Term

Long-term monitoring of the cap and of the CDF are proposed; however, only water quality samples from groundwater quality monitoring wells installed in the CDF were available for review (Parsons-Brinckerhoff, 1998). The project was recently completed and, therefore, limited long-term data exist. Based on a conversation with Ken Marcy, the Year 1 OMMP Data Report discussed results of: 1) habitat performance at the Shel-Chelb estuary (mitigation site), 2) groundwater monitoring results inside the CDF, 3) site and stormwater inspections, and 4) eelgrass performance outside of the dredge and cap areas of West Eagle Harbor where it was naturally growing (ThermoRetec, 1999; Herrera, 1998a and b). No sediment sampling was conducted, but it is planned for next year. Results of the eelgrass survey indicated that the eelgrass was not performing well. However, the results were deemed inconclusive since the algae did not die off this winter and may have influenced the decreased rate of growth by limiting the amount of light able to reach the eelgrass. EPA will continue to monitor the results.

Table 1 Summary of Monitoring Results

Testing Parameter	Concentration (ppm dry-weight)			
	Baseline 1995	During 1997	Post	Long Term [1]
Bathymetry	Yes	Yes	Yes, met target depth	Unknown
Water Column	Yes, to establish baseline	Yes	None	Unknown
Surface Sediments	32 mg/kg Hg 148 mg/kg PAHs	NC	All samples met chemical criteria in non-cap areas	Planned
Sediment Toxicity	NA	NC	Unknown	NC
Biological	One impaired community	Monitoring for TSS, TOC, temperature, pH, turbidity and mercury; no significant exceedances	NC	Macroinvertebrate and macroalgae abundance assessment to be collected; eelgrass restoration

Notes:

Long-term defined as 30 years.
NA - Data not available for review.
NC - Not collected.

8 Performance Evaluation

8.1 Meet Target Objectives

Post-verification sediment samples from dredge prism DU-2 met the chemical compliance criteria, and supposedly all the post-verification sediment sampling met the SMS chemical criteria. Based on chemical compliance of confirmation samples, one foot of overdredge designed into the remedy, the mind-set of "environmental dredging" by the contractor, and the immediate verification sampling of each dredging prism prior to demobilization indicate that the dredging effort successfully met the short-term goals. Remedial success of long-term goals (no surface contamination within 10 years of remedial action) have yet to be evaluated.

8.2 Design Components

Several design components including: the mind set of "environmental dredging" by the contractors, adaptive dredging management enabling the contractor to modify onsite equipment operations to try and meet the target objectives, and the design of 1-foot overdredge into the remedy all likely contributed to the success of this remedial project.

8.3 Lessons Learned

Water quality monitoring conducted during dredging and dewatering operations met the performance criteria. Verification sediment sampling met design criteria. Selection of a qualified contractor with environmental experience and good communication skills with the other members of the team proved critical to successful implementation of the project. Public involvement and acceptance were important consider-ations during the design phase. The original ROD specified dredge and offsite disposal of dredge material. However, the community was concerned about the loss of their local shipyard from redevelopment efforts and the ROD was changed, allowing construction of a nearshore fill to accommodate the redevelopment plans and allowing the boatyard to remain.

9 Costs

In the 1995 ROD amendment, the estimated total remedy costs for CDF disposal, dredging and removal, and habitat mitigation was approximately $3.8 million ($630 per cubic yard).

10 Project Contact

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11 References

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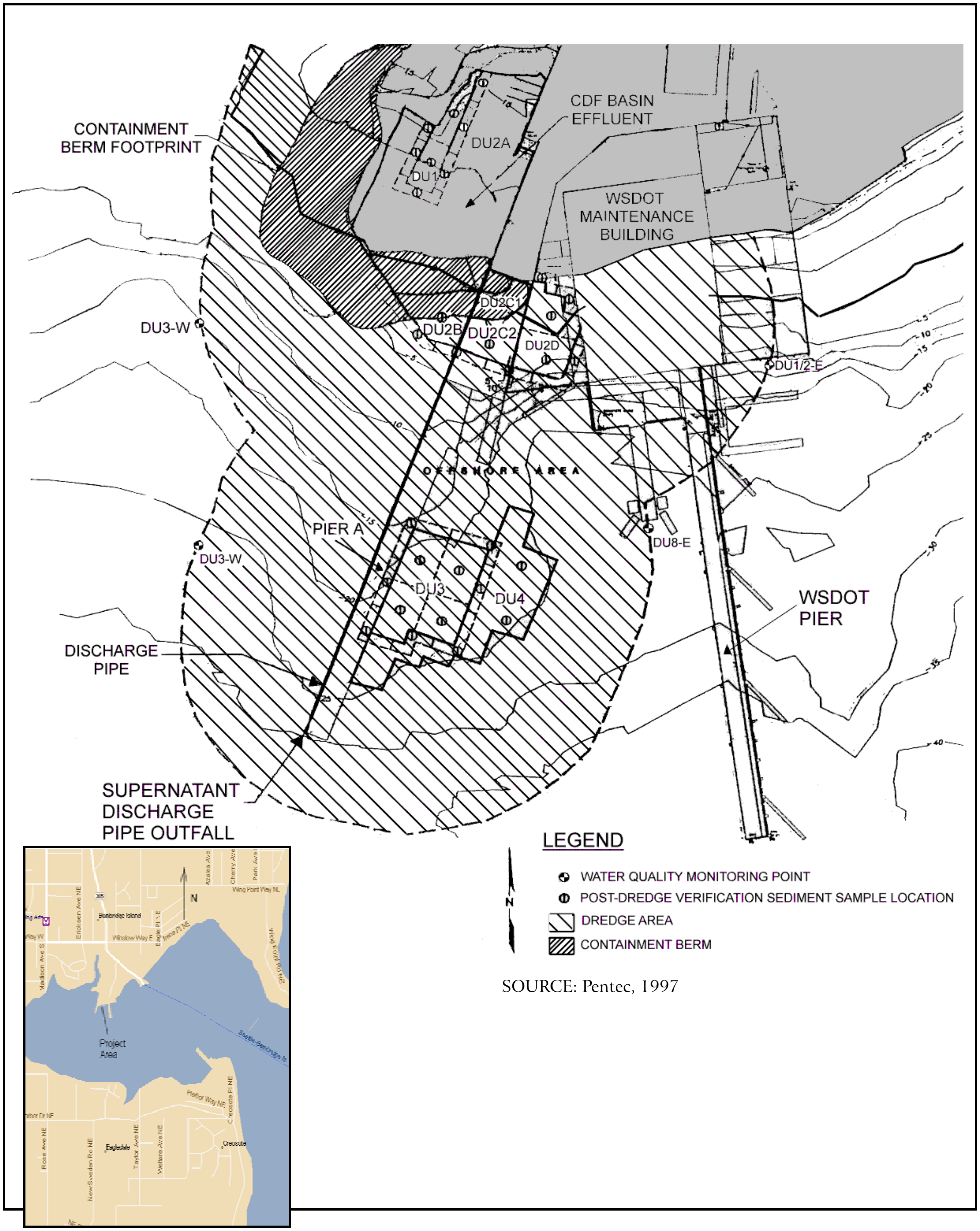
Figure 1 Remedial Dredge Plan - Wyckoff/West Eagle Harbor Operable Unit



SOURCE: Pentec, 1997

Attachment 2

Long-term Monitoring Plan Designs

Project Name: Black River Dredging Project

Location: Northwest Ohio, USA

Contaminants of Concern: PAH

Period of Performance: Dredged from 1989 to 1990

Water Body Type: Riverine

Background:
The Black River flows northwesterly through Ohio and into Lake Erie at Lorain Harbor. PAH-contaminated sediments were present primarily from discharges of USX/Kobe Steel (formerly USS Lorain) coking facility. High sediment PAH levels corresponded to a high frequency of liver tumors in resident populations of brown bullheads. Although sediment PAH levels had declined since the USX's coking facility was shut down, elevated levels were still of concern due to fish consumption advisories for PAHs.

Project Goals and Objectives:
The primary cleanup target was the removal of sediment to the underlying shale bedrock in the area of the former USX-Kobe coke plant. The goal of the sediment remediation project was to remove PAH-contaminated sediment in order to reduce risk to brown bullhead, catfish, and other resident aquatic organisms. Monitoring was implemented to measure biological effects through reduction of liver neoplasms in resident brown bullhead populations. Liver neoplasms were measured as the indicator for biological effects because PAHs are rapidly metabolized and excreted by fish.

Remedial Actions:
Sediment remediation occurred as a result of an enforcement action upstream of the federal navigational channel in the vicinity of the coke plant outfall. Dredging of the sediment began in 1989 and was completed in December 1990. A total of 38,000 m^3 of sediment were removed during the operation. Dredging was performed using a closed, watertight clamshell dredge to reduce the loss of sediment to the water column. Dredged sediment was placed in an upland confined disposal facility on the USX-Kobe facility. Following placement, sediment was dewatered and capped (IJC, 1999).

Long-Term Monitoring:
Following completion of dredging in 1990, long-term monitoring of sediment and fish was conducted annually from 1992 through 1994.

Physical: No physical monitoring is known to be included in the long-term monitoring program.

Chemical: Surface sediments were collected using an Ekman dredge sampler. Samples were collected as three-point composites across the river from 14 locations. The distribution included two upstream samples, seven samples from the dredged area, and five downstream samples. Discrete samples were also collected from two locations.

Biological: Biological monitoring consisted of measurements of the frequency of liver neoplasms in brown bullhead (Bauman et. al, 1998). Biological monitoring included fish tissue analysis and liver deformities. Resident adult brown bullheads greater than 250 mm (age 2+) were collected using overnight sets of fyke nets from the Black River and a reference site. Samples were analyzed for serum analysis, necropsy and histopathology of liver neoplasms. Net locations extended above 0.5 km above and below the coke plant outfall. Sampling stations were randomly selected, and sample sizes per year ranged from 44 to 99 individuals (age 3 or older).

Project Outcome:
As a result of this sediment remediation project, PAH levels in sediment have declined substantially and cancerous liver tumors have now been reduced to less than 1 percent in the resident brown bullhead population. PAH fish consumption advisories for the general population were rescinded in 1997 for all fish species located in the Black River (EPA, 2000).

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References:
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Project Name: Dokai Bay Dredging Project

Location: Kitakyushu City, Dokai Bay, Japan

Contaminants of Concern: Organic overloading, mercury, cadmium

Water Body Type: Marine

Period of Performance: Discharge regulations since 1970; dredged in 1974 to 1975

Background:
Dokai Bay lies adjacent to Kitakyushu city, one of Japan's major cities with a population of more than one million. Various heavy chemical-industrial plants have been established in this city since the 1900s. Wastewater from factories and untreated sewage effluent have heavily polluted the water and marine bottom environment of the bay. The bay was referred to as the 'dead sea' in the 1960s due to the apparent absence of aquatic organisms.

Project Goals and Objectives:
The project goal was the recovery of the Bay ecosystem. Since 1970, the local government has carried out environmental recovery projects in an attempt to remove pollutants and control nutrient loading.

Remedial Actions:
Stringent regulations have been implemented for discharge of effluent and wastewater. Dredging was performed in 1974 and 1975, removing 350,000 cubic yards of contaminated sediments (Gros, 1999).

Long-Term Monitoring:

Physical: No long-term physical monitoring is known to have occurred.

Chemical: Monitoring of sediment chemistry was conducted in 1990 for acid volatile sulfides, COD, mercury, and cadmium. Surface sediment grab samples (0 to 2 cm) were collected from 13 locations randomly distributed throughout the bay using Ekman and Smith McIntyre grab samplers. Three grab samples were collected per station (two for chemical and one for biological). Surface and bottom water were analyzed for dissolved oxygen. The schedule for additional monitoring was not available for review.

Biological: Biological recovery was monitored by benthic infaunal analysis from collocated sediment grab samples at 13 stations. Benthic animals were sieved through a 1-mm mesh screen and counted, weighed, and identified down to species (Ueda et al., 1994).

Project Outcome:
Since 1989, the authors have assessed the water and benthic conditions of the bay to describe the recovery of the benthic ecosystems, and to monitor the effects of environmental recovery projects on the bottom environment of the bay since 1970. The results of these studies indicate a significant decrease in the levels of heavy metals in the bottom sediments and the recolonization of various benthic organisms, although the innermost areas of the bay remain seriously organically polluted.

Project Contact:
None available

References:

Gros, X. E., 1999. Let's Pollute: A Tribute to Japan's Disregard for the Environment. Electronic Green Journal. Issue 11. December. Website. http://egj.lib.uidaho.edu/egi11/gros1.html.

Ueda, N. et al., 1994. Recovery of the marine bottom environment of a Japanese Bay. *Mar. Poll. Bull.* Vol. 28, No. 11, pp. 676-682.

Project Name: Ford Outfall/River Raisin Dredging Project

Location: Monroe, Michigan

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1997

Background:
The project area is a 2.6-mile section of the lower River Raisin in the southeastern portion of Michigan. PCB-contaminated wastewater generated by cleaning, painting, and plating processes was discharged directly into the River Raisin by the Ford Monroe Stamping Plant from 1949 to 1972. Elevated PCB concentrations were detected in wastewater, sediment and fish surrounding Ford's wastewater discharge pipe. A state fish consumption advisory is in effect for carp and white bass in the Raisin River below the Monroe Dam.

Project Goals and Objectives:
The remedial project goal was to remove contaminated sediment from a hotspot located near the Ford plant's wastewater outfall under a Superfund Emergency Removal Action. The proposed hotspot measured 600 feet by 200 feet containing 28,000 cubic yards of sediment. The target goal was removal of all sediment within the dredge prism down to hardpan and removal of sediment in excess of the 10 ppm PCB cleanup criteria. The long-term remedial action objective was to reduce PCB concentrations in fish and to protect human health (GE/AEM/BBL, 2000).

Remedial Actions:
Approximately 27,000 cubic yards of sediment were removed from the hotspot area from July to September 1997. Sediments were mechanically dredged with a clamshell bucket. Contaminant transport was minimized through the use of silt curtains. Contaminated sediment was stabilized with Portland cement and disposed of in a Toxic Substances Control Act (TSCA) landfill located on site (ACOE, 1998).

Long-Term Monitoring:
Ongoing post-remediation monitoring is being conducted by the Michigan Department of Environmental Quality. Data was available from sampling conducted in the fall of 1988. The schedule or extent of additional sampling events was not available.

Physical: No physical monitoring data was reviewed.

Chemical: Sediment cores were collected from 20 locations in the 1998 sampling event. Samples from two surface intervals (0 to 6 inches and 0 to 18 inches) were analyzed for PCBs (MDEQ, 1998b).

Biological: Biological monitoring for the 1998 sampling event included caged fish bioaccumulation studies and fish tissue analysis for PCBs. Caged fish were placed at one upstream and two downstream locations. Samples of edible portions of 30 resident fish were used for the fish tissue analysis (MDEQ, 1998a).

Project Outcome:
Monitoring has demonstrated significant decreases in sediment and fish tissue PCB concentrations. PCB concentrations in sediment exceed target criteria in some locations. For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:

ACOE, 1998. Ford Outfall Superfund Site Closeout Report. Prepared by the U.S. Army Corps of Engineers for the U.S. Environmental Protection Agency Region 5 Superfund Division. November 30.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

MDEQ, 1998a. Caged Fish Tissue Concentrations from Three Locations in the River Raisin. Unpublished.

MDEQ, 1998b. PCB Sediment Investigation: River Raisin Area of Concern, Monroe, Michigan 1995, 1997 and 1998. Michigan Department of Environmental Quality, Surface Water Quality Division Staff Report No. MI/DEQ/SWQ-99/108.

Project Name: General Motors Foundry Dredging Project

Location: St. Lawrence River, Massena, New York

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Remedial action from 1994 to 2000; dredged in 1995

Background:
The site is located in the St. Lawrence River adjacent to the General Motors Foundry facility in Massena, New York. The General Motors Central Foundry used PCBs in hydraulic fluids for use in aluminum casting processes. Approximately 30,000 cubic yards of PCB-contaminated sludges were produced from 1959 to 1973 resulting in the contamination of sediment in the St. Lawrence River, the Raquette River, and Turtle Cove. At least 11 fish advisories were posted for the St. Lawrence River.

Project Goals and Objectives:
The remediation goal was to remove contaminated sediment to a target concentration of 1 ppm PCBs from a shallow bay shelf adjacent to the General Motors Foundry. The remedy was chosen to protect human health and the environment based on requirements of the Toxic Substances Control Act (TSCA) and human health and ecological risk assessments (GE/AEM/BBL, 2000).

Remedial Actions:
A total of 13,800 cubic yards of contaminated sediments were removed from the St. Lawrence River using an 8-foot horizontal auger head hydraulic dredge. Sheetpile walls were installed around the dredge area to provide containment for disturbed sediment. A cap was installed over a portion of the dredged area due to elevated post-dredge PCB concentrations. Dredged sediment was transported to an equalization basin via pipeline and dewatered (BBL, 1996b). The dewatered sediment was stored until the summer of 1999 when EPA announced the decision to transport it to a licensed disposal facility in Utah.

Long-Term Monitoring:
A long-term monitoring and maintenance plan was developed for the GM Foundry St. Lawrence River site and includes inspection activities and biological monitoring (BBL, 1996a).

> *Physical:* Annual inspection and documentation of the sediment cap condition (underwater video cameras).
>
> *Chemical:* No long-term chemical monitoring was noted in the review.
>
> *Biological:* Annual fish tissue sampling of resident juvenile spottail shiners commenced in 1997 for the St. Lawrence River long-term monitoring plan. Spottail shiner fish samples were collected in the general vicinity of GM's main outfall and composited into seven 15-fish composite samples. Samples were photographed, weighed, measured for length, and analyzed for whole body total PCBs, PCB Aroclors, and percent lipids. If spottail shiner samples were not available, then emerald shiner or longnose dace were sampled. Annual fish tissue sampling is expected to continue for 5 years (BBL, 1999).

Project Outcome:
Sediment removal was not successful in achieving the target PCB concentration of 1 ppm. An average PCB concentration of 27 ppm in one portion of the dredged area led to the capping of the location. The remaining areas of the site did not receive a cap, although an average PCB concentration of 3 ppm was measured. Although high variability was present and limited post-monitoring data was available, average PCB concentrations have decreased from pre-dredging measurements. For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:

BBL, 1996a. St. Lawrence River Monitoring and Maintenance Plan, General Motors Powertrain. BBL Environmental Services, Inc., Massena, New York. December.

BBL, 1996b. St. Lawrence River Sediment Removal Project Remedial Action Completion Report. BBL Environmental Services, Inc., Massena, New York. June.

BBL, 1999. St. Lawrence River Monitoring and Maintenance Annual Inspection Report. BBL Environmental Services, Inc., Massena, New York. January.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

Project Name: Grasse River Pilot Dredging Project

Location: Massena, New York

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1995 (Pilot)

Background:
The area of concern is an 8.5-mile stretch of the Grasse River extending upstream from the confluence with the St. Lawrence Seaway. The river bottom consists of glacial till, large boulders, cobbles, and rock overlain with soft sediment. A Non-Time-Critical Removal Action (NTCRA) was proposed by ALCOA as a voluntary cleanup of Grasse River sediment located adjacent to the ALCOA Outfall No. 001. Dredging was conducted in response to a 1993 risk assessment which concluded that the site presented unacceptable risk to human health through ingestion of fish, ingestion and dermal contact with sediment, and dermal contact with surface water.

Project Goals and Objectives:
The project goal was to dredge 3,550 cubic yards of highly contaminated sediment from a hotspot located adjacent to the ALCOA outfall. No target concentration criteria were established for the removal. The pilot study was intended to provide site-specific information towards formulation of a full-scale remedy.

Remedial Actions:
Prior to dredging, boulders and cobbles were removed from the study area and silt curtains were installed. Contaminated sediments were dredged from a hotspot area measuring approximately 100 feet by 500 feet in 1995 using a horizontal auger dredge. Approximately 550 cubic yards of sediment were left in-place due to limited accessibility from the unforeseen presence of boulders and cobbles. Dewatered sediment, boulders, and cobbles were disposed of in an ALCOA on-site secure landfill (OHM, 1995).

Long-Term Monitoring:
Monitoring reviewed in this section was conducted in the 4- to 6-month period following completion of dredging with the exception of benthic community monitoring. Benthic community monitoring was scheduled for 1996, but results were not available for review. Results of additional long-term monitoring were also not reviewed.

Physical: A post-dredge bathymetric survey was conducted to determine final elevations for the project. No known long-term physical data was collected.

Chemical: Post-dredging chemical analysis was conducted on sediment and water column samples after completion of dredging in 1995. Monitoring of sediment and water PCB concentrations is ongoing, although data was not available for review.

Biological: PCB concentrations were analyzed in the tissue of both caged and resident fish immediately after dredging. Caged fish were analyzed from four locations adjacent to the dredging site and immediately outside of the silt curtains. Samples were collected in October and November 1995. Resident fish analyses included samples of brown bullhead, smallmouth bass, and spottail shiners collected immediately after dredging in October 1995 from three locations in the Grasse River. A survey of the benthic community was scheduled for 1996. Additional long-term monitoring of fish tissue and the benthic community was to be collected; however, the data was not available for review.

Project Outcome:
Baseline pre-NTCRA dredging samples contained PCB concentrations ranging from non-detect to 11,000 mg/kg, while post-removal PCB samples contained concentrations ranging from 1.1 to 260 mg/kg (BBL, 1995). Only approximately 84 percent of the target volume of sediment was removed because of impediments from rocks and boulders. As expected, caged and resident fish tissue data indicated significant increases in PCB concentrations compared to upstream samples during and immediately following dredging. To date, state fish consumption advisories (general and special populations) are in effect for all fish species from PCB levels. The extent of the advisory is from the mouth of the Grasse River to the Massena Power Canal (EPA, 2000).

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References:

BBL, 1995. Non-Time-Critical Removal Action, Documentation Report, Vol. 1, Grasse River Study Area, Massena, New York. Blasland, Bouck & Lee, Inc. December 1995.

EPA, 2000. Listing of Fish and Wildlife Advisories. Prepared by the U.S. Environmental Protection Agency Office of Science and Technology. Website. http://www.epa.gov/ost/fish.

OHM, 1995. Final Implementation Plan for the Grasse River Study Area Non-Time-Critical Removal Action, Massena, New York. OHM Remediation Services Corp., Massena, New York. April 21.

Project Name: Lake Jarnsjön/River Emån Dredging Project

Location: Municipality of Hultsfred, Sweden

Contaminants of Concern: PCBs

Water Body Type: Lacustrine, Riverine

Period of Performance: Dredged from 1993 to 1994

Background:
In 1981, PCB contamination was found at the mouth of the river Emån. The main source of PCB contamination was traced to Lake Jarnsjön, located along the river. The small lake is situated about 10 km downstream of a paper mill that earlier handled the recycling of waste paper containing PCBs. Large quantities of PCBs were discharged from the paper mill and accumulated in Lake Jarnsjön. Studies have shown that the sediments in Lake Jarnsjön were the dominating source of PCBs in the river system. Approximately 1 kg of PCBs reached Lake Jarnsjön from upstream areas, but approximately 7 kg of PCBs left the sediment every year. Based on this yearly discharge, the 400 kg of PCBs in the sediments would cause biological problems for many years in the river system. In 1991, PCB concentrations were significantly higher in both surface water and resident fish downstream of Lake Jarnsjön as compared to upstream samples.

Project Goals and Objectives:
Dredging and monitoring were conducted to protect human health and the environment.

Remedial Actions:
PCB-contaminated sediments were removed using a horizontal auger suction dredge specially designed to minimize leakage. Dredging started in June 1993, ceased during the winter months, and resumed from May through September. Approximately 192,000 cubic yards of sediment were dredged, dewatered and disposed of in a nearby landfill (Ahlen, 1998).

Long-Term Monitoring:
Although no long-term monitoring was specified in the reviewed documents, post-remedial monitoring was conducted from the completion of dredging until 1996.

> *Physical:* Total suspended solids were monitored at two upstream locations; one station at the outlet of the lake, and two stations downstream of the lake at 10-week intervals from the end of dredging until 1996. The results were not obtained for this review.
>
> *Chemical:* Surface water was monitored weekly for PCBs from May 1995 until 1996. PCB concentrations were also analyzed in surface cores (0 to 0.2 meters) at 54 locations in 1996. Groundwater was analyzed for PCBs through 1997 in the vicinity of the disposal site (Bremle et al., 1998).
>
> *Biological:* Whole fish analysis of 1-year-old perch was completed in 1996 at four locations located near the water sampling locations. Five female and five male fish were collected at each location and analyzed for PCBs. Caged fish studies of perch and trout were performed to measure physiological responses. Measurements included the liver somatic index (LSI), ethoxyresorufin-O-deethylase (EROD) activity, plasma parameters, and histopathological characteristics (Bremle and Larsson, 1998).

Project Outcome:
Remedial dredging at Lake Jarnsjön removed 99 percent of PCB-contaminated sediment from the site. Post-remedial monitoring has shown declines in PCB concentrations in sediment, lake water, and fish.

Project Contact:
None available

References:

Ahlen, 1998. Remediation of PCB-contaminated Sediments in Lake Jarnsjön: Investigations, Considerations, and Remedial Actions. Website. http://www.ambio.kva.se/1998/Nr5_98/aug98_1.html.

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Hultsfred, 2000. Remediation of PCB-Contaminated Sediments in Lake Jarnsjön, Municipality of Hultsfred, Sweden. Last updated June 19. Website. http://nywww.hultsfred.se/miljo/ironeng.htm.

Project Name: Minamata Bay Dredging Project

Location: Minamata Bay, Japan

Contaminants of Concern: Methylmercury

Water Body Type: Marine

Period of Performance: Remedial action from 1977 to 1990; dredged from 1977 to 1987

Background:
Minamata disease is a poisoning disease of the central nervous system caused by methylmercury. The first Minamata disease patient was reported initially as suffering from nervous symptoms of an unknown cause in 1956. It took 12 years to reach the official conclusion that methylmercury was the cause of the disease (Gros, 1999). Between 1953 and 1972, at least 69 people died of methylmercury poisoning. Methylmercury contamination in Minamata Bay and the Agano River were the result of discharges from the manufacture of acetaldehyde by Chisso Co., Ltd. in Minamata City and Showa Senko Co., Ltd located upstream of the Agano River. Discharges of methylmercury to Minamata Bay were estimated to be in excess of 70 to 150 tons.

Project Goals and Objectives:
The goal of the Minamata Bay Dredging and Reclaiming Project, sponsored by the national and prefectural governments and Chisso Co., Ltd. was to rapidly and safely dispose of the methylmercury-contaminated sediment (Hosokawa, 1993). The sediment cleanup criterion was established in 1973 (Provisional Standard for Removal of Mercury-Contaminated Bottom Sediment) at a concentration of 25 mg/kg. The target concentration for mercury in fish tissue was established at 0.4 mg/kg in 1994 based on human health risk assessments. Monitoring was conducted to measure compliance with the target objectives.

Remedial Actions:
Remedial actions commenced in 1977 and consisted of installing dividing nets to trap contaminated fish, dredging and disposal of contaminated sediment, and environmental monitoring. A total of 1,975,000 cubic yards of contaminated sediment were removed from Minamata Bay through dredging (1,025,000 cubic yards) and the creation of a confined disposal facility (950,000 cubic yards) (Yoshinaga, 1995). Dredging continued until 1987. The confined disposal facility created 58 hectares of land and received its final cover in 1990 (Zarull et al., 1999).

Long-Term Monitoring:

Physical: No long-term physical monitoring was obtained for review.

Chemical: Chemical monitoring was conducted to measure concentrations of mercury in water and surficial sediment.

Biological: Long-term monitoring was conducted on fish and shellfish. In the 3-year period from 1994 to 1997, samples of dace, Japanese barbel, and Crucian carp were collected twice a year and analyzed for mercury. Hair samples were also analyzed to measure human exposure.

Project Outcome:
Mercury concentrations in fish declined below the 0.4 mg/kg target level in 1994. The target sediment concentration was also met, with an average surficial sediment concentration of 5 mg/kg and a maximum

concentration of 8.75 mg/kg. Dividing nets were removed and fishing restrictions were lifted in 1997 (Environmental Health Department, 1997).

Project Contact:
None available

References:

Environmental Health Department, 1997. Our Intensive Efforts to Overcome the Tragic History of Minamata Disease. Government of Japan. Website. http://www.eic.or.jp/eanet/en/topic/minamata/index.html.

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Hosokawa, Y. 1993. Remediation work for mercury contaminated bay – experiences of Minamata Bay project, Japan. *Water Sci. Tech.* Vol. 28, No. 8-9, pp. 339-348.

Yoshinaga, K., 1995. Mercury-contaminated sludge treatment by dredging in Minamata Bay. Dredging, Remediation and Containment of Contaminated Sediments, ASTM STP 1293, K. R. Demars, G. N. Richardson, R. N. Yong, and R. C. Chaney, Eds. ASTM, Philadelphia, pp. 182-191.

Zarull, A. M., J. H. Hartig, and L. Maynard, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin. August. Website. http://www.ijc.org/boards/wqb/ecolsed/csae.html.

Project Name: New Bedford Harbor Dredging Project

Location: Bristol County, Massachusetts

Contaminants of Concern: Primarily PCBs; some heavy metals

Water Body Type: Marine/Estuarine

Period of Performance: Dredged from 1994 to 1995 (hotspot removal)

Background:
The 18,000-acre New Bedford site is an urban tidal estuary with sediments that were highly contaminated with polychlorinated biphenyls (PCBs) and heavy metals. Manufacturers in the area used PCBs while producing electric devices from 1940 to the late 1970s. Factories discharged industrial process wastes containing PCBs directly into the harbor and indirectly via the city's sewerage system. As a result, 6 miles of the harbor was contaminated, extending from the upper Acushnet River through the Upper and Lower Harbors, and downstream to Buzzards Bay (Otis, 1994). Levels of PCBs in some fish and lobsters at the site exceeded the Food and Drug Administration's (FDA) limit for PCBs in edible seafood. Bioaccumulation of PCBs within the food chain resulted in closing the area to lobstering and fishing, and recreational activities and harbor development have been limited by the widespread nature of the PCB problem. A final Record of Decision (ROD) was issued in 1998 for remediation of the Upper and Lower Harbors.

Project Goals and Objectives:
The goal of the project was to perform source control remediation by removing contaminated sediments with greater than 4,000 ppm PCBs (mostly in the river). A long-term monitoring program was developed to assess the effectiveness of this remediation through measurements of spatial and temporal biological and chemical change. Monitoring was also conducted to measure compliance with water quality standards and FDA standards for PCBs in seafood.

Remedial Actions:
Contaminated sediments were dredged from hotspot areas located upstream in the upper Acushnet River in 1994 and 1995. A total of 14,000 cubic yards of sediment were removed using a hydraulic cutterhead dredge from an area of approximately 5 acres. The dredged slurry was transported to a holding area through a floating pipeline for dewatering and storage. Although the ROD specified on-site incineration, contaminated sediments were transported to an off-site landfill due to public opposition.

Long-Term Monitoring:
The long-term monitoring program has been proposed with full-scale sampling events every 3 to 5 years, or before and after major remedial actions. Additional remedial actions are anticipated for the Upper and Lower Harbors, and the long-term monitoring will likely serve as post-remediation verification sampling data. In addition, mussel bioaccumulation will be conducted twice a year and a wetland assessment will be conducted every 10 years (EPA, 1996). Since the post-remedial verification sampling event, one round of long-term monitoring samples have been collected. Measurements included in the monitoring program are summarized below.

Physical: Physical measurements in the long-term monitoring program included total organic carbon, grain size, and texture for sediment samples.

Chemical: Grab samples from the top 2 cm of surficial sediments were collected with a Young-modified Van Veen grab sampler. Chemical analyses were conducted for PCBs, PCB congeners, metals, and acid volatile sulfide. Surface water samples for PCBs were not included in the monitoring program due to high cost and the low concentrations present (Bergen, 1998). Results of *Mytilus edulis* (blue mussel) bioaccumulation were used to assess water quality instead (see biological section).

Biological: Biological testing in the long-term monitoring program included sediment toxicity testing, benthic community analysis, and bioaccumulation. Sediment toxicity tests were conducted on surface grab samples of the top 2 cm. Acute sediment toxicity was evaluated as a percentage of control survival of the benthic amphipod, *Ampelisca abdita*. Surface grabs of the top 7 cm were collected for benthic community analyses. Specific endpoints measured included species richness, the EMAP index of benthic community condition, and community structure. Bioaccumulation of PCBs in the water column was evaluated through analysis of *Mytilus edulis* (blue mussel) tissue. Tissue of *Fudulus heteroclitus* (mammichog) were also examined because they feed mainly on material coming from sediment and spend their life cycle in a relatively small area.

Project Outcome:
A qualitative graphical technique was combined with exploratory statistical techniques to examine the spatial and temporal variability in concentrations of PCBs and proportions of the congeners. The combination of the two techniques with PCB congener ratios revealed subtle changes after remediation that were not evident by a more traditional statistical analysis of total PCB concentrations. Although major redistribution of contaminated sediments were confined to the immediate vicinity of remedial activities, there is evidence that low molecular weight PCBs were transported farther (EPA, 1996). For more detailed information regarding remedial actions, site-specific difficulties, analytical results, and lessons learned, refer to the Sediment Technologies Memorandum located in Appendix B of the Lower Fox River Feasibility Study document.

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References:

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EPA, 1996. New Bedford Harbor Long-Term Monitoring Assessment Report: Baseline Sampling. Research Report. U.S. Environmental Protection Agency. Document 600/R-96/097. October.

Otis, M. J., 1994. New Bedford Harbor, Massachusetts dredging/disposal of PCB-contaminated sediments. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. p. 579-587.

Project Name: Santa Gilla Lagoon Dredging Project

Location: Santa Gilla Lagoon, Southern coast of Sardinia Island, Italy

Contaminants of Concern: Mercury, Lead, Zinc

Water Body Type: Estuarine

Period of Performance: Dredging completed in 1992

Background:
The Santa Gilla lagoon, on the southern coast of the island of Sardinia, received industrial discharge of mercury, lead, and zinc compounds, as well as municipal untreated sewage for several decades from the urban area of Cagliari (about 400,000 inhabitants). An estimated 26 tons of mercury, discharged from a chlor-alkali plant, have been deposited in the lagoon since the mid-1960s, mostly confined to a 2-km^2 area located in front of the industrial area. The lagoon, which covers an area of 15 km^2 of shallow water, represents an important source of fish and shellfish for the island. Pollution sources were brought under control in the mid-1980s, when a costly restoration program (still in progress) was started; however, metals contamination has resulted in the restriction of fishing in the lagoon since 1974.

Project Goals and Objectives:
The purpose of the project was to restore productive use to the area for aquaculture through removal of contaminants. Another objective was to improve the water exchange with the Mediterranean Sea to increase salinity, which was important for the productive reuse of the area for commercial fishing.

Remedial Actions:
The cleanup action included dredging of sediments from polluted areas of the lagoon and isolating the most mercury-contaminated sector through construction of a dyke. Dredged sediment was placed in the dyked area and capped with clean sediment. Dredging was completed in 1992, resulting in the removal of approximately 6,000,000 m^3 of sediment. To increase salinity, a channel 1.5 to 3 meters deep and 300 meters wide was dredged along the central axis of the lagoon, along with a series of smaller parallel channels that branched away from the main canal.

Long-Term Monitoring (post construction to 1 year):
Although implementation of a long-term monitoring program had not occurred at the time of this review, actions recommended in the 1997 publication (Degetto et al., 1997) included:

- Determination of the different chemical forms of mercury, which play a critical role in the partitioning of this element within the biosphere.

- *In-situ* and on-site field experiments for the confined disposal facility (CDF) site, using enclosed area structures, to determine fish and/or crustacean contamination by mercury and other heavy metals present.

Physical: No physical monitoring data was available for review.

Chemical: Mercury concentrations were measured in surficial sediment samples collected from five stations 1 year following dredging.

Biological: No biological monitoring data was available for review.

Project Outcome:
According to Degetto et al, the actual degree of success in restoring this part of the lagoon, which is still connected to the sea, can be completely established only after an ad hoc monitoring program is carried out in the near future.

Project Contact:
None available

Reference:
Degetto, S., M. Schintu, A. Contu, and G. Sbrignadello, 1997. Santa Gilla lagoon (Italy): A mercury sediment pollution case study, Contamination assessment and restoration of the site. *The Science of the Total Environment.* 204:49-56.

Project Name: Shiawassee River Dredging Project

Location: Howell, Michigan

Contaminants of Concern: PCBs

Water Body Type: Riverine

Period of Performance: Dredged in 1982 (pilot); monitored in 1982 and 1983

Background:
Discharge of PCB-contaminated wastewater derived from the manufacture of aluminum cast products resulted in sediment contamination along a 14-mile stretch of the Shiawassee River. The State of Michigan decided that dredging was the best way to remove PCB contamination from the south branch of the Shiawassee River. PCBs in the Shiawassee River presented risk through ingestion of fish and direct contact with river sediments.

Project Goals and Objectives:
Monitoring was used at the Shiawassee River to measure the efficiency of dredging as a means of sediment-bound contaminants and its potential for increasing toxicant concentrations and bioavailability downstream. The remedial objective was to remove contaminated sediments in areas with PCB concentrations in excess of 10 ppm to achieve a PCB concentration of 1 ppm (GE/AEM/BBL, 2000). Conclusions were drawn from monitoring conducted prior to dredging, during dredging, and up to 6 months following dredging.

Remedial Actions:
Pilot dredging of approximately 1 mile of the most contaminated sediment was completed between August and November 1982. The action resulted in the removal of 1,974 cubic yards of river sediment containing an estimated 2,531 pounds of PCBs through hydraulic dredging with a dragline by divers and mechanical removal with a backhoe (EPA, 1998).

Long-Term Monitoring:
To coincide with cleanup operations conducted in 1982, the University of Michigan monitored the impact and results of dredging through studies of PCB uptake by caged fingernail clams and fathead minnows. Monitoring was completed during the 6 months following dredging. Although not considered part of an established monitoring program, additional resident fish tissue analysis was completed by Michigan Department of Natural Resources (MDNR) in 1994 and 1995. A third investigation was completed by Malcolm Pirnie in 1994. This investigation included analysis of PCB aroclor concentrations in 28 river sediment samples, nine wetland sediment samples, resident fish (rock bass, white suckers, pumkinseed, and bluegill), and resident crayfish (Malcolm Pirnie, 1995).

> *Physical:* Physical monitoring of surface water included pH, temperature, dissolved oxygen, specific conductance, and total suspended solids. One control and four study sites were monitored for physical parameters. The study sites were located 0.25 mile, 1.0 mile, 3.3 miles, and 6.8 miles downstream of the contamination source outfall. The dredge area included areas from the outfall to approximately 1.5 miles downstream. Two of the monitoring locations were therefore located within the area of the river where dredging took place.
>
> *Chemical:* Stream water was collected every 2 to 3 weeks in the spring and summer of 1983 following dredging. Both filtered surface water and suspended solids from surface water samples

were analyzed for PCBs. Water chemistry was analyzed at the same control and study sites used for physical monitoring.

Biological: Caged fish studies of fathead minnows, *Pimephales promelas*, were analyzed for PCBs after exposure periods of 62 days. Samples were collected from the control site and the study sites located 1.0 mile downstream and 6.8 miles downstream. Caged PCB bioaccumulation studies were also conducted on the fingernail clam, *Sphaerium striatinum*. Concentrations of PCBs were evaluated after exposure periods of 14 to 45 days. Caged fingernail clams were analyzed from the same locations as physical and chemical water samples (Rice and White, 1987).

Project Outcome:
Post-dredge monitoring of water, clams, and fish confirmed that significant amounts of PCBs were released from the sediments during dredging. At all locations downstream and in the area of the dredging, there were increases in the biological availability of PCBs for at least 6 months. PCB concentrations in caged fingernail clams and fathead minnows in the dredged zone increased from 64.5 to 87.95 µg/g dry weight and from 13.82 to 18.30 µg/g dry weight, respectively. There was no noticeable change in total PCB concentration in the water.

Project Contact:
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References:
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Malcolm Pirnie, 1995. Development of Sediment Quality Objectives for PCBs for South Branch Shiawassee River, Livingston County, Michigan. Prepared for Michigan Department of Natural Resources. June.

Rice, C. P., and D. S. White, 1987. PCB availability assessment of river dredging using caged clams and fish. *Environmental Toxicology and Chemistry.* Vol. 6. pp 259-274.

Project Name: United Heckathorn Dredging Project

Location: Richmond, California

Contaminants of Concern: Pesticides (primarily DDT and dieldrin)

Water Body Type: Marine

Period of Performance: Dredged in 1996 and 1997; monitoring ongoing

Background:
Pesticides, including DDT and dieldrin, were formulated and packaged at the United Heckathorn Site in Richmond Harbor. Contamination was present in sediment, surface water, and biota in 13.5 acres of the Lauritzen Channel and Parr Canal. The Lauritzen Channel and Parr Canal are dead-end channels branching from the Santa Fe Channel, which flows into Richmond Harbor in San Francisco Bay. Fish in the Lauritzen Channel exceeded the Food and Drug Action Levels for DDT and dieldrin (USFWS, 2000).

Project Goals and Objectives:
The goal of the remedy was to provide overall protection of human health and the environment and enable natural recovery of the benthic and water column communities. A target level of 590 ppb DDT was established for removal of sediment to meet a human health risk of 10^{-6}. Project cleanup levels in water were 0.59 ppt for total DDT and 0.14 ppt for dieldrin. A 5-year monitoring program has been implemented to measure achievement of project goals and objectives.

Remedial Actions:
Pesticide-contaminated soft sediment was mechanically dredged down to hard underlying deposits using long-stick excavators between August 1996 and April 1997. A cable arm clamshell was used for soft sediment and a conventional clamshell was used for harder material below. A total of 108,000 cubic yards of sediment were removed, solidified, and disposed in off-site landfills. Dredged areas were backfilled to a depth of 6 to 18 inches with 15,700 cubic yards of sand (GE/AEM/BBL, 2000).

Long-Term Monitoring:
The long-term monitoring program established to evaluate the United Heckathorn project was initiated 6 months after completion of remediation and is scheduled to continue for a period of 5 years. A provision was included to extend the monitoring program if monitoring goals were not achieved (Lincoff & Kohn, 1997).

Physical: No physical monitoring is known to be included in the program.

Chemical: Samples were collected from the water column at various stations and analyzed for DDT and dieldrin. Although not a part of the monitoring program, four samples of the top 10 inches of sediment were collected by EPA in November 1998 based observation of elevated DDT concentrations in a sediment sample collected by the institute of Marine Sciences at the University of California, Santa Cruz in October 1998.

Biological: Biological monitoring included analysis of California mussels (*Mytilus californianus*) and resident mussels for pesticides. California mussels were placed at four stations for a period of 4 months each year. Resident mussels were collected to measure long-term exposure. Tissues were analyzed and lipid normalized. The biological monitoring program was designed to be comparable with the California State Mussel Watch Program, which monitored mussel pesticide concentrations in the harbor from 1987 to 1993 (Battelle, 1999).

Project Outcome:
Sediment and water column sampling indicate that elevated concentrations of DDT and dieldrin are present at concentrations significantly higher than remediation goals. Biological monitoring, however, has shown dramatic reductions of DDT and dieldrin in resident and transplanted mussels.

Project Contact:
None available

References:

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Lincoff, A. and N. Kohn, 1997. The United Heckathorn Superfund Site: NPL Listing to Sediment Remediation. Presented at the SETAC 18th Annual Meeting. San Francisco, California. November 16-20.

Project Name: Waukegan Harbor Dredging Project

Location: Waukegan, Illinois

Contaminants of Concern: PCBs

Water Body Type: Lacustrine

Period of Performance: Remedial action from 1990 to 1994; dredged from 1991 to 1992

Background:
The Waukegan Harbor Area of Concern (AOC) is located in Lake County, Illinois, on the west shore of Lake Michigan. The harbor receives drainage from Waukegan River basin and subsequently discharges to Lake Michigan. Hydraulic fluid containing PCBs used in die cast works was discharged to Waukegan Harbor from 1961 to 1972. Approximately 300,000 pounds of PCBs were released to the harbor resulting in sediment contamination, benthos degradation, dredging restrictions, beach closings, degradation of phytoplankton and zooplankton populations, and fish advisories.

Project Goals and Objectives:
After a lengthy litigation process, a Consent Decree was entered by the U.S. Justice Department in District Court in 1989. The Consent Decree called for remediation of the contaminated sediments greater than 50 ppm PCBs. EPA calculations showed that removal of sediment to a concentration of 50 ppm would result in removal of 96 percent of the PCB mass in the Upper Harbor. Long-term remedial action objectives were protection of human health and the environment (GE/AEM/BBL, 1998).

Remedial Actions:
Remedial activities were conducted between 1990 and 1994. Hydraulic dredging took place in late 1991 and early 1992 using an 8-inch cutterhead and a 10-inch cutterhead. Dredged sediment was placed in a confined disposal facility (CDF) created from Slip 3 and capped after 2 years and 5 months of settling. Approximately 32,000 cubic yards of PCB-contaminated sediment were removed from the Harbor and an additional 6,300 cubic yards of PCB-contaminated sediment (in excess of 500 mg/kg PCBs) were removed from Slip 3. Sediment removed from Slip 3 was treated and returned to the Slip 3 containment cell. To offset the loss of Slip 3, another slip was constructed and opened to the public in July 1991 (IJC, 1999).

Long-Term Monitoring:
Long-term fish tissue monitoring was conducted by the U.S. EPA from 1978 through 1983 and is now monitored by the Illinois State EPA (1991 through present). A one-time sampling event was conducted in 1996, approximately 4 years after the harbor was dredged. Monitoring parameters in the 1996 event included surface sediment chemistry, sediment toxicity testing, and bioaccumulation studies. No other long-term monitoring programs for biological parameters were known to exist. A 30-year operation and maintenance plan (OMMP) is in place for long-term monitoring of the CDF site.

> *Physical:* A network of groundwater monitoring wells were installed around the CDF and are periodically sampled for PCBs in accordance with the OMMP. No other physical monitoring data was available for review.
>
> *Chemical:* Sediment samples from 18 locations in Waukegan Harbor were collected and analyzed for PCBs in April 1996. Although not contaminants of concern (COCs) for the remedial project, samples were also analyzed for metals and PAHs.

Biological: Sediment toxicity was evaluated in 20 samples collected in April 1996. Toxicity testing included 42-day whole sediment toxicity analysis of the amphipod *Hyalella azteca* for survival, growth, and reproduction, 28-day whole sediment bioaccumulation tests of the oligochaete *Lumbriculus variegatus*, and bacteria sediment toxicity measurements through luminescent light emission (EPA, 1998).

Carp fillet samples were collected and analyzed for PCBs from 1993 to 1998. More recent data was not available for review. Sample sizes ranged between one and six fish.

Project Outcome:
As a result of the dramatic decline in PCBs in fish, some posted Waukegan Harbor fish advisories were removed, although fish advisories still exist for carp and other harbor fish. PCB concentrations in Waukegan Harbor fish are now considered to approximate fish found elsewhere in Lake Michigan.

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References:
EPA, 1998. Evaluation of the Toxicity and Bioaccumulation of Contaminants in Sediments Samples from Waukegan Harbor, Illinois. U.S. Environmental Protection Agency. Website. http://www.epa.gov/glnpo/sediment/waukegan/index.html.

GE/AEM/BBL, 1998. Outboard Marine. Website. http://www.hudsonwatch.com.

IJC, 1999. Ecological Benefits of Contaminated Sediment Remediation in the Great Lakes Basin, Case Study: PCB Contaminated Sediment Remediation in Waukegan Harbor. International Joint Commission. Website. http://www.ijc.org/boards/wqb/ecolsed/cases.html.

Project Name: Hamilton Harbour *In-Situ* Capping Demonstration Project

Location: Hamilton Harbour, Lake Ontario, Canada

Contaminants of Concern: Metals (Zn, Cu, Pb, Cr, Ni, Cd, As, Hg)

Water Body Type: Lacustrine

Period of Performance: Demonstration *in-situ* capping in 1995; monitoring from 1995 to Present

Background:
Sediments in Hamilton Harbour exceeded the Ontario Ministry of Environmental and Energy (OMEE) sediment quality guidelines at the severe effect level for several metals. The industrial-contaminated sediments were generally confined to the upper 30 cm of very soft clay underlain by very soft silty clay (natural sediment). Environmental impacts included risks to human health through exposure and fish consumption and risks to the environment including adverse impacts to fish and wildlife.

Project Goals and Objectives:
A demonstration project was implemented to assess the feasibility of capping as a remedy for containment of contaminated sediments. A monitoring program was established to assess the long-term mobility of trace elements through the cap material and the physical stability of the cap.

Remedial Actions:
A demonstration *in-situ* capping project was performed on a 100-meter by 100-meter area of contaminated sediments in Hamilton Harbour in 1995 (Zeman and Patterson, 2000). The capping material was clean sand with an average grain size of 0.5 mm. The cap was placed using a custom-designed hopper and a series of 20 130-mm diameter by 12-meter long tremie tubes. Sand was applied in three lifts to achieve a final thickness of approximately 35 cm (Azcue et. al, 1998).

Long-Term Monitoring:

Physical: Bathymetry was completed by acoustic surveys. The cap thickness was measured by divers using handheld probes. Grain size and shear strength were analyzed on cores taken from the cap.

Chemical: Sediment cores were collected and analyzed for metals in sediment and pore water. Cores were collected one to two times per year from 1995 through 1998. Pore water analysis for metals will continue thorough 2000. Results were evaluated to monitor contaminant migration through the cap and the redox state of the metals.

Biological: Biological monitoring was limited because results were not considered useful for evaluation of the project. This was due to the small area of the cap and the presence of contamination surrounding the capping area. A single sampling event was conducted after completion of the cap for biological toxicity (Zeman, 2000). Toxicity was evaluated through bioassays on the chironomid, *Chironomid riparius*, the amphipod, *Hyalella azteca*, the mayfly, *Hexagenia*, and the oligochaete worm, *Tubifex tubifex* (Zeman et. al, 2000).

Project Outcome:
Significant reductions in the flux of site contaminants were observed after capping of the contaminated sediments. Oxygen-sensitive elements such as iron and magnesium were shown to remobilize in anoxic sediments and precipitate in the oxic interface.

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References:

Azcue, J. M., A. J. Zeman, A. Murdoch, F. Rosa, and T. Patterson, 1998. Assessment of sediment and pore water after one year of subaqueous capping of contaminated sediments in Hamilton Harbour, Canada. *Wat. Sci. Tech.* Vol. 37, No. 6-7, pp. 323-329.

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Zeman, A. J., T. S. Patterson, A. Mudroch, F. Rosa, T. B. Reynoldson, and K. E. Day, 2000. Results of Baseline Geotechnical Chemical and Biological Tests for a Proposed *In-Situ* Sediment Capping Site in Hamilton Harbour. Submitted to the Water Quality Research Journal of Canada for publication. Website. http://www.hsrc.org/capping/zeman1.html.

Zeman, A. J. and T. S. Patterson, 2000. Preliminary Results of Demonstration Capping Project in Hamilton Harbour, Ontario. Submitted to the Water Quality Research Journal of Canada for publication. Website. http://www.hsrc.org/capping/zeman4.html.

Project Name: New York Mud Dump Capping Project

Location: New York, New York

Contaminants of Concern: Dioxin

Water Body Type: Marine

Period of Performance: Placement of dredged sediment and cap from 1993 to 1994; monitoring from 1992 to Present

Background:
The mud dump site is an open-water sediment disposal site located off the coast of New York. Sediments from the berthing areas at the Port Authority of New York and New Jersey were placed at the dump site and contained trace levels of dioxin. After disposal of contaminated material, a clean sand cap was placed over the material to prevent contaminant migration. Due to concern over the potential effects of dredging and disposal of the material, a comprehensive monitoring and management program was implemented to evaluate long-term effectiveness of capping dioxin-contaminated sediments at the New York Mud Dump Site.

Project Goals and Objectives:
The purpose of long-term monitoring was to document the physical integrity of the cap and the effectiveness of the sand cap for preventing vertical migration of dioxin from the dredged material into the overlying water and benthic community.

Remedial Actions:
Under a permit issued to the Port Authority of New York and New Jersey by the Corps of Engineers, New York District, over 500,000 cubic yards of dioxin-contaminated sediments were disposed of within the New York Mud Dump Site. Sediments were capped with roughly 2,500,000 cubic yards of sand to achieve a cap thickness of 1 meter as required by the disposal permit (McDowell et al., 1994).

Long-Term Monitoring:
Long-term monitoring is being conducted to verify that the cap has effectively isolated the contaminated dredged material from the benthic environment and overlying water column.

> *Physical:* A high-resolution bathymetry survey was conducted on the capped disposal mound and compared to baseline data. Additional physical data collection included REMOTS® sediment profile photography, subbottom profiling to determine cap thickness and assess changes in thickness over time, and geotechnical analysis of cores taken of the cap material and underlying dredged material.
>
> *Chemical:* Chemical analyses were conducted on surficial sediment samples of the capped mound. Sediment cores were analyzed to obtain chemical data for the capping material sediment and underlying sediment.
>
> *Biological:* Tissue sampling was conducted for chemical analysis. No further information is available at this time.

Project Outcome:
Engineering of cap construction was considered a success.

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Reference:

McDowell, S., B. May, and D. Pabst, 1994. The dioxin capping project at the NY mud dump site. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1270-1277.

Project Name: Simpson Capping Project

Location: Tacoma, Washington

Contaminants of Concern: Phenolics, PAHs

Water Body Type: Marine/Estuarine

Period of Performance: Remedial action from 1987 to 1988; Capping in 1988

Background:
The Simpson Cap, located near the St. Paul Waterway, was the first aquatic remedial action in the Commencement Bay Nearshore Tideflats Superfund Site located in Tacoma, Washington. Discharge of untreated wastewater from pulp and paper mills, log storage and handling, wood chip handling, and stormwater runoff led to contamination of marine sediments with phenolic compounds and PAHs. Sediment concentrations were above sediment quality guidelines considered protective of environmental health.

Project Goals and Objectives:
The project goal was designed to permanently isolate the chemical contamination found in the marine sediments, and restore intertidal and shallow water habitat. These two objectives were met by capping contaminated marine sediments in-place and by providing habitat features on the surface of the cap to encourage recolonization by benthic infauna and macrophytes (algae) and usage by fish and birds. A 10-year monitoring program was developed to measure achievement of project goals and objectives.

Remedial Actions:
Remediation of the 17-acre area of contaminated sediment occurred in 1987 and 1988. Application of the cap took place in July and August of 1988. Black sand obtained from the nearby Puyallup River was used as the clean capping material because it was physically suitable for isolation of contaminated sediment and would provide a desirable substrate for marine life. The capping material was hydraulically dredged through a pipeline and placed with a downpipe diffuser. The final cap thickness ranged from approximately 2.5 meters to 6.5 meters. Riprap was placed to prevent erosion from wave action in high intertidal areas (Stivers and Sullivan, 1994).

Long-Term Monitoring (10-year):
A 10-year monitoring program was developed to evaluate performance of capping in achieving physical and chemical isolation of contaminated sediments and provision of habitat for benthic infauna.

Physical: Periodic bathymetry surveys were completed to examine the project for large-scale changes in cap structure. Five transects were established to measure elevation changes.

Chemical: Through-cap sediment cores were periodically taken from 6 to 12 permanent sampling locations. Cores were collected from a hollow-stem auger drill rig on a barge using the rig to drive shelby tubes. Bulk chemistry samples were collected from depths of 25 to 45 cm and 75 to 95 cm above the cap/underlying sediment interface and 25 to 45 cm below the cap surface.

Surface sediments were sampled for bulk chemistry at six permanent locations. Samples were collected using a Van Veen grab sampler. Additionally, bulk chemistry samples were collected and analyzed at intertidal seeps and naturally occurring methane vents to determine if contaminant transfer was present in these locations.

Biological: Habitat restoration monitoring included benthic infauna and epibenthos sampling at six stations and qualitative macrophyte sampling. Benthic organisms were sieved from the top layer of sediment, enumerated, and taxonomically identified to the lowest taxonomic level possible. Epibenthos were sampled using a suction pump sampler, enumerated, and identified. Qualitative macrophyte monitoring was completed through annual aerial photographs and visual surveys during low tides in late summer.

Project Outcome:
Remediation of contaminated sediment was integrated with natural resource restoration to produce 6 acres of intertidal and 11 acres of subtidal habitat. In general, monitoring results indicate that the cap and new habitat are both functioning as planned. The chemical contaminants in the original sediments appear to be remaining in place, effectively isolated from the biologically important environment of Commencement Bay (Murray et al., 1994).

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References:

Murray, P., D. Carey, and T. J. Fredette, 1994. Chemical flux of pore water through sediment caps. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1008-1015.

Stivers, C. E. and R. Sullivan, 1994. Restoration and capping of contaminated sediments. *Dredging '94: Proceedings of 2nd International Conference on Dredging and Dredged Material Placement, 14-16 November 1994, Orlando, Florida.* E. C. McNair, ed. American Society of Civil Engineers, New York. pp. 1017-1026.

Project Name: Wyckoff/East Eagle Harbor *In-Situ* Capping Project

Location: Bainbridge Island, Washington

Contaminants of Concern: Polyaromatic Hydrocarbons (PAHs)

Water Body Type: Marine

Period of Performance: Capping from 1993 to 1994; monitoring from 1993 to Present

Background:
Eagle Harbor is an embayment of Puget Sound near Seattle, Washington. Chemicals seeping from a former wood treatment plant located in adjacent uplands resulted in PAH sediment contamination. The area was listed as a Superfund site in 1987 by the Environmental Protection Agency (EPA). The site was divided into east and west operable units because sediments were primarily contaminated with mercury in the West Harbor, while PAHs were the primary contaminant in the East Harbor. Elevated PAH Concentrations in surface sediment were above the state management standards for protection of benthic invertebrates. Capping was chosen as the remedial action for PAH contamination in the East Harbor.

Project Goals and Objectives:
The intent of the cap application was to ensure that sediment contamination was within or below the range of minor biological effects and protective of human health. Objectives of the monitoring program were to measure effectiveness of the cap, compare results to contaminant concentrations in off-cap subtidal sediments in East Eagle Harbor, and evaluate source control within the capping area. Specific objectives for each of these categories are outlined below (Nelson et al., 1994).

The monitoring objectives for the cap area were presented as four monitoring objectives:

1. Is the cap material physically stable, remaining in place at the desired thickness?

2. Is the cap effectively isolating the underlying contaminated sediments?

3. Are sediments in the biologically active zone (0 to 10cm) remaining clean relative to the Washington State sediment management standards (SMS)?

4. Is the cap being recolonized by benthic (bottom-dwelling) organisms (i.e., benthic invertebrates and fishes)?

The objectives for source control were presented as three monitoring objectives:

1. Determine whether intertidal seeps of product have been reduced or controlled.
2. Determine whether suspended particulates in the operable unit are contaminated.
3. Determine whether recently deposited sediments in the operable unit are contaminated.

Remedial Actions:
During the fall and winter of 1993-1994, the U.S. Army Corps of Engineers placed approximately 250,000 cubic meters of dredged material over approximately 54 acres of PAH-contaminated sediment in Eagle Harbor. Capping material was obtained from a navigational dredging project approximately 30 miles away. The proposed capping approach divided the capping area into two application areas based on physical characteristics of the bottom sediments. The first area was capped with fine to medium sands,

and the second with predominantly silt. The cap was designed as a 0.9-meter layer of dredged material over the existing bottom (EPA et al., 1994).

Long-Term Monitoring:
The long-term monitoring program is a tiered program focusing on the first 10 years after completion of the remedial action (SAIC, 1996; SAIC, 1998; EPA et al., 1995). The type and frequency of monitoring may be adjusted or monitoring may be discontinued provided project objectives are met.

Physical: Long-term physical motoring of the cap included bathymetry, subbottom profiling, REMOTS® sediment profile photography, and video surveys.

Chemical: Measurements of chemical parameters were made through on-cap cores, surface sediment samples collected at seeps, and sediment collected in sediment traps.

Biological: Biological monitoring included observations using towed underwater video surveys, and REMOTS® sediment profile photography. Benthic infauna measurements were also conducted to assess recolonization of the cap.

Project Outcome:
As of 1997 (year 3 monitoring), the following observations have been made regarding the cap:

- The cap appears to be physically stable, with the exception of some erosion near the Washington State Ferry terminal.
- Creosote contamination may have migrated up into the cap at two locations.
- PAH concentrations in suspended particulate material captured in sediment traps appear to be decreasing.
- Surface sediment concentrations of PAHs have generally increased.
- Biological habitat quality of the cap is improving with time, as suggested by the organism-sediment index (OSI) values derived from the REMOTS® sediment profile photography.

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References:
EPA, USACE, SAIC, 1994. On-Scene Coordinator's Report, Statement of Findings: East Harbor Operable Unit Removal Action, Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington. Final Report. Prepared by U.S. Environmental Protection Agency, Region 10, and the U.S. Army Corps of Engineers, Seattle District with assistance by Science Applications International Corporation, Bothell Washington.

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Final Report. Prepared by U.S. Environmental Protection Agency, Region 10, and the U.S. Army Corps of Engineers, Seattle District with assistance by Science Applications International Corporation, Bothell Washington.

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Project Name: James River Monitored Natural Recovery (MNR) Project

Location: Hopewell, Virginia

Water Body Type: Estuarine

Period of Performance: No active remediation; monitoring from 1978 to Present

Background:
A pesticide factory located in Hopewell, Virginia discharged kepone, a chlorinated pesticide, to the James River through the municipal sewage system, surface runoff and solid waste dumping. The 81-mile James River estuary extends from 7 miles above the contaminant source to Chesapeake Bay. Pesticide contamination was present in sediments, water column, biota, and small mammals. The estimated volume of contaminated sediment was 221 million cubic yards. Average kepone concentrations in the river channel ranged from 20 to 193 ppb. The maximum concentration (12 ppm) was detected close to the source. The regulatory action was a mitigation feasibility study with oversight by EPA (GE/AEM/BBL, 1998).

Project Goals and Objectives:
The principal goal of the remedial action was to reduce concentrations of kepone in fish and crab and to eliminate all consumption advisories for protection of human health. The action levels established for biota were 0.3 ppm in fish and 0.4 ppm in blue crab. Advisories included a commercial fishing ban and a subsistence fish consumption advisory. A secondary goal of the remedy was to eventually lift a moratorium on maintenance dredging of the main channel.

Remedial Actions:
An investigation of remedial options (stabilization, dredging, and retrievable sorbents) conducted in 1978 indicated a minimum cost of $3 billion for active remediation. The high cost and concern over biological effects of resuspension led to selection of natural recovery remedy though burial by natural sedimentation. A long-term monitoring program was implemented beginning in 1978 (Committee on Contaminated Marine Sediments, 1997).

Long-Term Monitoring:
The monitoring program was based primarily on biological sampling because the remedy was to be protective of human health through bioaccumulation and consumption. No kepone criteria was established for sediment or surface water.

Physical: No long-term physical monitoring is known to exist.

Chemical: Sediment cores and surface water samples were collected and analyzed for kepone concentrations. Monitoring of sediment and surface water was discontinued several years ago (Unger, 2000).

Biological: Tissues of fish, crab, and oyster have been included in long-term monitoring for kepone concentrations. The extent of biological monitoring has changed significantly over time as more data has become available and kepone concentrations have decreased. Crab and oyster sampling was discontinued in 1985. Fish monitoring is still conducted, although the monitoring has declined from intensive to approximately 100 to 150 fish per year. Early in the study, many species of fish were analyzed. Recent fish sampling has been limited to mostly piscivorous fish, especially striped bass, because historic data has measured the highest biological kepone concentrations in these fish (Unger, 2000).

Project Outcome:
Kepone concentrations were reduced in crab and oyster from 0.8 ppm in 1976 to 0.1 to 0.2 ppm in 1985. The commercial fishing ban was lifted in 1988. A restricted consumption advisory for the general population remains in place for all fish (EPA, 1998).

Project Contact:
None available

References:

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Project Name: Sangamo-Weston Monitored Natural Processes (MNP) Project

Location: Pickens, South Carolina

Contaminants of Concern: PCBs

Water Body Type: Riverine/Lacustrine

Period of Performance: No active remediation; monitoring ongoing from 1992 to Present.

Background:
Discharges from Sangamo-Weston, Inc. a capacitor manufacturing plant, resulted in PCB contamination of sediments along a 7-mile portion of Twelvemile Creek and into Hartwell Lake. Typical surface sediment PCB concentrations in Twelvemile Creek ranged from 1 to 3 ppm with slightly higher concentrations in deeper sediment. Maximum concentrations in depositional areas measured as high as 61 ppm. Maximum PCB concentrations in upper Lake Hartwell measured from 5 to 11 ppm. Typical PCB concentrations in the lower lake measured below 1 ppm. Elevated PCB sediment and fish tissue concentrations resulted in posting of fish consumption advisories for all fish species collected in the project area.

Project Goals and Objectives:
The target sediment cleanup level was established at 1 ppm PCBs for the protection of human health based on technical feasibility. Estimates were made through modeling that FDA safe fish consumption levels of 2 ppm PCBs would be reached in largemouth bass after 12 years of MNP (1992 to 2004). A carcinogenic risk-based study determined that a fish concentration of 0.036 ppm resulted in a 10^{-4} risk to anglers through ingestion of fish. However, the risk-based fish cleanup goal was determined to be technically impractical and the FDA level was considered acceptable based on cost versus risk reduction estimates (GE/AEM/BBL, 2000).

Remedial Actions:
The removal, treatment, and disposal of contaminated sediment was rejected as too costly ($500 million) and judged technically infeasible to achieve the 1 ppm cleanup level. Aggressive engineering controls were also rejected as too costly and not providing significant risk reduction.

Natural recovery supplemented by institutional controls (periodic flushing) was selected as the only remedy. A long-term monitoring program commenced in 1995 to fulfill the requirements of the June 1994 Final Record of Decision requiring aquatic biota monitoring and sediment sampling. EPA Region 4 issued a Unilateral Administrative Order on September 25, 1998 requiring the potentially responsible parties to implement a fish consumption advisory and public education program, to perform annual aquatic biota and sediment monitoring to determine PCB levels in fish and other aquatic life, and to periodically flush sediment past three impoundments to facilitate burial of PCB-impacted sediments located downstream.

Long-Term Monitoring:
The long-term monitoring program design included chemical analysis of sediment, surface water, fish tissue and clam tissue. Annual monitoring was conducted in the spring of each year for sediment at 20 locations and fish at six stations beginning in 1995. Sampling will continue for a minimum of 15 years.

Physical: No physical monitoring data was available for review.

Chemical: Sediment chemistry analysis was conducted on surface grabs from the top 6 inches. At sampling locations in the stream, one grab sample was collected. Composites of three grabs were obtained along transects for sampling locations in impounded water. Although surface water was initially tested for PCBs, none were detected and surface water sampling was discontinued.

Biological: Biological tissue sampling for PCBs includes resident game fish, forage fish, and freshwater clams. Fish sampling was conducted from six sampling locations in the impoundment. Three species of fish were collected including one migratory species (stock hybrid bass) and two non-migratory species (bass and channel catfish). Forage fish were collected from locations corresponding to high, medium, and low concentrations of PCBs. Samples of forage fish from each location consisted of composites of 10 fish. PCBs were also measured in 28-day bioaccumulation tests of the native freshwater clam *Corbicula*.

Project Outcome:
Monitoring since 1994 has shown measurable decreases in sediment concentrations of PCBs. Whether the decrease has proven to be statistically significant remains to be determined. Concentrations of PCBs in resident biological tissue have been erratic to date and have not shown noticeable trends. Although attempts have been made to consider lipid content, migration, rainfall, age of the fish, etc. to demonstrate trends, they have not been successful (Zeller, 2000). A no-consumption advisory remains in-place for all species of fish for the general population in Twelvemile Creek and Lake Hartwell (EPA, 1998). Annual monitoring is continuing at the site.

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References:
EPA, 1998. Listing of Fish and Wildlife Advisories. Prepared by the U.S. Environmental Protection Agency Office of Science and Technology. December 31. Website: http://www.epa.gov/ost/fish.

GE/AEM/BBL, 2000. Major Contaminated Sediment Site Database. Last updated August 1998. Website. http://www.hudsonwatch.com.

Zeller, 2000. Personal communication between Damon Morris of ThermoRetec and Craig Zeller of EPA Region 4 regarding the Sangamo-Weston MNP project. June 2.

Appendix C

Long-term Monitoring Plan

Model Long-term Monitoring Plan for the Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

♦ **The RETEC Group, Inc.**

RETEC Project No.: WISCN-14414

December 2002

Model Long-term Monitoring Plan

Feasibility Study for the Lower Fox River and Green Bay, Wisconsin

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December 2002

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List of Acronyms

μg/kg	micrograms per kilogram
AOC	Area of Concern
ARARs	Applicable or Relevant and Appropriate Requirements
ARCS	Assessment and Remediation of Contaminated Sediments Program
BBL	Blasland, Bouck, and Lee Engineers
bw	body weight
CAD	confined aquatic disposal
CCMA	Center for Coastal Monitoring and Assessment
CDF	confined disposal facility
CENR	Committee on Environmental and Natural Resources
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cm	centimeter
COC	contaminant of concern
COPC	contaminant of potential concern
DAMOS	Disposal Area Monitoring System
DDD	dichlorodiphenyl-dichloroethane
DDE	dichlorodiphenyl-dichhloroethylene
DDT	dichlorodiphenyl-trichloroethane
DOC	dissolved organic carbon
Ecology	Washington State Department of Ecology
ELIZA	enzyme-linked immunosorbent assay
EMAP	Environmental Monitoring and Assessment Program
EP	Estuary Program - San Francisco
EPA	United States Environmental Protection Agency
EROD	ethoxynesorusin-o-deethylase
FDA	Food and Drug Administration
FRG	Fox River Group
FS	feasibility study
g	grams
GAS	Graef, Anhalt, Schloemer and Associates, Inc.
GBMB	Green Bay Mass Balance Study
GLNP	Great Lakes National Program
GLNPO	Great Lakes National Program Office
Hg	mercury
kg	kilogram
LaMP	Lake-wide Management Program
LFR	Lower Fox River

List of Acronyms

LLBdM	Little Lake Butte des Morts
LTMP	long-term monitoring plan
MDEQ	Michigan Department of Environmental Quality
mg	milligrams
mg/kg	milligrams per kilogram
MNA	monitored natural attenuation
MNR	monitored natural recovery
NCP	National Contingency Plan
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRDA	National Resource Damage Assessment
NS&T	National Status and Trends
OSWER	Office of Solid Waste and Emergency Response
PCB	polychlorinated biphenyl
PSAMP	Puget Sound Ambient Monitoring Program
QA	quality assurance
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
SAIC	Science Applications International Corporation
SF	San Francisco
SMU	sediment management unit
SWQD	Surface Water Quality Division
TBC	To Be Considered
TOC	total organic carbon
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
wt	weight
WWC	Woodward-Clyde
YOY	young-of-the-year

1 Introduction

This document presents a model long-term monitoring plan for the Lower Fox River and Green Bay feasibility study (FS). In accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the National Contingency Plan (NCP), the Wisconsin Department of Natural Resources is conducting a remedial investigation/feasibility study (RI/FS) for the Lower Fox River and Green Bay to address the current risk to human health and the environment and present feasible remedial alternatives. As part of this FS process, EPA has requested that a proposed long-term monitoring plan be developed. The long-term goal of the remediation project will be to reduce the concentrations of polychlorinated biphenyls (PCBs) and other contaminants in fish and invertebrates, thus reducing ecological and human health risk.

The purpose of this long-term monitoring plan will be to verify reduced risk to ecological receptors in the event that selected remedial strategies and outcomes leave residual PCBs or other site contaminants in surface sediments. Environmental monitoring can be defined as a continuing program of modeling, measurement, analysis, and synthesis that predicts and quantifies environmental conditions or contaminants and incorporates that information effectively into decision-making in environmental management (NRC, 1990). This proposed long-term monitoring plan would be implemented for all remedial alternatives including monitored natural recovery (MNR), however, it does not pre-suppose one remedy over another. It serves as a generic monitoring plan that will require modifications and/or additions depending upon the final remedy selection and design. The final plan would likely be determined and negotiated during the design phase.

The Baseline Risk Assessment (ThermoRetec, 2000b) for the Lower Fox River and Green Bay concluded that PCBs, mercury, and DDE pose the greatest long-term risk to human health and the environment. Therefore, long-term monitoring will focus on monitoring these compounds in several ecological media to assess the long-term effectiveness of the remedial alternatives proposed in the FS. For this project, effectiveness is defined as attainment of the long-term remedial action objectives (RAOs) defined for the Lower Fox River and Green Bay FS. Monitoring parameters described in this document include media, frequency, duration, location, and chemical analyses to verify achievement of project goals.

Long-term monitoring begins after completion of remedial actions or after the decision to implement a MNR strategy. However, adequate baseline data will be collected prior to remediation to ensure establishment of a data set comparable to post-remedy measurements.

1.1 Monitoring Plan Development

The proposed long-term monitoring plan was developed after careful review of regional and national monitoring programs, guidance documents related to management of contaminated sediments, case study projects, and scientifically-based recommendations presented by sediment work-groups, regulatory agencies and resource trustees (Sections 2 and 3). A possible list of monitoring options was developed from these documents, and the final list of monitoring elements selected for the Lower Fox River/Green Bay project were screened through five important management factors developed by the National Research Council (NRC). These factors were defined by the NRC as essential rudiments of a well-defined and implementable monitoring plan (Section 4). The potential monitoring elements retained from the NRC-based screening process were categorized into their intended use for verification of the project remedial action objectives. A detailed description of the monitoring strategy for each element includes the media, sampling location, frequency, sample type, approximate number of samples, and duration developed for each RAO (Section 5).

1.2 Document Organization

This document is organized into five major sections summarized as:

- Section 1 - background, purpose, and scope;
- Section 2 - a review of national, regional, and local monitoring programs;
- Section 3 - a review of applicable guidance documents used on contaminated sediment projects;
- Section 4 - selection of a monitoring plan strategy; and
- Section 5 - the proposed long-term monitoring plan for the Lower Fox River/Green Bay remediation project.

Attachment 1 located at the end of the main text provides additional detail on selected monitoring programs. Attachment 2 presents a draft report of the ongoing Lake Michigan Monitoring Project for the Fox-Wolf River Basin. The Sediment Technologies Memorandum (Appendix B of the FS) also provides useful information on the monitoring programs and lessons learned for site-specific remediation projects that include dredging, capping, and monitored natural recovery alternatives. Attachment 3 presents a cost estimate for the Lower Fox River and Green Bay monitoring program. Labor, equipment, and analytical costs are estimated per sampling event year.

1.3 Background

Background describes historical sources, status of fish and waterfowl consumption advisories, and contaminants of concern (COCs) carried forward for long-term monitoring. The RAOs and exit criteria are also defined in the purpose, goals, and scope subsections.

1.3.1 Historical Sources

An estimated 190,000 kilograms (kg) (418,000 pounds) of PCBs were released into the Fox River and Green Bay between 1954 and the present, mostly during the production of carbonless copy paper by paper mills located along the Lower Fox River (ThermoRetec, 2000a). It is estimated that by 1971 (when use of PCBs in carbonless paper manufacturing ceased), over 98 percent of the PCBs present within the Lower Fox River had been introduced into the system and a portion of these PCBs settled into the river sediments.

The PCB concentrations detected in site sediments along the entire river ranged from 0.34 to 710,000 micrograms per kilogram (μg/kg) with an average sediment concentration of 9,496 μg/kg (median of 1,700 μg/kg) (ThermoRetec, 2000a). Mercury concentrations detected in sediment samples from the river and bay ranged from 0.01 to 9.82 mg/kg with an approximate average sediment concentration of 1.27 mg/kg in the river and 0.22 mg/kg in the bay. Presence of DDT and its metabolites in Green Bay stem from agricultural activities along the shores of Green Bay and its tributaries. DDE concentrations detected in site sediments ranged from 1.9 to 22 mg/kg in the Lower Fox River with an average sediment concentration of 5.54 mg/kg. DDE was not detected in Green Bay sediments, but was detected in several Green Bay fish at adverse risk levels.

1.3.2 Consumption Advisories

Due to the elevated levels of PCBs detected in fish tissue from the Lower Fox River and Green Bay, the Wisconsin Department of Natural Resources (WDNR) issued consumption advisories in 1976 and 1987 for fish and waterfowl, respectively; Michigan issued fish consumption advisories for Green Bay in 1977. General fish consumption advisories are currently in effect for seven species of fish located in the Lower Fox River from Little Lake Butte des Morts (LLBdM) to the De Pere dam, 13 species of fish located from the De Pere dam to the mouth of

Green Bay (WDNR, 2000), and at least 11 species of fish located in Green Bay (MDEQ, 2000) for PCBs (Tables 1-1 and 1-2).

In 1984, Wisconsin initiated its wildlife contaminant monitoring program. Results of the monitoring program indicated that elevated PCB concentrations were present in waterfowl species harvested by sportsmen from Green Bay. Wisconsin then developed procedures for issuing consumption advisories for waterfowl, and issued its first waterfowl consumption advisory for mallard ducks in 1987 (Table 1-3). The advisory has remained in place every year. The advisories are issued each year in the annual hunting guide distributed by the WDNR (Stratus, 1999). WDNR adopted the federal Food and Drug Administration (FDA) threshold level for poultry of 3 milligrams per kilogram (mg/kg) wet weight PCBs on a fat basis.

1.3.3 Contaminants of Concern

Contaminants of potential concern (COPCs) to human and ecological receptors in the Lower Fox River and Green Bay were identified in a Screening Level Risk Assessment for the Lower Fox River (RETEC, 1998) and include: PCBs (total and coplanar congeners), dioxins and furans, DDT and its metabolites (DDE, DDD), dieldrin, and heavy metals (arsenic, lead, and mercury). This COPC list was further delimited in the Baseline Risk Assessment (ThermoRetec, 2000b) to a final list of contaminants of concern (COCs) which include: PCBs (total and coplanar congeners), mercury, and DDE. PCBs, mercury, and DDE are carried forward in the FS and the long-term monitoring plan.

PCBs in the Lower Fox River pose a potential threat to human health and ecological receptors due to their tendency to sorb to sediments, persist in the environment, and bioaccumulate in aquatic organisms (EPA, 1999a). Organochlorine contaminants (i.e., DDE and PCBs) are known to adversely effect the reproductive rates of local bald eagle populations nesting along Green Bay (Dykstra and Miller, 1996). In Green Bay, DDE has been identified as a significant risk factor to local bird populations linking DDE concentration measured in tissue to reproductive success (Custer *et al.*, 1999). Remedial alternatives were developed in the FS to address risks associated with these COCs. In summary, this long-term monitoring plan will include chemical analyses of PCBs, mercury, and DDE in sediments, surface water, and resident bird, fish, and invertebrate populations.

1.4 Purpose and Goals

The purpose of any long-term monitoring plan for a contaminated sediment remediation project should be the protection of human health and the environment.

The purpose of this document is to review relevant sediment monitoring programs, and guidance documents to help formulate a scientifically-based long-term monitoring plan for the Lower Fox River and Green Bay RI/FS process founded on precedent, implementability, appropriateness, and long-term goals. The long-term monitoring program will be designed to verify achievement of, or progress towards, the RAOs for the Lower Fox River and Green Bay. The program will also be consistent with the long-term goals of the Lake Michigan Lake-wide Management Plan (LaMP) (EPA, 2000a).

The goals of the Lower Fox River and Green Bay long-term monitoring plan can be summarized as follows:

- To verify achievement of, or progress towards, the project remedial action objectives (defined below);
- To determine the magnitude of residual risk by collecting fish, bird, and invertebrate tissue data and monitoring the reproductive viability of birds in the project area;
- To determine if suitable mink habitat exists along the shorelines of the Lower Fox River and Green Bay and potentially use this baseline data as a launching point for future mink population surveys.
- To design an effective and technically sound data collection plan that can verify reduced risk and protection of human health and the environment in order to lift fish and waterfowl consumption advisory restrictions over time;
- To formulate clear goals and procedures for the project that will build upon the existing 20-year database and improve sampling consistency and analysis between collection efforts;
- To utilize and continue, to the extent practicable, existing state and federal monitoring programs ongoing in the Lower Fox River and Green Bay; and
- To recognize the long-term goals of the (LaMP).

1.4.1 Project Remedial Action Objectives

For the Lower Fox River and Green Bay contaminated sediment project, five RAOs were defined in the draft FS document (ThermoRetec, 2000c). The primary routes of exposure to human receptors and the measurement endpoints used to verify the condition of ecological receptors for each RAO were defined in the draft Baseline Risk Assessment (ThermoRetec, 2000b). They include:

- **RAO 1 -** Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.

  Primary routes of exposure for surface water to human and ecological receptors are dermal contact with surface water, or incidental ingestion of surface water. Measurement endpoints will be surface water quality.

- **RAO 2 -** Protect humans who consume fish from exposure to COCs that exceed protective levels.

  The primary route of exposure for PCBs and mercury to human receptors identified in the Baseline Risk Assessment (ThermoRetec, 2000b) is direct ingestion of fish or waterfowl. Measurement endpoints will be edible fish and bird tissue.

- **RAO 3 -** Protect ecological receptors from exposure to COCs above protective levels.

  The primary routes of exposure for PCBs, mercury, and DDE to ecological receptors is bioaccumulation and biomagnification from the sediments up through the aquatic food web. Measurement endpoints will include bird, fish and invertebrate tissue, mink habitat, and reproductive viability of local bird populations. Surface sediment samples will also be collected to verify the reduced exposure pathway.

- **RAO 4 -** Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.

  The primary mechanism of concern for PCB transport to Green Bay is by storm events or scour effects that significantly increase the sediment bedload and resuspend contaminated sediments that are buried under surficial layers of clean sediment. Measurement endpoints will be surface water and surface sediment quality.

- **RAO 5 -** Minimize the downstream movement of PCBs during implementation of the remedy.

  The primary concern for contaminant releases during active remediation is resuspension of dredged or capped material and downstream transport. This RAO is a short-term objective and is not included in the long-term monitoring plan.

More specifically, the project expectations can be placed on an approximate time line as follows:

- Remediation will be completed within 10 years;
- The sport fish consumption advisories will be lifted within 10 years after remediation (in 20 years); and
- The fish consumption advisories for the general population will be lifted within 30 years after remediation (in 40 years).

1.4.2 Exit Criteria from Monitoring Efforts

The duration of long-term monitoring is expected to last 40 years from the onset of an implemented remediation remedy, including the no action or monitored natural recovery option for the Lower Fox River and Green Bay. Long-term monitoring may be discontinued if decision-making evaluations show that the "exit criteria" for the project have been achieved or that meaningful change has occurred as a result of the remedy. The exit criteria for each remedial action objective can be defined as a numeric or action-related threshold value designed to protect human health and the environment. Attainment of a threshold value must be evaluated before exiting the monitoring program. The exit criteria for this FS are described below.

Proposed exit criteria for the Lower Fox River and Green Bay (RAOs are considered achieved when):

- **RAO 1 -** PCBs measured in surface waters are at or below background levels in Lake Winnebago.
- **RAO 2 -** The fish and waterfowl consumption advisories for the Lower Fox River and Green Bay are removed.
- **RAO 3 -** The levels of PCBs, mercury, and DDE fall below the levels known to effect ecological communities;
  - Whole body PCB, mercury, and DDE levels in resident fish fall below the levels known to effect reproduction;

- ‣ Whole body PCB, mercury, and DDE levels in resident fish-eating birds fall below levels known to cause reproductive dysfunction;

- ‣ Levels of PCBs and mercury in site sediments fall below levels known to effect benthic communities;

- ‣ Bald eagle reproduction along the Lower Fox River and Green Bay consistently achieve levels observed for inland eagle nests in Wisconsin and Michigan; and

- ‣ Total PCB and mercury levels in resident eagle eggs fall to levels observed in background samples.

- **RAO 4 -** Mass balance calculations demonstrate the PCB loads exported from the Lower Fox River to Green Bay, or from Green Bay to Lake Michigan, are equal to input sources external to the river/bay system (e.g., atmospheric deposition).

- **RAO 5 -** (Not included as part of the long-term monitoring plan.) This objective will be assessed during development of active remediation work plans.

1.5 Scope

Before developing a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS project, a review of national and regional monitoring programs and guidance documents was needed to determine a scientifically-based approach with precedent in other regulatory programs. The scope of the review included the following:

- **National and Regional Monitoring Programs.** A review of national and regional monitoring programs describing the types of monitoring elements used to determine current site conditions and environmental impacts to valued receptors. Programs selected were some of largest and most comprehensive monitoring programs currently in operation throughout the United States.

- **Site-specific Remediation Projects.** A review of site-specific sediment remediation projects conducted throughout the United States, Canada, Europe, and Asia, describing the types of monitoring conducted at each site. Projects were selected from a variety of different aquatic systems (lake, river, marine, estuary) with a variety of different implemented remedies (dredging, capping, and MNR) with the intent of presenting a cross section of different physical constraints, receptors, and remediation goals. Discussions and findings are presented in Appendix B, Sediment Technologies Memorandum.

- **Wisconsin and Michigan State Monitoring Programs.** A discussion of long-term monitoring programs currently conducted in Wisconsin and Michigan describing the appropriate regional indicators of biological health (e.g., fish tissue concentrations, bird reproduction). The review focused on fish tissue sampling used for updating the consumption advisories.

- **Guidance Documents.** A review of relevant guidance documents pertaining to the remediation, management, and monitoring of contaminated sediments. This review summarized the perspective and level of expectations by regulatory agencies for the protection of human health and the environment. The goals of this review were to increase consistency between monitoring programs and sites, optimize efforts and resources, focus our ability to detect changes in biological health over time, and support the implementation of national monitoring programs.

- **Recommendations Used for Final Selection of a Monitoring Strategy.** The NRC reviewed numerous reports and monitoring programs related to the management of contaminated sediments. They evaluated the major policy and technical limitations of existing monitoring programs. Based on their review, they developed a conceptual model for the design and implementation of monitoring programs and defined the role of monitoring in marine environmental management. Several management factors were developed to ensure an adequately designed monitoring program. These factors were used to select appropriate monitoring elements (i.e., sediment chemistry, fish tissue chemistry, surface water chemistry, benthic abundance) for the Lower Fox River and Green Bay project. Recommendations put forth by other regulatory groups regarding the management of contaminated sediments are also discussed.

Based upon this review of current monitoring programs, guidance documents, and recommendations, a proposed long-term monitoring plan was developed for the Lower Fox River and Green Bay (presented in Section 5). The proposed approach will be used to refine the expectations and implementability of monitoring measurements, to help determine the costs associated with each alternative, and to coordinate efforts early on with local, regional, and state agencies. Early coordination between different interest groups will help integrate data management needs, optimize use of available resources, and establish useful baseline data sets that will be comparable spatially and temporally with post-project sampling events.

As discussed in other sections of the FS, monitoring of a sediment remediation project is grouped into five categories:

1. Pre-action monitoring prior to remediation to establish baseline conditions (sediment, water, tissue);

2. Monitoring during implementation (water, air);

3. Post-verification monitoring to verify completion of a remedy (sediment);

4. Construction monitoring of containment facilities to verify continued source control (sediment, water); and

5. Long-term monitoring to verify effectiveness of the remedy and attainment of the project RAOs (sediment, water, tissue).

This long-term monitoring plan focuses primarily on Category 5, post-remediation sampling events to verify achievement. Construction monitoring is independent of the long-term monitoring plan (LTMP) and will be designed specifically for disposal sites (i.e., CADs, CDFs, or sand caps). Implementation monitoring pertains to water and air quality monitoring during dredging and capping activities and is not included in the LTMP. However, an adequate baseline data set will be necessary to draw comparisons with post-remedy data. Therefore, this proposed LTMP also applies to categories 1, 2, and 3 for development of a comprehensive baseline data set spanning 10 years. Sample media will include a combination of sediment, water, and tissue for all sampling events.

Table 1-1 Wisconsin Fish Consumption Advisories for the Lower Fox River and Green Bay

Water Body/Fish Species	Unlimited	Limit One Meal/Week	Limit One Meal/Month	Limit One Meal/2 Months	Do Not Eat
Fox River from Little Lake Butte des Morts to De Pere Dam					
Carp					all sizes
Northern Pike			all sizes		
Smallmouth Bass			all sizes		
Walleye			all sizes		
White Bass			all sizes		
White Perch			all sizes		
Yellow Perch		all sizes			
Fox River from De Pere Dam to Mouth					
Black Crappie			less than 9"	larger than 9"	
Bluegill			all sizes		
Carp					all sizes
Channel Catfish					all sizes
Northern Pike			less than 25"	larger than 25"	
Rock Bass			all sizes		
Sheepshead			less than 10"	10"–13"	larger than 13"
Smallmouth Bass				all sizes	
Walleye			less than 16"	16"–22"	larger than 22"
White Bass					all sizes
White Perch				all sizes	
White Sucker				all sizes	
Yellow Perch			all sizes		
Green Bay South of Marinette and Its Tributaries (except the Lower Fox River)					
Brown Trout			less than 17"	17"–28"	larger than 28"
Carp					all sizes
Channel Catfish				all sizes	
Chinook Salmon			less than 30"	larger than 30"	
Northern Pike		less than 22"	larger than 22"		
Rainbow Trout			all sizes		
Smallmouth Bass			all sizes		
Splake			less than 16"	16"–20"	larger than 20"
Sturgeon					all sizes
Walleye			less than 17"	17"–26"	larger than 26"
White Bass					all sizes
Whitefish				all sizes	
White Perch				all sizes	
White Sucker			all sizes		
Yellow Perch		all sizes			

Source: State of Wisconsin, 2000.

Table 1-2 Michigan Fish Consumption Advisories for Green Bay

▲ Unlimited consumption.
● One meal per month
◆ Do no eat these fish.
▼ One meal per week.
■ Six meals per year.

			General Population									Women and Children								
			Length (inches)									Length (inches)								
Water Body	Species	Contaminant(s)	6–8	8–10	10–12	12–14	14–18	18–22	22–26	26–30	30+	6–8	8–10	10–12	12–14	14–18	18–22	22–26	26–30	30+
Lake Michigan Watershed - All other locations refer to general advice.																				
Green Bay # (South of Cedar River applies to Michigan waters including Menominee and Cedar rivers below first dam. See also **Lake Michigan North of Frankfort**.)	Brown Trout	PCBs			▼	▼	▼	◆	◆	◆	◆			●	●	■	◆	◆	◆	◆
	Burbot	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼	●	●
	Carp	PCBs	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Channel Catfish	PCBs				▼	▼	▼	▼	▼	▼				■	■	■	■	■	■
	Chinook Salmon	PCBs			▲	▲	▲	▲	▲	▲	▲			●	●	●	●	●	●	●
	Lake Trout	PCBs			▲	▲	▲	▲	▼	▼	▼			●	●	●	●	●	■	■
	Longnose Sucker	PCBs	▼	▼	▼	▼	▼	▼	▼			■	■	■	■	■	■	■		
	Northern Pike	PCBs							▲	▲	▲							●	●	●
	Rainbow Trout	PCBs			▲	▲	▲	▲	▲	▲	▲			●	●	●	●	●	●	●
	Smallmouth Bass	PCBs, Mercury					▲	▼	▼	▼						●	●	●	●	
	Splake	PCBs			▼	▼	▼	◆	◆	◆	◆			●	●	■	◆	◆	◆	◆
	Sturgeon	PCBs									◆									◆
	Walleye	PCBs, Mercury					▲	▼	▼	◆	◆					●	■	■	◆	◆
	White Bass	PCBs	◆	◆	◆	◆	◆	◆				◆	◆	◆	◆	◆	◆			
	Whitefish	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	■	■	■	■	■	■	■	■	■
	White Perch	PCBs	◆	◆	◆	◆						◆	◆	◆	◆					
	White Sucker	PCBs	▲	▲	▲	▲	▲	▲	▲	▲	▲	●	●	●	●	●	●	●	●	●
	Yellow Perch	PCBs	▲	▲	▲	▲	▲	▲				▼	▼	▼	▼	▼	▼			

Table 1-3 Wisconsin Waterfowl Consumption Advisory

Location	Species	Health Advisory Recommendations	Date
Lower Fox River and Lower Green Bay			
Lake Winnebago downstream through Little Lake Butte des Morts (LLBdM) to the city of Kaukauna	Mallard duck	Remove all skin and visible fat before cooking. Discard drippings or stuffings because they may retain fat that contains PCBs.	1987 to present
De Pere dam downstream to the river mouth and includes lower Green Bay south of line from Point au Sable west to the west shore of Green Bay	Mallard duck	Same.	1987 to present

Source: WDNR annual hunting pamphlets. Latest listing year 2000.

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2 Review of National, Regional and State Monitoring Programs

Numerous long-term monitoring programs were reviewed to inventory monitoring elements commonly used in national, regional, and local programs. Two national programs (EMAP, NOAA NS&T) were selected to represent comprehensive national programs focused on assessing the conditions of natural aquatic ecosystems of the United States. Four regional programs (Puget Sound, San Francisco, Great Lakes, and East Coast) were selected to represent progressive and comprehensive regional programs established to understand the human impacts on aquatic resources and to improve the management of these resources. Local and/or state long-term monitoring programs currently in place for the Lower Fox River and Green Bay were also reviewed, consisting primarily of fish tissue sampling for consumption advisory monitoring.

In addition, numerous site-specific contaminated sediment projects were reviewed in the Sediment Technologies Memorandum to document monitoring parameters selected for verification of dredging, capping, and monitored natural recovery remediation alternatives under approval of the Environmental Protection Agency (EPA) and/or state-led agencies (Appendix B of the FS).

The purpose of identifying and reviewing these programs was to point out the recurrence of certain environmental quality measurements in a majority of scientifically based and peer-reviewed programs focused on monitoring the remediation and/or condition of contaminated sediments. Some of the similarities among the national and regional programs in terms of measuring environmental quality are presented in Table 2-1. Table 2-2 summarizes the monitoring elements utilized for site-specific sediment remediation projects. Table 2-3 is a summary of the fish species, including size class and quantity, included in the State of Wisconsin annual fish sampling program for the consumption advisories. Tables 2-4 through 2-7 summarize the distribution and the quantity of existing data collected from the Lower Fox River and Green Bay over time. Detailed descriptions for many of these monitoring programs can be found in Attachment 1 - National and Regional Monitoring Programs and Appendix B of the FS - Sediment Technologies Memorandum.

2.1 National Monitoring Programs

Two of the most comprehensive national monitoring programs include the EMAP and NOAA NS&T programs, which are collecting data on the physical and chemical characteristics of sediments, the bioavailability of contaminants, levels of contaminant residues in the tissues of aquatic organisms, and the health of benthic communities (EPA, 1999a). Each program is briefly described below. Elements of each monitoring program are described in Attachment 1.

2.1.1 EPA Environmental Monitoring and Assessment Program (EMAP)

EMAP is a research program used for developing the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition. These assessments will be used to forecast future risks to the sustainability of our natural resources (EPA, 2000c). EMAP's research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources (CENR).

The objectives of EMAP are to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate the CENR framework through large regional projects. EMAP will develop and demonstrate indicators to monitor the condition of ecological resources, and investigate multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources.

2.1.2 NOAA National Status and Trends Program (NOAA NS&T)

In 1984, NOAA initiated the NS&T Program to determine the current status of, and to detect changes in, the environmental quality of our Nation's estuarine and coastal waters. The NS&T Program is managed by the Center for Coastal Monitoring and Assessment (CCMA) in NOAA's National Ocean Service. The NS&T: 1) conducts long-term monitoring of contaminants and other environmental conditions at more than 350 sites along United States coasts, 2) studies biotic effects intensively at more than 25 coastal ecosystems, 3) partners with other agencies in a variety of environmental activities, and 4) advises and participates in local, regional, national, and international projects related to coastal monitoring and assessment (NOAA, 2000).

The NS&T Program is comprised of several projects, including: the Benthic Surveillance Project, the Mussel Watch Project, the Quality Assurance Project, Historic Trends, the Sediment Coring Project, the Specimen Banking Project, Sediment Toxicity Surveys, Biomarkers, Environmental Indices, and regional assessment and topical reports.

2.2 Regional Programs

The regional monitoring programs reviewed were intended to provide information regarding a variety of programs extending from the west coast (Puget Sound Ambient Monitoring Program [PSAMP] and San Francisco Bay Estuary Program), to the Great Lakes (Great Lakes National Program Office [GLNPO]), and the East Coast (Disposal Area Monitoring System [DAMOS] disposal site program). Each program is briefly described below. Elements of each monitoring program are described in Attachment 1.

2.2.1 Puget Sound Ambient Monitoring Program (PSAMP)

As part of the PSAMP, the Washington State Department of Ecology has collected sediment samples throughout Puget Sound, Hood Canal, and the Strait of Georgia from 1989 through 1995 (Ecology, 2000). The PSAMP was implemented for the following purposes:

- Provide a record of the condition of Puget Sound sediments.
- Aid in the identification of reference sites/values.
- Provide data for use by researchers concerned with sediment quality.

The following are specific objectives to be addressed by the PSAMP:

- Collect baseline and long-term data on Puget Sound sediments and macro-invertebrate communities in uncontaminated and contaminated areas.

- Identify areas of Puget Sound that are accumulating toxic chemicals.

- Assess the potential sediment toxicity resulting from accumulating toxic chemicals.

- Evaluate the condition of Puget Sound benthic macro-invertebrate communities in relation to the concentration of toxic chemicals in sediments.

- Document both natural and anthropogenic changes to sediment quality.

The current PSAMP program consists of both temporal (long-term) monitoring and spatial monitoring.

2.2.2 San Francisco Bay Estuary Program

The San Francisco Bay Estuary Program is part of the National Estuary Program (NEP) which was established in 1987 by amendments to the Clean Water Act to identify, restore, and protect nationally significant estuaries of the United States (National Estuary Program, 2000). The NEP targets a broad range of issues and engages local communities in the process. The program focuses not just on improving water quality in an estuary, but on maintaining the integrity of the whole system—its chemical, physical, and biological properties, as well as its economic, recreational, and aesthetic values.

To assist in coordinating research and monitoring programs, the San Francisco Estuary Project has fostered the development of a Regional Monitoring Strategy (Monitoring Strategy). The primary purposes of the Monitoring Strategy are to:

- Provide information to assess the effectiveness of management actions that have been taken to improve conditions in the estuary and to protect its resources.

- Evaluate the ecological "health" of the estuary and enhance scientific understanding of the ecosystem.

Implementation of the Monitoring Strategy will strengthen the Estuary Project's continuing effort to promote environmentally sound management of the bay and delta. The Monitoring Strategy will improve the ability to define human-induced stresses on the estuary, help to assess the effectiveness of current estuary management, and monitor the long-term health of the estuary.

2.2.3 EPA Great Lakes National Program Office (GLNPO)

The Great Lakes National Program (GLNP) is part of the EPA. Annual monitoring of the Great Lakes by the GLNP began in 1983 for Lakes Michigan, Huron, and Erie; in 1986 in Lake Ontario; and in 1992 for Lake Superior (EPA, 2000b). GLNPO's Great Lakes Monitoring Program consists of several different elements, including the following:

- Green Bay Mass Balance Study,
- Lake Michigan Mass Balance Project,
- Benthic Invertebrate Monitoring Program,
- Limnology Program, and
- GLNP Indicators Monitoring Program.

Each of these program elements is briefly described below.

The Green Bay Mass Balance (GBMB) Study was conducted in 1989 through 1990 to pilot the technique of mass balance analysis in understanding the sources and effects of toxic pollutants in the Great Lakes food chain. The study was headed by EPA's GLNPO and the Wisconsin Department of Natural Resources. The study focused on four representative chemicals or chemical classes: PCBs, dieldrin, cadmium, and lead (EPA, 2000b).

The Lake Michigan Mass Balance Project began in 1994 and was concluded in 1999. In addition to baseline environmental conditions (air and water temperature, transmissivity, etc.), samples of air, water, sediment and fish tissue have been analyzed for four particular biochemical chemicals of concern: mercury, PCBs, atrazine, and trans-nonachlor. The Lake Michigan Mass Balance study is helping scientists understand where these chemicals are entering the Lake and what happens to them as they move through the ecosystem.

The GLNP has recognized the potential importance of benthic indicator/integrator organisms in the evaluation and management of the Great Lakes, and in 1997 initiated a Benthic Invertebrate Biomonitoring Program to complement its current surveillance sampling. The data is used in conjunction with other physical, chemical, and biological data generated by GLNPO's surveillance program to provide an extensive picture of the condition of the lakes and how benthic invertebrates respond to it.

The GLNP's annual Limnology Program for the Great Lakes began in 1983. The limnology program provides information on key environmental factors that influence the food chain and fish of the Great Lakes. The sampling strategy is to collect water and biota samples at specific water depths from a limited number of locations in each lake twice every year.

The GLNP's Indicators Monitoring Program monitors plants and organisms that are particularly suitable for use as indicators of environmental conditions. The GLNP monitors diatom communities, zooplankton populations, benthic invertebrates, and exotic species in the Indicators Monitoring Program.

All of the GLNPO programs recognize the significance of environmental contamination, and all of them include the collection and chemical analyses of sediments. This indicates the usefulness of sediments as a sentinel of chemical contamination in the environment even when the monitoring objective is not focused on the effectiveness of sediment remediation. Table 2-1 shows some of the similarities among these five national and regional programs in terms of measuring environmental quality.

2.2.4 Disposal Area Monitoring System (DAMOS)

The New England district of the U.S. Army Corps of Engineers (USACE) created the DAMOS program in 1977. The DAMOS program was established to ensure that the disposal of dredged material from numerous industrialized harbors in New England placed in offshore disposal sites had no adverse effect on the environment. After placement of contaminated material, these sites were subsequently capped with clean material. These offshore, open-water disposal sites are located between Long Island Sound and Maine, and are under the jurisdiction of the New England Corps district.

The DAMOS monitoring program was implemented to: 1) ensure the physical integrity and stability of disposal mounds, 2) measure the impacts to bottom organisms around and returning to the disposal mounds, and 3) measure the effectiveness of capping in isolating disposed contaminated sediments (USACE, 1992). Monitoring under the DAMOS program follows a tiered approach, under which techniques in the higher tiers are used only when monitoring results of lower tiers indicate the need for further monitoring.

2.3 State Monitoring Programs—Wisconsin and Michigan

Before finalizing the long-term monitoring plan for the Lower Fox River and Green Bay remediation project, it was important to consider other ongoing state monitoring programs intended to evaluate many of the same valued resources and aquatic receptors under consideration for the Lower Fox River/Green Bay project. Sampling protocols, monitoring methods, species selection, and resource locations have already been determined for many of these programs where extensive databases have already been established. The goal of this review was to consider other programs already in place and how to efficiently adapt the Lower Fox River/Green Bay monitoring plan to complement these pre-existing programs. These programs may have larger goals to consider beyond the scope and spatial extent of the project area, but were helpful for developing the Lower Fox River/Green Bay monitoring plan.

2.3.1 Wisconsin State Fish Monitoring Program

The Wisconsin Department of Natural Resources conducts fish tissue monitoring as part of Wisconsin's Fish Contaminant Monitoring Program. Fish tissue sampling is conducted every 3 to 5 years and collection efforts are focused on the tributaries to Green Bay including the Lower Fox River. The program has two goals: 1) updating the state fish consumption advisories for consumable fish and 2) determining temporal trends in fish indicator species. Spatial differences and temporal trends in consumption are examined by collecting several species of fish from three different river reaches of the Lower Fox River: 1) Little Lake Butte des Morts, 2) Appleton to the De Pere dam, and 3) below the De Pere dam to the mouth. Multiple samples are collected from at least three size classes of fish from each species (Table 2-3). Sampling events are conducted in the spring during spawning seasons.

Fish species used for evaluation of the consumption advisories include: walleye, carp, white bass, yellow perch, catfish, northern pike and two pan fish species (crappie and bluegill). Yellow perch are also collected from the south end of Green Bay. Although Lake perch is an exotic species, it may be added to the game fish collection list since it is desirable by anglers (Amhrein, 2000). These species and sizes represent WDNR's "guideline" of catches, but actual sampling catches may vary from year to year depending upon site conditions. The top fish species caught in the Lower Fox River are generally walleye, white perch, yellow perch, and smallmouth bass. Discrete fish samples are analyzed as skin-on-fillet samples (skin-off-fillet for catfish) and analyzed for total PCBs, percent lipids, DDT for carp, and mercury for walleye. PCB congeners are not typically analyzed as part of this program. Fish length, weight, sex, and presence of external and internal fish tumors are also recorded (Amhrein, 2000).

The second goal of the monitoring program is to observe trends in contaminant concentrations for assessing the status of environmental health. Gizzard shad tissues are used to observe environmental trends. Although gizzard shad are not a desirable fish catch by anglers, they serve as a good indicators of environmental health. Samples are collected in the same manner as the fish consumption advisory sampling events, with the exception that whole body fish tissue samples are analyzed (Amhrein, 2000).

2.3.2 Wisconsin State Bird Monitoring Programs

The Wisconsin Department of Natural Resources conducts waterfowl, double-crested cormorant, and bald eagle monitoring as discussed below.

Waterfowl

The WDNR conducted a game bird sampling event in the mid-1980s to assess PCB and pesticide concentrations in bird tissue ingested by hunters. This sampling event led to the listing of mallard ducks on the waterfowl consumption advisory in 1987. The sampling event was conducted around the state at several locations with multiple samples per location (approximate sample size N = 8). Although a formal monitoring program is not currently in-place and no additional waterfowl sampling has been conducted by WDNR since the late 1980s (additional sampling data have been collected by USFWS in the 1990s), WDNR intends to conduct additional waterfowl tissue sampling events to update the advisory (Peterson, 2000).

Double-crested Cormorants

The WDNR and the U.S. Fish and Wildlife Service (USFWS) periodically conduct bioaccumulation and productivity monitoring studies on resident double-crested cormorant species. Following a ban on the use of DDT in North America in the 1970s, egg tissue residues have decreased by more than 80 percent and the Green Bay population has increased by a factor of 45 in the past 20 years (Stratus, 1999). A summary of the types of monitoring conducted on resident populations in the past 20 years include:

- Whole body tissue (male and female) for total PCB and DDE analysis;
- Incidence of bill and head deformities among nestlings;
- Eggshell thickness;
- Biomarker activity—EROD activity in embryo livers;
- Edema of the head and neck of nestlings, and hemorrhaging;
- Annual productivity and nesting sites;
  - Number of nests
  - Number of hatches per active nest
  - Number of dead embryos
- Foraging areas; and
- Comparison to inland reference sites.

Details regarding sample collection efforts were not specified; however, it appears that several colonies were sampled per year with up to 40 nests and over 100 egg samples per colony for an annual sampling event. Egg samples were analyzed for total PCBs, PCB congeners, and DDE. Based on numerous correlation analyses, the best monitoring indicators of bird health were whole body and egg tissue chemical analysis, reproductive hatching success, and embryonic deformations. The main breeding colonies reside on Cat, Jack, Hat, and Snake Islands in Green Bay, and on Spider Island on the east side of Door peninsula. Breeding times occur between April and September/October before the colonies migrate south.

Recent studies by the USGS and USFWS identified DDE, and not other contaminants of concern, as the significant risk factor effecting reproductive success to double-crested cormorants (Custer *et al.*, 1999). Egg hatching success was positively correlated with shell thickness and negatively correlated with DDE concentration. Results did not support the hypothesized relationship between PCB concentrations in eggs and reproductive success in double-crested cormorants (Custer *et al.*, 1999). In summary, double-crested cormorant populations are recovering in Green Bay, are no longer a threatened species in Wisconsin, and are not good indicators of PCB risk to ecological receptors. However, they are vulnerable to PCB uptake by feeding almost exclusively on forage fish (alewife and smelt) with high lipid contents (Stratus, 1999) and have notably higher PCB concentrations in colonies residing on Cat Island (close to the Lower Fox River) than other colonies. They could serve as resident indicators of changes in PCB exposure and uptake over time.

Bald Eagles

The WDNR has conducted annual monitoring of bald eagles in the Lower Fox River/Green Bay region since 1974 (Dykstra and Miller, 1996). The USFWS also periodically conducts bald eagle monitoring for productivity, and PCB and DDE bioaccumulation in eggs and plasma. In 1997, the State of Wisconsin "threatened species" status was removed since bald eagle populations have significantly increased in the last 10 years; however, the bald eagle is still listed on the USFWS threatened species list. A summary of the types of monitoring conducted on resident bald eagle populations in the past 20 years include:

- Egg tissue for total PCB and DDE analysis (1986 to 1997);
- Blood plasma for total PCB and DDE analysis (1987 to 1995);
- Annual productivity and nesting sites;
  - Number of occupied and unoccupied nests
  - Number of large young produced per active nest
- Prey species and prey remains;
- Food availability and foraging areas; and
- Comparison to inland nesting sites.

In Green Bay, 12 nests were sampled with two to three eggs collected per nest. In the Lower Fox River, only one nest was sampled with one egg analyzed. Chemical analysis focused on PCBs and DDE because: 1) they are the only contaminants that have been found in the Great Lakes bald eagle tissues in high enough concentrations to result in adverse effects, 2) they are the most closely correlated with bald eagle reproductive success, and 3) they are known to result in the types of adverse effects observed in the area assessment of bald eagles

(Stratus, 1999). Reproductive rates have slowly increased since 1987, but rates are still 60 percent lower than inland nesting samples. PCB concentrations in eggs and blood samples from Green Bay were 10 times higher than inland samples (Dykstra and Miller, 1996). The annual productivity rate required to maintain a healthy bald eagle population is a minimum of 1.0 young per active nest.

2.3.3 Michigan State Fish Monitoring for Consumption Advisories

The state of Michigan conducts annual fish tissue monitoring as part of Michigan's Fish Contaminant Monitoring Program. In 1986, a comprehensive program was initiated by the Michigan Department of Environmental Quality-Surface Water Quality Division (MDEQ-SWQD) to assess the degree of chemical contamination in fish from surface waters of the state, and over 12,000 fish tissue samples have been analyzed since 1980. The program has four program goals: 1) to develop and maintain the Michigan Fish Advisory, 2) to regulate sales of commercial catch, 3) to identify spatial differences and temporal trends in the quality of Michigan's surface waters, and 4) to determine whether existing regulatory and remedial programs are effectively reducing chemical contamination in the aquatic environment (MDEQ, 1999). Temporal trends and spatial differences are examined by collecting whole-fish and caged-fish samples in addition to the edible portion samples. The presence of even extremely low concentrations of some bioaccumulative pollutants in surface water can result in concentrations in fish tissue that pose a human and wildlife health risk. Verification of the achievement of, or progress towards, the program goals is evaluated primarily through the collection and analysis of fish tissues.

Components of the fish monitoring program include:

- Edible fish monitoring;
- Whole fish trend monitoring (initiated in 1990); and
- Caged fish chemical bioconcentration studies.

Edible fish monitoring samples are collected every year from inland lakes and rivers, tributary rivers, and Lake Michigan (Day, 2000). In 1998, 1,059 fish were collected from 58 locations and included 21 species of fish; however, none of these 1998 stations were located in the project area. The sampling stations are not on a fixed schedule; samples are collected opportunistically based on fish catches. Collection and analysis focus on key species of concern and fish samples are generally processed as headless, gutless, and skin-off fillets for most fish, with the exception of game fish which are mostly skin-on-fillet. Samples are discrete(no compositing) since MDEQ rarely collects composite samples except for coho and chinook salmon species (Day, 2000).

Whole fish trend monitoring samples are collected every 2 to 5 years from 26 trend locations to assess the spatial and temporal trends in contaminant concentrations. However, only four rounds of data sets have been collected to date, and significant trends have not been detected in most of these data sets, possibly due to sample variability. Only two stations are located with the project area; one station is located near Little Bay de Noc in Green Bay and other is located in the Menominee River tributary to Green Bay.

Caged fish bioconcentration studies are used as a tool to identify sources of bioaccumulative contaminants and identify spatial trends in contaminant concentrations. MDEQ generally places approximately 10 to 30 cages per year (Day, 2000). The caged-fish studies consist of a 28-day test using channel fish (4 to 6 inches long) and are conducted primarily in river watersheds (River Raisin, Saginaw River) and none are located in the project area.

In addition to the Michigan Fish Contaminant Monitoring Program, several agencies in the Great Lakes Basin are monitoring fish contaminant trends. The EPA collects and analyzes whole lake trout or walleye from the open waters of each of the Great Lakes. The Great Lake states work cooperatively with the EPA to collect and analyze coho and chinook salmon from select Great Lake tributaries during the fall spawning migration. The coho and chinook salmon are analyzed as composites of skin-on fillets.

2.3.4 Existing Data for the Lower Fox River and Green Bay

The sediment, water, and tissue data sets used for the Lower Fox River and Green Bay RI/FS project were compiled from over 16 different site characterization studies (Table 2-4). The compiled data set spans over 20 years for certain parameters, and was used to calculate sediment quality thresholds as part of the Baseline Ecological and Human Health Risk Assessment (ThermoRetec, 2000b). The data set includes primarily surface sediment, sediment core, and water quality data.

The purpose of presenting this compilation of existing data for the Lower Fox River and Green Bay is to summarize the types of monitoring parameters already collected in the project area. This data constitutes a remarkable set of baseline data that could be used to detect and determine long-term trends at the site well after post-project remediation. This compilation is not intended to replace a well-developed long-term monitoring plan including a revised set of baseline data that would be directly comparable to long-term data (similar sites, sizes, depths, and types of data), but serves to augment and detect temporal trends.

As summarized in Table 2-5, the types of monitoring elements commonly collected in the Lower Fox River and Green Bay include: surface and subsurface sediment sampling, fish tissue sampling, and mammal sampling with lesser amounts of air, water, and caged fish sampling data. Benthic community abundance and fish tissue deformities/histopathology were not commonly collected.

As described in the Lower Fox River RI/FS Data Management Summary Report (EcoChem, 2000), several of the studies used many different analytical laboratories with different detection limits, different analyte lists, and a wide range of reported percent recoveries and data validation procedures. Thus, it was determined that, in general, the data from the Green Bay Mass Balance Study, along with many other studies listed in this document, should be used as supporting data only. When planning the long-term monitoring plan for the Lower Fox River and Green Bay, consistency between years, laboratories, analytical methods, and detection limits will assist with reliable interpretations of temporal and spatial trends.

Table 2-1 Regional and National Monitoring Programs

Monitoring Program	Environmental Quality Measurement Elements									
	Physical	Chemical		Biological						
	Bathymetry and Sediment	Surface Water Quality	Surface Sediment Quality	Benthic Abundance	Fish Community	Sediment Invertebrate Toxicity	Water Toxicity	Fish and Shellfish Tissue	Invertebrate Tissue	Histological Studies
National Programs										
EMAP	◆		◆	◆	◆			◆	◆	
NOAA NS&T			◆					◆	◆	◆
Regional Programs										
DAMOS	◆		◆	◆		◆		◆	◆	
GLNP		◆	◆	◆	◆			◆	◆	
PSAMP	◆		◆	◆		◆				
SF-Bay Estuary Program	◆	◆	◆	◆		◆	◆	◆	◆	

Table 2-2 State Monitoring Programs—Wisconsin and Michigan

State Monitoring Program	Physical	Chemical			Biological			
	Other	Sediment	Surface Water	Sediment Traps	Benthic Abundance	Toxicity	Concentration Tissue	Histological Studies
Wisconsin State Fish Consumption Monitoring Program							◆	
Wisconsin State Bird Monitoring Program							◆	
Waterfowl							◆	
Double-crested Cormorant							◆	◆
Bald Eagle							◆	
Wisconsin Sensitive Areas Index Monitoring	◆							
Michigan State Fish Consumption Monitor Program							◆	
USACE Navigational Depth Monitoring	◆							

Table 2-3 1998 Wisconsin Fish Contaminant Sample Collection Schedule

Sampling Location	Species	Sampling Guidelines (source: J. Amhrein)			
		Size Class (in inches)	No. of Samples	Sample Form	Parameters
Little Lake Butte des Morts	Walleye	12-15	1	fillet	PCBs
		15-18	4	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	1	fillet	PCBs/Hg
	Northern Pike	15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-26	2	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Smallmouth Bass	10-12	1	fillet	PCBs
		12-15	3	fillet	PCBs
		15-17	2	fillet	PCBs
	White Bass	9-11	2	fillet	PCBs
		11-14	3	fillet	PCBs
		14+	1	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Lower Fox River below the De Pere Dam	Walleye	10-12	2	fillet	PCBs
		12-15	3	fillet	PCBs
		15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	2	fillet	PCBs/Hg
	Northern Pike	15-18	2	fillet	PCBs
		18-22	2	fillet	PCBs
		22-26	2	fillet	PCBs
	Smallmouth Bass	10-12	2	fillet	PCBs
		12-15	2	fillet	PCBs
		15-18	2	fillet	PCBs
	White Bass	many	5	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Lower Fox River above the De Pere Dam	Walleye	10-12	2	fillet	PCBs
		12-15	3	fillet	PCBs
		15-18	3	fillet	PCBs
		18-22	3	fillet	PCBs
		22-24	2	fillet	PCBs/Hg
	Northern Pike	15-18	2	fillet	PCBs
		18-22	2	fillet	PCBs
		22-26	2	fillet	PCBs
	Smallmouth Bass	10-12	2	fillet	PCBs
		12-15	2	fillet	PCBs
		15-18	2	fillet	PCBs
	White Bass	many	5	fillet	PCBs
	Bluegill	many	5	fillet	PCBs
	Crappie	many	5	fillet	PCBs
	Yellow Perch	many	5	fillet	PCBs
	Carp	many	5	fillet	PCBs
	Gizzard Shad	2-25 fish composites	50	whole	PCBs
	Shiner spp.	2-25 fish composites	50	whole	PCBs
Green Bay	Gizzard Shad	1 lb young-of-the-year	3	whole	PCBs, Chlor, Dieldrin, DDT
	Yellow Perch	2-5 fish composites	10	fillet	PCBs, Chlor, Dieldrin, DDT

Table 2-4 Compilation of Existing Data for the Lower Fox River and Green Bay RI/FS Project

Study	Years	Location	Monitoring Matrix	OK to Use
WDNR Fox River and Green Bay Mass Balance Studies	1989/1990	river-wide, bay-wide	Over 4,000 sediment and surface water samples	(1)
Deposit A Sampling Collection	1992–1994	Deposit A	Sediment and water samples (BBL, 1993; WWC, 1994)	Yes
Lake Michigan Mass Balance Study	1994–1995	bay-wide	7,000 sediment, water, tissue, and air samples	Yes
1994 GAS/SAIC Sediment Sampling	1994	De Pere to Green Bay	253 sediment samples	Yes
FRG 1996 Sediment and Tissue Sampling	1996, 1998	river-wide, bay-wide	Over 1,000 sediment, water and fish tissue samples	Yes
WDNR Fish Tissue Collection	1996	river-wide	20 fish tissue samples	Yes
WDNR Bird and Mammal Tissue Collection	1984–1996	river-wide	Bird and mink tissue	(1)
USFWS NRDA Fish Tissue Collection	1996	De Pere and Green Bay	376 fish tissue samples	Yes
USFWS NRDA Bird Tissue Collection	1993–1997	De Pere and Green Bay	193 cormorant tissue, 200 tree swallow tissue, 31 eagle samples	(1)
Fish Consumption Advisory Data	1971–1996	river-wide, bay-wide	Over 2,000 fish tissue samples	(1)
Lake Michigan Fish Consumption Advisory Data	1983–1999	Green Bay zones 3 & 4	434 fish tissue samples	(1)
Lake Michigan Tributary Study	1990?	river-wide	88 surface water samples	Yes
USGS National Water Quality Program	1992–1997	only 10% from LFR	441 samples of sediment, water, and tissue	(1)
RETEC RI/FS Data Collection	1998	river-wide	252 sediment and fish tissue samples	Yes
Deposit N Demonstration Project	1997–1999	Deposit N	Sediment, water, 25 caged fish	Yes
SMU 56/57 Demonstration Project	1998–1999	SMU 56/57	Sediment, water, caged fish	Yes

Source: Lower Fox River and Green Bay RI/FS Project Database. Database Management Report (EcoChem, 2000).

Table 2-5 Distribution of Existing Sediment, Water, and Tissue Data in the Lower Fox River and Green Bay over Time

Year	Number of Samples Analyzed for Total PCBs				QA Status		
	Sediment	Tissue (caged)	Tissue (resident)	Water	Validated	Supporting	Blank
1971			14			14	
1975			26			26	
1976			53			53	
1977			62			62	
1978			70			70	
1979			67			67	
1980			69			69	
1981			73			73	
1982			68			68	
1983			51			51	
1984			92			92	
1985			195			195	
1986			97			97	
1987	203		118			321	
1988	161		70			231	
1989	1,354		604	615		2,573	
1990	104		54	197		355	
1991			40			40	
1992	35		233	8	27	249	
1993	70		106	5	67	114	
1994	296		122	54	299	152	21
1995	484		87	40	484	109	18
1996	8		416		255	169	
1997	288		119		370	37	
1998	528	20	375	310	1,233		
1999	43	6	9	20	70	8	
TOTAL	**3,574**	**26**	**3,290**	**1,249**	**2,805**	**5,295**	**39**

8,139 Records

Summary of Data Query		
TOTAL RECORDS	453,394	
Total PCBs (lipid normalized)	80	(not used)
Total Aroclor	215	(not used)
"TOTAL PCBs" Query	9,710	used
YEAR = NONE	31	discarded
	9,679	
Locations outside of project area	1,540	discarded
Total # of samples in query	8,139	

Notes:

1 Resident caged tissue includes fathead minnows only.
2 Refer to the resident tissue worksheet tables for a breakdown of tissue types for the Lower Fox River and Green Bay.
3 The data query was for all samples collected over time for "total PCBs" analysis, and includes the sum of PCB congeners analyses.
4 The data query was limited to the four reaches of Lower Fox River and the four zones of Green Bay.
5 Samples without a year or location designation were eliminated from the data query.
6 The database does not have any air samples for total PCBs analysis.
7 Approximately 100 of the water samples collected in 1998 were from the Deposit N and SMU 56/57 demonstration project studies (during dredging).

Table 2-6 Distribution of Resident Tissue Samples over Time in the Lower Fox River

Year[3]	Fish												Birds					Mammals	Other
	Benthic Fish			Game Fish			Pelagic Fish			Trout			Raptors	Swallow	Upland Game Bird	Waterfowl		Fur Bearer	Insect/ Invertebrate
	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Samples	No. of Samples	No. of Samples	No. of Species	No. of Samples	No. of Samples
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	6	2	0	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	24	3	6	12	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	24	3	9	14	3	8	0	0	0	4	1	0	0	0	0	0	0	0	0
1979	12	3	8	16	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	36	4	11	25	5	9	1	1	1	0	0	0	0	0	0	0	0	0	0
1981	23	3	14	18	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	28	3	5	24	6	3	2	1	0	0	0	0	0	0	0	0	0	0	0
1983	8	3	2	10	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	8	2	2	14	7	0	0	0	0	0	0	0	0	0	1	3	1	1	1
1985	15	3	0	35	4	0	0	0	0	0	0	0	1	0	0	12	1	0	0
1986	16	4	2	18	3	2	1	1	1	0	0	0	0	0	0	28	1	0	0
1987	34	5	1	43	7	1	1	1	1	0	0	0	0	0	0	22	1	0	0
1988	7	2	0	6	2	0	0	0	0	0	0	0	0	0	0	6	1	0	0
1989	42	3	24	38	1	26	20	2	20	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1991	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	20	2	8	111	9	9	4	1	4	0	0	0	0	0	0	0	0	0	0
1993	15	1	15	0	0	0	0	0	0	0	0	0	0	51	0	0	0	0	1
1994	10	2	5	13	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1996	109	6	84	185	7	34	13	3	13	0	0	0	0	0	0	0	0	0	0
1997	3	1	3	17	1	0	0	0	0	0	0	0	0	0	0	22	2	0	0
1998	93	4	48	198	7	59	17	3	17	0	0	0	0	0	0	0	0	0	10
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes:

1 No piscivorous birds were collected in the Lower Fox River.
2 No cormorants were collected in the Lower Fox River.
3 Samples included in the Lower Fox River and Green Bay RI/FS database.

Table 2-7 Distribution of Resident Tissue Samples over Time in Green Bay

Year[4]	Fish												Birds									Mammals		Other
	Benthic Fish			Game Fish			Pelagic Fish			Trout			Cormorant		Piscivorous Birds		Raptors	Swallow		Waterfowl		Deer	Fur Bearer	
	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Whole Fish Samples	No. of Samples	No. of Species	No. of Samples	No. of Species	No. of Samples	No. of Samples	No. of Species	No. of Samples	No. of Species	No. of Samples	No. of Samples	No. of Samples
1971	0	0	0	0	0	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	7	1	0	18	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	15	3	0	20	8	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	5	2	0	21	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	7	2	1	9	2	2	7	3	1	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1979	8	4	8	17	4	9	9	3	9	5	3	5	0	0	0	0	0	0	0	0	0	0	0	0
1980	3	1	0	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	15	1	15	13	2	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	5	1	0	4	1	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	12	3	2	13	4	0	4	1	2	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	8	3	0	23	6	0	9	4	4	20	4	0	0	0	0	0	0	0	0	4	2	0	0	0
1985	0	0	0	3	2	0	4	3	3	125	5	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	5	1	0	9	3	0	2	1	2	3	2	0	0	0	1	1	0	0	0	13	1	0	0	1
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	16	3	1	0	0
1988	20	2	0	11	2	0	10	1	0	0	0	0	0	0	0	0	0	0	0	10	2	0	0	0
1989	166	1	77	101	2	66	169	3	169	68	3	39	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	22	3	0	9	2	9	22	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	5	1	0	16	2	0	18	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	10	1	10	35	3	10	7	2	7	46	5	3	0	0	0	0	0	0	0	0	0	0	0	0
1993	6	2	4	0	0	0	2	1	2	16	2	0	0	0	0	0	0	15	1	0	0	0	0	0
1994	0	0	0	19	2	0	4	1	4	16	3	0	60	1	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	1	1	0	4	1	4	0	0	0	80	1	0	0	0	0	0	0	0	0	0	1
1996	0	0	0	60	3	24	0	0	0	29	4	19	0	0	15	2	0	0	0	5	1	0	0	0
1997	0	0	0	71	2	15	0	0	0	1	1	0	0	0	5	1	0	0	0	0	0	0	0	0
1998	12	2	12	32	4	22	8	2	8	0	0	0	0	0	0	0	0	0	0	2	1	0	0	3
1999	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Notes:

1. No reptiles were collected in Green Bay.
2. No upland game birds were collected in Green Bay.
3. Date query included all samply body types. The number of whole samples included whole fish and whole fish composites for fish, and whole body for birds.
4. Samples included in the Lower Fox River and Green Bay RI/FS database.

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3 Guidance Documents for the Development of Monitoring Programs

The primary goal of monitoring is to produce information that is useful in making management decisions. The creation of useful information depends on clear monitoring objectives and appropriate technical design. The goals and objectives established for a monitoring plan should be scientifically, technologically, logistically, and financially achievable and comparable to management parameters. To determine appropriate technical design for monitoring programs and to ensure adequate data collection, analysis, and interpretation for management-based decisions, a review of relevant regulatory and agency guidance documents was conducted.

Guidance documents reviewed fell into two categories: 1) research and panel-type discussions that identified general but important elements needed for a successful evaluation of remediation projects, and 2) detailed regional guidance documents that specifically recommend the quantity, types, and frequency of sampling parameters. The guidance documents reviewed included:

- EPA Guidance for Development of Fish Consumption Advisories;
- EPA Guidance for Conducting RI/FS Studies Under CERCLA;
- Great Lakes Protocol for Sport Fish Consumption Advisories;
- EPA ARCS Program Assessment Guidance Document; and
- OSWER Use of Monitored Natural Recovery at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.

Since a comprehensive guidance document for designing and implementing a long-term monitoring program for contaminated sediments does not exist, these relevant guidance documents could be applied to the Lower Fox River and Green Bay remediation project.

3.1 EPA Guidance for Development of Fish Consumption Advisories

The EPA document titled *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (EPA, 1995), provides technical guidance to State and local agencies on methods for sampling and analyzing contaminants in fish and shellfish tissue that will promote consistency between data sets used to determine the need for fish consumption advisories. State agencies routinely conduct chemical contaminant analysis of fish and shellfish tissues as part of their comprehensive water quality monitoring programs. If states conclude that consumption of chemically contaminated fish and shellfish poses an unacceptable risk to human health via consumption, they may issue local fish consumption advisories or bans for specific fish species and water bodies. Although the document does not constitute regulatory requirements for the states, it was formulated to improve data consistency after inconsistencies were identified between 150 publications on seafood contamination. The primary shortcomings included: 1) analysis of nonedible portions of fish, 2) different reporting methods, and 3) lack of crucial information regarding percent lipid, fish size and weight, and contaminant concentrations.

A summary of the recommendations provided in the guidance document are listed below, many of which maybe helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS. The recommendations include:

- Target fish species should include at least one bottom feeder and one predator.

- Target species for Great Lakes waters should include a combination of species from the selected list of: white bass, smallmouth bass, walleye, common carp, white sucker, channel catfish, muskellunge, chinook salmon, lake trout, brown trout, or rainbow trout.

- For the bottom feeder target species, the recommended selection, whenever practical, is common carp, channel catfish, and white sucker, respectively.

- Samples should be collected from harvest areas that have a high probability of contamination.

- Samples should be collected during the legal harvest season when target species are most available to consumers.

- In fresh waters, as a general rule, the most desirable sampling period is from late summer to early fall (August through October). The lipid content of many species (which represent an important reservoir for organic pollutants) is generally highest at this time.

- Collect composite fillet samples for each target fish species (200 g). Individual organisms used in composite samples should be of similar size and collected at the same time. Use skin-on fillets (with belly flap) for scaled species and skin-off fillets for scaleless species. Use edible portions of shellfish. States may use individual fish samples or whole fish and other sample types if necessary to improve exposure estimates of local seafood-consuming populations.

- Samples should include three size classes of the target species. For cost effectiveness, if only one size class of a target species is collected, then the collection effort should focus on larger individuals commonly harvested by the local population.

- Replicate composite samples are recommended.

- For each target species, compare target analyte arithmetic mean concentrations or replicate composite samples with screening values.

- Sampling sites should be located near sites selected for water and sediment sampling for the possibility of correlating contaminant concentrations in different media.

- Each sample location should include: sample site name, water body name, type of water body, coordinates, scientific and common name of species, sampling date and time, sampling gear type used, sampling depth, number of individual organisms used in composite, predominant characteristics of specimens (sex, life stage, total length, body size), description of sample type (fillet, whole fish), total weight, percent lipid, analytical methods, and concentrations (for wet weight in grams).

If resources allow, states may wish to consider documenting external gross morphological conditions in fish from contaminated waters. Severely polluted aquatic habitats have been shown to produce a higher frequency of gross pathological disorders than similar less polluted habitats. Morphological conditions acceptable for use in monitoring programs include: fin erosion, skin ulcers, skeletal anomalies, and neoplasms (i.e., tumors).

3.2 EPA Guidance for Conducting RI/FS Studies Under CERCLA

In the EPA document titled *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988), monitoring for long-term effectiveness and permanence is discussed when evaluating alternatives and costing (EPA, 1998). The document does not propose regulations, but rather describes how existing statutory and regulatory authorities will be used by EPA to deal with contaminated sediment problems (Zar, 1995). The primary focus of the discussion is to evaluate the risk remaining at the site after response objectives have been met. Although specific elements required for a long-term monitoring plan were not stated, the guidance document included specific components that should be addressed for each alternative:

1. Magnitude of residual risk; and
2. Adequacy and reliability of controls.

The magnitude of residual risk should be analyzed by identifying the remaining sources of risks and how much of the risk is due to untreated residual contamination verses continued source inputs. The adequacy and reliability of controls should be analyzed by identifying the difficulties and uncertainties associated with long-term monitoring and maintenance, the degree of confidence that controls can adequately handle potential problems, and what operation and maintenance functions must be performed.

A summary of the recommendations provided in the guidance document that may be helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS study include:

- Calculate the magnitude of residual risk;

- Carefully consider the integrity of institutional controls and isolation mechanisms, and the amount of sampling that can be applied to each remedy over time without compromising function; and

- Carefully consider the need for source control monitoring.

3.3 Great Lakes Protocol for Fish Consumption Advisories

A Great Lakes Advisory Task Force was convened in the early 1990s to develop uniform protocols for developing Great Lakes fish consumption advisories. The resulting document was titled *Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory* (Anderson *et al.*, 1993) after realizing the need to develop a uniform procedure for sampling, analyzing, and listing of fish species on a state consumption advisory list. The states involved in the drafting committee included state regulators from Wisconsin, Michigan, and Minnesota. Details regarding the fish collection procedures, analyses, and recommended species were not reviewed. However, the 1998 Wisconsin Fish Contaminant Sample Collection Schedule list described in Section 2 represents ongoing fish sampling activities that are in general accordance with the recommendations of the Great Lakes Advisory Task Force.

The task force assumed that the health protection value developed for PCB concentrations in fish would in most instances account for the majority of potential risk from a mixture of chemicals present in fish. For areas where other contaminants are present but not predominant, the health protection value for PCBs would be protective even considering possible additive effects (Anderson *et al.*, 1993). The State of Wisconsin risk-based advisory for the Great Lakes and inland waters sets a "health protection" value for PCBs at 5.0×10^{-5} mg PCB/kg-bw-day. Fish under 0.05 ppm PCB have no consumption restrictions. The FDA's interstate commerce level for the protection of human health is set at 2.0 ppm PCB.

Based on our review of this document, recommendations for development of the Lower Fox River and Green Bay monitoring plan include:

- Use recommended fish species listed in the 1998 Wisconsin fish collection schedule for the protection of human health, and

- Focus our analyses of fish tissue samples on PCBs and mercury for the protection of human health.

3.4 EPA ARCS Program Guidance Document

The EPA document titled *Assessment and Remediation of Contaminated Sediments (ARCS) Program - Assessment Guidance Document* (EPA, 1994) describes types of monitoring elements (sediment chemistry, sediment toxicity, and benthic community structure) commonly used in the Great Lakes regions. The document provides guidance on procedures for assessing the nature and extent of sediment contamination as applied to areas in the Great Lakes region. It was prepared under the Assessment and Remediation of Contaminated Sediments (ARCS) Program, administered by the EPA GLNPO. Although the document does not represent enforcement measures for long-term monitoring requirements, it does provide a foundation of acceptable methods for monitoring and assessing the status and trends of a contaminated sediment site. Monitoring methods used by the ARCS program to determine the nature and extent of sediment contamination in the Great Lakes Areas of Concern (AOC) basically expanded on the sediment quality triad approach and included:

- Sediment chemistry,
- Sediment toxicity,

- Benthic invertebrate community structure, and
- Fish tumors and abnormalities.

General recommendations summarized in the ARCS document that may be applicable to the Lower Fox River and Green Bay RI/FS monitoring program include:

- Use several complimentary methods to assess sediment impacts to biological organisms rather than relying on a single monitoring parameter.

- If conclusions differ between many monitoring parameters, then the differences indicate a need for caution when interpreting the data. Unusual site-specific circumstances may be confounding a clear interpretation of the data.

- If sediment toxicity tests are used, then a minimum of two or three toxicity tests should be used with at least three measured responses (i.e., survival, growth, or reproduction).

- Benthic community structure analysis should be considered in addition to toxicity tests to provide an important compliment to laboratory tests because changes in benthic communities are likely the result of long-term exposures not adequately simulated in the laboratory.

- Surveys of liver lesions in bottom-dwelling fishes have been shown to provide valuable evidence of damage to resident organisms potentially resulting from exposure to contaminated sediments.

Although these recommendations are useful, they focus mostly on the assessment of sediment quality and environmental impacts to the benthic community and not on the risk to human health and fish health. Monitoring efforts will focus on fish, bird, and invertebrate tissue sampling to assess the bioaccumulation of contaminants in biological receptors, as opposed to sediment toxicity tests. Tissue monitoring, along with reproductive viability of birds and mammals, are appropriate methods for verifying achievement of the project RAOs.

3.5 EPA Use of Monitored Natural Attenuation

The EPA's Office of Solid Waste and Emergency Response (OSWER) produced a document titled *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA, 1999b) describing the appropriateness of using monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under all OSWER programs. Although this guidance document is not explicitly intended for remediation of contaminated sediments, it will serve as a point of reference for natural attenuation considerations on the Lower Fox River and Green Bay since no other guidance documents currently exist. The purpose of this directive is to clarify EPA's policy regarding the use of monitored natural attenuation (MNA) and to provide technical guidance to the public and the regulated community on how EPA intends to exercise its discretion in implementing its regulations; however it is not a regulation itself.

The term "monitored natural attenuation" refers to the reliance on natural attenuation processes to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active remediation methods. These processes work to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in-situ* processes include: biodegradation, dispersion, dilution, sorption, volatilization, radioactive decay, and chemical or biological stabilization, transformation, or destruction of contaminants.

EPA generally expects that MNA will only be appropriate for sites that have a low potential for contaminant migration and that the use of MNA must be protective of human health and the environment. Performance monitoring for MNA is of even greater importance than other remedies due to the potentially longer remediation time frames, potential for ongoing contaminant migrations, and other uncertainties associated with using MNA. The frequency of monitoring should be adequate to detect, in a timely manner, potential changes in site conditions. At a minimum, the monitoring program should be sufficient to enable determination of the attenuation rate and how that rate is changing with time. The monitoring plan should allow flexibility in the sampling frequency over the life of the remedy to allow for changing conditions. When establishing contingency and/or action plans based on unacceptable monitoring results, care is needed to ensure that sampling variability or seasonal fluctuations do not unnecessarily trigger a contingency. Performance monitoring should continue until remediation objectives have been achieved and verified.

For the Lower Fox River and Green Bay RI/FS project, the term "monitored natural attenuation" will be referred to as "monitored natural recovery" or "MNR." A summary of the recommendations provided in the guidance document that may be helpful during the formulation of a long-term monitoring plan for the Lower Fox River and Green Bay RI/FS study follows:

- Monitored natural recovery should be considered for areas where there is adequate source control.
- MNR alternative should be able to compare upgradient and downgradient sampling results.
- Sampling strategy should allow for flexibility and adaptive management over time.

4 Recommendations and Selection of a Monitoring Plan Strategy

The National Research Council (NRC) reviewed numerous reports and monitoring programs related to the management of contaminated sediments. Based on their review, they developed a conceptual model for the design and implementation of monitoring programs and defined the role of monitoring in marine environmental management (NRC, 1990). Several evaluation parameters were identified to ensure development of an adequately designed monitoring program. These management factors were used as a screening process to select appropriate monitoring elements (i.e., sediment chemistry, fish tissue chemistry, surface water chemistry, benthic abundance) for the Lower Fox River and Green Bay RI/FS project. Recommendations put forth by other regulatory groups regarding the management of contaminated sediments and recommendations based upon our review of monitoring programs (Section 2) are also discussed below.

4.1 National Research Council Contaminated Sediment Monitoring Recommendations

The Marine Board of the National Research Council has examined issues pertaining to the effectiveness of marine environmental monitoring in several studies over the period of a decade. Recognizing the growing need for national guidance on how to improve these monitoring programs, the National Research Council convened the Committee on a Systems Assessment of Marine Environmental Monitoring under the auspices of the Marine Board. The committee was asked to evaluate and make recommendations to improve the usefulness of monitoring information as a component of sound environmental management, and identify needed improvements in monitoring strategies and practices (NRC, 1990).

According to the committee, effective monitoring programs depend on formulating clear goals and objectives, developing an effective technical design, and translating data into information that is relevant and accessible to decision makers and the interested public (Figure 4-1). The recommended parameters of an effective monitoring program are discussed below.

4.1.1 Formulation of Clear Goals and Objectives

The ultimate goal of monitoring is to produce information that is useful in making management decisions. The creation of useful information depends on clear monitoring objectives. In order to develop clear monitoring objectives, the relevant questions and hypotheses to be addressed in the monitoring program must first be clearly identified. These specific questions to be answered by the monitoring program should be designed to meet specific information needs, and the questions should be testable. In addition, the goals and objectives established for a monitoring program should be achievable scientifically, technologically, logistically, and financially.

4.1.2 Effective Technical Design

An appropriate technical design is critical to the success of monitoring programs because it provides the means for ensuring that data collection, analysis, and interpretation address the needs and objectives of management. The goal of a monitoring plan design should be the detection of specific kinds and amounts of changes that are meaningful with respect to the resources at risk. Meaningful change is often confused with significant change. Significant change often refers to change in terms of statistical differences. However, whether changes in the environment are statistically significant has no bearing on the extent to which the changes may be either meaningful or important, for example, in terms of ecological or human consequences. An effective technical program design should also identify and quantify the sources of variability that may obscure or confound responses. The technical program design should also identify which variables to measure, in light of logistical constraints and limitations on scientific knowledge. An important consideration for any monitored variable is that it should be tied directly to the specific questions to be answered and the resources at risk. Changes in the status of the variable must unambiguously reflect changes in the resources at risk. Finally, the technical program design should be capable of being modified as a result of monitoring results.

4.1.3 Translation of Data into Useful and Accessible Information

An effective monitoring program also depends on the translation of data into information that is relevant and accessible to decision makers and the interested public. The monitoring program should provide mechanisms to ensure that knowledge is used to convert data collected into useful information. Effective data management is an essential tool for achieving this task. In addition, clear guidance is required on how data are to be used and what type of decisions are to be made.

Many monitoring programs have proved to be ineffective because they devote too little attention to the above topics. The committee reached the following overall conclusion related to designing and implementing monitoring programs:

> "Failure to commit adequate resources of time, funding, and expertise to up-front program design and to the synthesis, interpretation and reporting of information will result in failure of the entire program" (NRC, 1990).

Without the above commitments, effort and money will be spent collecting data and producing information that may prove to be useless. Figure 4-1 presents a flow chart for designing and implementing a monitoring plan which includes many of the elements discussed above. These recommendations are used later in Section 4 during the monitoring element selection process for application to the Lower Fox River and Green Bay long-term monitoring plan.

4.2 EPA Contaminated Sediment Remediation Strategy Recommendations

One of the key points repeatedly referenced in the EPA document titled *EPA's Contaminated Sediment Remediation Strategy* (EPA, 1998) is the development of standardized protocols for monitoring and interpretation of aquatic systems. EPA believes that they need to develop an agency-wide strategy for coordinating and managing contaminated sediments. The Office of Water intends to use standardized sediment toxicity and bioaccumulation test methods for monitoring of narrative water quality standards and dredged material disposal testing. When appropriate, EPA program offices intend to develop and use sediment quality criteria to assess contaminated sediment sites.

As stated in the document, EPA will consider a range of risk management alternatives including monitored natural recovery. EPA plans to develop criteria for determining when natural recovery is an appropriate remedial alternative using rates of recovery of benthic communities under different environmental conditions and stresses. Factors influencing the recovery rates (i.e., community types, physical factors, types of stresses) will be evaluated. One of the major uncertainties in assessing the effects of sediment-associated contaminants is the ecological significance of bioaccumulated compounds. The EPA Office of Research and Development will continue research on the bioavailability and trophic transfer of contaminants in sediment to shellfish and higher trophic level aquatic species resulting in both lethal and sublethal effects.

In summary, EPA plans to use standard sediment toxicity, bioaccumulation tests, and site-specific field-based methods (i.e., ELIZA immunoassay testing) to identify potential sites for remediation, to assist in determining cleanup goals for contaminated sites, and to monitor the effectiveness of remedial actions. Although EPA did not state specific requirements for long-term monitoring of contaminated sediment remediation projects in the *EPA's Contaminated Sediment Management Strategy* document (EPA, 1998), their research and attention over the upcoming years will likely focus on monitoring of sediment toxicity, benthic community abundance, and bioaccumulation testing as their management strategy is implemented. These elements identified by EPA as important management tools for contaminated sediment projects will help the Fox River and Green Bay remediation project formulate a long-term monitoring plan that will be consistent with EPA's long-term management strategies.

4.3 Monitoring Plan Recommendations Extracted from National, Regional and State Programs

Based on our review of regional, national, and state monitoring programs in Section 2, our recommendations for the Lower Fox River and Green Bay long-term monitoring plan are summarized below:

- Focus on surface water quality and fish tissue sampling to verify protection of human health.

- Conduct surface sediment sampling in areas selected for monitored natural recovery to assess potential recontamination of these areas.

- Long-term biological monitoring to assess environmental health should focus on either: 1) sediment toxicity and benthic community structure; or 2) fish, bird, shellfish, and invertebrate tissue sampling to assess declines in COC concentrations in tissue. This monitoring plan will focus on fish, bird, and invertebrate tissue sampling for PCBs, mercury, and DDE.

- Build upon the existing Fox River and Green Bay database which consists primarily of fish tissue data (20 years), sediment chemistry (15 years), and surface water chemistry (11 years).

- Focus fish tissue sampling on species presented in the project food web model and species of concern for evaluating fish consumption advisories.

- Focus bird tissue sampling on species of interest that have demonstrated sensitivity to contaminant uptake and reduced reproductive success when exposed to contaminants in the food chain (i.e, bald eagles).

- Focus on bird species of concern for evaluating waterfowl consumption advisories (i.e., mallard duck).

- Do not conduct air monitoring as part of the long-term monitoring program. It does not directly relate to the project RAOs, but may be included during remedial design efforts to assess downstream transport of PCBs via volatilization and atmospheric deposition.

- Coordinate data management efforts with other regional monitoring programs to build a comprehensive multi-media database of the project area that is accessible and usable by multiple parties.

4.4 Consistency with the Lake Michigan Lake-wide Management Plan (LaMP)

The Lake Michigan LaMP was created under the auspices of the Great Lakes Water Quality Agreement between the United States and Canada to restore and protect the integrity of the Lake Michigan ecosystem through collaborative, placed-based partnerships. The document was initially created in 1993 by an EPA-directed committee comprised of local and state governments, national trustees, industry, environmental groups, fishers, academia, and native tribes. The plan is considered a working document that will be revised every 2 years based on new findings and public discussion. Lake Michigan has 10 designated AOCs that have contributed toxic contaminants to the Lake Michigan watershed and the degradation of aquatic life. These 10 AOCs, including the Lower Fox River, have been designated as top priority areas where ecosystem management of contaminants and stressors must occur.

Under this program, the Lake Michigan Monitoring Coordination Council was established to provide a forum for coordinating and supporting monitoring activities in the Lake Michigan basin and to develop a shared resource of information, based on accepted standards and protocols, that are usable across agency and jurisdictional boundaries (EPA, 2000a). This council is currently analyzing data collected from an inventory of monitoring programs in the Lake Michigan Basin to determine whether the current monitoring coverage is sufficient to support indicators proposed in the Lake Michigan LaMP. A summary of the proposed indicators are presented in Table 4-1 as they relate to the valued ecological endpoint criteria including: fish community structure and function, fish habitat, and exotic species. The table also lists the metrics to be measured, the parameters for measurement, and the objectives/expectations for each of the valued endpoints.

These endpoints were identified in the Lake Michigan LaMP as important long-term management goals for contaminated sediment projects contributing to the Lake Michigan receiving water body. These goals will help the Fox River and

Green Bay remediation project formulate a long-term monitoring plan that will be consistent with Lake Michigan's long-term management strategies.

4.5 Final Selection of Monitoring Plan Elements

Post-project monitoring plan elements commonly implemented on contaminated sediment management and remediation projects can be summarized into physical, chemical, and biological components including:

- Physical
  - Bathymetry and side-scan sonar surveys
  - Underwater video surveys
  - Sediment characteristics

- Chemical
  - Surface water and groundwater for chemical analyses
  - Suspended and bedded surface sediment for physical and chemical analyses
  - Subsurface sediment cores for chemical analyses
  - Air samples for chemical analysis (usually collected during implementation)

- Biological
  - Benthic biota population and community studies
  - Resident and caged fish tissue for chemical analyses
  - Resident fish observations for physical deformities and histopathology
  - Caged mussels for chemical analyses (usually collected during implementation)
  - Sediment and water column acute and chronic toxicity testing
  - Bird tissue and eggs for chemical analyses
  - Bird observations for physical deformities and sublethal effects
  - Fish tissue for enzymatic indicators
  - Plant assemblage and coverage
  - Plant tissue for chemical analyses

4.5.1 Selection Factors

the possible types of monitoring plan elements listed above, monitoring methods considered most valuable for: 1) documenting contaminant reduction changes in the Lower Fox River and Green Bay, and 2) measuring achievement of the project RAOs will be selected. Final selection of monitoring elements were screened using the five management factors put forth by the sediment systems review committee organized by the Marine Board of the National Research Council. Committee members were selected to ensure a wide range of expertise needed to include a broad spectrum of viewpoints (academic, industry, laboratories, and public agencies). The committee was asked to evaluate and make recommendations to improve the usefulness of monitoring information (NRC, 1990). The five management factors initially described by the National Research Council during their assessment of marine environmental monitoring programs (NRC, 1990) include:

- Simplicity and affordability,
- Comparability against regulatory standards or other significant criteria,
- Implementable and appropriate for the site,
- Social relevance or importance, and
- Ability to be understood by laymen.

In the NRC document titled *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, these factors are loosely defined as fundamentals of a sound program design which are required for successful implementation. Simple refers to a program that is sufficiently flexible to allow for modifications when changes in conditions or new information suggests the need. Affordable refers to a program that has adequate resources not only for the data collection efforts, but allows for detailed analysis and evaluation over the long term. The monitoring program should integrate the regulatory, data, and management needs and responsibilities with the local, state, regional, and federal agencies to optimize use of available resources. Comparability refers to a program where the data gathered can have adequate management, synthesis, interpretation, and analysis. Adequate interpretation generally requires comparison to a regulatory or site-specific standard, reference data, or baseline conditions. The monitoring program should be integrated into the decision-making system, with the decision points and feedback loops clearly established before the data are collected (NRC, 1990).

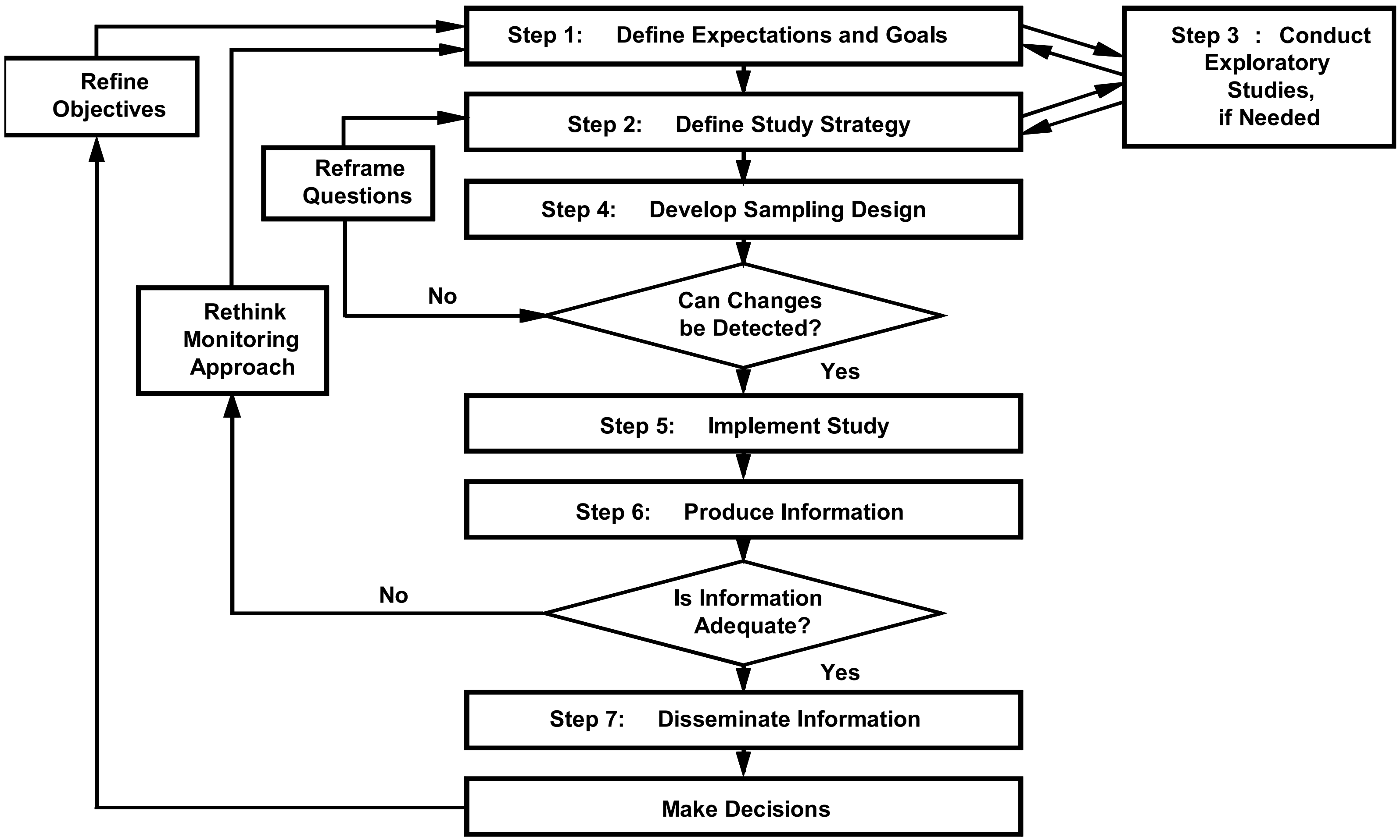
Implementability and appropriateness refers to a program in which the monitoring program can answer the questions being posed, a quality assurance program can be applied, and the data can be interpreted. The goals established should be achievable scientifically, technologically, logistically, and financially (NRC, 1990). Social relevance refers to a program in which the goals and objectives of the monitoring program can be clearly articulated in terms that pose questions that are meaningful to the public. The public generally understands fish tissue concentrations, and perhaps surface water concentrations. Most anglers and local residents want to know: "Can I eat the fish?" "Can I eat the birds?" and "Can I swim in the water?" Ability to be understood by laymen refers to a program where the information is made available to all interested parties in a form that is useful and meaningful to them. These generally include numerical and quantifiable data. Although these management factors are somewhat subjective without well-defined scales of measurement, they provide a useful and relative tool for comparison between different monitoring elements.

The monitoring elements retained after the screening process (compared to our five management factors) are presented in Table 4-2. Elements that met at least 50 percent of the valued factors criteria were retained for further consideration in the Lower Fox River monitoring plan. Surface and subsurface sediment chemistry along with resident fish tissue analyses were among the most commonly implemented measurement endpoints used in the majority of projects reviewed. In addition, these monitoring elements were often measured regardless of the type of remedy selected (removal, isolation, or natural recovery) ensuring their appropriateness to the Lower Fox River and Green Bay project, which will likely have a combination of selected alternatives. The final step in the selection process was to ensure that the retained monitoring elements were diverse in nature and output in order to verify achievement of (or progress towards) the project RAOs. As discussed in the following section, each one of the retained monitoring elements will be used to assess one or more of the project RAOs.

4.5.2 Results

The monitoring elements retained for the long-term monitoring plan (Table 4-2) include: surface water, surface sediment, fish tissue, bird tissue, bird reproductive assessment, and mammal reproductive assessment. Although the monitoring elements for mammals did not satisfy at least three factors (minimum needed for retainment), it was considered a significant data gap and a sensitive receptor identified in the project food web model. A few other monitoring elements, such as groundwater and sediment cores, will be utilized specifically for construction monitoring of engineered CDFs and sediment caps, and are not included in this long-term monitoring plan.

Figure 4-1 Flow Chart for Designing and Implementing a Monitoring Program



Source: *Managing Troubled Waters: The Role of Marine Environmental Monitoring* (NRC, 1990).

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function	To restore and maintain the biological integrity of the fish community so that production of desirable fish is sustainable and ecologically efficient.				
	Salmonines: Maintain a diverse salmonine community consisting of both wild and planted fish, and capable of sustaining an annual harvest of 6 to 15 million pounds, of which 20% to 25% is lake trout.	Standing stock (biomass) of salmonines.	A predicted standing stock of salmonines ranging from about 21 to 58 million pounds (Lake Michigan Salmonine Stocking Task Group, 1998, CONNECT model).	Based upon historical yields of native lake trout, a range in catch of about 5.7 to 7.3 million pounds annually is considered to be a minimum measure of the lake's capacity to yield salmonines; the theoretical maximum yield has been estimated at about 15.4 million pounds (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).	Current standing stock biomass of salmonines is thought to be about 65 million pounds (Salmonine Stocking Task Group, 1998. CONNECT model).
	Establish self-sustaining lake trout populations.	Percentage of unmarked lake trout in assessment and sport catches.	The percentage of unmarked lake trout in assessment and sport catches is increasing towards 100% (all stocked lake trout are marked).	The percentage of unmarked lake trout in lake-wide assessment catches has ranged from 0% to 8.8% since the mid-1980s without an apparent trend.	No recruitment from natural reproduction is occurring and the lake trout population is comprised entirely of stocked fish.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Enhance natural reproduction of coho and chinook salmon, and rainbow and brown trout.	Proportion of unmarked salmon and trout in assessment and sport catches (**a known portion of each species must be marked prior to release**).	Stable or increasing numbers of naturally-produced fish from each species.	Naturally-produced chinook comprised an estimated 32% of the 1990–1993 cohorts in Michigan waters; naturally-produced coho comprised an estimated 9.3% of the 1979 lake-wide sport catch; naturally-produced rainbow trout (steelhead) comprised 6% to 18% of annual smolt production in Michigan streams in the 1980s.	Coho and chinook salmon, rainbow and brown trout are naturally-reproducing in some watersheds tributary to the lake. The Michigan DNR has estimated that from 2.2 to 2.7 million chinook smolts have been produced annually in the 1990s as compared to 0.6 to 0.8 million in the 1970s (Salmonine Stocking Task Group, 1998).
	Planktivores: Maintain a diversity of prey species at population levels matched to primary production and to predator demands; expectations are for a lake-wide planktivore (alewife, smelt and bloater) biomass of 1.2 to 1.7 billion pounds.	Lake-wide biomass estimates of alewife, smelt and bloater.	Alewife, smelt and bloater in varying proportions constitute the bulk of the prey fish biomass; biomass size-spectrum models suggest that a total biomass of planktivores amounting to 1.2 to 1.7 billion pounds is a reasonable range for Lake Michigan (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).	Lake-wide planktivore biomass estimates (portion of population available to bottom trawls) since 1973 have increased from 0.14 to 0.88 billion pounds as the dominant planktivore shifted from alewife to bloater (USGS-BRD); **catches in bottom trawls represent only a portion of prey fish biomass and will therefore always be lower than the actual biomass**.	The 1996 lake-wide planktivore biomass estimate was 0.65 billion pounds from bottom trawls (Note: studies are needed to understand how shifts in species composition affect biomass estimates, and the relationship between trawl catches and total biomass).

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Inshore Fishes: Maintain self-sustaining stocks of yellow perch, walleye, smallmouth bass, esocids, catfish and panfish; expected annual yields are 2 to 4 million pounds for yellow perch and 0.2 to 0.4 million pounds for walleye.	Indices of relative abundance (CPUE).	CPUEs for yellow perch and walleye capable of sustaining the expected ranges of annual yield have not been calculated and must be derived from lake-wide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lake-wide assessment plan which will include yellow perch and walleye, as well as other inshore species.	Self-sustaining populations of all these species exist, however, the relative abundance of yellow perch declined an estimated 90% in the southern portion of the lake from 1990 to 1996.
	Benthivores: Maintain self-sustaining stocks of whitefish, sturgeon, suckers and carp; expected annual yield of lake whitefish is 4 to 6 million pounds.	Indices of relative abundance (CPUE).	CPUEs for lake whitefish capable of sustaining the expected range of annual yield have not been calculated and must be derived from lake-wide assessment data.	The Lake Michigan fishery management agencies are in the process of developing a lake-wide assessment plan which will include lake whitefish, as well as other benthivores.	Self-sustaining populations of all these species exist, however, the lake sturgeon and longnose sucker are still listed as protected within the basin.
	Maintain a self-sustaining burbot population compatible with the rehabilitation and self-sustainability of lake trout.	Relative abundance indices (CPUE).	A ratio of relative abundance of lake trout to burbot at about 3.5:1 in the southern portion of the lake and 1:1 in the northern portion.	Historical catches of native lake trout and burbot in small mesh gill nets fished lake-wide for chubs by the vessel *Fulmar* (U.S. Bureau of Fisheries) in 1931–1932 suggest mean ratios of 3.5 lake trout per burbot in southern waters and a 1 to 1 ratio in northern waters.	Current ratios have not been available from annual stock assessments, but will be as the new lake-wide assessment plan is implemented; studies comparing the catchability of these two species are needed to evaluate th reliability of using the proposed ratios.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Community Structure and Function (Continued)	Other Species: Protect and sustain a diverse community of native fishes including species such as cyprinids, gar, bowfin, brook trout, sculpins and others not previously mentioned.	Species richness.	A species is considered to be present in the lake if at least one individual (any life stage) is captured.	By 1970, five species of deepwater ciscoes had been extirpated from the lake as well as the paddlefish (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC); lake herring and emerald shiner populations also have never recovered to their historical levels of abundance.	A total of 92 species are known to occur in the lake proper, of which 75 are native and 13 are naturalized (*Fish Community Objectives for Lake Michigan*, Eshenroder *et al.*, 1995, GLFC).
	Sea Lamprey: Suppress the sea lamprey to allow the achievement of other fish community objectives.	Wounding rates on lake trout.	A lake-wide mean wounding rate not greater than 5 per 100 lake trout of all sizes.	The 1984–1996 mean wounding rate was 4 per 100 trout, but has generally been increasing since 1987 (*Sea Lamprey Wounding of Lake Trout in Lake Michigan*, Ebener, 1997, GLFC).	The lake-wide mean wounding rate was 5 per 100 lake trout in 1996.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Fish Habitat	Protect and enhance fish habitat and rehabilitate degraded habitats, including historic riverine spawning and nursery areas fo anadromous species.	Measure key features of the physical (substrate, water depth), chemical (dissolved oxygen, total phosphorus), and biological (vegetation) components of aquatic habitats.	A formal process such as the Classification and Inventory of Great Lakes Aquatic Habitats (CIGLAH) should be considered to classify and inventory habitats in the lake basin.	Inventories have been compiled on the general locations of many important fish spawning habitats in Lake Michigan (*Atlas of the Spawning and Nursery Areas of Great Lakes Fishes*, Vol. IV, Goodyear *et al.*, 1982, USFWS), but specific locations, habitat characteristics (e.g., chemical and biological features), and current status has not been addressed but for a few spawning shoals for lake trout.	The classification, location, and status of important fish habitats in Lake Michigan has not been addressed in a comprehensive fashion.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Ecological Criteria and Beneficial Use Impairments	Objectives/Expectations	Metrics to be Measured	Criteria for Measurement	Baseline Data	Status
Exotic Species	Minimize the unintentional introduction of new exotic species and the spread of existing exotics that may negatively impact the structure and function of existing fish communities.	The appearance of new exotic species and the expansion in range (number of locations) of existing exotic species.	An exotic species is considered to be present in the lake or in a specific area if at least one individual of any life stage is captured.	Since the 1800s, some 136 non-indigenous aquatic organisms have become established in the Great Lakes (*Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions*, Mills *et al.*, 1991, GLFC); most of these have come from Europe (47%), the Atlantic Coast (18%), and Asia (14%), and the rate of introduction has increased as the rate of human activity has increased; more than one-third of the organisms have been introduced in the past 30 years, coincident with the opening of the St. Lawrence Seaway in 1959.	Although various ballast water and aquaculture control measures, and importation and possession bans (bait buckets, pet stores) have been implemented at the state, provincial and federal levels to address potential pathways for the unintentional introduction of exotic species, the appearance of new introductions and range expansion of existing exotics remains a constant threat, and a vigilant watch must be kept throughout Lake Michigan.

Table 4-1 Lake Michigan Lake-wide Management Plan (LaMP) Expectations (Continued)

Chapter 2	Chapter 3		Chapter 4 Lake Michigan LaMP: Current Status of the Ecosystem,	Chapter 5 Lake Michigan Stressor Sources and Loads	Chapter 6	
Lake Michigan LaMP: Vision, Goals and Ecosystem Objectives	Indicators and Monitoring of the Health of the Lake Michigan Ecosystem				Strategic Action Agenda: Next Steps	
Endpoint Goal	Monitoring	Human Activity			Means to an End Goal	Recom-mendations
1. We can all eat any fish.	• Chemical contamination in fish • Site assessments • Eagle reproduction	• Fish advisories • Congressional reports on ‣ Great Water ‣ Mercury ‣ Dioxin				
2. We can all drink the water.	• Raw water quality data • Source water assessments	• Water utility notifications • Source water protection				
3. We can all swim in the water.	• E Coli levels in recreational water	• Beach closing advisories • State 305(b) WQ reports				
4. All habitats are healthy, naturally diverse and sufficient to sustain viable biological communities.	• Fish assessments • Bird counts • Wetlands inventories and assessments • Stream flows • Eco-rich area assessments	• Endangered species list • Wetland mitigation and protection • Zoning • Fish stocking • Fish refuges • USFWS refuges • Ballast water exchange • Dune protection • Eco-rich cluster map				
5. Public access to open space, shoreline and natural areas is abundant and provides enhanced opportunities for human interaction with the Lake Michigan ecosystem, aquatic habitat and biological population.	• Urban density • Coastal parks acreage • Conservation easements	• Open space funding and protection statutes • Coastal zone management				
6. Land use, recreation and economic activities are sustainable and support a healthy ecosystem.	• Contaminants in recreational fish • Sustainable forests • Land conversion	• Superfund cleanups dredging • CRP percent of eligible farm lands • Brownfields to greenfields redevelopment				

Table 4-2 Selection of Monitoring Program Elements Using Five Management Factors

Monitoring Element	Management Factors [4]					Retain
	Simple and Affordable	Comparable to Standards	Appropriate to Site	Socially Important	Clear to Layman	
Surface Water	Yes	Yes	Yes	Yes	Yes	Yes
Groundwater [1]	Yes	Yes	Unknown	No	Yes	Yes [1]
Surface Sediment	Yes	Yes	Yes	No	Yes	Yes
Sediment Cores [2]	Yes	Yes	Yes	No	Yes	Yes [2]
Benthic Abundance	Yes	No	No	No	No	No
Fish Tissue	Yes	Yes	Yes	Yes	Yes	Yes
Fish Deformity	Yes	No	No	No	Yes	No
Toxicity Test	Yes	Yes	Yes	No	No	No
Bird Tissue	No	Yes	Yes	Yes	Yes	Yes
Bird Deformity	No	No	No	No	Yes	No
Bird Reproductive Assessment	Yes	No	Yes	No	Yes	Yes
Mammal Tissue	No	No	Yes	Yes	No	No
Mammal Reproductive Assessment	Yes	No	Yes	No	No	No [3]
Habitat Assessment	Yes	No	Yes	No	No	Yes [3]
Enzyme Test	Yes	No	NA	No	No	No
Plant Assemblage	No	No	No	No	No	No
Plant Tissue	Yes	No	Yes	No	No	No

Notes:

1. Groundwater will be monitored in areas where CDFs are installed.
2. Sediment cores will be advanced in areas where sediment caps are placed.
3. Retained for the long-term monitoring plan for mink because it is a significant data gap and a valued receptor.
4. Management factors derived from NRC 1990 document *Managing Troubled Waters: The Role of Marine Environmental Monitoring*.

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5 Model Long-term Monitoring Plan for the Lower Fox River and Green Bay

This section presents the proposed model long-term monitoring plan for the Lower Fox River and Green Bay RI/FS remediation project. The focus of this document was to design a post-project, long-term monitoring plan based on project expectations, valued endpoints, a review of national and regional monitoring programs, case study precedent, lessons learned, guidance documents, and scientifically-based recommendations. The plan was formulated around achievement of the five RAOs listed in the Lower Fox River and Green Bay feasibility study. A summary of the monitoring plan elements selected for verification of long-term RAOs (RAO-1 through RAO-4) are presented in Table 5-1. RAO-5 is not included in this model plan. Table 5-2 presents a summary of the monitoring elements proposed for long-term monitoring.

In sequential order, this section: 1) summarizes the long-term project RAOs and their associated expectations, 2) discusses the timing and onset of long-term monitoring between different reaches and zones, and 3) presents the monitoring elements (surface water chemistry, sediment chemistry, fish tissue, bird tissue, invertebrate tissue, and reproductive assessments) that will be used to verify achievement of the long-term RAOs. Sampling methods for each monitoring element are described in some detail regarding the frequency, number of samples, location, species selection, and chemical analyses.

5.1 Plan Overview

5.1.1 Defining the Remedial Action Objectives and Expectations

As described in the previous chapters, this long-term monitoring plan is designed to verify achievement of the project RAOs and to monitor the integrity of the physical, chemical, and biological components of the aquatic system. The five RAOs defined for the Lower Fox River and Green Bay project can be translated into expectations and viable measurement endpoints that lay the groundwork for developing a long-term monitoring plan. The project expectations that correlate to the defined RAOs for the Lower Fox River and Green Bay include:

RAO	Expectation	Lower Fox River	Green Bay
Surface Water Quality	Reduction in contaminant concentrations in suspended sediments and surface water	✓	✓
Human Health	Reduction in contaminant concentrations in fish and waterfowl consumed by humans	✓	✓
Health of Environment	Reduction in contaminant concentrations in fish, piscivorous birds, benthos, and mammals	✓	✓
Sediment Transport	Reduction in contaminant loading to Green Bay		✓
Minimize Contaminant Releases	Maintain low contaminant concentrations in surface water during active remediation (short-term)	✓	✓

More specifically, project expectations include the following:

- Remediation will be completed within 10 years;
- Surface water quality will eventually meet background conditions;
- The removal of sport fish consumption advisories will be achieved within 10 years after remediation (in 20 years);
- The removal of all fish consumption advisories within 20 years after remediation (in 40 years);
- The removal of all waterfowl consumption advisories within 20 years after remediation (in 40 years).
- Resident bird populations will achieve sustainable reproductive viability when compared to reference sites;
- Resident fish, bird, and invertebrate populations will achieve safe levels of contaminants in tissue determined by risk-based models and state/federal criteria;
- Annual mass loading of contaminants from the Lower Fox River to Green Bay will not exceed the annual non-point source loading of PCBs and mercury to Green Bay and subsequent loading to Lake Michigan; and

- The plan should be compatible with other regional program objectives, and compliment the long-term goals of the Lake Michigan LaMP. A detailed design of the long-term monitoring program is presented in Table 5-2.

Most of the project RAOs (RAO-1 through RAO-4) address long-term goals that may require 20 to 40 years to achieve. This long-term monitoring plan was designed to address these RAOs. The RAO concerning "minimizing contaminant releases during active remediation" (RAO-5) is a short-term goal to be utilized during active remediation. This long-term monitoring plan does not address this short-term goal. Short-term goals will be used to confirm and verify success of an implemented active remedy, and will be important components of a well-defined remedial action plan for the Lower Fox River and Green Bay project. Short-term monitoring components will be discussed during development of a final remedial action plan and will likely include many elements discussed below.

5.1.2 Initiation of Long-term Monitoring

Long-term monitoring will begin after completion of an active remedy (removal or isolation) or after an area has been designated for monitored natural recovery instead of active remediation. Long-term monitoring is defined as sampling events that begin after post-project completion of a remedy or decision not to remediate. However, sampling data collected during a long-term monitoring program needs to be testable and comparable to pre-remedy conditions. In order to assess the spatial and temporal trends in contaminant concentrations, an adequate baseline data set should be developed. Therefore, the pre-remedy sampling event and the post-project verification sampling event should follow the same technical design as the long-term monitoring plan. Pre-remedy sampling is conducted to verify initial conditions immediately prior to remedy implementation. Post-project verification sampling is conducted to verify achievement of the remedy. While both of these monitoring plans may have a different scope and objectives than a long-term monitoring plan, they will serve as the baseline data set for subsequent long-term monitoring events. They should have, at a minimum, the same monitoring elements proposed in this long-term model. In areas designated for MNR, a pre-remedial baseline sampling event will be conducted for long-term monitoring comparisons. In summary, the baseline data set will be collected prior to initiation of active remediation (or initiation of MNR) and immediately after completion of a remedy for comparison with long-term monitoring elements.

For example, if the Appleton to Little Rapids Reach of the Lower Fox River has 10 years of active remediation planned, then long-term monitoring for that reach will not begin until after final completion of the remedy. If a deposit of contaminated sediment within that reach (identified in the FS) will not be remediated, then long-term monitoring of natural recovery for that deposit may begin at Time 0 while other deposits within the same reach are being remediated. The entire reach will not begin long-term monitoring for another 10 years, after completion of all active remediation within the reach. The extent of sampling within the reach will need to be coordinated within a reasonable effort, scope, and budget to ensure that contaminated deposits remaining in-place are not serving as new sources of recontamination and not contributing to contaminant transport to newly remediated areas.

For a second example, if Green Bay is monitored for natural recovery, then long-term monitoring for these areas begins at Time 0 although the Lower Fox River may undergo active remediation in some areas. The technical design of the river monitoring (during remediation) should be comparable to the bay monitoring over the same time period.

5.1.3 Scales of Measurement

Based on the complexity and duration of the proposed remediation plan for the Lower Fox River and Green Bay, the examples described above reinforce the need for defining different levels of monitoring. For the purposes of this project, three levels of monitoring are defined:

- **"Deposit-wide" Scale -** monitoring around a specific deposit, CAD site, nearshore fill, disposal site, or other physical feature generally confined to within a reach;

- **"Reach-wide" Scale -** holistic monitoring of a reach, generally at the end of a reach to measure transport of contaminants to the next reach, or for fish with home ranges spanning an entire reach; and

- **"River-wide" Scale -** monitoring of the Lower Fox River or Green Bay to compare differences between the river and bay system.

Most of the monitoring elements proposed in this plan are on the reach-wide scale. However, some of these elements may be considered river-wide or bay-wide (i.e., bald eagles or mink habitat) depending upon the final monitoring design. Elements may also be considered on a deposit-wide scale if active remedies are implemented at different times within a reach or if a unique physical feature warrants more detailed attention.

5.1.4 Limitations

The focus of this monitoring plan will be on verification of the valued endpoints and not on continued correlation analysis between physical and chemical components of the Lower Fox River system and observed effects. For example, one valued endpoint is protection of human health via consumption of resident fish in the Lower Fox River, so the monitoring plan will include fish tissue measurements of consumable fish species to verify protection of human health. The plan does not intend to use indicator variables such as sediment chemistry or water chemistry to imply protection of human health. Also, the plan does not intend to further develop a correlation analysis between sediment chemistry and fish tissue concentrations. However, sediments samples will be collected at specified intervals within each reach to assess sediment transport concerns and may be used to verify protection of pathway exposures to resident fish.

5.2 Monitoring Plan Approach

This proposed monitoring plan is designed to verify achievement of (or progress towards) attainment of the long-term project goals summarized as the RAOs. The proposed monitoring plan is organized into measurable physical, chemical, and biological elements that are used to assess the spatial and temporal trends towards these long-term goals. Monitoring plan elements include surface sediment chemistry; surface water chemistry; fish, bird, and invertebrate tissue analyses; and bird and mammal population counts (Tables 5-1 and 5-2). For FS cost estimates, all monitoring elements will be conducted for a period of 40 years, with sampling frequencies of every 5 years. Sampling frequencies and media may change after selection of the final remedy.

These elements are listed as a model framework of sampling methods for long-term monitoring on the Fox River and Green Bay, but are not intended to comprise detailed sampling and analysis design components. Specific management factors such as sample sizes, number of replicates, locations and chemical analysis will be finalized after completion of the RI/FS report and selection of environmental remedies.

Statistical models will be used to determine the appropriate sample sizes based on the desired power of detection (alpha and beta) and the confidence limits surrounding the data results (change of Type I and II errors). However, eight or nine fish samples will be expected per reach/zone. The sampling plan will be designed to minimize the influence of confounding factors and sampling variability as much as possible.

5.2.1 Monitoring for Surface Water Quality

Monitoring elements used to verify long-term achievement of surface water quality will consist of surface water samples collected from fixed locations over time. Collection of surface water samples at sediment remediation sites were used at several site-specific projects including United Heckathorn, Lake Jarnsjön, Minamata Bay, and James River, Virginia.

Surface water sampling will be conducted on a "reach-wide" scale at seven locations: one station in each river reach (4 locations), two stations in Green Bay—zones 2 and 3B (2 locations), and one station in Lake Winnebago. Water samples will be collected near the end of a reach or at fixed locations in a lake over time, to assess the net contribution of contaminated sediments located along each reach to the overlying surface water. The sampling frequency is modeled after the sampling scheme conducted for the Green Bay Mass Balance Study.

For the Green Bay Mass Balance Study, samples were collected intensively at numerous stations over a 1-year period (1989 and again in 1994) to quantify the maximum PCB mass loading during periods of maximum flow events. Since higher mass loading is expected during storm and rainfall events when river flow is highest, the sampling events were structured at monthly intervals during the wet season to predict flow variability and at daily intervals (as needed) during storm events to capture the highest possible PCB loading events. The 1-year sampling events were conducted every 5 years.

The focus of the Lower Fox River/Green Bay monitoring plan will be to assess temporal changes in surface water quality as opposed to horizontal and vertical spatial heterogeneity. Prior to long-term monitoring, pre-remedial and post-remedial baseline sampling will be conducted. Samples will be collected at designated intervals from March through November every 10 years. Several samples will be collected from within each reach/zone at fixed locations over time. Additional samples will be collected during periods of maximum flow events to capture the highest possible PCB-mass loading estimates. Samples will be analyzed for PCB congeners, co-planar PCB congeners, mercury, TSS, DOC and TOC for particulate and dissolved fractions (Table 5-2). Sample concentrations will be compared to project water quality criteria designed to be protective of human health (ingestion and dermal contact).

5.2.2 Monitoring for Protection of Human Health

Monitoring elements used to verify long-term achievement of "reduced potential for chemicals to cause adverse effects to human health" as stated in the Lower Fox River and Green Bay FS will consist of fish tissue sampling from specific reaches over time. Similar methods are described and/or recommended in regional monitoring programs (NOAA NS&T, SF-Bay Estuary and GLNP) and guidance documents, and were used on several Great Lakes projects (Sheboygan River, Waukegan Harbor, Grasse River, Ford Outfall, Collingwood Harbour) and other national and international projects (Bayou Bonfouca, GM Foundry, River Emån, Minamata Bay).

Fish Tissue Sampling

Fish tissue sampling will be conducted on a "reach-wide" scale within each reach of the Lower Fox River (4 regions) and within each zone of Green Bay (4 regions) to assess the uptake of contaminants into fish tissue. The reach-wide scale is appropriate since fish generally have large home ranges, the exact location of fish feeding grounds cannot be determined, and the reaches are separated by dams limiting the fish ranges. The focus will be to assess changes in fish bioaccumulation uptake within each reach over time. The long-term goal of the sampling program will be to support the removal of Wisconsin and Michigan state general fish consumption advisories currently in-place for numerous fish species (EPA, 2000d), assuming fish tissue concentrations show reduced PCB and mercury levels over time.

Resident fish samples will be collected in pre-remedial and post-remedial baseline sampling events, and every 5 years thereafter, after initiation of the long-term monitoring program. These will be concurrent with the surface water sampling years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Fish species collected in the Lower Fox River will include resident walleye, carp, and white bass alewife. Discrete whole fish and skin-on-fillet samples will be analyzed for PCB congeners[1], mercury, and lipids. Fish species collected in Green Bay will include walleye, carp, lake trout, white perch, and white bass for the same analyses. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of fish to the best practicable extent. Three size classes of fish per fish species will be specified.

Bird Tissue Sampling

Bird tissue sampling will be conducted on a "reach-wide" scale within each zone of Green Bay (5 regions including Zone 1) to assess the uptake of contaminants into bird tissue. The reach-wide scale is appropriate since birds generally have large home ranges and the exact location of feeding grounds cannot be determined. The focus will be to assess temporal changes in bird chemical body burdens within each zone. The long-term goal of the sampling program will be to support the removal of the Wisconsin state waterfowl consumption advisory

[1] PCB congeners include the Wisconsin State Laboratory PCB Congener List as well as co-planar dioxin-like PCB congeners.

currently in-place for mallard ducks, if bird tissue concentrations show reduced PCB levels over time.

Resident mallard duck samples and one other sensitive bird species (i.e., coots or mergansers) will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with surface water sampling events. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Samples will be analyzed for PCB congeners, mercury, and lipids. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of waterfowl to the best practicable extent. A minimum of one size class per bird species will be specified.

5.2.3 Monitoring for Protection of Environmental Health

Monitoring elements used to verify long-term achievement of environmental health defined as "the reduced potential for chemicals to cause adverse effects to environmental receptors," will consist of resident fish, invertebrate, and bird tissue sampling over time. Monitoring elements will also include reproductive observations such as number of nesting sites, number of eggs, and population counts for bird and mammal populations. Similar fish tissue monitoring methods were used in several national monitoring programs (NOAA NS&T, EMAP and GLNP) and on several Great Lakes projects (Sheboygan River, Waukegan Harbor, Grasse River, Ford Outfall, and Collingwood Harbour). Invertebrate mussel tissue monitoring was used in two regional monitoring programs (San Francisco-EP and EMAP). However, long-term bird tissue monitoring, bird population nor mammal population monitoring have not been documented in any regional, national, or site-specific monitoring programs reviewed.

Frequency of sample collection for all media will include pre-remedial and post-remedial baseline sampling events, and every 2 to 5 years for 10 years thereafter, after initiation of the long-term monitoring plan. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Sampling events will be concurrent with surface water sampling years. The final selection of sampling media and frequency will be revised after selection of the remedy and project expectations. For the purposes of the FS cost estimate, monitoring elements were sampled every 5 years for 40 years.

Fish Tissue Sampling

Fish tissue sampling will be conducted on a "reach-wide" scale. Samples will be collected for each river reach (4 regions) and each zone of Green Bay (4 regions—zones 2, 3A, 3B, and 4) to assess the bioaccumulation of contaminants in resident fish. The focus will be to assess temporal changes in contaminant uptake over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to verify if resident fish tissue concentrations are below screening levels determined to be protective of sublethal fish effects such as growth, health, and reproductive potential.

Resident fish samples will be collected in pre-remedial and post-remedial baseline sampling events, and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with the surface water sampling years. Resident fish species collected in the Lower Fox River and Green Bay will include: walleye, carp, perch, emerald shiners, gizzard shad, and alewife. Discrete, adult, whole fish samples will be analyzed for PCB congeners, mercury, DDE and lipids, except shiners and shad will be collected as composites. Young-of-the-year fish samples will also be collected for walleye and gizzard shad as 25-fish composites. The sampling design will include consistent seasonal sampling events, species, sizes, and age classes of fish to the best practicable extent. The length, weight, and sex of each fish will be recorded during collection. A minimum of one size class will be specified per fish species.

Invertebrate Tissue Sampling

Invertebrate tissue sampling will be conducted on a “reach-wide” scale. Samples will be collected from each river reach (4 regions) and each zone of Green Bay (4 regions) to assess the bioaccumulation of contaminants in resident zebra mussels and/or caged mussels. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to determine the rate of decline in PCB concentrations to sessile invertebrate organisms.

Resident zebra mussel samples or caged mussel samples will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program, and will be concurrent with the surface water sampling years. Resident whole body composite samples will be analyzed for PCB congeners, mercury, DDE and lipids. Statistical models will be used to determine the appropriate samples sizes, however, a minimum of seven composite samples will be expected per reach/zone for a total of 70 samples per sampling year. The size, location, and weight of each sample will be recorded during collection.

Although an extensive zebra mussel data set does not exist for the Lower Fox River and only one year of sampling has been conducted in Green Bay, zebra mussels will serve as a good indicator of PCB bioaccumulation potential for benthic organisms with small home ranges. Zebra mussels were specifically selected because they are relatively large with adequate tissue volume for analysis, they are found in all reaches of the Lower Fox River and Green Bay, they are easy to collect, and they readily uptake PCB contaminants after exposure. Caged mussels would also serve as valuable indicators of PCB exposure and uptake with minimal interference from the inherent site variability often associated with resident species.

Piscivorous Bird Tissue Sampling

Bird tissue sampling will be conducted on a "reach-wide" scale. Piscivorous bird tissue samples will be collected from each zone of Green Bay (5 regions—zones 1, 2, 3A, 3B, and 4) to assess changes in contaminant exposure and uptake by resident double-crested cormorants from fixed areas over time. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between reaches and zones. The long-term goal of the sampling program will be to verify if resident bird populations exhibit reduced exposure from site contaminants. Resident double-crested cormorants will serve as surrogate indicators of PCB exposure and uptake over time. However, they will not serve as good indicators of residual risk to other sensitive bird species (i.e., Forster's terns) since current populations are rapidly recovering and reproductive rates are not correlated to PCB levels (Custer *et al.*, 1999).

Bird tissue samples will be collected in pre-remedial and post-remedial baseline sampling events and every 5 years thereafter, after initiation of the long-term monitoring program and will be concurrent with the surface water sampling years. Discrete resident whole body samples will be analyzed for PCB congeners, mercury, DDE, and lipids.

Bald Eagle Tissue Sampling

Raptor egg and blood plasma sampling will be conducted on a "river-wide" scale. Samples will be collected from two sites along the Lower Fox River (2 locations) and two sites along the shores of Green Bay (2 locations) to assess the bioaccumulation of contaminants in resident bald eagles. The focus will be to assess temporal changes in contaminant uptake from fixed locations over time and spatial variability between the river and bay. The long-term goal of the sampling program will be to verify if the resident populations are at risk from PCB uptake. The location and number of sampling sites will be dependent upon field observations and the stability of the population, and may vary between sampling events. Sampling will be consistent with the previous work performed by Dykstra and Meyer (1996).

Bald eagle samples will be collected every 5 years after initiation of the long-term monitoring program and will be concurrent with surface water sampling years, if possible. Whole body egg and blood plasma samples will be analyzed for PCB congeners, mercury, and DDE. If possible, two or three field replicates per nest will be collected. In addition to whole body chemical analyses, a population assessment will be conducted during field collection events. This data will build upon the existing bald eagle tissue already recorded in the Fox River database and will be a continuation of WDNR sampling programs.

Bird Reproductive Assessment Monitoring

Nesting counts will be conducted on a "bay-wide" scale for double-crested cormorants and a "river-wide" scale for bald eagles during collection of tissue data. The focus will be to assess temporal changes in reproductive viability and population stability from fixed locations over time. The long-term goal of the sampling program will be to verify if the resident populations are increasing/declining. At each sampling station, the number of occupied/unoccupied nests and the number of eggs per nest will be recorded. Population counts will be collected every 5 years, concurrent with the tissue collection events. These data sets will build upon the existing double-crested cormorant and bald eagle data already recorded in the Fox River database and will be a continuation of WDNR sampling programs.

Mammal Habitat Evaluation

Mammal population assessments will be conducted on a "reach-wide" scale. The assessment will be conducted from multiple sites along the shores of Lower Fox River and Green Bay to assess the presence/absence of mink or river otter populations in the project area. Mink are predatory, semiaquatic mammals generally associated with stream and river banks, lake shores, and freshwater marshes (USFWS, 1986). Mink are known to readily bioaccumulate PCBs via consumption of fish, their main dietary staple. The focus will be to establish baseline conditions and assess temporal changes in population sustainability from fixed locations over time and spatial variability between the river and bay. A future long-term goal of the sampling program may be to verify if the resident populations are present in the project area after habitat suitability has been determined. The location and number of sampling sites will be dependent upon field observations and the site access, and may vary between sampling events.

Mink habitat assessments will be conducted every 5 years after initiation of the long-term monitoring within each river reach. The USFWS habitat suitability index model for mink (USFWS, 1986) will be used to: 1) first determine where suitable habitats exist along the shoreline of the Lower Fox River and Green Bay, then 2) observe each suitable habitat for presence/absence of mink populations.

5.2.4 Monitoring for Sediment Transport

Monitoring elements used to verify long-term achievement of "reduced potential for future transport of PCBs from the Lower Fox River to Green Bay" as defined in the Lower Fox River FS will consist primarily of water column sampling, surface sediment sampling, and bathymetry over time. Similar monitoring methods were used on almost every site-specific sediment remediation project reviewed, and many of the regional monitoring programs.

Water Column Sampling

Surface water column sampling will be conducted on a "reach-wide" scale in a combined effort with verification of surface water quality. The sampling frequency and technical design is modeled after the Green Bay Mass Balance Study. These samples will also serve as useful indicators of potential downstream transport of contaminants and mass-loading estimates.

Surface Sediment Sampling

Surface sediment sampling (0 to 10 cm) will be conducted on a "reach-wide" scale to primarily assess the potential downstream transport of contaminants to areas without active remediation. Areas selected for passive remediation will be monitored over time for attenuation, diffusion, dispersion, or burial of contaminants and are referred to as monitored natural recovery (MNR) areas. Sampling locations will be placed at fixed locations in depositional areas and will include six locations per river reach (24 locations) and six locations per zone in Green Bay—zones 2, 3A, 3B, and 4 (24 locations). The focus of this monitoring effort will be to verify that physical processes are decreasing the levels of PCBs, DDE and mercury in surface sediments over time via sediment burial, and chemical recovery.

Sediment samples will be collected every other year for the first 10 years following a baseline sampling event, and will coincide with surface water sampling years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. Sediment (0 to 10 cm) will be collected as discrete samples and submitted for physical (grain size and TOC) and chemical testing (PCB congeners, DDE, and mercury).

Bathymetry

Bathymetric soundings will be conducted every 3 to 5 years for the first 10 years. At the 10-year mark, the sampling plan will be reevaluated based on the data collected. This effort will compliment the USACE annual assessment of shoaling in the navigational channels of De Pere to Green Bay Reach and Green Bay Zone 2. Survey locations will include transects running perpendicular and parallel to shoreline and include a bisect of the Lower Fox River from one shoreline to the other. Survey locations will include areas of active remediation in addition to areas designated as MNR to assess potential scouring events that may inadvertently cause significant resuspension and downstream transport of residual contaminants in the surface and subsurface sediments.

5.2.5 Monitoring for Potential Contaminant Releases During Active Remediation

Potential releases of contaminants during active remediation (project RAO 5) is a short-term goal that will be covered during development of deposit-specific and/or reach-specific remediation and monitoring plans. An adequate verification sampling program will be developed as part of each selected remedy to verify the implementability and success of a selected remedial action. These programs will likely include many of the same monitoring elements selected for the long-term monitoring program. However, this long-term monitoring plan is not designed or intended to address contaminant releases during remediation.

Table 5-1 A Summary of Monitoring Elements for Verification of Project RAOs

Remedial Action Objective Lower Fox River and Green Bay	Proposed Monitoring Program Elements Used to Determine Verification of RAOs							
	Physical	Chemical [1]		Biological				
	Bathymetry	Surface Water	Surface Sediment	Fish Tissue	Invertebrate Tissue	Bird Tissue or Eggs	Bird Nest Counts	Mink Counts
1 Achieve, to the extent practicable, **surface water quality** throughout the Lower Fox River and Green Bay.		◆						
2 Protect **humans** who consume fish from exposure to COCs that exceed protective levels.				◆		◆		
3 Protect **ecological receptors** from exposure to COCs above protective levels.		◆	◆	◆	◆	◆	◆	◆
4 Reduce **transport of PCBs** from the Lower Fox River into Green Bay and Lake Michigan.[2]	◆	◆	◆					
5 Minimize the downstream movement of PCBs during implementation of the remedy.[3]	◆	◆	◆					

Notes:

[1] Sediment traps and air sampling stations were not included in the chemical list because they are not proposed monitoring elements in the long-term monitoring plan.

[2] The long-term monitoring plan does not discuss nor include verification of isolation and source control of sediment caps, CADs, and CDFs.

[3] RAO 5 is not included in the long-term

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Surface Water Quality (RAO 1)	Water column [1]	Depth composite sample through water column; fixed locations over time.	One station at end of each reach in LFR (4 stations), two stations in Green Bay - zones 2 and 3B (2 stations), and one station in Lake Winnebago (1 station) to quantify input loads.	Intensive sampling every 10 years with numerous samples collected over the year from each reach/zone. Collect most samples from March through November, with additional samples (up to 10) during periods of max flow events (approx. N = 20 per reach).	1989/1990 1994/1995	40 years	PCB congeners, coplanar congener PCBs, mercury, TSS, DOC, TOC; particulate and dissolved fractions.
Human Health (RAO 2)	Fish tissue (in LFR)	Resident whole fish and skin-on-fillet for walleye, carp, and white bass. Discrete samples.	Collect discrete samples from each reach. Rely on statistical models to determine sample sizes (approx. N = 8 per reach).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, lipids
	Fish tissue (in Green Bay)	Resident whole fish and skin-on-fillet for walleye, carp, lake trout, white perch, and white bass. Discrete samples.	Collect discrete samples from each zone (zone 2, 3A, 3B and 4). Rely on statistical models to determine sample sizes (approx. N = 8 per zone).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, lipids
	Waterfowl bird tissue	Resident whole body and breast for mallard ducks and one other bottom-feeding duck species (mergansers). Discrete samples.	Collect discrete samples from each zone. Rely on statistical models to determine sample sizes (approx. N = 8).	Every 5 years and concurrent with water sampling years.	1987	40 years	PCB congeners, mercury
Environment Health (RAO 3)	Fish tissue	Whole body for food web model fish (walleye, carp, emerald shiners, gizzard shad, alewife). Discrete samples except YOY. Collect YOY (for walleye and gizzard shad) as 25 fish composites.	Collect discrete samples from each reach and each zone (zones 2, 3A, 3B, and 4). Rely on statistical models to determine samples sizes (approx. N = 8).	Every 5 years and concurrent with water sampling years.	1976–1998	40 years	PCB congeners, mercury, DDE, lipids

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay (Continued)

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Environment Health (RAO 3) (Continued)	Invertebrate tissue (benthos)	Whole body composites of zebra mussels. Fixed nearshore locations over time.	Collect samples from each reach near the dams (end of reach) and each Green Bay zone. When possible, co-locate near water sample locations (approx. N = 8 composites).	Every 5 years and concurrent with water sampling years.	1987/1988 Green Bay only	40 years	PCB congeners, mercury, DDE
	Bird tissue - piscivorous	Resident whole body common terns. Fixed locations over time.	Collect samples from Green Bay - zones 1, 2, 3A, 3B, and 4. Sample 2 to 3 nest sites (approx. N = 10 per nest site).	Every 5 years and concurrent with water sampling years	1986, 1996, 1997	40 years	PCB congeners, mercury, DDE, lipids
	Bird tissue- bald eagles	Collect eggs and blood plasma.	Collect from 2 sites along the LFR and 2 sites from Green Bay. If possible, three samples per site.	Every 5 years and concurrent with water sampling years.	Limited: 1985, 1987, 1990	40 years	PCB congeners, mercury, DDE
	Birds - reproductive assessment	Resident terns. Collect nest counts and egg counts per nest.	Collect samples from Green Bay - zones 1, 2, 3A, 3B, and 4.	Every 5 years concurrent with bird tissue sampling years	unknown	40 years	Compare to reference areas
	Birds - reproductive assessment for raptors	Resident bald eagles. Collect occupied nest counts, egg counts per nest, YOY counts per nest.	Collect from 2 sites along the LFR and 2 sites from Green Bay. If possible, three samples per site.	Every 5 years and concurrent with bird tissue sampling years.	unknown	40 years	Compare to reference areas
	Mammal reproductive assessment	Observational survey along shoreline of river and bay.	Collect data from multiple sites along river and bay in areas with suitable habitat.	Every other year for 10 years.	unknown	40 years	Compare to previous years

Table 5-2 Proposed Long-term Monitoring Plan for the Lower Fox River and Green Bay (Continued)

RAO	Monitoring Element	Sample Type	Location [4, 5]	Frequency	Years with Historical Data	Expected Duration Over Time [2]	Analyses [3, 6]
Contaminant Transport (RAO 4)	Surface sediment	0 to 10 cm discrete surface grabs at fixed stations over time.	Collect from 6 fixed locations per reach and per zone (Green Bay zones 2, 3A, 3B, and 4). Stations will be located in depositional areas.	Every 10 years and concurrent with water sampling years.	1987–1999	40 years	PCB congeners, mercury, DDE, grain size and TOC
	Bathymetry	Echo soundings.	Multiple transects per reach and zone and include nearshore areas.	Every 3 years for 10 years.	many	40 years	Compare to previous years
	Water column	Discussed under RAO 1.					
Releases During Remediation (RAO 5)	As appropriate [1]	Not included in the long-term monitoring plan.					

Notes:

[1] An adequate confimration/verification sampling program with physical, chemical, and biological elements will be in-place prior to initiation of the long-term program to verify implementation of an active remedy. Sediment, tissue, and water data will be collected during active remediation to supplement the baseline data set.

[2] Duration includes 10 years during before and during remediation for baseline, 10 years until angler fish consumption, and 20 years for general fish consumption.

[3] Use consistent sampling methods over time. For fish, sample same time of year. Include physical data about fish: size, length, weight, sex, and age of fish.

[4] The four reaches of the Lower Fox River include Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (also Zone 1). The four zones of Green Bay include 2, 3A, 3B, and 4.

[5] Most monitoring parameters will also include a background/reference station for comparison with Lower Fox River and Green Bay sampling station data.

[6] PCB congeners include Wisconsin State Laboratory PCB Congener List and coplanar dioxin-like PCB congeners.

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Attachment 1

Summary of Regional and National Monitoring Programs

Project Name: Disposal Area Monitoring System (DAMOS)

Location: New York, Connecticut, Rhode Island, Maine

Management Issues: Monitoring at open water disposal sites.

Water Body Type: Marine

Period of Performance: 1977 to Present

Background:
Dredged materials from numerous industrialized harbors in New England were placed in offshore subaqueous disposal sites between Long Island Sound and Maine. The contaminated material was subsequently capped with cleaner material. The New England district of the U.S. Army Corps of Engineers created the Disposal Area Monitoring System (DAMOS) in 1977. The DAMOS program was established to ensure disposal of dredged material had no adverse effect on the environment.

Project Goals and Objectives:
The DAMOS monitoring program was implemented to ensure the physical integrity and stability of disposal mounds, to measure the impacts to bottom organisms around the disposal mounds during placement and subsequent recolonization success, and to measure the effectiveness of capping in isolating disposed contaminated sediments (USACE, 1992).

Long-Term Monitoring:
Monitoring under the DAMOS program followed a tiered approach, under which techniques in the higher tiers were used only when monitoring results of lower tiers indicate the need for further monitoring. Although the schedule varied greatly depending on time and location, sampling generally occurred annually with additional sampling conducted after major storm events. Samples were routinely collected at reference sites to provide comparison with background results.

> *Physical:* High-resolution bathymetric surveys have been included in all monitoring surveys conducted under the DAMOS program. Additional physical monitoring included physical sediment description, grain size analysis, and sediment volume determinations made using diver surveys, and after 1982, the REMOTS® sediment-profiling camera.
>
> *Chemical:* Chemical monitoring was limited to routine analyses of surface sediments to assess contaminant levels (USACE, 1995). Sediments were collected using a 0.1-m^2 Smith-McIntyre mechanical grab sampler. Subsamples were collected with plastic core liners measuring approximately 6.5 cm in diameter by 10 cm in length. Occasionally, divers collected sediment samples for chemical analysis directly in plastic core liners.
>
> *Biological:* The biological component of the monitoring program has varied with respect to time and disposal site. Biological monitoring conducted under the DAMOS program included benthic infauna observations at all monitoring sites. Benthic infauna studies were conducted on surface grab samples obtained with a 0.1-m^2 Smith-McIntyre sampler. Samples were sieved through a 1.0-mm sieve and macrofauna were sorted, identified, and counted to measure community structure. Since 1982, the benthic community has been assessed using sediment profile imaging with the REMOTS® camera. In areas where monitoring demonstrated a decline in biological quality, the tiered approach triggered additional monitoring. Additional monitoring analyses

included measurements of bioaccumulation in caged mussels and resident worms (*Nephtys incisa*), and sediment amphipod toxicity tests.

Project Outcome:
Monitoring results obtained in the DAMOS program have not shown any evidence of physical or chemical breaching of capped areas. Physical data collection has shown that the sand caps are stable. Chemical data have shown the cap is effective in isolating contaminants, and biological measurements have demonstrated recolonization of the capped areas and the absence of toxicity.

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References:
USACE, 1995. Sediment Capping of Subaqueous Dredged Material Disposal Mounds: An Overview of the New England Experience, 1979-1993. U.S. Army Corps of Engineers, New England Division. Report No. SAIC-90/7573&C84. August.

USACE, 1992. Dredged Material Management Program. U.S. Army Corps of Engineers, New England Division. Report NEDEP-360-1-21. May.

Project Name: Environmental Monitoring & Assessment Program (EMAP)

Location: National

Management Issues: Condition of ecological resources.

Water Body: Estuarine

Period of Performance: Ongoing from 1984 to Present

Background:
The Environmental Monitoring and Assessment Program (EMAP) is an EPA research program used to develop the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of future risks to the sustainability of our natural resources. EMAP's research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources (CENR).

Project Goals and Objectives:
EMAP objectives are to advance the science of ecological monitoring and ecological risk assessment, guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate the CENR framework through large regional projects. EMAP will develop and demonstrate indicators to monitor the condition of ecological resources, and investigate multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources (EPA, 2000).

Long-Term Monitoring:
EMAP's sampling scheme consists of systematic, random, and fixed location sampling elements. Large, continuously distributed estuaries are sampled using a randomly placed systematic grid, with grid points about 18 km apart. Large tidal rivers are sampled along systematically spaced lateral transects. Transects are located about 25 km apart. Two sampling points are located on each transect, one randomly selected, and one using scientific judgement to identify sampling locations that may be indicative of degraded conditions in the system. Small estuaries are sampled by partitioning them in groups of four, selecting one estuary randomly from each group of four, and sampling at two stations in each small estuary selected. EMAP operates on a 4-year sampling cycle, with one-fourth of the sites in a region sampled each year. Sampling is undertaken only during the months of July and August (EPA, 1995). Monitoring elements selected for a project are site-specific but likely include the following physical, chemical and biological parameters:

> *Physical:* Monitoring data collected for physical parameters includes sediment grain size and water quality vertical profile data.
>
> *Chemical:* Sediment samples are analyzed for chemical parameters of concern in a project area.
>
> *Biological:* Biological monitoring is conducted on the benthic community, fish, invertebrates, and demersal trawl samples. Analyses include species abundance, community data, tissue chemistry, length data by taxa, and community abundance.

Project Outcome:
EMAP's Estuaries Group assessed the status and trends on the condition of the nation's estuaries extending from low to high tide elevations. In addition to coastal embayments, bays, inland waterways, and tidal rivers, the Estuaries Group also monitored coastal wetland areas and salt-water marshes. Monitoring and assessment activities were conducted jointly by the USEPA and the National Oceanic and Atmospheric Administration (NOAA). Monitoring results were not specified.

Project Contact:
None available

References:

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EPA, 1995. Office of Water. NEP Monitoring Guidance. U.S. Environmental Protection Agency. Last updated September 15, 1995. Website. http://www.epa.gov/OWOW/estuaries/guidance/nmg43.html

EPA, 1997. Environmental Monitoring and Assessment Program (EMAP) Research Strategy. U.S. Environmental Protection Agency, Office of Research and Development. EPA/620/R-98/001. October.

Project Name: Great Lakes National Program

Location: Chicago, Illinois

Management Issues: Restore and preserve ecological resources in the Great Lakes and protect human health in accordance with the Great Lakes Water Quality Agreement between U.S. and Canada.

Water Body Type: Lacustrine

Period of Performance: 1972 to Present

Background:
The Great Lakes National Program Office (GLNPO) was created in 1978 to coordinate the U.S. response to the Great Lakes Water Quality Agreement with Canada mandated by the Clean Water Act. The GLNPO, located in Chicago, Illinois, is made up of scientists, engineers, and other professionals. The GLNPO works with EPA, Environment Canada, Ontario Provincial government, International Joint Commission, and other agencies to achieve specific environmental goals through coordinated activities. Surveillance and monitoring began in 1972 under the Great Lakes Water Quality Agreement between the United States and Canada to identify problems and to measure progress in solving problems. A new Great Lakes Water Quality Agreement was signed in 1978, continuing the basic features of the previous agreement. Biannual surveillance and monitoring are continuing to the present.

Project Goals and Objectives:
The Great Lakes Water Quality Agreement with Canada, signed in 1972 established the environmental goals to restore the chemical, physical, and biological of the Great Lakes, achieve healthy plant, fish, and wildlife populations, and to protect human health. After assessing risks to the Great Lakes ecosystem the following objectives were established:

- Reduction of the level of toxic substances in the Great lakes and the surrounding habitat, with an emphasis on persistent toxic substances, so that all organisms are adequately protected and the substances are virtually eliminated from the Great Lakes Ecosystem.

- Protection and restoration of habitats vital for the support of healthy and diverse communities of plants, fish, and wildlife, with an emphasis on interjurisdictional fish and wildlife habitats, wetland habitats, and those habitats needed by threatened and endangered species.

- Protection of human and non-human health by restoring and maintaining stable, diverse, and self-sustaining populations of fish and other aquatic organisms, wildlife, and plants.

Long-Term Monitoring:
Surveys are completed biannually from the R/V Lake Guardian. Samples are taken from eight to 20 stations in each lake.

Physical: Standard sampling locations were tested for conductivity, temperature, and depth. In some locations additional visual surveys were conducted by divers, a remotely operated vehicle, or a submersible probe.

Chemical: Surface water samples were collected with vertical water samplers and a rosette water sampler and analyzed for chemical contaminants. Sediment samples were collected with a box corer, vibracore, or Mudpuppy. Contaminants of concern analyzed in water and sediment samples included mercury, PCBs, and pesticides.

Biological: Plankton and zooplankton samples were collected with plankton nets. Fish samples were collected to assess populations and contaminant concentrations. A number of fish species were collected including Coho salmon, bloater chub, and lake trout. A benthic invertebrate sampling program was initiated for Great Lakes in 1997. Sampling is conducted annually at a minimum of 45 stations.

Project Outcome:
Significant advances have been made to eliminate pollutant sources and contaminant concentrations in the Great Lakes since the Great Lakes Nation Program Office was established. The organization continues to coordinate efforts between numerous agencies and the public.

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References:
EPA, 2000a. Protecting the Great Lakes, A Joint Federal/State 5-Year Strategy (1992-1997). U.S. Environmental Protection Agency. April 1992 Draft. Website. http://www.epa.gov/glnpo/plans/5yrstrat.html.

EPA, 2000b. United States Great Lakes Program Report on the Great Lakes Water Quality Agreement. U.S. Environmental Protection Agency. Last Revised February 3, 1998. Website. http://www.epa.gov/glnpo/glwqa/usreport.

Sea Grant, 2000. Glossary of the Great Lakes. Last updated October 13, 1998. Website. http://www.d.umn.edu/seagr/pubs/GGL/G.html.

Project Name: National Status and Trends Program

Location: National

Management Issues: The program was established to measure the effect of human activities on coastal and estuarine waters.

Water Body Type: Estuarine and Marine

Period of Performance: National Benthic Surveillance Project from 1984 to present; Mussel Watch Project from 1986 to 1992

Background:
The National Status and Trends (NS&T) Program is administered by the National Oceanic and Atmospheric Administration (NOAA). The NS&T program was initiated in response to the need to gather information of the effect of human activities on environmental quality of coastal and estuarine areas. In October 1983, marine scientists from government, academia, and the private sector met to discuss the feasibility of a nationwide monitoring program. The workshop developed a list of contaminants of concern which have a demonstrated health risk, have been released into the environment in significant quantities, have long half-lives, and have a high potential for bioaccumulation. The NS&T sampling program was initiated in 1984 and continues to collect information from United States estuarine and coastal waters to date.

Project Goals and Objectives:
The NS&T program was developed to determine the status and trend of changes in the environmental quality of estuarine and coastal waters of the United States. In 1987, the program was expanded to measure the biological effects due to contaminant exposure (NOAA, 2000a).

Long-Term Monitoring:
Monitoring included in the NS&T program is divided into the National Benthic Surveillance Project (NBSP) and the Mussel Watch Project (MWP). The NBSP is responsible for quantification of contamination in fish tissue and sediment, and for developing and implementing new methods to define the biological significance of environmental contamination. The MWP monitors contaminant concentrations by quantifying chemicals in bivalve mollusks and sediments. These two subprograms are described below.

Physical: No physical monitoring parameters were included in these programs.

Chemical: Sediment samples were collected for both the NBSP and the MWP. Sediment samples were collected concurrently with fish samples at each NBSP site. Samples of the top 3 cm of sediment were collected using a specially constructed box corer or a Smith-MacIntyre grab sampler. At MWP sites, sediment samples of the top 1 cm of sediment were collected from three locations and composited. Samples were collected using a Kynar-coated Young-modified Van Veen grab sampler, stainless steel box-cores, or Kynar-coated scoops. Sediment samples for both programs were analyzed for organic and metal contaminants. Organic contaminants included PAHs, PCBs, and chlorinated pesticides.

Biological: Fish tissue samples were collected for the NBSP from 1984 to 1993 (unknown if fish samples are still being collected). Fish were usually collected with otter trawls, although hook and line or gill nets were occasionally used. Samples were collected from three stations at each

2-km diameter NBSP site. A number of different benthic fish were collected including flatfish at least 15 cm in length and roundfishes at least 12.5 cm in length. Tissues analyzed in the NBSP program included liver, muscle, and stomach contents. Liver tissue was the most commonly measured matrix in fish samples. Analyses included metals, histopathology, organics, aryl hydrocarbon hydroxylase, and xenobiotic-DNA adducts. Organic analyses included butyltins, PCBs, DDT and metabolites, and other chlorinated pesticides. PAHs were not analyzed in fish liver tissue because they are readily metabolized. Muscle analytical methods were similar to liver tissue. Stomach contents were analyzed for organic compounds, metals, and food item taxonomy (NOAA, 2000b).

Bivalve mollusks were collected on an annual basis from 1986 to 1992 for the MWP. After 1992, samples were collected biennially. Samples were collected from 150 sites in 1986 and over 250 sites in 1992. Samples were collected between mid-November and the end of March, and within three weeks of the date the site was first sampled to avoid effects of spawning on chemical concentrations. Several species were collected including blue mussels (*Mytilus edulis*) from the U.S. North Atlantic, blue mussels (*Mytilis sp.*) and California mussels (*M. californianus*) from the Pacific coast, American oysters (*Crassostrea virginica*) from the South Atlantic and the Gulf of Mexico, smooth-edge jewelbox (*Chama sinuosa*) from the Florida Keys, Caribbean oyster (*C. rhizophorae*) from Puerto Rico, tropical oysters (*Ostrea sandvicensis*) from Hawaii, and zebra mussels (*Dreissena polymorpha* and *D. bugensis*) from the Great Lakes (NOAA, 2000c). Bivalves were collected at intertidal sites by hand and at subtidal sites with an oyster dredge or oyster tongs. Zebra mussels were collected by snorkeling or with an epibenthic dredge. Composite samples of 30 mussels or 20 oysters (or approximately 200 zebra mussels) were analyzed for organic and metal contaminants. Organic contaminants included PAHs, PCBs, and chlorinated pesticides (NOAA, 1993).

Project Outcome:
The program established an extensive database with the attempt to evaluate the success of recent attempts to improve environmental quality. While the project maintained the same core of station sites and analytical parameters to establish long-term trends, the program evolved to included better analytical methods and new information.

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References:
NOAA, 2000a. National Status and Trends Benthic Surveillance Project. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 2000b. National Status and Trends Mussel Watch Project. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 2000c. National Status and Trends Program. Website. http://ccmaserver.nos.noaa.gov/NSandT/NsandTmethods.html.

NOAA, 1993. Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects, 1984-1992. Volume I. National Oceanic and Atmospheric Administration. Technical Memorandum NOS ORCA 71. July.

Project Name: Puget Sound Ambient Monitoring Program (PSAMP)

Location: Puget Sound, Washington

Management Issues: Measurement of effects of human activities on environmental conditions.

Water Body Type: Estuarine and Marine

Period of Performance: 1989 to Present

Background:
This program is managed by the Washington State Department of Ecology and often coordinates efforts with NOAA's NS&T program (NOAA and Ecology, 1999). An interdisciplinary group of sediment and water quality professionals was appointed by the Puget Sound Water Quality Authority to develop a comprehensive monitoring program for Puget Sound in 1986. The group designed the Puget Sound Ambient Monitoring Program (PSAMP) to provide long-term monitoring of water quality, sediment quality, biological resources, nearshore habitats, and rivers in the Puget Sound Basin (Llanso et. al, 1998a). Two subprograms of PSAMP include the Marine Sediment Monitoring Program (MSMP) and the Marine Water Column Ambient Monitoring Program. The Marine Sediment Monitoring Program (MSMP) operated under PSAMP from 1989 until 1995. The Marine Water Column Ambient Monitoring Program was initiated in 1967 and joined PSAMP in 1989. Details of the subprograms are discussed below.

Project Goals and Objectives:
The objectives of the MSMP were to collect data on Puget Sound sediments and macro-invertebrate communities in contaminated and uncontaminated areas and to evaluate the condition of Puget Sound benthic communities in relation to contaminant concentrations. The objectives of Marine Water Column Ambient Monitoring Program were to collect data for the maintenance of regulatory listings of various water bodies throughout the state and to implement marine water quality management activities based on water quality data (Ecology, 2000).

Long-Term Monitoring:
Sediment samples were collected from 76 stations throughout Puget Sound, Hood Canal, and the Strait of Georgia from 1989 to 1995. Thirty-four stations were sampled annually. Stations were analyzed using the sediment quality triad approach which included sediment chemistry, sediment toxicity, and benthic community structure assessments. The remaining 42 stations were sampled on a 3-year rotational basis in north, central, and south Puget Sound. Five replicate sediment samples were collected at each station using a double 0.1-m^2 stainless steel Van Veen grab sampler. The top 2 cm were composited and analyzed for physical, chemical, and biological parameters (Llanso et. al, 1998b).

Water column monitoring in 1996 consisted of 16 annually sampled stations and 13 stations sampled on a 3-year rotational basis. In 1997, water column monitoring took place at 19 stations annually and six stations on a rotational basis. The numbers of sampling stations in other years were not available. Water samples were collected at depths of 0.5, 10, and 30 meters with a 1.2-liter Niskin® bottle (Newton et. al, 1998).

Physical: Sediment samples were inspected for visual and olfactory character and analyzed for particle size. A Secchi disk was used to indicate water clarity at water column sampling stations.

Chemical: Sediment samples were analyzed for metals, volatile and semivolatile organic compounds, chlorinated pesticides, PCBs, total organic carbon (TOC), and total sulfides. Water column samples were analyzed for dissolved nutrients (ammonium-N, nitrate + nitrite-N, and orthophosphate-P), pigments (chlorophyll-a and phaeopigment), dissolved oxygen, and fecal coliform bacteria.

Biological: Sediment sample bioassays were conducted on the amphipod, *Rhepoxynius abronius*, as a measure of acute sediment toxicity. Bioassays were conducted on sediment from each sampling location, although no bioassays were conducted in 1994 or 1995. Benthic infauna enumeration was completed at all sediment sampling locations annually from 1989 through 1995 (Llanso et al., 1998a and 1998b).

Project Outcome:
Water column monitoring measured diverse conditions in Puget Sound. Open basins generally had good water quality, however, individual locations had reduced water quality. Estuarine water quality was good with the exception of chronic fecal coliform bacteria. Sediment monitoring succeeded in measuring the type of contamination in Puget Sound locations, although little is known of the extent of contamination. Overall the extent of contamination was low, but elevated contaminant concentrations were present in localized areas, particularly in urban bays.

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References:
Ecology, 2000. Washington State Department of Ecology, Marine Sediment Monitoring. Last updated September 22, 1999. Website. http://www.wa.gov/ecology/eils/mar_sed/msm_intr.html.

Llanso, R. J., S. Aasen, and K. Welch, 1998a. Marine Sediment Monitoring Program, I. Chemistry and Toxicity Testing, 1989-1995. Washington State Department of Ecology. Publication No. 98-323. August.

Llanso, R. J., S. Aasen, and K. Welch, 1998b. Marine Sediment Monitoring Program, II. Distribution and Structure of Benthic Communities in Puget Sound, 1989-1993. Washington State Department of Ecology. Publication No. 98-328. September.

Newton, J. A., Albertson, S. L., K. Nakata, and C. Clishe, 1998. Washington State Marine Water Quality in 1996 and 1997. Washington State Department of Ecology. Publication No. 98-338. December.

NOAA and Ecology, 1999. Sediment Quality in Puget Sound Year 1 – Northern Puget Sound. Puget Sound Ambient Monitoring Program and NOAA NS&T. Publication No. 99-347. December.

Project Name: San Francisco Estuary Project/National Estuary Program

Location: San Francisco, California

Management Issues: Toxic compounds in sediment, habitat loss and alteration, species loss and decline, fisheries loss and decline, introduced and pest species, and problems with the quantity of freshwater inflow.

Water Body Type: Marine/Estuarine

Period of Performance: 1993 to Present

Background:
The San Francisco Estuary Project is part of the National Estuary Program which was established in 1987 by amendments to the Clean Water Act to identify, restore, and protect nationally significant estuaries of the United States. The NEP targets a broad range of issues and engages local communities in the process. The program focuses on improving water quality in an estuary through maintaining the integrity of the whole system including chemical, physical, and biological properties, as well as its economic, recreational, and aesthetic values.

Project Goals and Objectives:
The National Estuary Program (NEP) is designed to encourage local communities to take responsibility for managing their own estuaries. Each NEP is made up of representatives from federal, state and local government agencies responsible for managing the estuary's resources, as well as members of the community—citizens, business leaders, educators, and researchers. These stakeholders work together to identify problems in the estuary, develop specific actions to address those problems, and create and implement a formal management plan to restore and protect the estuary.

The Comprehensive Conservation Management Plan (CCMP) presents a blueprint of 145 specific actions to restore and maintain the chemical, physical and biological integrity of San Francisco Bay and Delta. It seeks to achieve high standards of water quality; to maintain an appropriate indigenous population of fish, shellfish and wildlife; to support recreational activities; and to protect the beneficial uses of the Estuary.

To assist in coordinating research and monitoring programs, the San Francisco Estuary Project has fostered the development of a Regiona1 Monitoring Strategy (Monitoring Strategy). Project staff have worked with representatives of government agencies and scientific institutions to establish the Monitoring Strategy, which fulfills an action recommended in the CCMP's Research and Monitoring Program. The primary purposes of the Regional Monitoring Strategy are: 1) to provide information to assess the effectiveness of management actions that have been taken, 2) to improve conditions in the Estuary to protect its resources, 3) to evaluate the ecological "health" of the Estuary, and 4) to enhance scientific understanding of the ecosystem (San Francisco Estuary Project, 1998).

Long-Term Monitoring:
The San Francisco Estuary Institute (SFEI) serves as the coordinating entity for the Regional Monitoring Strategy. Monitoring is performed annually by the SFEI under the Regional Monitoring Program (RMP). Monitoring began in 1993. In an effort to capture seasonal variability, samples are collected three times per year: during the rainy season (March-April), during a period of declining delta outflow (May-June), and during the dry season (August-September). Two dozen sampling stations are located throughout the Estuary and its major tributaries. Most station locations are chosen as far as possible from the influence of local contaminant sources to best represent "background" contaminant concentrations. Other stations

are close to wastewater outfalls or creek mouths for comparison purposes. To ensure that the data collected by different groups participating in the monitoring program are directly comparable, protocols that included performance-based and standardized sampling, analytical, and QA/QC protocols are employed (San Francisco Estuary Institute, 2000).

Physical: Sediment is analyzed for physical characteristics such as particle size.

Chemical: Chemical monitoring is conducted both for water and sediment. Conventional water quality data are collected including salinity, dissolved oxygen, and temperature. Water is also analyzed for chemical contaminants such as metals, pesticides, and other synthetic hydrocarbons.

Biological: The biological monitoring program includes sediment toxicity, benthic infauna, water column toxicity, and contaminant bioaccumulation. Sediment samples consist of the top 5 cm of grab samples. Benthic infauna is also measured from grab samples and sediment toxicity is evaluated through the effect of the sediment on laboratory organisms.

Water column toxicity is evaluated using a 48-hour bivalve embryo development test and a 7-day growth test using the estuarine mysid *Mysidopsis bahia*. The RMP uses two sediment bioassays: a 10-day acute mortality test using the estuarine amphipod *Eohaustorius estuarius* exposed to whole sediment, and a sediment elutriate test where larval bivalves are exposed to the material dissolved from whole sediment in a water extract. Water column samples are collected approximately 1 meter below the water surface.

Contaminant bioaccumulation is evaluated in transplanted shellfish. For the bivalve bioaccumulation sampling, bivalves are collected from uncontaminated sites and transplanted to 15 stations in the estuary during the wet season (February through May) and the dry season (June through September). Contaminant concentrations in the animals' tissues and the animals' biological condition are measured before deployment and at the end of the 90- to 100-day deployment period. Since the RMP sites encompass a range of salinities, three species of bivalves are used, according to the expected salinities in each area and the known tolerances of the organisms. Organisms used in the bioaccumulation studies are mussel (*Mytilus californianus*) with 49- to 81-mm shell length, oyster (*Crassostrea gigas*) with 71- to 149-mm shell length, and clams (*Corbicula fluminea*) with 25- to 36-mm shell length.

Project Outcome:
None specified. Results are ongoing.

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References:
San Francisco Estuary Project, 1998. Last updated July 1, 1998. Website. http://www.abag.ca.gov/bayarea/sfep/.

San Francisco Estuary Institute, 2000. Last updated March 18, 2000. Website. http://www.sfei.org.

Attachment 2

Draft Report on the Lake Michigan Tributary Monitoring Project

Assessment of the Lake Michigan Monitoring Inventory

A Report on the Lake Michigan Tributary Monitoring Project

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Executive Summary

Introduction

Through a cooperative agreement, the Great Lakes Commission worked with the U.S. Environmental Protection Agency (U.S. EPA) Region 5, and its partners in the Lake Michigan Lakewide Management Plan (LaMP) process, to assess existing monitoring efforts in the Lake Michigan basin and subwatersheds, including the ten Lake Michigan Areas of Concern (AOC) and four other tributary watersheds. This report is one of the outcomes of the project, and includes a comprehensive review of monitoring programs at the federal, state and local levels for the targeted watersheds; an analysis of gaps, inconsistencies and unmet needs; an assessment of the adequacy of existing efforts to support critical ecosystem indicators; and recommendations for addressing major monitoring needs, particularly those considered most important for lakewide management decision making. The report has also been used to inform members of the Lake Michigan Forum, local public advisory councils (PACs), and other stakeholders about identifying current, local monitoring efforts and establishing community-based monitoring programs.

Monitoring was broadly defined for this project to include not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. It is intended that the report and future project outcomes will provide U.S. EPA, the PACs and other stakeholders with important tools for developing their Remedial Action Plans (RAPs) and will enable them to engage their community in a valuable dialogue regarding the status of knowledge on their local watershed. Working closely with the states and tribal authorities, they will benefit from the exchange of information and the opportunity to enhance local participation in state-sponsored monitoring programs.

Project participants were responsible for conducting this assessment at the local level in their watersheds. This consisted primarily of implementing a survey of potential local monitoring organizations and conducting follow-up interviews. The Great Lakes Commission, in collaboration with the U.S. EPA and other agencies, assessed monitoring being conducted by state and federal agencies. The Commission then compiled the results of this collaborative effort into an inventory database, which was the basis for this report. Please see the methodology chapter for a background on project participants, as well as methods used to gain information to build the inventory.

Results

The results from an analysis of the monitoring inventory are organized along several lines. First, each tributary watershed is reviewed separately, with an additional chapter on open lake and basinwide monitoring. Watersheds for the following tributaries are covered in this report:

Grand Traverse Bay
White Lake
Muskegon Lake
Grand River
Kalamazoo River
St. Joseph River
Grand Calumet River
Waukegan Harbor
Milwaukee River and Estuary
Sheboygan River
Fox-Wolf River Basin
Door County
Menominee River
Manistique River

Within each of these chapters, findings from the inventory are presented in the following nine categories:

- LaMP pollutants
- Nutrients and bacteria
- Meteorological and flow monitoring
- Sediments
- Fish contaminants, fish health, and aquatic nuisance species
- Benthos monitoring
- Air monitoring
- Wildlife monitoring
- Land use

In addition to discussing findings for each of the watersheds, monitoring locations (where available) are also displayed for each watershed. The combination of database analysis and geographical analysis was designed to present the most complete assessment of monitoring within each watershed.

Following the open lake chapter, a more general analysis of monitoring coverage is presented in chapter 18, Overall Discussion. In this section, the monitoring infrastructure was analyzed for its ability to provide sufficient data for assessing the 70 Lake Michigan LaMP indicators. A qualitative rating is given to each LaMP indicator, based on the availability and specificity of monitoring related to the indicator.

Findings and Recommendations

The final section of this report centers on general issues that were uncovered throughout the course of research. There are three key areas under which the monitoring inventory provided valuable information and recommendations for improving overall monitoring in the Lake Michigan basin. These include data gaps and unmet needs; underutilized resources; and monitoring coordination and information sharing. Findings and recommendations within these areas are summarized below. More detail can be found in the last chapter of the report. For reference purposes, sections are labeled with letters and findings and recommendations are numbered.

A. Data Gaps and Unmet Needs
This report, and the inventory on which it is based, represent the first effort to account for the range of environmental monitoring in the Lake Michigan basin. The inventory represents the initial approach toward achieving this ambitious goal. It is a framework on which a more complete inventory will eventually be built.

(1) Finding: There are several gaps in the inventory that are listed below and throughout the report. While some of these gaps are areas that have not been well covered in the inventory, others may represent gaps in the monitoring coverage. At this point, it is difficult to tell which are gaps in the monitoring inventory and which are actual monitoring gaps. Further improvement of the inventory database is needed to better clarify this distinction.

(1.1) Recommendation: *Continue to update the inventory and expand data collection to include all tributaries.*

(2) Finding: There are several key monitoring areas where little information was received, but where more monitoring is believed to exist. These areas include monitoring for *E. coli*, fish population characteristics, aquatic nuisance species, benthic organisms, wildlife, and habitat.

(2.1) Recommendation: *Establish better lines of communication with state Departments of Natural Resources (DNR), U. S. Fsih and Wildlife Service (USFWS), U. S. Forestry Service (USFS), and U. S. Department of Agriculture (USDA).*

(2.2) Recommendation: *Better integrate habitat and wildlife monitoring with traditional water quality monitoring.*

(3) Finding: Another result of this initial approach to the monitoring inventory for the Lake Michigan basin was that much of the information included only general information about the geographic location of monitoring sites. Many organizations reported monitoring for parameters across a broad geographic area but did not include specific site references. Locational information is critical if the inventory is to be brought online in a geographically-searchable format.

(3.1) Recommendation: *Improve information on the geographic location of monitoring sites.*

(4) Finding: A further gap in the monitoring information obtained for this report, was the lack of complete and continuing coverage of Lake Michigan Mass Balance data. Data obtained for this report on the Lake Michigan Mass Balance Project was limited by the timing of the release of data to the public. However, information in the inventory database will be improved when the project is finalized. Additionally, the value of coordinated sampling data (as collected in the Mass Balance project) would be greatly enhanced by a repeat of the sampling event ten years following completion of the original sampling.

(4.1) Recommendation: *Initiate planning for a coordinated sampling event for ten years following the initial Mass Balance project, and share data and modeling results with the public in a timely fashion through numerous outlets.*

(5) Finding: This initial project specifically avoided attempting to collect information about university monitoring projects. However, some academic institutions conduct a number of important ongoing, long-term projects, and information on these projects should be included in the inventory. Other programs catalog the university work they fund. Closer ties need to be established with these programs and such efforts need to be expanded throughout the basin.

(5.1) Recommendation: *Include academic research and data collection efforts in future updates to the monitoring inventory.*

(6) Finding: While a number of LaMP pollutants, such as mercury and copper, are monitored extensively across the basin, it has been difficult to find monitoring information on some of the other pollutants. These under-monitored pollutants include all the emerging LaMP pollutants, along with DDT, HCBs, toxaphene, and PAHs.

(6.1) Recommendation: *Further examine the monitoring coverage of specific LaMP critical pollutants and emerging pollutants.*

B. Underutilized Resources

Along with the gaps in monitoring coverage identified in this project, some resources in the basin were also discovered that do not appear to be fully utilized. Monitoring is an area of environmental management that has often been underfunded in the past. Therefore, in order to achieve the most complete monitoring coverage possible, all available resources must work in concert.

(1) Finding: One of these underutilized resources is volunteer groups. Most of the volunteer groups currently engage in some form of monitoring, but often their efforts are not incorporated into state or regional monitoring plans, and the information collected is only reported internally or locally.

(1.1) Recommendation: *Take better advantage of relatively untapped volunteer monitoring resources.*

(2) Finding: Another group that is underutilized is local agencies. Examples of such agencies are health departments, conservation districts and planning agencies. In many cases, these agencies are already engaged in monitoring to serve their local needs.

(2.1) Recommendation: *Take better advantage of local agencies such as health departments, conservation districts and planning agencies.*

(3) Finding: To best capitalize on these underutilized resources, it is important that these local groups (both volunteer groups and local agencies) be linked into basinwide efforts, but at the same time retain their local focus and discretion.

(3.1) Recommendation: *Establish a better framework for bottom-up monitoring program linkages.*

(4) Finding: Part of the difficulty in using data collected at the local level is that there are few standards at the basinwide level to integrate data. The local focus of the data collection effort often will leave the data incompatible with other data from neighboring localities.

(4.1) Recommendation: *Standardize data collection and reporting*.

C. Monitoring Coordination and Information Sharing
The final issue area does not involve direct monitoring, but responds to the need to coordinate monitoring efforts. There are a wide array of organizations involved in monitoring at the federal, state and local levels. However, no single organization is responsible for planning, coordinating, or disseminating monitoring efforts for the entire Lake Michigan basin.

(1) Finding: A major coordination problem is the lack of a central source for monitoring information. The inventory that this report evaluates is the first step toward creating such a central source. However, this one-time inventory is currently not universally accessible and may quickly become dated if the database is not continually updated by monitoring organizations in the basin.

(1.1) Recommendation: *Encourage state, federal, tribal, and local agencies to report monitoring coverage and results to a meta-database with universal access.*

(1.2) Recommendation: *Develop an online database of monitoring information that is geographically-based, and content-searchable.*

(2) Finding: In general, organizations make most, if not all, decisions about their monitoring programs based on goals for their local coverage areas. Rarely does this area cover the entire Lake Michigan basin.

(2.1) Recommendation: *Develop and coordinate the implementation of comparable methods to collect indicator data in a coordinated network.*

Acknowledgments

The primary authors of this report were Ric Lawson of the Great Lakes Commission, and the Lake Michigan Tributary Monitoring Project participants from the 14 participating tributary watersheds around the Lake Michigan basin. Mr. Lawson compiled state and federal monitoring information; designed and analyzed the monitoring inventory survey and database; integrated all other information into this final report; and provided day-to-day project management. The project participants collected information on local monitoring programs in their watersheds; compiled this information for population of the inventory database; reported on their findings (much of which is included directly in this report); and provided review comments to Mr. Lawson. These project participants, and their respective watersheds, are as follows:

Chris Wright — Grand Traverse Bay
Susan Russell — Grand Traverse Bay
Kathy Evans — White Lake and Muskegon Lake
Dr. Janet Vail — Grand River
Melissa Welsh — Grand River
Bruce Merchant — Kalamazoo River
Andrew Laucher — Kalamazoo River
Al Smith — St. Joseph River
John Wuepper — St. Joseph River
Kathy Luther — Grand Calumet River
Dr. Greg Olyphant — Grand Calumet River
Susie Scheiber — Waukegan Harbor
Paul Geiselhart — Waukegan Harbor
Dr. Vicky Harris — Milwaukee, Sheboygan, and Menominee Rivers
Nate Hawley — Milwaukee, Sheboygan, and Menominee Rivers
Bruce Johnson — Fox-Wolf River Basin
Jim Pinkham — Fox-Wolf River Basin
Roy Aiken — Door County
Jim Anderson — Manistique River

Contact information for these individuals is included in Appendix B.

In addition to the authors, several individuals made important contributions to the development of the inventory and this report. Judy Beck, Lake Michigan Team Manager with U.S. EPA, Region 5, served as the technical contact. Through the U.S. EPA she provided funding for the project, as well as project guidance, federal contacts, and overall support of the project through the LaMP process. Matt Doss, Program Manager with the Great Lakes Commission, provided project leadership, oversight, administration, and extensive editorial and task support for all aspects of the project. Dr. Michael Donahue and Tom Crane with the Great Lakes Commission provided guidance and important contact information.

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1. Introduction and Background

Lake Michigan Background

Lake Michigan is the second largest Great Lake, by volume. The lake is 307 miles long and 118 miles wide, with an average depth of 279 feet and a maximum depth of 925 feet. The Lake Michigan drainage basin covers more than 45,000 square miles. The shoreline of the lake stretches 1,660 miles.

Lake Michigan flows into Lake Huron through the Straits of Mackinac. The flow rate into Lake Huron allows Lake Michigan to be recharged once every 100 years, which is considered a relatively slow recharge rate. The lake supports a unique ecology, with colder forested regions dominating the northern half of the basin, and more temperate, fertile regions in the southern section.

Lake Michigan is located entirely in the United States, which made it uniquely situated for this project. Four states border the lake – predominately Michigan to the east and north, and Wisconsin on the western shore. Indiana and Illinois make up the southern shore of the lake, and while a small proportion of the basin area exists in these states, these areas contain significant natural areas, and high population and pollution sources.

The Lake Michigan basin consists of a variety of land uses. About 44 percent of the land in the basin is taken up in agricultural production. Roughly 41 percent exists as managed or unmanaged forest land. Nine percent of the remaining land is divided up into residential units, with a variety of uses making up the remaining 6 percent of the basin.

Monitoring Relevance to the Lake Michigan LaMP

Pursuant to the 1987 protocol to the Great Lakes Water Quality Agreement (GLWQA), Lakewide Management Plans (LaMP) have been developed for four of the five Great Lakes. The Lake Michigan LaMP effort was led by the U.S. Environmental Protection Agency (U.S. EPA), Region 5, in cooperation with its partners in the states of Michigan, Indiana, Illinois and Wisconsin, the public and other federal and tribal agencies. Additionally, Remedial Action Plans (RAPs) are being prepared and updated for ten Lake Michigan tributaries designated as Areas of Concern by the parties to the GLWQA.

According to the 1987 protocol, "LaMPs shall embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in ... open lake waters." The LaMP process involves setting goals to reduce toxics, improve habitat, and restore beneficial uses to the environment in the Lake Michigan basin. The RAPs follow a similar approach in specific geographic areas where significant pollution problems have impaired beneficial uses of the water body.

An additional feature of the LaMPs and RAPs is a strong emphasis on public consultation and local involvement. For the Lake Michigan LaMP, this is achieved through the Lake Michigan Forum, a broad-based stakeholder group with members from tribes, industry, environmental groups, local government agencies, community organizations, academia, recreational organizations, and the ten Lake Michigan AOCs. Public advisory councils (PACs) are the primary vehicle for facilitating public involvement in the AOCs. The PACs include broad representation from the AOC community and guide the RAP process at the local level.

While the original draft Lake Michigan LaMP focused strongly on toxic pollutants, the participating agencies and stakeholders recognized that other stressors contribute to impairments of the lake and the tributaries that feed into it. In response, the latest version of the LaMP expanded its scope to address a broader array of management issues, including loss of habitat and biodiversity and introduction of damaging exotic species. The year 2000 draft of the LaMP includes the results of a number of studies and monitoring efforts to determine the fate of pollutants entering the Lake, and how they move through air or water or sediments into the food chain.

A critical component of this broader approach will be a monitoring regime that is coordinated from one jurisdiction to another and sufficiently comprehensive to support the ecosystem indicators which inform management decisions. The Lake Michigan Mass Balance Study will provide important data on the amount of several critical pollutants entering the lake, their movement and how they are made available to fish and plant life. An outstanding need remains, however, to assess the status and scope of monitoring being conducted at the state and local levels on major tributaries to Lake Michigan; to develop a plan for coordinating and enhancing these efforts; and to address gaps and unmet needs in the collective monitoring and reporting regime that hamper decision making at all levels.

Project Goals

Through a cooperative agreement, the Great Lakes Commission worked with U.S. EPA Region 5, and its partners in the Lake Michigan LaMP process, to assess existing monitoring efforts in Lake Michigan basin and subwatersheds, including the ten AOCs and four other tributary watersheds. This report is one of the outcomes of the project. The report includes a comprehensive review of monitoring programs at the federal, state and local levels for the targeted watersheds; an analysis of gaps, inconsistencies and unmet needs; an assessment of the adequacy of existing efforts to support critical ecosystem indicators; and a plan for addressing major monitoring needs, particularly those considered most important for lakewide management decision making. The report has also been used in training members of the Lake Michigan Forum, PACs, and other stakeholders on determining current, local monitoring efforts and establishing community-based monitoring programs.

The project and report are consistent with the ecosystem approach of the LaMPs and RAPs as well as their emphasis on community involvement and participation. Monitoring has been viewed in the broadest sense, including not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. It is intended that the report and future project outcomes will provide the PACs and other stakeholders with important tools for developing their RAPs and will enable them to engage their community in a valuable dialogue regarding the status of knowledge on their local watershed.

Scope of the Assessment Effort

This report assesses monitoring efforts in the broadest sense, including not only traditional water quality parameters, but also habitat, wildlife, land use, nonpoint source pollution and other measures of ecosystem health. Project participants were responsible for conducting this assessment at the local level in their watersheds. There were fourteen major Lake Michigan tributaries selected for local analysis. The watersheds impacting these tributaries were selected as the base unit of analysis. These watersheds are illustrated in Figure 1. The Great Lakes Commission, in collaboration U.S. EPA and other agencies, assessed monitoring being conducted by state and federal agencies. Please see the methodology chapter for a background on project participants, as well as methods used to gain information to build the inventory.

Figure 1. Watersheds included in the Lake Michigan Monitoring Inventory.

Report Framework

This report is structured along the lines of a typical research report. This introduction is followed by a discussion of the methodologies used to collect the information in the inventory and this subsequent report. The methodology is followed by a series of chapters that present the project findings and inventory content. Summaries of inventory results from each of the fourteen tributaries included in this project are presented in the following categories:

- *LaMP pollutants:* This category includes substances classified as water quality pollutants at three levels. Critical pollutants are those that have been found to impair beneficial uses of the lake and its tributaries. Included in this category are polychlorinated biphenyls (PCB), dieldrin, chlordane, dichlorodiphenyltrichloroethane (DDT) and metabolites, mercury, and dioxins and furans. Pollutants of Concern are those toxic substances that are associated with local or regional use impairments. These include arsenic, cadmium, chromium, copper, cyanide, lead, zinc, hexachlorobenzene (HCB), toxaphene, and polynuclear aromatic hydrocarbons (PAH). Finally, Emerging Pollutants include those toxic substances that have characteristics that indicate a potential to affect the physical or biological integrity of Lake Michigan. These include atrazine, selenium, and PCB substitute compounds.[1]

- *Nutrients and bacteria:* Nutrients, when present in high levels, can impair water bodies by encouraging the overproduction of algae and other plant life, leading to low oxygen levels and ultimately eutrophication. Several organisms which proliferate in high nutrient conditions include *E. coli* and coliform forms of bacteria. These bacteria can locally impair beneficial uses of water bodies.
- *Meteorological and flow monitoring:* Meteorological and flow monitoring represent two types of physical parameters that can be measured for water bodies. Meteorology (mostly relating to precipitation) and flow data help researchers develop water quality models, which have many uses, including source determination, Total Maximum Daily Load (TMDL) development, and other types of predictive modeling, to name just a few.
- *Sediments:* Contamination of bottom sediments is a common source of water quality impairment in AOCs in the Lake Michigan basin. Monitoring these sediments is important for determining the overall quality of a waterbody and its adjoining ecosystems.
- *Fish contaminants, fish health, and aquatic nuisance species:* Many species of fish in the basin take up chemical pollutants through the food web. Often, the effect is a bioaccumulation or concentration of pollutants within the fish tissue. This presents a significant health hazard to humans who consume this fish. Also, the health of fish populations in the lake and tributaries serves to indicate the health of the ecosystem to some degree. Nonindigenous Aquatic nuisance species can affect native aquatic species in a variety of ways. Monitoring of all these aspects of fish populations is important for tracking the health of life in the lake.
- *Benthos monitoring:* Similar to fish, there are a wide number of other organisms that exist deep within lakes and streams within the Lake Michigan basin. Many of these organisms are very sensitive to pollution and other aspects of a healthy aquatic system. Monitoring for the health and diversity of these species helps to determine the overall health of the aquatic ecosystem.
- *Air monitoring:* While monitoring the content of the air is an important task to determine intrinsic air quality, it is also important for tracking potential sources of water quality impairment. Much research is ongoing in the basin to determine how pollutants can be passed through the air to water bodies through air deposition.
- *Wildlife monitoring:* Any effort to track the health and quality of ecosystems must include some measure of the diversity and health of wildlife populations. Several types of public and private organizations are monitoring a variety of wildlife populations.
- *Land use:* One of the measures of human impact on the natural world is tracking the development of land. Changing the use of land from a naturally-controlled environment to agricultural production or urban or suburban habitation can have a wide range of impacts on the surrounding ecosystems. It is important to track these changes, along with measures of ecosystem health, to help determine the overall impacts from changes in land use.

In addition, each chapter begins with background about the watershed or region of focus, and ends with a local assessment of monitoring efforts. Both of these sections were written directly by the local project participants. Actual survey results will be made available for public use via a geographically-searchable Internet database, which is currently under development.

The tributary chapters are followed by a chapter assessing the monitoring coverage of the open lake and a discussion of state and federal monitoring programs which have a multiple watershed focus. This chapter is followed by a general discussion of the monitoring coverage in the Lake Michigan basin, focusing on gaps

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[1]Definitions for LaMP pollutants were excerpted from the *Lake Michigan Lakewide Management Plan (LaMP 2000)*; U.S. EPA, 2000.

and unmet needs. The final chapter contains recommendations from the project participants, in consultation with numerous monitoring stakeholders, such as members of the Lake Michigan Monitoring Coordination Council.

2. Methodology

Attempting to take an inventory of all ecological monitoring efforts in a basin as wide in area as the Lake Michigan basin is a mammoth undertaking. Thousands of separate efforts may be ongoing, and few people outside project participants may be aware of many of them. Striving to become aware of all of these efforts is high goal — a goal that one cannot expect to achieve on the first attempt. We view the products of Lake Michigan Tributary Monitoring Project as comprising a foundation of a monitoring inventory. Over time, if the foundation is strong enough and enough people become aware of it, the inventory can be built upon so that it will eventually become complete. We envision the inventory as a dynamic product that should constantly be updated to reflect new discoveries and changes in monitoring efforts.

In this vein, the methods used to collect information and develop the inventory consisted of the following general elements:

- A two-tiered survey of potential monitoring organizations;
- Review and collection of supplemental or specific geographic monitoring information; and
- Development of an organizing framework for the inventory.

Monitoring Inventory Survey

A short survey (25 questions, 2 pages) was developed to solicit information about possible monitoring projects in the basin (See Appendix C for the survey). Questions in the survey ask respondents to provide information on a variety of characteristics about monitoring projects. Generally, these characteristics include basic contact information, locational information, indicators monitored, logistical information, quality assurance and controls, and staff and training information.

The survey was distributed on two levels – local and state/federal. In an effort to collect a greater amount and higher quality of local monitoring information, the Great Lakes Commission partnered with local groups in 14 key tributaries to Lake Michigan. The tributaries included all ten Areas of Concern (AOCs), as well as Grand Traverse Bay, Grand River, St. Joseph River, and Door County (see Appendix B for a list of project participants). The GLC conducted the survey of state, federal and other basinwide organizations.

Two workshops were conducted to provide training and technical assistance to project participants so that the survey could be administered as effectively as possible. At the first workshop, the survey, along with a set of supporting materials, was distributed to project participants. These materials were reviewed and subsequently adapted to reflect participant feedback. A process was established at the meeting, whereby participants committed to carry out the following steps:

- *Develop a contact list for delivering surveys.* Participants were encouraged to meet with their local advisory groups and develop a list of entities in the watersheds that might be conducting monitoring programs, including local municipalities, utilities, educational institutions, business/industry groups, environmental and conservation organizations and recreational groups among others.
- *Distribute surveys with informational materials.* Participants were subsequently sent a set of materials that could be tailored to their local area. Methods to encourage high response were also discussed.
- *Enter returned surveys into electronic format.* Participants were given a database template to be used for data entry. The final datasets were sent to the GLC for encorporation into the project database. The final database is being developed for public use on the Internet as a geographically-searchable database.
- *Follow up to encourage high response.* Several strategies were discussed to increase the response rate.

- *Report findings.* A framework and timeline were established for reporting on local survey results. These reports were submitted to the GLC for integration into this final report.
- *Final workshop.* A workshop was held to review the overall findings of the project and to share information and ideas about how local groups could build on the results in future projects.

A second meeting was held midway through the project to troubleshoot survey and reporting difficulties. The main difficulty was determined to be response rate. Following the meeting, GLC crafted a press release that the project participants adapted and sent out to local media outlets. This was used to create greater awareness of the project, thereby encouraging better response.

Local Methodologies

Each project participant tailored the general methodology to achieve the best results for their watersheds. The specific methodologies used by the project participants, along with general information about survey results, are provided below.

Grand Traverse Bay

Description of the Research Process

The purpose of this research project is to identify the overall state of ecosystem monitoring being conducted in the Grand Traverse Bay watershed. In addition to water quality monitoring, ecosystem monitoring includes collecting data on selected parameters that effect the biological, physical, chemical, and human health condition of the watershed**.** Parameters such as fish and wildlife habitat, wetland coverage, land use development patterns, construction of infrastructure, atmospheric deposition, climatic conditions, groundwater contamination, watershed hydrology, and others are useful in assessing the condition of a watershed.

Collaboration and Communication With Watershed Groups

The survey project was presented to the Grand Traverse Bay Water Quality Monitoring Team to solicit their support and assistance in identifying organizations to receive the survey. Promotion of the survey was also made at public meetings, monthly meetings with natural resource managers, monthly meetings with the Grand Traverse Regional Environmental Health Committee, and presentations about Grand Traverse Bay sponsored by Grand Traverse Bay Watershed Initiative (GTBWI).

Number of Entities Contacted and Number of Responses

The Grand Traverse Bay Watershed Monitoring Inventory Form was mailed to 96 selected organizations located in the Grand Traverse Bay Watershed.

Of the 96 organizations receiving the survey, 24 returned the survey. Of the 24 respondents, 17 administer a monitoring program.

Muskegon and White Lakes

Surveys were mailed to over 275 potential monitoring entities in the Muskegon and White Lake AOC/River Watersheds. All county level governments, drain commissions, health departments, road commissions and conservation districts were surveyed. Contacts with the PACs and other conservation organizations initially helped to form a mailing list of townships, planning commissions, schools, sport fishing/conservation and lake associations with an interest in water quality, habitat and environmental education projects. This mailing list was compiled and used in the survey. Through a network of conservation districts, individuals and organizations throughout the watershed, a list of individuals, businesses, city governments, schools and university contacts was developed and used in the survey. Personal contacts, phone calls and follow up mailings were performed as more information became available.

Of the survey contacts made, 70 responses were received by the Muskegon Conservation District. Of these, 23 responded with monitoring information. Thirteen of these respondents were from the Muskegon Lake AOC/River Watershed and eight were from the White Lake AOC/River Watershed. A total of 47 respondents indicated that they did not perform any monitoring.

Four public meetings were held to support the RAPs and two newsletters were developed in conjunction with the Muskegon and White Lake Public Advisory Councils to raise awareness and solicit participation for this project. The newsletters were mailed and/or distributed to over 2000 members of the public. An additional survey mailing about the occurrence of "projects" in the Muskegon River Watershed was completed to supplement knowledge about activities and opportunities which could be useful to the Muskegon River Watershed Assembly. A meeting to discuss public involvement in contaminated sediments remediation will be held in the White Lake area as part of this project as well. An educational brochure about Muskegon County watersheds (Muskegon and White being the two largest) is also being developed to promote watershed awareness and public involvement opportunities.

Grand River

Research began with contacting Grand Valley State University-Water Resources Institute (GVSU-WRI) and obtaining mailing lists for different individuals involved in water related projects that were already known to the Institute. This proved to be the best resource since the Grand River does not have a public advisory council or committee established at the time of this study.

A list was also comprised from the Michigan Water Environment Association's 1998-99 membership directory. Surveys sent to these organizations were asked to provide information on monitoring that was above and beyond what they report for compliance purposes.

Contacts were obtained by searching through publications, reports, and news articles for individuals and groups that were in the media. Internet sites were also searched, but unfortunately most of the information found was outdated and websites did not give a good representation of the watershed as a whole. Another search method was the Know Your Watershed software published by Conservation Technology Information Center, which can be found at **http://www.ctic.purdue.edu/KYW/**. The information was obtained for local groups working within different watersheds. The publication date was in 1996, so some of the groups were no longer active. Other names came from individuals that completed the survey.

A total of 325 surveys were sent out in two bulk mailings. Additional surveys were mailed individually as more contacts were discovered. The University had 25 successful responses and 28 negative responses. The majority of surveys sent out were never returned. Inquiries were made by non-monitoring groups on the project, and results will be sent to them.

Kalamazoo River

In an effort to share responsibilities on this project, as well as avoid repetition of surveying, the Kalamazoo River Watershed Public Advisory Council (KRWPAC) partnered with a local project known as the Watershed Information Management Project (WIMP). This group seeks to compile monitoring data and store it in a publically accessible format. After several initial meetings with this group, it became evident that the decision making process between the two groups was preventing our project from commencing on schedule for our November 1, 1999 deadline. We decided to go ahead with our surveying efforts, and agree to share the information acquired with the WIMP group when the time had come.

Utilizing a mailing list obtained from the Michigan Department of Environmental Quality (MDEQ) for the Allegan Lake TMDL project, our first contact included a mailing of 272 surveys to the various contact persons on the list. Initial response yielded about 20 surveys. The surveys requested a two week turnaround time. At four weeks past the date they were mailed an intern conducted follow up calls. Most agencies did not respond to the surveys because they are not conducting any monitoring. We did receive a few surveys that were mailed or faxed back indicating that no monitoring efforts were taking place. The follow up calls did yield an additional four surveys.

A second mailing utilized a list obtained from the Kalamazoo Foundation, a private non-profit foundation that had recently held a Sustainable Community Watershed Conference. Using a list generated from those attending the conference, an additional 50 surveys were sent out. Response from this mailing yielded approximately five responses. Follow up calls did not yield any responses.

In early August, a press release was sent to the major newspapers in the Watershed as well as a few news-oriented radio stations. It is unclear as to how many of these publications actually ran the article. A few responses were received via phone, but these were general inquiry about the Watershed Council. No survey results were attained from the press release.

St. Joseph River
The first stage of the assessment was to identify various organizations that might be monitoring for information on the St. Joseph River watershed, either on water, land, wildlife or any other benchmark. Numerous telephone calls were made to speak with individuals involved in some kind of watershed monitoring. Newspapers serving all watershed counties except Berrien published the press release, proposed by the GLC. The next step was to utilize the survey form designed by the GLC/EPA. Telephone interviews were conducted with several individuals. If they did not return the survey form, the details of their programs were not made available. Comments from some of the organizations that did not return forms are included in the Excel spreadsheet under the comment column. A few personal interviews were conducted and these actually are most effective way to conduct surveys but time or lack of available resources did not permit this as a routine method. The names of the contacts are listed in the Excel spreadsheet even if they did not respond. The ones that responded with a completed form are designated in italics.

A total of about 40 organizations were contacted but only nine completed survey forms were returned. The organizations that were contacted included county health departments, wetland conservation groups, nature centers, volunteer "water watchers", lake and stream association members, river environmental groups, "steelheaders", county conservation offices, colleges and newspapers. The small number of returned forms reflects what appears to be a low level of formal programs that are in place that possess the discipline and resources required to monitor the parameters listed on the survey form. For example, only one organization, "Water Watcher", of Indiana, reported monitoring Atrazine and Acetichlor.

Grand Calumet River
An initial list of likely monitoring organizations or contact people was constructed from the membership of the Citizens Advisory for the Remediation of the Environment (CARE) Committee, the Interagency Task Force on *E. coli* member lists, participants in the TMDL stakeholder process, and other local partnership efforts. The Indiana Department of Environmental Management (IDEM) Volunteer Monitoring Coordinator and the Indiana Department of Natural Resources Hoosier Riverwatch Coordinator was also consulted for a list of local participants in their volunteer water quality monitoring programs. The Riverwatch program did supply a list of past participants in their projects in Lake, Porter, and LaPorte County, Indiana. This information confirmed that in fact, no volunteer water quality or aquatic biota monitoring actually occurs in the Grand Calumet River system. This is most likely the result of the real or perceived dangers of exposing

volunteers to a waterbody with a large accumulation of highly contaminated sediments. Despite this limitation, a substantial list of contacts and organizations was constructed. Groups which might be collecting water quality data in other Lake Michigan tributaries and those which might collect other types of environmental information where added to the list. An internet search was conducted for local chapters of national organization such as Audubon and Sierra Club which might participate in bird and wildlife counting activities. Faculty members involved in ecological or environmental research at local universities were also included. In addition, lists of local governments such as park departments, water departments, and others were provided by the Northwest Indiana Regional Planning Commission. Most of the lists provided by others provided addresses only.

In addition to Internet and phone research, information about this project was presented at a number of local meetings and partnerships. Members of the CARE Committee, the Interagency Task Force on *E. Coli*, and the TMDL stakeholders were informed of the project and advised that they would likely be receiving surveys. Presentations and surveys where also distributed at the annual meeting of the Indiana Hub of the Great Lakes Aquatic Habitat Network, a consortium of local environmental organizations and individuals interested in environmental issues.

An initial mailing of letters, fact sheets, and surveys was distributed to 20 individuals and organizations. Since project funding was actually received by Indiana University as a member of the *E. Coli* Task Force, the letters where sent on Task Force letterhead and signed by Kathy Luther as the Task Force Co-Chair. No responses where received as a result of this initial mailing.

Limited follow up calling was done to those organizations known to be conducting monitoring. A total of two responses were received as a result of this calling effort. Because of earlier decisions regarding project funding, there was insufficient staff time dedicated to this project to permit more extensive calling efforts. Based on conversations with other project participants, 10 percent seems to be a fairly consistent response rate. Follow up phone calls indicated that many recipients did not consider the work they might be doing to be monitoring. This may be one reason for poor survey response rates.

After a mid-term Lake Michigan Tributary Monitoring Project participant meeting in Chicago revealed that GLC was having limited response from state and federal agencies, an effort was made to contact local branches ofsome of these agencies by phone and fax out surveys. Surveys where sent to the IDNR, to Illinois-Indiana Sea Grant, and the USGS Research Station at the Indiana Dunes National Lakeshore. No responses where received as a result of these surveys. IDEM completed survey forms for those partnerships and organizations for which IDEM is a substantial participant. Despite limited responses to surveys IDEM is confident that a comprehensive list of state agency efforts will capture most if not all ongoing water quality monitoring that is occurring in the Grand Calumet River and this Area of Concern. As a result staff time was largely dedicated to completing online the surveys for all IDEM monitoring programs.

Initially, IDEM believed that all information necessary for the Tributary Monitoring Project would be collected in the TMDL process. While this was not the case, some important data was discovered which might not have been learned from the survey project. Information was collected about data that National Pollutant Discharge Elimination System (NPDES) dischargers have collected during discrete time periods as part of special projects. This information is not part of ongoing continuous data collection efforts or any organized monitoring programs and so is not a good fit with the database format of this project. The information was included because it might be useful for any efforts to compile historical data. The regular monitoring of operations and outfalls which NPDES holders undertake as part of the regulatory requirements of their permits is not included in this report. However, it may be useful to remember that information of this type is collected regularly and reported to state agencies.

Waukegan Harbor
The following steps were implemented prior to contacting a company or agency:

- A press release was sent to all local newspapers. Lake County Chamber of Commerce Newsletter published the press release.
- Announcements of the survey were made at the Audubon Society, Waukegan Harbor Citizens Advisory Group, and Liberty Prairie Conservancy meetings.
- Networking was done by telephoning approximately 150 companies, agencies, schools, and lead contacts furnished by telephone contacts. For future reference of sources for information, a database of 52 contacts was developed. Some contacts expressed interest in being a part of future monitoring programs. There were eight surveys returned out of fourteen mailed.

Milwaukee River
Meetings were held with Wisconsin Department of Natural Resources (WDNR) staff, RAP leaders, and others to develop a list of stakeholders and managers working in the basin (DNR, County Land Conservation Departments, University of Wisconsin-Extension Offices, Non-Governmental Organizations (NGOs) etc.). Identified organizations were then contacted by telephone to describe the goals and objectives of the project. Some of the entities contacted provided valuable information regarding their monitoring activities and mentioned some other entities that should be contacted. In most cases however this was not the case, either the groups were no longer active or they were monitoring for compliance with state and federal regulations. In total, over 200 entities were contacted with only 63 actively monitoring. However, of the 63 active programs, only 16 were applicable and responded to this project. After further investigation it was apparent that many of the applicable programs were connected in some way or form to state agencies, mainly the DNR and UW-Extension.

Sheboygan River
A procedure similar to the one used for the Milwaukee River watershed was used to collect information on the Sheboygan River watershed. In total, over 100 entities were contacted with only 28 actively monitoring. However, of the 28 active programs, only 12 were applicable to this project, as many were subsets of a broader program. For example, Testing the Waters involves numerous schools, teachers, and students in the basin. After further investigation it was apparent that many of the applicable programs were connected in some way or form to state agencies, mainly the DNR and the UW-Extension.

The two largest and most active monitoring programs in the Sheboygan River Basin, Testing the Waters and the Pigeon River Water Action Volunteers (WAV), fit the trend previously mentioned. The DNR and the UW-Extension have played active roles in providing equipment and technical guidance for both programs. The Testing the Waters program incorporates local high school and middle school students to actively monitor various tributaries throughout the Sheboygan River Basin (Pigeon, Sheboygan, and Mullet River Watersheds). This program has been very successful, involving several schools over the past eight years. The WAV program, very similar to the Testing the Waters program, utilizes local citizens to monitor water quality. WAV monitoring teams consisted of either adult volunteers or school classes. In both cases, the DNR and UW-Extension provided the initial support and training to develop these programs, but now rely on their local team leaders (teachers and others) to facilitate the efforts. This initial involvement by the DNR and UW-Extension (training, quality control, and equipment) has provided the assurance that the data collected by Testing the Waters and WAV are deemed worthy for ecological assessment, as stated by various stakeholders.

Other smaller programs were also found monitoring in the Sheboygan River Basin. These programs or projects involved land trust and conservation offices, local colleges/universities, as well as a few industrial facilities.

Fox-Wolf Basin
Fox-Wolf Basin 2000 established a list of 131 individuals or entities thought to be conducting some kind of ongoing monitoring program in the basin. This list was derived from our database--focusing on agencies, organizations and university researchers. Additional contacts were provided through a Wisconsin Department of Natural Resources Water Action Volunteer (WAV) database.

Cover letters and survey forms were distributed to those for whom addresses were readily available. After waiting a few weeks, follow-up calls were made to selected contacts. Additional e-mail requests were made in early January prior to the compilation of this report. Seventeen responses were received from eight different individuals and entities. The lack of adequate monitoring in the Fox-Wolf basin has long been lamented by citizens and resource managers alike. However, it is likely there are additional monitoring programs being conducted in a Basin of this size. The limited response in this survey is believed to be more the result of FWB 2000 not having the staff or time available to be more diligent in making additional, repeated contacts.

Door County
Research as to the degree to which monitoring or collecting of data is done on a regular basis was conducted in three modes: personal contact; written communications to determine what, if any, monitoring was being done; and personal interviews with key personal in local and state agencies.

There are no specific nonprofit or volunteer watershed groups in the area, other than two lake associations.

Pursuant to 21 telephone and personal contact interviews, ten letters of inquiry were sent to local organizations and individuals. Personal contact interviews were conducted with three staff personal within the Department of Natural Resources, each with different areas of responsibility. Companies located in Sturgeon Bay's Industrial Park gave indications that their activities were not of a nature that monitoring would be a concern.

Menominee River
A procedure similar to the one used for the Milwaukee River watershed and Sheboygan River watershed was used to collect information on the Menominee River watershed. Many of the national environmental organizations (Isaac Walton League, Trout Unlimited, etc) had representatives or chapters in the basin, but were not actively monitoring at the present time. In total, over 50 organizations were contacted with only 8 actively monitoring. After reviewing the list with County Land Conservation managers and WDNR staff, it was apparent that the list was comprehensive.

Manistique River

Description of the research process

Schoolcraft County Economic Development Corporation coordinated research to determine groups, agencies, businesses, governmental entities, and individuals conducting research and monitoring within the Manistique River Watershed.

The following was the process used to collect data for this process:

1) List of potential contacts generated by the Corporation and Manistique River/Harbor Public Advisory Council.
2) Initial mailing sent to entire mailing list. Mailing included an introductory letter, background document describing basin-wide project, and a survey form. All three of these documents were developed by the Great Lakes Commission with comment by all partners.

3) Follow-up mailings of the same packets were delivered to new persons identified by respondents identified and contacted during step two.
4) Surveys returned to the Corporation were entered into the required Excel spreadsheet. Respondents were contacted for additional information if needed.
5) James Anderson met with Michael Tansy, chairperson of the Manistique River Watershed, and director of the Seney National Wildlife Refuge, and George Lyon with the Luce-Mackinac-Schoolcraft Soil and Water Conservation District office.
6) Telephone or personal contacts were made to recipients of the survey who did not respond to determine their level of monitoring activities within the Watershed.

Collaboration / communication with the public advisory council or other watershed groups

During the course of the research the Corporation worked with the Manistique River/Harbor Public Advisory Council to brainstorm monitoring activities occurring within the Watershed, and to develop an initial mailing list for the survey instrument.

The Corporation met with the lead staff person with the local Soil and Water Conservation office, and the chairperson of the organization and director of the Seney Wildlife Refuge to discuss their activities within the watershed. Both shared that beyond the activities of the Refuge, there are very few monitoring activities happening within the watershed. The response from the survey instrument verifies that the assessment made by Mr. Tansy and Mr. Lyon was correct.

Other outreach efforts

In addition to the above activities, a press release developed by the Great Lakes Commission was modified for local informational content, and sent to the local media including radio (WTIQ), and the local newspapers - *Pioneer Tribune* (Manistique / Schoolcraft County), *Munising News* (Alger County), and the *Newberry News* (Luce County). James Anderson, executive director provided updates and information at Corporation board meetings concerning the project which were covered by the media, and discussed the project during a quarterly half-hour interview on WTIQ AM 1490 Community Focus program.

Number of entities contracted and number of responses

Of the 34 surveys sent out, six (6) responses were received. George Lyon with the Soil and Water Conservation indicated that he did not believe either dam operator was involved with any monitoring activities.

General comments on results

Only five surveys were returned indicating that a rather large watershed has very little monitoring or coordination of conservation activities occurring within it. Further, the data returned indicated that most monitoring is for regulatory requirements, with some additional data collection beyond the required level. There does not appear to be any monitoring in terms of land use, soil, and very little monitoring of Fish and Biota / Wildlife beyond that of the Seney National Wildlife Refuge and the United States Department of Agriculture - Hiawatha National Forest.

In terms of the indicators being collected, all 18 indicators are being collected by at least one organization - City of Manistique, Department of Public Works. Further, most monitoring appears to be completed by paid staff who are trained in data collection methodology as well as quality assurance / quality control methods.

Further, the Corporation was surprised to find that only one of three universities in the region has any interest in conducting research within the watershed, and the only effort is driven primarily due to the contamination of the lower watershed with PCB’s.

Federal and State Data Collection

The GLC was primarily responsible for collecting data from federal, state, and other organizations conducting monitoring programs basinwide. This was accomplished through two efforts — a survey, and supplemental data search. First, the GLC, in consultation with project participants and members of the Lake Michigan Monitoring Coordination Council (LMMCC), developed a list of federal and state entities that were likely to be conducting monitoring efforts in the basin (see Appendix D for the LMMCC membership list, and Appendix E for a list of survey contacts). In an effort to maintain efficiency, every effort was made to select specific contacts who could respond generally about monitoring programs in their agency, or who would collect information from relevant people in their agency. Follow up phone calls and e-mails were made to non-respondents to solicit a higher response rate. These phone calls led to further contacts (sometimes in other agencies), and additional surveys were distributed. In addition, the survey form was transformed into a web-based format to ease completion by respondents. This generated further responses, as agency contacts often asked multiple people within their agency to complete the web-based form. From an initial distribution of 72 surveys, the GLC received 27 responses. An accurate response rate cannot be calculated, since some agencies returned several surveys (some not directly solicited), while others returned none. The full database of survey responses (including local responses) can be obtained upon request.

The data received from the surveys was supplemented with information on monitoring collected through a general information search. This consisted of a general web review, as well as follow-up from conversations with agency and participant contacts. In many cases, the information collected through this method made it unnecessary to pursue further contacts with specific agencies. Several databases of monitoring information were discovered through this process. The most useful database was the *Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)* system developed by Tetra Tech, Inc. for the U.S. EPA, Office of Water. This system consolidates a number of federal databases to allow easy extraction and use of ecological information on a watershed basis. Several datasets were used in the analysis for this report.

Datasets used to provide monitoring information for this report (including those extracted from BASINS and those obtained elsewhere, are included below. Where possible, dataset summaries are taken directly from metadata provided with the dataset.

The Storage and Retrieval (STORET) System
This dataset provided statistical summaries of water quality monitoring for 47 physical and chemical-related parameters. The parameter specific statistics were computed by station for five-year intervals from 1970 to 1994 and a three-year interval from 1995 to 1997. The data are contributed by a number of organizations including federal, state, interstate agencies, universities, contractors, individuals and water laboratories. Information was extracted from the STORET system for analysis of monitoring coverage for all LaMP pollutants, bacteria, nutrients, and some physical characteristics.

Permit Compliance System (PCS)
PCS is a national computerized management information system that automates entry, updating, and retrieval of National Pollutant Discharge Elimination System (NPDES) data and tracks permit issuance, permit limits and monitoring data, and other data pertaining to facilities regulated under the NPDES program. PCS records water-discharge permit data on more than 75,000 facilities nationwide.

The NPDES permit program regulates direct discharges from municipal and industrial wastewater treatment facilities that discharge into the navigable waters of the United States. Wastewater treatment facilities (also called "point sources") are issued NPDES permits regulating their discharge. Information on the point locations of sites reporting discharges from 1991 through 1996 were included in the analysis for this report.

Toxic Release Inventory (TRI)
This database contains data on annual estimated releases of over 300 toxic chemicals to air, water, and land by the manufacturing industry.

Industrial facilities provide the information, which includes the location of the facility where chemicals are manufactured, processed, or otherwise used; amounts of chemicals stored on-site; estimated quantities of chemicals released; on-site source reduction and recycling practices; and estimated amounts of chemicals transferred to treatment, recycling, or waste facilities.

The TRI data for chemical releases to land are limited to releases within the boundary of a facility. Releases to land include landfills; land treatment/application farming; and surface impoundments, such as topographic depressions, man-made excavations, or diked areas. Air releases are identified as either point source releases or as non-point (i.e. fugitive) releases, such as those occurring from vents, ducts, pipes, or any confined air stream. Surface water releases included discharges to rivers, lakes, streams, and other bodies of water. In addition, the database covers releases to underground injection wells (where chemicals are injected into the groundwater) and off-site transfers of chemicals to either publicly owned treatment works (POTWs) or any other disposal, treatment, storage, or recycling facility.

For use in the assessment for this report, information on the locations of facilities discharging pollutants through any of the above media streams from the years 1987 through 1995 were included.

National Sediment Inventory
This dataset describes the accumulation of chemical contaminants in river, lake, ocean, and estuary bottoms and includes a screening assessment of the potential for associated adverse effects on human and environmental health. The U.S. EPA evaluated more than 21,000 sampling stations nationwide using sediment chemistry data, chemical residue levels in edible tissue of aquatic organisms, and sediment toxicity data. Of the sampling stations evaluated, 5,521 stations were classified as Tier 1 (associated adverse effects are probable), 10,401 stations were classified as Tier 2 (associated adverse effects are possible, but expected infrequently), and 5,174 stations were classified as Tier 3 (no indication of associated adverse effects). Ninety-six watersheds were identified as areas of probable concern for sediment contamination. U.S. EPA believes that these watersheds represent the highest priority for further ecotoxicological assessments, risk analysis, temporal and spatial trend assessments, contaminant source evaluation, and management action because of the preponderance of evidence in these areas (although further evaluation is necessary). Also see the related report entitled the *Incidence and Severity of Sediment Contamination in Surface Waters of the United States, Volume 1, National Sediment Quality Survey* (EPA 823-R-97-006, **http://www.epa.gov/OST**) that was published in September 1997.

Stations monitoring for sediment chemistry data, chemical residue levels in edible tissue of aquatic organisms, and sediment toxicity data were used for the inventory. For this report, information on monitoring station locations, monitoring agency, and type of sampling conducted (i.e. sediment chemistry or biotoxicity/tissue residue).

U. S. Geological Survey Gage Stations
This dataset contains the locations and summary data from USGS stream gaging stations. The gage data were retrieved from the Gage File database. These stations are used primarily to collect continuous stream flow and water level information on target waterbodies. Only gage locations were used in this report.

Aerometric Information Retrieval System (AIRS)
The AIRS system inventories and summarizes air pollutant data from air monitoring stations throughout the United States. The system is funded and maintained by U.S. EPA Office of Air Quality Planning and Standards (OAQPS). The system contains information about and from stations that monitor the following criteria pollutants:

CO - carbon monoxide (gas)
NO2 - nitrogen dioxide (gas)
O3 - ozone (gas)
SO2 - sulfur dioxide (gas)
PB - lead (a constituent of particulate matter)
PM10 - particulate matter (particles smaller than 10 micrometers)

Additionally, AIRS data includes emissions estimates for two more pollutants:

PT - particulate matter (total, all particle sizes - reported in lieu of PM10)
VOC - volatile organic compounds (precursors that can lead to the formation of ground level ozone)

Data on site locations and pollutant monitored were extracted for use in this report.

National Oceanic and Atmospheric Administration (NOAA) Weather Stations and Weather Data Management (WDM) Sites
This data set provides a location map in ARCVIEW Shapefile format of weather stations and WDM stations for the entire United States and U. S. territories. The spatial data was prepared from the National Climatic Data Center Hourly Precipitation database available from EarthInfo, Inc. (**http://www.earthinfo.com/earthinfo/**). The shapefile is prepared and distributed by U.S. EPA regions or states. Information on site locations of weather stations was used for this report.

Fish and Wildlife Consumption Advisory Database
The 1996 update for the database, *Listing of Fish Consumption Advisories*, is now available from the U.S. Environmental Protection Agency. This database includes all available information describing state-, tribal-, and federally issued fish consumption advisories in the United States for the 50 states, the District of Columbia, and four U.S. Territories, and has been expanded to include the 12 Canadian provinces and territories. The database contains information provided to U.S. EPA by the states, tribes, and Canada as of December 1996. This includes advisories issued by several Native American tribes.

The number of advisories in the United States rose by 453 in 1996 to a total of 2,193 representing a 25 percent increase over 1995. The number of waterbodies under advisory represents 15 percent of the nation's total lake acres and 5 percent of the nation's total river miles. In addition, 100 percent of the Great Lakes waters and their connecting waters and a large portion of the nation's coastal waters are also under advisory. The number of advisories in the United States increased for four major contaminants (mercury, PCBs, chlordane, and DDT). In 1996, the U.S. EPA contacted health officials in Canada in an effort to identify fish consumption advisories in effect. In Canada, a total of 2,617 advisories were in effect in 1996. All of the Canadian advisories resulted from contamination from five pollutants: mercury, PCBs, dioxin/furans, toxaphene, and mirex. Ninety-six percent of all the advisories resulted from mercury contamination in fish tissues. In addition, 87 percent of the advisories were issued by the provinces of Ontario and Quebec. Information on the location of advisories, species affected, and flagged pollutants were used in this report.

Lake Michigan Mass Balance (LMMB) Monitoring Sites
This is an unpublished dataset that contains information on sites providing information for the Lake Michigan Mass Balance Project. Information includes locations, and purposes for sampling stations, project names and organizations, and indicators analyzed. The information is contained in three separate datasets, and linkages are based only on project names. Data quality is undefined. Information for this report was extracted from this dataset for monitoring locations, media and pollutants monitored, and organizations conducting the monitoring. The sample data itself has been quality assured and is available upon request from GLNPO.

National Water Quality Assessment Monitoring Sites (NAWQA)
This dataset includes the monitoring stations used in the Western Lake Michigan Drainages study unit for the NAWQA program. Information was collected through the study unit's online database, found through **http://wwwdwimdn.er.usgs.gov/nawqa/index.html**. Information included station identification, location, and flags for one of four types of monitoring conducted: surface water, ground water, sediment and tissue, and biological. More extensive data can also be obtained from this site, including parametric measurements.

Additional Federal/State Datasets

Several monitoring data sets were discovered just prior to final publication of this report. Discussion and general analysis of these sets have been included in the report, but in the interest of time, geographic analysis of monitoring site locations was not completed. Geographic locations of monitoring stations in these data sets will be included in the online version of the monitoring inventory when it is released. General information on these data sets are included below.

Regional Toxic Air Emissions Inventory
This is a multijurisdictional inventory of point, area, and mobile sources of toxic air emissions that have the potential to impact environmental quality in the Great Lakes basin. This initiative was undertaken through an intergovernmental partnership involving the eight Great Lakes states, the province of Ontario, and the U.S. Environmental Protection Agency (U.S. EPA). The objective of this ongoing initiative is to present researchers and policy makers with detailed, basin wide data on the source and emission levels of 82 toxic contaminants. Source and emission levels are projected by each state or province using the *Regional Air Pollutant Inventory Development System (RAPIDS).* The most recent inventory report uses 1996 data and can be found at: **http://www.glc.org/air/1996/1996.html**.

Integrated Atmospheric Deposition Network (IADN)
The Integrated Atmospheric Deposition Network is a joint effort of the United States and Canada to measure atmospheric deposition of toxic materials to the Great Lakes. This network includes a number of stations throughout the Great Lakes, but only one is found in the Lake Michigan basin at Sleeping Bear Dunes National Lakeshore. This station monitors for PCBs, chlorinated pesticides, PAHs, and trace metals in air and precipitation. This site was also included in the analysis of the Lake Michigan Mass Balance Project. Please see discussions on that program for more details.

Sea Lamprey Assessment
Through the Great Lakes Fishery Commission, the Sea Lamprey Integration Committee (SLIC) was established to monitor and control Sea Lamprey infestation throughout the Great Lakes. The Sea Lamprey Assessment Task Force within SLIC establishes plans for monitoring to assess the extent of infestation. In general, tributaries of the Great Lakes systematically are assessed for abundance of sea lamprey larvae (quantitative surveys) and distribution (qualitative surveys) to determine when and where lampricide

treatments are required and effectiveness of past treatments. Results of these assessments are published in annual reports.

***R/V Lake Guardian* Sampling**

The U.S. EPA's Great Lakes National Program Office (GLNPO) annually tours the Great Lakes and samples for phyto- and zooplankton at specified locations. The *R/V Lake Guardian* is used to conduct sampling tows at different depths to obtain data on changes in plankton populations. In addition, the vessel takes a set of standard baseline measurements including conductivity, temperature and depth.

Lakewide Assessment Plan for Lake Michigan Fish Communities

This plan was developed through the Great Lakes Fishery Commission (GLFC) by Departments of Natural Resources from Wisconsin, Michigan and Illinois, as well as the USFWS and USGS-BRD. The plan establishes guidelines for annual sampling of lake trout, chinook salmon, and burbot populations throughout Lake Michigan. For lake trout and burbot, six sampling sites are randomly selected from within eleven regions each year for a total of 66 sampling locations. For chinook salmon, randomly-selected sites are selected along the length (south to north) of the lake in the spring and summer, with 22 sites selected in each season.

Status and Trends of Prey Fish Populations in Lake Michigan, 1999

This report from the USGS Great Lakes Science Center details the monitoring and findings related to sampling of prey fish populations through 1999. The surveys are performed using standard 12-meter bottom trawls towed along contour at depths of 9 to 110 m at each of seven to nine index transects. Information is collected on abundance, species composition, population characteristics, and general fish health.

3. Inventory Results

The ultimate result of nearly one year's work by the GLC, 14 local tributary groups, and other stakeholders, this report represents an inventory of ecological monitoring projects throughout the Lake Michigan basin. The results that follow originate from two basic sources — the survey data, and a supplementary search of relevant datasets. All data is combined into analyses for each of the 14 tributaries, as well as one for the open waters of Lake Michigan.

General Survey Results

Altogether 334 surveys were returned from efforts made by local groups and the GLC. Agencies from all levels of government (federal, state, and local), as well as business, academic, and volunteer organizations from diverse regions of the basin participated in this survey, and added their information to the inventory. Of the responses, 63 percent of the projects primarily monitor water, 5 percent monitor land, 2 percent monitor air, 3 percent monitor soils, 18 percent primarily monitor biota or wildlife, and 9 percent primarily monitor other media (see Figure 2). See specific watershed chapters for discussions about general monitoring characteristics. The frequency of monitoring broke down as follows: daily – 6 percent, weekly – 8 percent, monthly – 10 percent, semiannually – 12 percent, annually – 16 percent, other – 48 percent. Projects staffed the monitoring as follows: paid staff – 65 percent, volunteers – 17 percent, students – 11 percent, other – 7 percent (see Figure 3). The number of staff on monitoring projects range from one to 1000, with the median equal to three people. Nearly 93 percent of the programs provide some sort of training to staff. Budgets for the monitoring projects surveyed range from zero to $12 million, with a median budget of $15,000. Nearly 63 percent reported that funding for the monitoring project was relatively reliable.

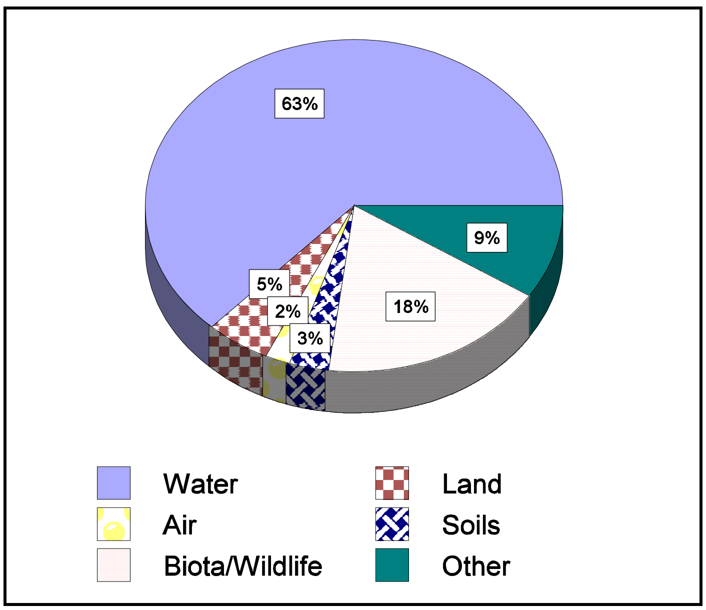

Figure 2. Proportion of survey responses by the primary medium monitored.

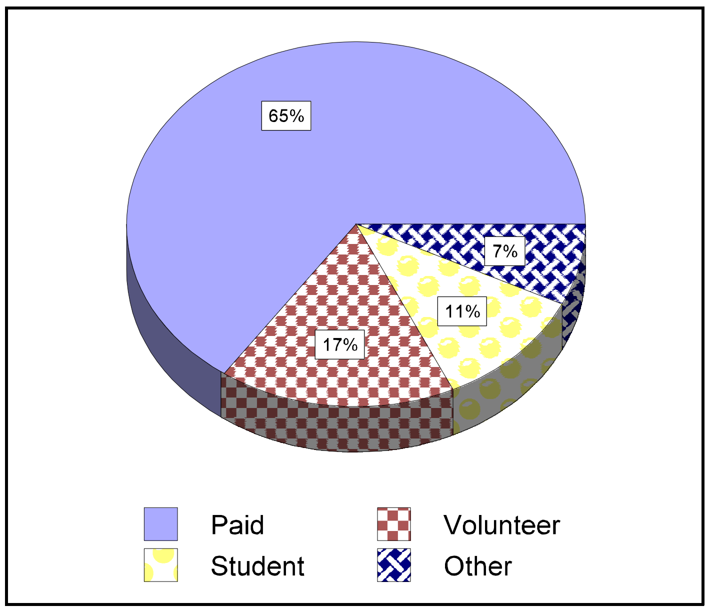

Figure 3. Proportion of survey responses by the type of monitoring staff.

Results Framework

The following chapters contain the analysis of inventory results for all 14 tributaries and the open waters of Lake Michigan, as well as generalized projects which cover multiple watersheds. The chapters are segmented as follows:

- Background
- LaMP pollutants
- Nutrients and bacteria
- Meteorological and flow monitoring
- Sediments
- Fish contaminants, fish health, and aquatic nuisance species
- Benthos monitoring
- Air monitoring
- Wildlife monitoring
- Land use
- Local assessment

Information in the background and local assessment sections was provided by the project participants, with editing by GLC to establish a continuity of flow. The other results-based sections contain integrated information from local project participant surveys, GLC surveys, and external datasets. Where possible, data is geographically displayed. However, each section discusses all monitoring projects, including those for which no specific geographic information was available.

13. Fox-Wolf River Basin

Background

The Fox-Wolf River basin of Northeast Wisconsin is a 6,400 square mile drainage area with three distinct sub-basins: the Wolf River, the Upper Fox and Lower Fox River. The Wolf and Upper Fox Rivers drain south and east (respectively) into the Lake Winnebago "pool" lakes and then north through the Lower Fox River to the bay of Green Bay. The Fox-Wolf Basin is the largest drainage basin to Lake Michigan and the third largest to the Great Lakes.

For purposes of this report, the discussion will address all three sub-basins and Lake Winnebago. However, the graphic display and majority of the discussion will focus on the Lower Fox River watershed. Lower Green Bay is also part of the AOC in this area, however, the bay is assessed as part of greater Lake Michigan Open Water chapter. Please see that chapter for further information.

Status of Watershed Management Efforts in the Study Area

Watershed management in the Fox-Wolf basin is conducted under a variety of program initiatives – primarily Wisconsin's Nonpoint Source Pollution Abatement Program (a.k.a. the Priority Watershed Program) and the Wisconsin Pollution Discharge Elimination System program. Ten of the basin=s 41 watersheds have been identified as priority watersheds. County Land Conservation Departments are provided with state funds for staff and overhead to conduct watershed inventories, develop management plans, contact landowners, and offer cost-share funds to install BMPs.

Funds are also available to other local units of government in urban or urbanizing areas of the watershed. Recently, this program has undergone a re-design which has yet to be completed. No additional watersheds are expected to be selected under the new program, but efforts will continue through local governments on a more limited scope and time frame.

Many other local, state and federal initiatives work on some component of watershed management in the Fox-Wolf basin, too numerous to mention in this introduction. Initiatives range in function from voluntary cost-share programs to local ordinances to state and federal permitting. A recent reorganization of the Department of Natural Resources has established geographic management units (GMUs) designed to better coordinate programs and involve all agencies and individuals. GMU (or Basin) Partner Teams have been established in the Upper Fox, Lower Fox and Wolf River Basins.

Pollutants of Concern

Aquatic Monitoring

Monitoring coverage for LaMP pollutants reported into the STORET system is shown in Figure 43. This maps indicates that stations exist for two (mercury and PCBs) of seven critical pollutants, six out of ten pollutants of concern, and none of the listed emerging pollutants. Monitoring for all pollutants is relatively light compared to other watersheds in this analysis. The monitoring is heaviest along the lowest section of the Fox River where it flows out into Green Bay. There are 12 stations monitoring mercury at our near the Fox River outfall, while there are 28 stations for the rest of the Fox-Wolf basin (four in the Lower Fox, three at the entrance and exit of the Fox River to Lake Winnebago, three in the Upper Fox, and 18 in the Wolf River watershed). Ten PCB stations have been placed along the Lower Fox, with one on the shore of Lake

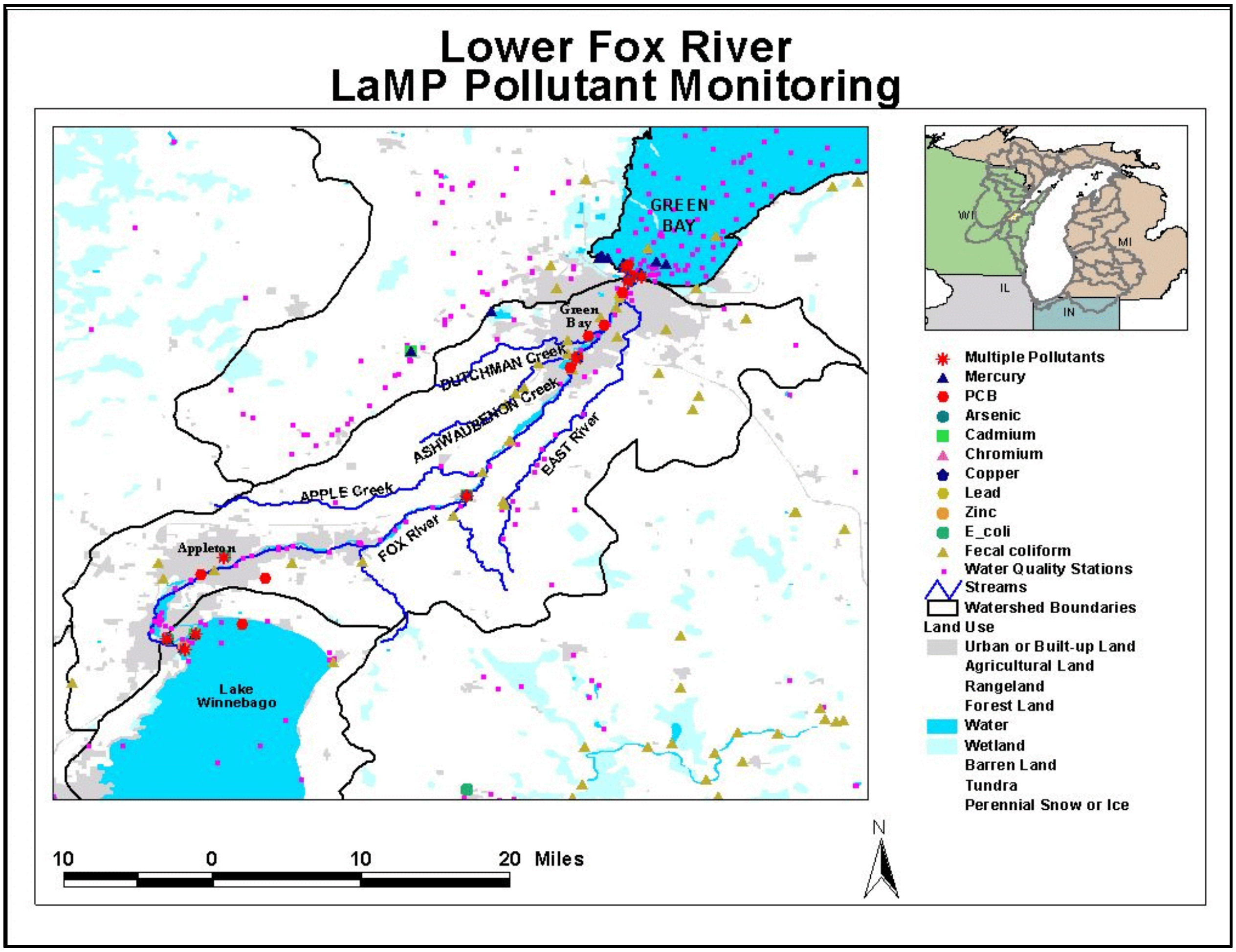

Figure 43. The Lower Fox River watershed with ambient water quality and bacteria monitoring stations from U.S. EPA's STORET system displayed by indicators measured.

Winnebago. The stations monitoring for LaMP pollutants are maintained by WDNR, U.S. EPA (3 programs), COE, USGS-WRD (NAWQA and baseline stations), or EPRI.

In addition, surveys indicate that the Green Bay MSD monitors for all LaMP pollutants with the exceptions of dioxins/furans, hexachlorobenzene, PAHs, and atrazine. This monitoring is conducted on the Lower Fox River at its outflow to Green Bay. Also, the University of Wisconsin-Stevens Point tracks atrazine in the Tomorrow-Waupaca River watershed.

Pollutant Release Monitoring

An examination of Permit Compliance System and Toxic Release Inventory reporting locations in the Fox-Wolf basin indicates a large number of monitoring locations for potential pollution sources throughout the basin (see Figure 44). Clusters of these locations can be found all along the Lower Fox River, as well as in Oshkosh on the western shore of Lake Winnebago, in Fond du Lac on the south shore, and on the shore of Shawano Lake in the Wolf River watershed.

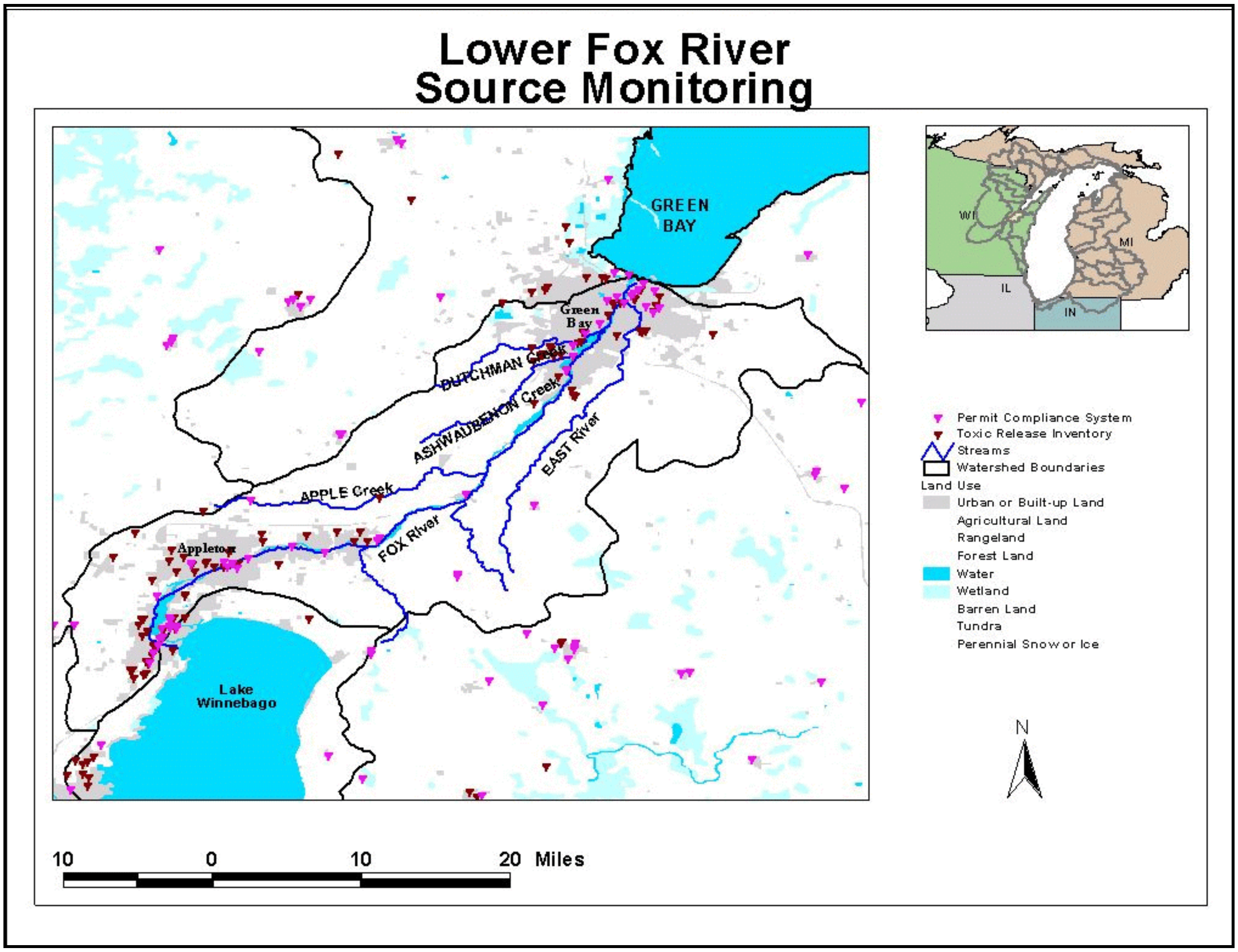

Figure 44. Lower Fox River watershed with pollutant sources from the Permit Compliance System and Toxic Release Inventory databases indicated.

Nutrients and Bacteria

There are more than 120 water quality monitoring stations within the Lower Fox River watershed listed in the STORET system. An additional 720 stations are located throughout the remaining watersheds in the Fox-Wolf basin. Also, there are a large number of stations in the near shore region of Green Bay. A vast majority of these stations (shown in Figure 43) monitor for some form of nitrogen and phosphorus, the chief nutrients impacting water quality. Thus, where monitoring stations exist, they are likely tracking nitrogen and phosphorus. The density of stations is greater at the Fox River outfall to Green Bay, but the rest of the stations are distributed fairly evenly throughout the basin. According to our surveys, there are several other organizations in the basin monitoring for nutrients. These include the Brown County Land Conservation Department, the University of Wisconsin-Stevens Point, the Green Bay MSD, Waupaca County Land Conservation Department, University of Wisconsin-Milwaukee, Green Bay RAP, and Green Bay Public Schools WAV.

Eleven stations monitor *E. coli* in the Fox-Wolf basin — three in the Lower Fox, six in the Upper Fox (including three on Lake Butte Des Morts), and two in the Wolf watershed. All 11 stations are maintained by WDNR. Monitoring for fecal coliform is significantly more extensive. About 120 stations can be found throughout the basin. As with other monitoring coverage in the basin, monitoring of fecal coliform levels is

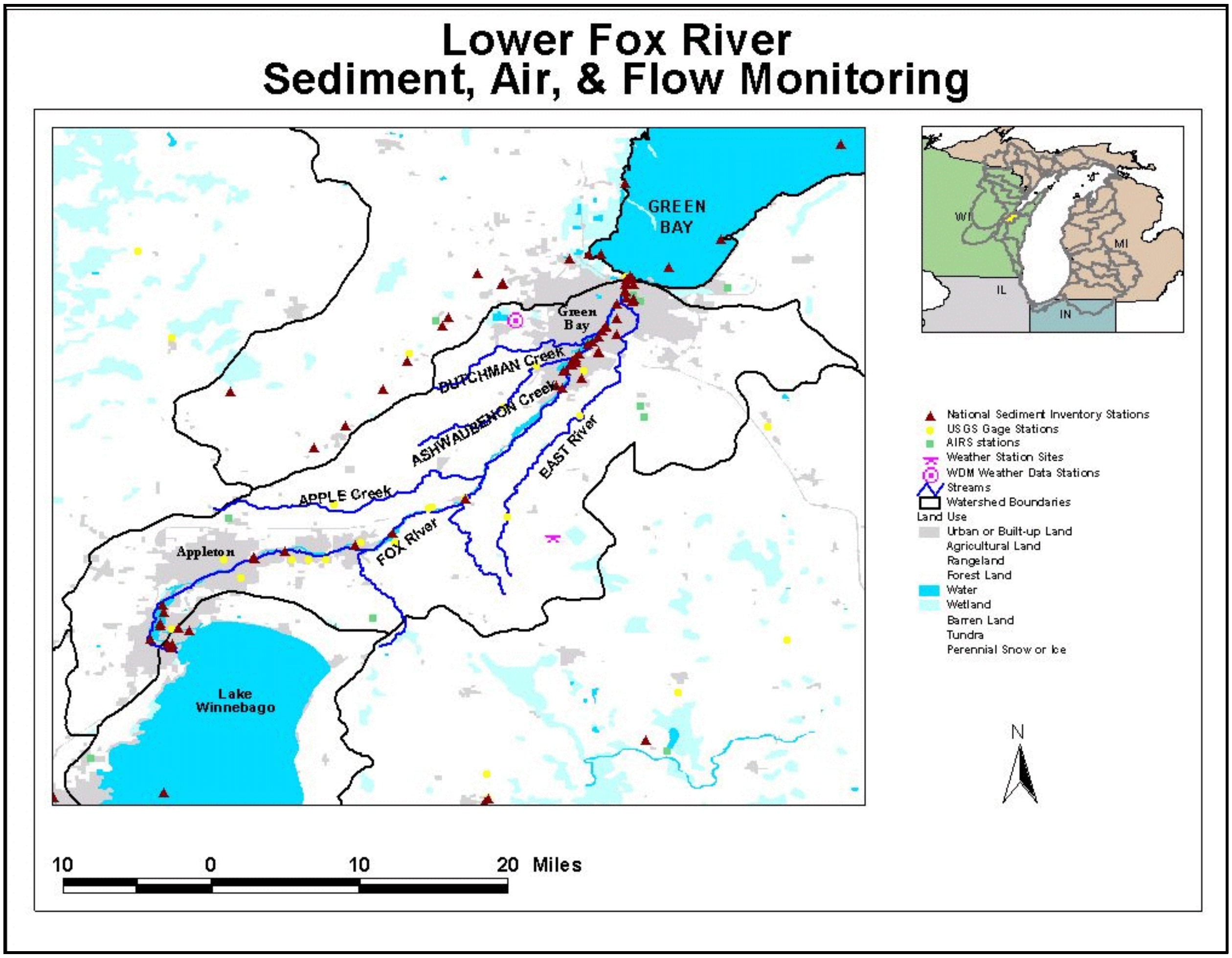

Figure 45. Lower Fox River watershed with National Sediment Inventory stations, USGS gage stations, U.S. EPA's Aerometric Information Retrieval System (AIRS) stations, and NOAA weather stations indicated.

clustered near Green Bay. However, there are numerous stations distributed throughout the rest of the basin. Organizations monitoring for fecal coliform in the watersheds include WDNR, USGS-WRD, U.S. EPA, and the U.S. Forest Service (USFS). In addition, two other organizations report through surveys to monitor bacteria in the basin. These include Brown County Land Conservation Department and Brown County Health Department.

Meteorological and Flow Monitoring

USGS maintains 85 gage stations throughout the Fox-Wolf basin to measure flow rates and various other physical characteristics of streams (see Figure 45). Some of these stations have been used for physical and chemical monitoring through the NAWQA program. Gage stations are located on all major rivers and streams in the watershed.

Several organizations also reported that they monitor numerous physical properties in streams in the basin. These include the Brown County Land Conservation Department, WDNR, the Oneida Tribe of Indians, and Green Bay MSD. Paper mills also monitor physical properties through their Industry Rivers Study

Committee. Physical properties measured by all these organizations include stream flow, temperature, pH, dissolved oxygen, biological oxygen demand, chlorophyll, suspended solids, and turbidity.

Three NOAA weather stations are located in the Fox-Wolf basin, and one other station is located just outside the northern boundary of the Wolf watershed. The stations inside the watershed are located within and south of Green Bay in the Lower Fox, and in New London in the southern portion of the Wolf watershed. The station north of the Wolf is located at the Laona Ranger Station in the Nicolet National Forest. These stations measure continuous precipitation data, as well as other meteorological data.
Sediments

There are 97 National Sediment Inventory sites within the Fox-Wolf basin (see Figure 45). The sites are clustered along the Lower Fox, at the inlets and outlets of the "pool" lakes, and along the Red River in the Wolf watershed. Other sites are located more randomly throughout the watersheds in the basin. These sites are administered by the WDNR, USGS-WRD, and U.S. EPA. Some of these sites are involved in cooperative projects between USGS-WRD, WDNR, and Oneida and Menominee Tribes, involving PCB sediment remediation, agricultural BMPs, and trace elements from the Crandon Mine. The Green Bay MSD also reports to conduct some sediment sampling. About 50 of the sites monitor sediment chemistry to assess human health and aquatic life impacts. A total of 48 sites monitor benthic organism tissue, discussed below.

Fish Contaminants, Fish Health, and Aquatic Nuisance Species

As discussed earlier, we have been unable to find specific locational information (i.e. sampling locations) for programs monitoring fish populations or their health. There are statewide programs in existence, but these are discussed in the overall findings discussion. The National Sediment Inventory lists 48 stations that monitor fish tissue to assess the impacts of sediment contamination. These are located throughout the basin, and are administered by WDNR and the U.S. EPA. USGS also maintained NAWQA stations in the basin to examine fish tissue. Two organizations also conduct fish habitat assessments. These include WDNR and the Oneida Tribe of Indians.

A search of the Fish and Wildlife Advisory database on all major Fow-Wolf basin waterbodies revealed fish consumption advisories for nine locations in the basin. Advisories had been issued for six sections of the Fox River, all of the Lake Winnebago "pool" lakes, Shawano Lake, and a section of the Wolf River. In addition, fish advisories have been issued for most of Green Bay. The advisories were all state issued, covered a variety of fish species and related to PCB and mercury levels.

One program was discovered to be monitoring for zebra mussels within the Fox-Wolf basin. The WDNR monitors zebra mussel veligers in the Fox River. Refer to the overall discussion of Lake Michigan monitoring for a discussion about programs that cover multiple tributary watersheds.

Benthos Monitoring

No specific locational information was discovered for state or national programs monitoring benthic organisms. However, several organizations report that they collect macroinvertebrate data (including community composition, and structural and functional integrity) in numerous locations in the basin. These organizations include WDNR (for the Index of Biotic Integrity (IBI)), Brown County Land Conservation Department, Integrated Paper Services, Inc. Other organizations may be monitoring benthic organisms generally in the watershed, among others. These are discussed in the overall discussion of Lake Michigan monitoring (see the NAWQA discussion, for example).

Air Monitoring

Figure 45 illustrates the locations of the 13 air monitoring stations in the basin, according to the U.S. EPA's AIRS database. The stations are distributed evenly throughout the basin. The stations monitor for three of eight indicators in the database, including low-level ozone, particulate matter, and sulfur dioxide.

Wildlife Monitoring

Several organizations are monitoring wildlife in the basin. The Northeast Wisconsin Audubon cunducts an annual bird count; the University of Wisconsin-Green Bay Richer Museum monitors colonial nesting birds; Long Point Bird Observatory monitors breeding marsh birds and amphibians at a couple of sites; and Barkhausen and Green Bay Wildlife Sanctuaries track various bird populations. In addition, there are organizations monitoring wildlife species in the basin on a more regional basis. These are discussed in the overall discussion of Lake Michigan monitoring.

Land Use

The Lower Fox watershed consists of a large portion of urbanized land with relatively few wetlands. Large developments include Green Bay, Appleton, Menasha, Oshkosh, Neenah and Fond du Lac. A substantial portion of the rest of the basin does exist as wetlands. Large wetland areas can be found throughout the Wolf watershed, especially around the headwaters of the Wolf River. The wetlands are not extensively monitored, except in the Wolf headwaters.

Local Assessment

One of the best examples of monitoring data put to beneficial use is "The State of the Bay: A Watershed Perspective" produced by UW-Green Bay's Bud Harris. This very simple, graphicly based format has been an exceptional education tool in a variety of contexts. Dr. Harris is initiating, with Fox/Wolf Basin 2000 assistance, a Strategic Data Acquisition Task Force to help expand monitoring coordination, improve data analysis and guide future activity.

From the perspective of a non-profit watershed alliance (Fox/Wolf Basin 2000), there are several important points to be made with regard to monitoring in the Fox-Wolf basin. First, where data is collected and disseminated, it has been particularly helpful in making the case for enhanced watershed management efforts as well as adding to the understanding of watershed functions and conditions. However, there is likely a large amount of monitoring that was not discovered through this project. Further efforts need to be made to complete the Fox-Wolf basin content in the monitoring database.

When the data collection is not coordinated from a geographic perspective consistently over the years, the ability to effectively manage resources on a watershed basis is lost. Evidence of this is found in this statement taken from the Lake Winnebago Comprehensive Management Plan compiled by the Wisconsin Department of Natural Resources in 1989:

> "There are no current ongoing programs in DNR or other agencies to collect the short- or long-term information necessary to allow adequate assessment of any efforts to reduce nutrient or sediment loading."

Granted, there are some monitoring programs designed to help resource managers, for example the "Single Sites Program" initiated by the WDNR and assisted by USGS. However, according to an observation made by a WDNR employee during a recent Fox-Wolf Basin Strategic Data Acquisition Task Force meeting, WDNR's current "Baseline Monitoring Program" is constrained by U.S. EPA guidelines for data collection in support of Clean Water Act Section 305(b) reports — guidelines that may not be conducive to monitoring to understand ecosystems, evaluate programs or enhance watershed resource management.

Fox-Wolf Basin 2000's own experience in the Pigeon River Watershed (Wolf sub-basin) provides an example. Data collected on the watershed and its impoundment were somewhat scattered among a variety of locations and program files. When brought together, the information was helpful in developing an understanding of the condition of the watershed and the history leading to those conditions. Two data points 20 years apart suggested an annual sedimentation rate in the impoundment near the outlet of the watershed. But because little assessment was done upstream of the impoundment in that time, interpretations of the problem ranged from blaming eroded stream banks to poor farmland management to a golf course upstream to shoreline erosion on the impoundment itself. While those arguments ensued, many citizens responded to additional monitoring efforts by calling for action in the place of monitoring. One recent action, at a cost of about $100,000, was a series of highly visible shoreline stabilization projects that will do little to address the upstream soil and nutrient inputs.

It should also be noted that the information that was derived from the limited data available in the Piegeon River Watershed paralleled some of the "gut" feelings of long-time users or managers of the resource. This suggests anecdotal data and information also needs to be recorded and made accessible. However, this gives rise to another limitation we have encountered – the "quality" of data. The state has a Self-Help Monitoring Program and a Water Action Volunteer Program that encourages citizens to collect basic data (water clarity, phosphorus concentrations and temperature, for example). Efforts to expand such activity have been met with staunch criticism because the data collected would not be reliable and could not meet the rigors of quality assurance and control. Indeed, the uncertainty of anecdotal or non-professionally gathered data have made it easy for those asked to change land use practices or behaviors to question whether they are really the problem.

Another limitation has to do with the measurement of the efficacy of nonpoint source best management practices (BMPs) on a broader (subwatershed or catchment) scale. Much of the research available on BMPs was done in very narrowly defined contexts, which creates a lot of uncertainty when applying pollution reduction efficacy on a broader scale. Little, if any, of the studies look at long term efficiency – how well a practice performs after several years or what kind of maintenance needs and costs can be expected. In addition, literature reviews generally provide a broad range of efficacy estimates. For example, nutrient and sediment reduction rates of 5-90 percent were reported in studies assessing the effectiveness of vegetative filter strips (or buffers). Paired watershed study-designs have been proposed (and implemented in some areas) to address this deficiency. However, they are longer term, a bit unwieldy in garnering adequate participation and quite costly to conduct.

Several observations have been made in the past that there is plenty of data, but little information. The current movement in the Fox-Wolf basin to develop a coordinated monitoring framework is indicative of the inadequate quantity of data, quality of analysis and availability of information necessary to improve watershed management activity.

14. Door County

Background

The study area, Door County, is located in northeast Wisconsin and lies entirely on the Door Peninsula in the Door-Kewaunee watershed. The peninsula is bordered by Lake Michigan on one side and Green Bay on the other. The geology of the peninsula is comprised primarily of dominantly Silurian-aged dolomite. This fractured, calcareous bedrock is easily modified by the dissolution of the bedrock into karst features. These karst features, combined with the relatively thin soil layer found through much of the peninsula, create a high potential for groundwater and surface water contamination.

Status of Watershed Management Efforts in the Study Area

The nature of the geology has been a concern for soil and water conservationists. In particular, these concerns have in large part been at the heart of many of the initiatives and projects of the county's Soil and Water Conservation Department (SWCD). Additionally, the Wisconsin Department of Natural Resources developed a *Water Quality Management Plan* in March of 1995 serving as a guide to water resource activities with a focus on the Door-Kewaunee watershed. Initiatives of the SWCD and the WDNR remain in place as part of a comprehensive watershed management program. These have been the more visible efforts at resource management on the peninsula.

Pollutants of Concern

Aquatic Monitoring
Monitoring coverage for LaMP pollutants reported into the STORET system is shown in Figure 46. As should be obvious from the map, there appears to be no monitoring of LaMP pollutants on the penninsula. In total, there are only 57 water quality monitoring stations in the entire peninsular watershed.

Pollutant Release Monitoring
An examination of Permit Compliance System and Toxic Release Inventory reporting locations in Door County indicates only a few monitoring locations for potential pollution sources throughout the county (see Figure 47). There are now distinct clusters of these locations.

Nutrients and Bacteria

As mentioned previously, there are 57 water quality monitoring stations within the Door-Kewaunee watershed listed in the STORET system. Several others can be found around the peninsula in Green Bay and Lake Michigan. A vast majority of these stations (shown in Figure 46) monitor for some form of nitrogen and phosphorus, the chief nutrients impacting water quality. Thus, where monitoring stations exist, they are likely tracking nitrogen and phosphorus. The stations are distributed fairly evenly across the peninsula. These stations are maintained by WDNR, U.S. EPA, and USGS-WRD. According to our surveys, the Village of Ephraim WWTP monitors phosphorus inputs into Green Bay. The Fish Creek Watershed Study Committee may also be conducting some nutrient tracking along Fish Creek. Additionally, the Door County Sanitation Department monitors ground water for unspecified contamination.

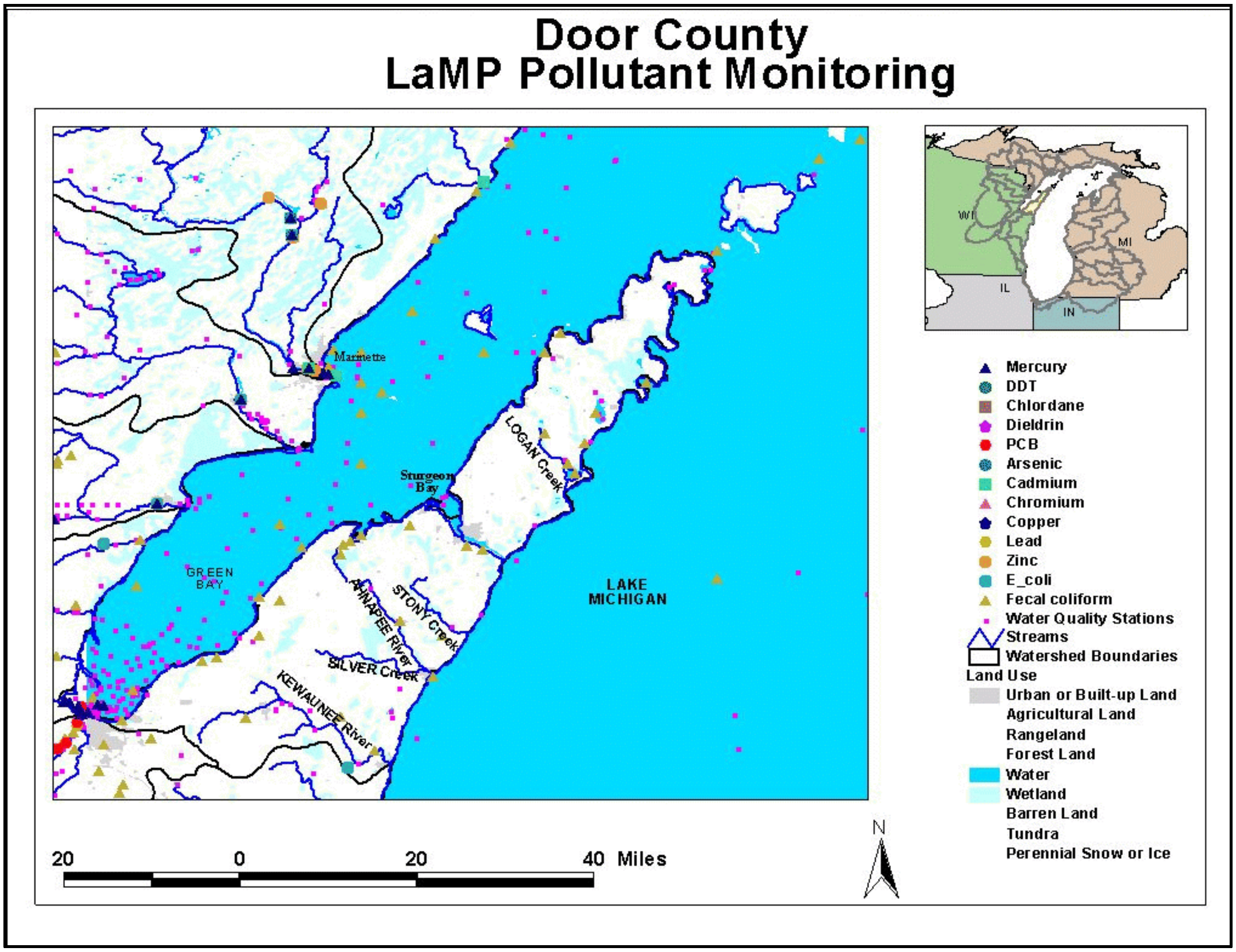

Figure 46. The Door-Kewaunee watershed with ambient water quality and bacteria monitoring stations from U.S. EPA's STORET system displayed by indicators measured.

One station monitors *E. coli* in the watershed on the Kewanee River. The station is maintained by WDNR. Monitoring for fecal coliform is significantly more extensive. About 29 stations can be found throughout the watershed. Most of the stations are located along the shoreline, but there are a number of stations distributed throughout the rest of the peninsula. WDNR maintains all the fecal coliform monitoring stations in the watershed.

Meteorological and Flow Monitoring

USGS maintains five gage stations throughout the Door-Kewaunee watershed to measure flow rates and various other physical characteristics of streams (see Figure 48). All gage stations are located on the Lake Michigan side of the watershed. In addition, the Village of Ephraim WWTP monitors suspended solids near their output into Green Bay.

One NOAA weather station is located on the peninsula. The station is located in Kewaunee at the southeastern corner of the watershed. NOAA stations measure continuous precipitation data, as well as other meteorological data.

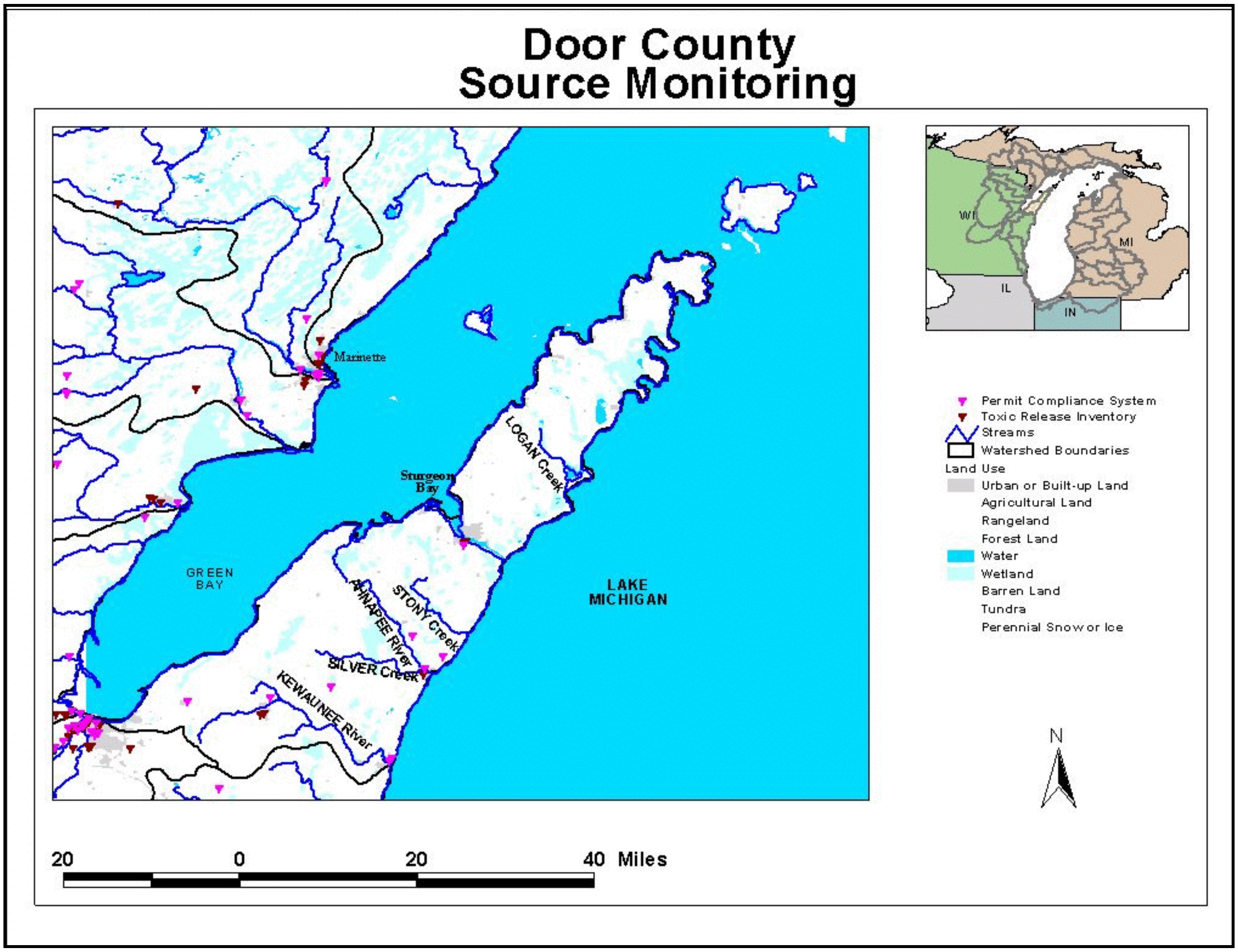

Figure 47. Door-Kewaunee watershed with pollutant sources from the Permit Compliance System and Toxic Release Inventory databases indicated.

Sediments

There are 20 National Sediment Inventory sites within the watershed (see Figure 48). A cluster of sites are located in Sturgeon Bay and the rest are distributed along the shoreline around the peninsula. These sites are all administered by the WDNR. About half of the sites monitor sediment chemistry to assess human health and aquatic life impacts. A total of 11 sites monitor benthic organism tissue, discussed below.

Fish Contaminants, Fish Health, and Aquatic Nuisance Species

As discussed earlier, we have been unable to find specific locational information (such as sampling locations) for programs monitoring fish populations or their health. There are statewide programs in existence, but these are discussed in the overall findings discussion. The National Sediment Inventory lists 11 stations that monitor fish tissue for bottom contamination. These are located throughout the basin, and are administered by the WDNR.

A search of the Fish and Wildlife Advisory database on all major Door County waterbodies revealed fish consumption advisories for two locations in the basin. Advisories had been issued for the Kewaunee River,

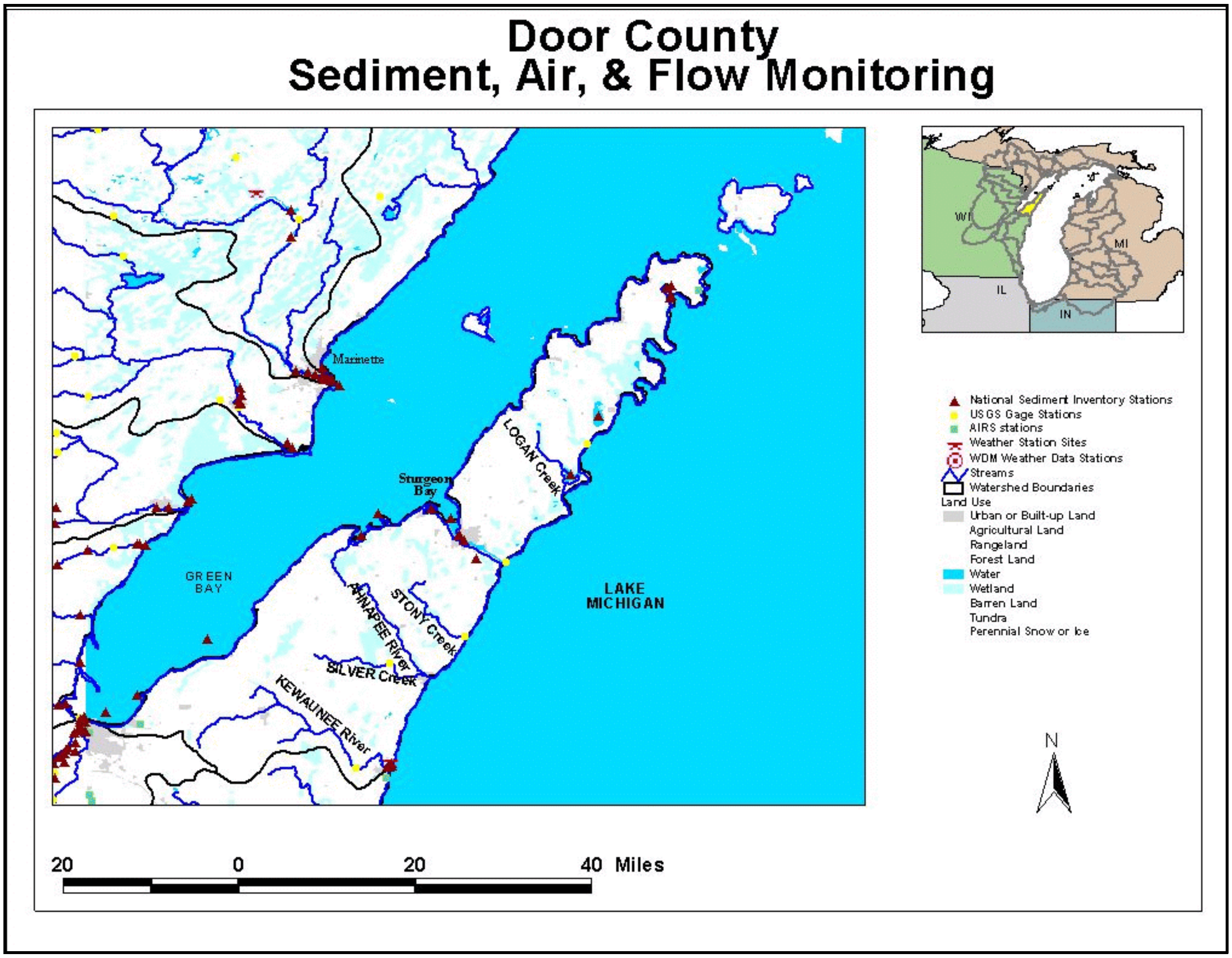

Figure 48. Door-Kewaunee watershed with National Sediment Inventory stations, USGS gage stations, U.S. EPA's Aerometric Information Retrieval System (AIRS) stations, and NOAA weather stations indicated.

and the Ahnapee River. The advisories were all state issued, covered a variety of fish species and related to PCB levels.

No programs were discovered to be monitoring for aquatic nuisance species within the watershed. Refer to the overall discussion of Lake Michigan monitoring for a discussion about programs that cover multiple tributary watersheds.

Benthos Monitoring

No specific locational information was discovered for state or national programs monitoring benthic organisms. Several organizations may be monitoring benthic organisms generally in the watershed, among others. These are discussed in the overall discussion of Lake Michigan monitoring.

Air Monitoring

Figure 48 illustrates the locations of the two air monitoring stations on the peninsula, according to the U.S. EPA's AIRS database. One station is paced at the far western border of the watershed, while the other is on the easternmost tip of the peninsula. Both stations monitor low-level ozone.

Wildlife Monitoring

One private citizen reports to be monitoring wildlife abundance at an unspecified site on the peninsula. There are other organizations monitoring wildlife species generally throughout the Lake Michigan basin. These are discussed in the overall discussion of Lake Michigan monitoring.

Land Use

Many large wetland areas exist across the peninsula. The Lower Fox watershed consists of a large portion of urbanized land with relatively few wetlands. The wetlands are not extensively monitored by water quality stations. The only urbanized development in the watershed is Sturgeon Bay. Most of the watershed consists of agricultural and forest lands.

Local Assessment

Three of the seven area watersheds are designated as Priority Watershed Projects and continue to receive attention through multiple state and local programs designed to reduce water pollution. These programs include nutrient and pest management, soil erosion, and pollution abatement cost-share programs. Door County recently prepared a *Land and Water Resource Management Plan* setting goals and objectives in moving toward improved management of the landscape and protection of water and other natural resources in the county.

The *Water Quality Management Plan* developed for the Door-Kewaunee Basin (1995) identified a number of problem areas and offered a number of recommendations, many of which are in process of implementation. However, a comprehensive area-wide monitoring initiative involving broad collaboration between volunteer organizations and local and state agencies may prove to be a possibility in light of the increasing pressures of development.

Duplication of monitoring efforts does not appear to be an issue, but rather the issue is one of a consistent set of monitoring programs directed toward lakes and streams.

There are several particular areas where attention could be beneficial:

- Improvement in data collection from water quality sampling and well drilling operations, wherein data could be assembled in a form that would allow for qualitative and quantitative analysis on a county-wide basis.

- Creation of additional lake associations, whose members and volunteers could institute regular water monitoring programs. Preliminary work is in process to organize additional lake associations and energize the two that exist to help develop monitoring programs similar to others throughout the state. The Wisconsin Association of Lakes is the reference source for this work.

- The most significant of emerging issues focus on growth and development and the implication toward development pressure from the planned expansion of Highway 42-57. This highway runs from Green Bay to Sturgeon Bay, and is planned for expansion from the current two lane road to a four lane divided highway.

- Collaborative partnerships such as the Door County Stewardship Council offer opportunities to enhance coordination of long-term monitoring programs.

- The Stewardship Council is working to develop coherent strategies that leverage the resources of all local and state agencies and some federal agencies. While we are moving toward cooperative relationships with various organizations, including local governments, a number of people foresee opportunities for coordinated programs that will leverage current standard or routine programs. One missing piece is for the council activities to bridge connections to neighborhood and Lake Associations that would generate an increased interest in watershed protection issues.

19. Findings and Recommendations

The final section of this report centers on general issues that were uncovered throughout the course of research. There are three key areas under which the monitoring inventory provided valuable information and recommendations for improving overall monitoring in the Lake Michigan basin. These include data gaps and unmet needs; underutilized resources; and monitoring coordination and information sharing. Findings are summarized below for these areas, followed by recommendations for improving monitoring infrastructure and use. For reference purposes, sections are labeled with letters and findings and recommendations are numbered.

A. Data Gaps and Unmet Needs

This report, and the inventory on which it is based, represent the first effort to account for the range of environmental monitoring in the Lake Michigan basin. The inventory represents the initial approach toward achieving this ambitious goal. It is a framework on which a more complete inventory will eventually be built.

(1) Finding: There are several gaps in the inventory that are listed below and throughout the report. While some of these gaps are areas that have not been well covered in the inventory, others may represent gaps in the monitoring coverage. At this point, it is difficult to tell which are gaps in the monitoring inventory and which are actual monitoring gaps. Further improvement of the inventory database is needed to better clarify this distinction.

(1.1) Recommendation: *Continue to update the inventory and expand data collection to include all tributaries.* Fourteen tributaries were covered extensively in this project. The update should carry out the same research process with the other tributary watersheds in the basin.

(2) Finding: There are several key monitoring areas where little information was received, but where more monitoring is believed to exist. These areas include monitoring for *E. coli*, fish population characteristics, aquatic nuisance species, benthic organisms, wildlife, and habitat. We received some information about *E. coli* monitoring from county health departments and other local agencies, but believe more local agencies conduct such monitoring. For the other areas, we have some evidence to believe that state Departments of Natural Resources and federal agencies such as the U.S. Fish and Wildlife Service, U.S. Forest Service, and U.S. Department of Agriculture conduct monitoring programs in these areas. We received limited information about efforts made in specific watersheds by these agencies, but most of this information came from indirect sources. It is important that these agencies supply more complete information on their monitoring efforts to improve the overall completeness inventory.

(2.1) Recommendation: *Establish better lines of communication with state DNRs, USFWS, USFS, and USDA.* Further work needs to be carried out in order to obtain information from these agencies on their monitoring programs. This will fill in some of the major gaps in the inventory database.

(2.2) Recommendation: *Better integrate habitat and wildlife monitoring with traditional water quality monitoring.* One of the most difficult tasks needed to complete the monitoring inventory was to convince natural resource agencies that wildlife and habitat monitoring should be included in the inventory along with more traditional water quality monitoring. Agencies conducting monitoring in these areas must develop a better understanding of how all monitoring information can fit together so that policy makers, residents, and other stakeholders have access to a complete database of environmental monitoring information.

(3) Finding: Another result of this initial approach to the monitoring inventory for the Lake Michigan basin was that much of the information included only general information about the geographic location of monitoring sites. Many organizations reported monitoring for parameters across a broad geographic area but did not include specific site references. Locational information is critical if the inventory is to be brought online in a geographically-searchable format.

(3.1) Recommendation: *Improve information on the geographic location of monitoring sites.* This is especially true for monitoring programs at the local level. This will require extensive follow-up communication with those who originally reported into the inventory database.

(4) Finding: A further gap in the monitoring information obtained for this report, was the lack of complete and continuing coverage of Lake Michigan Mass Balance data. The Mass Balance project was a first of its kind sampling event designed to collect data across several variables in a coordinated fashion. The information produced by a project of this magnitude is valuable throughout the monitoring community. However, a project as large and complex as the Mass Balance project requires substantial time to collect, verify, validate, integrate, analyze, and report on the data. At the time the research for this report was conducted, most of the data from the Mass Balance project was not readily available for public consumption. Therefore, information contained in this report on sampling within the Lake Michigan Mass Balance project is incomplete and limited mostly to sampling location and general sampling focus. The data collected for the project has been quality assured, and, when released, will be more detailed. When these results are released, they will be added to the online version of the inventory database. Additionally, the value of coordinated sampling data (as collected in the Mass Balance project) would be greatly enhanced by a repeat of the sampling event ten years following completion of the original sampling.

(4.1) Recommendation: *Initiate planning for a coordinated sampling event for ten years following the initial Mass Balance project, and share data and modeling results with the public in a timely fashion through numerous outlets.*

(5) Finding: This initial project specifically avoided attempting to collect information about university monitoring projects. There were two reasons for this. First, much academic research is conducted in one-time, short-term projects, and therefore does not meet the need for baseline information and ongoing monitoring. Second, universities are complex environments with numerous independent research projects being conducted across each campus. However, some academic institutions conduct a number of important ongoing, long-term projects, and information on these projects should be included in the inventory. Sea Grant programs and other institutes catalog the university work they fund. Closer ties need to be established with these programs and such efforts need to be expanded throughout the basin.

(5.1) Recommendation: *Include academic research and data collection efforts in future updates to the monitoring inventory.*

(6) Finding: While a number of LaMP pollutants, such as mercury and copper, are monitored extensively across the basin, it has been difficult to find monitoring information on some of the other pollutants. These under-monitored pollutants include all the emerging LaMP pollutants, along with DDT, HCBs, toxaphene, and PAHs. The need for monitoring of these pollutants should be clarified.

(6.1) Recommendation: *Further examine the monitoring coverage of specific LaMP critical pollutants and emerging pollutants.*

B. Underutilized Resources

Along with the gaps in monitoring coverage identified in this project, some resources in the basin were also discovered that do not appear to be fully utilized. Monitoring is an area of environmental management that has often been underfunded in the past. Therefore, in order to achieve the most complete monitoring coverage possible, one must take advantage of all available resources. If resources, such as monitoring personnel, go unutilized, then some aspects of a complete monitoring coverage must be sacrificed. To avoid such a sacrifice, creative methods must be used to combine these underutilized resources with other monitoring programs.

(1) Finding: One of these underutilized resources is volunteer groups. These groups represent a vast pool of potential data collection personnel. Most of the volunteer groups currently engage in some form of monitoring, but often their efforts are not incorporated into state or regional monitoring plans, and the information collected is only reported internally or locally. These volunteers need to be better enabled to contribute to regional monitoring efforts. The challenge lies in preparing volunteers to collect environmental information in such a way that it is both accurate and relevant to regional needs, and of sufficient quality to be useful for resource managers and policy makers.

(1.1) Recommendation: *Take better advantage of relatively untapped volunteer monitoring resources.*

(2) Finding: Another group that is underutilized is local agencies. Examples of such agencies are health departments, conservation districts, and planning agencies. In many cases, these agencies are already engaged in monitoring to serve their local needs. Most of the agencies employ professionals trained to accurately monitor environmental parameters. These groups were discovered sporadically in the process of constructing the monitoring inventory. Several health departments reported monitoring of surface and ground waters for *E. coli*, coliform, and other contaminants of special interest to public health officials. Conservation districts may individually be monitoring for a number of parameters related to nonpoint source pollution, general water quality, or other issues. Planning agencies or commissions track population, mass transportation status and other land use characteristics for planning and funding purposes. It is likely that other similar agencies are also conducting monitoring programs. Information on these programs needs to be incorporated into the inventory. Also, there is an opportunity to link these agencies into basinwide monitoring efforts.

(2.1) Recommendation: *Take better advantage of local agencies such as health departments, conservation districts and planning agencies.*

(3) Finding: To best capitalize on these underutilized resources, it is important that these local groups (both volunteer groups and local agencies) be linked into basinwide efforts, but at the same time retain their local focus and discretion. Much of the energy that maintains these groups arises from a focus on local problems. While this is important, the value of their data to the larger basin is often overlooked. Linkages need to be made between local groups throughout the basin. However, such a basinwide focus needs to incorporate local data collectors in a way that is locally-driven.

(3.1) Recommendation: *Establish a better framework for bottom-up monitoring program linkages.*

(4) Finding: Part of the difficulty in using data collected at the local level is that there are few standards at the basinwide level to knit the data together. The local focus of the data collection effort often will leave the data incompatible with other data from neighboring localities. In order to use locally-driven data, the aspects of the collection and reporting processes need to be standardized across the basin. This standardization will make local monitoring results more widely usable and allow for aggregation and analysis across the basin as a whole.

(4.1) Recommendation: *Standardize data collection and reporting*.

C. Monitoring Coordination and Information Sharing

The final issue area does not involve direct monitoring, but responds to the need to coordinate monitoring efforts. As should be obvious from this report, there are a wide array of organizations involved in monitoring at the federal, state and local levels. However, no single organization is responsible for planning, coordinating, or disseminating monitoring efforts for the entire Lake Michigan basin. In the absence of a single organization, a council of organizations has formed to take on this task — the Lake Michigan Monitoring Coordination Council. The council's task — to coordinate monitoring efforts for basinwide goals — is a difficult one. However, several steps could be taken to improve the prospects of this coordination.

(1) Finding: A major coordination problem is the lack of a central source for monitoring information. The inventory that this report evaluates is the first step toward creating such a central source. However, this one-time inventory is currently not universally accessible and may quickly become dated if the database is not continually updated by monitoring organizations in the basin. Therefore, these monitoring organizations need to be encouraged to report on their monitoring projects continually into a universally-accessible database. This database should contain proper metadata about the monitoring program and the data that is reported. Eventually, this database should directly link to monitoring data, wherever possible. The database should be developed for the Internet and allow for the metadata to be searched geographically and by metadata content.

(1.1) Recommendation: *Encourage state, federal, tribal, and local agencies to report monitoring coverage and results to a meta-database with universal access.*

(1.2) Recommendation: *Develop an online database of monitoring information that is geographically-based, and content-searchable.*

(2) Finding: Beyond creating and reporting to a shared database of monitoring program information, it would be most effective to link monitoring programs into a coordinated network. As it is, organizations make most, if not all, decisions about their monitoring programs based on goals for their local coverage area. Rarely does this area cover the entire Lake Michigan basin. Without a coordinated network, basinwide goals may go unmet. Several actions must be taken to make sure this network can successfully address basinwide goals. First, the network must contain all the necessary components for complete coverage. This means that common indicators need to be agreed upon for the basin, and all organizations monitoring for indicator data need to be included in the network. State of the Lake Ecosystem Conference (SOLEC) and LaMP indicators have already been established and should be adapted or condensed for use in the network. After this, a set of standard methods should be established for monitoring the agreed upon indicators within the basin. Standard methods will ensure that data is comparable and able to be combined for analysis across the basin.

(2.1) Recommendation: *Develop and coordinate the implementation of comparable methods to collect indicator data in a coordinated network.*

Appendix A.

Acronyms and Glossary

AOC	Area of Concern
AIRS	U.S. EPA's Aerometric Information Retrieval System
BMP	Best Management Practice
BSFWD	Bureau of Sport Fisheries and Wildlife Data
CLMP	Cooperative Lakes Management Program
COE	U.S. Army Corps of Engineers
EPRI	Electric Power Research Institute
GLC	Great Lakes Commission
GLFC	Great Lakes Fishery Commission
GLNPO	Great Lakes National Program Office
GLERL	Great Lakes Environmental Research Laboratory
IDEM	Indiana Department of Environmental Management
IEPA	Illinois Environmental Protection Agency
IJC	International Joint Commission
LMMCC	Lake Michigan Monitoring Coordination Council
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
MMSD	Milwaukee Metropolitan Sewage District
MSD	Metropolitan Sanitary District or Metropolitan Sewage District
NCDC	National Climatic Data Center
NIPC	Northeast Illinois Planning Commission
RAP	Remedial Action Plan
SLIC	Sea Lamprey Integration Committee
TMDL	Total Maximum Daily Load
U.S. EPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service

USGS-WRD	U.S. Geological Survey – Water Resources Division
WAV	Water Action Volunteers
WDNR	Wisconsin Department of Natural Resources
WWTP	Waste-water treatment plant

Appendix B.

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Illinois

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Wisconsin

Milwaukee Estuary
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Appendix C.

Lake Michigan Monitoring Inventory Form

Following is the form that was distributed to organizations thought to be possibly conducting monitoring programs. The form was slightly tailored for use in local areas. A web-based form was also developed to enhance return rates. This form can currently be found at: http://www.glc.org/projects/lamps/monitor.html.

Lake Michigan Monitoring Inventory Form

The following form is intended to provide us with an inventory of federal and state agency monitoring programs in the Lake Michigan Basin. Please complete this form to the best of your ability, indicating the monitoring efforts that your agency currently undertakes, and return it to us as soon as possible. If you conduct more than one monitoring effort, please copy and complete a separate form for each program. This should take less than 20 minutes to complete.

General Information

The questions below will provide us with important background on your organization and monitoring efforts and may eventually result in greater use of your monitoring results.

1) Please provide your primary contact information.

Name: ____________________

Organization: ____________________

Address: ____________________

City: ____________________ State: _____ Zip Code: __________

Phone: ____________________ Fax: ____________________

E-mail: ____________________ Website: ____________________

Watersheds covered: ____________________

____

2) Who is the manager for the monitoring program?

____

3) Briefly describe the overall purpose or goal of the monitoring/information collection effort.

____

____

4) Approximately, when did the monitoring program begin? (month / year) _____/_____

Monitoring Information

The following questions ask about specific details of your monitoring program. They will help us understand what is being done in your area to monitor the health of the ecosystem.

5) As specifically as possible, please describe the boundary of the location or geographic scope of your monitoring effort (e.g., named or numbered river reach, watershed, county or township boundary, latitude/longitude). Please include as much descriptive information as possible.

____

____

6) Medium being monitored:

❑ Water ❑ Land ❑ Air ❑ Soil ❑ Biota/Wildlife ❑ Other (specify: __________)

7) Please select the category that best fits the type of information being collected.

- ❑ Chemical (e.g. pH, BOD, mercury, phosphorus, PCBs)
- ❑ Microbiological (e.g. bacteria or other microbial organisms)
- ❑ Fish or aquatic invertebrates
- ❑ Other wildlife (e.g. turtles, beavers, deer, etc)
- ❑ Physical characteristics (e.g. hydrology, habitat, geology, soil, vegetation, forests, wetlands)
- ❑ Land uses (e.g. urbanized, agricultural, residential, industrial, brownfields sites)
- ❑ Other (specify: ____________________ ____________________)

8) Do you collect data on any of the following? ❑ PCBs ❑ Dieldrin ❑ Chlordane

❑ DDT ❑ Lead ❑ Zinc ❑ Cyanide ❑ PAHs ❑ None of the above

❑ Mercury ❑ Cadmium ❑ Chromium ❑ Hexachlorobenzene ❑ Atrazine

❑ Dioxins/Furans ❑ Copper ❑ Arsenic ❑ Toxaphene ❑ Selenium

9) Please give a specific description of any other information being collected (i.e. list specific indicators measured).

____

____

10) How often is the information collected?

❑ Daily ❑ Weekly ❑ Monthly ❑ Semiannually ❑ Annually ❑ Other (specify: __________)

Program Information

We need some final information about your monitoring program so that we can assess the extent and needs for monitoring funding and training.

11) **Please list the name or type of any standardized methodology used (e.g. EPA guidelines, standard methods texts, or kit procedures).**

____

12) **Please list any standardized quality assurance or quality control procedures that are followed.**

____

____

13) **Select the classification that best describes the individuals who collect monitoring data.**

❑ Paid staff ❑ Volunteers ❑ Students ❑ Other (specify: __________________)

14) **How many staff or volunteers participate in the monitoring project, on average?** __________

15) **Was training provided to data gatherers?** ❑ Yes ❑ No

16) **If yes, who provided the training?** ________________________

17) **Where is the monitoring data reported and stored (e.g., which office or agency)?**

____

18) **Which format is used to store the data (i.e., which electronic format or software is used, or is it stored in a hard copy format)?**

____

19) **Is the data stored indefinitely?** ❑ Yes ❑ No

20) **If no, how long is the information stored?** ________________________

21) **How is the monitoring data ultimately used (e.g. in Remedial Action Plans, educational materials, research, watershed planning, regulatory compliance)?**

____

____

22) **(Optional) Please list the approximate annual budget for the monitoring effort.** $__________.00

23) **Is this funding ongoing and reliable?** ❑ Yes ❑ No

24) **Please list any other parameters that you would like to monitor or other areas that you feel need additional monitoring in your region.**

____

____

25) **Please provide us with any other relevant information that you think would give us a more complete understanding of your monitoring efforts. Feel free to append any additional documentation that you think would be helpful.**

____

____

____

Thank you for your assistance.
Your input will help us better determine the scope and need for monitoring efforts in the Lake Michigan basin.

When completed, please return this form by mail or fax, to:

Ric Lawson
Great Lakes Commission
400 Fourth Street
Ann Arbor, MI 48103
Fax: (734) 665-4370

Attachment 3

Cost Estimate for Long-term Monitoring

Table C.1 - MNR Costs for Sampling (One Event/ 5 Yrs) - Long-Term Monitoring Plan Lower Fox River/Green Bay

Task 100 – Surface Water Sampling (30 days, 4 people)
Task 200 – Surface Sediment Sampling (2 weeks, 4 people)
Task 300 – Fish and Invertebrate Tissue Sampling (8 weeks,3 people – J.Amrhein) (also for Institutional Controls)
Task 400 – Mallard duck, Bald Eagle and Cormorant Bird Tissue Sampling (4 weeks, 4 people)
Task 500 – Mink Habitat Chacterization (one month, 2 people)
Task 600 – Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Task 600	Hours	Rate	Cost
Director E12	10	10	10	10	10	20	70	$125	$8,750
Sr.Tech Manager E11	50	50	50	50	50	20	270	$110	$29,700
Tech Manager E10	50	50	50	50	50	80	330	$98	$32,340
Project E8	350	120	350	180	180	80	1260	$75	$94,500
Senior Staff E7	350	120	350	180	180	300	1480	$62	$91,760
Staff Scientist E6	350	120	350	180	180	300	1480	$52	$76,960
Scientist1 E5	350	120	350	180	180	120	1300	$45	$58,500
P.A./Technician E4	150	50	160	80	80	80	600	$50	$30,000
Drafter E2	150	50	160	80	80	150	670	$38	$25,460
Word Processing E1	150	50	160	80	80	150	670	$40	$26,800
Labor Subtotal	$112,750	$46,130	$114,030	$64,010	$64,010	$73,840	Labor Subtotal:		$474,770
DIRECT COSTS									
Travel/per diem	$5,000	$5,000	$5,000	$5,000	$5,000	$0			$25,000
Supplies/Phone/Repro	$7,000	$7,000	$7,000	$7,000	$20,000	$30,000			$78,000
Equipment	$10,000	$10,000	$10,000	$10,000	$10,000	$10,000			$60,000
Sampling vessel	$30,000	$20,000	$30,000	$30,000	$10,000	$0			$120,000
Other	$5,000	$5,000	$5,000	$5,000	$5,000	$30,000			$55,000
Location control	$2,000	$2,000	$2,000	$2,000	$2,000	$0			$10,000
Direct Costs Subtotal	$59,000	$49,000	$59,000	$59,000	$52,000	$70,000	Direct Subtotal:		$348,000
							(add 8% to subs):		$0
Task Total	$171,750	$95,130	$173,030	$123,010	$116,010		Total:		$822,770

ANALYTICAL COSTS	No. of samples						Sum	Unit Cost	Total
PCB congeners	260	100	900	460	0		1720	$900	$1,548,000
mercury	260	100	900	460	0		1720	$200	$344,000
%lipids	0	0	450	230	0		680	$50	$34,000
TOC	260	100	0	0	0		360	$30	$10,800
Grain Size	0	100	0	0	0		100	$150	$15,000
DDE	0	0	550	440	0		990	$150	$148,500
Conventionals	260	100	0	0	0		360	$100	$36,000
Analytical Subtotal	$319,800	$138,000	$1,095,000	$583,500	$0				$2,136,300
Task Total (for 5 years)	$491,550	$233,130	$1,268,030	$706,510	$116,010		**5 YR TOTAL:**		**$2,959,070**
							Cost per year:		**$591,814**

Notes:

1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels

2) Assume 320 duck samples, 120 DCC samples, and 20 eagle samples

3) Conduct this sampling event once every five years

4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.2 - Estimated Costs for CDF or CAD Sampling (Per Year) - Lower Fox River/Green Bay

Task 100 – CDF Groundwater Monitoring (3 events/year, 6 wells/ CDF, 6 CDF, 3 people – 108 days at 10hr/day)
Task 200 – CDF Surface Water Sampling (2 events/year, 1 station/CDF, 6 CDF, 2 people)
Task 300 – CDF Surface Sediment Sampling (1 event/year, 5 to 10 stations/CDF, 4 people)
Task 400 – CDF Seep Sampling (same as above)
Task 500 – Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	5	5	5	5	5	25	$125	$3,125
Sr.Tech Manager E11	10	10	10	10	10	50	$110	$5,500
Tech Manager E10	20	20	20	20	20	100	$98	$9,800
Project E8	1080	80	80	80	70	1390	$75	$104,250
Senior Staff E7	1080	80	80	80	70	1390	$62	$86,180
Staff Scientist E6	1080	30	80	80	120	1390	$52	$72,280
Scientist1 E5	100	30	80	80	120	410	$45	$18,450
P.A./Technician E4	80	5	5	5	40	135	$50	$6,750
Drafter E2	80	5	5	5	40	135	$38	$5,130
Word Processing E1	80	5	5	5	40	135	$40	$5,400
Labor Subtotal	$222,545	$18,195	$23,045	$23,045	$30,035		Labor Subtotal:	$316,865
DIRECT COSTS								
Travel/per diem	$5,000	$1,000	$1,000	$1,000	$0			$8,000
Supplies/Phone/Repro	$2,000	$2,000	$2,000	$2,000	$5,000			$13,000
Equipment	$5,000	$5,000	$5,000	$5,000	$10,000			$30,000
Sampling vessel	$5,000	$10,000	$10,000	$10,000	$0			$35,000
Other	$5,000	$5,000	$5,000	$5,000	$5,000			$25,000
Location control	$1,000	$1,000	$1,000	$1,000	$0			$4,000
Direct Costs Subtotal	$23,000	$24,000	$24,000	$24,000	$20,000		Direct Subtotal:	$115,000
							(add 8% to subs):	$0
Task Total	$245,545	$42,195	$47,045	$47,045	$50,035		Total:	$431,865
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	110	15	15	10	6	156	$900	$140,400
mercury	110	15	15	10	6	156	$200	$31,200
% lipids	0	0	0	0	0	0	$50	$0
TOC	110	15	15	10	6	156	$30	$4,680
Grain Size	0	0	15	0	6	21	$150	$3,150
DDE	110	15	15	10	6	156	$150	$23,400
Conventionals	110	15	15	10	6	156	$100	$15,600
Analytical Subtotal	$151,800	$20,700	$22,950	$13,800	$9,180			$218,430
Task Total (for 5 years)	$397,345	$62,895	$69,995	$60,845	$59,215		**TOTAL:**	**$650,295**
							Cost per year:	**$650,295**

Notes:
1) All values are ballpark estimates
2) Costs do not include monitoring well installations
3) Conduct this sampling event every year for the first 5 years, but frequency may diminish over the years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.3 - Estimated Costs for *In Situ* Cap Sampling (Per Year) - Lower Fox River/Green Bay

Task 100 – Visual Assessments (bathymetry, camera surveys) (1 event/year, 2 people, 1 week)
Task 200 – Surface Water Sampling (2 event/year, 1 station/cap, 2 people)
Task 300 – Surface Sediment and PoreWater Sampling (1 event/year, 5 to 10 stations/cap, 4 people)
Task 400 – Sediment Cores through CAP (1 event/year, 5 to 10 stations/cap, 4 people)
Task 500 – Data Analysis

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost	
Director E12	5	5	5	5	5	25	$125	$3,125	
Sr.Tech Manager E11	10	10	10	10	10	50	$110	$5,500	
Tech Manager E10	20	20	20	20	20	100	$98	$9,800	
Project E8	40	80	80	80	70	350	$75	$26,250	
Senior Staff E7	100	80	80	120	150	530	$62	$32,860	
Staff Scientist E6	100	30	80	120	150	480	$52	$24,960	
Scientist1 E5	20	30	80	120	120	370	$45	$16,650	
P.A./Technician E4	5	5	5	5	40	60	$50	$3,000	
Drafter E2	5	5	5	5	40	60	$38	$2,280	
Word Processing E1	5	5	5	5	40	60	$40	$2,400	
Labor Subtotal	$19,625	$18,195	$23,045	$29,405	$36,555		Labor Subtotal:	$126,825	
DIRECT COSTS									
Travel/per diem	$1,000	$1,000	$1,000	$1,000	$0			$4,000	
Supplies/Phone/Repro	$2,000	$2,000	$2,000	$2,000	$10,000			$18,000	
Equipment	$15,000	$5,000	$5,000	$5,000	$10,000			$40,000	
Sampling vessel	$10,000	$10,000	$10,000	$10,000	$0			$40,000	
Other	$5,000	$5,000	$5,000	$5,000	$10,000			$30,000	
Location control	$1,000	$1,000	$1,000	$1,000	$0			$4,000	
Direct Costs Subtotal	$34,000	$24,000	$24,000	$24,000	$30,000		Direct Subtotal:	$136,000	$136,000
							(add 8% to subs):	$0	
Task Total	$53,625	$42,195	$47,045	$53,405	$66,555		Total:	$262,825	$262,825
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total	
PCB congeners		6	45	50		101	$900	$90,900	
mercury		6	45	50		101	$200	$20,200	
% lipids		0	0	0		0	$50	$0	
TOC		6	45	50		101	$30	$3,030	
Grain Size		0	45	0		45	$150	$6,750	
DDE		6	45	50		101	$150	$15,150	
Conventionals		6	45	50		101	$100	$10,100	
Analytical Subtotal	$0	$8,280	$68,850	$69,000	$0			$146,130	$146,130
Task Total (for 5 years)	$53,625	$50,475	$115,895	$122,405	$66,555		**TOTAL:**	**$408,955**	$408,955
							Cost per year:	**$408,955**	

Notes:

1) All values are ballpark estimates

2) Costs do not include monitoring well installations

3) Conduct this sampling event every year for the first 5 years, but frequency may diminish over the years

4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.4 - Estimated Costs for Institutional Controls and No Action Alternatives (Per Year)

Maintain fish consumption advisories and deed restrictions (No Action and Institutional controls)

Task 100 - Deed restrictions
Task 200 - NA
Task 300 - Fish and Invertebrate Tissue Sampling (8 weeks,3 people - J.Amrhein) (also for Institutional Controls)
Task 400 - Data Analysis
Task 500 - NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	10		20	20		50	$125	$6,250
Sr.Tech Manager E11	10		60	50		120	$110	$13,200
Tech Manager E10	20		60	50		130	$98	$12,740
Senior Project E9						0	$87	$0
Project E8	100		400	200		700	$75	$52,500
Senior Staff E7	100		400	200		700	$62	$43,400
Staff Scientist E6	100		400	200		700	$52	$36,400
Scientist1 E5			400	200		600	$45	$27,000
P.A./Technician E4	20		200	200		420	$50	$21,000
Drafter E2	20		200	100		320	$38	$12,160
Word Processing E1	10		200	100		310	$40	$12,400
Labor Subtotal	$26,370	$0	$134,180	$77,500	$0	Labor Subtotal:		$238,050
DIRECT COSTS								
Travel/per diem	$0	$0	$5,000	$0	$0			$5,000
Supplies/Phone/Repro	$0	$0	$7,000	$0	$0			$7,000
Equipment	$20,000	$0	$10,000	$10,000	$0			$40,000
Sampling vessel	$0	$0	$20,000	$0	$0			$20,000
Other	$10,000	$0	$5,000	$20,000	$0			$35,000
Location control	$0	$0	$2,000	$0	$0			$2,000
Direct Costs Subtotal	$30,000	$0	$49,000	$30,000	$0	Direct Subtotal:		$109,000
						(add 8% to subs):		$0
Task Total	$56,370	$0	$183,180	$107,500	$0	Total:		$347,050

ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	0	0	900	0	0	900	$900	$810,000
mercury	0	0	900	0	0	900	$200	$180,000
%lipids	0	0	450	0	0	450	$50	$22,500
TOC	0	0	0	0	0	0	$30	$0
Grain Size	0	0	0	0	0	0	$150	$0
DDE	0	0	550	0	0	550	$150	$82,500
Conventionals	0	0	0	0	0	0	$100	$0
Analytical Subtotal	$0	$0	$1,095,000	$0	$0			$1,095,000
Task Total (for 5 years)	$56,370	$0	$1,278,180	$107,500	$0		**TOTAL:**	**$1,442,050**
							Cost per year:	**$288,410**

Notes:
1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels
3) Conduct this sampling event once every five years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.5 - Estimated Costs for No Action (Per Year)

Maintain fish consumption advisories and deed restrictions (No Action and Institutional controls)

Task 100 - Deed restrictions
Task 200 - NA
Task 300 - Fish and Invertebrate Tissue Sampling (8 weeks,3 people - J.Amrhein) (also for Institutional Controls)
Task 400 - Data Analysis
Task 500 - NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost
Director E12	10		20	20		50	$125	$6,250
Sr.Tech Manager E11	10		60	50		120	$110	$13,200
Tech Manager E10	20		60	50		130	$98	$12,740
Senior Project E9						0	$87	$0
Project E8	100		400	200		700	$75	$52,500
Senior Staff E7	100		400	200		700	$62	$43,400
Staff Scientist E6	100		400	200		700	$52	$36,400
Scientist1 E5			400	200		600	$45	$27,000
P.A./Technician E4	20		200	200		420	$50	$21,000
Drafter E2	20		200	100		320	$38	$12,160
Word Processing E1	10		200	100		310	$40	$12,400
Labor Subtotal	$26,370	$0	$134,180	$77,500	$0		Labor Subtotal:	$238,050

DIRECT COSTS	Task 100	Task 200	Task 300	Task 400	Task 500			Cost
Travel/per diem	$0	$0	$5,000	$0	$0			$5,000
Supplies/Phone/Repro	$0	$0	$7,000	$0	$0			$7,000
Equipment	$20,000	$0	$10,000	$10,000	$0			$40,000
Sampling vessel	$0	$0	$20,000	$0	$0			$20,000
Other	$10,000	$0	$5,000	$20,000	$0			$35,000
Location control	$0	$0	$2,000	$0	$0			$2,000
Direct Costs Subtotal	$30,000	$0	$49,000	$30,000	$0		Direct Subtotal:	$109,000
							(add 8% to subs):	$0
Task Total	$56,370	$0	$183,180	$107,500	$0		Total:	$347,050

ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total
PCB congeners	0	0	900	0	0	900	$900	$810,000
mercury	0	0	900	0	0	900	$200	$180,000
%lipids	0	0	450	0	0	450	$50	$22,500
TOC	0	0	0	0	0	0	$30	$0
Grain Size	0	0	0	0	0	0	$150	$0
DDE	0	0	550	0	0	550	$150	$82,500
Conventionals	0	0	0	0	0	0	$100	$0
Analytical Subtotal	$0	$0	$1,095,000	$0	$0			$1,095,000
Task Total (for 5 years)	$56,370	$0	$1,278,180	$107,500	$0		**TOTAL:**	**$1,442,050**
							Cost per year:	**$288,410**

Notes:
1) Assume 550 fish samples for human health,250 fish for environment, 100 mussels
3) Conduct this sampling event once every five years
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Table C.6 - Sampling Costs During Dredging Per Alternative (Assume 5 years duration)

Task 100 – Surface Water Sampling (30 days, 4 people)
Task 200 – Caged Tissue Sampling
Task 300 – Surface Sediment Sampling
Task 400 – Data Analysis
Task 500 – NA

LABOR/PERSONNEL (HOURS)	Task 100	Task 200	Task 300	Task 400	Task 500	Hours	Rate	Cost	
Director E12	5	5	5	5		20	$125	$2,500	
Sr.Tech Manager E11	50	50	50	50		200	$110	$22,000	
Tech Manager E10	50	50	50	50		200	$98	$19,600	
Senior Project E9				0		0	$87	$0	
Project E8	500	100	400	160		1160	$75	$87,000	
Senior Staff E7	500	100	400	160		1160	$62	$71,920	
Staff Scientist E6	500	100	400	160		1160	$52	$60,320	
Scientist1 E5	500	100	400	160		1160	$45	$52,200	
P.A./Technician E4	200	50	160	80		490	$50	$24,500	
Senior Drafter E3				0		0	$50	$0	
Drafter E2	200	50	160	80		490	$38	$18,620	
Word Processing E1	200	50	160	80		490	$40	$19,600	
Labor Subtotal	$153,625	$40,825	$125,105	$58,705	$0	Labor Subtotal:		$378,260	
DIRECT COSTS									
Travel/per diem	$10,000	$5,000	$10,000	$0	$0			$25,000	
Supplies/Phone/Repro	$10,000	$7,000	$10,000	$0	$0			$27,000	
Equipment	$40,000	$20,000	$40,000	$10,000	$0			$110,000	
Sampling vessel	$50,000	$20,000	$50,000	$10,000	$0			$130,000	
Other	$5,000	$5,000	$5,000	$5,000	$0			$20,000	
Location control	$2,000	$2,000	$2,000	$0	$0			$6,000	
Direct Costs Subtotal	$117,000	$59,000	$117,000	$25,000	$0	Direct Subtotal:		$318,000	$318,000
						(add 8% to subs):		$0	
Task Total	$270,625	$99,825	$242,105	$83,705	$0		Total:	$696,260	$696,260
ANALYTICAL COSTS	No. of samples					Sum	Unit Cost	Total	
PCB congeners	600	60	200	0	0	860	$900	$774,000	
mercury	600	60	200	0	0	860	$200	$172,000	
%lipids	0	60	0	0	0	60	$50	$3,000	
TOC	0	0	200	0	0	200	$30	$6,000	
Grain Size	0	0	200	0	0	200	$150	$30,000	
DDE	0	0	200	0	0	200	$150	$30,000	
Conventionals	600	0	200	0	0	800	$100	$80,000	
Analytical Subtotal	$720,000	$69,000	$306,000	$0	$0			$1,095,000	$1,095,000
Task Total	$990,625	$168,825	$548,105	$83,705	$0		**TOTAL:**	**$1,791,260**	$1,791,260
							Cost per year:	**$358,252**	

Notes:
4) PCB congener analysis cost estimate from Triangle Lab ($500) and J. Amhrein of WDNR ($900)

Appendix D

Summary of Capping Projects

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
Puget Sound							
Duwamish Waterway Seattle, Washington	Heavy metals, PCBs		1–3	Sand (4,000 cy)	1984	• No chemical migration • No erosion of cap	Monitoring as recent as 1996 showed cap remains effective and stable. Split-hull dump barge placed sand over relocated sediments (CAD site) in 70' water.
One Tree Island Olympia, Washington	Heavy metals, PAHs		4	Sand	1987	• No chemical migration • No erosion of cap	Last monitoring occurred in 1989 showed that sediment contaminants were contained.
St Paul Waterway Tacoma, Washington	Phenols, PAHs, dioxins		2–12	Coarse sand	1988	• No chemical migration • Cap within specifications	Some redistribution of cap materials has occurred, but overall remains >1.5 m (4.9'). C. californieus found in sediments, but never >1 m (3.3').
Pier 51 Ferry Terminal Seattle, Washington	Mercury, PAHs, PCBs		1.5	Coarse sand (4 acres) (*in situ*)	1989	• No chemical migration • Cap within specifications • Recolonization observed	As recent as 1994, cap thickness remained within design specifications. While benthic infauna have recolonized the cap, there is not indication of cap breach due to bioturbation.
Denny Way CSO Seattle, Washington	Heavy metals, PAHs, PCBs	Water depth 18 - 50 ft	2–3	Sand (3 acres)	1990	• No data available	Cores taken in 1994 show that while cap surface chemistry shows signs of recontamination, there is no migration of isolated chemicals through the cap.
Piers 53–55 CSO Seattle, Washington	Heavy metals, PAHs		1.3–2.6	Sand (4.5 acres) (*in situ*)	1992	• No chemical migration • Cap stable, and increased by 15 cm (6") of new deposition	Pre-cap infaunal communities were destroyed in the rapid burial associated with cap construction.
Pier 64 Seattle, Washington	Heavy metals, PAHs, phthalates, dibenzofuran		0.5–1.5	Sand	1994	• Some loss of cap thickness • Reduction in surface chemical concentrations	Thin-layer capping was used to enhance natural recovery and to reduce resuspension of contaminants during pile driving.
GP lagoon Bellingham, Washington (insitu)	Mercury	Shallow intertidal lagoon	3	Sand	2001	• No chemical migration at 3-months • Cap successfully placed	Ongoing monitoring
East Eagle Harbor/Wyckoff Bainbridge Island, Washington	Mercury, PAHs		1–3	Sand (275,000 cy)	1994	• No chemical migration • Cap erosion in ferry lanes • Some chemicals observed in cap	Cap erosion measured within first year of monitoring only in area proximal to heavily-used Washington ferry lane. Chemicals also observed in sediment traps. Ongoing monitoring.
West Eagle Harbor/Wyckoff Bainbridge Island, Washington (in situ)	Mercury, PAHs	500 acre site	Thin cap 0.5' over 6 acres and Thick cap 3' over 0.6 acres	Sand (22,600 tons for thin cap and 7,400 tons for thick cap)	Partial dredge and cap 1997	• No chemical migration	To date, post-verification surface sediment samples have met the cleanup criteria established for the project. Ongoing monitoring.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
California and Oregon							
PSWH Los Angeles, California	Heavy metals, PAHs		15	Sand	1995	• No data to date	Overall effective cap was >15'. This was not a function of design, but rather a function of the low contaminated-to-clean sediment volume.
Convair Lagoon San Diego, California	PCBs	5.7 acre cap in 10 acre site; water depth 10-18 ft	2' of sand over 1' rock	Sand over crushed rock	1998	• No chemical migration • Cap was successfully placed in very shallow water • Some chemicals observed in cap	Ongoing monitoring for 20 to 50 years including diver inspection, cap coring, biological monitoring
CAD Long Beach, California	Heavy metals, PAHs		5	Sand	planned, but not constructed	• No data to date	Design cap thickness was a function of deepest depth for prevention of bioturbation by thallassinid burrowing shrimp.
McCormick and Baxter Portland, Oregon	Heavy metals, PAHs	15 acres of nearshore sediments and soils	NA	Sand	planned, but not constructed	• No data to date	Long-term monitoring, OMMP, and institutional controls were also specified
Great Lakes							
Sheboygan Falls Wisconsin (pilot)	PCBs	9 hotspots totalling 1,200 sq yds	1 ft of coarse material and upper geotextile over lower geotextile	Composite	1992	• No monitoring data	Composite armored cap required as sediments were located in high-energy river environment. Gabions placed around the corners for anchoring. Additional course material placed into voids/gaps.
Sheboygan River/Harbor Wisconsin	PCBs		unknown	Armored stone composite	1989–1990	• Undetermined cap • effectiveness Some erosion of fine-grained	Demonstration bench-scale project.
Areas C and D Manistique, Michigan	PCBs		2.7	Composite	planned, but not implemented (site remediation was dredging)	• Project is unbuilt	Composite cap over a 17-acre site that includes armoring and geotextiles.
Manistique Capping Project Wisconsin	PCBs		40-mil (0.1')	HDPE	1993	• Physical inspection of the temporary cap approximately 1 year after installation showed cap was physically intact and most anchors still in place	A 240' by 100' HDPE temporary cap was anchored by 38 2 ton concrete blocks placed around the perimeter of the cap. This temporary cap was installed to prevent erosion of contaminated sediments within a river hotspot with elevated surface concentrations.
Hamilton Harbor Ontario, Canada	PAHs		1.6	Sand (2.5 acres) (*in situ*)	1995	• No monitoring data	Cap recently completed.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
New England/New York							
Stamford-New Haven-N New Haven, Connecticut	Metals, PAHs		1.6	Sand	1978	• No chemical migration	Cores collected in 1990.
Stamford-New Haven-S New Haven, Connecticut	Metals, PAHs		1.6	Silt	1978	• No chemical migration	Cores collected in 1990.
New York Mud Dump Disposal Site New York	Metals (from multiple harbor		unknown	Sand (12 million cy)	1980	• No chemical migration	Cores taken in 1993 (3.5 years later) showed cap integrity over relocated sediments in 80' of water.
Mill-Quinniapiac River Connecticut	Metals, PAHs		1.6	Silt	1981	• Required additional cap	Cores collected in 1991.
Norwalk, Connecticut	Metals, PAHs		1.6	Silt	1981	• No problems	Routine monitoring.
Central Long Island Sound Disposal Site (CLIS) New York	Multiple harbor sources		unknown	Sand	1979–1983	• Some cores uniform structure with low-level chemicals • Some cores no chemical migration • Some slumping	Extensive coring study at multiple mounds showed cap stable at many locations. Poor recolonization in many areas.
Cap Site 1 Connecticut	Metals, PAHs		1.6	Silt	1983	• No chemical migration	Cores collected in 1990.
Cap Site 2 Connecticut	Metals, PAHs		1.6	Sand	1983	• Required additional cap	Cores collected in 1990.
Experimental Mud Dam New York	Metals, PAHs		3.3	Sand	1983	• No chemical migration	Cores collected in 1990.
New Haven Harbor New Haven, Connecticut	Metals, PAHs		1.6	Silt	1993	• No chemical migration	Extensive coring study.
Port Newark/Elizabeth New York	Metals, PAHs		5.3	Sand	1993	• No chemical migration	Extensive coring study.
52 Smaller Projects New England	Metals, PAHs		1.6	Silt	1980–1995	• No chemical migration	Routine monitoring.

Appendix D Summary of Contaminated Sediment Capping Projects

Sediment Project	Chemicals of Concern	Site Conditions	Design Thickness (feet)	Cap Material	Year Constructed	Performance	Comments
International Projects							
Rotterdam Harbor Netherlands	Oils	Water depth 5 to 12 m	2–3	Silt/Clay sediments	1984	• No available monitoring data	As pollution of groundwater was a potential concern, the site was lined with clay prior to sediment disposal and capping.
Hiroshima Bay Japan		Water depth 21 m	5.3	Sand	1983	• No available data	

References:

EPA, 1998. *Manistique River/Harbor AOC Draft Responsiveness Summary, Section 4: In-place Containment at Other Sites.* Sent by Jim Hahnenberg of United States Environmental Protection Agency Region 5 and Ed Lynch of Wisconsin Department of Natural Resources on September 25, 1998.

SAIC, 1996. *Year 11 Monitoring of the Duwamish CAD Site, Seattle, Washington.* Report prepared for the United States Army Corps of Engineers, Seattle District by Science Applications International Corporation, Bothell, Washington.

Sumeri, A., 1984. Capped in-water disposal of contaminated dredged material: Duwamish Waterway site. In: *Proceedings of the Conference Dredging '84, Dredging and Dredged Material Disposal, Volume 2.* United States Army Corps of Engineers, Seattle, Washington.

Truitt, C. L., 1986. *The Duwamish Waterway Capping Demonstration Project: Engineering Analysis and Results of Physical Monitoring.* Final Report. Technical Report D-86-2. United States Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. March.

Appendix E

Wisconsin Disposal Information

CORRESPONDENCE/MEMORANDUM — **State of Wisconsin**

DATE: December 15, 1998

TO: Paul Putzier - RETEC
Chris Carleo - RETEC

FROM: Ed Lynch - DNR RR/3 EKL

SUBJECT: Fox River Disposal Issues

Purpose. The purpose of this memo is to outline State upland and in water disposal requirements for use in the preparation of the FS. State laws that need to be considered in evaluating in-river disposal options include Wisconsin's solid waste statutes found in ch.. 289,Wis. Stats., and statutes concerning in-water placement of materials found in ch. 30, Wis. Stats. Ch. 289, Wis Stats., is also applicable to upland disposal options.

Please note that this memo is intended as an overview of the issues and that, as proposals are considered, there will need to be case by case determinations regarding the State's various authorities. This concern is that, if you look at the summary re: public trust issues and the potential types of remedies available (bulkhead lines, lakebed grants, etc.) someone can, and probably will, argue in the future that DNR indicated these methods for placing fill were determined to be acceptable in the various reaches of river. All we are saying is that these are potential mechanisms to deal with these stretches, and we will have to review the specific designs and impacts on a case by case basis.

The feasibility study should provide a sufficient analysis of the institutional feasibility of all technically feasible disposal options to select a remedy. Therefore, the feasibility study must be complete in terms of the hurdles to implement an alternative and fully describe them. Discussion such as "the state would have to approve of this but we don't know if they will" is not acceptable. If a decision needs to be made on the institutional feasibility of an alternative that requires a case by case decision by us based on the merits of the technical proposal, then the FS should describe that proposal in sufficient detail so we can make that decision before the FS is finalized. Deferral of the tough issues to after the FS and ROD is not expected.

Applicable State Disposal Laws and Regulations. Dredged sediment material is a solid waste in Wisconsin, defined by the statutory definition of solid waste and by case law. Sediment in place in a water body does not come under solid waste regulation until a person picks it up, say, in a dredging operation. In that case, solid waste authority comes into play only due to the act of dredging and managing the sediment. As a general rule, the solid waste facility siting process in ch. 289, Wis. Stats., (feasibility report, plan of operation, needs, negotiation/arbitration, etc.) applies to any new solid waste disposal facility, including in-water facilities for the disposal of solid waste. The siting process administrative requirements may not apply to on-site Superfund actions (see discussion on this below). There are locational criteria in NR 504.04 (setbacks from navigational waters, flood plains) which may not be met for such facilities, so a DNR exemption or CERCLA waiver would be necessary to allow in-water disposal. DNR has authority to issue exemptions from regulation under ch. 289, Wis. Stats., under some circumstances. For confined engineered, disposal sites, the Waste management program has regulatory authority. For in water disposal in what is essentially a non engineered fill, discharge of dredged material would be subject to Watershed Management Requirements.

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DNR Solid Waste Program Exemptions. The primary exemption exists in s. NR 500.08(3), Wis. Adm. Code (June, 1996) that covers dredged materials. This exemption reads as follows:
"(3) DREDGED MATERIAL EXEMPTIONS. The following facilities are exempt from the licensing and plan review requirements of chs. NR 500 to 536 but shall be developed in accordance with the following requirements:
(a) Facilities for the disposal of non hazardous dredged material consisting of less than 3000 cubic yards from Lake Michigan, Lake Superior, the Wisconsin River, the Sheboygan River, the Milwaukee River, the Brule and Menomonee rivers, the Fox rivers, or from any inland lakes or ponds treated with arsenicals provided the facility complies with the performance standards in s. NR 504.04(4).
(b) Facilities for the disposal of non-hazardous dredged material from rivers not listed in par. (a) provided the facility complies with the performance standards specified in s. NR 504.04(4).
(c) Facilities for the disposal of non hazardous dredged material from inland lakes or ponds that have not been treated with arsenicals provided the facility complies with the performance standards specified in s. NR 504.04(4)."

Paragraph (a) allows for the disposal of small amounts of dredged sediment materials (less than 3000 cubic yards) from listed bodies of water to be disposed of into upland land disposal sites without plan review or licensing provided solid waste location and performance standards are met. Paragraph (b) applies to non-listed water bodies and rivers and is similar to (a) but does not have a quantity limit. The focus of par. (c) is dredged sediment material from inland lakes or ponds that have not been treated with arsenicals. S. NR 500.08(3)(a), Wis. Adm. Code, does not seem to apply to the Fox River for this project (because more than 3000 cubic yards of material will be dredged). The underlying assumption is that unengineered upland disposal sites would not affect groundwater or other protected resources. If we suspect that is not the case, the Department can require upgrading or relocation of the disposal site even if volumes or sources fall within exemptions categories listed in the code.

Another option is to seek a Low Hazard Exemption as identified in s. NR 500.08(4) and s. 289.43(8), Wis. Stats. (formerly s. 144.44(7)(g), Wis. Stats.). Finally, the dredge sediment material may be suitable for a Beneficial Reuse Exemption under s. NR 500.08(5), Wis. Adm. Code. Note that the criteria for a low hazard exemption do not apply solely to waste itself, but also considers the way the waste is managed within the specifics of the conditions of the low hazard determination. In practice, this type of exemption should be applied to non hazardous, nontoxic wastes situations.

Examples of past exemptions include the granting of a conditional "low hazard exemption" under s. 289.43(8), Wis. Stats., authorizing disposal of dredge materials in the Kidney Island CDF in Green Bay. This had the effect of waiving the statutory siting process for that solid waste disposal facility. Use of that exemption by DNR in that situation was upheld by the courts in Public Intervenor v. DNR, 156 Wis2d 376. DNR has used the low hazard exemption process for the Bayport facility. We required the full landfill siting process for an upland dredge spoil disposal facility in Green Bay (Schuster Pit). For small projects, exemptions have been issued for a variety of disposal options, including disposal in covered mass, land spreading, use in landfills as daily covers and confined disposal facilities. Given the degree of contamination of the dredged material coming from the river, it is not likely that either the beneficial reuse or low hazard exemptions are viable options.

Other Regulations Related to Solid Waste Requirements. Ch. NR 347, Wis. Adm. Code, covers Sediment Sampling and Analysis, Monitoring Protocol and Disposal for Dredging Projects. This code is interpreted by Watershed Management for site specific sampling and analysis needs based on existing knowledge of the site. The code is used by Fish & Habitat Protection, Watershed Management, Waste Management and Air Management programs in evaluation of permit application as well as other submittals. Section NR 347.04 (1)(b) indicates that all dredging projects must be reviewed under s. 144.44, Wis. Stats. (s. 289.31, Wis. Stats., as of January 1, 1997), and chs. NR 500 to 520 for disposal of dredged material under the Waste Management program. Section NR 347.04 (1)(g) states that sites for the disposal of hazardous waste and PCBs require review under ss. 144.64 (now ss. 291.23 and 291.25, Wis. Stats.) and 144.79 (now s. 299.45.), Wis. Stats., respectively, and chs. NR 600 to 685. (While not stated in Par. (g), ch. NR157 must also be considered when PCBs are being disposed of.) Paragraphs NR 347.04 (1) (b) & (g) apply when the dredged sediment material is removed from the water body for upland disposal and are Waste Management program responsibilities.

There are two additional items to note. The first is that on January 24, 1995, the U.S. EPA issued DNR an approval under the Toxics Substances Control Act (TSCA) allowing the disposal of PCB contaminated sediments resulting from certain sediment remediation projects into solid waste landfills. The second item deals with hazardous waste determination on the PCB contaminated dredge materials. In Wisconsin, unlike some other states, PCB contamination is not a basis for classifying a waste as hazardous. Additionally, there is no basis for stating that any of the dredged material would be listed hazardous waste. In the absence of listing criteria being met, the basis for a hazardous waste determination would be if the sediment failed the toxicity characteristic leaching procedure or TCLP analysis. We ask that you review Fox River data base for TCLP data. Based upon that evaluation you may be able to determine that none of the dredged material is hazardous waste and consequently we can then dismiss RCRA and the State hazardous waste ARARs at this time.

Upland disposal options by River Reach. The following table identifies the possibility of applying exemptions to upland disposal by River Reach.

Table 1

River Reach	*Beneficial Reuse*	*Low hazard*	*Site a Landfill*	*Use Existing Commercial or Private Landfill Capacity*
Little Lake Buttes Des Mortes	Not Likely	Possible for low level material	Possible	Yes
Appleton to Little Rapids[1]	No	No	Possible	No
Little Rapids to DePere	Not Likely	Possible for low level material	Possible	Yes
DePere to Green Bay	Not Likely	Possible for low level material	Possible	Yes

1. At this time we do not anticipate removing any sediment from the Appleton to Little Rapids reach of the river.

Applicable State In Water Disposal Laws. For more than 25 years, Wisconsin has had legislation which bans the open water disposal of dredged material on the bed of all navigable waters. This ban has had a significant effect on the ease with which navigational dredging can occur, in particular in the Great Lakes commercial ports in Wisconsin. This ban can be found in s. 30.12(1)(a) Wis. Stats. Structures and deposits in navigable waters prohibited; exceptions; penalty. (1) GENERAL PROHIBITION. Except as provided under sub. (4), unless a permit has been granted by the department pursuant to statute or the legislature has otherwise authorized structures or deposits in navigable waters, it is unlawful:

(a) To deposit any material or to place any structure upon the bed of any navigable water where no bulkhead line has been established; or

(b) To deposit any material or to place any structure upon the bed of any navigable water beyond a lawfully established bulkhead line.

The following discussion outlines how the law concerning in-water disposal has been applied and interpreted and how some permitted operations have been allowed. Since the law states that open water disposal is prohibited without a permit, the real question becomes when can a permit be issued. The law only authorizes the issuance of permits for the construction of structures on the bed of navigable waters and prohibits the deposition of materials except into structures which are permitted or authorized under statute or other legislative means. A structure has been defined by the Attorney General and the DNR as something which has "form, function and utility" in order to receive a permit. Open water disposal without a structure designed to contain dredged material does not meet this test.

Deposits on the bed of navigable waters in Wisconsin have been authorized under four scenarios. Exceptions to open water disposal prohibition include:

a) Legislative Authorization. Legislative authorization with riparian owners as applicants or co-applicants (examples: s. 30.202 & 30.203). This must be consistent with the public trust doctrine.

b) Lakebed Grants. Lakebed grants have been used in the past to authorize CDFs (s.30.05) - limited to natural lakebed, not the bed of a raised lake (dammed lake) unless the is agreement of riparian property owners and special legislation (Note: this is not always straight forward; A lakebed grant has been used in Lake Buttes Des Mortes, which is in part a dammed lake. Need to consider area of raised river versus actual lake bed area). Special legislation can result in the issuance of a lakebed grant. While the lakebed grant removes the specific area of the grant from the prohibition of deposits, the structure built to contain the materials deposited in the area must comply with all approvals and permits required to protect the water quality of the surrounding water body.

c) Bulkhead Lines. Bulkhead lines (s.30.11) can be used, however these are explicitly limited by statute to "conform as nearly as practicable to the existing shores, except in the case of leases...". Bulkhead lines cannot be used to fill large areas or lake or riverbed. Under s. 30.11, a municipality by ordinance and with DNR approval may establish a bulkhead line along the shore of any navigable water within its boundaries. Once a bulkhead line has been established, filling of the area behind the bulkhead line may occur in conformance with DNR conditions and limitations relating to off-site impacts.

d) Leases. Leases can be granted (s.24.29), but are only applicable to construct or enlarge harbors or improve navigation. This involves the Commission of Public Lands (the State Treasurer, the Secretary State and the Attorney General). This mechanism allows for the issuance of a lease to a municipality for the use of submerged lands, and for deposits on those submerged lands, under s. 24.39(4). A lease can be issued only for the purpose of improvement of navigation or for the improvement or construction of harbor facilities. Prior to granting such a lease, the Department of Natural Resources must find that the issuance of such a lease is in the public interest. As is the case for the establishment of bulkhead lines, the Department may include conditions of use and operation of the site in order to assure the public interest is protected. By statute, the board of commissioners of public lands must include these conditions as part of the lease agreement.

While each of these methods of acquiring the right to deposit materials on the bed of navigable waters has specific statutory authorization, each must still meet the conditions and limitations of the state relating to the protection of water quality and protection of other water related interests in the areas involved.

In Water Options by River Reach and In Green Bay. The following table identifies which in water disposal options are possible by River Reach.

Table 2

River Reach	*Legislative Authorization*	*Lakebed Grants*	*Bulkhead Lines*	*Leases*
Little Lake Buttes Des Mortes	Yes	Yes	No	No
Appleton to Little Rapids[2]	Yes	No	Yes	No
Little Rapids to DePere	Yes	No	Yes	No
DePere to Green Bay	Yes	No	Yes	Yes
Green Bay	Yes	Yes	No	Yes

2. At this time we do not anticipate removing any sediment from the Appleton to Little Rapids reach of the river.

CERCLA On Site Permit Exemption. The "on-site permit exemption" found in section 121(e) of CERCLA (42 U.S.C. ss. 9621(e)) only applies if U.S. EPA is going to be conducting the work or has issued an order or signed a consent decree with PRPs (and, potentially, the state as well) under the authority of CERCLA, which requires the PRPs to conduct the work. The "on-site permit exemption" does not apply if the State of Wisconsin conducts the work or if DNR issues an order or signs a consent decree with PRPs under the authority of state law.

The definition of "on-site" is in sections 300.5 and 300.400(e) of the NCP. Discussion of the topic in the NCP preamble begins on FR 8688, 3/8/90. "On-site" means the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action. The distinction between substantive and administrative requirements is discussed in relation to the definitions of "applicable" and "relevant and "appropriate" requirements in section 300.5. This discussion begins on FR 8756, 3/8/90.

CERCLA does not authorize states to issue orders or require PRPs to conduct cleanup actions under CERCLA. Only EPA can do those things under CERCLA. In order for the "on-site permit exemption" to be applicable, CERCLA authority must be used and only EPA can use it. If DNR issues an order under spill law (ch. 292.11, Wis. Stats.), the federal on-site permit exemption does not apply and all required permits and approvals must be obtained.

For this site, DNR's position is upland disposal units immediately adjacent to the River and in-water disposal units are the only ones that could be considered "on-site" under CERCLA. DNR also believes permanent upland disposal units close enough to the river to be considered "on-site" would not meet locational criteria ARARs, and those ARARs should not be exempted or waived.

Please contact me at 608/266-3084 if you have questions.

CC: Bob Paulson - WT/2
Linda Meyer - LS/5
Chuck Hammer - LS/5
Kevin Kessler - WA/3
Tim Thompson - RETEC
Mike Cain - LS/5
Chuck Leveque - LS/5
Gary Edelstein - RR/3
Len Polczinski - NER

3.5.6 ✓ 5/8/18

CORRESPONDENCE/MEMORANDUM — State of Wisconsin

w/ 8/6/98 Memo from Ekl - Landfills

DATE: January 31, 1997

TO: RR Regional Team Supervisors Mark Giesfeldt - RR/3
BRR Section Chiefs & Team Leaders - RR/3

FROM: Ed Lynch - RR/3 EXL

SUBJECT: Dredged Sediment Materials Management

At the November 5 & 6, 1996 RR team leaders meeting, Pat McCutcheon of SCR requested information on how regions managed dredged sediment material. The discussion that followed indicated that in most cases this material is handled as a solid waste that may be covered by a waste management program exemption. I agreed to review available information on the management of dredge sediment materials and relay my findings back to you. This memo summarizes my findings. It is not meant to address all the technical or programmatic issues related to dredge sediment materials management. Please share this information with your staff. In preparing this memo, I discussed this topic with staff from the Waste Management program and they concur with the content of this memo. For the most part, upland disposal of dredged sediments is a Waste Management program issue. Please remember to maintain open communications with other programs when dealing with dredge materials management issues.

Dredged sediment material is a solid waste in Wisconsin, defined by the statutory definition of solid waste and by case law. Sediment in place in a water body is not a regulated solid waste operation until someone picks it up in a dredging operation. Contaminated or unwanted sediment in a water body may be a problem for someone and may deserve cleanup, but solid waste authority comes into play only due to the act of dredging and managing the sediment. Liability for discharges from contaminated sediment may fall under state spill law and other authorities in other circumstances.

Department rules and State statutes provide for a range of options for the regulation of dredged sediment materials based on the degree of risk that the materials may present to human health and the environment. In a broad sense ch. NR 150, Wis. Adm. Code and various manual codes provide for a cross program review of the potential for harm to human health and the environment of dredging projects including the effects of removal and disposal of the material.

Management options for dredged sediment material range from low restriction beneficial reuse to highly restrictive disposal due to toxic or hazardous properties or other threats to human health and the environment. The evaluation of the risk of disposal may be based upon information on the dredge sediment material, the proposed disposal site and disposal methods, data requested by Waste Management from the applicant, data from the reporting requirements of ch. NR 347, Wis. Adm. Code, existing data on sediment chemistry, and where applicable ch. NR 150, Wis. Adm. Code requirements.

First of all, there are several specific solid waste rules and statutes that apply to the management of dredged materials and provide exemptions to certain solid waste rules. The primary exemption exists in s. NR 500.08(3), Wis. Adm. Code (June, 1996) that covers dredged materials. This exemption reads as follows:

"(3) DREDGED MATERIAL EXEMPTIONS. The following facilities are exempt from the licensing and plan review requirements of chs. NR 500 to 536 but shall be developed in accordance with the following requirements:

(a) Facilities for the disposal of nonhazardous dredged material consisting of less than 3000 cubic yards from Lake Michigan, Lake Superior, the Wisconsin River, the Sheboygan River, the Milwaukee River, the Brule and Menomonee rivers, the Fox rivers, or from any inland lakes or ponds treated with arsenicals provided the facility complies with the performance standards in s. NR 504.04(4).

(b) Facilities for the disposal of non-hazardous dredged material from rivers not listed in par. (a) provided the facility complies with the performance standards specified in s. NR 504.04(4).

(c) Facilities for the disposal of nonhazardous dredged material from inland lakes or ponds that have not been treated with arsenicals provided the facility complies with the performance standards specified in s. NR 504.04(4)."

Chapter NR 504, Wis. Adm. Code covers Landfill Location, Performance, Design and Construction Criteria and s. NR 504.04(4) (attachment A) is the performance standards section. This section allows property to be used for a solid waste land disposal facility provided the facility is properly located and there are no significant adverse impacts or detrimental effects. Waste Management staff are the appropriate personnel to make these determinations regarding the effects or impacts from this type of disposal facility.

With regards to s. NR 500.08(3)(a), this allows for the disposal of small amounts of dredged sediment materials (less than 3000 cubic yards) from listed bodies of water to be disposed of into upland land disposal sites without plan review or licensing provided solid waste location and performance standards are met. Paragraph (b) applies to non-listed water bodies and rivers and is similar to (a) but does not have a quantity limit. The focus of par. (c) is dredged sediment material from inland lakes or ponds that have not been treated with arsenicals. It is up to the Watershed Management program and the Waste Management program to make decisions concerning in-water disposal. (This memo is not meant to address issues related to the need for obtaining any COE approvals or permits.)

In cases where the exemption criteria of s. NR 500.08(3) are not met, other options exist. One option is to follow the siting process and eventually establish a solid waste disposal facility. Another option is to seek a Low Hazard Exemption as identified in s. NR 500.08(4) and s. 289.43(8) Stats. (formerly s. 144.44(7)(g), Stats; see attachment B). Finally, the dredge sediment material may be suitable for a beneficial reuse exemption per s. NR 500.08(5), Wis. Adm. Code. The Waste Management program is responsible for making these decisions and for issuing low hazard exemptions. Note that the criteria for a low hazard exemption do not apply solely to waste itself, but also considers the way the waste is managed within the specifics of the conditions of the low hazard determination.

Solid waste staff have generally provided feedback by way of interprogram memos for small projects, for use by dredging permit writers to include as conditions of dredging permits. Larger harbor projects or dredge sediment projects have historically been subject to formal grants of exemptions. Most of the reviews have involved contaminated sediments or disposal locations that would affect protected resources such as wetlands. Exemptions have been issued for a variety of disposal options, including disposal in covered mass, land spreading, use in landfills as daily covers and confined disposal facilities.

Generally, the Waste Management program is part of the multiprogram review of a proposed dredging project. A dredging project coordinator should usually be appointed to address water regulation and environmental impact responsibilities. Historically, the Waste Management program has not been brought into projects until basic decisions have been made concerning the overall dredging project.

In addition, ch. NR 347, Wis. Adm. Code, (attachment C) covers Sediment Sampling and Analysis, Monitoring Protocol and Disposal for Dredging Projects. This code is interpreted by Watershed Management for site specific sampling and analysis needs based on existing knowledge of the site. The code is used by Fish & Habitat Protection, Watershed Management, Waste Management and Air Management programs in evaluation of permit application as well as other submittals. Section NR 347.04 (1)(b) requires all dredging projects be reviewed under s. 144.44, Stats., and chs. NR 500 to 520 for disposal of dredged material under the

Waste Management program. Section NR 347.04 (1)(g) states that sites for the disposal of hazardous waste and PCBs require review under ss. 144.64 and 144.79, Stats., respectively, and chs. NR 500 to 520 and chs. NR 600 to 685. (While not stated in Par. (g), ch. NR 157 must also be considered when PCBs are of a concern.) Parens. (b) & (g) apply when the dredged sediment material is removed from the waterbody for upland disposal and are Waste Management program responsibilities.

An additional item to note is that on January 24, 1995, the U.S. EPA issued DNR an approval under the Toxics Substances Control Act (TSCA) allowing the disposal of PCB contaminated sediments resulting from certain sediment remediation projects into solid waste landfills. It is important to note that this was a conditional approval and there are a number of issues related to this determination. These issues are discussed in a March 20, 1995 memo from Dave Carper to the district solid waste program supervisors and staff (attachment D). Please review this memo closely. EPA's approval is far from an open invitation to dispose of PCB contaminated sediments into Wisconsin landfills

Application of ch. NR 720. As indicated previously, dredged sediment material *is* a solid waste and there is no direct connection between table values in ch. NR 720, Wis. Adm. Code, and the land disposal of contaminated dredge sediment materials. In addition, NR 720 table values *were not* developed for the purpose of managing contaminated dredge sediment material at an off-site location (NR 720 *was* developed for on-site management of contaminated soils and not developed to be a waste management regulation). However, as the NR 720 table values are risk-based, there may be some validity in using those values as a basis for evaluating the risk associated with management of the dredge sediment material on a case by case basis and for determining the need for subsequent management. Regardless of the sediment contamination level, the Waste Management program is responsible for determining whether a proposed waste management practice is appropriate based upon the level of risk posed by the dredged sediment material.

In summary, management of dredge sediment material at upland locations fall primarily within the confines of the Waste Management program. The above mentioned statutes, rules and guidance should be considered for any dredging project be it remediation related or not. As I indicated before, communications with other programs when dealing with dredge materials management is important and should not be overlooked.

I hope this information is useful. Should you have any questions, you may wish to contact Bob Grefe of the Bureau of Waste Management at 608/266-2178 or Chuck Leveque of the Bureau of Legal Services at 608/266-0228. Questions concerning the TSCA PCB approval from EPA can be directed to Dave Carper at 608/267-6823.

Concurrence:

Paul P. Didier

Paul P. Didier, P.E., Director
Bureau of Waste Management

1/31/97
Date

Attachments: A. Section 504.04(4), Wis. Adm. Code.
B. Section 289.43(8), Stats.
C. Chapter NR 347, Wis. Adm. Code.
D. DNR Memo dated March 20, 1995 concerning TSCA PCB Approval

cc: WA Section Chiefs - WA/3
Bob Grefe - WA/3
RR Program Attorneys - LS/5
Paulette Harder/Sue Bangert - WT/2
Mary Ellen Vollbrecht - FH/4
Regional WA Team Leaders
Dave Carper - WA/3
Chuck Leveque - LS/5
Bill Fitzpatrick - WT/2

a:dredge.ckl.rrl

department by up to 2 years if the owner or operator demonstrates that there is no available alternative disposal capacity and there is no immediate threat to human health and the environment.

Note: Owners or operators proposing to site a new or expand an existing municipal solid waste landfill within a 5 mile radius of any airport runway end used by turbojet or piston type aircraft must notify the owner or operator of the affected airport and the federal aviation administration (FAA).

(f) Within 1,200 feet of any public or private water supply well.

(g) Within 200 feet of a fault that has had displacement in Holocene time.

(h) Within seismic impact zones.

(i) Within unstable areas.

(4) PERFORMANCE STANDARDS. No person may establish, construct, operate, maintain or permit the use of property for a landfill if there is a reasonable probability that the landfill will cause:

(a) A significant adverse impact on wetlands as provided in ch. NR 103.

(b) A significant adverse impact on critical habitat areas.

(c) A detrimental effect on any surface water.

(d) A detrimental effect on groundwater quality or will cause or exacerbate an attainment or exceedance of any preventive action limit or enforcement standard at a point of standards application as defined in ch. NR 140. For the purposes of design the point of standards application is defined by s. NR 140.22 (1).

(e) The migration and concentration of explosive gases in any landfill structures excluding the leachate collection system or gas control or recovery system components in excess of 25% of the lower explosive limit for such gases at any time. The migration and concentration of explosive gases in the soils outside of the limits of filling within 200 feet of the landfill property boundary or beyond the landfill property boundary in excess of the lower explosive limit for such gases at any time. The migration and concentration of explosive gases in the air outside of the limits of filling within 200 feet of the landfill boundary or beyond the landfill property boundary in excess of the lower explosive limit for such gases at any time.

(f) The emission of any hazardous air contaminant exceeding the limitations for those substances contained in s. NR 445.03.

History: Cr. January, 1988, No. 385, eff. 2-6-88; am. (1), (2) (a), (b), (3) (intro.), (a), (d), (4) (intro.), (a), (3), r. and recr. (3) (e), cr. (3) (g) to (i).

NR 504.05 General design and construction criteria.

(1) Unless otherwise specified in this chapter, the minimum design criteria in ss. NR 504.06 to 504.09 apply to all new landfills and to the expansion of existing landfills for which the plan of operation was approved after July 1, 1996, as well as to proposed design changes for all landfills which are submitted after July 1, 1996. Landfills designed in substantial conformance with these design criteria are presumed to be capable of meeting the performance standards of s. NR 504.04(4)(d) regarding groundwater quality.

(2) If the proposed design differs from the requirements in ss. NR 504.06 to 504.09, the applicant shall provide supporting justification for any differences.

(3) The design capacity of all proposed landfills, except landfills that are exempted in s. 144.44(2)(nr), Stats., shall be determined such that the projected operating life of the landfill is not less than 10 years nor more than 15 years. Expansions of existing landfills are not subject to the 10-year minimum design capacity requirement. Waste approved for use in construction of landfill components is not considered part of the design capacity.

History: Cr. Register, January, 1988, No. 385, eff. 2-6-88; r. and recr., Register, June, 1996, No. 486, eff. 7-1-96.

NR 504.06 Minimum design and construction criteria for landfill liners and leachate collection systems.

(1) GENERAL. (a) All major phases of landfills initially accepting municipal solid waste after July 1, 1996, shall be designed with a composite liner and a leachate collection system capable of limiting the average leachate head level on the composite liner to one foot or less during operation and after closure of the landfill, except as provided in s. NR 504.10(1) (c). The composite liner shall consist of 2 components; the upper component shall consist of a nominal 60-mil or thicker geomembrane liner with no thickness measurements falling below the minimum industry accepted manufacturing tolerances, and the lower component shall consist of a minimum 4 foot thick layer of compacted clay meeting the specifications of s. NR 504.06(2)(a). The geomembrane component shall be installed in direct and uniform contact with the compacted clay soil component, and the landfill shall meet or exceed the standards in the applicable portions of subs. (2), (3) and (4). All other landfills shall be designed to contain and collect leachate to the maximum practical extent. This shall be accomplished by designing the landfill to meet the standards contained in the applicable portions of subs. (2), (3) and (4), unless the department approves the applicant's alternative design as per s. NR 504.10, which provides an equivalent or better level of performance than the standards contained in this chapter.

(b) If the applicant does not complete construction of the first major phase of the landfill within 2 years from the date of the plan of operation approval, the applicant shall reapply to the department for approval to construct the landfill. This application does not constitute a feasibility report as defined in s. 144.44(2), Stats. The department may require additional conditions of approval and require redesign of the landfill in accordance with state-of-the-art design criteria.

(2) COMPOSITE OR CLAY LINED LANDFILLS. All landfills designed with a composite liner or a clay liner shall meet the following requirements:

(a) All clay used in liner construction shall meet the following specifications:

1. A minimum of 50% by weight which passes the 200 sieve.

2. A saturated hydraulic conductivity of $1x10^{-7}$ cm/sec or less, when compacted to required moisture contents and densities based on the modified Proctor method, standard Proctor method, or a line of optimums method approved by the department.

3. An average liquid limit of 25 or greater with no values less than 20.

4. An average plasticity index of 12 or greater with no values less than 10.

(b) The separation distance between the seasonal high groundwater table and the bottom of the clay component of a composite liner or a clay liner shall be at least 10 feet except for zone-of-saturation landfills.

(c) The separation distance between the top of the bedrock surface and the bottom of the clay component of a composite liner or a clay liner shall be at least 10 feet.

(d) The slope of the liner surface toward the leachate collection lines shall be at least 2%.

(e) The minimum thickness of the clay component of a composite liner at all locations shall be at least 4 feet. The minimum thickness of a clay liner at all locations shall be at least 5 feet.

(f) The clay component of a composite liner or a clay liner shall be constructed in the following manner:

1. All clay layers in the liner shall be constructed in lift heights no greater than 6 inches after compaction using footed compaction equipment having feet at least as long as the loose lift height. As needed, clay shall be disked or otherwise mechanically processed prior to compaction to break up clods and allow for moisture content adjustment. Clod size shall be no greater than 4 inches. All compaction equipment utilized shall have a minimum static weight of 30,000 pounds. Lighter equipment may be used in small areas where it is not possible to use full size equipment. Alternative procedures or equipment may be proposed for approval by the department.

Attachment A

under this chapter or conditions of operation made applicable to a solid waste disposal facility by the department.

(2) (a) No person engaged in the construction, operation or maintenance of a solid waste disposal facility or hazardous waste disposal facility may dismiss, discipline, demote, transfer, reprimand, harass, reduce the pay of, discriminate against or otherwise retaliate against any employe, or threaten to take any of those actions, because the employe reported to any supervisor, appointing authority, law enforcement official, member of the governing body of the local governmental unit in which the solid waste disposal facility or hazardous waste disposal facility is located or the department any information gained by the employe which the employe reasonably believes demonstrates a violation of this chapter or rules promulgated under this chapter.

(b) Paragraph (a) does not restrict the right of an employer to take appropriate disciplinary action against an employe who knowingly makes an untrue statement or discloses information the disclosure of which is expressly prohibited by state or federal law.

(c) 1. Any employe who believes that his or her rights under par. (a) have been violated may, within 30 days after the violation occurs or the employe obtains knowledge of the violation, whichever is later, file a written complaint with the department specifying the nature of the retaliatory action or threat of retaliatory action and requesting relief. The department shall investigate the complaint and shall determine whether there is probable cause to believe that a violation of par. (a) has occurred. If the department finds that probable cause exists, it shall attempt to resolve the complaint by conference, conciliation or persuasion. If the complaint is not resolved, the department shall proceed with notice and a contested case hearing on the complaint as provided in ch. 227. The hearing shall be held within 60 days after receipt of the complaint by the department, unless the parties to the proceeding agree otherwise.

2. The department shall issue its decision and order on the complaint within 30 days after the hearing. If the department finds that a violation of par. (a) has occurred, it may order the employer to take action to remedy the effects of the violation, including reinstating the employe, providing back pay to the employe or taking disciplinary action against employes responsible for the violation.

(d) This subsection does not limit other protections or remedies available to an employe, including those granted by ordinance, statute, rule, contract or collective bargaining agreement.

History: 1995 a. 227 ss. 531, 532, 991.

289.43 Waivers; exemptions. **(1)** DEFINITION. In this section, "recycling" means the process by which solid waste is returned to productive use as material or energy, but does not include the collection of solid waste.

(2) WAIVER: EMERGENCY CONDITION. The department may waive compliance with any requirement of ss. 289.21 to 289.32, 289.47, 289.53 or 289.95 or shorten the time periods under ss. 289.21 to 289.32, 289.47, 289.53 or 289.95 provided to the extent necessary to prevent an emergency condition threatening public health, safety or welfare.

(3) WAIVER: RESEARCH PROJECTS. The intent of this subsection is to encourage research projects designed to demonstrate the feasibility of recycling certain solid wastes while providing adequate and reasonable safeguards for the environment. The department may waive compliance with the requirements of this chapter for a project developed for research purposes to evaluate the potential for the recycling of high-volume industrial waste if the following conditions are met:

(a) The project is designed to demonstrate the feasibility of recycling solid waste or the feasibility of improved solid waste disposal methods.

(b) The department determines that the project is unlikely to violate any law relating to surface water or groundwater quality including this chapter or ch. 160 or 283.

(c) The department reviews and approves the project prior to its initiation.

(d) The owner or operator of the project agrees to provide all data, reports and research publications relating to the project to the department.

(e) The owner or operator of the project agrees to take necessary action to maintain compliance with surface water and groundwater laws, including this chapter and chs. 160 and 283 and to take necessary action to regain compliance with these laws if a violation occurs because of the functioning or malfunctioning of the project.

(4) EXEMPTION FROM LICENSING OR REGULATION; DEVELOPMENT OF IMPROVED METHODS. For the purpose of encouraging the development of improved methods of solid waste disposal, the department may specify by rule types of solid waste facilities that are not required to be licensed under ss. 289.21 to 289.32 or types of solid waste that need not be disposed of at a licensed solid waste disposal facility.

(5) EXEMPTION FROM REGULATION; SINGLE-FAMILY WASTE DISPOSAL. The department may not regulate under chs. 281, 285 or 289 to 299 any solid waste from a single family or household disposed of on the property where it is generated.

(6) EXEMPTION FROM LICENSING; AGRICULTURAL LANDSPREADING OF SLUDGE. The department may not require a license under ss. 289.21 to 289.32 for agricultural land on which nonhazardous sludges from a treatment work, as defined under s. 283.01 (18), are land spread for purpose of a soil conditioner or nutrient.

(6m) EXEMPTION FROM LICENSING, AGRICULTURAL USE OF WOOD ASH. No license is required under ss. 289.21 to 289.32 for the agricultural use of wood ash.

(7) EXEMPTION FROM LICENSING; RECYCLING OF HIGH-VOLUME INDUSTRIAL WASTE. (a) Any person who generates, treats, stores or disposes of high-volume industrial waste may request the department to exempt an individual solid waste facility or specified types of solid waste facilities from this chapter for the purpose of allowing the recycling of any high-volume industrial waste.

(b) A person who requests an exemption under par. (a) shall provide any information requested by the department relating to the characteristics of the high-volume industrial waste, the characteristics of the site of the recycling and the proposed methods of recycling.

(c) The department shall approve the requester's exemption proposal if the department finds that the proposal, as approved, will comply with this chapter and chs. 30, 31, 160 and 280 to 299 and ss. 1.11, 23.40, 59.692, 59.693, 60.627, 61.351, 61.354, 62.231, 62.234 and 87.30. If the proposal does not comply with one or more of the requirements specified in this paragraph, the department shall provide a written statement describing how the proposal fails to comply with those requirements. The department shall respond to an application for an exemption under this subsection within 90 days.

NOTE: Par. (c) is shown as affected by two acts of the 1995 legislature and as merged by the revisor under s. 13.93 (2) (c).

(d) The department may require periodic testing and may impose other conditions on any exemption granted under this subsection. The department may require a person granted an exemption under this subsection to identify the location of any site where high-volume industrial waste is recycled.

(e) 1. Each applicant for an exemption under this subsection shall submit a nonrefundable fee of $500 with the application to cover the department's cost for the initial screening of the application. The department may waive this fee if the cost of the initial screening to the department will be minimal.

2. The department shall, by rule, establish fees for approved applications which, together with the $500 application fees, shall, as closely as possible, equal the actual cost of reviewing applications.

– Attachment B –

3. All fees collected under this paragraph shall be credited to the appropriation under s. 20.370 (2) (dg).

(8) *Exemption from regulation; low-hazard waste.* (a) The department shall conduct a continuing review of the potential hazard to public health or the environment of various types of solid wastes and solid waste facilities. The department shall consider information submitted by any person concerning the potential hazard to public health or the environment of any type of solid waste.

(b) If the department, after a review under par. (a), finds that regulation under this chapter is not warranted in light of the potential hazard to public health or the environment, the department shall either:

1. Promulgate a rule specifying types of solid waste that need not be disposed of at a licensed solid waste disposal facility.

2. On a case-by-case basis, exempt from regulation under this chapter specified types of solid waste facilities.

3. Authorize an individual generator to dispose of a specified type of solid waste at a site other than a licensed solid waste disposal facility.

(c) The department may require periodic testing of solid wastes and impose other conditions on exemptions granted under par. (b).

(9) EXEMPTION FROM REGULATION; ANIMAL CARCASSES. The department may not regulate under chs. 281, 285 or 289 to 299 any animal carcass buried or disposed of, in accordance with ss. 95.35 and 95.50, on the property owned or operated by the owner of the carcass, if the owner is a farmer, as defined under s. 102.04 (3).

History: 1995 a. 227 ss. 574, 577 to 580; s. 13.93 (2) (c).

Exemption from regulation under sub. (7) (g) does not prevent municipal regulation but instead places the municipality in the position it would be in regarding regulation if the statutory scheme under ss. 144.43 to 144.47 did not exist. DeRosso Landfill Co. v. City of Oak Creek, 191 W (2d) 46, 528 NW (2d) 468 (Ct. App. 1995).

289.44 Exemption for certain alcohol fuel production systems. (1) DEFINITIONS. As used in this section:

(a) "Distillate waste product" means solid, semisolid or liquid by-products or wastes from the distillation or functionally equivalent process of an alcohol fuel production system.

(b) "Environmentally sound storage facility" means a facility, including a holding lagoon, which is used to store distillate waste products so that no waste products from the facility enter or leach into the waters of the state.

(c) "Private alcohol fuel production system" means an alcohol fuel production system from which no alcohol is sold and from which all the alcohol is used as a fuel by the owner.

(2) EXEMPTION. No permit, license or plan approval is required under this chapter for the owner of a private alcohol fuel production system to establish, construct or operate a system for the treatment, storage or disposal of distillate waste products if the distillate waste product is stored in an environmentally sound storage facility and disposed of using an environmentally safe land spreading technique and the storage, treatment or disposal is confined to the property of the owner.

History: 1979 c. 221; 1995 a. 227 s. 537.

289.445 Exemption for certain fruit and vegetable washing facilities. (1) DEFINITIONS. As used in this section:

(b) "Washing station" has the meaning given in s. 283.62 (1) (b).

(c) "Wash water" has the meaning given in s. 283.62 (1) (c).

(d) "Wash water storage facility" has the meaning given in s. 283.62 (1) (d).

(2) EXEMPTION. No permit, license or, except as provided in par. (d), plan approval is required under this chapter for the owner of a washing station to establish, construct or operate a solid waste facility for the treatment, storage or disposal of wash water or to compost or land spread plant parts separated from wash water if all of the following requirements are met:

(a) The washing station is not adjacent to or operated as part of a food processing plant, as defined in s. 97.29 (1) (h).

(b) All wash water is either stored in a sealed wash water storage facility or is dispersed on land owned or leased by the owner of the washing station in a manner which avoids ponding, runoff or nuisance conditions and in accordance with acceptable agricultural practices or acceptable practices for the land spreading of waste.

(c) All plant parts that are separated from wash water are either composted or stored in a plant parts storage facility and disposed of using an environmentally safe land spreading technique. The treatment, storage, disposal or composting under this paragraph must be confined to property owned or leased by the owner of the washing station.

(d) For a washing station that anticipates operating at least 100 days per year or that operated at least 100 days during the immediately preceding year, do all of the following:

1. Register annually with the department as a washing station.

2. Submit annually an operating plan that implements best management practices and that is approved by the department.

3. Operate only in accordance with the approved operating plan.

History: 1995 a. 99; 1995 a. 227 s. 538; Stats. 1995 s. 289.445.

289.45 Solid waste storage. No person may store or cause the storage of solid waste in a manner which causes environmental pollution.

History: 1981 c. 374; 1995 a. 227 s. 539; Stats. 1995 s. 289.45.

289.46 Transference of responsibility. (1) Any person acquiring rights of ownership, possession or operation in a licensed solid or hazardous waste facility at any time after the facility begins to accept waste is subject to all requirements of the license approved for the facility including any requirements relating to long-term care of the facility and is subject to any negotiated agreement or arbitration award related to the facility under s. 289.33. Upon acquisition of the rights, the department shall issue a new operating license if the previous licensee is no longer connected with the operation of the facility, if the new licensee meets all requirements specified in the previous license, the approved plan of operation, if any, and the rules promulgated under s. 291.05 or 291.07, if applicable.

(2) Any person having or acquiring rights of ownership in land where a solid or hazardous waste disposal facility was previously operated may not undertake any activities on the land which interfere with the closed facility causing a significant threat to public health, safety or welfare.

History: 1977 c. 377; 1981 c. 374; 1983 a. 410 ss. 62, 2202 (38); Stats. 1983 s. 144.444; 1989 a. 31; 1995 a. 227 s. 625; Stats. 1995 s. 289.46.

See note to 144.60, citing Kelly, 67 MLR 691 (1984).

289.47 Closure notice. At least 120 days prior to the closing of a solid waste disposal facility or at least 180 days prior to the closing of a hazardous waste facility, the owner or operator shall notify the department in writing of the intent to close the facility.

History: 1995 a. 227 s. 573.

SUBCHAPTER V

FACILITIES; REGULATION OF SPECIFIC FACILITY OR WASTE TYPES

289.51 Solid waste open burning standards. (1) As used in this section:

(a) "Air curtain destructor" means a solid waste disposal operation that combines a fixed wall open pit and a mechanical air supply which uses an excess of oxygen and turbulence to accomplish the smokeless combustion of clean wood wastes.

Chapter NR 347

SEDIMENT SAMPLING AND ANALYSIS, MONITORING PROTOCOL AND DISPOSAL CRITERIA FOR DREDGING PROJECTS

Note: Chapter NR 347 as it existed on February 28, 1989 was repealed and new chapter NR 347 was created effective March 1, 1989.

NR 347.01 Purpose and policy. (1) The purpose of this chapter is to protect the public rights and interest in the waters of the state by specifying definitions, sediment sampling and analysis requirements, disposal criteria and monitoring requirements for dredging projects regulated under one or more of the following statutes: s. 30.20, Stats., which requires a contract or permit for the removal of material from the beds of waterways; s. 144.04, Stats., which establishes a wastewater treatment facility plan approval program; ss. 144.43 to 144.47, Stats., which establish the solid waste management program; ss. 144.60 to 144.74, Stats., which establish the hazardous waste program; and ch. 147, Stats., which establishes the Wisconsin pollutant discharge elimination system (WPDES) program.

(2) It is department policy to encourage reuse of dredged material and to minimize environmental harm resulting from a dredging project.

History: Cr. Register, February, 1989, No. 398, eff. 3–1–89.

NR 347.02 Applicability. The provisions of this chapter apply to the removal and disposal of material from the beds of waterways except where exempted by statute.

History: Cr. Register, February, 1989, No. 398, eff. 3–1–89.

NR 347.03 Definitions. (1) "Analyte" means the chemical substance or physical property being tested for in a sample.

(2) "Bathymetry" means the measurement of depth of water in lakes or rivers to determine lake or river bed topography.

(3) "Beach nourishment disposal" means the disposal of dredged material on the beaches or in the water landward from the ordinary high–water mark of Lakes Michigan and Superior for the purpose of adding, replenishing or preventing erosion of beach material.

(4) "Bioassay" means a method for determining the acute or chronic toxicity of a material by studying its effects on test organisms under controlled conditions.

(5) "Bulk sediment analysis" means a test to measure the total concentration of a specific constituent in a sample being analyzed.

(6) "Carriage water" means the water portion of a slurry of water and dredged material.

(7) "Carriage water return flow" means the carriage water which is returned to a receiving water after separation of the dredged material from the carriage water in a disposal, rehandling or treatment facility.

(8) "Connecting waterways" means a portion of a navigable lake or stream which is directly joined to Lake Michigan or Lake Superior and which contains a navigation channel providing access for commercial or recreational watercraft to Lake Michigan or Lake Superior.

(9) "Contamination" means a solid, liquid or gaseous material, microorganism, noise, heat, odor, or radiation, alone or in any combination, that may harm the quality of the environment in any way.

(10) "Contract" means a binding written agreement between the department and a dredging applicant authorizing the removal of material from the bed of a natural navigable lake or outlying water.

(11) "Department" means the department of natural resources

(12) "Disposal facility" means a site or facility for the disposal of dredged material.

(13) "Dredged material" means any material removed from the bed of any waterway by dredging.

(14) "Dredging" means any part of the process of the removal of material from the beds of waterways; transport of the material to a disposal, rehandling or treatment facility; treatment of the material; discharge of carriage or interstitial water; and disposal of the material.

(15) "Grain size analysis" means a method to determine dredged material and disposal site sediment particle size distribution.

(16) "Hazardous waste", as defined in s. 144.61(5), Stats., means any solid waste identified as a hazardous waste under ch. NR 605.

(17) "Interstitial water" means water contained in the interstices or voids of soil or rock in the dredged material.

(18) "Limit of detection" means the lowest concentration level that can be determined to be statistically different from a blank sample for that analytical test method and sample matrix.

(19) "Limit of quantitation" (LOQ) means the concentration of an analyte at which one can state with a stated degree of confidence for that analytical test method and sample matrix that an analyte is present at a specific concentration in the sample tested.

(20) "Parent material" means the native unconsolidated material which overlies the bedrock.

(21) "PCBs" means those materials defined in s. 144.79(1)(a), Stats.

(22) "Particle size distribution" means a cumulative frequency distribution or frequency distribution of percentages of particles of specified diameters in a sample.

(23) "Rehandling facility" means a temporary storage site or facility used during the transportation of dredged material to a treatment or disposal facility.

(24) "Treatment facility" in this chapter means a natural or artificial confinement facility used for the separation of dredged material solids from the interstitial or carriage water.

(25) "Upland disposal" means the disposal of dredged materials landward from the ordinary high–water mark of a waterway or waterbody.

History: Cr. Register, February, 1989, No. 398, eff. 3–1–89; correction in (16) made under s. 13.93 (2m) (b) 7., Stats., Register, October, 1995, No. 478.

NR 347.04 Permits, approvals and reviews required. (1) The following are the permit, approval and review requirements for dredging projects:

(a) Except where otherwise provided by law, all private and municipal dredging projects require a permit or contract under s. 30.20, Stats., and ch. NR 346. Dredging in portions of the Missis-

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sippi. St. Croix and Black rivers by the U.S. army corps of engineers is governed by s. 30.202, Stats.

(b) All dredging projects require review under s. 144.44, Stats., and chs. NR 500 to 520 for disposal of dredged material under the solid waste management program.

(c) All dredging projects shall be reviewed under ss. 1.11 and 23.11(5), Stats., and ch. NR 150 for compliance with the Wisconsin environmental policy act.

(d) All federally funded, permitted or sponsored dredging projects require water quality certification under ss. 144.025 and 147.01, Stats., and ch. NR 299.

(e) A Wisconsin pollutant discharge elimination system (WPDES) permit under ch. 147, Stats., is required for dredging projects with carriage water return flows to surface water or groundwater.

(f) Plan approval under s. 144.04, Stats., is required for dredging projects which include a dredged material treatment facility.

(g) Sites and facilities for the disposal of hazardous waste and PCBs require review under ss. 144.64 and 144.79, Stats., and chs. NR 500 to 520 and chs. NR 600 to 685.

(2) The project application process shall be coordinated by the department. Except as otherwise provided by law, decisions on all applicable department approvals, permits, contracts and licenses relating to a dredging project shall be made concurrently and with the decision on:

(a) Water quality certification under ch. NR 299 for all federally funded, permitted or sponsored projects, or

(b) Permit or contract under s. 30.20, Stats., and ch. NR 346 for all other projects.

History: Cr. Register, February, 1989, No. 398, eff. 3–1–89; corrections in (1) made under s. 13.93 (2m) (b) 7., Stats., Register, October, 1995, No. 478.

NR 347.05 Preliminary application and analytical requirements. **(1)** Prior to submission of a formal application, anyone seeking to remove material from the beds of waterways shall provide the department with preliminary information including:

(a) Name of waterbody and location of project;

(b) Volume of material to be dredged;

(c) Brief description of dredging method and equipment;

(d) Brief description of proposed disposal method and location and, if a disposal facility is to be used, size of the disposal facility;

(e) Any previous sediment sampling (including field observations) and analysis data from the area to be dredged or from the proposed disposal site;

(f) Copy of a map showing the area to be dredged, the depth of cut, the specific location of the proposed sediment sampling sites and the bathymetry of the area to be dredged; and

(g) Anticipated starting and completion dates of the proposed project.

(2) An initial evaluation shall be conducted by the department within 30 business days after receipt of the information under sub. (1) to determine if there is reason to believe that the material proposed to be dredged is contaminated. This initial evaluation shall be used by the department in specifying sediment sampling and analysis requirements to the applicant under s. NR 347.06 and shall be accomplished with existing data. Factors which shall be considered by the department in its evaluation of the dredging site and, if appropriate the disposal site, include, but are not limited to, the following:

(a) Potential that contaminants may be present. Potential routes that may have introduced contaminants into the dredging site shall be identified by examining appropriate maps, aerial photographs, or other graphic materials that show surface watercourses and groundwater flow patterns, surface relief, proximity to surface and groundwater movement, private and public roads, location of buildings, agricultural land, municipal and industrial sewage and stormwater outfalls, etc., or by making supplemental field inspections.

(b) Previous tests of the material at the dredging site or from other projects in the vicinity when there are similar sources and types of contaminants, water circulation and stratification, accumulation of sediments, general sediment characteristics, and potential for impact on the aquatic environment, as long as nothing is known to have occurred which would render the comparisons inappropriate.

(c) The probability of past introduction of contaminants from land runoff.

(d) Spills of toxic or hazardous substances.

(e) Introduction of contaminants from point sources.

(f) Source and previous use of materials used or proposed to be used as fill.

(g) Natural deposits of minerals and other natural substances.

(h) Any other relevant information available to the department.

History: Cr. Register, February, 1989, No. 398, eff. 3–1–89.

NR 347.06 Sampling and analysis. Upon completion of the initial evaluation, the department shall establish sampling and analysis requirements.

(1) EXCEPTION. Except as provided in subs. (3)(a) and (6), the applicant shall collect and analyze data on sediments to be dredged in the manner outlined in this section.

(2) CORRECT METHODS. Unless otherwise specified, sampling, sample handling and sample analysis to demonstrate compliance with this section shall be in accordance with methods from applicable sources enumerated in ch. NR 149.

(3) NUMBER OF SAMPLES. (a) Sediment sampling may be waived by the department if it determines from its review of available information under s. NR 347.05(2) that sediment contamination is unlikely.

(b) If available information is either insufficient to determine the possibility for sediment contamination, or shows a possibility for sediment contamination, the department shall require the applicant to collect sufficient samples to describe the chemical, physical and biological properties of the sediment. The exact number and location of sediment samples required and analyses to be conducted shall be specified by the department, in consultation with the applicant, based on the initial evaluation and on other factors including, but not limited to, the potential for possibility of contamination, volume and aerial extent of material to be dredged, depth of cut and proposed method of disposal.

(c) For a project involving the disposal of dredged material at an upland disposal site, the department may require samples to be taken from the proposed disposal site and analyzed for parameters found to be elevated in the dredged material sediment samples. The number and location of disposal site samples required shall be specified by the department based on the size and other characteristics of the site.

(d) For a project to be conducted in the Great Lakes with beach nourishment disposal, at least one sample every 250 linear feet of beach with a minimum of 2 samples shall be taken from the proposed beach nourishment disposal site and analyzed for particle size and color. Core or grab samplers may be used.

(4) METHOD OF TAKING SAMPLES. (a) All samples shall be taken with a core sampler except as provided in sub. (3)(d). The department may approve other sampling methods if it finds them to be appropriate.

(b) All sampling equipment shall be properly cleaned prior to and following each sample collection.

(c) Samples collected for PCB, pesticide and other organic analyses shall be collected and processed using metallic (stainless steel preferred) liners, tubs, spoons and spatulas. Samples collected for other chemical analysis, including heavy metals, shall be collected and processed using non–metallic liners, tubs, spoons and spatulas.

(d) Core samples from the dredging site shall be taken to the proposed dredging depth plus 2 feet.

(e) Core samples shall be visually inspected for the existence of strata formation, and a written description including position, length, odor, texture and color of the strata shall be provided to the department.

(5) SAMPLE HANDLING AFTER COLLECTION AND PRIOR TO ANALYSIS. Sample handling and storage prior to analysis shall be in accordance with the maximum holding times and container types given in table F of ch. NR 219. Samples shall be preserved at the time of collection by cooling to 4°C.

(6) ANALYSES TO BE PERFORMED ON SEDIMENT SAMPLES. Analyses shall be done in accordance with methods from applicable sources enumerated in ch. NR 149. Analyses submitted to the department under this chapter shall be done by a laboratory certified or registered under ch. NR 149.

(a) Samples shall be analyzed from each distinct layer observed in the material to be dredged. If no strata formation exists, core samples shall be divided into 2–foot segments, and each segment shall be analyzed for the required chemicals and characteristics. For cores extending into parent material, analysis of only the top 2–foot segment of parent material is required. The department may approve other subsampling methods if it finds them to be appropriate.

(b) All samples shall be analyzed for those parameters listed in table 1 unless waived by the department as provided in par. (d). Elutriate testing may be required for all chemicals listed in Table 1 unless waived by the department as provided in par. (d).

(c) If previous sampling data or other adequate available information indicates the possibility of contamination by chemicals not listed in table 1, the department may require analysis for those chemicals.

(d) If previous sampling data or other adequate available information demonstrates that the possibility of contamination is negligible, analysis for any chemical may be waived, in writing, by the department.

(e) The department may require additional samples and analyses as specified by law or for other appropriate reasons.

TABLE 1
ANALYSES TO BE PERFORMED ON SEDIMENT SAMPLES

	GREAT LAKES	INLAND WATERS
PCB (Total)	X	X
Total 2,3,7,8 TCDD	X	X
Total 2,3,7,8 TCDF	X	X
	GREAT LAKES	INLAND WATERS
Aldrin	X	X
Dieldrin	X	X
Chlordane	X	X
Endrin	X	X
Heptachlor	X	X
Lindane	X	X
Toxaphene	X	X
DDT	X	X
DDE	X	X
Arsenic	X	X
Barium	X	X
Cadmium	X	X
Chromium	X	
Copper	X	X
Cyanide	X	
Iron	X	
Lead	X	X
Manganese	X	
Mercury	X	X
Nickel	X	X
Selenium	X	X
Zinc	X	X
Oil and Grease	X	X
NO^2, NO^3, NH^3 –N, TKN	X	X
Total P	X	X
Grain–size	X	X
Percent Solids	X	X
Total Organic Carbon	X	X

Moisture Content	X	X
Settleability (if return water)	X	X

History: Cr. Register, February, 1989, No. 398, eff. 3-1-89; am. (5) and (6) (intro.), Register, November, 1992, No. 443, eff. 12-1-92.

NR 347.07 Review procedures and review criteria. **(1)** When sediment sampling and analyses have been completed, the applicant shall submit a copy of the testing report to the department. This report shall include raw data for all analyses, a map of the project area showing the specific locations of sediment sampling sites and the name and address of the laboratory which performed the tests. All testing and quality control procedures shall be described and analytical methods, detection limits and quantification limits shall be identified.

(2) The department shall review the information submitted under sub. (1) within 30 business days after receipt and determine the applicable statutory and administrative rule provisions and any additional information required from the applicant under this section.

(3) Based on the submitted testing report the department may after consultation with the applicant require additional sediment sampling and analyses when there is evidence of contamination.

(4) For projects in the Great Lakes involving beach nourishment disposal, grain-size analysis results of the proposed dredged material and the beach shall be compared by the department.

(a) The department may allow beach nourishment disposal if:

1. The average percentage of silt plus clay (material passing a #200 sieve or less than .074 mm dia.) in the dredged material does not exceed the average percentage of silt plus clay in the existing beach by more than 15% and the color of the dredged material does not differ significantly from the color of the beach material.

Note: For example, if the silt plus clay content of the existing beach is 10%, suitable dredged material must have a silt plus clay content of less than 25%.

2. The criteria of any general permit regulating wastewater discharges under the Wisconsin pollutant discharge elimination system is not exceeded.

(5) For all projects where upland disposal is required or planned, the results of sediment sampling and analysis shall be compared by the department to the solid waste disposal standards and criteria specified in chs. NR 500 to 520.

(6) If the bulk sediment analysis criteria in sub. (4) is exceeded, the applicant shall have the option of demonstrating to the department through use of bioassay, or other methods approved by the department, that the dredging and sediment disposal operations will have minimum effects on the environment.

History: Cr. Register, February, 1989, No. 398, eff. 3-1-89; correction in (5) made under s. 13.93 (2m) (b) 7., Stats., Register, October, 1995, No. 478.

NR 347.08 Monitoring, reporting and enforcement. **(1)** SURVEILLANCE. (a) The permittee shall contact the department 5 business days prior to the commencement of dredging to provide an opportunity for the department to review all required environmental safeguards to ensure they are in place and operable.

(b) The department may inspect the dredging project at any time during operation to determine whether requirements of permits and approvals are being met or to conduct effluent sampling.

(2) MONITORING. (a) For those projects authorized in part by a WPDES permit, monitoring, analyses and reporting shall be performed as specified in the WPDES permit.

(b) For all other projects, monitoring, analyses and reporting shall be performed as specified in ss. NR 347.06 (2) and 347.07 (1).

(c) Project characteristics to be monitored may include, but are not limited to, carriage water return flow, total suspended solids, dissolved oxygen concentrations, effluent and receiving water temperatures, receiving stream flow rates, effluent ammonia-nitrogen concentrations, and pH.

(3) SUSPENSION OF WORK. If the department determines that project performance is not in compliance with permit or contract conditions, the permittee shall suspend work upon written notification from the department. This shall be a condition of any permit or contract issued by the department. The permittee shall be accorded an opportunity for hearing in accordance with s. 227.51 (3), Stats. The issuance of a suspension order under this subsection shall not limit other enforcement actions or penalties. The department and permittee shall analyze operational deficiencies and the department shall prescribe changes necessary to bring project operation into conformance with permit or contract conditions.

(4) PENALTIES. (a) Each violation of the conditions of a permit or contract issued under s. 30.20, Stats., or this chapter, may result in a forfeiture of not less than $100 nor more than $10,000 for the first offense and shall forfeit not less than $500 nor more than $10,000 upon conviction of the same offense a second or subsequent time. The permit or contract may be rescinded and appropriate restoration orders may be issued as authorized by ss. 23.79, 30.03, 30.12, 30.15, 30.20, 30.292, 30.294 and 30.298, Stats.

(b) The enforcement provisions of s. 147.21, Stats., shall apply to any violations of WPDES permits associated with dredging projects.

(c) The enforcement provisions of ss. 144.47 and 144.99, Stats., and chs. NR 500 to 520 shall apply to violations of solid waste management approvals for this chapter.

(d) The enforcement provisions of ss. 144.73 and 144.74, Stats., shall apply to violations of any hazardous waste approvals for disposal activities associated with dredging projects authorized by this chapter.

History: Cr. Register, February, 1989, No. 398, eff. 3-1-89; correction in (4) made under s. 13.93 (2m) (b) 7., Stats., Register, October, 1995, No. 478.

CORRESPONDENCE/MEMORANDUM — **State of Wiscons**
Department of Natural Resour

DATE: March 20, 1995

TO: District Solid Waste Program Supervisors/Staff

FROM: Dave Carper - SW/3 DC

SUBJECT: Solid Waste issues related to disposal of PCB contaminated sediments in Wisconsin landfills

The Environmental Protection Agency, on January 24, 1995, issued an approval to the department allowing disposal of PCB contaminated sediments resulting from remediation projects conducted at sites in Wisconsin. There are a number of issues related to disposal of these sediments in Wisconsin's landfills. In an effort to inform those landfills interested in accepting these sediments of the types of requirements they might expect from the department, we have developed a list of the minimum general requirements. A number of these requirements are specifically related to the EPA approval. The remainder are requirements related to Wisconsin's statutes and administrative codes. Please be advised that this is a general list, and that each individual landfill will have specific conditions related to their facility.

Additionally, a number of landfill owner/operators have inquired about pre-qualification for approval to accept PCB contaminated sediments at their facilities. The Department is prepared to review proposals which address the requirements of this memorandum and discuss general wastehandling criteria for the sediments specific to the individual facilities. Upon review of this information, the Department will issue a preliminary opinion to the landfill owner/operators as to whether they substantially meet the requirements for disposal of PCB contaminated sediments. This would not be in the form of a plan of operation modification approval and should not be considered by the landfill owner/operators as an approval to accept sediments for disposal. The intent would be to enable landfills to commit, for bidding purposes, to a specific remediation. A landfill associated with the selected contractor for sediment remediation/excavation would then have to request a modification to their plan of operation to accept PCB contaminated sediment. The landfill owner/operator would be required to adhere to the public notification requirements of this memorandum, which would require a minimum 30-day public notice period, an informational public meeting, a public comment period, and response to any comments received. It is hoped that the Department's notice of "pre-qualification" would streamline the approval process for a facility requesting approval to accept these contaminated sediments.

Issues related to the TSCA approval:

1. The EPA approval allows the department to approve individual landfills to accept for disposal PCB containing sediments at 50 ppm or greater only if they originate from a specified department project.

2. The landfill is required by the conditions of the TSCA approval and s. 40 CFR Section 761.205(a)(1) to notify U.S. EPA of the landfill's PCB

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waste handling activities by filing U.S. EPA Form 7710-53, which identifies the EPA identification number; name, owner, contact and location of the facility; and the type of PCB waste activity engaged in at the facility. The landfill operator is also required by 40 CFR Section 761.207 to sign and maintain copies of the PCB manifest accompanying each load of PCB waste received, and to notify the originator of the PCB waste at the end of each business day of confirmation that the loads were received.

3. PCB contaminated sediments must not be commingled with any potentially incompatible waste. Potentially incompatible wastes include organic solvents and waste products containing organic solvents which can increase the mobility of PCBs.

4. Initial testing of the landfill's leachate for PCBs must be performed. This is required to establish site leachate characteristics prior to accepting contaminated dredge material. The specific analytical method is defined as method 8080 found in "Test Methods for Evaluating Solid Waste", SW-846, U.S. EPA, 3rd edition, November, 1986.

5. The landfill will be required to perform quarterly PCB testing of the leachate for the first four quarters after accepting PCB contaminated dredged material and would use the analytical method previously cited. Notification of detectable levels of PCBs in the leachate is required within 60 days of sampling.

6. Annual PCB testing of the leachate will be required after the first year of quarterly sampling is completed, and will continue through the active life and long-term care period of the facility. The analytical method previously cited must be used. Should significant change in the levels of PCBs detected in the leachate occur, this monitoring schedule may be modified.

7. PCB testing for groundwater. Should significant change in the levels of PCBs detected in the leachate occur, groundwater monitoring may be required. A decision would be made based on indicator parameters in groundwater, levels of PCBs detected, and other site conditions. If determined to be required, PCB monitoring would be added to analytical parameters for the Subtitle D wells at MSW landfills, or as otherwise appropriate for the specific landfill to adequately characterize groundwater conditions.

8. Prior to acceptance of sediments by landfills, the landfill must notify the receiving POTW that the landfill intends to accept PCB contaminated sediments.

9. Groundwater sampled at the landfill monitoring wells must meet s. NR 140.10 groundwater preventative action limit for PCBs (0.003 micrograms per liter). The specific analytical method is defined as method 8080 found in "Test Methods for Evaluating Solid Waste", SW-843, U. S. EPA, 3rd edition, November, 1986. This method currently has a minimum detection limit of approximately 0.01 micrograms per liter.

10. Monitoring well water suspected or known to contain PCBs in excess of s. NR 140.10 groundwater enforcement standards for PCBs (0.03 micrograms per liter) must not be allowed to be discharged directly to the ground or to receiving waters and must be contained, managed and treated as leachate.

11. PCB contaminated sediments must be dewatered or solidified to pass the paint filter test prior to disposal at the landfill.

12. The landfill is required to comply with the record keeping requirements of the TSCA PCB regulations s. 40 CFR Part 761.180(b), which require an annual document log identifying the disposal facility, manifest numbers, dates, quantities, and date of confirmation of PCB waste accepted at the landfill in the calendar year covered. Additionally, the landfill must submit an annual report, which briefly summarizes the records and annual document log, to the Regional Administrator of EPA Region 5 by July 15 of each year. This information must also be submitted to the department as part of the annual report requirements for the landfill.

Additional issues:

13. The landfill owner/operator must submit a request for a modification to the plan of operation for the landfill. The request must include a detailed discussion of dredged material disposal procedures, including but not limited to: material handling; placement location; testing; monitoring; and impacts on financial assurance for long-term care. Additionally, a review fee of $1,500.00 is required to be submitted to the department's Solid Waste Management program.

14. The dredged materials need to be segregated to the degree practical in the landfill. The following type of controls may be required:

   a. Dredged material should be placed as a "monolith", rather than mixed directly with other waste. A thicker mass of sediments over a smaller lateral area is preferred to the extent allowable by stability considerations. Dredged material should be placed in the landfill cell adjacent to the sideslope liner and as close as practical to the final cover to minimize the measures necessary to reduce commingling with other wastes and the amount of waste materials placed above the dredged material.

   b. The "monolith" should be underlain by a geofabric of sufficient mesh size to prevent migration of silt-sized particles from the dredged material. The side slopes of the "monolith" should be no greater than 3 horizontal to 1 vertical and the top slopes should be a minimum of 5%. The final surface should be flat-rolled and covered with 12 inches of granular material with a hydraulic conductivity greater than or equal to 1 X 10' cm/sec at the anticipated field density to facilitate water movement around the dredged material rather than through it. A geonet/geotextile combination with equivalent hydraulic properties may also be considered for this drainage layer.

c. The "monolith" of dredged material must have adequate stability to support it's own weight and the weight of any other materials placed over it without slumping and be able to maintain stable slopes. A minimum unconfined compressive strength of one ton per square foot for finer grained (silt/clay/organic) or a minimum 60% solids for granular material will be used to determine the stability of the dredged material as placed in the landfill. If addition of stabilizing material such as lime, cement or pozzolanic ash is needed to achieve the required specifications, bench scale testing must be performed on the dredged material to determine proper moisture content ranges and compactability prior to disposal.

d. Dredged material should be compacted in maximum 6-inch lifts at the landfill. Thicker lifts would be considered if it can be demonstrated that minimum densities are achievable. Dry density and as-placed moisture content will be determined on the dredged material placed. At least 3 sets of tests should be performed for each acre for every one-foot thickness of dredged material placed.

e. The location of the dredged material must be identified by survey, and records maintained. The disturbance of the sediments must be minimized once they are placed in the landfill (as in drilling of gas extraction wells, or during remedial actions).

f. Dredged material must be disposed of in a manner which prevents wind-blown dust exposure. The department may require daily cover to be placed over the dredged material if necessary to prevent fugitive dust problems.

15. Measures must be taken to contain PCB contaminated dredged material to the specified disposal area. These would include a vehicle wash for cleaning equipment as necessary. Wash water will need to be collected and treated as leachate.

16. Health and safety considerations for the disposal project must be addressed with a site-specific health and safety plan meeting Occupational Safety and Health Administration guidance as outlined in 29 C.F.R. § 1910.120.

Long Term Care Costs

17. The established long-term care financial responsibility account would need to be modified to reflect the additional cost associated with PCB leachate monitoring. Financial responsibility in anticipation of leachate treatment or groundwater monitoring will not be required initially. If problems occur in the future which require additional monitoring or remedial action, financial responsibility for monitoring/remediation will have to be established at that time.

Specific conditions will be required for any landfill requesting a plan modification to accept these sediments. The preferred disposal location in a landfill would be such that a minimum amount of municipal solid waste be placed above the "monolith" of dredged material. Priority will be given landfills which can selectively place this dredged material or, ideally, dedicate a monofill for dredged material disposal with a discreet leachate collection system.

APPROVED:

Lakshmi Sridharan

Lakshmi Sridharan, Ph.D, P.E., Chief
Solid Waste Management Section
Bureau of Solid & Hazardous Waste Management

cc: Paul Didier - SW/3
Kevin Kessler - SW/3
Mark Giesfeldt - SW/3
→ Barb Zellmer - SW/3
Chuck Leveque - SW/3

CORRESPONDENCE/MEMORANDUM — State of Wisconsin

DATE: August 6, 1998

TO: Paul Putzier - RETEC
Alessandro Battaglia - RETEC

FROM: Ed Lynch - DNR

SUBJECT: Landfill Location and Disposal Capacity Information

Attached to this table is a statewide list of municipal and non-municipal solid waste disposal facilities. Municipal sites include those operated by counties and non-municipal sites include company owned landfills. For instance, Brown County -East is the first site listed under municipal and Appleton Papers is the first site listed under non-municipal. Also attached is a separate list of landfills with the facilities' contacts identified. You may need to contact these people to identify the specific location of the landfills. I have also have included an attachment identifying the DNR waste management staff assigned to the counties. These staff may also be contacted for location information.

These landfills are operated in accordance with the requirements of the chapter NR 500 series of the Wis. Adm. Code. The municipal sites and many of the non-municipal sites may be capable of receiving plan modifications for disposal of PCB contaminated sediments should it be necessary. I am forwarding this information to you so you are aware of the available landfill capacity and haul distance in the Northeast Region (NER) as well as other locations that may be near the Fox River for the Feasibility Study. Please note that landfills under construction or proposed are not on the list. In NER, that includes two facilities. One is in Calumet County which will be operated by Superior Environmental Services. The other will be county operated facility in Brown County.

Please note that the Bayport sediment management facility is not included on the attached list. Bayport is not a licensed solid waste landfill because it had an exemption from the normal NR 500 series design and location requirements. This is a key point because DNR could not allow Bayport to accept PCB sediment under the state's TSCA approval from EPA. In your evaluation of alternatives, consideration of available landfill capacity at facilities operated by the PRPs for the management of dredged sediment sludge is an appropriate option, should dredging be necessary. Please be aware that these PRP industrial sites may not meet the requirements to obtain an approval under the DNR's TSCA approval.

You may wish to discuss these existing and proposed facilities with Len Polczinski who is the NER Waste Management Team Supervisor. Len's phone number is 920/492-5870. Len may also help with facilitating communications and discussions with county and local governments as well as serve as a sounding board for ideas dealing with dredged sediment management. You may also want to consider the requirements of the Wisconsin Solid Waste Landfill Siting law when you evaluate the feasibility of alternative using Bayport or the PRP industrial landfills.

For your information I have also attached to this memo a DNR guidance memo discussing applicability or department regulations to dredge sediment material management. Please distribute this information to the appropriate members of your Feasibility Study team. You may give me a call if you have any questions at 608/266-3084.

Attachments:

CC: Len Polczinski - NER
Bob Paulson - WT/2
Tim Thompson - RETEC
Paul Huebner - WA/3
Kevin Kessler - WA/3
George Boronow - NER
Steve Westenbroek - Baird
Jim Hahnenberg - EPA SR/6J

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WISCONSIN SOLID WASTE LANDFILL /AGE/CAPACITY REPORT
WISCONSIN DEPARTMENT OF NATURAL RESOURCES-BUREAU OF WASTE MANAGEMENT

REVISED , 1998

Municipal Waste Sites

FACILITY NAME	LIC NO	RE	TYPE	INITIAL CAPACITY	CAPACITY AS OF 1/1/97 CU YDS	1997 TONNAGE* Cat. 1 TONNAGE	1997 TONNAGE* Cat. 2-6,20 TONNAGE	CAPACITY AS OF 1/1/98 CU YDS	STATUS	Out-of-State Waste (In Tons) Received in 1997: IL	IN	IA	MI	MN	Other
BROWN COUNTY EAST LANDFILL	2569	NE	LF3	4,500,000	1,311,871	161,336	47,893	934,875		0	0	0	0	0	0
BROWN COUNTY WEST LANDFILL	2568	NE	LF3	3,500,000	0	0	0	0	Closed	0	0	0	0	0	0
DOOR COUNTY SANITARY LANDFILL	2937	NE	LF3	741,000	69,500	17,277	0	31,184		0	0	0	0	0	0
KEWAUNEE COUNTY SW BALEFILL & COMPOST SITE	2975	NE	LF3	517,000	267,679	11,638	0	259,367		0	0	0	0	0	0
MAR-OCO LANDFILL	3095	NE	LF3	1,480,000	1,114,336	16,791	0	1,080,754		0	0	0	0	0	0
OUTAGAMIE COUNTY SW DIV LANDFILL	2484	NE	LF3	4,740,000	1,255,491	167,189	43,305	1,653,029	exp 710,000	0	0	0	0	0	0
SHAWANO CTY PHASE 2 LANDFILL	3069	NE	LF3	405,000	11,752	13,865	8,342	88,088		0	0	0	0	0	0
W M W I - RIDGEVIEW RECYCLING & DISPOSAL	3041	NE	LF3	9,689,000	1,830,600	241,974	200,313	1,490,800		0	0	0	0	0	0
W M W I - VALLEY TRAIL	3066	NE	LF3	2,813,000	4,829,736	239,846	265,269	4,252,805		0	0	0	0	1,200	0
WASHINGTON ISLAND LANDFILL/COMPOST SITE	2837	NE	LF1	9,320	876	25	10	818		0	0	0	0	0	0
WINNEBAGO COUNTY SUNNYVIEW LF/COMPOST SITI	3175	NE	LF3	8,000,000	5,362,798	194,655	25,098	5,015,557		0	0	0	0	0	0
ANTIGO CITY LANDFILL	3294	NO	LF2	203,000	25,559	2,268	0	21,779		0	0	0	0	0	0
ASHLAND CITY OF LANDFILL	3087	NO	LF2	159,415	27,000	2,585	0	18,337		0	0	0	0	0	0
BFI WASTE SYSTEMS OF NORTH AMERICA INC	3144	NO	LF3	978,000	9,000	12,964	8,155	0		0	0	0	6,955	9,233	0
BFI WASTE SYSTEMS OF NORTH AMERICA INC	3474	NO	LF3	4,347,900	329,012	93,341	29,993	219,415		0	0	0	0	69,298	0
HIGHWAY G SANITARY LANDFILL	3100	NO	LF2	250,000	183,330	8,025	0	169,995		0	0	0	0	0	0
LINCOLN COUNTY SANITARY LANDFILL	3141	NO	LF3	825,000	638,549	14,246	0	606,966		0	0	0	0	0	0
ONEIDA COUNTY	2805	NO	LF3	1,100,000	130,918	19,749	6,477	165,000		0	0	0	0	0	0
SANITARY NORTHWOODS REFUSE DISPOSAL INC	3212	NO	LF3	500,000	363,479	7,471	0	328,320		0	0	0	0	0	0
SUPERIOR CITY OF MOCASSIN MIKE LANDFILL	2627	NO	LF3	1,500,000	298,318	70,726	3,031	217,488		0	0	0	0	42,866	0
W M W I - TIMBERLINE TRAIL RDF	3455	NO	LF3	2,933,000	2,513,335	224,580	50,871	2,155,505		0	0	0	0	122,959	0
DANE COUNTY LF #2 RODEFELD	3018	SC	LF3	3,800,000	2,913,936	83,448	35,499	2,745,273		0	0	0	0	0	0
DEER TRACK PARK INC	3230	SC	LF3	2,862,000	1,873,396	229,762	15,692	1,368,862		0	0	0	0	0	0
GREEN COUNTY LANDFILL	2990	SC	LF3	495,000	127,086	15,260	0	117,167		0	0	0	0	0	0
RICHLAND CENTER CITY LANDFILL	3065	SC	LF2	250,000	177,336	0	0	177,336	Site Inactive	0	0	0	0	0	0
ROCK COUNTY/JANESVILLE CITY OF LANDFILL	3023	SC	LF3	4,200,000	1,821,900	124,704	8,731	1,279,449		19,461	0	0	0	0	0
SAUK COUNTY SANITARY LANDFILL	2978	SC	LF3	1,284,000	627,417	24,286	0	586,940		0	0	0	0	0	0
SUPERIOR GLACIER RIDGE LANDFILL	3068	SC	LF3	3,885,800	1,461,667	254,032	61,800	1,051,994		0	0	0	0	0	0
SUPERIOR VALLEY MEADOWS LANDFILL	2686	SC	LF3	1,594,700	325,724	89,780	45,910	159,000		2,744	412	2,884	0	0	0
KESTREL HAWK PARK	572	SE	LF3	5,000,000	7,652,670	115,905	33,995	7,347,615		36,509	0	0	0	0	0
SUPERIOR EMERALD PARK INC	3290	SE	LF3	3,550,360	2,591,771	473,417	219,968	1,776,867		2,559	0	2,245	0	0	0
W M W I - MALLARD RIDGE NORTHERN EXPANSION	3244	SE	LF3	5,197,000	3,891,504	264,141	50,083	3,423,708		100,560	0	4,450	0	0	0
W M W I - METRO RECYCLING & DISPOSAL FACILTY	1099	SE	LF3	19,000,000	1,986,335	377,593	85,670	1,432,000		0	0	0	0	0	0
W M W I - ORCHARD RIDGE RECYCLING & DISP FAC	3360	SE		9,352,900	7,582,181	283,127	138,524	6,928,360		135		2,844	0	0	0
W M W I - PHEASANT RUN RECYCLING & DISPOSAL	3062	SE	LF3	6,936,900	3,488,400	771,774	65,847	2,280,600		722,188	0	0	0	0	0
ABBOTSFORD CTY LANDFILL	2932	WC	LF1	50,000	8,545	420	0	7,495		0	0	0	0	0	0
ADAMS COUNTY LANDFILL & RECYCLING CENTER	3150	WC	LF3	700,000	464,486	6,272	0	451,942		0	0	0	0	0	0
JACKSON COUNTY SANITARY LANDFILL INC	2004	WC	LF3	700,000	94,929	15,119	2,585	68,153		0	0	0	0	0	0
JUNEAU COUNTY LANDFILL #2	3070	WC	LF2	420,000	237,320	6,383	0	225,265		0	0	0	0	0	0
LA CROSSE COUNTY	3253	WC	LF3	1,840,000	1,359,983	34,689	10,377	1,300,270		0	0	0	0	4,392	0
MARATHON COUNTY LANDFILL AREA B	3338	WC	LF3	2,508,000	1,847,300	93,535	40,028	1,651,300		0	0	0	0	0	0
MONROE COUNTY RIDGEVILLE SITE & DEMO LF	2858	WC	LF3	823,000	229,000	19,644	4,234	193,000		0	0	0	0	0	0
PORTAGE COUNTY LANDFILL	2966	WC	LF3	1,280,000	356,160	30,360	0	295,440		0	0	0	0	0	0
SUPERIOR CRANBERRY CREEK	2967	WC	LF3	1,200,000	1,400,000	127,344	0	1,250,000		0	0	0	153	0	0
SUPERIOR SEVEN MILE CREEK LANDFILL INC-SEC#2	3097	WC	LF3	3,000,000	2,217,800	124,627	6,010	2,039,000		0	0	0	0	10,369	0
VERNON COUNTY SOLID WASTE/RECYCLING FACILIT	3268	WC	LF2	314,942	232,623	8,042	0	216,539		0	0	0	0	0	0
TOTALS (MUNICIPAL)				129,435,237	65,542,608	5,094,214	1,513,712	57,083,657		884,157	412	12,423	7,108	260,317	0

FACILITY NAME	LIC NO	RE	TYPE	INITIAL CAPACITY	CAPACITY AS OF 1/1/97 CU YDS	1997 TONNAGE* Cat. 1 TONNAGE	Cat. 2-6,20 TONNAGE	CAPACITY AS OF 1/1/98 CU YDS	STATUS	IL	Out-of-State Waste (In Tons) Received In 1997 IN	IA	MI	MN	Other
Non-Municipal Waste Sites															
APPLETON PAPERS INC-LOCKS MILL LF	3036	NE	LF2	425,000	42,900	0	22,863	65,800		0	0	0	0	0	0
BADGER PAPER MILLS INC	1344	NE	LF2	375,000		0	0		Closed	0	0	0	0	0	0
FORT JAMES CORP GREEN BAY WEST LANDFILL	2332	NE	LF4	9,360,000	4,302,810	0	351,716	3,972,964		0	0	0	0	0	0
GENERAL CHEMICAL CORP ALUM LF	1907	NE	LF2	300,000	128,361	0	1,150	127,334		0	0	0	0	0	0
JAMES RIVER OPERATING CO-NORTHLAND LANDFILL	2893	NE	LF4	700,200	729,000	0	14,038	265,000		0	0	0	0	0	0
SADOFF & RUDOY INDUSTRIES	1554	NE	LF3	700,000	500,000	0	34,425	500,000	cap >500,000	0	0	0	0	0	0
SHAWANO PAPER MILLS LANDFILL	2719	NE	LF2	108,000	7,554	0	2,376	4,941		0	0	0	0	0	0
THILMANY PHASE 5 RED HILLS LANDFILL	3251	NE	LF3	2,749,471	2,454,460	0	91,963	2,325,954		0	0	0	0	0	0
WAUPACA FOUNDRY INC LANDFILL #3	3412	NE		1,339,000	1,030,218		200,817	881,464		0	0	0	0	0	0
WISCONSIN TISSUE MILLS INC LF	3131	NE	LF4	1,710,300	139,081	0	121,362	0		0	0	0	0	0	0
WISCONSIN TISSUE MILLS NORTH SITE	3275	NE	LF4	3,062,000	378,400	0	57,176	312,869		0	0	0	0	0	0
FORT JAMES OPERATING CO	2826	NO	LF2	410,000	29,963	0	23,986	10,838		0	0	0	0	0	0
FRASER PAPERS INC LANDFILL	3051	NO	LF2	490,000	164,455	0	30,678	133,845		0	0	0	0	0	0
NSP WOODFIELD ASH LF	3233	NO	LF2	255,000	220,870	0	15,911	202,203		0	0	0	0	0	0
RHINELANDER PAPER CO LANDFILL	2965	NO	LF2	394,000	53,000	0	0	53,000		0	0	0	0	0	0
TENNECO PACKAGING INC-TOMAHAWK LANDFILL	3114	NO	LF4	3,014,000	2,548,000	0	25,011	2,467,700		0	0	0	0	0	0
DAIRYLAND POWER COOP	3122	SC	LF2	83,400	59,764	0	0	59,764		0	0	0	0	0	0
GREDE-REEDSBURG FOUNDRY LANDFILL	2974	SC	LF2	375,000	104,414	0	19,594	89,342		0	0	0	0	0	0
TERRA ENGINEERING & CONSTRUCTION	1912	SC	LF2	75,000	54,668	0	16	54,642		0	0	0	0	0	0
US ARMY BADGER ARMY AMMUNITION PLT LANDFILL	3118	SC	LF2	130,000	83,424	0	335	82,508		0	0	0	0	0	0
W M W I - MADISON PRAIRIE	3318	SC	LF3	4,284,000	2,715,562	0	113,006	2,556,606		0	0	0	0	0	0
WIS POWER & LIGHT CO COLUMBIA GEN STN	2325	SC	LF4	500,000	2,360	0	0	2,360		3,932	0	0	0	6	0
WIS POWER & LIGHT CO COLUMBIA GEN STN	3025	SC	LF4	6,529,200	5,106,341	0	59,233	5,056,980		0	0	0	0	0	0
WIS POWER & LIGHT CO NELSON DEWEY GEN STATI	2525	SC	LF4	607,000	48,000	0	12,825	22,853		0	0	0	0	0	0
WIS POWER & LIGHT CO ROCK RIVER GEN STN	728	SC	LF2	350,000	91,018	0	3,128	20,000	98 cap - survey	0	0	0	0	0	0
FALK CORP	1882	SE	LF4	569,000	243,676	0	47,535	208,465		0	0	0	0	0	0
FUTURE PARKLAND DEVELOPMENT INC	3120	SE	LF4	448,000	200,822	0	42,486	163,224		0	0	0	0	0	0
KOHLER CO LANDFILL	1508	SE	LF4	4,240,000	500,000	0	65,010	512,000	cap >500,000	0	0	0	0	0	0
MANN BROS LANDFILL	1996	SE	LF2	110,000	110,000	0	5,000	100,000		0	0	0	0	0	0
WEPCO CALEDONIA LANDFILL	3232	SE	LF4	4,050,000	3,180,175	0	186,412	2,993,763		0	0	0	0	0	0
WEPCO HWY 32 LANDFILL	2801	SE	LF4	2,000,000	926,566	0	61,599	864,967		0	0	0	0	0	0
WEPCO PLEASANT PRAIRIE LNDFL	2786	SE	LF4	1,470,000	4,067,000	0	8,302	4,058,698		0	0	0	0	0	0
WEPCO SYSTEMS CONTROL CENTER ASH LANDFILL	2887	SE	LF4	560,000	1,444,646	0	7,009	1,437,637		0	0	0	0	0	0
WIS POWER & LIGHT CO-EDGEWATER POWER PLANT	2853	SE	LF4	1,150,000	747,000	0	38,978	714,518		0	0	0	0	0	0
COLTEC INDUSTRIES-FARNAM MEILLOR SEALING SY	640	WC	LF2			0	0	0	Closed	0	0	0	0	0	0
CONSOLIDATED PAPERS-WATER QUALITY CENTER L	2488	WC	LF4	2,954,600	679,384	0	26,836	647,040		0	0	0	0	0	0
CONSOLIDATED PAPERS INC-KRAFT DIV	1838	WC	LF4	2,000,000	276,500	0	98,909	161,478		0	0	0	0	0	0
CONSOLIDATED PAPERS WATER RENEWAL CENTER	1686	WC	LF4	1,551,000	659,534	0	53,433	591,001		0	0	0	0	0	0
DAIRYLAND POWER COOPERATIVE	2927	WC	LF4	1,655,700	664,516	0	77,772	724,723		0	0	0	0	0	0
MOSINEE PAPER CORP LANDFILL	2806	WC	LF2	500,000	106,450	0	6,316	100,000		0	0	0	0	0	0
NEENAH PAPER - WHITING MILL LANDFILL	2576	WC	LF2	169,000	107,453	0	0	0	Closing	0	0	0	0	0	0
NEKOOSA PAPERS INC ASH BARK SITE	1365	WC	LF4	1,260,000	973,099	0	30,106	935,524		0	0	0	0	0	0
NEKOOSA PAPERS INC WW TREATMENT SITE	2613	WC	LF4	2,736,369	820,642	0	52,303	745,852		0	0	0	0	0	0
PLAINWELL TISSUE	2695	WC	LF4	1,200,000	125,452	0	33,107	45,000		0	0	0	0	0	0
WAUSAU-MOSINEE PAPER CO LANDFILL #3	3115	WC	LF2	368,900	0	0	14,216	0		0	0	0	0	0	0
WIS PUBLIC SERV CORP-WESTON ASH DISP SITE #3	3067	WC	LF4	873,000	863,768	0	0	863,768		0	0	0	0	0	0

FACILITY NAME	LIC NO	RE	TYPE	INITIAL CAPACITY	CAPACITY AS OF 1/1/97 CU YDS	1997 TONNAGE* Cat. 1 TONNAGE	Cat. 2-6,20 TONNAGE	CAPACITY AS OF 1/1/98 CU YDS	STATUS	Out-of-State Waste (In Tons) Received in 1997 IL	IN	IA	MI	MN	Other
WIS PUBLIC SERVICE CORP WESTON #3 LANDFILL	2879	WC	LF2	350,000	46,448	0	847	45,742		0	0	0	0	0	0
TOTAL (NON-MUNICIPAL)				68,541,140	37,737,754	0	2,057,785	35,182,367		3,932	0	0	0	6	0
TOTAL(combined)				197,976,377	103,280,362	5,094,214	3,571,497	92,266,024		888,089	412	12,423	7,108	260,323	0

LF1=<50,000 CYDS; LF2=50,000-500,000 CYDS;LF3=>500,000 CYDS;LF4>500,000 CYDS(MONOFILL)
CAT. 1=MUNICIPAL SOLID WASTE
CAT. 2-6=ASHES & SLUDGES FROM UTILITY POWER PLANTS; PULP OR PAPERMILL WASTE/SLUDGES;FOUNDRY MFG
WASTES WASTEWATER TREATMENT PLANT WASTE SLUDGES; AND ALL OTHER SOLID WASTE NOT DESIGNATED AS HAZARDOUS OR MINING WASTE
CAT. 20=ASH FROM INCINERATION FOR ENERGY RECOVERY
EXCLUDED ARE WASTES EXEMPT FROM ENVIRONMENTAL
OUT OF STATE WASTE=ALL WASTE CATEGORIES, INCLUDING WASTE EXEMPT FROM FEES
(APPROX 28,976 TONS OF OUT OF STATE WASTE WAS WASTE EXEMPT FROM FEES)

***Tonnages which have been reported as exempt from environmental fees are not included in these two columns. However, both exempt and non-exempt tonnages are reported in the columns representing waste received from other states. 28,976 tons of waste received from other states were reported as being exempt from environmental fees.**

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

1/27/95

REPLY TO THE ATTENTION OF

R-19J

George E. Meyer
Secretary
Wisconsin Department of Natural Resources
Box 7921
Madison, Wisconsin 53707

RECEIVED

Dear Mr. Meyer:

Pursuant to the Federal Polychlorinated Biphenyl (PCB) regulations published on February 17, 1978, 40 Code of Federal Regulations (C.F.R.) § 761.60 (a) (5), under the authority of the Toxic Substances Control Act (TSCA) of 1976 (Public Law 94-469), 15 U.S.C. §§ 2605 and 2617, the United States Environmental Protection Agency, Region 5 (U.S. EPA) is issuing the enclosed document entitled "In The Matter of The State of Wisconsin, Department of Natural Resources, Approval To Dispose of Polychlorinated Biphenyls (PCBs)." This approval allows the Wisconsin Department of Natural Resources (WDNR) to select disposal facilities that comply with Wisconsin Administrative Code Chapters NR 500-520 for the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater from sediment remediation projects conducted under the authority and supervision of the WDNR. In granting this approval, the U.S. EPA retains all of its authority to issue PCB disposal approvals in the State of Wisconsin under 40 C.F.R. §§ 761.60, 761.70, and 761.75.

This approval is based upon the WDNR's May 6, 1994 application to dispose of dredged sediments by an alternative disposal method, under 40 C.F.R. § 761.60 (a) (5), and upon the U.S. EPA's evaluation of the State of Wisconsin's solid waste landfill regulations (Wisconsin Administrative Code Chapters NR 500-520). In addition, the approval is based upon the Agency's conclusion that the disposal of PCB contaminated sediments in a State of Wisconsin solid waste landfill will provide adequate protection to human health and the environment. In evaluating this application, the U.S. EPA has given great weight to the WDNR's record of commitment to environmental protection and demonstrated ability to administer its programs.

This approval shall be effective upon the date of my signature, and it may be terminated at any time by either the WDNR or the U.S. EPA by written notice to the other party. The WDNR and the U.S. EPA will meet at the end of each year to discuss the progress made under this program and to discuss the objectives for the next year.

While the U.S. EPA anticipates no significant problems with the State's administration of this approval, it is the responsibility of the WDNR and of the disposal facilities selected under this approval to ensure that all applicable provisions of TSCA, the Federal PCB regulations, and the terms of this approval are followed. Violation of any of the applicable provisions may be cause for an enforcement action under Section 15 of TSCA, 15 U.S.C. § 2614.

In closing, I applaud the WDNR's plans for remediation of PCB contaminated sediments from State waters. The WDNR is clearly at the forefront of such efforts. We at Region 5 also place a high priority on remediation of contaminated sediments from our rivers and lakes. It is my hope that by issuing this disposal approval the U.S. EPA will help to realize WDNR's ambitious sediment program.

Please contact Phyllis Reed of my staff, at (312) 886-6086, if you have any questions pertaining to this matter.

Sincerely yours,

David A. Ullrich

for Valdas V. Adamkus
Regional Administrator

Enclosure

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5

IN THE MATTER OF:	)	APPROVAL TO DISPOSE OF POLYCHLORINATED BIPHENYLS (PCBs)
THE STATE OF WISCONSIN	)	
DEPARTMENT OF NATURAL RESOURCES	)	

AUTHORITY

This approval is issued pursuant to Sections 6(e)(1) and 18(a)(2)(B) of the Toxic Substances Control Act of 1976 (TSCA), Public Law No. 94-469, 15 U.S.C. §§ 2605 and 2617, and the Federal PCB Regulations, 40 C.F.R. § 761.60(a)(5).

EFFECTIVE DATE

This approval shall be effective upon the signature of the Regional Administrator.

BACKGROUND

Section 6(e)(1)(A) of TSCA requires the United States Environmental Protection Agency (U.S. EPA) to promulgate rules for the disposal of polychlorinated biphenyls (PCBs). The rules implementing section 6(e)(1)(A) were published in the Federal Register of May 31, 1979 (44 FR 31514) and recodified in the Federal Register of May 6, 1982 (47 FR 19527). Those rules require, among other things, that various types of PCBs and PCB Articles be disposed of in U.S. EPA-approved landfills (40 C.F.R. § 761.75), incinerators (40 C.F.R. § 761.70), high efficiency boilers (40 C.F.R. § 761.60), or by alternative methods (40 C.F.R. § 761.60(e)) that demonstrate a level of performance equivalent to U.S. EPA-approved incinerators. Those rules also allow for the approval to dispose of dredged materials by an alternate method (40 C.F.R. § 761.60(a)(5)) that provides adequate protection to health and the environment, provided that disposal in a U.S. EPA-approved incinerator (40 C.F.R. § 761.70) or chemical waste landfill (40 C.F.R. § 761.75) is not reasonable and appropriate based on technical, environmental, and economic considerations. The May 31, 1979 Federal Register designated Regional Administrators as the approval authority for PCB disposal facilities.

Section 18(a)(2)(B) of TSCA prohibits any State or political subdivision of a State from establishing or continuing in effect any requirement applicable to any chemical substance or mixture or article containing such substance or mixture regulated under

Sections 5 or 6 of TSCA, except that a State may regulate the disposal of such chemicals, mixtures, and articles as described at Section 6(a)(6) of TSCA. U.S. EPA has determined that under TSCA, State requirements regarding disposal of PCBs are completely exempt from Federal preemption insofar as they prescribe what may be done within the State boundaries, but that a State may not require PCBs generated within its boundaries to be disposed of by a method less restrictive than prescribed by TSCA (43 FR 7153, February 17,1978).

FINDINGS

1. On May 6, 1994, the Wisconsin Department of Natural Resources (WDNR) submitted a written application to the Regional Administrator of Region 5 to dispose of sediments containing PCBs at concentrations of 50 ug/g (ppm) or greater from remediation projects authorized and supervised by the WDNR in landfills within Wisconsin which comply with Wisconsin Administrative Code (Wis. Adm. Code) chapters (chs.) NR 500-520 and have been authorized under § NR 157.07, Wis. Adm. Code, to accept PCB contaminated sediments.

2. In 1989, the Wisconsin State Legislature recognized the serious problem contaminated sediments present to the State by providing funding to establish WDNR's sediment remediation program. The goal of the program is to restore the surface waters of the state where the resource uses have been impaired or damaged by the presence of contaminated sediments.

3. Sediments contaminated with PCBs represent a serious risk to human health through consumption of contaminated fish; represent risks to aquatic ecosystems, which include endangered species; and present limitations to economic well-being by impairing commercial fisheries, recreational uses, and commerce through increased dredging costs.

4. The WDNR sediment remediation program has set goals to fully restore aquatic environments with cleanup standards for PCBs in the parts per billion range where environmentally and technically feasible.

5. The PCB contaminated sediment problem in Wisconsin is large in scope. There are approximately seven million cubic yards of sediments contaminated with PCBs which need to be remediated to restore full beneficial uses of impaired overlying waters.

6. Presently, there is no U.S. EPA-approved PCB disposal facility within the State of Wisconsin.

7. The disposal of PCB containing sediments from WDNR remediation projects in existing out of state PCB disposal facilities is not reasonable and appropriate because the WDNR's cleanup goals and the technical constraints of sediment remediation will likely generate a significantly larger volume of TSCA regulated sediments during remediation than existed in situ; because of the risk presented by delaying remediation efforts in dynamic, often high energy, and ecologically sensitive aquatic environments and the additional risk of spills presented by long distance shipping of such large quantities of contaminated sediments; and because increased disposal costs could limit planned State sediment remediation efforts and would prevent much needed sediment remediation and risk reduction in the State of Wisconsin.

8. Based on technical, environmental, and economic considerations, disposal of PCB contaminated sediments within the scope of the WDNR application in a TSCA incinerator or TSCA chemical waste landfill is not reasonable and appropriate.

9. PCBs are regulated in the State of Wisconsin by ch. NR 157, Wis. Adm. Code. Section NR 157.07, Wis. Adm. Code, authorizes the WDNR to approve the disposal of PCB contaminated sediments into chs. NR 500-520, Wis. Adm. Code, landfills as an alternate disposal option.

10. The disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater in a landfill which fully complies with chs. NR 500-520, Wis. Adm. Code, and with the additional conditions of this approval, as set out herein, provides adequate protection to human health and the environment as required under 40 C.F.R. § 761.60(a)(5).

11. Under the supervision of the WDNR, the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater in a landfill which fully complies with chs. NR 500-520, Wis. Adm. Code, and with the additional conditions of this approval set out herein, provides the same level of protection required for these sediments by U.S. EPA, Region 5, and therefore is not less restrictive than TSCA.

CONDITIONS OF APPROVAL

40 C.F.R. § 761.60(a)(5) provides that the Regional Administrator may set limitations in an alternate disposal approval. This approval is conditioned upon the WDNR sediment remediation program's compliance with the following conditions:

1. This approval applies only to sediments contaminated at PCB concentrations of 50 ppm or greater which have originated in Wisconsin waterways. Dilution of sediments to reduce the PCB concentration to below 50 ppm is not allowed. Disposal of sediments contaminated at concentrations of 500 ppm or greater is subject to concurrence by both U.S. EPA, Region 5, and the WDNR on a case by case basis.

2. This approval applies only to sediment remediation projects conducted under the authority and supervision of WDNR.

3. WDNR shall provide a written notice of project activity to U.S. EPA, Region 5 within 30-days following the selection of each sediment disposal landfill under this approval.

4. WDNR shall provide public notification at least 30-days prior to the selection of each sediment disposal landfill under this approval. If this notification generates sufficient public interest, WDNR shall hold a public meeting to discuss the selection of the landfill. WDNR shall consider all oral and written comments received prior to issuing a landfill plan modification to accept PCB contaminated sediments.

5. WDNR shall give full consideration to issues of environmental justice in selecting or siting the sediment disposal landfills under this approval.

6. WDNR shall issue a plan modification to the selected landfill requiring the landfill to comply with approval conditions numbered 11, 12, 14, 16, 18, 19, 21, 24, and 25, as set forth herein.

7. In issuing a plan modification to a chs. NR 500-520, Wis. Adm. Code, landfill for disposal of PCB contaminated sediments, WDNR shall specify to the selected landfill(s) the nature of the remediation and disposal project. This plan modification shall also include a statement that the facility may be used for the disposal of PCB containing sediments at 50 ppm or greater only if they originated from a specified WDNR project.

8. Prior to issuing a plan modification for a landfill to accept PCB contaminated sediment, WDNR shall review all past exemptions from chs. NR 500-520, Wis. Adm. Code, granted to said landfill and determine whether any exemption is relevant to TSCA and the conditions of this approval. If the exemption is relevant to TSCA or the conditions of this approval, WDNR shall receive U.S. EPA concurrence with the exemption before issuing the plan modification.

9. If WDNR issues additional exemptions from chs. NR 500-520, Wis. Adm. Code, relevant to this approval, after a landfill

has received a plan modification, WDNR shall obtain U.S. EPA concurrence before placing additional PCB contaminated sediments in the landfill.

10. WDNR shall provide written notice to each selected landfill that the landfill is required under 40 C.F.R. § 761.205(a)(1) to notify U.S. EPA of the landfill's PCB waste handling activities by filing U.S. EPA Form 7710-53.

11. Prior to placing any PCB contaminated sediment in a landfill, the selected landfill shall file U.S. EPA Form 7710-53, as required by 40 C.F.R. § 761.205(a)(1).

12. PCB contaminated sediments placed in a chs. NR 500-520, Wis. Adm. Code, landfill may not be commingled with any potentially incompatible waste. Potentially incompatible wastes are those wastes that have the capacity to mobilize PCBs.

13. WDNR shall conduct an annual evaluation of PCB (≥50 ppm) sediment disposal projects. WDNR shall submit an evaluation report to the Regional Administrator, U.S. EPA, Region 5, by July 1 of each year covering the previous calendar year's activities under the approval. The report shall include the total volume of PCB contaminated sediment disposed under this approval during the year. The conditions of this permit shall serve as a basis for this evaluation. Upon receipt of the WDNR annual evaluation report, U.S. EPA, Region 5 shall comment either by concurring with the evaluation or by indicating where U.S. EPA disagrees with the results.

14. In the event that this permit is terminated by either the U.S. EPA or WDNR, PCB contaminated sediments previously disposed in a landfill designated pursuant to this approval shall be considered by U.S. EPA to have been properly disposed of and in full compliance with 40 C.F.R. § 761.60 requirements, provided that the sediment was disposed of according to State regulatory requirements and the conditions of this approval and that the landfill continues to operate under the terms and conditions of this approval.

15. In the event that this approval is terminated, WDNR shall ensure that the landfill continues to comply with the monitoring and corrective action requirements of this approval.

16. Owners or operators of landfills accepting PCB contaminated sediments under this approval shall be required by WDNR to test for PCBs in the leachate on a quarterly basis for the first year following disposal. If no PCBs are detected in leachate, the WDNR may allow testing on an annual basis. The landfill owner or operator shall be required by WDNR to

perform PCB sampling at site groundwater monitoring wells in the event of any significant change to PCB levels in the leachate. Leachate or groundwater known or suspected of having concentrations of 50 ppm or greater shall be managed as PCB waste in accordance with § NR 157.07, Wis. Adm. Code, and 40 C.F.R. § 761.60.

17. Prior to WDNR issuing a plan modification for a landfill to accept PCB contaminated sediment, the owner or operator of the landfill shall analyze their leachate for PCBs and shall provide WDNR with a copy of the analytical results.

18. Prior to the discharge of leachate to a publicly owned treatment works (POTW), and regardless of the actual PCB concentration in the leachate, a landfill selected under this approval shall notify the POTW that the landfill accepts PCB contaminated sediments.

19. Groundwater at any landfill accepting PCB contaminated sediments under this approval shall meet § NR 140.10, Wis. Adm. Code, groundwater preventive action and enforcement standards for PCBs, as defined in the point of standards application at § NR 140.22, Wis. Adm. Code.

20. The WDNR shall respond to exceedances of groundwater standards in accordance with §§ NR 140.24, NR 140.26, and ch. NR 708, Wis. Adm. Code.

21. Monitoring well water suspected or known to contain PCBs in excess of § NR 140.10, Wis. Adm. Code, groundwater standards for PCBs of 0.03 parts per billion shall not be discharged directly to the ground or to receiving waters and shall be contained, managed, and treated as leachate.

22. The Department shall provide written notice to Region 5 within 10 days of any state-ordered remedial action related to PCB waste at a landfill authorized to accept PCB contaminated sediments under this approval. Remedial response to spills or exceedances of groundwater standards shall be performed under §§ NR 140.24. and NR 140.26 and chs. NR 158 and NR 708, Wis. Adm. Code, authority and 40 C.F.R. § 761.125.

23. Landfills selected under this approval may not be located in the 100 year floodplain.

24. PCB contaminated sediments shall be dewatered or solidified prior to arrival at a landfill selected under this approval.

25. PCB contaminated sediments disposed under this approval may not be used as daily cover.

26. WDNR shall notify each landfill selected under this approval that the landfill shall provide U.S. EPA with an annual document log, complying with 40 C.F.R. § 761.180(b), for each year that the landfill accepts PCB contaminated sediments.

27. This approval will expire five (5) years from the date of the Regional Administrator's signature on the approval. This approval may be renewed upon the concurrence of both parties to the approval at five year intervals. Discussions on approval renewal will begin 180 days before the approval's next expiration date.

APPROVAL

Providing the above mentioned conditions are met, and in accordance with 40 C.F.R. § 761.60(a)(5), and consistent with the WDNR's May 6, 1994 sediment disposal application and its attachments, the WDNR is granted an approval to select disposal facilities having approved plans of operation under § 144.44(3) Wis. Stats. that comply with chs. NR 500-520, Wis. Adm. Code, and are authorized under § NR 157.07, Wis. Adm. Code, for the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater. This approval applies only to the disposal of PCB containing sediment originating in Wisconsin and remediated under the authority and supervision of WDNR. WDNR may not approve facilities within the State of Wisconsin to accept sediments containing PCBs at 50 ppm or greater from projects not conducted under the authority and supervision of WDNR. In addition to the terms and conditions of this approval, selected facilities shall comply with all applicable State and Federal environmental statutes and regulations. This approval may be terminated at any time by either the WDNR or U.S. EPA by written notice to the other party.

for Valdas V. Adamkus
Regional Administrator
U.S. Environmental Protection Agency
Region 5

1/24/95
Date

BOB PAULSON WT/2

CORRESPONDENCE/MEMORANDUM

DATE: June 26, 1998

TO: Bernie Robertson - WT/2

FROM: Duane Schuettpelz - WT/2

SUBJECT: Effluent limitations for the Fox River Demonstration Projects

The attached report contains an analysis and recommendations we will use in the development of final recommendations for effluent limitations for the Deposit N and Deposit 56/57 demonstration project sites on the Fox River. Please use this information to develop the WQBEL recommendations for PCB and other substances for these sites. Prepare the memoranda containing this information for my approval and signature.

My conclusions stated in this report indicate that the removal of contaminants from Deposits N and 56/57 will rid the river of hundreds of pounds of PCB. Through well-designed handling and treatment techniques, only a small amount of PCB(less than one pound) will return to the river with the carriage return water and these operations will occur over only a relatively short period of time. These removal actions will not, themselves, cause the water quality criteria for PCB in the Fox River to come into compliance with the water quality standards. They will, however, move the River in a direction toward water quality standards attainment.

Our recommended effluent limitations for PCB at both sites shall not be less than 1.2 ug/L and are to be established on the basis of treatment technology which does not involve additional carbon adsorption treatment processes. Such limitations are appropriate within the overall context of these specific demonstration projects discussed in this report and are not to be used as a precedent for future effluent limitations or requirements for sediment remediation projects. Permits should be proposed for issuance to allow these projects to be implemented in this manner. The result will be the best overall environmental solution to the problem of contaminants in the Fox River.

cc: Fox River Guidance Team
Bob Masnado - WT/2
Mike Witt - WT/2

DEVELOPMENT OF EFFLUENT LIMITATIONS FOR THE FOX RIVER FIELD-SCALE DEMONSTRATION OF RESTORATION PROJECTS

by
Duane H. Schuettpelz
June 26, 1998

1.0 INTRODUCTION

The Department of Natural Resources, in cooperation with several parties in the Fox River Valley(Fox River Group), have agreed to conduct "field-scale demonstration of restoration projects" at two locations along the Fox River. In order to assure completion of these demonstration projects, certain permit or other regulatory and non-regulatory decisions must be made. The purpose of this document is to provide an overall rationale and perspective for use in the decision processes associated with the WPDES permits(and others as it may apply) which must be issued by the Department. This document will not address the handling and disposal of the residual sediments which are removed from the river.

The restoration of the Fox River to the full range of uses which are safe for humans and the ecological integrity of the River and the downstream areas of Green Bay, Lake Michigan and the other Great Lakes requires a reduction in the amount of contaminated sediments which exist in the river. Through on-going erosion and transport, the bioaccumulating contaminants in the sediments continue to move slowly through the system, eventually making their way to the downstream areas. In both the Fox River and downstream, the contaminants are, through various physicochemical and biological processes, available for uptake through the food chain into fish and, eventually, humans and wildlife. Once bioaccumulating substances reach Green Bay and Lake Michigan, they have escaped any realistic means to effect their eventual removal or isolation from the ecosystem.

In removing or otherwise dealing with these sediments, certain activities may result in the release of toxic substances into the water through resuspension, the return of carriage water from dewatering operations, etc. This discussion is specific with respect to the WQBELs for the carriage return water discharges, but may be considered for other decisions as well. Although WPDES permits are required for the discharge of carriage return water from contaminated sediment sites, the application of specific provisions of existing rules to such discharges may not be logical in the context under which the rules were developed. It is with this dilemma as the backdrop that this document is provided.

The conclusions reached in this report are based solely on the situation which is present with respect to these specific projects, including:

- these projects are demonstration projects
- these projects are of limited scope and duration

- these projects are designed to help answer questions for future work
- these projects will provide directions for future decision processes, including need for changes in statutes, rules and guidance

Therefore, these projects must not be considered precedent setting and the decisions reached will not be considered as establishing the process or decision result for any future project which may or may not have similarities to these projects.

2.0 WATER QUALITY STANDARDS

Water quality standards are contained in NR 102 through NR 106, Wis. Adm. Code. Criteria which serve as the basis for actions of the Department in regulatory or other decisions are contained in NR 102 and NR 105. For purposes of this discussion, only the application of the criterion for PCB will be evaluated and this substance may be used as a surrogate for other substances(toxic or otherwise) in reviewing the decisions which must be made.[1]

The applicable PCB criteria for the Fox River are as follows:

Wildlife	0.12 ng/L[2]
Human health	0.003 ng/L(criterion applies to all waters of the Great Lakes system)

3.0 SETTING

There are two specific areas which have been designated for the "demonstration of restoration projects". They are called Deposit N and Deposit 56/57(the Agreement describes this latter deposit only as a site below DePere Dam).

3.1 Deposit N

Deposit N is located a short distance upstream of the lock and dam at the Village of Kimberly and near the south shore of the river. It is a small deposit of soft sediment which contains high concentrations of PCBs. Based on sampling of the Deposit, sediment PCB concentrations range from zero to 180 mg/kg[3], with an average of about 45 mg/kg. The estimated mass of PCB in the designated deposition area is 414 pounds(188 kg).

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[1]Investigation of the contaminants in the sediments at the Deposit 56/57 site have indicated the presence of the substance dioxin in one layer of a single core sample and in the simulated effluent. See Attachment A for additional information.

[2]A water concentration expressed as ng/L is equivalent to parts per trillion

[3]A sediment concentration expressed as mg/kg is equivalent to part per million.

Fox River water PCB concentrations at or near this location range from 10 to 200 ng/L depending on the time of year and analytical method. The average measured concentration is approximately 33 ng/L. Fish collected from the River near this location within the past 5 years contain PCB in concentrations ranging from 0.5 mg/kg[4] to more than 4.0 mg/kg depending on the species, its size and type of sample(fillet or whole fish). Under the existing condition, water quality criteria for PCB in the Fox River are, therefore, being exceeded. Current point-source discharges of PCB are generally less than the analytical detection levels, and the primary source of PCB in the water column is release from the sediments or attached to sediment particles moving with the water.

At this site, the average annual mass of PCB moving with the water in the river from upstream locations is estimated to be 300 pounds per year, including the amount of PCB transported during high flow events. On an annual basis, the Green Bay Mass Balance Study predicted that the loss of PCB from Deposit N is approximately 46 pounds per year, both through release to the water and sediment movement downstream.

3.2 Deposit 56/57

This deposit is located in the lower part of the Fox River below the DePere Dam, the last downstream dam on the River. The River at this point is influenced by the seiche and backwater effects of Green Bay. It is off-shore of the property occupied by the Fort James Corporation paper mill. This deposit is a significantly larger deposit of soft sediments containing, on average, a higher concentration of PCB(85 mg/kg) than Deposit N. This deposit is specifically characterized in the agreement as a large-scale sediment restoration project.

Sediment PCB concentrations at Deposit 56/57 range from zero to 700 mg/kg with an average concentration of 85 mg/kg. The currently estimated mass of PCB in this deposit is 4600 pounds(2090 kg). Water concentrations of PCB measured at or near this location range from 10 to 200 ng/L, with an average of approximately 50 ng/L. Fish collected from the River near this location within the past 5 years contained from 0.2 to over 5 mg/kg of PCB depending on species, size and type of sample(fillet or whole fish). At this location, however, fish are migratory, and not always reflective of residents of this part of the River. Under the existing condition, water quality criteria in the Fox River are not being attained. Current point-source discharges of PCB are less than analytical detection levels, and the primary source of PCB in the water column is release from the sediments.

The estimated average annual mass of PCB from upstream sources moving through the river at this location is 600 pounds per year[5] including that which is transported during

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[4]A tissue concentration expressed as mg/kg is equivalent to parts per million.

[5]River flow at the two project sites is similar as is the measured water column concentration. The difference in the mass loading of PCB at the two sites is caused by differences in the amount of

high flow events. Only about 4 pounds of PCB are predicted to move directly from this site on an annual basis due to the low velocities of the river at this location.

4.0 PROPOSALS FOR DEMONSTRATION OF RESTORATION

Considerable discussion has occurred regarding the best, most practicable, most environmentally sound, least expensive, etc. method for the restoration of the Fox River from the impacts caused by contaminated sediments. Sediment removal has been identified as the methodology which will be used to demonstrate how best to deal with the sediments. Consultants, working under the guidance of the Department and in collaboration with the Fox River Group, have evaluated several means to remove and treat the sediments and have concluded that dredging and on-land dewatering followed by disposal to landfill is the most efficient means to address these sediments. For purposes of these demonstration projects, the proposed restoration scenarios are as follows:

4.1 Deposit N

Sediment would be dredged from the River and piped to an on-shore dewatering facility located on the north shore of the river. Carriage water would be separated from the solids utilizing an active dewatering process, and be sent to a treatment facility from where it would discharge back to the River near the same location(but near the north bank of the River).

Existing design will remove approximately 10,000 cubic yards of sediment from Deposit N. Based on the amount of PCB in this sediment deposit, about 414 pounds(188 kg) of PCB will be removed from the River at this location. The design consultants estimate that no or little PCB will remain within the boundaries of the deposit site after the project. Silt curtains employing the current state of practicable technology would isolate the active dredging area from the surrounding waters of the Fox River. Using modern environmental dredging techniques, approximately 0.1 kg of PCB is predicted to be lost during dredging.

4.2 Deposit 56/57

At this site, environmentally sound dredging techniques will be used similar to the work at the upstream site. Under the current proposed design, the dredged materials would be piped to a passive dewatering facility on property(known as the former Shell Oil Company site) northeast of the railroad tracks which cross the river immediately adjacent to the Fort James paper mill in Green Bay. River velocities at this location may be either upstream or downstream depending on the seiche action.

The proposed passive dewatering facility for this site is a large lagoon which simply relies on quiescent settling of solid particles into the bed of the lagoon with water bled

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material transported during high flow events.

off the surface and passed through treatment prior to discharge back to the river a short distance downstream from the dredging site. Preliminary design conditions would allow for the removal of approximately 40,000 cubic yards of sediment from this deposit. Based on the amount of PCB in this sediment deposit, about 2,700 pounds(1,227 kg) of PCB will be removed from the River at this location while an estimated mass of PCBs remaining within the boundaries of the deposit site will be 1,900 pounds(864 kg). Silt curtains employing current state of practicable technology would isolate the active dredging area from the surrounding waters of the Fox River.

5.0 WPDES PERMIT EFFLUENT REQUIREMENTS

The overall purpose of addressing sediments in the Fox River is to remove these substances from continuing long term exposure and movement to Lake Michigan and the other downstream Great Lakes. Without removal from the River, the substances will continue to move with the sediments and into the water column down the river. From the long-term and large-scale perspective, therefore, removal and isolation of these contaminants in places which are not accessible by humans and other organisms in the food chain means the substance is generally not available to cause toxicological effects. Each molecule of contaminant removed from the river now is a molecule which will not be available for exposure through the food chain at a point in the future.

In developing effluent limitations for these discharges of PCB and certain other substances, several different provisions of NR 106 may apply. For bioaccumulative chemicals of concern(BCCs) like PCBs, the limitations for new discharges must be equal to the criterion for that substance. The basis for this provision is contained in the U.S. Environmental Protection Agency's Supplemental Information Document for the Water Quality Guidance for the Great Lakes System and is stated as follows:

> *The final Guidance is consistent with the Steering Committee's policy that every reasonable effort be made to reduce all loadings of BCCs to the Great Lakes System... A general principle of the Great Lakes Water Quality Agreement supports the elimination of point source impact zones(i.e., mixing zones) for toxic substances as consistent with the overall policy of the virtual elimination of persistent toxic substances.*

In summary, the rationale for this BCC provision is to assure that no new BCCs are added to the Great Lakes System.

In the case of these demonstration projects, any substances in the discharge of carriage return water are already present in the system. There is no new introduction of the substance to the system, but, rather, there is a significant net removal from the system.

Based on the above information, it is appropriate to apply the provisions of NR 106.06(6), Wis. Adm. Code. This section of the rule applies when the concentration of a substance in the background of the receiving water at the point of discharge is greater than the established water quality criterion for the substance. In the case of PCB, the concentration of the substance in the water column exceeds the water quality criterion.

If the source of the water being discharged is made up of more than 10% receiving water, the rule requires that the effluent limit be set equal to background . This is the case for these demonstration projects.

Alternatively, the rule allows an effluent limitation or other requirement to be established *"...in the event the discharger's relative contribution to the mass of the...substance...is negligible..."*. Furthermore, this is allowed when there is a demonstration that treatment provided is the *"...best demonstrated treatment technology reasonably achievable"*, a level of treatment applied on a case-by-case basis within the discretion of the Department.

The carriage return water from the dewatering facilities at both sites require that the Department issue a WPDES permit for these discharges. There are no specific technology-based effluent limitations which apply to such facilities. However, the provisions of NR 220 require the case-by-case establishment of treatment technology-based limitations. In addition, the Department must establish water quality based effluent limitations which are determined through the application of the provisions of NR 106, Wis. Adm. Code. This code is designed to assure that discharges do not result in the exceedance of the water quality criteria applicable at the point of discharge as implemented through the provisions contained in NR 106. For these projects, the following conditions will apply:

- PCB concentrations in the background(upstream) water of the River at these locations exceeds current water quality criteria
- PCB and other substances will be present in the material which is sent to the dewatering facilities
- Treatment of the dredged material should employ the best demonstrated treatment technology reasonably achievable given the nature, duration and overall objective of the each of the demonstration projects
- Treatment for the carriage return water should employ the best demonstrated treatment technology reasonably achievable given the nature, duration and overall objective of each of the demonstration projects

5.1 Deposit N

5.1.1 Wastewater treatment

The permit application design parameters for the carriage return water at this site include a discharge rate of approximately 360,000 gallons per day. Based on the relatively small amount of sediment removed, an active dewatering process has been proposed. Similarly, because this project also produces a relatively small volume of discharge, the treatment processes identified in The permit application has been prepared with the assumption that the treatment requirements for this discharge may include carbon adsorption, in addition to coagulation, settling and filtration. Carbon adsorption removes PCB to concentrations less than detectable levels. Without this latter treatment process, effluent PCB is projected to be between 0.9 ug/L and 1.2 ug/L[6].

5.1.2 Removal/discharge

As noted above, the mass of the substance PCB being removed from the Fox River at Deposit N is 414 pounds(188 kg). In the permit application for this discharge, the concentration of PCB in the simulated effluent from the system employing advanced treatment as described above was not detected at approximately 0.5 ug/L. The discharge volume will be not more than 360,000 gallons per day for 40 days.

NR 106 requires that whenever a substance in the receiving water is greater than the applicable criterion, the effluent limitation is equal to the background (0.33 ng/L) or an alternative is established according to the provisions contained in NR 106.06(6)(d). However, as reported in the permit application and as is the case for most wastewater discharges, the limit of detection is approximately 0.5 ug/L. NR 106 indicates that any effluent sample reported as less than the limit of detection is in compliance with the permit, and is assumed equal to zero. Therefore, even though a limit equal to 0.33 ng/L may be established in the permit, compliance is determined on the basis of the limit of detection.

For purposes of illustration, if it is assumed the discharge concentration is equal to the limit of detection(0.5 ug/L) and at the noted flow, then the mass of PCB returning to the river would be 0.0015 lbs/day(.0007 kg/day). In this instance the discharge will occur over a 40 day period and the total mass of PCB discharged to the river will not be greater than an estimated 0.06 pounds(.028 kg) over the life of the project.

If the additional carbon adsorption treatment process is removed from the wastewater treatment train, the concentration of PCB in the simulated effluent from the system ranged from 0.9 to 1.2 ug/L. Given the flow conditions noted above, this produces an effluent mass discharge of approximately between 0.108 and .144 pounds(0.049-0.065 kg) for the period of discharge.

Therefore, in removing 414 pounds of PCB from the Fox River system and its potential for long term exposure, the permit may allow, with additional carbon adsorption treatment, the reintroduction of less than one-tenth of a pound back to the River. Without the additional treatment, between one-tenth and two-tenths of a pound may be returned to the river.

5.1.3 Summary

The table below summarizes the several components associated with the removal and discharge of PCB at this site. The short-term discharge of PCB from this project will result in the return of a negligible amount of PCB to the Fox River in relation to the

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[6]A water concentration expressed as ug/L is equivalent to parts per billion.

amount being removed. It is also an insignificant amount when compared to the amount of PCB currently in the water column at the site.

PCB removed from River	414 pounds
PCB in River water moving across site during 40 day period	25 pounds
PCB discharged with additional treatment(effluent assumed = LOD)	0.06 pounds
PCB discharged without additional treatment	0.108 - 0.144 pounds

5.2 Deposit 56/57

5.2.1 Wastewater treatment

As described above, this site is proposing to remove a significantly larger volume of contaminated sediment from the River than the site further upstream. Accordingly, under the current proposed design, the amount of carriage return water is much larger both in terms of rate and overall total project volume. The design flow for the carriage return water at this site is projected to be approximately 2.1 mgd(million gallons per day) during the active dredging phase of the project lasting approximately 30 days. This will be followed by a flow rate of 0.14 mgd during the 120-day phase when the sediment in the dewatering facility is undergoing further drying. All flow will be diverted through a wastewater treatment system prior to discharge back to the Fox River.

Two wastewater treatment processes have been evaluated during the design of this project. The first process employs flocculation, coagulation and filtration. Wastewater treatment using this process train produces an effluent containing approximately 0.9 to 1.2 ug/L of PCB. The second involves additional treatment, in the form of carbon adsorption, to the above basic treatment. The addition of carbon adsorption removes PCB to concentrations less than detectable levels(<0.5 ug/L). Simulated effluent from the latter process was used to provide information for the WPDES permit application on the assumption this treatment technology may be required as part of the treatment process.

5.2.2 Removal/discharge

As noted above, the mass of the substance PCB proposed to be removed from the Fox River at Deposit 56/57 is 2,700 pounds(1,227 kg). NR 106 requires that whenever a substance in the receiving water is greater than the applicable criterion, the effluent limitation is equal to the background (0.33 ng/L) or an alternative may be established according to the provisions contained in NR 106.06(6)(d). However, as reported in the permit application, and as is the case for most wastewater discharges, the limit of detection is approximately 0.5 ug/L. NR 106 indicates that any effluent sample reported as less than the limit of detection is in compliance with the permit, and is assumed equal to zero. Therefore, even though a limit equal to 0.33 ng/L may be established in the permit, compliance is determined on the basis of the limit of detection.

In the permit application for this discharge, the concentration of PCB in simulated effluent from the system employing coagulation, flocculation and filtration plus carbon adsorption treatment system was provided. As with the Deposit N discharge, the concentration of PCB in the simulated effluent was not detected at 0.5 ug/L. However, for purposes of illustration, if it is assumed the discharge concentration is at the limit of detection(0.5 ug/l) and at the noted flow, then the mass of PCB returning to the river would be approximately 0.33 pounds(0.15 kg) for the period of discharge. This results from 0.26 pounds for the 30 day period of active dredging and 0.07 pounds for the estimated 120 day period of further sediment dewatering.

If the additional treatment process(as described) is removed from the wastewater treatment train, the concentration of PCB in the simulated effluent from the system ranged from 0.9 to 1.2 ug/L. Given the flow conditions noted above, this produces an effluent mass discharge of approximately between 0.61 and .80 pounds(0.28 - 0.37 kg) for the period of discharge.

Therefore, this project will result in the removal of 2,700 kg of PCB from the Fox River system and its potential for long term exposure. If a permit is issued to meet effluent concentrations equal to background, the permit could allow the reintroduction of less than one-third of a pound back to the River. If the additional treatment is not employed, then the discharge would be between six-tenths and eight-tenths of a pound.

5.2.3 Summary

The table below summarizes the several components associated with the removal and discharge of PCB at the project 56/57 site. The short-term discharge of PCB from this project will result in the return of a negligible amount of PCB to the Fox River in relation to the amount being removed. It is also an insignificant amount when compared to the amount of PCB currently in the water column at the site.

PCB removed from River	2,700 pounds
PCB in River water moving across site during 30 day period	50 pounds
PCB discharged with additional treatment (effluent assumed = LOD)	0.33 pounds
PCB discharged without additional treatment	0.61 - 0.80 pounds

6.0 COST FOR TREATMENT

Treatment costs increase with the provision of additional technologies to the coagulation-flocculation-filtration treatment trains. Based on the information in the design reports from the Department's consultants, costs for the additional treatment and for treatment without the carbon adsorption technology is provided in the following sections.

6.1 Deposit N

The additional treatment costs associated with providing carbon adsorption treatment for the carriage return water at this site is not available at this writing. However, assuming it is proportionately(based on a comparison of wastewater flow) the same as that for the Deposit 56/57 site(see discussion in Sec. 6.2), the cost are estimated to be approximately $45,000 to $50,000. Using the same comparison as shown in Sec. 6.2, an additional significant quantity of sediment may be removed at another river location with this funding.

6.2 Deposit 56/57

The additional treatment costs associated with providing carbon adsorption treatment for the carriage return water for this site is estimated at $250,000 based on providing this level of treatment for the entire period of discharge. Therefore, at an additional cost of $250,000, the effluent from the wastewater treatment system will be between 0.3 and 0.5 pounds less than without the additional treatment process. The estimated overall cost associated with the project is $180 per cubic yard of sediment removed. If the $250,000 is diverted from wastewater treatment to additional removal of sediment, an additional 1,400 cubic yards of sediment could be removed from this deposit. At the average concentration of PCB in this deposit, this 1,400 cubic yards of sediment would contain 82 pounds of PCB removed from the River.

7.0 DISCUSSION

The primary objective of the Memorandum of Agreement between the Department and the FRG as related to these projects is "to begin certain plans, studies or activities in the Lower Fox River/Green Bay area that will improve natural resources and will serve as the basis for evaluating certain sediment management techniques". More specifically, as stated above, these projects were envisioned to test field-scale demonstration projects for sediment restoration. The underlying purpose of the agreement is to undertake activities to restore the river from the damages which have been claimed due to the deposition of contaminants in the sediments.

The development and issuance of permits for these demonstration projects should, therefore, be in conformance with these principles contained in the agreement. The information in this report describes, to the extent possible, the environmental consequences associated the discharge of treated carriage return water to the Fox River from these specific projects. It compares those consequences with the overall benefits which will accrue from the removal of contaminants from the River. It is apparent, from the information presented, that these projects, when implemented, will result in the removal of significant quantities of PCB from further exposure in the Fox

River/Great Lakes environment. The planned activities will, however, result in the need to discharge back to the River carriage return water containing some of the contaminants which are removed in the dredging process. These projects are short-term in duration and are returning to the River only a small fraction of the material which is removed.

In establishing an alternative effluent limitation under NR 106.06(6)(d), the Department must determine that the "...relative contribution to the mass of the... substance is negligible..." (emphasis added). From the data presented in this document, there is no new contribution of PCB to the River beyond that which already exists in the River environment. The discharges back to the river are in the range of about 0.03% or less of the PCB removed at either site. Therefore, it is reasonable to conclude that these discharges are negligible according to the provisions of the rule.

Existing water quality in the Fox River already exceeds the water quality standards for parameters such as PCB. The addition of PCB in the effluent from the demonstration sites via carriage return water discharges will minimally add to the existing exceedances regardless of which of the treatment technologies described above is applied. The risk associated with these discharges in the over-all context of the existing and on-going risk is insignificant. On the other hand, the opportunity to eliminate the long term release of these contaminants to the water and the continuing level of exposure through uptake of contaminants in the food chain, is great.

In applying existing rules, the Department has discretion in the application of effluent limitations and treatment technologies for the wastewaters generated by these projects. The rule requires the application of best demonstrated treatment technology reasonable achievable whenever the Department determines that an alternative to the background concentration effluent limitation is established. As noted, there is little experience in Wisconsin to determine what technology meets this requirement, especially considering the unique nature of these projects. While the application of additional treatment could be required for these projects, the decision to establish a treatment technology as stated in this report is based on the overall goal of the projects to "...improve natural resources and...serve as a basis for evaluating certain sediment management techniques"(exerpt from the Agreement, part II).

This analysis has considered the individual impacts on the Fox River from the effluents from the demonstration project sites and any conclusions should not be extended to future sediment remediation projects along the River. Any proposals for sediment removal, treatment and disposal at other sites and projects(including whole river strategies) should undergo independent evaluation. However, it may be appropriate, following the implementation of these projects, to consider the development of rules and guidance which would provide more specific direction in decision-making regarding sediment contamination projects.

8.0 CONCLUSION

The removal of substantial quantities of PCBs(and other contaminants) from the Fox River through dredging and treatment of the residual carriage return water is being implemented to evaluate if a means exists to remove contaminants from the river and to effectively dispose of them in a manner which eliminates them from future exposure. The information presented here substantiates that the removal of contaminants from Deposits N and 56/57 in a manner consistent with the project designs will rid the river of hundreds of pounds of PCB. Through well-designed handling and treatment techniques, only a small amount of PCB(less than one pound) will return to the river with the carriage return water from each site. These operations will occur over only a relatively short period of time. The removal actions will not, themselves, cause the water quality criteria for PCB in the Fox River to come into compliance with the water quality standards. They will, however, move the River in a direction toward water quality standards attainment.

This report establishes that the discharges of carriage water from these specific "demonstration of restoration" projects are negligible In accordance with the provisions of NR 106.06(6)(d). Effluent limitations to meet background water quality are not needed to meet the requirements of the rule. Furthermore, effluent limitations established on the basis of treatment technology which does not involve carbon adsorption treatment processes(maximum effluent concentrations = 1.2 /L) are appropriate within the overall context of the demonstration projects discussed in this report. Permits should be proposed for issuance to allow these projects to be implemented in this manner. The result will be the best overall environmental solution to the problem of contaminants in the Fox River, and will provide data and information to all the parties seeking to identify methods to address contaminated sediment issues in the River.

ATTACHMENT A

IMPLICATIONS OF DIOXIN FOR THE DEPOSIT 56/57 DEMONSTRATION OF RESTORATION PROJECT

Investigation of the contaminants in the sediments at the Deposit 56/57 site have indicated the presence of the substance dioxin in one layer of a single core sample. This substance has the lowest water quality criteria values in current Department rules. Very limited data is available to suggest that the substance is present in the sediments of the river at low concentrations. The extent of dioxin within the sediments of this demonstration project area is unknown.

In the development of the design information for the site, the consultant had provided data which indicates that dioxin was present in the effluent from the bench-scale tests following the application of carbon adsorption treatment. Only one sample analysis is available. Although the reported result for this simulated effluent was qualified by the laboratory due to detection of dioxin in the method blank, the laboratory has confirmed that dioxin was present in the sample. The Department's position is that any such confirmed sample result is sufficient to establish it as "representative" for the purpose of establishing effluent limitations under the provisions of NR 106.

Based on tissue samples from fish in the Fox River, one may logically conclude that water concentrations for dioxin are not equal to zero. In reality, it may also be appropriate to assume that dioxin concentrations in the water column are greater than the most stringent water quality criterion of 0.003 pg/L(parts per quadrillion). As with PCB, therefore, effluent limits for dioxin may be established based upon negligible contributions from the demonstration project discharges. However, the base of data to support precise calculations is not available.

Dioxin is a substance which reacts in the environment similar to PCB. It is hydrophobic and it bioaccumulates in the food chain. It is reasonable dioxin will respond in a manner similar to PCB when treatment technology is employed. Therefore, given the uncertainties in the data with respect to dioxin in sediments, water column and fish, the use of PCB as a surrogate for dioxin in the demonstration projects is appropriate. Monitoring of this substance as part of the project evaluation is necessary, and action appropriate to the situation should be taken if the data reveal these assumptions are not true.

WISCONSIN'S LANDFILL SITING PROCESS

SEPTEMBER 1996

By Paul M. Huebner[1]

Wisconsin's landfill siting process is considered one of the most successful in the country because it strikes a balance between the statewide need for environmentally sound waste disposal capacity and the legitimate concerns of local citizens and municipalities. The siting process requires that landfills meet stringent siting, design, construction, operation, monitoring, performance and financial responsibility requirements to maximize the protection of public health and the environment.

In Wisconsin, all new landfills and expansions to existing landfills must obtain both state and any applicable local approvals prior to construction. Licensing of a landfill and the negotiation/arbitration of local approvals are two separate processes and occur concurrently. The landfill licensing process administered by the Wisconsin Department of Natural Resources (WDNR) is a technical decision-making process focusing on the ability of the proposed landfill design to meet all criteria and standards to protect public health and the environment. The local approval process focuses on the local economic, social and land use impacts of the landfill and is overseen by the Wisconsin Waste Facility Siting Board.

Over the last several years, a number of landfill applications in Wisconsin have been significantly delayed by new state and federal locational requirements regarding wetlands and airports and new state statutory changes made to the siting process since 1988. Other major factors contributing to such delays were lack of planning and poor site selection by some applicants, submittal of incomplete information, inadequate justification for exemptions or unique/alternative designs, and of course public opposition.

In 1995 with the assistance of a public technical advisory committee (TAC), the WDNR completed the task of incorporating the necessary changes into Wisconsin's solid waste management regulations (chs. NR 500 - 520, Wis. Adm. Codes) to conform to the new statutory requirements and the federal (Subtitle D) criteria for municipal solid waste landfills. Another primary goal of the TAC and the WDNR was to streamline the NR 500 series of codes without jeopardizing public health or the environment. Areas of duplication and unnecessary and burdensome requirements found over the past several years to not be providing any additional environmental protection were eliminated. Significant clarification was also added to make the codes more user friendly. Since the landfill siting process is laid out in state statutes it essentially remained unaltered. However, substantial changes made to the front of the technical decision making process and streamlining of the technical submittal requirements should lead to some efficiencies being realized.

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[1]Solid Waste Team Leader, Bureau of Waste Management, Wisconsin Department of Natural Resources, 101 South Webster Street, Madison, Wisconsin, 53707.

Landfill Licensing Process - The WDNR technical decision-making process is summarized in Figure 1. It includes the following mandatory steps:

INITIAL SITE INSPECTION

The purpose of an initial site inspection is to obtain a preliminary evaluation from the WDNR on the potential a proposed property has to comply with the locational criteria and performance standards specified in s. NR 504.04, Wis. Adm. Code. As specified in ch. NR 509, Wis. Adm. Code, an applicant must first submit a written request to the WDNR to arrange for an initial inspection. This request must include the following minimum information:

1. A cover letter identifying the applicant and authorized contact, type of landfill and operation being proposed, property ownership, location by quarter -quarter section and present land use.

2. A letter from the WDNR's Bureau of Endangered Resources addressing the known presence of critical habitat areas and state or local natural areas within one mile of the proposed landfill, in accordance with ch. NR 29, Wis. Adm. Code.

3. A letter from the Wisconsin State Historical Society identifying the presence of any historical, scientific or archaeological areas within the vicinity of the proposed landfill, in accordance with s. 44.40, Stats.

4. A map depicting existing conditions within one mile of the proposed boundaries of the proposed landfill.

5. A preliminary identification of all potential conflicts with the locational criteria and performance standards specified in s. NR 504.04, Wis. Adm. Code, for landfills, except for s. NR 504.04(4)(d) to (f).

Note: An initial site inspection is also required for all noncommercial soil borrow sources designated to be used in the construction, operation, or closure of a specific landfill. A written request for an inspection of a soil borrow source must include the information listed in items 1. through 4. above, and a preliminary identification of all potential effects on wetlands, critical habitat areas or surface waters.

During the inspection, WDNR staff evaluate whether or not the proposed landfill would be within a floodplain or within an area that would have an adverse impact on critical habitat, historical/archeological features, and wetlands. The WDNR staff also check to see if the anticipated landfill footprint would be within required setback distances to navigable waters, state and federal highways, public parks, airports, and water supply wells. After the inspection the applicant is notified in writing which locational criteria and performance standards the proposed property complies with and does not comply with and if further evaluations or additional studies are necessary. The initial site inspection letter from the WDNR can be used by an applicant to decide if the proposed property merits further investigation. If no follow up evaluations or studies are necessary to determine navigability of nearby surface waters, the presence of critical habitat, or to define wetland boundaries etc., the completion of this step by the WDNR generally should not take more than a couple of weeks.

LANDFILL LICENSING PROCESS

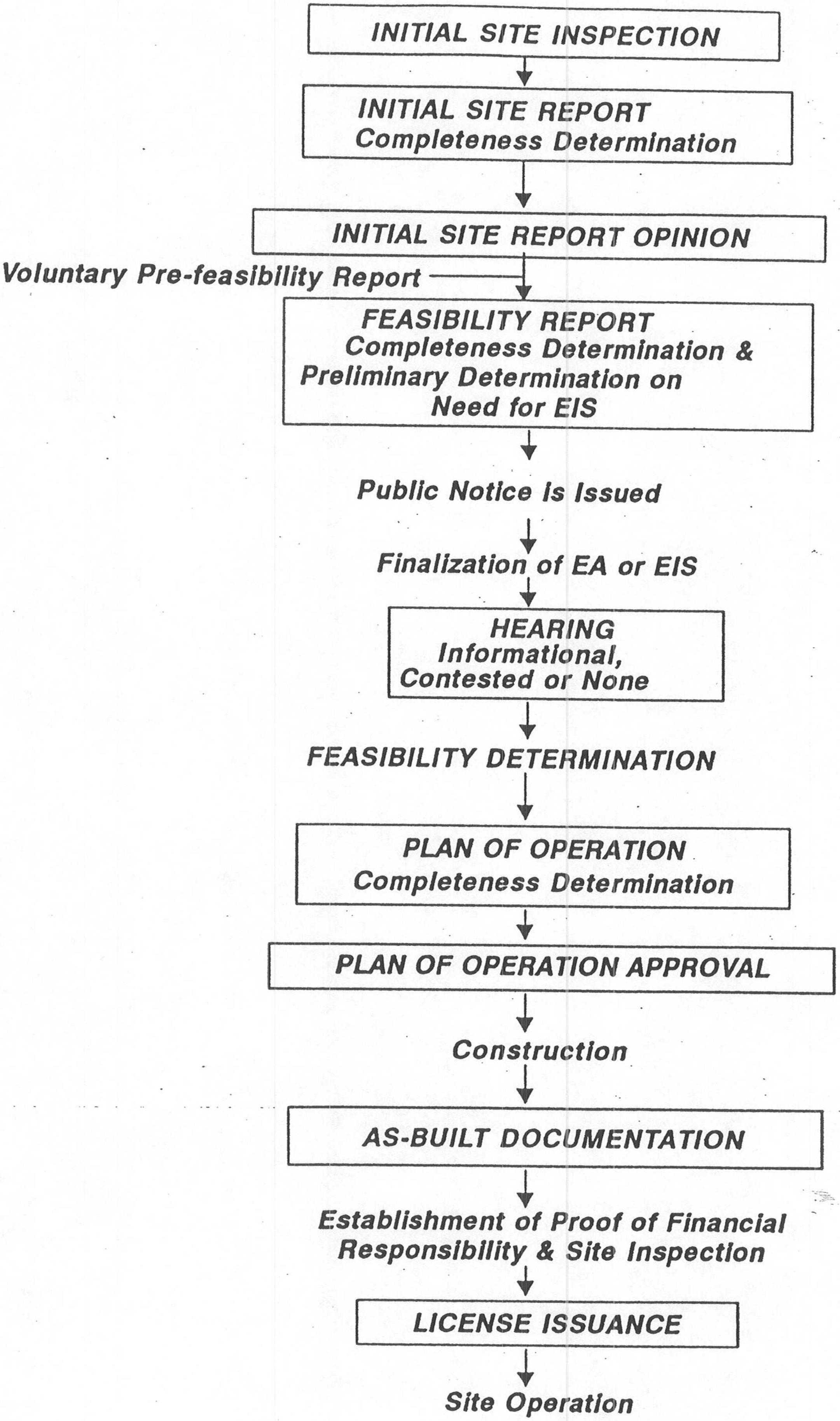

Figure 1. Landfill Licensing Process

INITIAL SITE REPORT

The next step in the landfill licensing process is for the applicant to submit an Initial Site Report (ISR). The ISR was originally developed as a voluntary screening tool to allow an applicant to receive an opinion from the WDNR on whether a proposed property had potential for development as a landfill before committing to the time and cost of a preparing a feasibility report. In 1990, the state's comprehensive recycling law became effective and it mandated that all applicant's proposing to site a new landfill or to expand an existing landfill shall submit an ISR to the WDNR. Over the years, some of the requirements originally specified for a feasibility report were moved to or added to the minimum ISR submittal requirements reducing the effectiveness of the report as an inexpensive screening tool. The new rule revisions returned this report back to its original purpose by significantly streamlining the minimum requirements for an ISR.

The minimum requirements for an ISR are found in ch. NR 509, Wis. Adm. Code. An ISR must include the information submitted for the initial site inspection and the WDNR's initial site inspection response letter; the proposed project's title; identification of the owner and proposed operator of the landfill and any consultant; a description of the proposed property and the anticipated limits of filling; proposed landfill life and disposal capacity; municipalities and industries to be served; anticipated waste types, characteristics and amount of waste to be handled; anticipated cover frequency; mode of operation; and the anticipated subbase, base and final grades. An ISR must also contain a thorough discussion of the land uses which may have an impact on the suitability of the property for waste disposal or on groundwater quality, and include a summary of the available published information concerning the regional geotechnical characteristics of the proposed location. No site-specific geotechnical investigation is required.

An ISR is evaluated by a WDNR plan review team consisting of a hydrogeologist and an environmental engineer. The hydrogeologist has the lead review responsibility and receives comments on the report from a waste management investigator in the applicable local WDNR field office. After completing a review of the ISR, the WDNR renders an opinion on the proposed property's potential for development as a landfill and notifies the applicant in writing. The ISR opinion letter is also used by the plan review team to identify any known constraints to feasibility. In a favorable ISR response, the WDNR specifies site-specific additional or unique information needed to be included in a feasibility report which is the next mandatory step in the siting process. An unfavorable opinion letter is used to discourage an applicant before an irrevocable financial or political commitment to an unsuitable property is made. The completion of this step by the WDNR generally should not take more than a couple of months.

Pre-feasibility report

In those cases where the regional geotechnical or any available site-specific geotechnical information indicates the proposed property may have poor geology or unusual hydrogeological conditions, the WDNR will suggest that a pre-feasibility report be submitted. Submitting a pre-feasibility report, however, is not a required step in the siting process. The level of site-specific geotechnical information specified for a pre-feasibility report is found in ch. NR 510, Wis. Adm. Code, and it is similar to the information formerly required for ISR's. The advantage of the voluntary pre-feasibility report option is that it allows a landfill applicant to obtain a revised opinion from the WDNR based on site-specific geotechnical information which should reduce the risk of proceeding directly from the reduced scope ISR to doing major feasibility studies on a property which may have little or no potential of being approved.

FEASIBILITY REPORT

Obtaining a favorable feasibility determination from the WDNR virtually assures the applicant the proposed landfill can be developed from a technical standpoint. Chapter NR 512, Wis. Adm. Code, specifies the minimum information that must be included in a feasibility report. Required items already addressed in an ISR or a pre-feasibility report can be cross referenced rather than included in the feasibility report. Along with information requested in the WDNR's ISR opinion letter and any revised pre-feasibility opinion letter, a feasibility report must contain a comprehensive and detailed site-specific geologic and hydrogeologic investigation that includes baseline groundwater quality data; a preliminary engineering design that includes a description of the proposed environmental monitoring for groundwater, leachate, surface water, gas, air quality, and soil moisture (if applicable); an environmental assessment; documentation of the need for the proposed landfill; and an analysis of the alternatives to landfilling such as waste reduction, reuse, recycling, composting, and energy recovery initiatives and services. Initial site inspection response letter(s) and soil test results for any proposed noncommercial soil borrow source(s) designated to be used in the construction, operation, or closure of the first phase of the proposed landfill also must be included in a feasibility report.

For a feasibility report, the hydrogeologist of the WDNR plan review team is once again the lead reviewer and receives comments from a waste management investigator and several other program specialists in the applicable local WDNR field office. The hydrogeologist fills out a feasibility completeness checklist to determine if all of the minimum information required by ch. NR 512, Wis. Adm. Code, has been submitted. If required information is found to be missing, the WDNR notifies the applicant in writing that the report is incomplete and lists the information needed to make the report complete. The incompleteness letter may also include a request for additional or unique information the plan review team believes is necessary before a feasibility determination can be made.

Environmental analysis

When a feasibility report is found to be complete, the hydrogeologist prepares an analysis of the significance of any impacts the proposed project would have on the public's health, welfare and the environment. After completing a draft of the analysis, the hydrogeologist recommends whether or not an Environmental Impact Statement (EIS) should be completed on the proposed project. If the WDNR decides that an EIS must be written, the feasibility determination is delayed until the EIS is completed. The completion of an EIS, and an associated mandatory public hearing on the completeness of the study, can take up to a year or more to complete.

Public hearings

If an EIS is not required or after an EIS is completed, the hydrogeologist prepares a short summary of the proposal and a public notice stating that the WDNR has received a complete feasibility report. The public notice is published in the local newspaper to invite public comment and provide information on how six citizens or an official of the host municipality or any municipality located within 1,200 feet of the proposed landfill can request that an informational public hearing or a contested case hearing be held on the technical feasibility of the proposal.

If no hearing is requested, the plan review team considers the public comments received before writing the feasibility determination. If an informational public hearing is held the feasibility determination is written within 60 days after the hearing. When a contested case hearing is held, it is conducted before a hearing examiner in much the same way as a court trial. The WDNR plan review team and the other parties to the hearing testify under oath and are subject to cross examination. After a contested case hearing, the feasibility determination is made by the Secretary of the WDNR or the WDNR Secretary's designee based only upon a review of the hearing record. A contested case hearing is intended to address technical issues of site feasibility including the need for the landfill and the ability of the proposal to meet design and performance standards and to protect the public's health, welfare and the environment.

Submittal of incomplete/inadequate information, public controversy, locational problems such as potential impacts to wetlands or the potential of creating a bird hazard to aircraft, and poor geology and unusual hydrogeologic conditions significantly impact the review time for some feasibility reports. Depending on the completeness of a feasibility report, any locational problems, and whether or not an EIS must be prepared or a public hearing must be held, the WDNR's completion of the feasibility step in the siting process can take six months to more than three years.

PLAN OF OPERATION REPORT

A plan of operation report includes the final engineering design, design calculations, details on the phases of construction, proposed construction documentation, sequencing of operations, daily operations, monitoring, closure design, long-term care of the proposed landfill after closure and a detailed estimate of the costs for construction, operation, closure and long-term care of the landfill. Chapter NR 514, Wis. Adm. Code, and the conditions in a feasibility determination specify the minimum information a plan of operation must contain. After the applicant receives a feasibility determination there is usually at least one meeting between the applicant and the WDNR to discuss the feasibility conditions of approval, prior to the submittal of the plan of operation report.

The WDNR plan review team is responsible for ensuring that all design, construction, operation, closure and financial responsibility details required by ch. NR 514, Wis. Adm. Code, and all of the conditions of feasibility are addressed in the plan of operation. The environmental engineer is the lead reviewer and makes sure that good engineering practices are being proposed. The hydrogeologist reviews the environmental monitoring proposal, any alternative concentration limits proposed for exemptions to the groundwater standards which were granted in the feasibility determination and preventative action limits proposed for the groundwater quality indicator parameters for each well at the site. The WDNR typically completes its review of a plan of operation in four to six months.

LANDFILL CONSTRUCTION DOCUMENTATION REPORT

Following WDNR approval of a plan of operation for the proposed landfill and after obtaining any required local approvals, the owner can begin construction of the facility. Landfills are constructed one phase or unit at a time. During major construction steps of the landfill, WDNR staff conduct inspections. Documentation (as-built) plans are prepared by the applicant's engineering consultant documenting the construction process such as the compaction of the clay liner and installation of the geomembrane liner (composite liners consisting of a 60-mil HDPE geomembrane and 4 foot thick clay liner are now required for municipal solid waste landfills) and leachate collection pipes.

After construction, the owner must submit a comprehensive report containing a detailed narrative describing the construction of the landfill phase or unit in chronological fashion with particular emphasis given to any deviations from the approved plan of operation. The report must also include detailed documentation of all aspects of construction. This includes surveys of various grades, field and laboratory soil test results, engineering plan sheets documenting the constructed grades, the precise location of all leachate collection storage and removal structures, the specifications of materials, and photo documentation.

Chapter NR 516, Wis. Adm. Code, describes what elements must be included in a landfill construction documentation report. After the as-built documentation has been reviewed and approved by the assigned WDNR engineer and the proofs of financial responsibility have been implemented, a final inspection of the constructed phase or unit is made before a license is issued. The landfill owner can only begin to accept waste after receipt of the license from the WDNR. The review of a landfill construction documentation report is usually concluded by the WDNR in a month.

Local Approval Process - Simultaneous to the WDNR technical decision-making process, the applicant must seek and obtain any applicable local approvals (see Figure 2). These would include any permits or approvals required by pre-existing local ordinances to construct or operate a landfill such as zoning variances, building permits, etc. Although local approvals need only be obtained prior to construction of a landfill, as a practical matter, many applicants do not proceed to develop a feasibility report until the issue of local approvals is resolved. The local approval process has two major components: negotiation and state arbitration if a negotiated agreement cannot be reached.

NEGOTIATION

A person proposing a new landfill or expansion of an existing landfill must apply for all local approvals at least 120 days before submitting a

LOCAL APPROVAL PROCESS

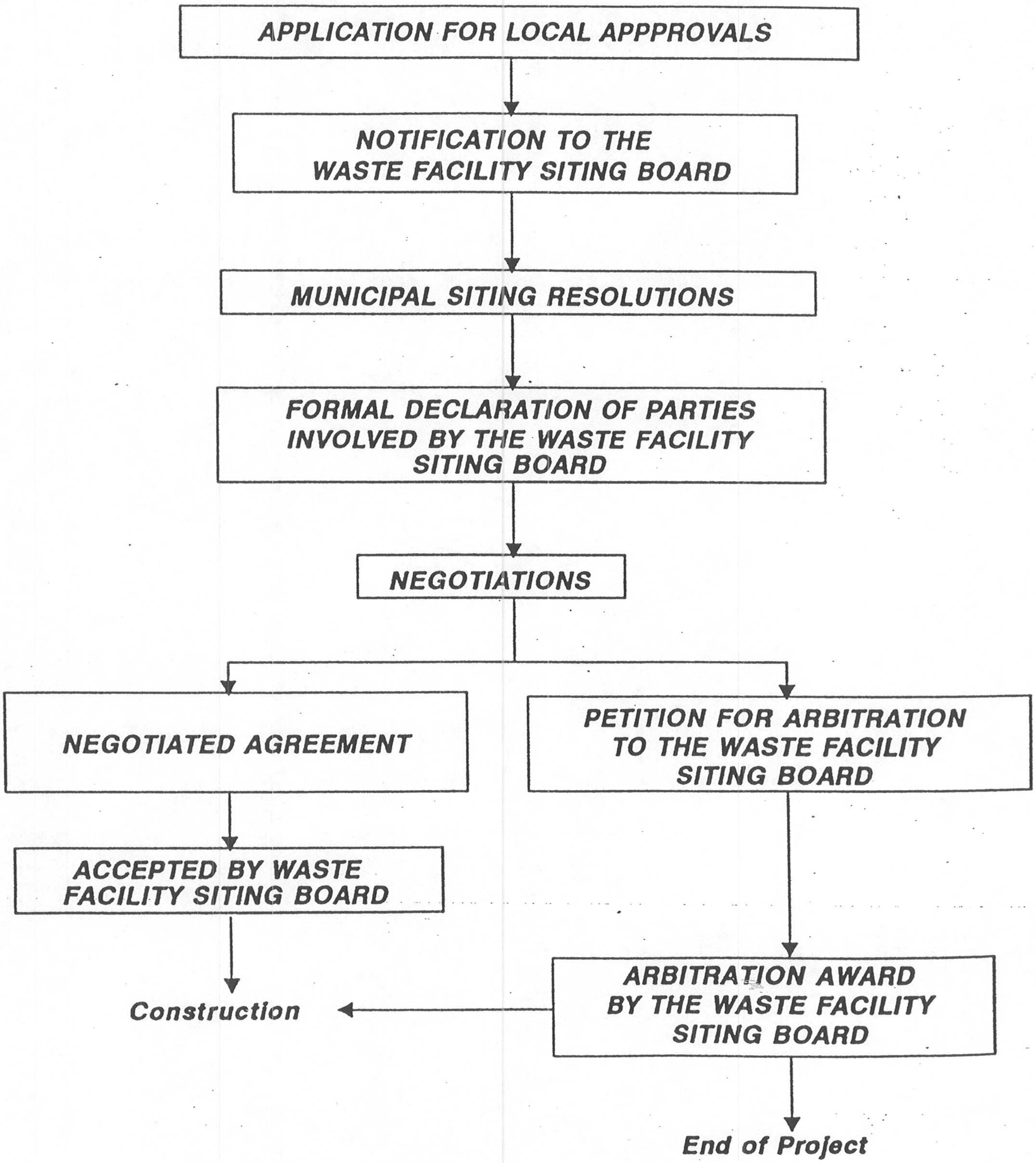

Figure 2. Local Approval Process

feasibility report to the WDNR. At that time, any affected municipality (county, township, village, or city within 1,200 feet of the proposed landfill's limits of filling) may choose to enter into negotiations with the applicant. Any municipality choosing not to negotiate waives its rights to enforce any local approval requirements. In general, the site owner will offer design, financial and operational incentives to the municipality in exchange for a negotiated agreement and to gain waiver or approval of local permits. Virtually any issue is negotiable except the need for the proposed landfill and agreements which would make the owner's responsibilities under the WDNR approved feasibility report less stringent. Commonly negotiated concessions on the part of the owner include: operational issues such as hours of operation, waste materials accepted, nuisance control, lighting, vehicle routes and access, aesthetic screening and fencing; recycling efforts to be implemented; private well monitoring and replacement if necessary; post-closure site use; payments to local governments for local costs of regulation, fire control, road maintenance, payments in lieu of taxes; economic protection of neighboring property owners for loss of property value; and establishment of a local advisory committee.

ARBITRATION

If the parties are unable to reach a negotiated settlement, they may petition the Wisconsin Waste Facility Siting Board (WWFSB) to issue an arbitration award. Each party must submit its final offer for a negotiated settlement to the WWFSB. After a hearing on the final offers, the WWFSB must select, without modification, the final offer of either the applicant or the local committee.

As described above, Wisconsin's landfill siting process is complex, comprehensive and time consuming. It can take three to five years or more to plan, design and construct a new facility.

If you should have questions on the WDNR technical decision-making process please contact Paul Huebner at (608) 267-7573. If you should have questions on the local approval process please contact Patti Cronin, Executive Director of the WWFSB at (608) 267-7854.

References

1. Schuff, R.G. 1986. Solid Waste Landfill Siting in Wisconsin an Effective Process. 12 pp.

2. Huebner, P.M. 1991. Wisconsin's Landfill Siting Process. 8 pp.

3. Sections 144.43 - 144.447, Stats.

4. Chapters NR 500 - 520, Wis. Adm. Code, Revisions Effective July 1, 1996.

PORT AND SOLID WASTE DEPARTMENT

Brown County

2561 SOUTH BROADWAY
GREEN BAY, WI 54304

CHARLES J. LARSCHEID

PHONE (920) 492-4950 FAX (920)492-4957

DIRECTOR OF PORT AND SOLID WASTE DEPARTMENT

RECEIVED APR
BUREAU FOR REMEDIATION & REDEVELOPMENT

April 9, 1999

Lower Fox River Cleanup, RR/3
WISCONSIN DEPARTMENT OF NATURAL RESOURCES
101 South Webster Street
P.O. Box 7921
Green Bay, WI 53707

RE: Draft RI/FS/RA Studies, Lower Fox River, Wisconsin Comments

Dear Sirs:

Brown County would like to bring up an issue that was not addressed in the Risk Assessment of the Draft RI/FS/RA Studies of the Lower Fox River. The study defines the Lower Fox River as the 39 miles stretch beginning at the outlet of Lake Winnebago and terminating at the mouth of the river. It is our contention that the problem of PCB impacted sediments does not end at the mouth of the river.

Brown County has an agreement with the US Army Corps of Engineers (USACE) to provide a disposal site for sediments removed during maintenance of the navigation channel. This channel, which must be dredged annually, starts approximately 8 miles north of the mouth of the river. Because the sediment is impacted with PCB's, the Wisconsin Department of Natural Resources, (WDNR) requires that all of the sediment must be deposited in a confined disposal facility (CDF). Over the last 25 years, the USACE has dredged millions of cubic yards of sediment and deposited it at the Bay Port upland CDF and the Renard Island in-water CDF.

Renard Island consists of a stone rubble dike with a steel sheet-pile cut-off wall. The total area enclosed by the cut-off wall is approximately 60 acres. The last load of sediment was deposited in the CDDF in 1997. Currently, there are discussions going on between the USACE and Brown County regarding the closure and long-term care of the CDF. The WDNR has identified minimum standards that must be met for the closure because PCB impacted sediment was disposed of in the CDF.

The 400 plus acre Bay Port CDF has restrictions on its use because PCB impacted sediments have and continue to be deposited there. Recently, 110 acres of Bay Port were reconstructed to facilitate dewatering sediment for eventual beneficial reuse. Off-site beneficial reuse projects can not take place yet because of the low levels of PCB's in the sediments. Without beneficial reuse projects, Bay Port will fill within 40 years, and the County will be required to locate another CDF for the disposal of sediment from maintenance dredging.

The County is of the opinion that the RI/RA/FS is incomplete because it fails to address the need to remediate the two CDF's. The County will be required to spend a significant amount of money to cap the Renard Island CDF and may have to spend additional money to eventually close the Bay Port CDF. These dollars would not have to be spent if the sediments were not impacted with PCB's.

The Brown County Port and Solid Waste Department encourages the SDNR to consider not only future transport of PCB's to the bay of Green Bay, but also the PCB's already located in the two CDF's. Of the eight alternatives evaluated in the Risk Assessment, our department prefers those alternatives that remove the greatest volume of PCB's. Since the Port of Green Bay is the recipient of the majority of sediment that moves down river, we (Brown County and the USACE) bear the additional cost of handling the PCB impacted sediment. Our costs for dredging will decrease significantly when the sediments are no longer impacted. Therefore, we encourage the quick remediation of the impacted sediments.

Brown County requests that the RI/RA/FS be corrected to reflect the costs associated with the closure of the Renard Island and Bay Port CDF's . The specific requirements for closure of Renard Island have not been finalized yet, but the WDNR has directed the County to follow the closure plan requirements of NR 514.08. Furthermore, the department indicated that as much as 3 feet of topsoil might have to be used to cover the complete CDF. Preliminary estimates place the cost to perform such work at $4-6 million.

Bay Port has cost over $2 million to construct and will cost $2-4 million in 1999 dollars to close, depending upon final requirements. Brown County does not believe that it is responsible for any past or future incremental costs associated with handling sediments impacted with PCB's. In conclusion, each of the eight alternatives identified in the RA must include the cost to close the two CDF's.

The Brown County Port and Solid Waste Department thanks you for the opportunity to comment on the draft report. Please call if you have any questions or comments.

Sincerely,

Charles J. Larscheid
Director

CJL:nl
Cc: Fox River RI/FS U.S. EPA
Len Polczinski, WDNR NER
Paul Vornholt, Assistant to County Executive
Dnr499.ltr

Ed — for the FS — Greg

Mark Reimer
Senior Counsel
Environmental

FORT JAMES

Fort James Corporation
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facsimile 847.317.5456
Mark.Reimer@fortjamesmail.com

PLEASE DELIVER THE FOLLOWING PAGES TO:

Date: 11/22/99

Name: Greg Hill

Fax No.: 608/267-2800

FROM:

Name: Mark Reimer

Fax No.: 847-317-5456

COMMENT:

Number of pages including this sheet:

If you do not receive all the pages or if they are not clear, please call Karen Weber (847) 317-5441.

This message is intended only for the use of the individual or entity to which it is addressed and may contain information that is privileged, confidential and exempt from disclosure under applicable law. If the reader of this message is not the intended recipient or the employee or agent responsible for delivering the message to the intended recipient, you are hereby notified that any dissemination, distribution or copying of this communication is strictly prohibited. If you have received this message in error, please notify us immediately by telephone and return the original message to us at the above address via the U.S. Postal Service. Thank you.

Mark Reimer
Senior Counsel Environmental

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November 22, 1999

Greg Hill
Wisconsin DNR
101 South Webster Street
P.O. Box 7921
Madison, WI., 53707-7921

RE: Preliminary PCB Sediment Cell 12A Budget and Costs

Dear Greg:

Per your request, enclosed please find a preliminary budget and costs incurred as of October 31, 1999 for the design, permitting, construction, operation, closure and post closure of Cell 12A located at Fort James Operating Company's Green Bay-West Landfill. Included in the spreadsheet is an estimate of transportation costs as well. Please note that the enclosed spreadsheet does note include the value of all of the services provided by Fort James on the SMU 56/57 sediment restoration demonstration project as provided in paragraph F of the agreement between Fort James and WDNR effective July 22, 1999 entitled "Agreement Between the State of Wisconsin and Fort James Corporation". For example, the value of services such as management time spent on Cell 12A, use of the Shell Property for a dewatering facility, or any imputed tipping fees, are not included. The value of those and other services will be valued at a later date.

If you have any questions, please feel free to contact me at 847/317-5326.

Sincerely,
Fort James Corporation

Mark S. Reimer
Mark S. Reimer
Senior Counsel

FILE No.647 11/22 '99 14:35 ID:LEGAL-DEPT-DEERFIELD FAX:18473175456 PAGE 2

C. Richard Jones -- Fort James

Mark Travers -- domaximis, inc.
103 North Eleventh Street, Suite 210
St. Charles, IL, 60174

John Hanson -- Beveridge & Diamond
1350 I Street NW
Suite 700
Washington DC, 20005-3311

Preliminary PCB Sed. Cell 12A Costs and Budget
As of 10/31/99

	BUDGETS		ACTUAL AND FORECASTED PROJECT COSTS			
	Original Budget	**Adjusted Budget**	**Paid to Date**	**Total Committed**	**Est. to Complete**	**Final Forecast**
01 040 Excavation/Berm Constr.	155,000	155,000	144,117	146,938	3,062	150,000
01 140 Roads	34,000	75,000	56,678	56,678	18,322	75,000
01 200 Transportation/Landfill[1]	544,000	544,000	-0-	-0-	544,000	544,000
01 400 Lysimeter	211,334	211,334	208,025	208,025	3,309	211,334
01 401 Primary Liner/Leachate	472,841	499,347	479,347	479,347	20,000	499,347
01-402 Final Cover System[2]	348,000	332,861	348,000	-0-	332,861	332,861
01 403 Miscellaneous	25,000	25,000	2,684	3,496	21,504	25,000
01 650 Power Dist. (Electrical)	15,000	15,000	12,483	13,594	1,406	15,000
01 800 Permitting Fees	10,000	10,000	3,500	3,500	6,500	10,000
01 801 Waste Disposal Permit Fee	20,400	20,400	-0-	-0-	20,400	20,400
01-820 Engineering (Fort James)[3]	96,700	96,700	45,535	45,535	51,165	96,700
01 821 Engineering (STS Consult)	230,000	230,000	109,956	142,200	87,800	230,000
01-900 Contingency	174,000	106,494	-0-	-0-	106,494	106,494
01 940 Port Closure Cost[4]	121,000	48,170	121,000	-0-	48,170	48,170
TOTAL	**2,423,275**	**2,369,306**	**1,531,325**	**1,099,313**	**1,264,993**	**2,364,306**

[1] Transportation costs assumes removal of 80,000 cubic yards of sediment from SMU 56/57
[2] $348,000 estimate was used to establish escrow account for financial assurance purposes.
[3] Does not include time spent on project by other internal Fort James personnel. That cost will be compiled at a later date.
[4] $121,000 estimate was used to establish escrow account for financial assurance purposes.

FORT JAMES WEST LANDFILL
GREEN BAY, WISCONSIN
Construction Cost Estimate
STS Project No.: 24702 Task 5000

The landfill has a planned area of 3.1 acres and an approximate disposal volume of 70,000 cubic yards.

ITEM	QUANTITY	UNITS	COST/UNIT	COST
PRELIMINARY WORK				
Mobilization	1	ea.	$50,000.00	$50,000.00
EXCAVATION and BERM CONSTRUCTION				
Structural Fill (onsite or borrow)	85,000	cy	$2.85	$242,250.00
Anchor Trench (excavation and backfilling)	1,500	lf	$7.60	$11,400.00
LYSIMETER				
60 mil HDPE Textured (sideslopes)	140,000	sf	$0.56	$78,400.00
GCL (base and sideslopes)	141,500	sf	$0.40	$56,600.00
Geocomposite	140,000	sf	$0.48	$67,200.00
18-inch dia. HDPE (SDR 17) riser pipe	140	lf	$15.50	$2,170.00
Pump and Controls	1	ea	$7,750.00	$7,750.00
PRIMARY LINER and LEACHATE SYSTEM				
5-foot-thick Compacted Clay Layer	25,000	cy	$10.00	$250,000.00
60 mil HDPE Textured	120,000	sf	$0.56	$67,200.00
Cushion Geotextile 12 oz. / sq. yd.	120,000	sf	$0.15	$18,000.00
1-18 inch HDPE (SDR 17) Risers Pipe	120	lf	$15.50	$1,860.00
6-inch dia. SDR 17 HDPE - Perforated	750	lf	$2.60	$1,950.00
6-inch dia. SDR 17 HDPE - solid	300	lf	$2.20	$660.00
Leachate Gravel	825	cy	$13.00	$10,725.00
12-inch Sand Drainage Blanket	4,600	cy	$14.00	$64,400.00
Pump and Controls	1	ea	$7,750.00	$7,750.00
LEACHATE CONVEYANCE AND STORAGE				
Leachate Storage Tank (20,000 gallon tank)	365	ea	$40.00	$14,600.00
Leachate Storage Tank Mobilization & Setup	1	ea	$1,430.00	$1,430.00
Tank Containment Area	1	ea	$5,000.00	$5,000.00
LANDFILL OPERATION				
Daily Operation - (2 dozers and operators, 6 days/week, 12 weeks)	72	days	$2,000.00	$144,000.00
Transportation (80,000 river yds = 48,000 stabilized tons)	48,000	tons	$3.00	$144,000.00
FINAL COVER SYSTEM				
12-inch Gas Venting/Drainage Layer	4,700	cy	$5.00	$23,500.00
24-inch Clay Cover	9,400	cy	$10.00	$94,000.00
40 mil VFPE Geomembrane	140,000	sq	$0.47	$65,800.00
36 inch Rooting Zone	15,000	cy	$2.50	$37,500.00
6 inch Topsoil Layer	2,500	cy	$6.50	$16,250.00
Seed, Fertilizer and Mulch	3.6	ac	$1,250.00	$4,500.00
4 inch Perforated Gas Vent Pipe	2,540	lf	$0.45	$1,143.00
Gas Vent Trench Backfill	100	cy	$13.00	$1,300.00
Gas Vent Trench Geotextile (8oz)	9,000	sf	$0.14	$1,260.00
Gas Vent Risers	5	ea	$350.00	$1,750.00
4 inch Perforated Cover Slope Drain Pipe w/sock	1,400	lf	$0.57	$798.00
8 inch Rip Rap	25	cy	$14.00	$350.00
MISCELLANEOUS ITEMS				
Power distribution	1	ea	$15,000.00	$15,000.00
Post Closure Cost (present worth at a 6% interest rate)	1	ea	$48,170.63	$48,170.63
Bidding and Construction Adminstration	1	ea	$100,000.00	$100,000.00
CQA Documentation	1	ea	$139,000.00	$139,000.00
Subtotal				$1,797,667
Contingency 15%				$269,650
TOTAL COST ESTIMATE				$2,067,317

Appendix F

Dechlorination Memorandum

Review of Natural PCB Degradation Processes in Sediments for the Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

♦ **The RETEC Group, Inc.**

RETEC Project No.: WISCN-14414

December 2002

Review of Natural PCB Degradation Processes in Sediments

Prepared by:

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RETEC Project No.: WISCN-14414-530

Prepared for:

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Paul Putzier, P.G.

Reviewed by:

Timothy Thompson

December 2002

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1 Introduction

This paper provides a review of literature documenting field and laboratory studies that examine the occurrence and extent of natural biodegradation processes (aerobic degradation and anaerobic dechlorination) of polychlorinated biphenyls (PCBs) at various sites both in the U.S and internationally. The review was prepared as part of the Lower Fox River Remedial Investigation/Feasibility Study.

The objective of this review was to evaluate information relating to the viability of natural biodegradation as a potential remedial action for the sediment-bound PCBs in the Lower Fox River and Green Bay. The information presented in this paper will be evaluated together with additional site-specific information generated for the Lower Fox River and Green Bay in the Feasibility Study. It is recognized that the rate at which *in situ* microbial processes can occur is an important element of any evaluation of such processes when assessing natural bioremediation as a potential remedial action. However, based on the results of the literature review presented here, no degradation (aerobic or anaerobic) rates have been reliably measured under field conditions. The only rates that have been estimated are for laboratory experiments done under controlled conditions. These rates are generally not applicable to field conditions; as such, they are not reported in this paper.

The paper consists of five sections, in addition to this introductory section, articulated as follows.

- Section 2 provides an overview of PCB chemistry and nomenclature;
- Section 3 provides a review of microbial processes relevant to PCBs;
- Section 4 provides a review of field and laboratory studies of natural degradation of PCBs in sediments;
- Section 5 provides the conclusion of the literature review; and
- Section 6 is a list of cited references.

2 PCB Chemistry, Nomenclature, and Toxicology

PCBs are a class of 209 individual chemicals (PCB congeners), in which one to ten chlorine atoms are attached to a biphenyl molecular frame. PCBs were commercially produced as mixtures for a variety of uses, including dielectric fluids in capacitors and transformers, and carbonless copy paper. Monsanto Industrial Chemicals Company (Monsanto) was the world's largest producer and sole manufacturer of commercial PCBs in the U.S. Monsanto marketed PCBs under the trade name Aroclor from 1930 to 1977 (Erickson 1986). Table 2-1 provides a list of the uses of PCBs and the type of Aroclor used.

Most Aroclors contained from 60 to 90 different PCB congeners and were identified by a four-digit number; the first two digits were usually 12, for 12 carbon atoms, and the last two digits indicated the percent substituted chlorine by weight. Thus, Aroclor 1242 contains 12 carbon atoms and 42% substituted chlorine by weight (Hutzinger *et al*., 1974; Bedard and Quensen 1995). Table 2-2 provides the chlorine content of various Aroclors.

Key to the discussion of natural degradation processes is an understanding of the nomenclature associated with the numbering and position of the chlorine atoms within the PCB biphenyl rings. The general chemical formula for PCBs is

$$C_{12}H_{10-n}Cl_n$$

with n indicating the number of chlorine substitutions; n=1 through 10.

PCB congeners with the same number of chlorine substitutions are defined as a class of PCB homologs. For example, the twenty-four PCB congeners with three chlorine substitutions form the trichlorobiphenyl homolog class. PCB congeners in a given homolog class are sometimes referred to as PCB isomers (Erickson, 1986).

The chlorine positions on the biphenyl rings are numbered as shown in Figure 2-1(a). Different congeners are specified by the positions of the chlorine atoms. For example, in Figure 2-1(b), the 2,4'-dichlorobiphenyl is shown. (As discussed later, this is the most abundant congener in Aroclor 1242). PCB congeners have been arranged in ascending numerical order between 0 (biphenyl) and 209 (2,2',3,3',4,4',5,5',6,6'–decachlorobiphenyl) and are commonly identified by this number, which is referred to as the "IUPAC" or "PCB" number. For example, the 2,4' dichlorobiphenyl congener is also referred to as PCB 8. Finally, some authors refer to individual congeners by listing the substituted positions on each ring, separated by a hyphen. Thus, in this notation 2,4' dichlorobiphenyl is referred to as 2-4 chlorobiphenyl or 2-4-CB. This paper reports on studies by a number of authors. To minimize the possibility of transcription errors, the notation used by each author is used when reporting on that author's results.

As shown in Figure 2-1(c), chlorine atoms at positions 2, 6, 2' and 6' are referred to as being oriented *ortho* with respect to the opposite phenyl ring. Positions 3, 5, 3' and 5' are oriented *meta*, while positions 4 and 4' are oriented *para* with respect to the opposite phenyl ring.

Table 2-1 Uses of PCBs (from Huntzinger *et al.*, 1974)

Use of PCB	Grade of Aroclor Used
Electrical capacitors	1016 (1221, 1254)
Electrical transformers	1242, 1254, 1260
Vacuum pumps	1248, 1254
Gas-transmission turbines	1221, 1242
Hydraulic fluids	1232, 1242, 1248, 1254, 1260
Plasticizer in synthetic resins	1248, 1254, 1260, 1262, 1268
Adhesives	1221, 1232, 1242, 1248, 1254
Plasticizer in rubbers	1221, 1232, 1242, 1248, 1254, 1268
Heat transfer systems	1242
Wax extenders	1242, 1254, 1268
Dedusting agents	1254, 1260
Pesticide extenders, inks, lubicants, cutting oils	1254
Carbonless reproducing paper	1242

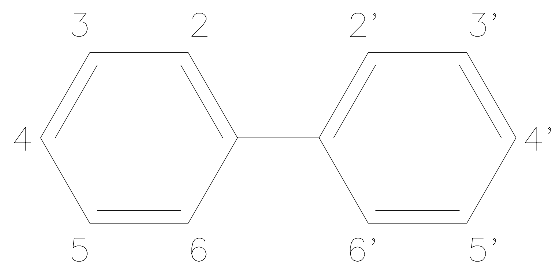
Table 2-2 Chlorine Content of Aroclor Preparations

Aroclor	% Cl	Average number of Cl per molecule	Average molecular weight
1221	20.5 – 21.5	1.15	192
1232	31.5 – 32.5	2.04	221
1242	42	3.10	261
1248	48	3.90	288
1254	54	4.96	327
1260	60	6.30	372
1262	61.5 – 62.5	6.80	389
1268	68	8.70	453

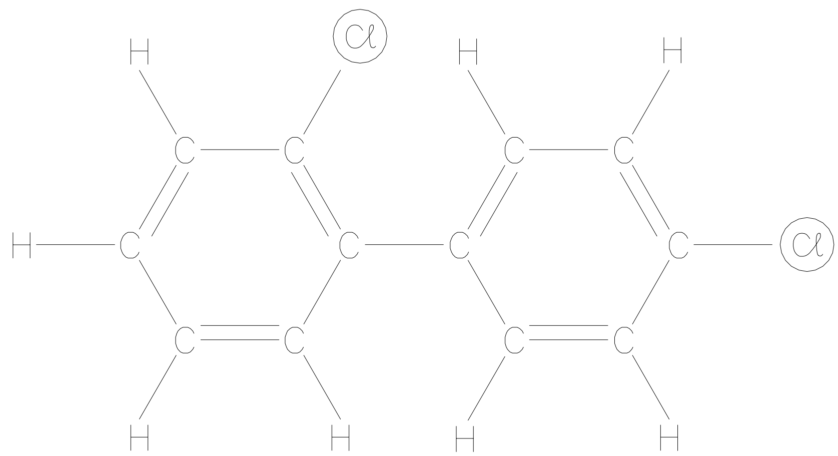
Selected physical and chemical properties of PCB congeners are presented in Tables 2-3 and 2-4. Table 2-5 presents the molecular composition of some Aroclors. This table shows that Aroclor 1242 is mostly comprised of tri-, tetra- and pentachlorobiphenyls, and that no congeners with more than six chlorine substitutions are present in Aroclor 1242.

Figure 2-1 PCB Structure and Nomenclature

a) Numbering in the Biphenyl Ring System



b) Structure of 2,4'- dichlorobiphenyl



c) Orientation of Chlorine Atoms in Biphenyl Ring System

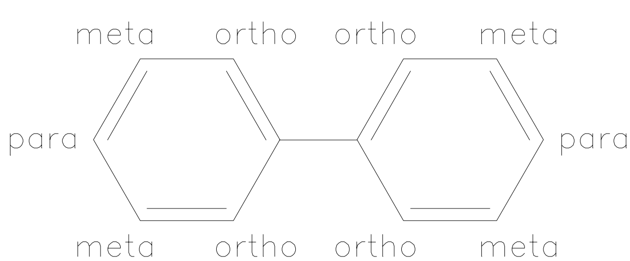


Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s $mmol/m^3$	Subcooled Liquid Concentration C_L $mmol/m^3$	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
0	0	154.21	1.3	3.69	7	45.39	129.7	3.9	53.5
1	2	188.66	2.04	2.5	5.5	29.15	35.66	4.3	70.1
2	3	188.66	1	1	2.5	13.25	13.24	4.6	75.55
3	4	188.66	0.271	0.9	1.2	6.36	21.15	4.5	42.56
4	2,2'	223.11	0.265	0.6	1	4.48	10.14	4.9	59.17
5	2,3	223.11							
6	2,3'	223.11							
7	2,4	223.11	0.254	0.25	1.25	5.6	5.51	5	45.39
8	2,4'	223.11			1	4.48	6.73	5.1	
9	2,5	223.11	0.18	0.18	2	8.96	8.95	5.1	20.1
10	2,6	223.11			1.4	6.28	7.84	5	
11	3,3'	223.11	0.027	0.03	0.354	1.587	1.738	5.3	17.26
12	3,4	223.11			0.008				
13	3,4'	223.11							
14	3,5	223.11	0.105	0.12					
15	4,4'	223.11	0.0048	0.08	0.06	0.269	4.56	5.3	17
16	2,2',3	257.56							
17	2,2',4	257.56							
18	2,2',5	257.56	0.143	0.22	0.4	1.55	2.39	5.6	92.21
19	2,2',6	257.56							
20	2,3,3'	257.56							
21	2,3,4	257.56							
22	2,3,4'	257.56							
23	2,3,5	257.56							
24	2,3,6	257.56							
25	2,3',4	257.56							
26	2,3',5	257.56			0.251	0.975	1.387		

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s $mmol/m^3$	Subcooled Liquid Concentration C_L $mmol/m^3$	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
27	2,3',6	257.56							
28	2,4,4'	257.56			0.16	0.621	1.28	5.8	
29	2,4,5	257.56	0.132	0.044	0.14	0.544	1.81	5.6	24.29
30	2,4,6		0.0384	0.09	0.2	0.777	1.82	5.5	49.51
31	2,4',5	257.56							
32	2,4',6	257.56							
33	2,3,4	257.56	0.0136	0.003	0.08	0.311	0.69	5.8	43.67
34	2',3,5	257.56							
35	3,3',4	257.56							
36	3,3',5	257.56							
37	3,4,4'	257.56			0.015	0.0582	0.24	5.9	
38	3,4,5	257.56							
39	3,4',5	257.56							
40	2,2',3,3'	292.01	0.00225	0.002	0.03	0.103	0.91	5.6	21.94
41	2,2',3,4	292.01							
42	2,2',3,4'	292.01							
43	2,2',3,5	292.01							
44	2,2',3,5'	292.01			0.1	0.342	0.565	6	
45	2,2',3,6	292.01							
46	2,2',3,6'	292.01							
47	2,2',4,4'	292.01	0.0054	0.002	0.09	0.308	1.15	5.9	17.38
48	2,2',4,5	292.01							
49	2,2',4,5'	292.01			0.016	0.0548	0.133	6.1	
50	2,2',4,6	292.01							
51	2,2',4,6'	292.01							
52	2,2',5,5'	292.01	0.0049	0.002	0.03	0.103	0.42	6.1	47.59
53	2,2,5,6'	292.01						5.5	
54	2,2',5,6'	292.01						5.48	

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s $mmol/m^3$	Subcooled Liquid Concentration C_L $mmol/m^3$	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
55	2,3,3',4	292.01							
56	2,3,3',4'	292.01							
57	2,3,3',5	292.01							
58	2,3,3',5'	292.01							
59	2,3,3',6	292.01							
60	2,3,4,4'	292.01						6.31	
61	2,3,4,5	292.01			0.02	0.0685	0.314	5.9	
62	2,3,4,6	292.01							
63	2,3,4',5	292.01							
64	2,3,4',6	292.01							
65	2,3',4,4'	292.01						5.94	
66	2,3',4,4'	292.01			0.04	0.0147	1.3	5.8	
67	2,3',4,5	292.01							
68	2,3',4,5'	292.01							
69	2,3',4,6	292.01							
70	2,3',4',5	292.01							
71	2,3',4',6	292.01							
72	2,3',5,5'	292.01							
73	2,3',5',6	292.01							
74	2,4,4',5	292.01							
75	2,4,4',6	292.01			0.091			6.21	
76	2',3,4,5	292.01							
77	3,3',4,4'	292.01	0.0000588	0.002	0.001	0.0342	1.165	6.5	1.72
78	3,3',4,5	292.01							
79	3,3',4,5'	292.01							
80	3,3',5,5'	292.01			0.0012	0.0041	0.0974		
81	3,4,4',5	292.01							
82	2,2',3,3',4	326.46							
83	2,2',3,3',5	326.46							

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m³	Solid Molar Concentration C^s mmol/m³	Subcooled Liquid Concentration C_L mmol/m³	Log K_{ow}	Henry's Law Const. H Pa m³/mol
84	2,2',3,3',6	326.46							
85	2,2',3,4,4'	326.46							
86	2,2'3,4,5	326.46	0.00927	0.051	0.02	0.0613	0.337	6.2	151.4
87	2,2',3,4,5'	326.46	0.000304	0.0023	0.004	0.0123	0.0927	6.5	24.81
88	2,2',3,4,6	326.46			0.012	0.0368	0.202	6.5	
89	2,2',3,4,6'	326.46							
90	2,2',3,4',5	326.46							
91	2,2',3,4',6	326.46							
92	2,2',3,5,5'	326.46							
93	2,2',3,5,6	326.46							
94	2,2',3,5,6'	326.46							
95	2,2',3,5',6	326.46							
96	2,2',3,6,6'	326.46							
97	2,2',3',4,5	326.46							
98	2,2',3',4,6	326.46							
99	2,2',4,4',5	326.46							
100	2,2',4,4',6	326.46							
101	2,2',4,5,5'	326.46	0.00109	0.0035	0.01	0.0306	0.0986	6.4	35.48
102	2,2',4,5,6'	326.46							
103	2,2',4,5,6'	326.46							
104	2,2',4,6,6'	326.46		0.00434	0.0156	0.0306	0.3103		13.98
105	2,3,3',4,4'	326.46						6	
106	2,3,3',4,5	326.46							
107	2,3,3',4',5	326.46							
108	2,3,3',4,5'	326.46							
109	2,3,3',4,6	326.46							
110	2,3,3',4',6	326.46			0.004			6.3	
111	2,3,3',5,5'	326.46							
112	2,3,3',5,6	326.46							

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s $mmol/m^3$	Subcooled Liquid Concentration C_L $mmol/m^3$	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
113	2,3,3',5',6	326.46							
114	2,3,4,4',5	326.46							
115	2,3,4,4',6	326.46							
116	2,3,4,5,6	326.46			0.008	0.0145	0.233	6.3	
117	2,3,4',5,6	326.46							
118	2,3',4,4',5	326.46							
119	2,3',4,4',6	326.46							
120	2,3',4,5,5'	326.46							
121	2,3',4,5',6	326.46							
122	2,3,3',4,5	326.46							
123	2',3,4,4',5	326.46							
124	2',3,4,5,5'	326.46							
125	2',3,4,5,6'	326.46							
126	3,3',4,4',5	326.46							
127	3,3',4,5,5'	326.46							
128	2,2',3,3',4,4'	360.91	0.0000198	0.00034	0.0006	0.00166	0.0286	7	11.91
129	2,2',3,3',4,5	360.91			0.0006	0.00166	0.0065	7.3	
130	2,2',3,3',4,5'	360.91							
131	2,2',3,3',4,6	360.91							
132	2,2',3,3',4,6'	360.91							
133	2,2',3,3',5,5'	360.91							
134	2,2',3,3',5,6	360.91			0.0004	0.00111	0.0061	7.3	
135	2,2',3,3',5,6'	360.91							
136	2,2',3,3',6,6'	360.91			0.0008	0.00222	0.0161	6.7	
137	2,2',3,4,4',5	360.91							
138	2,2',3,4,4',5'	360.91							
139	2,2',3,4,4',5'	360.91							
140	2,2',3,4,4',6'	360.91							
141	2,2',3,4,5,5'	360.91							

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s mmol/m^3	Subcooled Liquid Concentration C_L mmol/m^3	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
142	2,2',3,4,5,6	360.91							
143	2,2',3,4,5,6	360.91							
144	2,2',3,4,5',6	360.91							
145	2,2',3,4,5',6	360.91							
146	2,2',3,4',5,5'	360.91							
147	2,2',3,4,6,6'	360.91							
148	2,2',3,4',5,6'	360.91							
149	2,2',3,4',5',6	360.91							
150	2,2',3,4',6,6'	360.91							
151	2,2',3,5,5',6	360.91							
152	2,2',3,5,6,6'	360.91							
153	2,2',4,4',5,5'	360.91	0.000119	0.0007	0.001	0.00277	0.0163	6.9	42.9
154	2,2',4,4',5,6'	360.91							
155	2,2',4,4',6,6'	360.91	0.00048	0.00363	0.002	0.0055	0.042	7	86.616
156	2,3,3',4,4',5	360.91							
157	2,3,3',4,4',5'	360.91							
158	2,3,3',4,4',6	360.91							
159	2,3,3',4,5,5'	360.91							
160	2,3,3',4,5,6	360.91							
161	2,3,3',4,5',6	360.91							
162	2,3,3',4',5,5'	360.91							
163	2,3,3',4',5,6	360.91							
164	2,3,3',4',5',6	360.91							
165	2,3,3',5,5',6	360.91							
166	2,3,4,4',5,6	360.91							
167	2,3',4,4',5,5	360.91							
168	2,3',4,4',5',6	360.91							
169	3,3',4,4',5,5'	360.91							
170	2,2',3,3',4,4',5	395.36							

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s mmol/m^3	Subcooled Liquid Concentration C_L mmol/m^3	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
171	2,2',3,3',4,4',6	395.36	0.0000273	0.00025	0.002	0.00506	0.046	6.7	5.4
172	2,2',3,3',4,5,5'	395.36							
173	2,2',3,3',4,5,6	395.36							
174	2,2',3,3',4,5,6'	395.36							
175	2,2',3,3',4,5',6	395.36							
176	2,2',3,3',4,6,6'	395.36							
177	2,2',3,3',4',5,6	395.36							
178	2,2',3,3',5,5',6	395.36							
179	2,2',3,3',5,6,6'	395.36							
180	2,2',3,4,4',5,5'	395.36							
181	2,2',3,4,4',5,5'	395.36							
182	2,2',3,4,4',5,6'	395.36							
183	2,2',3,4,4',5',6	395.36							
184	2,2',3,4,4',6,6'	395.36							
185	2,2',3,4,5,5',6	395.36			0.00045	0.00114	0.0191	7	
186	2,2',3,4,5,6,6'	395.36							
187	2,2',3,4',5,5',6	395.36							
188	2,2',3,4',5,6,6'	395.36							
189	2,3,3',4,4',5,5'	395.36							
190	2,3,3',4,4',5,6	395.36							
191	2,3,3',4,4',5',6	395.36							
192	2,3,3',4,5,5',6	395.36							
193	2,3,3',4',5,5',6	395.36							
194	2,2',3,3',4,4',5,5'	429.81			0.0002	0.00047	0.0098	7.4	
195	2,2',3,3',4,4',5,6	429.81							
196	2,2',3,3',4,4',5',6	429.81							
197	2,2',3,3',4,4',6,6'	429.81							
198	2,2',3,3',4,5,5',6	429.81							
199	2,2',3,3',4,5,5',6'	429.81							

Table 2-3 Summary of Physical-Chemical Properties of PCB Congeners (Continued)

Number	Structure	Molecular Weight	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Water Solubility S g/m^3	Solid Molar Concentration C^s $mmol/m^3$	Subcooled Liquid Concentration C_L $mmol/m^3$	Log K_{ow}	Henry's Law Const. H Pa m^3/mol
200	2,2',3,3',4,5,6,6'	429.81							
201	2,2',3,3',4,5',6,6'	429.81							
202	2,2',3,3',5,5',6,6'	429.81	0.0000266	0.0006	0.0003	0.0007	0.0158	7.1	38.08
203	2,2',3,4,4',5,5',6	429.81							
204	2,2',3,4,4',5',6,6'	429.81							
205	2,3,3',4,4',5,5',6	429.81							
206	2,2',3,3',4,4',5,5',6	464.26	0.000000197	0.000012	0.00011	0.000237	0.0146	7.2	82.2
207	2,2',3,3',4,4',5,6,6'	464.26						7.52	
208	2,2',3,3',4,5,5',6,6'	464.26			0.000018	0.000038	0.00141	8.16	
209	2,2',3,3',4,4',5,5',6,6'	498.71	5.02E-08	0.00003	0.000001	0.000002	0.0144	8.26	20.84

Table 2-4 Summary of Physical-Chemical Properties of PCB Isomer Groups and Aroclor Mixtures at 20-25 Degrees Celsius

PCB Isomer Groups	Water Solubility S g/m^3	Solid Molar Concentration C^s mmol/m^3	Subcooled Liquid Concentration C_L mmol/m^3	Solid Vapor Pressure P^s Pa	Subcooled Liquid Vapor Pressure P_L Pa	Henry's Law Const. H Pa m^3/mol	Log K_{ow} range
Biphenyl	7.0	45.39	129.7	1.30	3.69	28.64	3.90
Mono-	1.21 - 5.50	6.36 - 29.15	113.24 - 35.66	0.271 - 2.04	0.9 - 2.5	42.56 - 75.55	4.3 - 4.60
Di-	0.060 - 2.0	0.269 - 8.96	4.56 - 10.14	0.0048 - 0.279	0.008 - 0.60	17.0 - 92.21	4.9 - 5.30
Tri-	0.015 - 0.40	0.0582 - 1.55	0.24 - 2.39	0.0136 - 0.143	0.003 - 0.22	24.29 - 92.21	5.5 - 5.90
Tetra-	0.0043 - 0.010	0.0147 - 0.342	0.133 - 1.30	0.000059 - 0.0054	0.002	1.72 - 47.59	5.6 - 6.50
Penta-	0.004 - 0.020	0.0123 - 0.0613	0.093 - 0.337	0.000304 - 0.0093	0.0023 - 0.051	24.8 - 151.4	6.2 - 6.50
Hexa-	0.0004 - 0.0007	0.0011 - 0.002	0.0061 - 0.0286	0.000020 - 0.0015	0.0007 - 0.012	11.9 - 818	6.7 - 7.30
Hepta-	0.000045 - 0.0002	0.00114 - 0.0051	0.0191 - 0.046	0.0000273	0.00025	5.40	6.7 - 7.0
Octa-	0.0002 - 0.0003	0.00047 - 0.0007	0.0098 - 0.0158	0.0000266	0.0006	38.08	7.10
Nona-	0.00018 - 0.0012	0.000038 - 0.00024	0.00141 - 0.0146				7.2 - 8.16
Deca-	0.000761	0.0000024	0.0144	0.00000005	0.00003	20.84	8.26

Arochlor Mixtures	Water Solubility S g/m^3		Subcooled Liquid Concentration C_L mmol/m^3		Subcooled Liquid Vapor Pressure P_L Pa	Henry's Law Const. H Pa m^3/mol	Log K_{ow} range
Arochlor 1016	0.22 - 0.84		0.856 - 0.216		0.06 - 0.2	70 - 900	4.4 - 5.8
Arochlor 1221	0.59 - 5.0		0.307 - 26.0		0.89 - 2.0	34 - 450	4.1 - 4.7
Arochlor 1232	1.45		6.56 - 2.0		0.54	82 - 270	4.5 - 5.2
Arochlor 1242	0.1 - 0.75		0.383 - 2.87		0.05 - 0.13	45 - 130	4.5 - 5.8
Arochlor 1248	0.1 - 0.5		0.347 - 1.74		0.0085 - 0.11	5 - 300	5.8 - 6.3
Arochlor 1254	0.01 - 0.30		0.306 - 0.92		0.008 - 0.02	20 - 260	6.1 - 6.8
Arochlor 1260	0.003 - 0.08		0.00806 - 0.215		0.0002 - 0.012	20 - 60	6.3 - 7.5

Table 2-5 Molecular Composition of Some Aroclors (from Huntzinger *et al.*, 1974)

Chlorobiphenyl Composition	Presence (%) in Aroclor			
	1242	1248	1254	1260
$C_{12}H_9Cl$	3			
$C_{12}H_8Cl_2$	13	2		
$C_{12}H_7Cl_3$	28	18		
$C_{12}H_6Cl_4$	30	40	11	
$C_{12}H_5Cl_5$	22	36	49	12
$C_{12}H_4Cl_6$	4	4	34	38
$C_{12}H_3Cl_7$			6	41
$C_{12}H_2Cl_8$				8
$C_{12}HCl_9$				1

Table 2-6 (from Schulz *et al*., 1989) and Figure 2-2 present the congener composition (on a weight basis) of Aroclor 1242. From this table, it can be seen that the most abundant congener in this Aroclor is 2,4'–dichlorobiphenyl (PCB 8) at 7.65% by weight. The congeners 2,4,4'–trichlorobiphenyl (PCB 28) and 2,2',5–trichlorobiphenyl (PCB 18) are also abundant at 6.52% and 6.28% by weight, respectively.

A large number of studies have linked PCBs with a variety of health effects, including cancer. A study of four commercial mixtures (Aroclors 1016, 1242, 1254, and 1260) demonstrated that all PCB mixtures can cause cancer, although different mixtures have different potencies (Brunner *et al*., 1996). The EPA used the study by Brunner *et al*. (1996) to develop cancer slope factors for different congeners (EPA, 1996). The cancer slope factors also vary depending on the route of exposure. Table 2-7 presents the cancer slope factors for different PCB aroclors and exposure pathways.

There is evidence that dioxin-like congeners may cause cancer by the same mechanism as 2,3,7,8 tetrachlorodibenzo-p-dioxin (dioxin). EPA (1996) has developed toxicity equivalency factors that allow the toxicity of dioxin-like congeners to be related to the toxicity of dioxin. Table 2-7 presents the cancer slope factors for specific congeners based on their similarity to dioxin. Congeners 77 (34-34), 126 (345-34) and 169 (345-345) are non-ortho chlorinated and most resemble dioxin (Sonzogni *et al*., 1991). These congeners have the highest cancer slope factors. The congeners with the most dioxin-like behavior have chlorine molecules in non-ortho positions. This is significant because PCBs with chlorines in non-*ortho* positions are the most suitable to anaerobic dechlorination, as discussed in detail later in this paper. The Aroclors and congeners presented in Table 2-7 are those evaluated in the human health risk assessment for the Lower Fox River and Green Bay.

Table 2-6 Percent Contribution of Individual Congeners to Aroclor 1242

Number	Structure	Weight Percent
0	0	0
1	2	0
2	3	0
3	4	0
4	2,2'	3.01
5	2,3	0.060
6	2,3'	1.38
7	2,4	0.60
8	2,4'	7.65
9	2,5	0.54
10	2,6	0.20
11	3,3'	0
12	3,4	0
13	3,4'	0
14	3,5	0
15	4,4'	1.51
16	2,2',3	2.01
17	2,2',4	2.88
18	2,2',5	6.28
19	2,2',6	0.53
20	2,3,3'	0.29
21	2,3,4	0
22	2,3,4'	3.41
23	2,3,5	0.00
24	2,3,6	0.22
25	2,3',4	0.79
26	2,3',5	1.33
27	2,3',6	0.28
28	2,4,4'	6.52
29	2,4,5	0.10
30	2,4,6	0
31	2,4',5	4.59
32	2,4',6	0.88
33	2,3,4	4.79
34	2',3,5	0.050
35	3,3',4	0.11
36	3,3',5	0
37	3,4,4'	0.27
38	3,4,5	0
39	3,4',5	0
40	2,2',3,3'	0.89
41	2,2',3,4	1.86
42	2,2',3,4'	0.83
43	2,2',3,5	0
44	2,2',3,5'	3.20
45	2,2',3,6	1.16
46	2,2',3,6'	0.49
47	2,2',4,4'	0.94
48	2,2',4,5	0.82
49	2,2',4,5'	3.60
50	2,2',4,6	0
51	2,2',4,6'	0.23
52	2,2',5,5'	4.04

Number	Structure	Weight Percent
53	2,2,5,6'	0.64
54	2,2',5,6'	0
55	2,3,3',4	0
56	2,3,3',4'	1.60
57	2,3,3',5	0
58	2,3,3',5'	0
59	2,3,3',6	0.34
60	2,3,4,4'	1.33
61	2,3,4,5	0
62	2,3,4,6	0
63	2,3,4',5	0.23
64	2,3,4',6	1.64
65	2,3',4,4'	0
66	2,3',4,4'	1.66
67	2,3',4,5	0.41
68	2,3',4,5'	0
69	2,3',4,6	0.11
70	2,3',4',5	3.89
71	2,3',4',6	0
72	2,3',5,5'	0
73	2,3',5',6	0
74	2,4,4',5	2.17
75	2,4,4',6	0.11
76	2',3,4,5	0
77	3,3',4,4'	0.45
78	3,3',4,5	0
79	3,3',4,5'	0
80	3,3',5,5'	0
81	3,4,4',5	0
82	2,2',3,3',4	0.44
83	2,2',3,3',5	0.12
84	2,2',3,3',6	0.72
85	2,2',3,4,4'	0.53
86	2,2'3,4,5	0
87	2,2',3,4,5'	0.77
88	2,2',3,4,6	0
89	2,2',3,4,6'	0
90	2,2',3,4',5	0.32
91	2,2',3,4',6	0.17
92	2,2',3,5,5'	0.25
93	2,2',3,5,6	0
94	2,2',3,5,6'	0
95	2,2',3,5',6	2.87
96	2,2',3,6,6'	0
97	2,2',3',4,5	0.65
98	2,2',3',4,6	0
99	2,2',4,4',5	0.86
100	2,2',4,4',6	0
101	2,2',4,5,5'	1.33
102	2,2',4,5,6'	0
103	2,2',4,5,6'	0
104	2,2',4,6,6'	0

Table 2-6 Percent Contribution of Individual Congeners to Aroclor 1242 (Con't)

Number	Structure	Weight Percent
105	2,3,3',4,4'	0.86
106	2,3,3',4,5	0
107	2,3,3',4',5	0.07
108	2,3,3',4,5'	0
109	2,3,3',4,6	0
110	2,3,3',4',6	1.53
111	2,3,3',5,5'	0
112	2,3,3',5,6	0
113	2,3,3',5',6	0
114	2,3,4,4',5	0
115	2,3,4,4',6	0
116	2,3,4,5,6	0
117	2,3,4',5,6	0
118	2,3',4,4',5	1.62
119	2,3',4,4',6	0.05
120	2,3',4,5,5'	0
121	2,3',4,5',6	0
122	2,3,3',4,5	0
123	2',3,4,4',5	0
124	2',3,4,5,5'	0
125	2',3,4,5,6'	0
126	3,3',4,4',5	0
127	3,3',4,5,5'	0
128	2,2',3,3',4,4'	0
129	2,2',3,3',4,5	0
130	2,2',3,3',4,5'	0
131	2,2',3,3',4,6	0
132	2,2',3,3',4,6'	0.30
133	2,2',3,3',5,5'	0
134	2,2',3,3',5,6	0
135	2,2',3,3',5,6'	0.08
136	2,2',3,3',6,6'	0.07
137	2,2',3,4,4',5	0
138	2,2',3,4,4',5'	0.54
139	2,2',3,4,4',5'	0
140	2,2',3,4,4',6'	0
141	2,2',3,4,5,5'	0
142	2,2',3,4,5,6	0
143	2,2',3,4,5,6	0
144	2,2',3,4,5',6	0
145	2,2',3,4,5',6	0
146	2,2',3,4',5,5'	0
147	2,2',3,4,6,6'	0
148	2,2',3,4',5,6'	0
149	2,2',3,4',5',6	0.63
150	2,2',3,4',6,6'	0
151	2,2',3,5,5',6	0
152	2,2',3,5,6,6'	0
153	2,2',4,4',5,5'	0.68
154	2,2',4,4',5,6'	0
155	2,2',4,4',6,6'	0
156	2,3,3',4,4',5	0.09
157	2,3,3',4,4',5'	0
158	2,3,3',4,4',6	0
159	2,3,3',4,5,5'	0
160	2,3,3',4,5,6	0
161	2,3,3',4,5',6	0
162	2,3,3',4',5,5'	0
163	2,3,3',4',5,6	0
164	2,3,3',4',5',6	0
165	2,3,3',5,5',6	0
166	2,3,4,4',5,6	0
167	2,3',4,4',5,5	0
168	2,3',4,4',5',6	0
169	3,3',4,4',5,5'	0
170	2,2',3,3',4,4',5	0.11
171	2,2',3,3',4,4',6	0.05
172	2,2',3,3',4,5,5'	0
173	2,2',3,3',4,5,6	0
174	2,2',3,3',4,5,6'	0
175	2,2',3,3',4,5',6	0
176	2,2',3,3',4,6,6'	0
177	2,2',3,3',4',5,6	0
178	2,2',3,3',5,5',6	0
179	2,2',3,3',5,6,6'	0
180	2,2',3,4,4',5,5'	0.06
181	2,2',3,4,4',5,5'	0
182	2,2',3,4,4',5,6'	0
183	2,2',3,4,4',5',6	0
184	2,2',3,4,4',6,6'	0
185	2,2',3,4,5,5',6	0
186	2,2',3,4,5,6,6'	0
187	2,2',3,4',5,5',6	0
188	2,2',3,4',5,6,6'	0
189	2,3,3',4,4',5,5'	0
190	2,3,3',4,4',5,6	0
191	2,3,3',4,4',5',6	0
192	2,3,3',4,5,5',6	0
193	2,3,3',4',5,5',6	0
194	2,2',3,3',4,4',5,5'	0
195	2,2',3,3',4,4',5,6	0
196	2,2',3,3',4,4',5',6	0
197	2,2',3,3',4,4',6,6'	0
198	2,2',3,3',4,5,5',6	0
199	2,2',3,3',4,5,5',6'	0
200	2,2',3,3',4,5,6,6'	0
201	2,2',3,3',4,5',6,6'	0
202	2,2',3,3',5,5',6,6'	0
203	2,2',3,4,4',5,5',6	0
204	2,2',3,4,4',5',6,6'	0
205	2,3,3',4,4',5,5',6	0
206	2,2',3,3',4,4',5,5',6	0
207	2,2',3,3',4,4',5,6,6'	0
208	2,2',3,3',4,5,5',6,6'	0
209	2,2',3,3',4,4',5,5',6,6'	0

Figure 2-2 Percent Contribution of Individual Congeners to Aroclor 1242

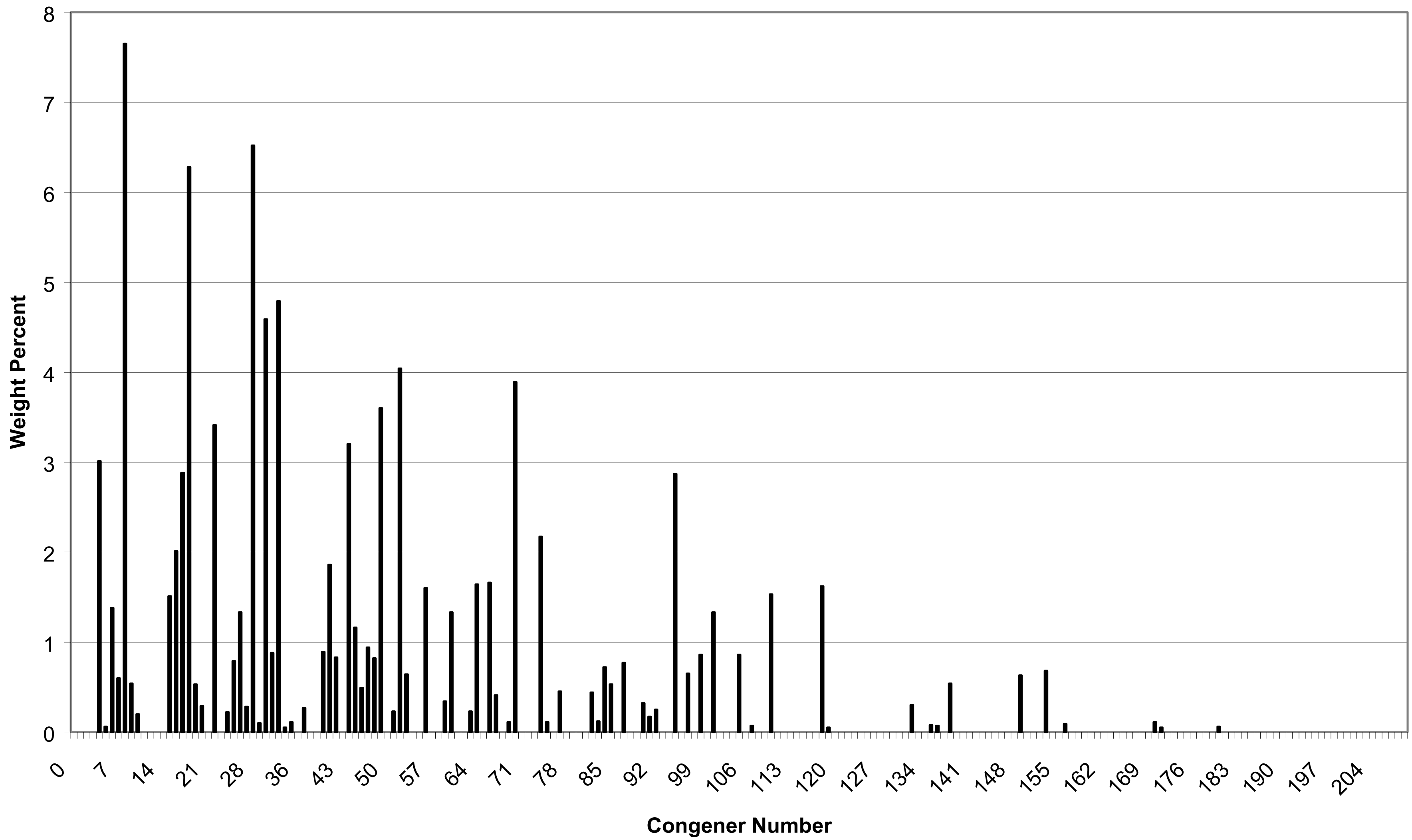


Table 2-7 Cancer Slope Factors for Selected Aroclors and PCB Congeners

Chemical of Potential Concern	Oral Soil/Sed CSFslo $(mg/Kg\text{-}day)^{-1}$	Oral Water CSFwo $(mg/Kg\text{-}day)^{-1}$	Oral Fish/Food CSFfo $(mg/Kg\text{-}day)^{-1}$	Dermal Soil/Sed CSFsld $(mg/Kg\text{-}day)^{-1}$	Dermal Water CSFwd $(mg/Kg\text{-}day)^{-1}$	Inhalation Vapor CSFavi $(mg/Kg\text{-}day)^{-1}$	Inhalation Particulate CSFapi $(mg/Kg\text{-}day)^{-1}$
Aroclor 1016	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Aroclor 1221	2	0.4	2	2	0.4	0.4	2
Aroclor 1232	2	0.4	2	2	0.4	0.4	2
Aroclor 1242	2	0.4	2	2	0.4	0.4	2
Aroclor 1248	2	0.4	2	2	0.4	0.4	2
Aroclor 1254	2	0.4	2	2	0.4	0.4	2
Aroclor 1260	2	0.4	2	2	0.4	0.4	2
3,3',4,4'-TeCB (PCB-77)	75	75	75	75	75	75	75
2,3,3',4,4'-PeCB (PCB-105)	15	15	15	15	15	15	15
2,3,4,4',5-PeCB (PCB-114)	75	75	75	75	75	75	75
2,3',4,4',5-PeCB (PCB-118)	15	15	15	15	15	15	15
2',3,4,4',5-PeCB (PCB-123)	15	15	15	15	15	15	15
3,3',4,4',5-PeCB (PCB-126)	15,000	15,000	15,000	15,000	15,000	15,000	15,000
2,3,3',4,4',5-HxCB (PCB-156)	75	75	75	75	75	75	75
2,3,3',4,4',5'-HxCB (PCB-157)	75	75	75	75	75	75	75
2,3',4,4',5,5'-HxCB (PCB-167)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
3,3',4,4',5,5'-HxCB (PCB-169)	1,500	1,500	1,500	1,500	1,500	1,500	1,500
2,2',3,3',4,4',5-HpCB (PCB-170)	15	15	15	15	15	15	15
2,2',3,4,4',5,5'-HpCB (PCB-180)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
2,3,3',4,4',5,5'-HpCB (PCB-189)	15	15	15	15	15	15	15

3 Review of PCB Microbial Degradation Processes

PCBs are stable compounds that do not degrade easily. Under certain conditions, they may be destroyed by chemical, thermal, and biological processes (Erickson, 1986). In the environment, photolysis is the only significant chemical degradation process. However, microbial processes are the main route of environmental degradation in PCBs.

Photochemical degradation in water or sediments is likely not a significant means of PCB losses in the environment due to the following facts (Hutzinger *et al*., 1974):

- PCBs have low solubilities in water; and
- UV and solar radiation do not penetrate deeply into solid media, making photodegradation in the solid state inefficient.

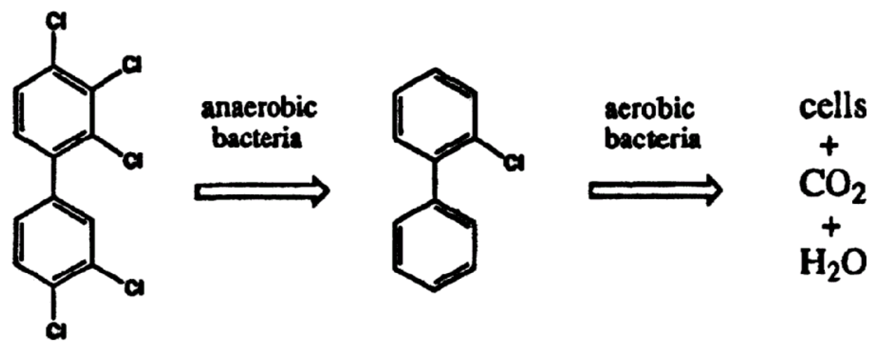
These facts also make experiments on the photodecompositions of PCBs difficult to carry out. Photodegradation in the atmosphere has been studied (see Erickson [1986] and references therein) and half lives for atmospheric photodegradation have been measured as ranging from 0.62 to 1.4 days for monochlorobiphenyls to 67 days pentachlorobiphenyls. (These data, however conradict information presented in Hutzinger, Safe *et al*. [1974] who state that "higher chlorinated biphenyls disappear faster than those with lower chlorine content on irradiation" [page 123].) Volatilization can result in significant removal of PCBs from an environmental department without any net loss of PCBs from the environment. Once volatilized, however, the chances of photodegradation are increased (Erickson, 1986).

PCBs can undergo microbial degradation in natural environments under both aerobic (i.e., in the presence of oxygen) and anaerobic (i.e., in the absence of oxygen) conditions. Under aerobic conditions, PCB congeners can be degraded by microbial processes that result in the breaking of a carbon to carbon bond of the biphenyl molecular frame, the net destruction of PCBs, and the generations of degradation by-products. Under anaerobic conditions, PCB congeners can be degraded by microbial processes that result in the substitution of chlorine atoms with hydrogen atoms within a PCB molecule. This results in the transformation of PCB congeners into other less chlorinated PCB congeners (Abramowicz, 1990). This process it referred to as dechlorination. Aerobic degradation results in a net PCB loss from a given PCB inventory, whereas anaerobic dechlorination does not.

In river sediments, aerobic conditions are typically found in the top few centimeters of the sediment core, while anaerobic conditions are found at greater depths.

Figure 3-1 (reproduced from Abramowicz [1990]) illustrates the effect of aerobic and anaerobic PCB degradation. In the first step, mediated by anaerobic bacteria, the pentachlorobiphenyl (five chlorine atoms) congener is transformed into a monochlorobiphenyl (a single chlorine atom). In the second step, mediated by aerobic bacteria, the monochlorobiphenyl is degraded to microbial cells, carbon dioxide and water.

Figure 3-1 Aerobic and Anaerobic PCB Degradation



3.1 Aerobic PCB Degradation

The microbial degradation of PCBs under aerobic conditions is well documented and studied (see for example: Abramowicz ,1990; Bedard, 1990 and references therein). Naturally occurring organisms that can degrade PCBs aerobically are quite common in nature and consist of many microbiological types. A diverse group of 25 strains of aerobic PCB-degrading bacteria has been isolated and characterized. All organisms isolated have the ability to degrade the less chlorinated PCBs, i.e., mono-, di-, some tri-, and possibly some tetrachlorinated biphenyls. However, as the number of chlorines per PCB increases, the fraction of organisms capable of degrading these congeners decreases. In particular, no aerobic microorganisms have been reported to degrade penta- and higher chlorinated PCB congeners (Abramowicz, 1990).

Furukawa (1986) reports that commercial PCB mixtures that contain predominantly mono- and dichlorobiphenyls readily undergo primary biodegradention by activated sludge microorganisms, and that as the levels of tri-, tetra-, and pentachlorobiphenyls increase, the degradation rates decrease accordingly. Furukawa (1986) reports degradation rates in laboratory experiments ranging from > 50 nmol/ml/h for some monochlorobiphenyls to 0 for some tetrachlorobiphenyls. He indicates that PCBs containing two chlorines in the *ortho* position of a single ring (i.e., 2,6) and in each ring (i.e., 2,2') show a striking resistance to degradation. The congener 2,4,6-trichlorobiphenyl is the exception to this rule.

In reference to the molecular composition of Aroclor 1242, which is the main contaminant originally discharged in the Fox River, the data presented in Table 2-4 indicates that 76% of this Aroclor is comprised of tetra- and lower chorobiphenyls. As such, based on the data discussed above, up to 76% of Aroclor 1242 can be degraded aerobically under the proper conditions. A greater percent might be degraded aerobically after the Aroclor has undergone some degree of dechlorination (see discussion in Section 3-2).

Even though laboratory studies have documented the existence of naturally occurring aerobic bacteria capable of degrading a large spectrum of PCB congeners, there is little direct evidence indicating that the aerobic degradation process is effective at reducing the PCB mass under field conditions. The difficulty of documenting such occurrences may explain the lack of direct observation. Another explanation may reside in the fact that a biphenyl must be present as the sole carbon source for effective PCB degradation under aerobic conditions. This may represent a major obstacle to PCB degradation *in situ*, since PCB congeners themselves apparently cannot support bacterial activity in the absence of a biphenyl substrate. No alternate substrate has been identified that is capable of sustaining or enhancing the activity of PCB-degrading bacteria under aerobic conditions (Bedard, 1990).

Of the papers reviewed, only a few addressed aerobic degradation of PCBs in sediments. Laboratory and controlled field studies (using caissons driven into the sediments to isolate them from the surrounding environment) were performed to assess the extent of aerobic biodegradation of PCBs in the Hudson River (Harkness *et al*., 1993; Harkness et al., 1994). These studies indicated that indigenous aerobic microorganisms can degrade the less chlorinated PCBs present in Hudson River sediments, and that aerobic PCB biodegradation can be stimulated by adding inorganic nutrients, biphenyl, and oxygen. Less than 60% of the PCBs in the Hudson River sediment samples that were collected in both field and laboratory experiments were biodegraded aerobically. In the laboratory studies, PCB losses were highest for mono- and dichlorobiphenyls (approximately 50% for monochorobiphenyls and 43% - 47% for dichlorobiphenyls). Losses for trichlorobiphenyls ranged between 26% and 30%. Losses for higher chlorinated congeners ranged between 17% and 5%. In the field studies, similar results were obtained with monochlorobiphenyl losses averaging greater than 60%, and dichlorobiphenyl losses averaging greater than 50%. Lesser losses of higher molecular congeners were also observed. Harkness *et al.* (1993) indicate that up to 90% of PCBs can potentially be degraded aerobically based on previous laboratory experiments. They state that a potential short-term biodegradation limit in both the laboratory and the field might be physically determined by the desorption kinetics of the PCBs from the sediments.

The occurrence of aerobic degradation of PCBs in Hudson River sediments is also supported by the presence of intermediate metabolites in the sediments, such as chlorobenzoic acids. A correlation between chlorobenzoic acids and PCB concentrations was demonstrated, supporting the hypothesis that these acids were formed as a by-product of the aerobic degradation of PCBs (Flanagan and May, 1993).

Grasse River sediments were demonstrated to contain microorganisms that can aerobically degrade the lower chlorinated congeners in Aroclor 1242 spiked sediments as the test substrate (Minkley *et al*., 1999a; Minkley, Blough *et al*., 1999b).

A study of PCB patterns in Green Bay sediments (PCB concentrations not exceeding 2 mg/kg) by Pham (1993) suggests that aerobic biodegradation is not a significant transformation mechanism in those sediments. Similarly, McLaughlin (1994) reports that no evidence of significant aerobic biodegradation was found in Lower Fox River sediments. A discussion of the findings of Pham (1993) and McLaughlin (1994) is provided in Sections 4.1 and 4.2.

Research in the application of bioremediation techniques for the treatment *in situ* of soils and sediments contaminated with PCBs is ongoing (see, for example, the review presented in Morris and Pritchard [1994]). Ongoing research focuses on the development of methods to improve the bioavailability of PCBs for degradation (Rogers, 1998). The engineered combination of aerobic and anaerobic biodegradation has been identified as a promising approach to remedy PCBs in soils or sediments. Laboratory comparison of reactor-based versus *in situ* PCB processes has demonstrated significantly higher rates of PCB destruction in soil slurry reactors. However, for many sites the advantages of not excavating continues to favor the *in situ* process configuration as a very viable, albeit slower, alternative (Shannon, Rothmel *et al*., 1994).

In summary, based on the literature reviewed, aerobic bacteria have been shown to be capable of degrading the less chlorinated PCBs under laboratory conditions. In addition, aerobic biodegradation of PCBs in sediments was observed under controlled field conditions and after the addition of amendments and oxygen. Finally, intermediate metabolites of aerobic PCB degradation were detected in one study of field sediments. However, significant intrinsic aerobic degradation has not been widely demonstrated under field conditions, nor have engineered approaches yet been discovered and implemented that would result in the effective aerobic degradation of PCBs in surface waters, soils or sediments. In particular, there is no significant evidence of longer scale natural PCB degradation occurring in sediments.

3.2 Anaerobic PCB Dechlorination

Reductive dechlorination under anaerobic conditions is generally viewed as an important means of biodegradation for numerous compounds including organochlorine pesticides (e.g., DDT, lindane), alkyl solvents (e.g., PCE, TCE, chloroform), and aryl halides (e.g., chlorobenzenes, PCBs, chlorophenols). Reductive dechlorination can alter the toxicity of these compounds and make them more readily degradable. Reductive dechlorination is mainly known to occur under anaerobic conditions, and it involves the substitution of a chlorine atom with a hydrogen atom within a PCB molecule (Mohn and Tiedje, 1992).

Starting in the mid 1980s, alterations in the composition of PCBs present in anaerobic river and lake sediments with respect to the original PCB composition have been widely documented. These alterations involve the removal of highly chlorinated PCB congeners with corresponding increases in the concentration of PCB congeners containing less chlorine substitutions (mono-, di-, and tri-dominated chlorobiphenyls). Three major patterns of alterations were observed for Hudson River sediments that were originally contaminated with Aroclor 1242. All three patterns showed lower levels of tri-, tetra-, and pentachlorobiphenyls and increased levels of mono- and dichlorobiphenyls. It was suggested that transformation processes such as evaporation or aerobic degradation could not account for the changes observed. It was, therefore, proposed that anaerobic microorganisms in the sediments were reductively dechlorinating the PCBs (Brown *et al*., 1985; Brown, Jr. *et al*., 1987).

The anaerobic dechlorination process is complex and diverse and can vary widely in the field, even at a scale of a few feet or less. There are at least five major factors that are of importance in determining whether or not the dechlorination of a particular chlorine on a PCB congener can occur in anaerobic sediments (Bedard and Quensen, 1995):

1) the nature of the active microbial population(s);
2) the type of chlorine substitution to be removed (*ortho*, *meta* or *para*);
3) the surrounding chlorine configuration on the phenyl ring;

4) the chlorine configuration on the opposite phenyl ring; and
5) the incubation conditions (temperature, redox conditions, ionic strength, type of carbon substrate, availability of electron acceptors, presence of oil, presence of other contaminants, etc.).

Anaerobic dechlorination of PCBs occurs via a set of specific, microbially mediated, reactions. A specific set of reactions is referred to as a dechlorination process. Depending on site- and chemical-specific conditions, one or more processes may control the overall PCB dechlorination rate. A number of individual dechlorination processes have been identified in sediments at different sites. The characteristics of these dechlorination processes, and the conditions and locations where they have been observed, are presented in Bedard and Quensen (1995). A discussion of these processes is provided below.

Bedard and Quensen (1995) identified at least six separable processes that dechlorinate Aroclors. These processes are labeled M, Q, H, H', N and P. These processes can occur alone or in combinations. For example, a dechlorination pattern, labeled C, has been identified that is the combination of processes M and Q, which are mediated by different microorganisms. Also, processes M and/or H and H' have been shown to occur concurrently at some sites. The processes can be distinguished by their congener selectivity patterns and by their chlorophenyl group reactivity patterns. Figure 3-2 (reproduced from Bedard and Quensen [1995]) provides, as an example, the dechlorination patterns for Process N.

Table 3-1 (reproduced from Bedard and Quensen [1995]) presents a summary of the chlorophenyl reactivity patterns of the various PCB dechlorination processes.

Table 3-2 (reproduced from Bedard and Quensen [1995]) summarizes the characteristics of the PCB dechlorination processes.

None of the processes described by Bedard and Quensen (1995) have been shown to remove chlorine in the *ortho* substitution. The dechlorination of *ortho*-substituted chlorine has, however, been reported to occur (albeit less prevalently than other types of dechlorination) both in the laboratory and the field (Brown, Jr. *et al*., 1987; Minkley, *et al*. 1999a; Minkley *et al*., 1999b).

Anaerobic dechlorination of Aroclor 1248–spiked sediments in an anaerobic bioreactor has been demonstrated by Pagano, Scrudato *et al*. (1995). The bioreactor was operated in a batch recycle mode and sanitary landfill leachate was used as a carbon, nutrient and/or microbial source. Research in this area is ongoing.

Figure 3-2 Dechlorination Process N

DECHLORINATION PROCESS N

234-4 → 24-4
236-4 → 26-4
245-4 → 24-4

25-34 → 25-4
234-34 → 24-34 → 24-4
245-34 → 24-34 → 24-4
236-34 → 26-34 → 26-4

234-25 → 24-25
245-25 → 24-25
236-25 → 25-26

234-236 → 236-24 → 24-26
236-245 → 236-24 → 24-26

234-234 → 234-24 → 24-24
2345-234 → 234-245 → 245-24 → 24-24
2356-234 → 2356-24 → 236-24 → 24-26

2345-2345 → 2345-245 → 245-245 → 245-24 → 24-24
2345-2346 → 2345-246 → 245-246 → 246-25
2345-2356 → 2356-245 → 2356-24 → 236-24 → 24-26

Specificity: Flanked meta Cl, doubly flanked meta Cl
Reactive Groups: 34, 234, 236, 245, 2345, 2346, 23456
Weak activity against 235, 2356
Unreactive meta Cl: 3, 23, 25
Comments: Very reactive on all tetra- through octa-CB with susceptible CP groups

Aroclor	Reported As	Source	Reference
1260	N	Silver Lake	Quensen et al., 1990, Tab 3, Fig 8
1260	--	Silver Lake	Alder et al., 1993, Fig 6
1260	N	Woods Pond	Bedard et al., 1993, Bedard & Van Dort, in prep.
1254	H	Hudson River	Rhee et al., 1993e, Fig 1B (biphenyl)

Table 3-1 Chlorophenyl Reactivity Patterns of Various PCB Dechlorination Processes

Dechlorination Reaction	Dechlorination Process						
	M	Q	C	H	H'	P	N
3[a] → 0	?		X				
4 → 0		X	X				
23 → 2	X	X	X		X		
24 → 2		X	X				
25 → 2	X		X				
34 → 3		X	X	X	X	X	
34 → 4	X		X				X
234 → 2		X	X				
234[b] → 23		?					
234[b] → 24	X	?		X	X		X
236 → 26	X	?	X		?		X
245 → 2			X				
245 → 24	?						X
245 → 25		X	X	X	X	X	
2345 → 24	NA[c]	NA	NA				X
2345 → 235	NA	NA	NA	X	X	X	

[a]It is not clear whether the ability to remove this chlorine is due to process M or to a separate activity that sometimes occurs with process M.
[b]For process Q it is not clear which chlorine is removed first, but the ultimate product is the 2-chlorophenyl group.
[c]Data not available.

Table 3-2 Characteristics of PCB Dechlorination Processes

Dechlorination Process	Characteristic Dechlorination Products[a]	Susceptible Chlorines	Susceptible Aroclors	Source of Microorganisms
M	2 2-2/26 2-4 24-2 24-4 26-2	Flanked and unflanked *meta*	1242 1248? 1254?	Upper Hudson Silver Lake
Q	2 2-2/26 2-3 25-2 26-2 26-3	Flanked and unflanked *para* *Meta* of 23	1242 1248 1254	Upper Hudson
C	2 2-2/26 26-2 26-3	Flanked and unflanked *meta* and *para*	1242 1248 1254	Upper Hudson
H’	2-3 2-4 24-2 25-2 24-3 25-3 26-3 24-4/25-4 24-24[b] 24-25 25-25 235-24[b] 235-25[b] 236-24[b] 236-25[b]	Flanked *para* *Meta* of 23, 24	1242 1248 1254 1260	Upper Hudson Lower Hudson? New Bedford
H	2-3 24-3 25-3 26-3 24-4/25-4 24-24 24-25 25-25 235-24 235-25 236-24 236-25	Flanked *para* Doubly flanked *meta*	1242 1248 1254 1260	Upper Hudson Lower Hudson New Bedford Silver Lake?
P	23-25 24-25 25-25 235-23 235-25	Flanked *para*	1254? 1260	Woods Pond Silver Lake?
N	24-4 24-24 24-25 24-26 246-24 2356-24	Flanked *meta*	1254 1260	Upper Hudson Silver Lake Woods Pond

[a]Products will vary depending on the congener composition of the PCB mixture being dechlorinated.
[b]Proposed products from Aroclors 1254 and 1260.

4 Review of Studies of Natural Degradation in Aquatic Sediments

This section discusses laboratory and field studies aimed at studying natural degradation processes, including reductive dechlorination and aerobic biodegradation, occurring in sediments at various sites. The discussion is organized by site, and (where available) the results of both laboratory and field studies are briefly discussed. The sites for which data were reviewed are the following:

- Lower Fox River;
- Green Bay;
- Sheboygan River and Harbor
- Hudson River;
- Grasse River;
- Woods Pond;
- St. Lawrence River;
- Silver Lake;
- Acushnet Estuary;
- Other Locations, including:
  - Escambia Bay,
  - Hoosic River,
  - Waukegan Harbor,
  - Lake Ketelmeer;
  - Lake Shinji (Japan), and
  - Otonabee River-Rice Lake (Canada).

4.1 Lower Fox River

Natural degradation processes in the Lower Fox River between Little Lake Buttes des Morts and the De Pere Dam were studied by McLaughlin (1994). He examined PCB congener distributions within 173 sediment cores from deposits proximate to known historical sources of PCBs to the river (deposits A and N), and from deposits 30-40 km (19-25 mi) downstream (deposits EE, GG, and HH).

McLaughlin (1994) estimated PCBs lost to weathering based on the weight fraction enrichment of congeners believed to be resistant to their respective weathering processes (desorption, biodegradation). He reports that depletion of low molecular weight congeners relative to both Aroclor 1242 and to deposits A and N was observed in downstream Fox River sediments (deposits EE, GG, and HH). This depletion is attributed mostly to desorptive losses to the water column taking place during sediment transport downstream, rather than aerobic biodegradation. No evidence of anaerobic dechlorination of PCBs was observed in downstream deposits EE, GG, and HH, where the maximum PCB concentration is approximately 30 mg/kg.

Volatilization is not explicitly accounted for in McLaughlin (1994). However, volatilization results in a mass loss from the water column to the atmosphere. As such, volatilization of PCB mass previously sorbed to sediment can only occur after such mass has desorbed to the water column. Therefore, the explicit quantification of mass loss to volatilization from the unit column does not affect the estimate of mass loss from sediments due to biodegradation and desorption.

The congener distribution data in deposits A and N support the conclusion that anaerobic dechlorination has occurred in these deposits, along with some physical/chemical weathering. The data suggest that dechlorinating activity is limited to sediment PCB concentrations of 30 mg/kg or greater. The overall PCB losses due to microbial degradation in deposits A and N were estimated to be approximately 10% (McLaughlin, 1994) with respect to the original inventory of PCBs deposited in the river.

It was estimated that no biodegradation losses have occurred in sediments in the Lower Fox River above the DePere Dam, and that 10% biodegradation has occurred in sediments from SMUs with a PCB concentration of 30 mg/kg or higher, resulting in an overall PCB mass loss from the river of approximately 1,600 kg. Conversely, an overall 33% desorption for all river sediments was estimated, resulting in an overall PCB mass loss from the river of approximately 15,000 kg (McLaughlin, 1998).

Another evaluation of aerobic and anaerobic degradation of PCBs in Deposit A of Little Lake Buttes des Mortes is provided in Appendix D, Deposit A - PCB Biodegradation Assessment from the *Remedial Investigation/Feasibility Study Little Lake Butte des Morts Sediment Deposit A* (Blasland & Bouck Engineers, 1993). Anaerobic dechlorination (as measured by a 20% decrease of the non-orthochlorine ratio with respect to the ratio of Aroclor 1242) was observed, with the exception of one sample which exhibited significantly higher levels of dechlorination. As a result of dechlorination, levels of PCB congener 2,3',4,4',5 were shown to have decreased in almost all samples. An examination of certain aerobically biodegradable congeners (2,3; 2,4'; 2,4,4'; and 2,5,4') relative to the Aroclor 1242 standard provided no evidence of aerobic degradation. Rather, the levels of these congeners were increased as a result of dechlorination. It was concluded that either no aerobic biodegradation had taken place, or its effect was being masked by the effects of anaerobic PCB dechlorination.

In another study of dechlorination patterns in the Lower Fox River (Hollifield, *et al*. 1995), PCB-contaminated sediments were collected from the southern portion of Little Lake Butte des Mortes and analyzed for their congener distribution. The results of these analyses are consistent with *in situ* dechlorination of PCBs. However, the extent of *in situ* dechlorination was less than that typically reported in the literature. It was estimated that the extent of dechlorination in these sediments ranged from 3.77% to 8.18% of total chlorine, and 10.1% to 16.9% of the *meta* and *para* chlorines relative to Aroclor 1242. The dechlorination appeared to have occurred primarily at the *meta* and *para* positions, with a preference for the *meta* position noted.

Attempts by Hollifield *et al*. (1995) to further dechlorinate Fox River sediments in the laboratory met with limited success. The range of additional dechlorination ranged from –0.65% to 6.86% on a total chlorine basis, and –0.65% to 11.2% on a *meta* and *para* chlorine basis. Furthermore, all samples displaying dechlorination in the laboratory tended to converge on a common chlorine distribution (removal of ~10% of total chlorine and ~20% of *meta* and *para* chlorines, relative to Aroclor 1242). The concentration in sediments also appeared to have an effect. Those sediments with higher PCB concentrations were observed to undergo more successful dechlorination to a greater extent (quantification of this effect is not provided in Hollifield, Park *et al*. [1995]). In addition, the data were consistent with the existence of a threshold below which dechlorination will not proceed.

In summary, a threshold of approximately 30 mg/kg appears to exist in Fox River sediments for PCB dechlorination. Below this threshold, no significant anaerobic dechlorination of PCBs is expected to occur. In addition, no significant aerobic degradation has been documented in sediments throughout the river.

4.2 Green Bay

The PCB congener patterns exhibited by PCBs in Green Bay sediments are different from the congener patterns associated with Lower Fox River sediments. The congener distribution was observed to shift from the lighter, lower chlorinated biphenyls, toward the heavier, higher chlorinated biphenyl. However, the depletion of the lighter chlorinated congeners does not show selective removal of non-*ortho*-chlorinated congeners, as would be expected if aerobic degradation were occurring. Furthermore, the shift toward higher chlorinated congeners suggests that anaerobic dechlorination is not a relevant process in the sediments in Green Bay (Pham, 1993). The latter observation is consistent with the absence of dechlorination in Lower Fox River sediments containing less than 30 mg/kg total PCBs (McLaughlin, 1994).

The concentrations of PCBs in Green Bay sediments (less than 2 mg/kg) appear to be below the levels necessary for microbial degradation to occur (McLaughlin, 1998), and the differences in congener distribution between Fox River and Green Bay sediments are attributed to chemical and physical processes such as diffusion into pore water, solubilization, and re-suspension, rather than biological processes such as aerobic degradation or anaerobic dechlorination (Pham, 1993).

4.3 Sheboygan River and Harbor

The Sheboygan River flows westward and drains into Lake Michigan at the city of Sheboygan, Wisconsin. The river is contaminated with PCBs from the mouth to about 22.6 km (14 miles) upstream (Sonzogni *et al*., 1991). Waste hydraulic fluids containing Aroclor 1248 and Aroclor 1254 were the source of the contamination (David, 1990).

The PCB congener distribution in the Sheboygan River between the Sheboygan Falls dam and the harbor in Sheboygan (22.4 km) was studied by David (1990) and Sonzogni, Maack *et al*. (1991). The conclusions of these studies are summarized below.

- The PCB congener distribution (congeners present as well as the weight percentages of each congener) from highly contaminated sediments (PCB concentration greater than 50 mg/kg) are considerably different from the PCB congener distribution of the Aroclor 1248 and 1254 which were originally discharged at the site.

- The weight percents of the toxic congeners in these sediments were generally lower than those found in Aroclor 1248 and 1254 (the primary PCB mixtures discharged to the river), and in Aroclor 1242 and 1260. The weight percents of the most toxic congeners (77, 118, and 105) were about an order of magnitude lower than the weight percents in Aroclor 1248. The average weight percents in Sheboygan River samples were 0.02%, 0.2% and 0.04% for congeners 77, 118 and 105, respectively. This compares with 0.3%, 3.35% and 0.55% for the same congeners in Aroclor 1248.

- The enrichment of the highly contaminated sediments with lower chlorinated congeners is not easily explained by known physical-chemical partitioning or known abiotic chemical reactions. This suggests that a biotic process might be responsible for the enrichment. It is suggested in David (1990) that this process is anaerobic dechlorination.

- In sediments containing concentrations less than 50 mg/kg, the congener distributions were similar to the original Aroclors, suggesting the existence of a threshold for dechlorination of approximately 50 mg/kg.

4.4 Hudson River

PCBs were first detected in fish from the Hudson River in 1969. The principal source of PCB contamination was related to the release of Aroclors to the river and river sediments.

In 1987, Brown Jr. *et al*. (Brown, Jr., Bedard *et al*., 1987; Brown, Jr., Wagner *et al*., 1987) reviewed chromatograms of hundreds of sediment, water, and soil samples contaminated with PCBs to determine changes in the relative concentrations of isomers with respect to the original PCB composition. They reported that in the upper Hudson River as a whole, approximately 40 to 70 metric tons of PCBs (out of an estimated total of 134 metric tons), have been converted from tri-, tetra- and higher chlorobiphenyls to mono-, di-, and predominantly *ortho*-substituted tri-chlorobiphenyls due to reductive dechlorination. Potential changes in sediment PCB congener distribution due to desorption and volatilization were not addressed in these studies. The extent of dechlorination was more pronounced in highly contaminated sediments (i.e., >50 mg/kg) but more modest in less contaminated sediments. As part of this study, the authors found evidence of dechlorination in sediments from adjacent Silver Lake, Hoosic River, Sheboygan River, and Acushnet Estuary. The dechlorination patterns were, however, different at these locations when compared with the Hudson River. The study also reported that all of the lower chlorinated PCB congeners formed by the observed reductive dechlorination could be biodegraded by one or more of the aerobic PCB-degrading bacteria that were isolated from soils and sediments. The authors proposed the hypothesis that a two-step sequence of dechlorination followed by oxidative biodegradation might eventually achieve total PCB destruction under properly engineered conditions.

In 1997, the U.S. Environmental Protection Agency (EPA) published an analysis of *in situ* dechlorination in the Hudson River from the results of a high-resolution sediment coring program (Tams Consultants, 1997). The main conclusions of this study are as follows.

- No evidence was found of extensive dechlorination within sediments in the Hudson River.
- Anaerobic dechlorination of PCBs in the Hudson River is limited to *meta* and *para* chlorines. Based on the composition of Aroclor 1242 (the main

contaminant) no more than 26% ultimate mass loss by dechlorination is possible.

- The data suggest that other PCB destruction processes are not effective at removing PCBs from the sediments.

- Dechlorination appears to proceed, to a limited degree, dependent on the initial PCB concentration and does not continue to occur indefinitely; all sediment mass loss via dechlorination has occurred for current contamination and no further significant amelioration can be expected.

- No sediments were found which had a calculated PCB mass loss of greater than 25%.

- Below a concentration of 30 mg/kg, dechlorination mass loss did not occur predictably and was frequently 0%.

- The data verify the general persistence of PCBs in the environment.

The EPA report concluded that PCBs in the sediments of the upper Hudson River can be expected to be available for sediment-water exchange, re-suspension and biological interaction for at least 35 years and probably longer.

A number of laboratory studies were performed on sediments collected from the Hudson River (or using anaerobic microorganisms obtained from these sediments). These studies were aimed at demonstrating the effectiveness of dechlorination of PCB congeners present in these sediments (Quensen III *et al*., 1988; Quensen III *et al*., 1990; Morris, Mohn *et al*., 1992; Abramowicz *et al*., 1993; Rhee *et al*., 1993a; Rhee *et al*., 1993b; Sokol *et al*., 1995; Williams, 1994). The following bullet items summarize the main findings of these laboratory studies.

- The laboratory studies consistently show that dechlorination at the *meta* and *para* positions under anaerobic conditions is readily achieved in laboratory studies. However, no significant *ortho* dechlorination was observed.

- Inocula prepared from PCB-contaminated sediments from the Hudson River can effect *meta* and *para* dechlorination of sediments spiked with mixtures of Aroclor 1242, 1248, 1254 and 1260.

- Biphenyl enrichment decreased both the rate and extent of dechlorination, and affected the dechlorination products.

- The extent and rate of dechlorination in Hudson River sediments, as well as the lag time before the onset of dechlorination activity, was consistently shown to depend on PCB concentrations. Dechlorination activity was generally determined to be directly related to PCB concentration (i.e., the greater the PCB concentration, the greater the extent of dechlorination). For example, Quensen *et al*. (1988) reported that in the 700 mg/kg PCB concentration samples, the average number of *meta* plus *para* chlorines per biphenyl decreased from an average of 1.98 to 0.31 after 16 weeks, but only decreased to 1.19 in the 140 mg/kg samples. At 14 mg/kg there was no difference between the live samples and the autoclaved controls, indicating that a threshold to dechlorination might exist at or above that concentration level. Two additional studies (Rhee *et al*. 1993a, Rhee *et al*. 1993b) also report the existence of a concentration threshold for dechlorination activity (no concentration values for this threshold were provided). The threshold level might be site- and congener-specific.

4.5 Grasse River

A stretch of the Grasse River near Massena, New York was contaminated with PCBs, primarily from the release of products containing Aroclor 1242. A comprehensive field and laboratory study of naturally occurring PCB biodegradation processes in Grasse River sediments was prepared by the Carnegie Mellon Research Institute Biotechnology Group (Minkley *et al*., 1999a; Minkley *et al*., 1999b). The following summarizes the results of this study.

- *In situ* PCB dechlorination is an ongoing process in Grasse River sediments.

- Dechlorination activity is dependent on PCB concentration. Dechlorination appears to be occurring in sediments having less than 10 mg/kg total PCB concentration, but the statistical evidence of dechlorination at concentrations below 7 to 10 mg/kg is less strong than at higher concentrations (i.e., the statistical confidence level is less than 95%).

- The study suggested that biphenyl detected in Grasse River sediments resulted from the dechlorination of PCB congeners and that congeners with *ortho*-substituted chlorines are being degraded. In addition, the study suggested the possibility for anaerobic biodegradation of biphenyl and PCB congeners with low chlorine substitutions.

In summary, the study concluded that the Grasse River sediments are undergoing both aerobic and anaerobic PCB biodegradation under field conditions. The rate and extent of this biodegradation have not yet been determined.

4.6 Woods Pond

Woods Pond (Lenox, Massachusetts) is a shallow impoundment on the Housatonic River located 10.5 miles downstream from Silver Lake. The pond's sediments are contaminated with hydrocarbon oil and PCBs from the release of products containing Aroclor 1260 (95%) and Aroclor 1254 (5%). The results of a core sampling study in Woods Pond indicated the following (Bedard, 1990; Van Dort and Bedard, 1991; Bedard, Bunnell *et al*., 1996; Bedard and May, 1996; Bedard, Van Dort *et al*., 1997; Van Dort, Smullen *et al*., 1997).

- The PCB congener distribution in Woods Pond sediments results from declorination of Aroclor 1260 and Aroclor 1254 (95:5).

- All samples collected from Woods Pond showed some evidence of reductive dechlorination when compared to Aroclor 1260. The sample with the most extensive dechlorination was depleted by only 13.7% of the *meta* and *para* chlorines (3.92% for Aroclor 1260 versus 3.38%, for the most extensively dechlorinated sample). The most extensively dechlorinated samples had lost 11% to 19% (2.27% to 2.08% versus 2.57% for Arclor 1260) of the *meta* chlorines, and 2% to 7% of the *para* chlorines (1.33% to 1.26% versus 1.35% for Aroclor 1260).

- The dechlorination process targeted most of the hexa-, hepta- and octachlorobiphenyls, and converted them into tetra- and pentachlorobiphenyls containing predominantly *ortho* and *para* chlorine substitutions. *Meta* dechlorination was favored over *para* dechlorination.

- The extent and type of dechlorination process varied considerably among samples, depending on the sample location within the pond.

- It is possible to stimulate, or "prime", in the laboratory indigenous microorganisms in Woods Pond to effect rapid dechlorination of PCBs that have persisted in the environment for decades. This was shown to be true even in the presence of high concentrations of oil (5 mg/kg).

- Under laboratory conditions, indigenous anaerobic microorganisms from Woods Pond are capable of removing chlorine from the *ortho* position of at least one PCB congener (2, 3, 5, 6-tetrachlorobiphenyl).

4.7 St. Lawrence River

The St. Lawrence River is located along the northeast border of New York State and has been contaminated with PCBs from industrial sources. The presence of PCBs was related to the release of products containing Aroclor 1248 and to a minor extent Aroclor 1260. The results of field and laboratory studies indicated the following (Sokol *et al*., 1994; Sokol, Bethoney *et al*., 1998a; Sokol *et al*., 1998b).

- Sediment cores taken on the St. Lawrence River showed evidence of *in situ* reductive dechlorination at all sites along the river where cores were collected, except for one location. The extent of dechlorination varied widely from site to site, ranging from 2% to 45% (with respect to Aroclor 1248), based on the average number of chlorines per biphenyl.

- At most sites, dechlorination resulted in the removal of *meta* and *para* chlorines. *Meta* dechlorination was favored over *para* dechlorination at most sites. There was no evidence of *ortho* dechlorination at any of the sites.

- The lack of dechlorination at the one site was not attributed to the lack of competent microorganisms, but appeared to be associated with a high level of contamination (93,000 mg/kg aluminum, 4,794 mg/kg, PAHs) that may have included non-aqueous fluids.

- Location specific sediment characteristics can significantly affect indigenous populations and thus affect the resulting dechlorination pattern and extent.

- Additional dechlorination in the laboratory of partially dechlorinated samples collected in the St. Lawrence River occured rapidly over the first four months of incubation. Over this period of time, total chlorines per biphenyl were reduced by 22% (from 3.2 to 2.5) with respect to the field samples. With further incubation, a second phase of dechlorination ensued after 15 months, with the total number of chlorines per biphenyl decreasing slightly further from 2.5 to 2.4. After this additional dechlorination the transformation reached a plateau with no further change until the end of incubation at 39 months, indicating an endpoint. These laboratory results, when compared to the field data, suggest that *in situ* dechlorination at the site has not yet reached a plateau, although they are not able to reveal the *in situ* dechlorination rate.

- Some earlier field data indicated no correlation between the extent of dechlorination and sediment PCB concentration (Sokol *et al*., 1994). However, more recent laboratory studies (Sokol *et al*., 1998) indicated a clear dechlorination threshold concentration of 35 to 45 ppm total PCBs. In addition, these laboratory studies indicated that above the threshold concentration, the dechlorination rate was a function of total PCB concentration.

4.8 Silver Lake

Silver Lake is a 26-acre urban pond in Pittsfield, Massachusetts. Products containing Aroclor 1254 and Aroclor 1260 were likely used and released at different times from facilities close to the lake (Bedard and Quensen, 1995).

Brown, Jr., Bedard *et al*. (1987) and Brown, Jr., Wagner *et al*. (1987) studied the PCB congener distribution in sediment and concluded that dechlorination had altered the congener distribution pattern, that the PCB deposited in Silver Lake sediments was originally virtually all Aroclor 1260, and that PCBs in Silver Lake had undergone *ortho* as well as *meta* and *para* dechlorination. Bedard and Quensen (1995), however, questioned the finding that *ortho* dechlorination occurred in Silver Lake sediments, and indicated that the observed PCB patterns can be attributed to *meta* and *para* dechlorination of Aroclor 1254.

Quensen III *et al*., (1990) studied the rate and pattern of dechlorination of four commercial Aroclors (1242, 1248, 1254 and 1260) by microbial cultures prepared from PCB-contaminated sediments from Silver Lake and compared then with those obtained from microbial cultures from PCB-contaminated sediments in the Hudson River. In both cases dechlorination of *meta* and *para* chlorines (ranging from 15% to 85%, with the respect to the original Aroclor) was observed. For each inoculum, the rate and extent of dechlorination tended to decrease as the degree of chlorination of the Aroclor increased. The results suggested that there are different groups of PCB-dechlorinating microorganism at the two sites, and that each group has specific characteristics for PCB-dechlorination. The issue of the existence of a potential dechlorination threshold was not examined in the Silver Lake references reviewed.

4.9 Acushnet Estuary

Congener-specific analyses of the PCBs in the Acushnet Estuary (New Bedford, Massachusetts) sediments and waters were undertaken to identify the alteration and transport processes of PCBs in a coastal marine environment. PCBs in the Acushnet Estuary are from the release of products containing Aroclor 1242 and 1254. (Brown, Jr. and Wagner, 1990). The study concluded that anaerobic microbial processes had selectively removed non-*ortho* chlorines from most of the higher chlorinated PCB congeners. The dechlorination process occurring within the Acushnet Estuary was identified as Process H. The dechlorination process appeared to have begun near the upper end of the estuary and not have yet reached the lower portions of the estuary. In addition, the study concluded that PCBs had undergone desorption into the water column and vertical movement within the sediments (rather than remaining stratified), but there was no horizontal translation between sites.

4.10 Other Locations

Limited evidence of *in situ* dechlorination at a number of additional locations is reported in Bedard and Quensen (1995). The following summarizes information from these locations and, where available, the Aroclor type constituting the bulk of the original PCB contamination. Complete quantitative congener-specific analyses of sediment PCBs was not available for any of these locations, but the data that are available suggest that PCB dechlorination has occurred to an observable extent at the following locations:

- Escambia Bay (near the mouth of the Pensacola River, FL);
- Hudson Estuary and River (near Troy, Mechanicville, Albany and Kingston, Catskill and Poughkeepsie, NY).
- Hoosic River (North Adams, MA).
- Waukegan Harbor, IL, contaminated with Aroclor 1248.
- Lake Ketelmeer, a sedimentation area of the Rhine River in the Netherlands.
- Lake Shinji, Japan, contaminated with Kanechlor 500, a commercial PCB mixture similar to Aroclor 1254.
- Otonabee River/Rice Lake, in Petersborough, Canada

5 Conclusions

The purpose of this review was to evaluate information relating to the viability of natural biodegradation as a potential remedial action for the sediment-bound PCBs in the lower Fox River and Green Bay. Based upon the evidence presented in the literature, the following conclusions can be drawn.

- Naturally occurring reductive dechlorination processes in sediments has been documented. There are three principle lines of evidence.

  — The PCB congener distribution in sediment cores has been analyzed and compared with the distribution of the original source of PCB contamination at a number of locations. This type of analysis has shown that, under the right conditions, a reduction of the concentrations of the highly chlorinated congeners and an increase in the concentrations of the medium- to lower-chlorinated congeners (indicating that dechlorination of the highly chlorinated congeners had occurred) can be documented.

  — Laboratory experiments have been performed on sediment samples contaminated with PCBs obtained from a number of different locations. These experiments have shown the ability of anaerobic microbial populations to effect dechlorination of PCBs under laboratory conditions.

  — Anaerobic microorganisms extracted from PCB-contaminated sediments have been shown to degrade sediment samples spiked with standard Aroclors.

- Anaerobic PCB degradation under field conditions was demonstrated to have occurred at almost all the sites studied. However, the reduction in PCB concentrations through anaerobic processes is site-dependent. In the Lower Fox River, only 10% reduction could be accounted for by anaerobic processes for deposits with average PCB concentrations greater than 30 mg/kg. No PCB reductions due to anaerobic processes could be accounted for in deposits with average concentrations less than 30 mg/kg. Conversely, it was estimated that 33% of the PCB mass originally deposited in the Lower Fox River was lost due to desorption (that is, the PCBs were re-suspended in the water column). Physical loss through desorption from sediments seems to exceed any biodegradation in the Lower Fox River environment.

- *Meta* and *para* dechlorination are most prevalent under both field and laboratory conditions. However, only limited evidence supports the occurrence of *ortho*-substituted PCB congeners under both field and laboratory conditions. The concentration of ortho-substituted congeners in the Aroclors deposited at any given site might represent a lower limit to the extent of dechlorination achievable at that site.

- The rate and extent of dechlorination under field and laboratory conditions appear to be influenced by the overall PCB concentration in sediments. The greater the PCB concentration, the greater the rate and extent of dechlorination.

- The most well documented of the PCB contaminated sites demonstrate that a threshold PCB concentration must exist before anaerobic dechlorination can occur. The threshold PCB concentration level is site specific. At different sites, thresholds have been shown to range from about 10 mg/kg up to about 50 mg/kg. The sediments from the Lower Fox River show a threshold of 30 mg/kg. At concentration levels below 30 mg/kg no reductions of PCBs have been documented in the Lower Fox River. Based on the available data, even if these sediments could be aerated, complete removal of PCBs by biological means might not be feasible, because the highly chlorinated congeners will not dechlorinate below the threshold values. It is possible that other active treatment options might promote dechlorination of the sediments, making the PCBs more amenable to aerobic biological destruction.

- The type, rate, and extent of dechlorination processes are influenced by a number of site-specific conditions, and can vary from sample to sample even within the same site. Based on the literature reviewed, it appears that site-specific predictions on dechlorination processes cannot be made without recourse to site-specific dechlorination studies.

- Aerobic degradation of the lower chlorinated PCB congeners (which results in the actual destruction of PCB molecules) has been documented in laboratory studies, but is poorly documented under field conditions. No field rates for aerobic PCB degradation have been measured at any sites. In particular, aerobic degradation has not been documented in the Lower Fox River and Green Bay. Aerobic processes might be effective in reducing PCB concentrations if used under controlled conditions (such as sediment management units).

- Aerobic degradation is not effective at degrading the higher chlorinated PCB congeners.

- Rates of PCB destruction are not available from field studies. These rates are critical to understanding whether natural biological processes can be relied on to eventually cleanup the sediments. One of the conclusions of the EPA study of the Hudson River is that unless action is taken, PCBs in the Hudson River can be expected to be available for sediment water exchange, re-suspension, and biological interaction for at least 35 years and, possibly longer.

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Appendix G

Glass Aggregate Feasibility Study

G Glass Aggregate Feasibility Study

Executive Summary

During the comment period of the 2001 draft of the Lower Fox River RI/FS, WDNR completed a project to evaluate the feasibility of a vitrification technology, based on standard glass furnace technology, to treat contaminated sediment. Following the release of the 1999 Draft RI/FS, Minergy Corporation prepared a proposal for a multi-phased study to determine the treatment and cost effectiveness of this technology to destroy organic contaminants (primarily PCBs) and immobilize inorganic contaminants (primarily heavy metals) in river sediments. Minergy Corporation proposed a four-phased feasibility study for the testing of a glass furnace technology and proposed to cost share the study. With funding assistance from EPA's GLNPO, WDNR accepted Minergy Corporation's proposal to conduct the Glass Furnace Technology Feasibility Study. Also, recognizing the extreme scrutiny PCBs have been under and the need for a thorough independent evaluation of contaminant fate, WDNR requested assistance from the EPA SITE Program. The SITE Program agreed to independently undertake the evaluation of cost and treatment effectiveness for this project.

Initially the four proposed phases of the study were:

- **Phase I:** Mineralogy and sediment characterization;
- **Phase II:** Crucible melt and preliminary design engineering;
- **Phase III:** Pilot-scale sediment melt of dewatered dredge material; and
- **Phase IV:** Full-scale facility construction.

WDNR and Minergy Corporation agreed to conduct Phases I through III. Minergy Corporation approached the feasibility of this technology from the perspective of designing a system that would produce a high quality, reusable glass aggregate product. They recognized that the conditions necessary to produce a quality glass aggregate product would also be ideal for destruction of organic contaminants, such as PCBs. Many trace metals found in sediment are permanently immobilized in the melting and quenching process, producing a final aggregate product that is very inert.

Phase I testing characterized the mineral composition of river sediments to estimate the glass quality, durability, and melting point. Sixteen archived river sediment samples, representing the entire 39 river miles, that were collected during previous investigations were analyzed for mineral composition and loss on ignition (LOI). The mineral composition of the river sediments was very consistent throughout the river and is very favorable for producing a quality glass product. The low results generated in the LOI tests confirm that a melting technology is more appropriate for river sediments than an incineration technology. With these positive results in hand, the project moved into Phase II.

During Phase II, crucible melts of Lower Fox River sediment were conducted to determine the actual melting conditions and glass characteristics/qualities of the sediment alone and when augmented with other materials (flux mixtures). Fluxes are added to the batch material to optimize the mineral composition, which in turn minimizes the amount of energy necessary to melt the material. The four different "recipes" were tested and all successfully melted the sediment into glass. The addition of limestone, as a fluxing agent, to the sediment provided the best results (Minergy Corporation, 1999). Phase II results included a proposed recipe for melting river sediment into glass aggregate and preliminary engineering designs for the pilot test facility proposed for Phase III. This preliminary engineering recommended not using an existing glass furnace for Phase III testing. Results of Phase II testing indicated that:

- The cost to retrofit an existing facility to the specification needed to melt sediment would be as much as building a pilot melter to these same specifications;

- Most existing facilities are too large to accommodate a limited duration test and would not provide the ability to adequately sample the various waste streams to determine destruction efficiency; and

- Use of oxy-fuel burners would be most energy efficient.

Together, the results of Phase I and II indicated that the glass furnace construction and operating costs could allow the processing and melting of the river sediments to be considered an economically viable option. Therefore, Minergy Corporation and WDNR initiated Phase III, the construction and operation of a pilot-scale glass furnace, specially designed to generate the operational data, treatment effectiveness data, and cost information needed for scale-up to a full-scale facility (Phase IV). The glass furnace technology process consists of two basic steps: a sediment drying step followed by the vitrification (melting) step. Due to the potential to release contaminants during both steps and the limited scale of this phase, treatment of approximately 60 tons of dredged and dewatered sediment, it was necessary to evaluate these two steps independently. Both processes were independently evaluated by the EPA SITE Program. The evaluation of the drying step was completed using a bench-scale

Holoflite® dryer at Hazen Research, Inc.'s Golden, Colorado facility. Results from the dryer will not be discussed here because the waste streams from this process can and will be incorporated directly into the design of the melter thus effectively treating these waste streams. However, the dryer evaluation did provide some insights into the material handling characteristics of the sediment including (Hazen, 2001):

- Fox River sediments can be physically modified to provide flowable feed to a dryer;
- The amount of moisture in the sediments can be reduced to less than 10 percent;
- Heat transfer coefficients and thermal efficiencies;
- Dewatered sediment exhibited stickiness or agglomerating characteristics at less than 65 percent solids; and
- Dewatered sediment at greater than 65 percent solids did not exhibit sticky or agglomerating characteristics.

The pilot-scale glass furnace is simply a refractory-lined rectangular melter (refer to Figure 6-11). The refractory is brick or concrete that has been specially treated to resist chemical and physical abrasion, has a high melting point, and provides a high degree of insulating value to the process. Natural gas is fired in the furnace, raising the internal temperatures to between 2600 and 3000 ˚F. Exhaust treatment is simplified and energy efficiency improved by the melter's use of purified oxygen (oxy-fuel) rather than ambient air as the oxygen source. At these temperatures, the sediment melts and flows out of the furnace as molten glass. Due to low gas volumes produced by the oxy-fuel melter and the large volume of gas space above the molten line, gases remain resident in the melter for a significant period of time (greater than 2 seconds). These conditions are more extreme than the conditions demonstrated to destruct PCBs. Other vitrification technologies have demonstrated greater than 99.9999 percent destruction of PCBs (cite NY/NJ WRDA work in WEDA). In addition, any trace metals in the molten glass will be stabilized when it is quenched and the glass matrix is formed.

The two primary objectives of Phase III testing were (EPA SITE, 2000):

- **P1** To determine the treatment efficiency (TE) of PCBs in dredged and dewatered river sediment when processed in the Minergy Corporation glass furnace technology (GFT); and

- **P2** To determine whether the GFT glass aggregate product meets the criteria for beneficial reuse under relevant federal and state regulations.

In addition, there were three secondary objectives:

- **S1** Determine the unit cost of operating the GFT on dewatered dredged river sediment;

- **S2** Quantify the organic and inorganic contaminant losses resulting from the existing or alternative drying process used for the dredged and dewatered river sediment; and

- **S3** Characterize organic and inorganic constituents in all GFT process input and output streams. Of principal concern is the formation of dioxin and furan during the vitrification step.

Phase III was completed in August 2001. During the pilot, approximately 50 tons of dredged and dewatered river sediment was processed through the melter. This phase clearly showed that the glass furnace technology created a quality glass aggregate material from river sediments. The properties of the glass aggregate were quite positive and were very consistent, producing a hard, dark, granular material (Minergy Corporation, 2001).

The EPA SITE Program has released the validated results of the chemical testing conducted during Phase III. As described in the Quality Assurance Project Plan (QAPP) (EPA SITE, 2001), all input and waste streams were sampled during the pilot. Testing was performed for a wide range of chemicals including congener PCBs (n = 78), dioxins/furans, SVOCs, VOCs, and heavy metals. In addition, the glass aggregate was subjected to both American Society for Testing and Materials (ASTM) water leaching procedures and SPLP procedures.

The sediment charged into the melter during the pilot testing averaged 28.1 milligrams of PCB per kilogram (mg-PCB/kg). Exhaust gas emissions were sampled on the pilot melter before and after the air quality control equipment. The average PCB concentration of the exhaust after the air quality control equipment was 36.6 nanograms per dry standard cubic meter (ng/DSCM) meter). In comparison, the average PCB concentration of the exhaust before the air quality control equipment was only slightly higher at 45.9 ng/DSCM. Thus, on an hourly average post-air quality control stack basis, this equates to PCB destruction of greater than 99.99993 percent during the pilot.

The formation of dioxins and furans during the thermal treatment of PCB-contaminated sediment was identified as a concern during the development of the sampling plan and were sampled. The sediment on average contained 23.5 and 65.6 ng/kg 2,3,7,8-TCDD and 2,3,7,8-TCDF, respectively. No 2,3,7,8-TCDD was detected in either the pre- or post-air quality control equipment samples. 2,3,7,8-TCDF was detected at an average of 0.0018 ng/DSCM post-air quality control equipment. Therefore, on an hourly average basis during the pilot, 8,815.5 ng of 2,3,7,8-TCDD and 2,3,7,8-TCDF were loaded into the melter while less than 0.1 ng of only 2,3,7,8-TCDF was emitted. This not only represents a greater than 99.998 percent reduction in 2,3,7,8-TCDD/TCDF, but more importantly that these compounds are not created to any extent during this treatment process.

Using the results from the pilot melter, the emissions from a 250 glass tons per day full-scale facility were calculated. The facility would meet all current state and federal air emissions regulations and is not expected to trigger the major source thresholds (Minergy Corporation, 2002).

The glass aggregate also demonstrated acceptable characteristics for beneficial reuse. As identified in the project QAPP (EPA SITE, 2001), the glass aggregate did not exceed any of the criteria specified. In fact, the ASTM water leach test and SPLP test did not detect any 2,3,7,8-TCDD/TCDF, not a single PCB congener, any SVOCs, nor any of the eight heavy metals.

In response to EPA SITE's need to also determine the cost of the technology, Minergy Corporation performed a *Unit Cost Study for Commercial-Scale Sediment Melter Facility* (Minergy Corporation, 2002). This report used standard build-up estimating approaches in developing the cost estimates. This approach used the information generated in Phases I, II, and III and on that basis requested relevant cost, performance, and sizing data from equipment suppliers. With this data, the general plant layout (Figure FVRS-GA-101 from Unit Cost Report presented in Appendix G), mass and energy balance, and equipment arrangements were made. From this, estimates were done for construction and operations and, through financial modeling, a unit-cost forecast. The base case estimates were made using a plant size of 250 glass tons per day. Sensitivity analysis was also conducted for various sized melter plants with and without integrated storage. Table 4 from the Unit Cost Report presented in Appendix G summarizes the unit costs developed during this study.

The glass furnace technology incorporates and optimizes several factors to achieve greater cost and treatment effectiveness than other thermal processes, including rotary kilns. These factors include:

1. **Oxy-Fuel.** The use of pure oxygen (rather than atmospheric air) and natural gas has the added benefits of:

    a. Substantially reducing pollutant emissions thereby reducing capital and annual operating expenses associated with air quality control equipment; and

    b. Higher heat transfer and thermal efficiencies which together increase throughput in an existing facility or reduce the size of new facilities (see Baukal, 1998 for a review of oxy-fuel combustion).

2. **The Use of Highly Insulating Refractory.** A glass furnace is able to utilize several layers of refractory brick, thus increasing the insulating value and keeping the oxy-fuel heat inside the furnace. In comparison, other thermal processes like rotary devices for vitrification can have thinner refractory linings and thus may have up to three times the amount of heat loss.

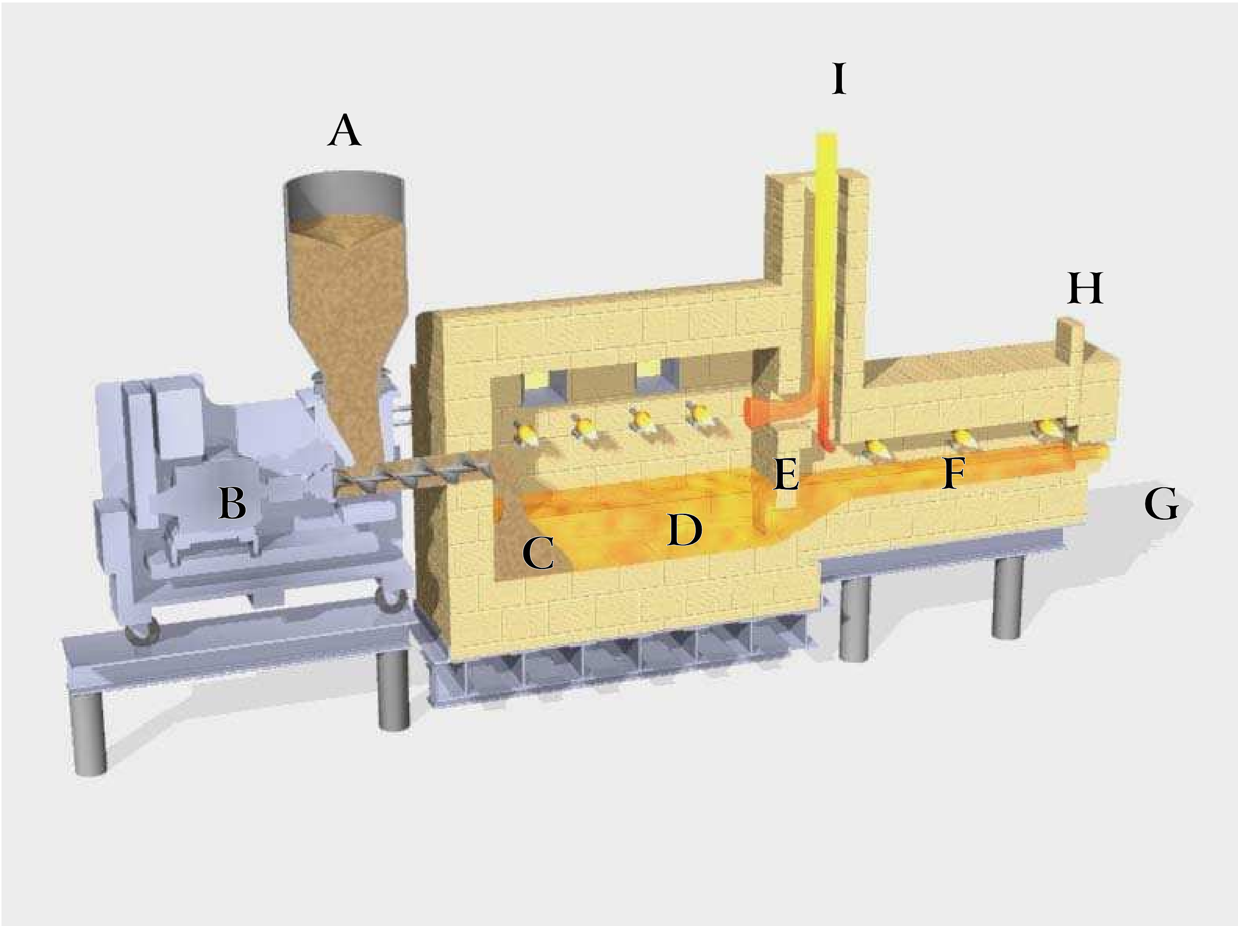
3. **Use of a Dryer to Remove Water from the Sediment.** Many other technologies process wetter material and, therefore, a substantial portion of the energy consumption is used in super-heating water to the same temperature as the sediment.

Thermal recovery from the glass furnace can provide a significant portion (85 percent) of the energy to pre-dry sediment before introduction into the glass furnace.

Table 1 X-Ray Fluorescence Elemental Analysis and Stepped Loss on Ignition Analysis

Date Collected		Nov. 11	Nov. 11								6/3/1998	6/3/1998	6/5/1998	6/5/1998	6/5/1998	6/5/1998
Lab #		**A**	**B**	**5297**	**5300**	**5290**	**5299**	**5298**	**5289**	**5291**	**5295**	**5296**	**5292**	**5293**	**5294**	**5301**
Al_2O_3	10.70	5.03	4.53	9.03	14.10	10.20	14.70	14.20	11.80	10.60	13.80	13.20	11.80	12.80	13.70	11.20
SiO_2	63.70	76.90	80.50	80.50	63.10	58.90	59.20	62.10	58.30	65.80	62.30	58.40	53.30	62.10	61.10	53.50
CaO	7.91	8.10	5.17	1.04	7.29	9.84	9.07	7.15	10.40	8.09	7.22	9.93	15.90	7.88	7.75	11.00
Fe_2O_3	4.58	1.90	1.32	3.19	5.84	3.62	6.00	5.55	4.66	3.73	6.45	5.40	5.29	5.49	5.35	4.61
TiO_2	0.55	0.10	0.07	0.37	0.61	0.54	1.17	0.80	0.71	0.53	0.65	0.89	0.63	0.68	0.68	0.67
Na_2O	0.98	0.88	0.73	0.90	0.52	0.77	0.61	0.71	0.70	0.74	0.56	0.71	0.71	0.74	0.69	0.65
MgO	6.09	4.58	3.87	1.46	6.28	8.16	6.70	6.86	6.53	5.66	6.81	7.92	4.56	7.17	7.96	8.80
P_2O_5	0.22	0.08	0.08	0.10	0.32	0.41	0.72	0.38	0.37	0.30	0.34	0.48	0.30	0.26	0.33	0.40
S	0.48	0.33	0.26	<0.05	0.41	0.66	0.56	0.36	0.52	0.35	0.48	0.69	0.35	0.27	0.27	0.56
Cl	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.03	<0.02	0.02	<0.02	<0.02	0.03	<0.02	<0.02	<0.02	0.03
K_2O	3.48	2.04	2.16	2.87	2.95	2.92	3.23	3.55	3.11	3.17	2.97	3.16	2.99	3.53	3.65	2.99
MnO	0.07	0.02	0.02	0.04	0.07	0.05	0.08	0.06	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.07
BaO	0.06	0.04	0.04	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.03
LOI-550				10.9	8.9	12.6	8.0	10.8	6.8	7.4	8.9	2.8	7.9	5.2	9.9	11.6
LOI-750				15.1	13.6	17.2	12.5	16.1	10.7	9.2	13.5	3.1	11.3	8.4	15.1	18.0
Sample Designation	Dep N	Marina	Marina	95001-01	95015-01	95049-01	95055-06	95075-04	95068-01	95100-01	SDC-EE22-1-G-45-55	SDC-EE22-1-G-45-55	SDC-X-4-G-45-55	SDC-W-5-G-45-55	SDC-E-4-G-45-55	SDC-C-1-G-45-55

Figure 1 Glass Furnace Process Description



Sediment (A) is fed into the hopper above the screw feeder (B). The feeder conveys the sediment continuously into the main section of the melter (C). The extremely high temperatures in the melter cause the sediment to become molten, liquid glass (D). The molten glass flows under a skimmer block (E) into the forehearth (F), where the material continues to form a stable glass. At the end of the melter, the glass flows out (G), into a water quenching tank (not shown). A removable block is included at the end of the forehearth (H) to stop the flow of glass if desired. Exhaust gases (I) flow out from the top of the furnace to the air quality control equipment (not shown).

Figure 2 Processing Facility Conceptual Layout

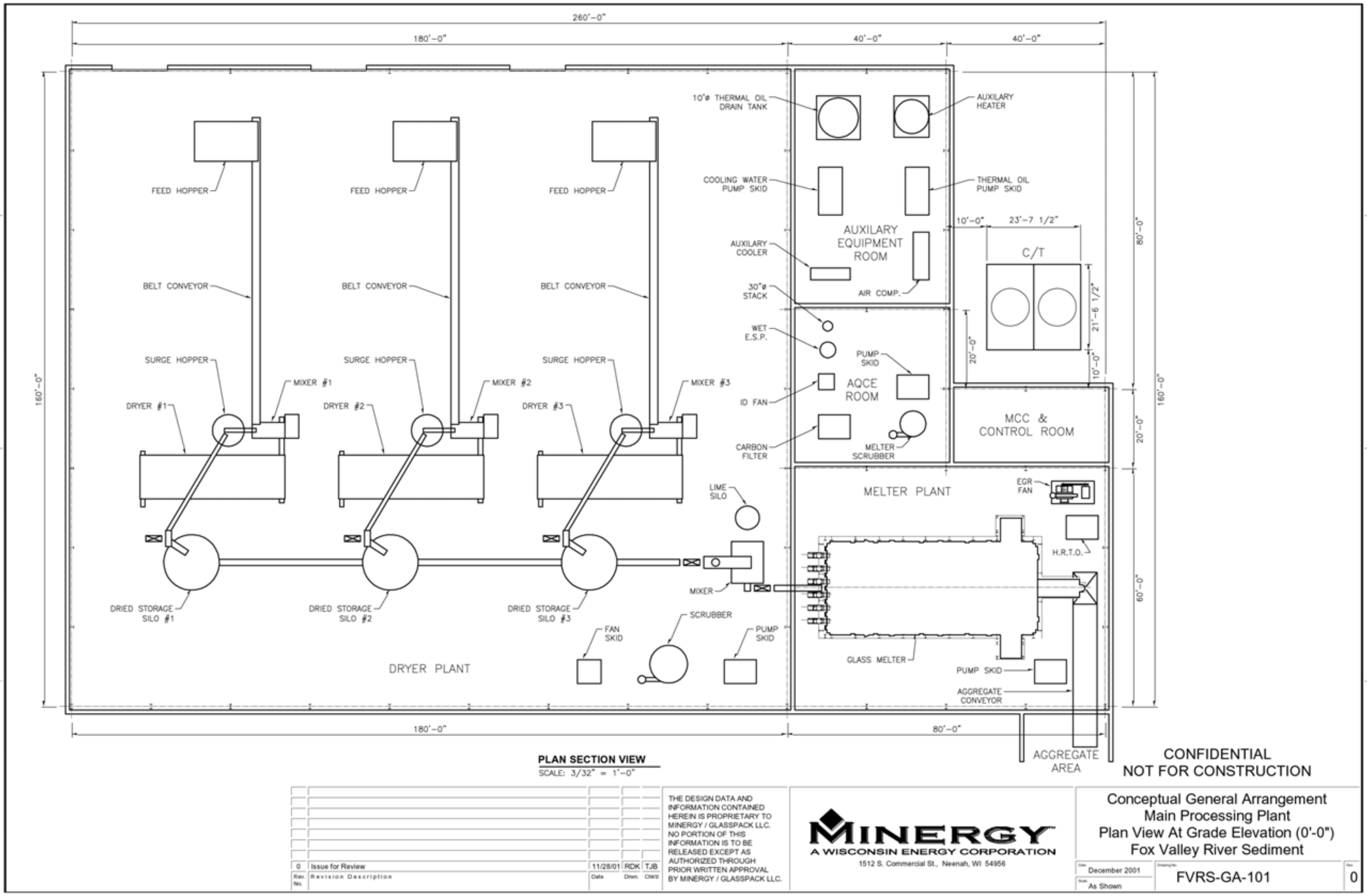


Table 2 Summary of Sensitivity Options: Sediment Melting Plant

	1×100 Integrated No Storage	1×100 Integrated Storage	1×250 Integrated No Storage	1×250 Integrated Storage	1×250 Standalone No Storage	1×250 Standalone Storage	2×250 Standalone No Storage	2×250 Standalone Storage	2×375 Standalone No Storage	2×375 Standalone Storage
Daily Capacity (tons)	240	240	613	613	613	613	1,226	1,226	1,840	1,840
Days/year Operation	240	350	240	350	240	350	240	350	240	350
Project Life (years)	15	15	15	15	15	15	15	15	15	15
Sediment Processed (million tons)	0.86	1.26	2.21	3.22	2.21	3.22	4.41	6.44	6.62	9.66
Capital ($ million)	25.50	26.25	36.99	38.79	34.97	36.77	63.19	66.79	87.39	92.79
Annual O&M ($ million)	2.30	2.76	4.73	6.13	5.44	6.84	9.29	12.17	12.57	16.74
NPV before Glass Sales ($ million)	49.35	54.86	86.04	102.40	91.44	107.81	159.58	193.16	217.88	266.50
Unit Cost (assuming $2 glass) (dollars per ton of wet cake)	**$56.54**	**$42.96**	**$38.41**	**$31.24**	**$40.86**	**$32.92**	**$35.58**	**$29.43**	**$32.32**	**$27.01**
Unit Cost (assuming $25 glass) (dollars per wet ton of cake)	**$49.91**	**$36.33**	**$31.78**	**$24.61**	**$34.23**	**$26.29**	**$28.95**	**$22.80**	**$25.68**	**$20.38**

FINAL REPORT
SEDIMENT MELTER
DEMONSTRATION PROJECT

TABLE OF CONTENTS

INTRODUCTION

The presence of PCBs in the lower Fox River in northeastern Wisconsin has been a concern for many years. Extensive investigations of the river bottom have taken place during the 1980s and 1990s. Two areas of the river have undergone demonstration dredging in the past five years.

While planning the appropriate remedial response to be undertaken, the Wisconsin Department of Natural Resources (DNR) requested input from the public. Minergy proposed a feasibility study to determine the potential to use a glass furnace capable of melting the contaminated river sediment at high temperature, thereby destroying the PCBs and binding any metals in the glass aggregate produced. Such furnaces have been used for decades to make glass. Feedstock consisting primarily of silica sand (which is the main constituent of river sediment) melts in the furnace. The molten product is cooled to form glass aggregate, which is a marketable construction material.

This report is written to summarize the activities undertaken during Phase 3 of the multi-phase glass furnace feasibility study. The first two phases of the feasibility study determined that the minerals contained in dredged sediments could form a stable glass, and that the variability of mineral concentrations along the lower Fox River appeared to be within acceptable ranges. Results from these phases are available in reports sent to the Department under separate cover.

During one of the demonstration dredging projects, the DNR containerized approximately 60 tons of de-watered, contaminated river sediment. The DNR contracted with Minergy for the design, construction, and operation of a pilot melter, to melt the sediment into a glass aggregate.

Sediment Loading into Containers

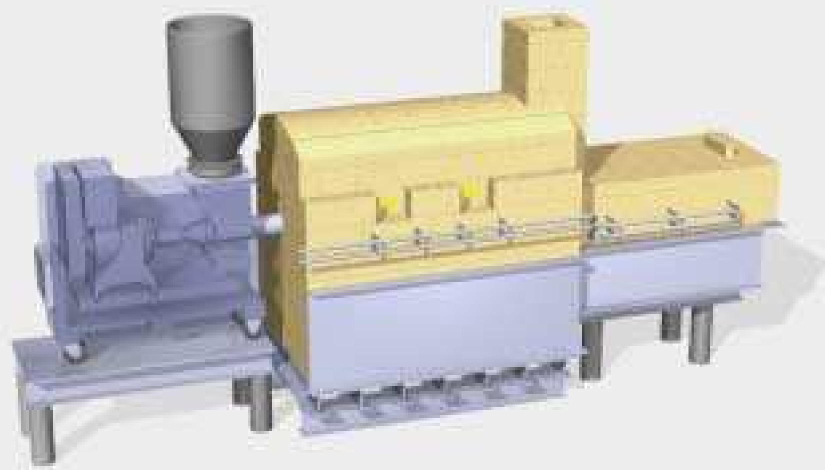
The U.S. EPA Superfund Innovative Technology Evaluation (SITE) program was used to perform an independent evaluation of the fate of PCB and other contaminants for Phase III. The dryer segment of the analysis was performed at the Hazen Research, Inc. facility in Golden, Colorado in January 2001. At that location, Hazen has a demonstration-scale dryer of the appropriate technology for use on sediments.

Sediment Melter

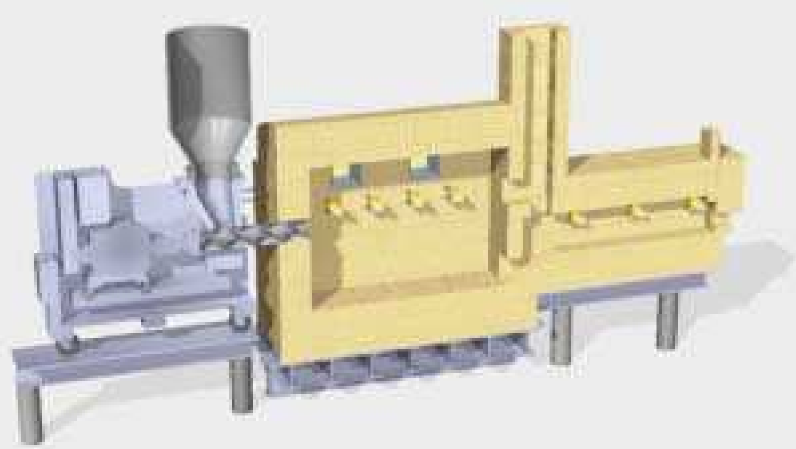
The melter evaluation was performed at Minergy's GlassPack Test Center in Winneconne, Wisconsin. A demonstration-scale melter was constructed, with operation of the melter from May to August, 2001. The pilot program was designed to confirm that the technology can destroy PCB contamination, stabilize trace metals, and convert the mineral content of river sediment into an inert, marketable construction material.

Under SITE program, the fate of PCBs and other compounds within the river sediment were monitored during the processing and melting of the river sediment. The SITE program test results will be submitted under separate cover by the EPA contractors responsible for gathering that data.

GLASS FURNACE TECHNOLOGY DESCRIPTION



External view of sediment melter



Internal view of empty melter with oxy-fuel burners in place (warm-up condition).

Introduction to Glass Furnaces

A Glass Furnace is a refractory-lined, rectangular melter.

Refractory is brick or concrete which has been specially treated to resist chemical and physical abrasion, has a high melting point, and provides a high degree of insulating value to the process.

Current glass furnaces use oxy-fuel burners, combining natural gas and oxygen for a bright flame above the glass. These burners raise the internal temperature of the melter to 2900 degrees Fahrenheit.

At these high temperatures, PCB contaminants are destroyed, and the sediment melts and flows out of the processing system as molten glass.

Melter Process Description

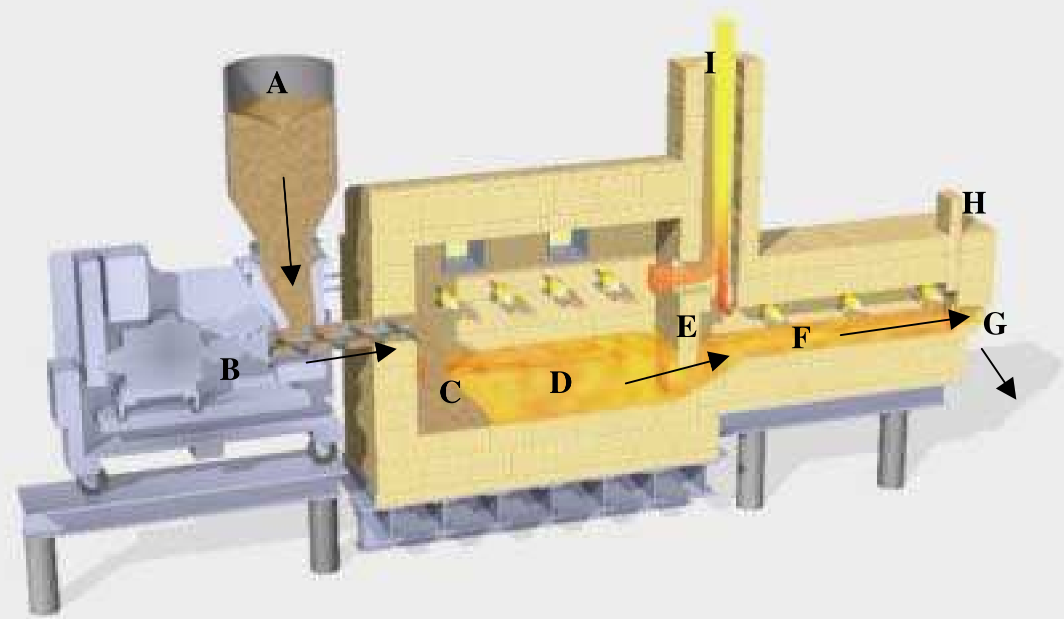


Fig 3. Internal view of melter (sediment feeding and melting)

Sediment (A) is fed to the hopper above the screw feeder (B). The feeder conveys the sediment continuously into the main section of the melter (C). The extremely high temperatures in the melter cause the sediment to become molten, liquid glass (D). The molten glass flows under a skimmer block (E), into the forehearth (F), where the material continues to form a stable glass. At the end of the melter, the glass flows out (G) into a water quenching tank. A removable block is included at the end of the forehearth (H) to stop the flow of glass if desired. Exhaust gases (I) flow out from the furnace up the square flue, to the air quality control equipment.

RIVER SEDIMENT MINERAL STUDY BY WDNR/MINERGY

Phase I of the feasibility study characterized the mineral composition of river sediments to estimate the glass quality, durability and melting points. Phase I conclusions include that river sediment characteristics are consistent throughout the river and are favorable for producing a quality glass product. Further, vitrification technology is more appropriate for river sediments than incineration as demonstrated by the low Loss on Ignition analyses.

River Mineralogy Study

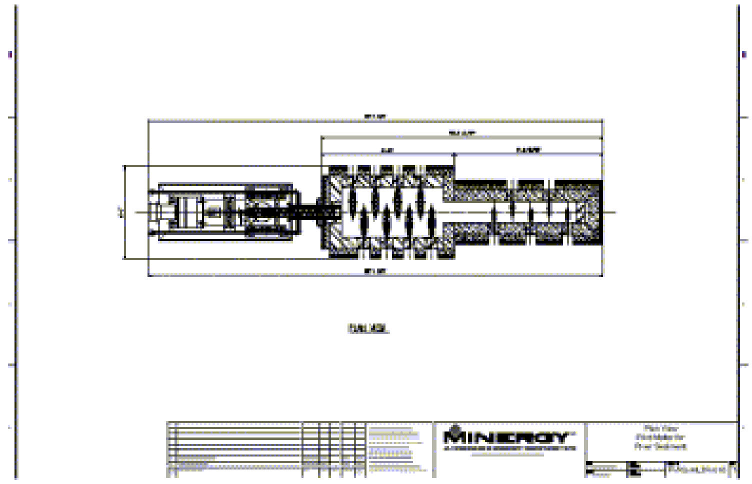
Date Collected	1/5/99	Nov. 11	Nov. 11	9/28/95	9/30/95	10/3/95	10/4/95	10/5/95	10/7/95	10/12/95	6/3/98	6/3/98	6/5/98	6/5/98	6/5/98	6/5/98
Lab #		A	B	5297	5300	5290	5299	5288	5289	5291	5295	5296	5292	5293	5294	5301
Al_2O_3	10.70	5.03	4.55	9.03	14.10	10.20	14.70	14.20	11.80	10.60	13.80	13.20	11.80	12.80	13.70	11.20
SiO_2	63.70	76.90	80.50	80.50	63.10	58.90	59.20	62.10	58.30	65.80	62.30	58.40	55.50	62.10	61.10	55.50
CaO	7.91	8.10	5.17	1.04	7.29	9.84	9.07	7.15	10.40	8.09	7.22	9.93	15.90	7.88	7.75	11.00
Fe_2O_3	4.58	1.90	1.32	3.19	5.84	3.62	6.00	5.55	4.66	3.73	6.45	5.40	5.29	5.49	5.35	4.61
TiO_2	0.55	0.10	0.07	0.37	0.61	0.54	1.17	0.80	0.71	0.53	0.65	0.89	0.63	0.68	0.68	0.67
Na_2O	0.98	0.88	0.75	0.90	0.52	0.77	0.61	0.71	0.70	0.74	0.56	0.71	0.71	0.74	0.69	0.65
MgO	6.09	4.58	3.87	1.46	6.28	8.16	6.70	6.86	6.53	5.66	6.81	7.92	4.56	7.17	7.96	8.80
P_2O_5	0.22	0.08	0.08	0.10	0.32	0.41	0.72	0.38	0.37	0.30	0.34	0.48	0.30	0.26	0.35	0.40
S	0.48	0.33	0.26	<0.05	0.41	0.66	0.56	0.36	0.52	0.35	0.48	0.69	0.35	0.27	0.27	0.56
Cl	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.03	<0.02	0.02	<0.02	<0.02	0.03	<0.02	<0.02	<0.02	0.03
K_2O	3.48	2.04	2.16	2.87	2.85	2.92	3.25	3.55	3.11	3.17	2.97	3.16	2.99	3.53	3.65	2.99
MnO	0.07	0.02	0.02	0.04	0.07	0.05	0.08	0.06	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.07
BaO	0.06	0.04	0.04	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.03

Phase II of the project, crucible melts of actual Lower Fox River sediment, were conducted to determine the actual melting conditions and glass characteristics/qualities of the sediment alone and when augmented with other materials (flux mixtures). Four different test "recipes" were included in the crucible melts and the sediment successfully melted into glass in all four tests. Phase II results include a proposed recipe for melting river sediment into glass aggregate and preliminary engineering designs for the pilot test facility proposed for Phase III. This preliminary engineering recommended

Melt #	Flux utilized	Viscosity	Glass Pouring
1	None	High	Sticky
2	Sodium carbonate	Low	Flowed
3	Dolomitic limestone	Very Low	Flowed
4	3-mix cullet	Medium	Flowed

Crucible Melt Results

not to use an existing glass furnace for Phase III testing. Results of Phase II engineering indicated that the cost to retrofit an existing facility for the purposes of a limited-term test would be as much as building a new pilot melter to those same specifications. Also, most existing facilities were far too large to accommodate a limited duration test.



Melter Preliminary Engineering

U.S. EPA Air Testing

Feasibility Study Phase III

The third phase of the feasibility study was broken into two segments, one to evaluate the sediment dryer and another to evaluate the sediment melter. The U.S. EPA Superfund Innovative Technology Evaluation program was used to perform an independent evaluation of the fate of PCB and other contaminants for both segments. The dryer segment was performed in Golden, Colorado, at the Hazen Research laboratory, where a demonstration-scale dryer of the appropriate technology for use on sediments was already in existence. The melter segment was performed at Minergy's GlassPack Test Center in Winneconne, Wisconsin.

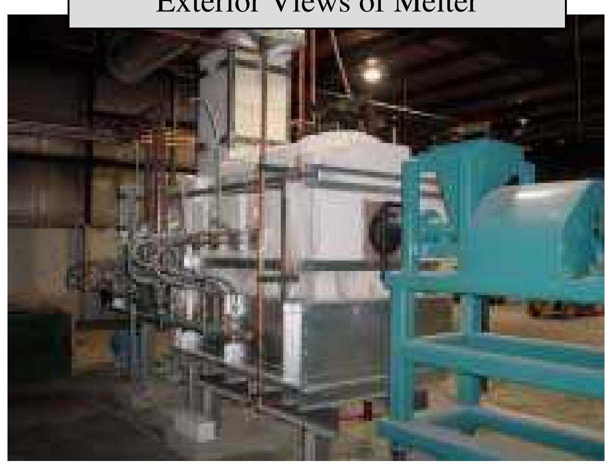
MELTER DESIGN

The pilot melter is designed to simulate a full-scale production melter for the generation of glass aggregate from sediments. In order to adequately produce a model, some assumptions have been made with regard to the full-scale melter in accordance with typical glass operating practices. The pilot melter is scaled down from the full-scale melter and has been designed to operate in a manner which would suggest design features for most major elements of the full scale melter.

Pilot Melter Characteristics

Aspect Ratio	2:1
Area	10 sq ft.
Melting Rate	5.4 $ft.^2$/ton
Dwell Time	6 hrs.
Gas Usage	1.7 MM Btu/hr.
Oxygen Usage	35 ccfh
MM Btu/Ton	20.9 mmbtu/ton
Output	2 tons/day

Exterior Views of Melter



Minergy has intellectual property protection for the application of glass furnace technology on contaminated sediments. Several modifications to the standard melter design have been incorporated to best suit this application. These modifications include:


Molten Glass in Quench Tank

- The use of a water quench system to quickly harden the molten glass and increase the inert characteristics of the final product. Glass melters typically use annealing or other slow-cooling products to enhance glass clarity and other product qualities. These product features are not significant in the manufacture of glass aggregate because its final use is as a construction product where glass clarity is not necessary. Determination of the leaching characteristics of the final product will be done as part of the S.I.T.E. investigation. Molten material is drained from the end of the melter into the water-filled quench tank. An inclined ¼-inch steel plate, cooled by a constant water stream, directs falling liquid aggregate into the hopper of an auger submerged in the quench tank. The auger moves the aggregate out of the quench tank into barrels.


Aggregate Screw Conveyor

- The pilot melter is 10 square feet with a 2:1 aspect ratio. The materials selected are typical for soda-lime glass operations in an oxy-fuel environment. Six inches of extra sidewall has been added to the height to accommodate organics contained in the sediment feedstock.
- The melter will have eight Split-Stream oxy-fuel burners to approximate the burners that would be used in a full-scale melter.

Top View of Melter

Flue Coupled to Outlet Duct

- The melter is oxy-fuel fired to utilize the B.A.C.T. for NO_X emissions and reduced particulate. The glass quality is adequate with 6 hours of dwell time, so it runs a shallow glass level.
- The flue is located in the front of the melter, which is not the traditional location for oxy-fuel furnaces. This is done so that any fine particulate that becomes entrapped into the exhaust gases will have the maximum time in the furnace to allow these particulates to be melted, or minimized.

- Sediment is fed in on one end of the melter through a water-cooled screw charger. The charger is a standard screw batch charger that has been used all over the world for charging batch in glass furnaces. The screw charger was chosen due to the ability to tightly seal the charging hopper to the charger and the charger to the furnace. This minimizes dusting of the raw material feedstock. The charger is similar in size to that which would be used in a full-scale unit. It has been retrofitted with a small screw barrel and flights for the pilot melter. This charger can be reused for a full-scale melter by modifying the barrel and flights. A variable-speed drive allows control of the feed rate.


Sediment Screw Charger


Air Filtration on Sediment Hopper

- Negative pressure is placed on the feed hopper during charging operations to control dust.
- The melter design capacity is 2 tons per day or 170 pounds of river sediment per hour. The sediment bags weighed approximately 50 gross pounds, so the feed rate was expected to be between four and five bags per hour.

- The pilot melter is controlled by control loops to the melter and forehearth. The control loops use thermocouple signals to maintain a constant temperature by automatically adjusting the gas and oxygen for each zone. The control panel contains two single loop controllers, two digital gas flow meters, two digital oxygen flow meters, six digital temperature meters, status lights for the main fuel train, E-stop, alarm horn, and alarm silence push button.

Control Panel

Oxy-Fuel Control System

- Both the gas and oxygen skids have essentially the same safety system. A strainer is utilized prior to a pressure regulator. A high/low pressure switch is tied to the double block automatic shut-off valves. A differential pressure switch is used to determine flow through the system. This is a safeguard against injecting raw natural gas or oxygen into the furnace. If flow is lost on either natural gas or oxygen, the skid shuts down that zone. Each zone is then automatically controlled for gas and oxygen flows via a signal from the mass flow meter to a control loop back to an automatic valve.


Melter Refractory

- Refractory selection has been developed for this pilot melter based on the heat flow analyses for each construction type. These are used to insure that none of the materials is placed in temperatures beyond their capability and to determine the total heat loss of the entire system.


Side of Melter in Operation

- The use of refractory selected by evaluating the abrasive qualities of the molten sediment. Glass products vary according to the chemical makeup of the feedstock. After the June run, an inspection of the inside of the forehearth verified that the refractory material at the glass line was seeing significant wear. The melter was relined with a higher grade refractory in place of the mullite originally installed in the melter for the August run.

- The melter was designed and built under a contract with Frazier-Simplex of Washington, Pennsylvania.

- The melter uses a "shallow" glass line. Glass melters typically have deeper pools of glass inside the melter, taking advantage of the low opacity of the glass being produced. Molten sediments are quite opaque, thus reducing energy transfer by radiation.

Inspection of Glass Line

Warm Up Burner

- Startup of the melter is performed gradually over 36-48 hours. A separate, dedicated warmup burner is used to raise the temperature of the melter to approximately 1,400 degrees F. After this temperature, the main burners are used to reach final temperature target of 2,900 degrees F.

EXTRACTION PROBE DESIGN AND CONSTRUCTION

- The purpose of the extraction probe is to cool the hot gas from the melter exhaust at a controlled rate. The rate of cooling would be equivalent to the heat recovery systems installed on a full scale melter system. The extraction probe was designed by Minergy. The section of the probe which is inserted into the melter is contained in a water-cooled jacket, and is hung from a rail that allows it to be inserted into the stack for testing, then removed when testing is not taking place.

Extraction Probe

- A cleanout port is placed on the back end of the probe, and a brush and rod are used to manually clean out particulate buildup within the probe.

Probe Clean-out

- Piping connects the extraction probe to a contact packed tower condenser. An induced draft fan pulls the exhaust gases through the tower condenser, and then through a carbon barrel, before discharging the air stream out of doors.

Packed Tower Condenser

Carbon Filter

- A heat exchanger loop cools the water in the packed tower condenser. Sampling ports are located before the condenser and after the carbon filter, to allow connection of air testing equipment.

SEDIMENT PREPARATION

The Fox River sediment supplied to Minergy for the pilot melter project contained about 50% moisture by weight. The melter was designed to process sediment containing approximately 10% moisture. Minergy contracted Hazen Research, Inc. (4601 Indiana St., Golden, CO) to determine the material handling characteristics of the sediments and to evaluate moisture removal by indirect drying. It was determined that Fox River sediment, when mixed with drier materials to reduce its moisture content to 37%, would handle easily when undergoing drying activities to bring its moisture content down to 10%.

Hazen dried a batch of Fox River sediment to approximately 10% moisture. The EPA sampled and tested the various medias involved to determine the fate of contaminants during the drying process. Results of that testing will be submitted by the contractors responsible for the testing.

Flux is often a necessary addition to the feed material in glass melters as an oxidizer and for scum control. Minergy contracted Corning Glass Works to mix various concentrations of fluxing compounds with sample sediment from the Fox River, melting the mixed material and observing its melt characteristics.

The pilot project used a flux mix ratio of 5% sodium sulfate by weight.

The pre-processing of the river sediment in the Winneconne facility occurred in a series of steps:

Drying


Barrel Drying Oven

Minergy purchased a 75-kW electrically-heated drying unit, and dried the river sediment at the Winneconne facility. Twelve barrels of sediment were dried together in a batch. Each batch underwent low-temperature drying, with sediment temperature below 210 degrees F, for 36 hours. A 10-inch diameter wire cage was placed inside each barrel prior to drying to increase heat transfer and evaporation rates. Thirty batches of river sediment were processed, filling 60 supersacks.


Dust Enclosure

A 20-foot by 20-foot dust enclosure was built for controlling dust during sediment processing activities. With the exception of the drying activities in the oven, all processing activities took place within the dust enclosure.

The dried river sediment was removed from the oven, and the barrels were dumped into supersacks. Each supersack contained six barrels of river sediment, so each oven batch was transferred into two supersacks. Each supersack weighed approximately 1,100 pounds.

Supersack of Dried Sediment

Each supersack was numbered, to identify when its material was dried, and the lugger from which its material originated.

RIVER SEDIMENT
MINERAL ANALYSIS by
XRF for MAJOR ELEMENTS

Batch Number	Na2O	MgO	Al2O3	SiO2	P2O5	K2O	CaO	TiO2	Fe2O3
1	0.43	9.95	9.60	35.3	0.37	1.75	35.9	0.71	2.85
2	0.43	9.71	9.12	34.5	0.38	1.65	34.1	0.66	2.53
3	0.39	10.1	9.42	34.3	0.36	1.56	37.6	0.70	2.75
4	0.43	11.3	9.33	33.3	0.38	1.49	36.3	0.69	2.75
5	0.38	10.1	9.35	35.2	0.36	1.58	35.7	0.69	2.04
6	0.49	10.2	10.1	38.4	0.36	1.82	31.3	0.69	2.71
7	0.50	10.3	10.1	38.4	0.38	1.76	31.1	0.72	2.82
8	0.38	9.30	9.40	34.8	0.38	1.74	36.5	0.68	2.50
9	0.50	8.98	10.1	38.7	0.38	1.83	33.3	0.71	2.71
10	0.45	8.79	9.80	36.8	0.37	1.88	35.1	0.71	2.70
11	0.47	8.98	9.81	37.5	0.37	1.74	34.7	0.71	2.69
12	0.44	8.78	9.82	35.1	0.37	1.59	36.4	0.70	2.66
13	0.51	9.82	9.84	38.0	0.36	1.43	33.2	0.70	2.73
14	0.43	9.64	9.87	35.5	0.37	1.78	35.6	0.70	2.66
15	0.44	11.6	9.77	37.6	0.35	1.88	33.7	0.71	2.69
16	0.44	10.3	9.93	36.6	0.37	1.73	35.0	0.75	2.79
17	0.47	10.2	9.86	37.2	0.36	1.82	35.4	0.72	2.74
18	0.44	9.37	9.59	35.8	0.35	1.82	37.9	0.71	2.83
19	0.49	10.4	9.60	37.7	0.36	1.73	34.8	0.69	2.83
20	0.57	9.77	9.87	38.1	0.33	1.81	32.7	0.68	2.96
21	0.43	8.72	9.45	35.8	0.35	1.77	34.0	0.67	2.54
22	0.45	9.20	9.98	36.0	0.37	1.86	35.7	0.72	4.28
23	0.46	10.8	9.88	38.0	0.37	1.94	33.3	0.70	4.26
24	0.40	8.59	9.75	37.2	0.36	1.81	36.4	0.69	4.52
25	0.40	8.53	9.48	35.8	0.35	1.72	30.4	0.68	4.10
26	0.40	8.83	9.64	36.0	0.36	1.63	35.8	0.71	4.24
27	0.41	9.10	10.2	36.6	0.36	1.73	37.1	0.74	4.41
28	0.37	10.6	9.54	34.3	0.37	1.87	36.9	0.69	4.21
29	0.39	8.86	9.82	36.8	0.36	1.74	37.8	0.69	4.31
30	0.39	9.91	9.57	34.8	0.37	1.62	36.1	0.72	4.74

Mineral Analysis of Dried Sediment

<u>Delumping</u>

The supersacks containing dried river sediment were unloaded through a delumper, reducing particle size of the sediment.

<u>Sampling</u>

Samples were retrieved from one foot below the surface of the material in each supersack to analyze for moisture and mineral content. Select material was also analyzed for loss on ignition. The results of the mineral analysis are included at left.

Metal Separation

The delumped sediment was passed through a grate containing 13 bar magnets, placed in four rows offset to each other. Significant amounts of magnetic material were separated.

Mixing/Bagging

The dried river sediment was mixed with a sodium sulfate flux. The ratio of sediment to flux varied from supersack to supersack due to variations in moisture content among the various runs. The appropriate amount of flux was added to each drum of dried river sediment, and the barrels were rolled on the floor to mix the contents. The mixture was then poured into approximately 50-pound bags, which were marked with their weight and the supersack number from which they originated. The bags were loaded on a pallet. Each pallet contained all the bags of sediment/flux mix produced from a single supersack, so that during melting operations, material processing could take place based on moisture content and lugger of origination..

Batch Bags of Dried Sediment

All sediment processing activities were carried out within the dust enclosure. Workers wore Tyvek suits with full-face air filtration. A negative air machine was connected to the dust enclosure to remove particulates from the air.

JUNE 2001 TRIAL

The June 2001 trial took place from June 16 – 23, 2001, on a 24 hours per day schedule. Featured during this test run was a series of four public and media relations events Monday and Tuesday, June 18-19.

Media Relations Activities

Shakedown of the melter system was delayed for several days due to a severe storm which occurred June 11, the originally planned startup date. The storm resulted in an extended power outage to the facility (approximately 4 days). Public relations had been planned for Monday June 18 and Tuesday June 19, featuring a number of high-profile visitors who had arranged their schedules to visit the demonstration. To maintain the schedule, shakedown of various systems was eliminated. Instead, the unit was put into continuous production at the earliest possible time.

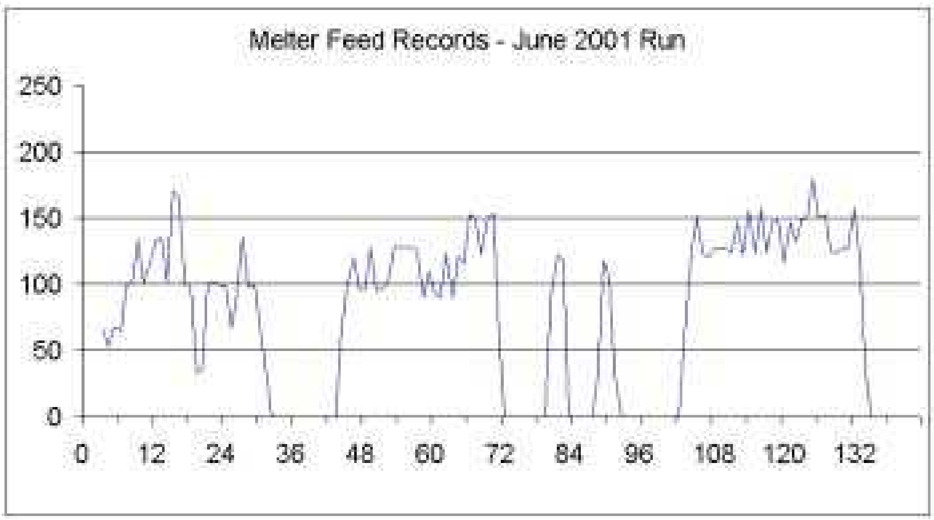
Public Relations Tours

The melter was brought up to temperature slowly from Saturday, June 16 to Monday, June 18. The first river sediment was fed into the melter at 3:00 a.m. on June 18.

The run was interrupted on a number of occasions, due to clogging of the batch charger, clogging of the tap, and a power outage. The operation of the extraction probe was shut down on a number of occasions due to plugging of the filters in the air testing equipment. Many of the equipment problems can be attributed to having performed what otherwise would have been shakedown during the operational timeframe.

The run was concluded when representatives from Frazier-Simplex suspected degradation of the forehearth section of the melter. The total run time was insufficient to provide adequate sampling required in the EPA's plan

Approximately 10,700 net pounds of river sediment had been processed at the time. The oxy-fuel train was shut down, and the melter was allowed to cool down over a period of a week.



Inspections And Modifications

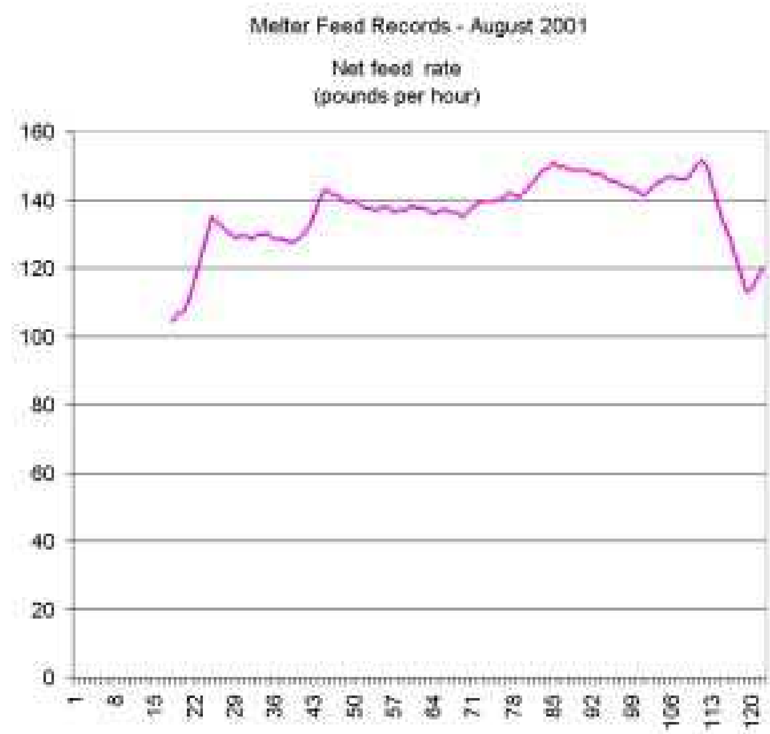
An inspection of the inside of the forehearth verified that the originally specified refractory material at the glass line was subject to accelerated wear. The melter was relined with a higher grade refractory in place of the mullite originally installed in the melter.

AUGUST 2001 TRIAL

The August 2001 trial took place from August 11 – 18, 2001. Melting operations took place 24 hours per day. This trial went smoothly, attributable to the fact that significant systems had been shaken down and tested during the June run. In the interim timeframe, optimizations were made that allowed for a successful run in August.

After the melter was rebuilt in July, the August run took place smoothly and uneventfully. Steady state conditions were achieved fairly quickly, and with the exception of two periods of downtime involving the extraction probe/air emissions assembly, steady state was maintained until completion of the testing.

The melter was brought up to temperature slowly from Saturday, August 11 to Monday, August 13. The first river sediment was fed into the melter at 6:00 a.m. on August 13. Air testing started at midnight on Tuesday, August 14, and was carried out routinely until 7:00 a.m., Saturday, August 18.



Approximately 16,500 net pounds of river sediment were processed during the August trial.

OBSERVATIONS

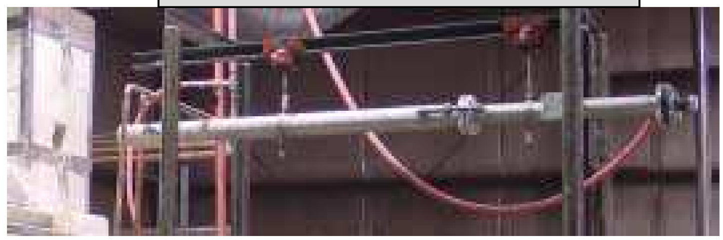
The pilot project determined that river sediment melts easily at high temperature into a hard, angular aggregate. The melter worked well with this type of feedstock, and the end product appeared consistent and marketable. When river sediment was being fed into the melter, temperatures within the melter were maintained between 2600 and 2900 degrees F.

Molten Glass Tapping

Clearing the Tap

The pilot melter was designed for a relatively low flow rate of glass through the melter tap. As expected, the tap refractory did not reach temperatures sufficient to provide for unattended tapping of glass. To keep the tap open, a secondary external gas fired burner was used, and operators used metal bars to loosen prematurely cooled aggregate.

Extraction Probe



The extraction probe needed routine maintenance. When hot exhaust gases were drawn into the water-cooled extraction probe, condensation took place, which tended to capture particulates moving through in the exhaust gas. When flow through the probe decreased significantly due to particulate build-up, the cleanout port was opened and the probe was cleaned.

Sediment Feed

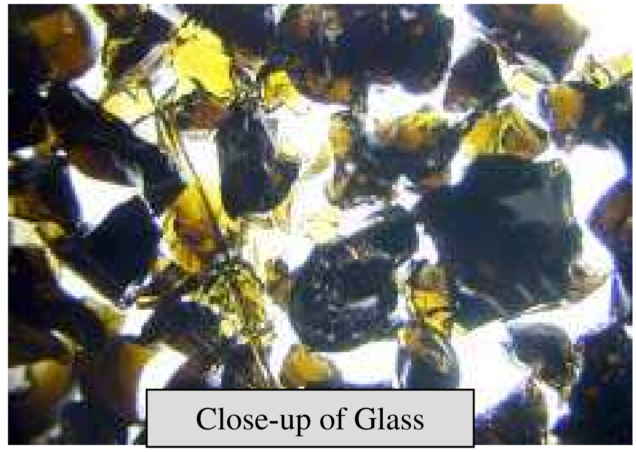
The moisture content of the river sediment affected feed rates. Moisture contents ranged from 5% to 20%. River sediment with higher moistures tended to bridge in the charger, and to cake around the auger. A technician permanently observed the feeding process, to make sure the charger was always feeding material to the melter.

The downstream end of the extraction probe assembly, involving the condenser, carbon barrel, and associated piping and pumps, suffered plugging due to accumulation of particulate and sulfates, primarily attributable to the use of sodium sulfate as a flux. The condenser cooling water was blown down periodically to alleviate the potential for low pH.

Air Quality Control

SUMMARY

The Phase III demonstration clearly showed that dried sediment will successfully create a quality glass aggregate material using a glass furnace. The properties of the glass aggregate product were quite positive. The aggregate was very consistent, producing a hard, dark, granular material.



Close-up of Glass

Leach tests performed on the aggregate by the WDNR showed no detect for PCBs or any trace metals. This confirms the original goal of the project: the glass aggregate product is a quality material, PCB-free, with excellent leaching characteristics.

DNR Parameter Description	Result value
ARSENIC TCLP	ND
BARIUM TCLP	0
CADMIUM TCLP	ND
CHROMIUM TCLP ICP	ND
LEAD TCLP	ND
MERCURY TCLP	ND
PCB SUM OF CONGENEI	ND
SELENIUM TCLP	ND
SILVER TCLP	<0
ZINC TCLP	ND

Shortly after the completion of the demonstration, the DNR participated in the construction and dedication of a picnic shelter along the Fox River. At the DNR's request, glass aggregate from the demonstration run was used in the foundation of the picnic shelter. A plaque was installed to inform the public about the success of the demonstration project.

Product marketing specialists are analyzing the glass qualities to determine the marketability of the material. Based on Minergy's experience in marketing similar glass products, and given the high quality of this material, we are confident that all of the glass aggregate produced in a commercial-sized facility would be successfully marketed. The indicated list shows the preliminary assessment of the suitability for using glass aggregate from river sediment in various markets.

Minergy Corporation
Glass Aggregate Marketing
Chemical and Physical Property Guidelines

Roofing Shingle Granules	Target	Glass Aggregate	Accept?	Method
Loose Bulk Density	> 80 lbs/cf	90 lbs/cu ft	Yes	Weight/volume
Fe2O3 (for opacity)	> 5%	7%	Yes	ASTM 4326
Hardness	>5.5	6.2	Yes	Moh's mineral scale
Crystalline Silica content	<1%	no detect	Yes	X-Ray Diffraction
Leachability	TCLP test	passes	Yes	TCLP method 1311
Particle size	>80% between #12-#30	passes (crushed)	Yes	ASTM C136

Industrial Abrasives	Target	Glass Aggregate	Accept?	Method
Loose Bulk Density	> 80 lbs/cf	90 lbs/cu ft	Yes	Weight/volume
CaO	< 50%	17%	Yes	ASTM 4326
Al2O3	< 40%	10%	Yes	ASTM 4326
Fe2O3	< 20%	7%	Yes	ASTM 4326
Hardness	>5.5	6.2	Yes	Moh's mineral scale
Crystalline Silica content	<1%	no detect	Yes	X-Ray Diffraction
Leachability	TCLP test	passes	Yes	TCLP method 1311
Particle Size	>80% between #16-#50	passes (crushed)	Yes	ASTM C136
Embedment	<20%	7%-15%	Yes	KTA Tater Test

Ceramic Floor Tile	Target	Glass Aggregate	Accept?	Method
Loose Bulk Density	> 80 lbs/cf	90 lbs/cu ft	Yes	Weight/volume
Crystalline Silica content	<1%	no detect	Yes	X-Ray Diffraction
CaO	< 50%	17%	Yes	ASTM 4326
Glass Melting Point	> 2000 °F	2200 °F	Yes	ASTM 965
Particle Size	>80% between #16-#50	passes (crushed)	Yes	ASTM C136
Tile Strength	> 15 Mpa	22 Mpa	Yes	MOR/3-E (*)

Cement Pozzolan	Target	Glass Aggregate	Accept?	Method
Particle Size	480 m2/kg	passes (crushed)	Yes	ASTM C618
Iron-Alumo-Silicate	> 50%	52% - 60%	Yes	ASTM 114
L.O.I.	<6%	no detect	Yes	ASTM 114 ch.16
Cement Strength (3 day)	2535 psi	2850 psi	Yes	ASTM C311
Cement Strength (7 day)	3470 psi	3680 psi	Yes	ASTM C311
Cement Strength (28 day)	3953 psi	5300 psi	Yes	ASTM C311

Construction Fill
Acceptable gradation and compaction.

UNIT COST STUDY
FOR COMMERCIAL-SCALE
SEDIMENT MELTER FACILITY

FOR

WISCONSIN DEPARTMENT OF
NATURAL RESOURCES

SUPPLEMENT TO

GLASS AGGREGATE FEASIBILITY
STUDY

JANUARY 19, 2002

UNIT COST STUDY
FOR COMMERCIAL-SCALE
SEDIMENT MELTER FACILITY

TABLE OF CONTENTS

INTRODUCTION

Minergy Corporation respectfully submits this report to the Wisconsin Department of Natural Resources (the "Department") containing the results of the Unit Cost Study For Commercial-Scale Sediment Melter Facility. This work was necessary to fulfill the requirements of the U.S. EPA's Quality Assurance Project Plan ("QAPP") as part of their reporting of the pilot sediment melter. The activities leading to this report are in conjunction with the Glass Aggregate Feasibility Study under the agreement between Minergy and the Department dated September 21, 2000, (State of Wisconsin purchase order number NMJ00001936), as amended under State of Wisconsin purchase order number NMB0000488.

Minergy used a standard build-up estimating approach in performing the Cost Study. This approach used the information derived from Phases 1, 2, and 3 of the Glass Aggregate Feasibility Study, and on that basis, Minergy requested relevant cost, performance, and sizing data from equipment suppliers. With this data, the general plant flowsheet, mass & energy balance, and equipment arrangements were made. From this, estimates were done for construction and operations, and through financial modeling, a unit-cost forecast.

The base case estimates are made using a plant size of 250 glass tons per day. This size is consistent with that used elsewhere in the Glass Aggregate Feasibility Study. A sensitivity analysis is included for various sized melter projects.

This report is the result of a Cost Study and not an offer to construct a facility. The engineering performed within the scope of this study does not represent final detail. Further detail engineering and design would improve the accuracy of the Cost Study results. Notwithstanding the Department's or any other party's desire to proceed with detail engineering or the development of a commercial scale facility, Minergy nonetheless reserves the right to make final determination on Minergy's participation.

PROCESS DESCRIPTION

This section describes the process and equipment used in the base project with a capacity of 250 glass tons per day. The facility is designed to melt 600 tons per day of partially dewatered river sediment that has been dredged from the Fox River.

The sediment enters the plant, is mixed with previously dried sediment to make it easier to handle, and is then dried to approximately 10% moisture. (See Drawing FVRS-PF-101 – Process Flow Diagram, Sediment Drying and Preparation, and Drawing FVRS-GA-101 – Conceptual General Arrangement, Main Processing Plant.) After the sediment is mixed with a fluxing material, it is fed into a large melter, capable of maintaining temperatures in the 2900 ^{o}F range. The sediment melts into a molten material, which drains from the melter, is quenched in a water bath, and turns into a glass aggregate. The melter is designed to produce 250 tons per day of aggregate, which will be sold for building products.

The entire process is optimized to conserve energy, reduce heat losses, and minimize labor requirements.

Sediment Preparation (pre-drying)

Sediment is dredged and hydraulically transported to the dewatering site, and mechanically dewatered by others at the site. The material is moved by front-end loader into the short-term storage/mixing area in the dryer plant. Three wet sediment mixers are installed in the dryer plant. (See Drawing FVRS-PF-101 – Process Flow Diagram, Sediment Drying and Preparation.) Each mixer has a rating of 11.3 tons per hour. Sediment, which has already been dried (total moisture content is approximately 10%), is added to the inlet of the mixer. The purpose for the mixing is to improve material handling and behavior in the dryers, by eliminating the self-agglomeration or“sticky phase” of the material. The moisture content of the sediment after mixing is approximately 39%.

Sediment Drying

After the sediment has been prepared by mixing, it is transported by enclosed conveyors to the sediment dryer (See Drawing PC1100309 – Holo-Flite Dryer.) The heat source for the dryers will be high temperature thermal oil. The sediment moisture content is reduced in the dryers from 39% to 10%. Water vapor from the drying of the sediment is exhausted to a vapor collection system, as described in *Dryer exhaust gas treatment system*, below.

Dry Sediment Storage and Dry Sediment Feed Mixer

Each drying line will have a 110-ton live bottom storage hopper, for a total of 330 tons of dry sediment storage. The dry sediment storage hopper discharges sediment to a small 9-ton surge hopper at the wet sediment mixers or to a dry sediment mixer. A 200-ton lime silo provides a supply of ground limestone to the feed mixer to work as a fluxing agent for control of the melting temperature. The dry sediment mixer will have a capacity of 9.2 tons. A conveyor will transport the material discharged form the dry sediment mixer to the melter inlet surge hopper.

Melter Feeding and Operation

A total of six chargers supply the melter with dry and fluxed river sediment. (See Drawing Q8596-006 – Melter Plan View.) The melter heats the sediment to 2500 ^{o}F to 2900 ^{o}F. The molten material exits the main melter section and enters the forehearth. The forehearth then drains the hot glass into a water-filled quench tank. The glass furnace is heated with oxy-fuel fired burners. The burners are supplied by the fuel rails. Oxygen is provided by an on-site oxygen generation plant. Hot exhaust gas generated by the melter is exhausted into a hot gas heat recovery system and air quality control system (AQCS) prior to the exhaust stack.

Melter Quench Tank

The quench tank is water-filled, and receives the hot glass flow from the melter. The direct contact of the hot gas with the water will cause the material to solidify and fracture into the glass aggregate product. A set of screws will withdraw, dewater and transport the material to an adjacent storage pile. The quench tank will be in a closed cooling water loop. The quench tank temperature will be maintained by constant circulation of water through a set of heat exchangers.

Melter Off-Gas Treatment

The exhaust gas from the melter exits at 2700 to 2850 ^{o}F into the exhaust flue. (See Drawing FVRS-PF-102 – Process Flow Diagram, Melter Exhaust Heat Recovery and AQCE.) The exhaust flue also receives cool exhaust gas from an exhaust gas recirculation fan, which blends the cooler and hotter gases together within the flue. The cooled flue gas enters a heat recovery/thermal oil (HRTO) unit. The HRTO heats thermal oil, which is used to supply energy to the sediment drying process. The flue gas exiting the HRTO is split into two parts. The first part is used as flue gas recirculation, and is routed back through a flue gas recirculation fan (FGR) into the blending section of the melter exhaust gas flue. The second part of the flue gas flow enters a high-energy venturi and packed tower section. The venturi section removes particulate from the exhaust, and the packed tower section removes SO_2. The water in the packed tower is in a closed recirculation loop. The packed tower operates in the condensing mode, requiring some blowdown water from the loop. Sodium hydroxide is added to the process to control pH and provide for optimum SO_2 removal.

After the exhaust gas exits the packed tower, the flue gas enters a wet electrostatic precipitator (wet ESP). This device provides additional control and is especially effective for fine particulate. The exhaust flow from the wet ESP proceeds to a carbon filter bed. The carbon filter bed provides for absorption of mercury, and can also absorb PCBs and other chlorinated organic compounds. After the exhaust gas exits the carbon absorber, the gas is exhausted through a 95-foot tall and 30-inch diameter stack.

Thermal Oil Energy Supply and Distribution System

The main purpose of the thermal oil system is to provide thermal energy to the sediment dryers for the drying process. (See Drawing FVRS-PF-104 – Process Flow Diagram, Thermal Oil Supply System.) The system consists of the following components:

(1) A thermal oil auxiliary heater, which uses natural gas to heat thermal oil. The amount of natural gas fired in the unit is a function of the dryer plant energy demand.

(2) The HRTO unit, which recovers energy from the melter hot exhaust gas.

(3) An auxiliary heat sink (AHS), which dissipates heat in the event that one or all of the sediment dryers are not operational, while the HRTO continues to recover heat from an operational melter. The AHS unit is a standard shell and tube heat exchanger. Heat will be dissipated to the circulation water system.
(4) Circulation pumps and control valves, which provide the necessary energy to force the circulation of the thermal oil at the required process conditions.
(5) A thermal oil expansion tank.
(6) A thermal oil drain tank. Both items (5) and (6) are standard features for thermal oil systems, and are necessary for proper operation and maintenance of the system.

Dryer Exhaust Gas Treatment System

The process of sediment drying forces water that is contained in the wet sediment feed to vaporize, while the sediment is in contact with the heated components of the sediment dryer. To assist in efficient removal of the water vapor, a controlled volume of sweep air is admitted into the dryer housing. (See Drawing FVRS-PF-103 – Process Flow Diagram, Dryer Off Gas Treatment.) At the opposite end of the dryer housing, the combined water vapor and sweep air are exhausted from the dryer unit. The exhaust gas passes through a mechanical collector. The mechanical collector removes a significant fraction of the sediment dust that is entrained in the water vapor/sweep air mixture that is exhausted from the dryer. The dust is collected and the material is recombined with the dry sediment in any one of the dry sediment storage silos.

To provide for a "zero emissions" design, the water vapor/sweep air mixture is introduced into a venturi scrubber and packed tower arrangement. This device is similar in function to the venturi collector and packed tower used on the melter exhaust gas treatment system. The venturi collector removes an additional fraction of entrained sediment dust from the dryer exhaust stream. The water vapor is then condensed and removed by the packed tower section of the unit. A steady stream of water is circulated from a closed cooling water loop to the top of the packed tower. The condensing process increases the water volume in the cooling loop, requiring some blowdown of water to a wastewater treatment facility.

The exhaust gas that exits the packed tower section is circulated by an exhaust fan. The entire dryer and exhaust system operates under a negative pressure condition to prevent fugitive dust emissions from the dryer casings. Since some inward air leakage is expected, a small vent stream will be split off from the exhaust fan. The exhaust stream will be directed to one of the burners on the melter. This will provide destruction of any organics in the dryer exhaust. The balance of the exhaust fan discharge is directed back to the sediment dryers as the sweep air source.

Circulating Cooling Water System

A number of systems will require a steady stream of cooling water to remove heat. All of the systems use non-contact heat exchangers to prevent contamination of the cooling water system. The cooling system is a closed system. Heat is dissipated through a mechanical draft cooling tower. Make-up water is required to recover some evaporative losses from the system. Blowdown water will need to be drained from the cooling tower to limit total dissolved solids (TDS) concentrations in the water.

Circulating water is pumped to the users by motor-driven centrifugal pumps. The major users of circulation water are:

(1) Indirect heat exchanger for exhaust gas packed tower cooling system.
(2) Indirect heat exchanger for dryer exhaust gas packed tower cooling system.
(3) Aggregate quench tank indirect cooling heat exchanger.
(4) Cooling water for the thermal oil auxiliary heat dissipation unit.
(5) Charger cooling water.
(6) Cooling water required for the oxygen generation system.

ASU Oxygen Supply

Oxygen will be generated on-site. The approximate oxygen volume needed will require the generation of 171 tons of oxygen per day. The oxygen will be generated with a technology called gaseous oxygen generation, or GOX. This technology generates oxygen at a purity of 99.5%. The oxygen is generated in the gas phase (non-cryogenic). The plant will be completely designed and constructed from the foundations up by a third party. No detailed process description is included in this scope document. The sediment drying and melting facility will need to interconnect utilities and infrastructure to the oxygen plant to minimize infrastructure development costs. The main requirement will be the supply of 4160V power from the dryer and melting facility electric substation to the ASU.

Dust Control System

All of the sediment conveyors, storage hoppers and silos will have a closed design. To prevent fugitive emissions from the conveyor systems, they will be ventilated continuously. The exhaust will be directed to a high efficiency fabric filter. All collected dust will be directed back to one of the dry sediment storage silos.

Plant Wastewater Summary

There are three sources of process wastewater for the operation. The condensate from the dryer exhaust results in a waste stream of 48 GPM. This waste stream has a wastewater loading of 1000 to 3000 ppm of total suspended solids (TSS). The suspended solids will consist of fines that are carried out of the dryers. There is a potential that PCBs are attached to the sediment particles, requiring this flow stream to be treated by the same wastewater treatment facility processing the dredged sediment.

The packed tower on the exhaust of the melter generates 15 GPM of constant blowdown. This flow stream will have high concentrations of both TSS and chemical oxygen demand (COD), and will need to be sent for additional wastewater treatment. The discharge volume and concentration levels will not require any pretreatment prior to discharge to the publicly owned treatment works (POTW).

The cooling tower generates a maximum blowdown flow of 37 GPM. This flow can be permitted as a non-contact cooling water source. If the proper permits are obtained, it is possible to either discharge the water into the stormwater sewer system or into the final effluent of the wastewater treatment facility for the dredge water.

SUMMARY OF ASSUMPTIONS

Several assumptions were made in preparing the Cost Study estimates contained in this report. These assumptions were made based on our understanding of the scope of the project at the time of the award of the Department's Purchase Order. Others were made based on equipment design features provided by suppliers and the data which was then available. Final engineering and design would address variances from the assumptions.

1. The following assumptions were made relative to incoming sediment:
   a. Previously de-watered to 50% solids
   b. Previous removal of all debris, including metal and other material greater than ¼-inch in size
   c. Received in a non-frozen state, even during winter operations
   d. Gross calorific value (GCV) of approximately 1300 Btu per pound
   e. Loss on ignition of approximately 29%
   f. Fluxing requirement of 15% lime
   g. Self-agglomeration does not occur at 39% moisture or lower
2. The following assumptions were made relative to facility permitting:
   a. No hazardous waste incinerator regulations apply
   b. Oxyfuel is best available control technology (BACT) for NO_x control
   c. Wet scrubber at 95% control is BACT for SO2
3. The following assumptions were made relative to the facility design:
   a. Facility is staffed for 24 hours per day, year-round
   b. Site soils are capable of loading to 2500 pounds per square foot
   c. No provisions have been incorporated for soil testing or boring
   d. No compactor is assumed necessary for feeding to the melter
   e. The dryers require 10 Btu per square foot per degree F
   f. Facility design will be for an industrial area
4. The following assumptions were made relative to the cost of supplies:
   a. The gas price was assumed to be $3.25 per million Btu
   b. The electricity price was assumed to be 4½ cents per kilowatt hour

c. The lime flux cost was assumed to be $25.00 per ton

d. The oxygen cost is assumed to be 6 cents per hundred cubic feet from a 3rd party

5. No provisions were included for the following items:

a. Salvage/removal at the end of the plant's economic life

b. Dredging, dewatering, and delivery of cake solids

c. Hedges or other financial instruments on commodity prices

d. Site development costs other than those explicitly listed

e. Financing costs during and after plant construction and working capital requirements

COST SUMMARIES

Capital Costs

The cost to build the melter facility is estimated to be approximately $36,800,000. (See Table 1 – Projected Capital Costs.) The primary equipment costs include the melter ($7,500,000, installation included), the material handling system ($3,000,000), and the dryers ($2,600,000). The main building is estimated at $2,600,000 and the sediment storage building is $1,800,000. Mechanical and electrical contracting is expected to be $10,000,000.

Operating Costs

The cost to operate the melter facility is estimated to be approximately $6,800,000 annually. (See Table 2 – Projected Operating Costs.) The primary cost drivers for the facility would be labor, supplies, and fuel.

Unit Cost Analysis

Over the 15-year projected life of the facility, approximately 3.15 million tons of contaminated river sediment would be processed. The present worth of the project, assuming construction and operating costs listed above, a State of Wisconsin interest rate of 5% (used as the discount rate), and glass sales of $2 to $25 per ton, is between $84,600,000 and $106,000,000. This results in a present worth unit cost between $26.29 and $32.92 per ton. (See Table 3 – Estimated Present Worth Cost for 250 Glass Ton per Day Sediment Melting Plant.)

SENSITIVITY ANALYSIS

Overview

A series of sensitivity analyses have been performed on the base project. These analyses estimate the capital, O&M, and unit cost of melter projects of varying sizes. These costs were derived using a combination of build-up estimates, generally accepted scale factors, and operational experience. The base case project was used as a reference.

Each major capital line item was analyzed to determine the new expected values, factoring in the impacts of the larger or smaller sized plants. For example, the slope of the cost curve of a melter is rather flat because a large portion of the cost of a melter is fixed. Sediment dryer plants, in comparison, scale fairly well due to the use of multiple dryer lines for each facility (increasing or decreasing the capacity of the plant is done by using more or fewer dryer lines).

The O&M line items were also analyzed individually to determine the new expected values. These items fall into two categories: fixed and variable O&M. Variable O&M items include natural gas, oxygen, electricity, and lime flux, the consumption of which varies in proportion to the amount of processing. Fixed O&M included staffing, G&A, and maintenance, although these items were individually estimated for each plant size.

Project Sizes

The project sizes were varied as indicated:

A. 1 x 250: This is the base case project described in this report. This facility has one sediment melter rated at 250 glass tons per day and three dryers rated at 200 wet ton per day (each), along with the associated balance of plant.
B. 2 x 250: This facility has two sediment melters each rated at 250 glass tons per day and six dryers rated at 200 wet ton per day (each), along with the associated balance of plant.
C. 2 x 375: This facility has two sediment melters each rated at 375 glass tons per day and ten dryers rated at 180 wet ton per day (each), along with the associated balance of plant.

D. 1 x 100: This facility has one sediment melter each rated at 100 glass tons per day and one dryer rated at 250 wet ton per day, along with the associated balance of plant.

Sediment Storage

The sensitivity analysis included provisions for each project to operate at 240 or 350 days per year. Limiting operations to 240 days per year would coincide with the 8-month dredging season, and avoid the capital expenditure of a building to store sediment and minimize potential permitting problems with storing such material and reduce. To operate 350 days per year, a storage would be used into which one-third of the de-watered sediments would be placed during the dredging season. During the non-dredging season, the accumulated inventory would be used as feedstock to the melter plant. For each 250 glass ton per day increment of capacity, sufficient storage could be accomplished using a 60,000 square foot building. The estimated cost of such a building would be $1.8 million per 250 glass ton/day unit.

Stand-alone Facility Design

The melter projects can be designed to be stand-alone facilities or integrated into the operation of an adjacent industrial facility with which it can share resources. Integration tends to be more applicable to the smaller projects (1x100 and 1x250). It was assumed that the 1x100 project would not be feasible without integration with an existing industrial facility. The 1x250 project was studied both as a stand-alone and as integrated. The 2x250 and 2x375 plants have sufficient volume to allow full independent staffing, and therefore were studied as stand-alone.

A provision was also included to account for special foundation requirements associated with integrated projects. This is because many area industrial plants are located along shorelines with poor soil load bearing capacities.

CONCLUSION

At the beginning of the Glass Aggregate Feasibility Study, Minergy had performed some preliminary analyses that indicated a unit cost in the range of $40 - $60 per ton. The results from the Cost Study confirm those initial results.

Table 1
Projected Capital Costs for 250 Glass Ton per Day Sediment Melting Plant

Item	Cost
Melter (delivered and installed)	$ 7,511,976
Dryer (total for 3, equipment only)	$ 2,588,505
Material handling system	$ 3,019,923
Dryer off gas system equipment	$ 394,515
Thermal oil system equipment	$ 995,579
AQCE system equipment	$ 468,931
BOP equipment	$ 845,081
Utilities equipment	$ 488,383
Mechanical contractor	$ 7,886,711
Electrical contractor	$ 2,113,548
Start-up costs	$ 763,277
Main building	$ 2,634,966
Engineering	$ 5,274,684
Sediment Storage Building	$ 1,800,000
TOTAL:	$ 36,768,000

Table 2
Projected Operating Costs for 250 Glass Ton per Day Sediment Melting Plant

Item	Annual Cost
Gas	$1,315,860
Electricity	$1,086,750
Labor	$2,125,000
Supplies	$1,612,310
Lime Flux	$447,125
G&A	$257,000
TOTAL:	$6,844,045

Table 3
Estimated Present Worth Cost for 250 Glass Ton per Day Sediment Melting Plant

Assumptions:		
Project life =	15	years
Interest rate =	5.0%	
Days per Year =	350	
Sediment processing rate =	613	tons daily
Total sediment processed =	3,218,250	tons over project life
Construction costs =	$36,768,000	
Operating costs =	$6,844,000	annually
Income from glass sales =	$2 - $25	per ton of glass sold
Glass production rate =	255	tons daily

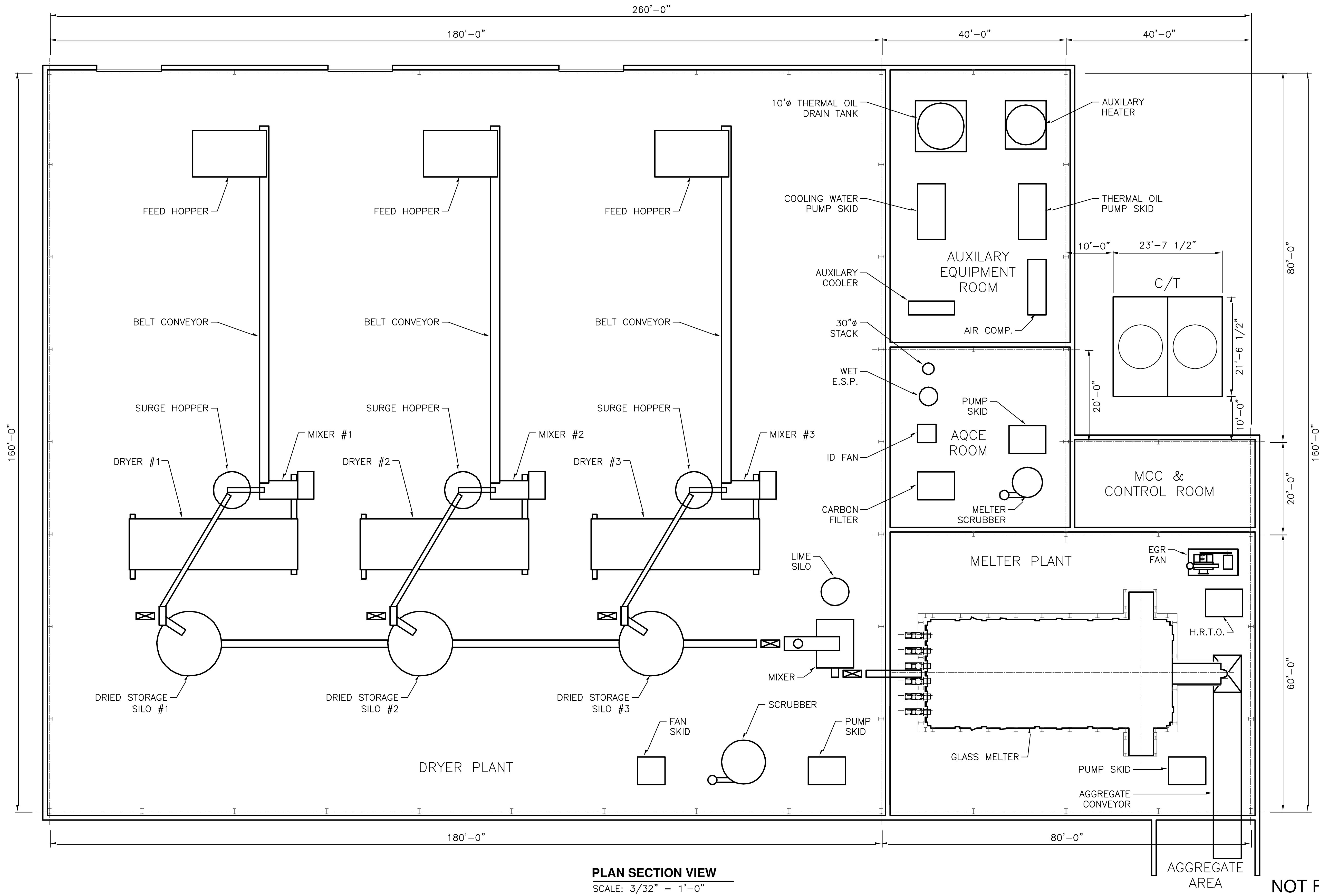
Estimated Costs:	**Initial Costs**	**Net Annual Costs**
Construction costs	$36,768,000	
Operating costs with no glass sales		$6,844,000
Operating costs minus glass income at $2/ton		$6,665,208
Operating costs minus glass income at $25/ton		$4,609,104

Total Present Worth Cost of Project:	
No glass sales	$107,806,380
With glass sales at $2/ton	$105,950,583
With glass sales at $25/ton	$84,608,925

Unit Costs (Per Ton of Sediment Processed):	
No glass sales	$33.50
With glass sales at $2/ton	$32.92
With glass sales at $25/ton	$26.29

Table 4
Summary of Sensitivity Options
Sediment Melting Plant

	1x100 Integrated No Storage	1x100 Integrated Storage	1x250 Integrated No Storage	1x250 Integrated Storage	1x250 Standalone No Storage	1x250 Standalone Storage	2x250 Standalone No Storage	2x250 Standalone Storage	2x375 Standalone No Storage	2x375 Standalone Storage
Daily capacity (tons)	240	240	613	613	613	613	1,226	1,226	1,840	1,840
Days/yr Operation	240	350	240	350	240	350	240	350	240	350
Project Life (years)	15	15	15	15	15	15	15	15	15	15
Sediment Processed (million tons)	0.86	1.26	2.21	3.22	2.21	3.22	4.41	6.44	6.62	9.66
Capital ($million)	25.50	26.25	36.99	38.79	34.97	36.77	63.19	66.79	87.39	92.79
Annual O&M ($million)	2.30	2.76	4.73	6.13	5.44	6.84	9.29	12.17	12.57	16.74
NPV before Glass Sales ($million)	49.35	54.86	86.04	102.40	91.44	107.81	159.58	193.16	217.88	266.50
Unit Cost (assuming $2 Glass) (dollars per ton of wet cake)	**$ 56.54**	**$ 42.96**	**$ 38.41**	**$ 31.24**	**$ 40.86**	**$ 32.92**	**$ 35.58**	**$ 29.43**	**$ 32.32**	**$ 27.01**
Unit Cost (assuming $25 Glass) (dollars per wet ton of cake)	**$ 49.91**	**$ 36.33**	**$ 31.78**	**$ 24.61**	**$ 34.23**	**$ 26.29**	**$ 28.95**	**$ 22.80**	**$ 25.68**	**$ 20.38**



PLAN SECTION VIEW

SCALE: 3/32" = 1'-0"

CONFIDENTIAL
NOT FOR CONSTRUCTION

Rev. No.	Revision Description	Date	Drwn.	Chk'd
0	Issue for Review	11/28/01	RDK	TJB

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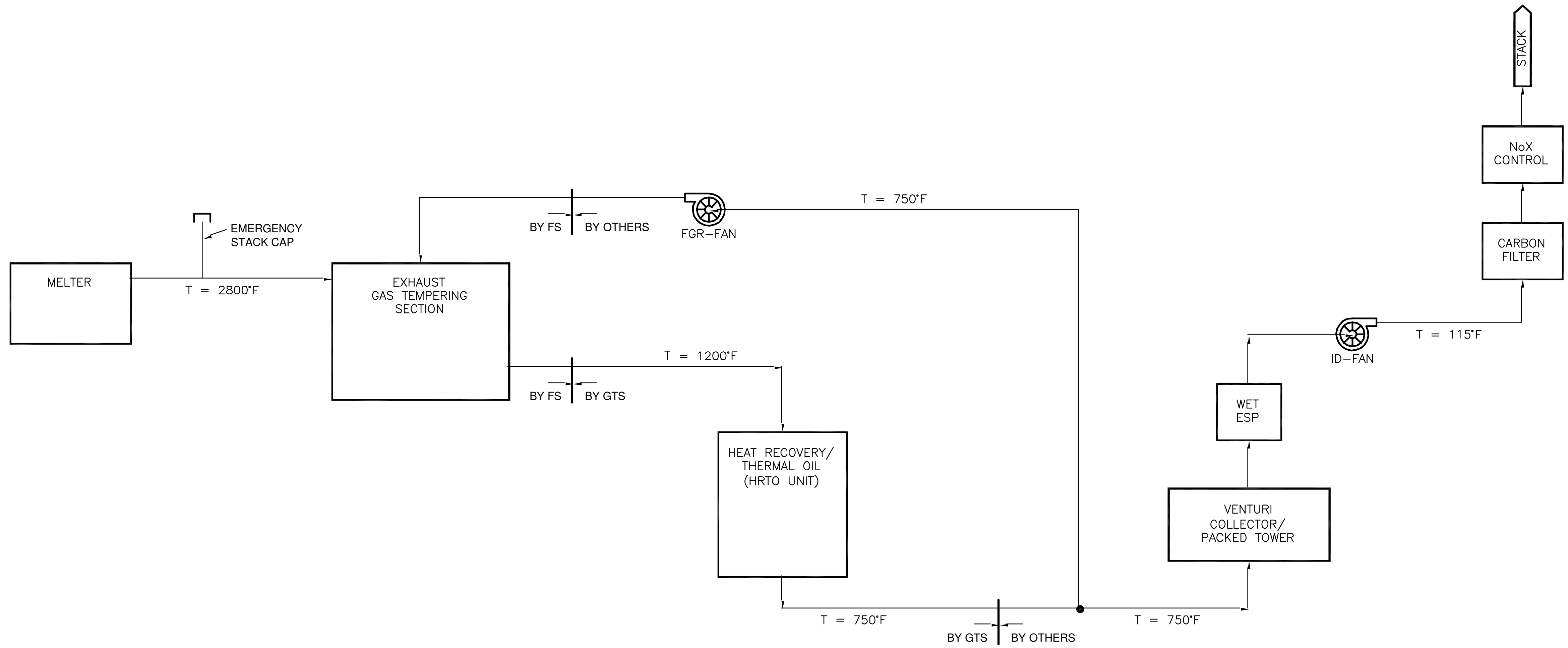
1512 S. Commercial St., Neenah, WI 54956

Conceptual General Arrangement
Main Processing Plant
Plan View At Grade Elevation (0'-0")
Fox Valley River Sediment

Date: December 2001
Drawing No.: FVRS-GA-101
Rev.: 0
Scale: As Shown



Rev. No.	Revision Description	Date	Drwn.	Chk'd

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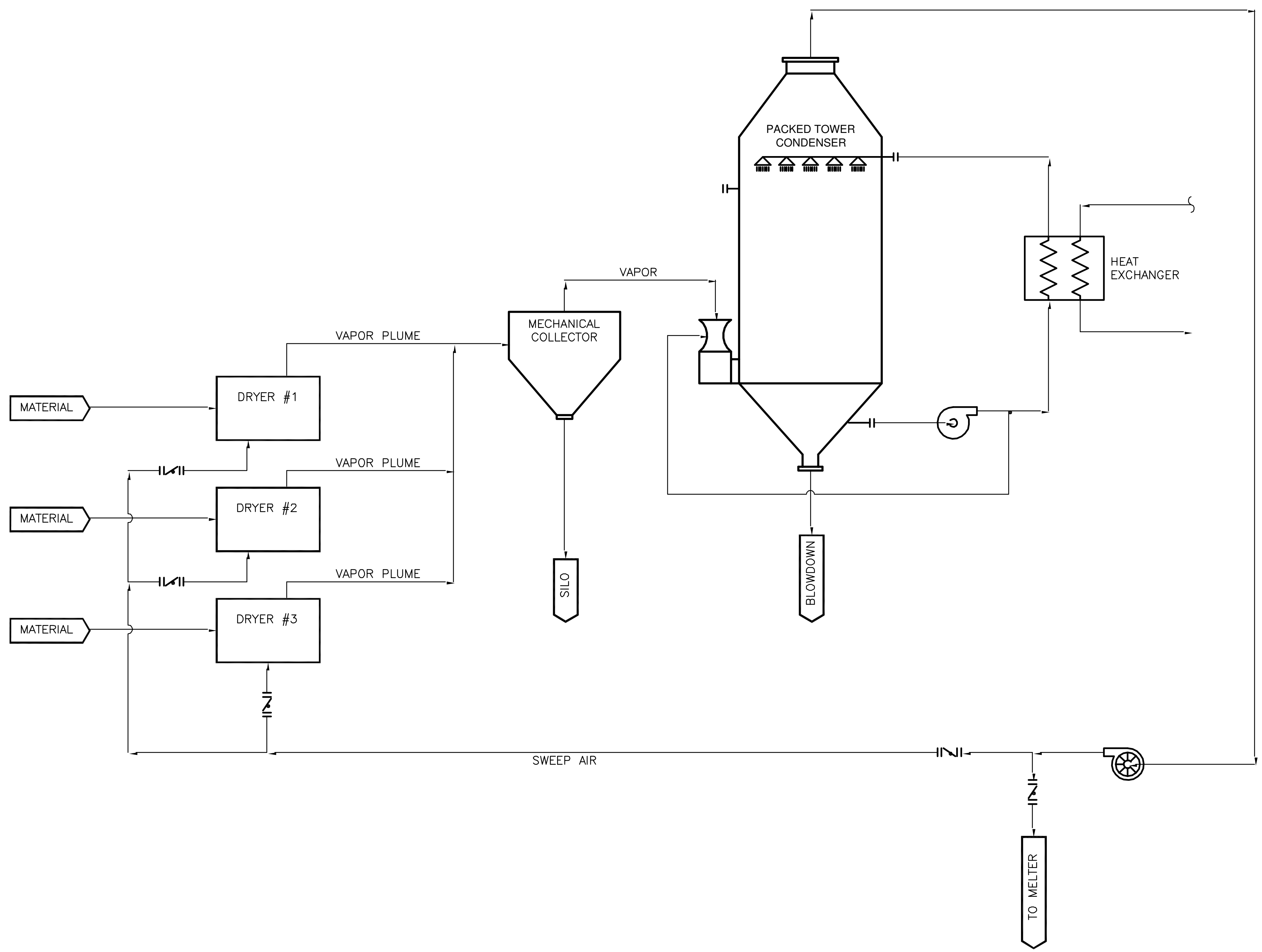
Process Flow Diagram
Melter Exhaust Heat Recovery & AQCE
250 Glass Ton Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No.: FVRS-PF-102
Rev.: 0



Rev. No.	Revision Description	Date	Drwn.	Chk'd

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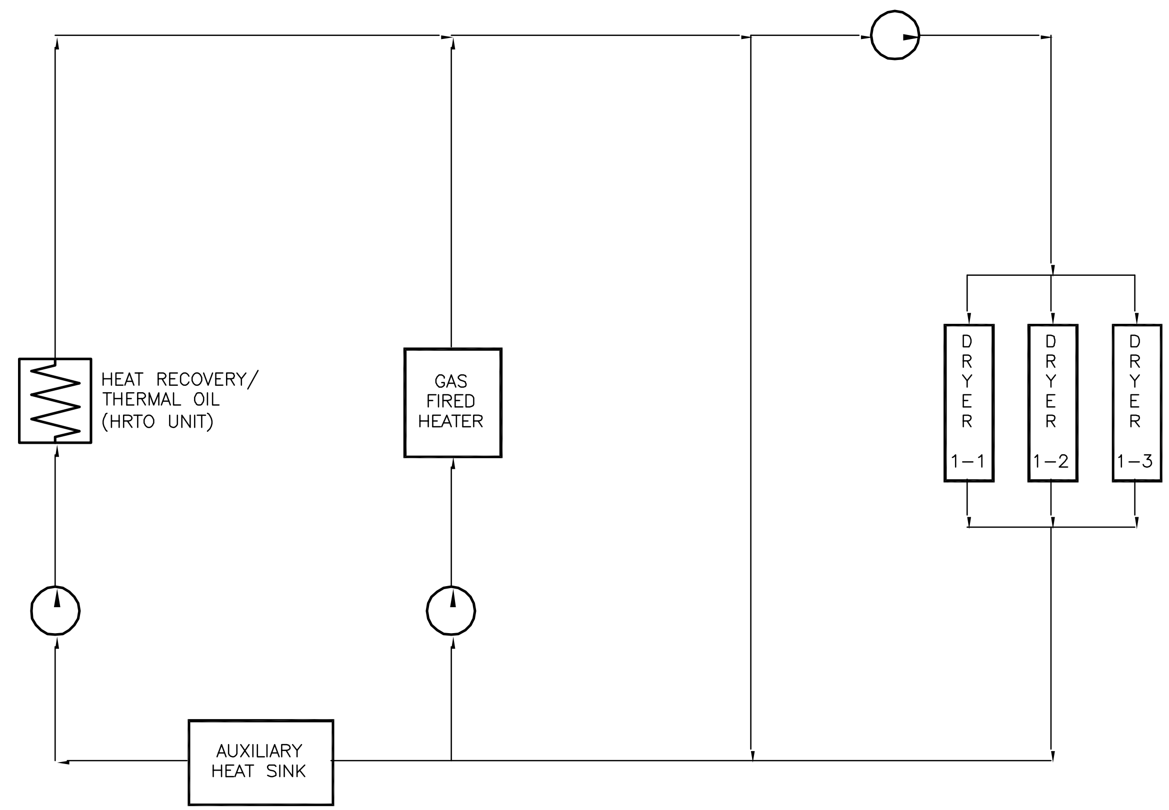
Process Flow Diagram
Dryer Off Gas Treatment
250 Glass Ton Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No.: FVRS-PF-103
Rev.: 0



Rev. No.	Revision Description	Date	Drwn.	Chk'd

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Process Flow Diagram
Thermal Oil Supply System
250 GlassTon Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No. FVRS-PF-104
Rev. 0

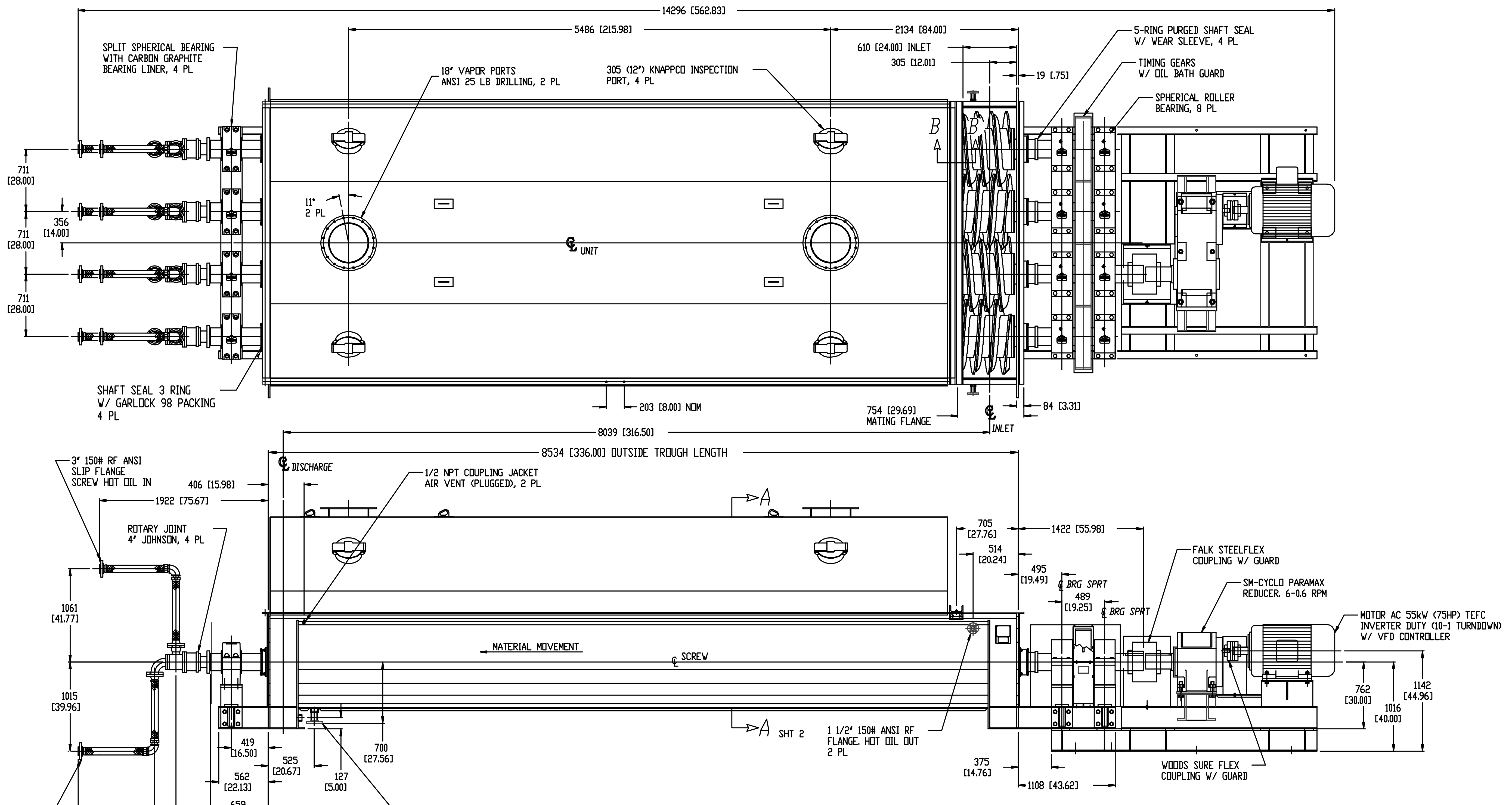
A	.	INITIAL DRAWING RELEASE

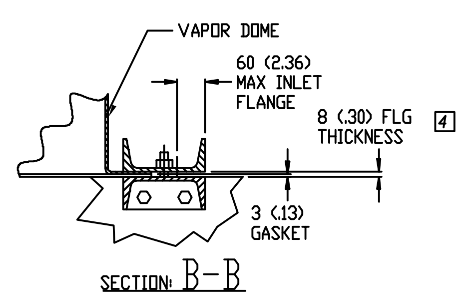
ALL DIMENSIONS ARE MILLIMETERS.

GENERAL ARRANGEMENT DRAWING TOLERANCES, ISO 2768-1, CLASS DESIGNATION COARSE (C)
VALUES SMALLER THAN THOSE LISTED BELOW TO BE NOTED NEAR DIMENSION ON FIELD OF DRAWING.

ALL DIMENSIONS ARE MILLIMETERS.

PERMISSIBLE DEVIATIONS FOR LINEAR DIMENSIONS, BASED ON LENGTH L (mm).										PERMISSIBLE DEVIATIONS FOR EXTERNAL RADII AND CHAMFER HEIGHTS, (mm).			PERMISSIBLE DEVIATIONS OF ANGULAR DIMENSIONS, USE SHORTER SIDE OF THE ANGLE L (mm).				
0.5 ≤L ≤3	3 ≤ L ≤ 6	6 < L ≤ 30	30 < L ≤120	120 < L ≤400	400 < L ≤1000	1000 < L ≤2000	2000 < L ≤4000	4000 < L ≤8000	8000 < L ≤12000	0.5 ≤L ≤3	3 < L ≤ 6	6 < L	L ≤ 10	10 < L ≤50	50 < L ≤120	120 < L ≤400	400 < L
± 0.2	± 0.3	± 0.5	± 0.8	± 1.2	± 2	± 3	± 4	± 5	± 6	± 0.4	± 1	± 2	± 1° 30′	± 1°	± 0° 30′	± 0° 15′	± 0° 10′





SECTION: B-B

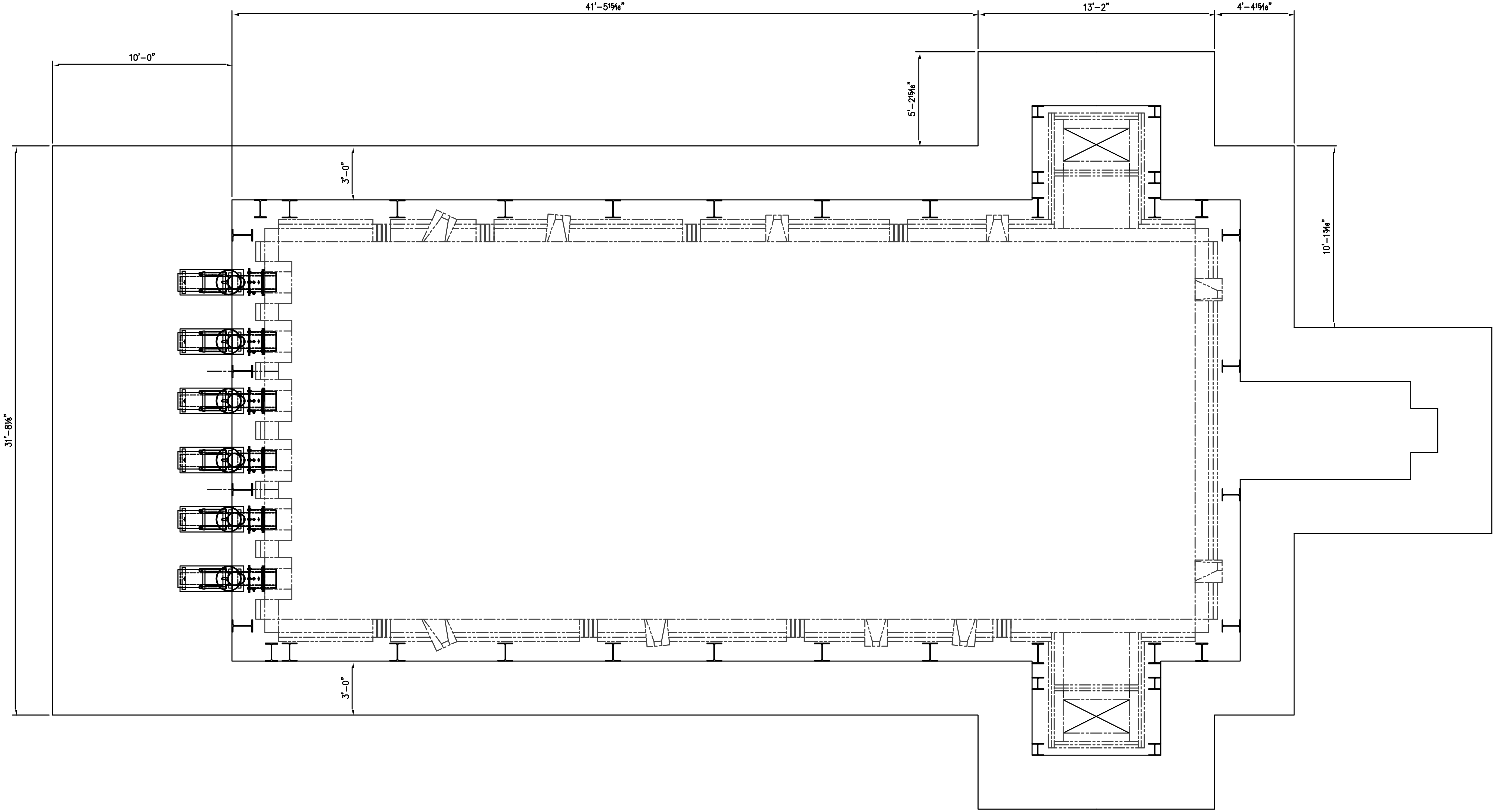
PRELIMINARY
NOT FOR CONSTRUCTION

No req.	Item no.	Part no.	Description	Material	Drawing	Mass kg each
.	.	.	.	.	.	.

Description: HOLO-FLITE DRYER-HOT OIL Q3628-8 GED A36 DIRECT 55 kw(75 hp) 6-0.6 RPM

Drawn: J. ANDERSON	Date: 6NOV01
Checked: D. CLEAR	Date: .
Approved: J. KRAMER	Date: .
Reference Dwg: .	

Projection: 3rd angle	File name: PC1100309-1	Scale: 1:22	Revision: A
	Size: A1	Drawing number: PC1100309	Sheet: 1



FRAZIER-SIMPLEX, INC. Engineers

ENGINEERS & CONSULTANTS TO THE GLASS & STEEL INDUSTRIES SINCE 1918.

250 TPD
GENERAL ARRANGEMENT
STEEL PLAN VIEW
FOR : MINERGY
WISCONSIN

DRAWN	DATE	FILE	CAD FILE
MPH	6/21/01		WIQ8596/Q8596-006
ENGINEER	SCALE 3/8"=1'-0"	DRAWING NO.	
CHK'D	CONTRACT 8596	Q8596-006	

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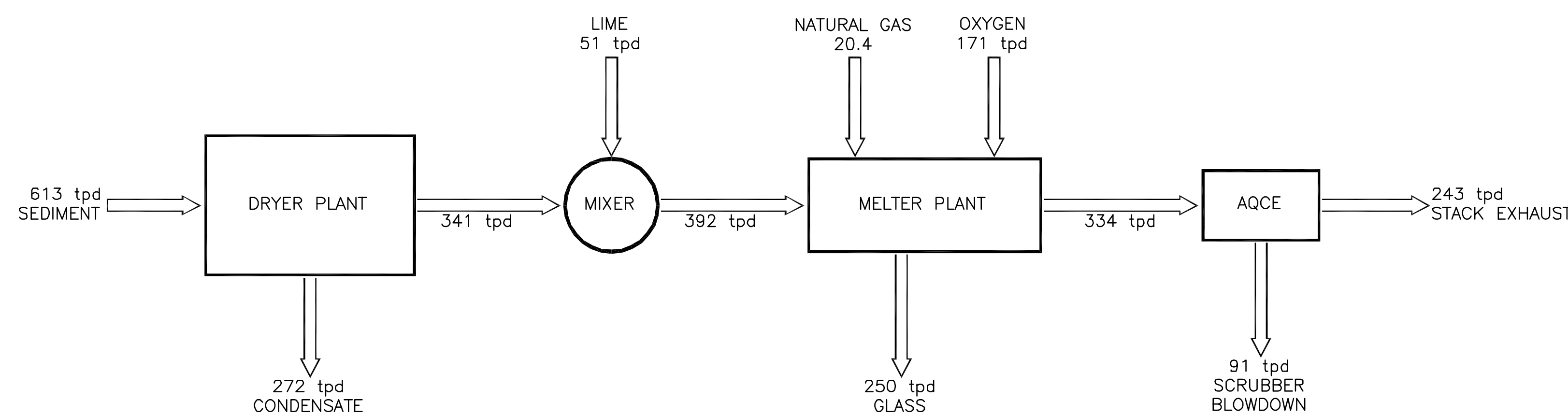

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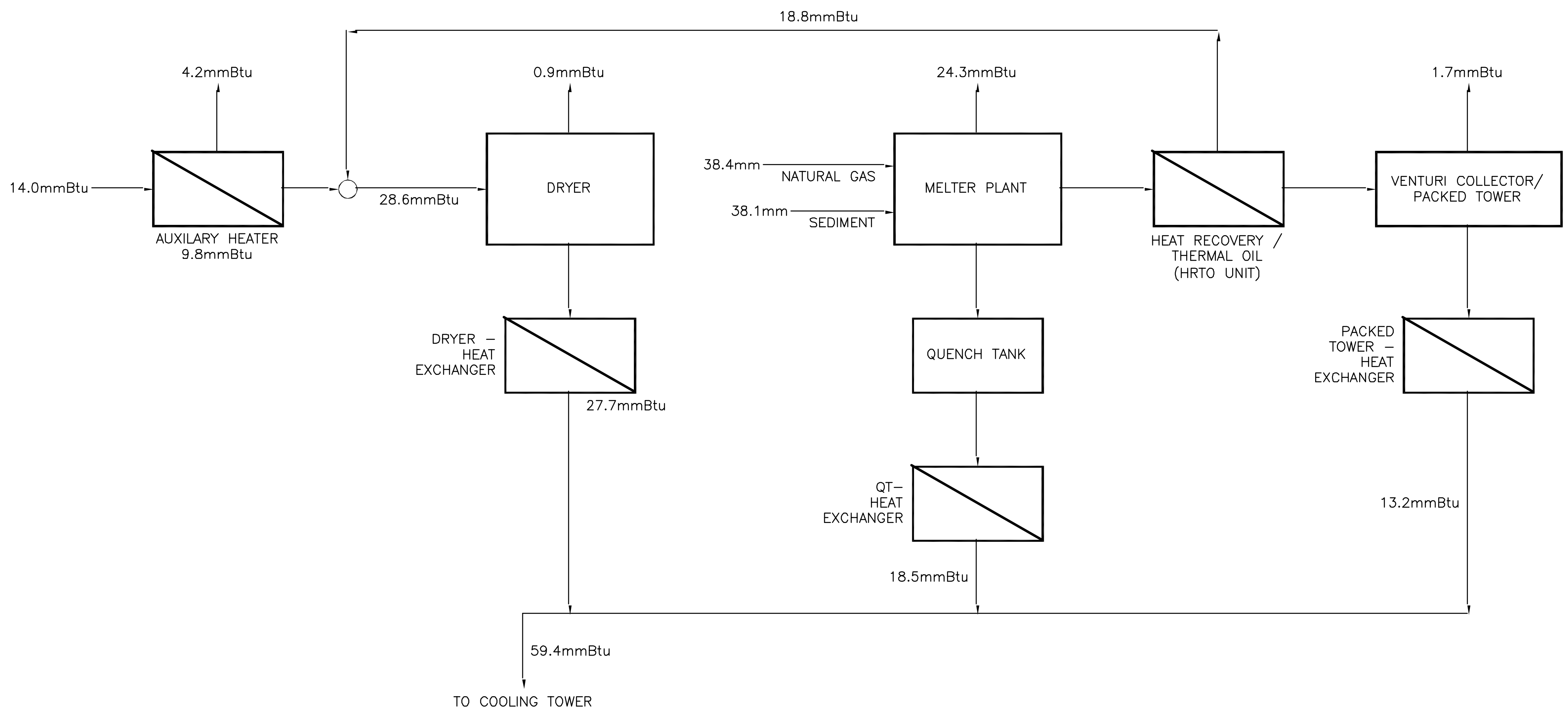
Mass Balance

250 Glass Ton Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No.: FVRS-MB-101
Rev.: 0



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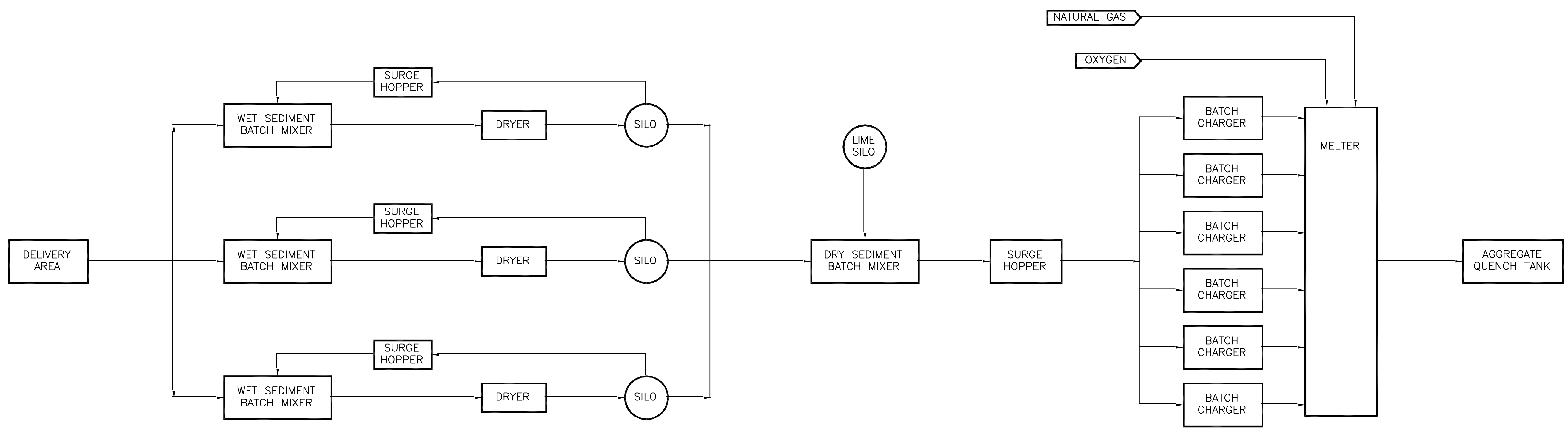
Energy Balance

250 Glass Ton Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No.: FVRS-EB-101
Rev.: 0



LEGEND:
mc = MOISTURE CONTROL
tpd = TONS PER DAY
ts = TOTAL SOLIDS CONTENT

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Process Flow Diagram
Sediment Drying and Preparation
250 Glass Ton Plant
Fox Valley River Sediment

Date: December 2001
Scale: None
Drawing No.: FVRS-PF-101
Rev.: 0

January 21, 2002

Mr. Robert Paulson
Wisconsin Department of Natural Resources
101 South Webster
P.O. Box 7921
Madison, WI 53707

Dear Sirs:

Subject: Permitting Feasibility – Sediment Melter Plant

Minergy Corp. has performed an analysis regarding the permitting feasibility of a commercial-scale sediment melter.

A full scale 250 glass ton per day melting facility emissions were based on values measured from the demonstration testing. Using good engineering practice, the results were extrapolated to commercial scale, and compared the results against the Wisconsin Administrative Code air regulations (NR400 series).

The expected emissions from a full scale operations would be very low, including a stack-basis destruction of PCBs of greater than 99.9999%. The facility would meet all current air state and federal emissions regulations. The expected annual emissions would not trigger the major source threshold. A discussion of the results of the analysis are listed below.

Background

During the week of August 14, 2001 a project team consisting of the Department, the U.S. EPA, Minergy Corp., Tetra Tech EMI, and EER Environmental conducted demonstration scale testing on a 2 glass ton per day demonstration melter. The project objectives and detailed testing procedures were included by the Quality Assurance and Project Plant (QAPP) which was developed and approved by the USEPA prior to the commencement of the testing.

The primary objective of the testing is "To determine the treatment efficiency (TE) of PCBs in dredged-and-dewatered sediment when processes in the Minergy GFT". To achieve the objectives the testing included sampling the feed material (contaminated sediment) to the melter, the finished product, and melter stack emissions for PCBs and other Contaminants of Concern (COC's). Demonstration scale air quality control equipment (AQCE) was also furnished and operated during the testing. The AQCE includes a wet scrubber and a carbon filter.

The data validation was completed by January 5, 2002 and the USEPA has released the data. This letter will review the data, and will make emissions projections to a full scale projection melter. The full scale facility is presently assumed to be a 250 glass ton per day operation. The emissions will be compared to the standards in the Wisconsin administrative code (NR400 series regulations) to determine the feasibility of permitting a full scale facility.

<u>PCB emissions</u>
Exhaust gas emissions were sampled on the demonstration unit before and after the air quality control equipment. PCB concentrations were measured using high resolution gas chromatography / high resolution mass spectrometry. The instrument has the capability of detecting PCBs to extremely low levels. The detection limit for most PCB congeners was 1.00 nanogram (10^{-9} gram). The controlled emissions were measured at an average of 36.6 ng/DSCM.

The full scale unit will have a exhaust gas flow of 4,940 DSCM per hour. The annual PCB emissions in the stack would equate to 1.58 grams per year or 0.0035 pounds per year. This is only 3.5 % of the Wisconsin Administrative Code section NR-445 table 3 values for PCB emissions. In summary, no additional study for the economic and technical feasibility for additional controls will be necessary at this emission level. A full scale facility producing 250 glass tons per day would process 341 tons per day of sediment (dry basis). With an average feed concentration of 28,000 ng/g of total PCBs into the melter the annual input of pure PCBs would be 6,983 pounds. On a stack emission basis this results in a PCB destruction of 99.999949%.

The annual PCB emissions projected above may be over-estimated for at least two reasons. First, during the demonstration, the water cooled extraction probe required frequent manual cleaning, causing a significant risk of contamination. Second, the full scale facility will have a significant increase in exhaust gas residence time over the demonstration scale. The demonstration scale glass melter had an average residence time for the exhaust gases of 2.1 seconds. The full scale is expected to have a residence time of approximately 16 seconds. The additional residence time will tend to increase the destruction of PCBs.

<u>Mercury emissions</u>
Mercury emissions were measured both before and after air quality control equipment. It is clear from the data that mercury removal is occurring in the AQCE equipment. The final melter exhaust emissions were measured at 1.924 ug/DSCM. This equates to 0.1834 lbs/year pounds per year of stack emissions for a full scale unit. The NR446 standard for mercury emissions is expressed as an ambient air concentration of 1.0 ug/m^3, and a mass limit of 3200 grams per day. The expected ambient air concentration for a full scale plant is 0.00011 ug/m^3, and a daily mass emissions of 0.228 g/day. The above ambient air concentrations are based on a 95' tall stack with a 3' inside diameter.

<u>Other HAP emissions</u>
The stack was also sampled for Silver, Arsenic, Barium, Cadmium, Chromium, Lead and Selenium. Testing was performed both before and after the AQCE. The above metals were not detected in the exhaust gas stream after the air quality control equipment for all 3 samples taken. It is not expected that the above metals will be an issue in the air permitting process.

Sampling and laboratory analysis for a total of 63 Semi-volatile organic compounds (SVOC) was conduced as part of the demonstration test. USEPA method 10 was used. The only semi volatile compound detected was Benzoic acid. The annual emissions for a full scale unit is projected at 2.37

pound per year. This compound is NOT listed as a hazardous air pollutant under the Wisconsin administrative code.

Sampling and laboratory analysis for a total of 51 specific Volatile organic compounds (VOC's) was conduced as part of the demonstration test. USEPA method 31 was used. None of the 51 specific VOC's were detected on any of the runs.

Sampling and laboratory analysis was also conducted for Polychlorinated Dibenzo Dioxins and Furans (PCDD/Fs). 2,3,7,8-TCDD is listed in the Wisconsin administrative codes hazardous pollutants listing in NR-445. No 2,3,7,8-TCDD was detected in the final exhaust after the air quality control equipment. Some PCDD/F's were detected in the exhaust gases prior to the air quality control equipment, however PCDD/F's were clearly present in the sediment feed material. The dioxin destruction factor on a toxic equivalency (TEQ) basis was 99.9894%. This type of a destruction factor provides a strong indication that post combustion reformation of PCDD/F was not occurring in the process.

<u>NOx Emissions</u>
High temperature thermal processes are usually associated with the formation of NOx (a combination of NO and NO_2.) During the demonstration testing a continuous emissions monitor (CEM) for NOx was connected to the melter exhaust. NOx emissions averaged 2450 ppmdv during the duration of the testing. The designers of the demonstration melter have seen a strong correlation between NOx emissions and melter scale up, with NOx emissions decreasing as melter capacity increases. At this time, the supplier estimates full-scale emissions of 1200 ppmdv. The resulting annual emissions will be 109.4 tons per year. This quantity is below the major source threshold of 250 tons per year established in chapter NR405 of the State regulations. If it is later determined that the emissions are not acceptable, additional end of pipe controls can be added to reduce NOx emissions by up to 90%.

<u>SO_2 emissions</u>
Traces of sulfur can be found in the dredged sediment. The sulfur is converted to SO_2 in the high temperature oxidizing environment inside the melter. During the demonstration testing a continuous emissions monitor (CEM) for SO_2 was connected to the melter exhaust. The efficiencies of SO_2 control equipment are well established and are accepted by the USEPA and WDNR. The expected full scale facility SO_2 emissions are 44.41 tons per year assuming a typical wet scrubber with 93% removal efficiency. This quantity is below the major source threshold.

<u>CO emissions</u>
The production of CO is associated with the incomplete thermal oxidization of organic materials. During the demonstration testing a continuous emissions monitors (CEM) for CO was connected to the melter exhaust. The CO emissions during the demonstration test were 3.3 ppm. The expected full scale facility CO emissions are 0.18 tons per year. This quantity is below the major source threshold.

<u>VOC emissions</u>

Much like CO the production of VOC's (Volatile Organic Compounds) is associated with the incomplete thermal oxidization of organic materials. During the demonstration testing a continuous emissions monitor (CEM) for VOC's was connected to the melter exhaust. This emissions monitor detects all VOC's; however, it is unable to identify specific compounds like USEPA method 10 and 31 discussed in the HAP Emissions section above. The VOC emissions during the demonstration test was 2.3 ppm. The expected full scale facility VOC emissions are 0.07 tons per year. This quantity is below the major source threshold.

Particulate Matter

Equipment vendors guarantee 0.01 grain per DSCF of exhaust gas for particulate control equipment. The resulting full scale emissions result in 1.09 tons per year. This quantity is below the major source threshold.

Summary of Emissions

The following is a summary of emissions from a 250 glass ton per day river sediment melter exhaust.

Air pollutant	Annual potential to emit	Unit of measure
Particulate	1.09	Tons per year
Sulfur dioxide	44.41	Tons per year
Organic compounds	0.07	Ton per year
Carbon monoxide	0.18	Ton per year
Nitrogen oxides	109.4	Tons per year
Mercury	0.183	pound per year
PCBs	0.0035	pound per year

Conclusion

A commercial-scale sediment melter facility appears to be fully permittable under Federal and Wisconsin regulations.

Please contact me at (920) 727-1411 if you have any questions.

Sincerely,

Terrence W. Carroll
Regional Manager

Appendix H

Detailed Cost Estimate Worksheets

Table 7-4 Cost Summary for Remedial Alternatives - Little Lake Butte des Morts

125 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,689,173	16,165	$37,700,000	---	---	$3,200,000	$1,900,000	---	---	$184,200,000	$4,500,000	$231,500,000	$46,300,000	$277,800,000
C2	1,689,173	16,165	$37,700,000	---	---	$36,200,000	$2,100,000	---	---	$45,700,000	$4,500,000	$126,200,000	$25,240,000	$151,440,000
D	1,689,173	16,165	$36,700,000	$1,700,000	---	---	$2,100,000	---	$69,300,000	$1,700,000	$4,500,000	$116,000,000	$23,200,000	$139,200,000
E	1,689,173	16,165	$37,700,000	---	---	$3,200,000	$1,900,000	$69,900,000	---	---	$4,500,000	$117,200,000	$23,440,000	$140,640,000
F	1,253,873	16,165	$32,300,000	$1,700,000	$33,600,000	---	$1,800,000	---	$69,300,000	$2,000,000	$4,500,000	$145,200,000	$29,040,000	$174,240,000

250 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,322,818	16,165	$32,000,000	---	---	$3,200,000	$1,600,000	---	---	$144,300,000	$4,500,000	$185,600,000	$37,120,000	$222,720,000
C2	1,322,818	16,165	$32,000,000	---	---	$28,400,000	$1,800,000	---	---	$35,800,000	$4,500,000	$102,500,000	$20,500,000	$123,000,000
D	1,322,818	16,165	$31,000,000	$1,700,000	---	---	$1,800,000	---	$69,300,000	$2,000,000	$4,500,000	$110,300,000	$22,060,000	$132,360,000
E	1,322,818	16,165	$32,000,000	---	---	$3,200,000	$1,600,000	$54,700,000	---	---	$4,500,000	$96,000,000	$19,200,000	$115,200,000
F	999,117	16,165	$27,900,000	$1,700,000	$31,600,000	---	$1,600,000	---	$69,300,000	$2,000,000	$4,500,000	$138,600,000	$27,720,000	$166,320,000

500 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,023,621	16,165	$27,000,000	---	---	$3,200,000	$1,400,000	---	---	$111,700,000	$4,500,000	$147,800,000	$29,560,000	$177,360,000
C2	1,023,621	16,165	$27,000,000	---	---	$22,000,000	$1,600,000	---	---	$27,700,000	$4,500,000	$82,800,000	$16,560,000	$99,360,000
D	1,023,621	16,165	$26,000,000	$1,700,000	---	---	$1,600,000	---	$69,300,000	$2,000,000	$4,500,000	$105,100,000	$21,020,000	$126,120,000
E	1,023,621	16,165	$27,000,000	---	---	$3,200,000	$1,400,000	$42,400,000	---	---	$4,500,000	$78,500,000	$15,700,000	$94,200,000
F	771,564	16,165	$23,700,000	$1,700,000	$28,700,000	---	$1,400,000	---	$37,300,000	$2,000,000	$4,500,000	$99,300,000	$19,860,000	$119,160,000

1000 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	784,192	16,165	$22,100,000	---	---	$3,200,000	$1,300,000	---	---	$85,600,000	$4,500,000	$116,700,000	$23,340,000	$140,040,000
C2	784,192	16,165	$22,100,000	---	---	$16,900,000	$1,400,000	---	---	$21,300,000	$4,500,000	$66,200,000	$13,240,000	$79,440,000
D	784,192	16,165	$21,100,000	$1,700,000	---	---	$1,400,000	---	$37,300,000	$2,000,000	$4,500,000	$68,000,000	$13,600,000	$81,600,000
E	784,192	16,165	$22,100,000	---	---	$3,200,000	$1,300,000	$32,500,000	---	---	$4,500,000	$63,600,000	$12,720,000	$76,320,000
F	635,547	16,165	$20,100,000	$1,700,000	$23,600,000	---	$1,300,000	---	$37,300,000	$2,000,000	$4,500,000	$90,500,000	$18,100,000	$108,600,000

5000 ppb

Alternative	Dredge Volume (cy)	TSCA Dredge Vol. (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	281,689	16,165	$8,900,000	---	---	$3,200,000	$1,000,000	---	---	$30,900,000	$4,500,000	$48,500,000	$9,700,000	$58,200,000
C2	281,689	16,165	$8,900,000	---	---	$6,100,000	$1,100,000	---	---	$7,700,000	$4,500,000	$28,300,000	$5,660,000	$33,960,000
D	281,689	16,165	$7,900,000	$1,700,000	---	---	$1,100,000	---	$37,300,000	$2,000,000	$4,500,000	$54,500,000	$10,900,000	$65,400,000
E	281,689	16,165	$8,900,000	---	---	$3,200,000	$1,000,000	$11,700,000	---	---	$4,500,000	$29,300,000	$5,860,000	$35,160,000
F	222,635	16,165	$8,000,000	$1,700,000	$11,700,000	---	$1,000,000	---	$37,300,000	$2,000,000	$4,500,000	$66,200,000	$13,240,000	$79,440,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE LAKE BUTTE DES MORTS
Action Level - 125 ppb

Material Handling Assumptions:							
Volume > 125 ppb	1,689,173	cy	761	ac	1,289,445	m3	Acres corresponds to dredge
Volume > 250 ppb	1,322,818	cy			1,009,785	m3	footprint area
Volume > 500 ppb	1,023,582	cy			781,360	m3	
Volume > 1,000 ppb	784,192	cy			598,620	m3	
Volume > 5,000 ppb	281,689	cy			215,030	m3	
Volume > 50,000 ppb	16,165	cy			12,340	m3	
Solids Specific Gravity	2.51						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.3%	v/v	0.99	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density (passive pond)	20%	w/w	9.1%	v/v	0.96	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	28.5%	v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.8%	w/w	60.0%	v/v	1.35	tons per cy	
Arrowhead/Menasha CDF Capacity	1,406,932	cy	in situ		1,337,963	m3	
HTTD Treatment Capacity	1,099,327	cy	in situ		1,650,000	tons	
Cap Volume	435,300	cy			332,290	m3	
Vitrification Treatment Capacity	4,496,073	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						Not Used
Sales Tax	5.5%						
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman (Oct 11, 2000)
Site Restoration	$600,000	per dredge launch site					pj
Mechanical - 3 cy bucket							
Dock Construction	$400,000	LS					pj
Mobilization - Equipment	$455,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$9,000	per shift					Ogden Beeman
Dredge Rate	630	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					pj
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Offload Crane Mobilization	$50,000	LS					pj
Site Restoration	$75,000	LS					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Vitrification (unit cost incl Cap and Op Costs)	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	9,322,396	sf	866,100			m2	
Sand Cap Depth	1.7	feet					
Sand Placement	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area	644,791	sf	14.80				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,212	lf	802.9890256				assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Alphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate (passive dewatering)	395	gpm					assume operate 24/7
Unit, Purchase (passive dewatering)	$691,096	LS					pj
Flow Rate (mechanical dewatering)	484	gpm					
Unit, Purchase (mechanical dewatering)	$781,094	LS					
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample/day
Disposal							
Off-Site Disposal							
Load Soil for Hauling	$2.80	per ton					pj
Round-trip Hauling	2	hours					pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours					pj
Tipping Fee (non-TSCA)	$43	per ton					St. Paul
Tipping Fee (TSCA)	$55	per ton					St. Paul
Truck Rate	$75	per hour					pj
Truck Load	32	tons					pj
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Off-site Disposal (Passive Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	761	acre		$12,176,000
Dredging - 12 hour shifts	1609	Day	12.37692308	$9,171,300
Dredge Monitoring (Water Quality)	1609	Day		$4,827,000
Sediment Removal QA	1609	Day		$1,930,800
Site Restoration	2	Each		$1,200,000
Direct Capital:				$29,675,100
Engineering, Procurement & Construction Management:				3,561,012
Contractor Overhead/Profit:				4,451,265
Total Capital:				**$37,700,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	1,280,733,951	gal	$512,294
Water Treatment QA	2,253	day	$450,600
Direct Capital:			$1,653,989
Engineering, Procurement & Construction Management:			198,479
Total Capital:			**$1,900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	2,015,159	ton		$50,378,975
Lime Purchase	201,516	ton		$12,090,960
Soil Loading	2,015,159	ton		$5,642,445
Soil Hauling	2,015,159	ton		$9,446,058
Tipping Fees (non-TSCA)	1,995,874	ton		$85,822,578
Tipping Fees (TSCA)	19,285	ton		$1,060,680
Direct Capital:				$164,441,696
Engineering, Procurement & Construction Management:				19,733,004
Total Capital:				**$184,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$231,500,000**

ALTERNATIVE C2: Dredge Sediment With Off-site Disposal (Mechanical Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	761	acre		$12,176,000
Dredging - 12 hour shifts	1609	Day	12.37692308	$9,171,300
Dredge Monitoring (Water Quality)	1609	Day		$4,827,000
Sediment Removal QA	1609	Day		$1,930,800
Site Restoration	2	Each		$1,200,000
Direct Capital:				$29,675,100
Engineering, Procurement & Construction Management:				3,561,012
Contractor Overhead/Profit:				4,451,265
Total Capital:				**$37,700,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	403,032	bdt	$32,242,544
Direct Capital:			$32,342,544
Engineering, Procurement & Construction Management:			3,881,105
Total Capital:			**$36,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	1,570,606,822	gal	$628,243
Water Treatment QA	2,253	day	$450,600
Direct Capital:			$1,859,937
Engineering, Procurement & Construction Management:			223,192
Total Capital:			**$2,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	806,064	ton	$2,256,978
Soil Hauling	806,064	ton	$3,778,423
Tipping Fees (non-TSCA)	798,350	ton	$34,329,031
Tipping Fees (TSCA)	7,714	ton	$424,272
Direct Capital:			$40,788,704
Engineering, Procurement & Construction Management:			4,894,645
Total Capital:			**$45,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$126,200,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	15,939	ton	$398,475
Lime Purchase	1,594	ton	$95,640
Soil Loading	15,939	ton	$44,629
Soil Hauling	15,939	ton	$74,714
Tipping Fees (TSCA)	15,939	ton	$876,645
Direct Capital:			$1,490,103
Engineering, Procurement & Construction Management:			178,812
Total Capital:			**$1,700,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	761	acre	$12,176,000
Dredging - 12 hour shifts	1594	Day	$9,085,800
Dredge Monitoring (Water Quality)	1594	Day	$4,782,000
Sediment Removal QA	1594	Day	$1,912,800
Site Restoration	1	LS	$600,000
Direct Capital:			$28,926,600
Engineering, Procurement & Construction Management:			3,471,192
Contractor Overhead/Profit:			4,338,990
Total Capital:			**$36,700,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	1,555,902,577	gal	$622,361
Water Treatment QA	2,253	day	$450,600
Direct Capital:			$1,854,055
Engineering, Procurement & Construction Management:			222,487
Total Capital:			**$2,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$116,000,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	761	acre	$12,176,000
Dredging - 12 hour shifts	1609	Day	$9,171,300
Dredge Monitoring (Water Quality)	1609	Day	$4,827,000
Sediment Removal QA	1609	Day	$1,930,800
Site Restoration	2	Each	$1,200,000
Direct Capital:			$29,675,100
Engineering, Procurement & Construction Management:			3,561,012
Contractor Overhead/Profit:			4,451,265
Total Capital:			**$37,700,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	1,280,733,951	gal	$512,294
Water Treatment QA	2,253	day	$450,600
Direct Capital:			$1,653,989
Engineering, Procurement & Construction Management:			198,479
Total Capital:			**$1,900,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	2,015,159	ton	$54,409,293
Soil Loading	2,015,159	ton	$5,642,445
Soil Hauling	2,015,159	ton	$2,361,514
Direct Capital:			$62,413,252
Engineering, Procurement & Construction Management:			$7,489,590
Total Capital:			**$69,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$117,200,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge to CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Lime Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	805,639	tons		$4,833,835
Sand Placement	575,457	cy		$3,452,739
Cobble Purchase and Placement	345,274	cy		$10,358,218
Cap Placement QA	1	LS		$100,000
Direct Capital:				$18,944,792
Engineering, Procurement & Construction Management:				2,273,375
Total Capital:				**$21,218,167**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$424,363	$6,385,097
Total Present Worth, Longer Term O&M Costs				$12,403,616
Total Project Capital and O&M Cost				**$33,600,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	761	acre	$12,176,000
Dredging - 12 hour shifts	1179	Day	$6,720,300
Dredge Monitoring (Water Quality)	1179	Day	$3,537,000
Sediment Removal QA	1179	Day	$1,414,800
Site Restoration	2	Each	$1,200,000
Direct Capital:			$25,418,100
Engineering, Procurement & Construction Management:			3,050,172
Contractor Overhead/Profit:			3,812,715
Total Capital:			**$32,300,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	1,151,157,170	gal	$460,463
Water Treatment QA	1,672	Day	$334,400
Direct Capital:			$1,575,957
Engineering, Procurement & Construction Management:			189,115
Total Capital:			**$1,800,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$113,200,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE LAKE BUTTE DES MORTS
Action Level - 250 ppb

Material Handling Assumptions:

Volume > 250 ppb	1,322,818	cy	697	ac	1,009,785	m3		Acres corresponds to dredge
Volume > 125 ppb	1,689,173	cy			1,289,445	m3		footprint area
Volume > 500 ppb	1,023,621	cy			781,390	m3		
Volume > 1,000 ppb	784,192	cy			598,620	m3		
Volume > 5,000 ppb	281,689	cy			215,030	m3		
Volume > 50,000 ppb	16,165	cy			12,340	m3		
Solids Specific Gravity	2.51							
Fresh Water Density	62.4	lb/ft3						
In Situ Density	24.2%	w/w	11.3%	v/v	0.99	tons per cy		
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy		Ogden Beeman
Dewatered Density (passive pond)	20%	w/w	9.1%	v/v	0.96	tons per cy		Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	28.5%	v/v	1.20	tons per cy		Foth & VanDyke
Treated Density	93.8%	w/w	60.0%	v/v	1.35	tons per cy		
Arrowhead/Menasha CDF Capacity	1,406,932	cy	in situ		1,337,963	m3		
HTTD Treatment Capacity	1,099,327	cy	in situ		1,650,000	tons		
Cap Volume	323,701	cy			247,100	m3		
Vitrification Treatment Capacity	4,496,073	cy	in situ		2145500.00	tons		

Cost Estimating Parameters & Methodology:

Interest Rate	6.0%				Not Used
Sales Tax	5.5%				
Engineering, Procurement and Construction Mgmt	12.0%				
Contractor Overhead and Profit - Dredging Only	15.0%				
<u>Dredging</u>					
Debris Sweep	$16,000	per acre			Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day			
Sediment Removal QA	$1,200	per day			
Hydraulic - 10-inch Cutterhead					
Site Preparation	$100,000	per dredge launch site			pj
Mobilization - Equipment	$135,000	per dredge			Ogden Beeman
Mobilization - Silt Curtain	$35,000				Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift			Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift			Ogden Beeman
Site Restoration	$600,000	per dredge launch site			pj
Mechanical - 3 cy bucket					
Dock Construction	$400,000	LS			pj
Mobilization - Equipment	$455,000	per dredge			Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS			Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea			Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$9,000	per shift			Ogden Beeman
Dredge Rate	630	cy in situ per 10 hour shift			Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area			pj
Free Water per cy Dredged (10%)	20	gal			Ogden Beeman
Offload Crane Mobilization	$50,000	LS			pj
Site Restoration	$75,000	LS			pj
High Temperature Thermal Desorption					
Setup Staging Area	$50,000				pj
Mobilization/Site Prep	$150,000				Maxymillian
Sediment Treatment QA	$2	per ton			
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1			
Sand Purchase and Deliver	$6	per ton			Ole
Blending	$25	per ton			Ole
HTTD (includes off-gas treatment)	$75	per ton			Maxymillian
Stack Testing	$50,000	LS			Maxymillian
Place Treated Material	$3	per ton			
Vitrification					
Vitrification (unit cost incl Cap and Op Costs)	$27.0	per ton (250 glass ton per day melter unit)			Unit Cost Study- Minergy
Capping					
Mobilization/Site Prep	$200,000				Ogden Beeman
Area	8,630,293	sf	801,800	m2	
Sand Cap Depth	1.7	feet			
Sand Placement	$6	per cy			Ogden Beeman
Sand Purchase	$6	per ton			Ole
Sand Density	1.4	tons per cy			
Armored Cap Depth	1.0	feet			
Cobbles	$30	per cy			Means
Cap Placement QA	$100,000	LS			Ogden Beeman
Long-term O&M	2%	of capital			pj
Long-term Monitoring	$400,000	per year			Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing

Dewatering - Upland Pond (2 cells)			
Land Lease or Purchase	$1.80	per sf	Ole
Area	644,791	sf	2 days slurry + 13 wk solids * 2 cell
Perimeter	3,212	lf	assume square
Depth of Material in Dewatering Cell	8	feet	based on size at Arrowhead Park
Cell Retention Time	24	hours	Not Used
Cell Depth	10	feet	
Mobilization	$20,000	LS	pj
Clear and Grub	$2,000	per acre	pj
Berm Volume	10.4	cy per lf	2:1 slope, 8-foot top
Berm Construction	$6	per cy	pj
Rough Grading	$0.25	per sf	pj
Alphalt Liner	$1.50	per sf	pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS	pj
Regrade Berm Soils	$6	per cy	pj
Seed/Sod	$1	per sy	Baird
Dewatering - Mechanical			
Mobilization	$100,000		pj
Holding Pond-Centrifuge	$80	per bone dry ton	Global Dewatering
Water Treatment			
Flow Rate (passive dewatering)	395	gpm	assume operate 24/7
Unit, Purchase (passive dewatering)	$691,096	LS	pj
Flow Rate (mechanical dewatering)	484	gpm	
Unit, Purchase (mechanical dewatering)	$781,094	LS	
Water Treatment (Including Operator)	$0.40	per 1,000 gallons	pj
Water Treatment QA	$200	per day	pj, 1 sample/day
Disposal			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	**Quantity**	**Units**		**Cost**
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Off-site Disposal (Passive Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	697	acre		$11,152,000
Dredging - 12 hour shifts	1260	Day	9.692307692	$7,182,000
Dredge Monitoring (Water Quality)	1260	Day		$3,780,000
Sediment Removal QA	1260	Day		$1,512,000
Site Restoration	2	Each		$1,200,000
Direct Capital:				$25,196,000
Engineering, Procurement & Construction Management:				3,023,520
Contractor Overhead/Profit:				3,779,400
Total Capital:				**$32,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	1,002,963,239	gal	$401,185
Water Treatment QA	1,764	day	$352,800
Direct Capital:			$1,445,081
Engineering, Procurement & Construction Management:			173,410
Total Capital:			**$1,600,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	1,578,104	ton		$39,452,600
Lime Purchase	157,811	ton		$9,468,660
Soil Loading	1,578,104	ton		$4,418,691
Soil Hauling	1,578,104	ton		$7,397,363
Tipping Fees (non-TSCA)	1,558,819	ton		$67,029,213
Tipping Fees (TSCA)	19,285	ton		$1,060,680
Direct Capital:				$128,827,207
Engineering, Procurement & Construction Management:				15,459,265
Total Capital:				**$144,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$185,600,000**

ALTERNATIVE C2: Dredge Sediment With Off-site Disposal (Mechanical Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	697	acre		$11,152,000
Dredging - 12 hour shifts	1260	Day	9.692307692	$7,182,000
Dredge Monitoring (Water Quality)	1260	Day		$3,780,000
Sediment Removal QA	1260	Day		$1,512,000
Site Restoration	2	Each		$1,200,000
Direct Capital:				$25,196,000
Engineering, Procurement & Construction Management:				3,023,520
Contractor Overhead/Profit:				3,779,400
Total Capital:				**$32,000,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	315,621	bdt	$25,249,652
Direct Capital:			$25,349,652
Engineering, Procurement & Construction Management:			3,041,958
Total Capital:			**$28,400,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	1,229,967,319	gal	$491,987
Water Treatment QA	1,764	day	$352,800
Direct Capital:			$1,625,881
Engineering, Procurement & Construction Management:			195,106
Total Capital:			**$1,800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	631,241	ton	$1,767,476
Soil Hauling	631,241	ton	$2,958,944
Tipping Fees (non-TSCA)	623,527	ton	$26,811,672
Tipping Fees (TSCA)	7,714	ton	$424,272
Direct Capital:			$31,962,363
Engineering, Procurement & Construction Management:			3,835,484
Total Capital:			**$35,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$102,500,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Lime Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	697	acre	$11,152,000
Dredging - 12 hour shifts	1245	Day	$7,096,500
Dredge Monitoring (Water Quality)	1245	Day	$3,735,000
Sediment Removal QA	1245	Day	$1,494,000
Site Restoration	1	LS	$600,000
Direct Capital:			$24,447,500
Engineering, Procurement & Construction Management:			2,933,700
Contractor Overhead/Profit:			3,667,125
Total Capital:			**$31,000,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	1,215,263,074	gal	$486,105
Water Treatment QA	1,764	day	$352,800
Direct Capital:			$1,619,999
Engineering, Procurement & Construction Management:			194,400
Total Capital:			**$1,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$110,300,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	697	acre	$11,152,000
Dredging - 12 hour shifts	1260	Day	$7,182,000
Dredge Monitoring (Water Quality)	1260	Day	$3,780,000
Sediment Removal QA	1260	Day	$1,512,000
Site Restoration	2	Each	$1,200,000
Direct Capital:			$25,196,000
Engineering, Procurement & Construction Management:			3,023,520
Contractor Overhead/Profit:			3,779,400
Total Capital:			**$32,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	1,002,963,239	gal	$401,185
Water Treatment QA	1,764	day	$352,800
Direct Capital:			$1,445,081
Engineering, Procurement & Construction Management:			173,410
Total Capital:			**$1,600,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	1,578,103	ton	$42,608,787
Soil Loading	1,578,103	ton	$4,418,689
Soil Hauling	1,578,103	ton	$1,849,340
Direct Capital:			$48,876,816
Engineering, Procurement & Construction Management:			$5,865,218
Total Capital:			**$54,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$96,000,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge to CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Cement Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

CAPPING

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$200,000
Sand Purchase	745,828	tons	$4,474,967
Sand Placement	532,734	cy	$3,196,405
Cobble Purchase and Placement	319,640	cy	$9,589,215
Cap Placement QA	1	LS	$100,000
Direct Capital:			$17,560,587
Engineering, Procurement & Construction Management:			2,107,270
Total Capital:			**$19,667,857**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$393,357	$5,918,568
Total Present Worth, Longer Term O&M Costs			$11,937,087
Total Project Capital and O&M Cost			**$31,600,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	697	acre	$11,152,000
Dredging - 12 hour shifts	937	Day	$5,340,900
Dredge Monitoring (Water Quality)	937	Day	$2,811,000
Sediment Removal QA	937	Day	$1,124,400
Site Restoration	2	Each	$1,200,000
Direct Capital:			$21,998,300
Engineering, Procurement & Construction Management:			2,639,796
Contractor Overhead/Profit:			3,299,745
Total Capital:			**$27,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	914,283,237	gal	$365,713
Water Treatment QA	1,333	Day	$266,600
Direct Capital:			$1,413,407
Engineering, Procurement & Construction Management:			169,609
Total Capital:			**$1,600,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$106,600,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE LAKE BUTTE DES MORTS
Action Level - 500 ppb

Material Handling Assumptions:						
Volume > 500 ppb	1,023,621	cy	625 ac	781,390	m3	Acres corresponds to dredge
Volume > 125 ppb	1,689,173	cy		1,289,445	m3	footprint area
Volume > 250 ppb	1,322,818	cy		1,009,785	m3	
Volume > 1,000 ppb	784,192	cy		598,620	m3	
Volume > 5,000 ppb	281,689	cy		215,030	m3	
Volume > 50,000 ppb	16,165	cy		12,340	m3	
Solids Specific Gravity	2.51					
Fresh Water Density	62.4	lb/ft3				
In Situ Density	24.2%	w/w	11.3% v/v	0.99	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3% v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density (passive pond)	20%	w/w	9.1% v/v	0.96	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	28.5% v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.8%	w/w	60.0% v/v	1.35	tons per cy	
Arrowhead/Menasha CDF Capacity	1,406,932	cy	in situ	1,337,963	m3	
HTTD Treatment Capacity	1,099,327	cy	in situ	1,650,000	tons	
Cap Volume	252,057	cy		192,410	m3	
Vitrification Treatment Capacity	4,496,073	cy	in situ	2145500.00	tons	
Cost Estimating Parameters & Methodology:						
Interest Rate	6.0%					Not Used
Sales Tax	5.5%					
Engineering, Procurement and Construction Mgmt	12.0%					
Contractor Overhead and Profit - Dredging Only	15.0%					
Dredging						
Debris Sweep	$16,000	per acre				Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day				
Sediment Removal QA	$1,200	per day				
Hydraulic - 10-inch Cutterhead						
Site Preparation	$100,000	per dredge launch site				pj
Mobilization - Equipment	$135,000	per dredge				Ogden Beeman
Mobilization - Silt Curtain	$35,000					Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift				Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift				Ogden Beeman
Site Restoration	$600,000	per dredge launch site				pj
Mechanical - 3 cy bucket						
Dock Construction	$400,000	LS				pj
Mobilization - Equipment	$455,000	per dredge				Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS				Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea				Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$9,000	per shift				Ogden Beeman
Dredge Rate	630	cy in situ per 10 hour shift				Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area				pj
Free Water per cy Dredged (10%)	20	gal				Ogden Beeman
Offload Crane Mobilization	$50,000	LS				pj
Site Restoration	$75,000	LS				pj
High Temperature Thermal Desorption						
Setup Staging Area	$50,000					pj
Mobilization/Site Prep	$150,000					Maxymillian
Sediment Treatment QA	$2	per ton				
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1				
Sand Purchase and Deliver	$6	per ton				Ole
Blending	$25	per ton				Ole
HTTD (includes off-gas treatment)	$75	per ton				Maxymillian
Stack Testing	$50,000	LS				Maxymillian
Place Treated Material	$3	per ton				
Vitrification						
Vitrification (unit cost incl Cap and Op Costs)	$27.0	per ton (250 glass ton per day melter unit)				Unit Cost Study- Minergy
Capping						
Mobilization/Site Prep	$200,000					Ogden Beeman
Area	7,636,809	sf	709,500		m2	
Sand Cap Depth	1.7	feet				
Sand Placement	$6	per cy				Ogden Beeman
Sand Purchase	$6	per ton				Ole
Sand Density	1.4	tons per cy				
Armored Cap Depth	1.0	feet				
Cobbles	$30	per cy				Means
Cap Placement QA	$100,000	LS				Ogden Beeman
Long-term O&M	2%	of capital				pj
Long-term Monitoring	$400,000	per year				Anne LTM

Nearshore CDF	Arrowhead		Menasha			
Land Lease or Purchase	$1.8	per sf	$1.8			Ole
Length	8,000	lf	9,200			Baird
Capping Volume	190,000	cy	170,000			Baird
Seeding Area	280,000	sy	250,000			Baird
Sheetpile Wall Length	8,000	lf	9,200			Baird
Sheetpile Depth	30	ft	30			based on bathymetry
Sheetpile Cost	$19	per sf	$19			pj
Shot Rock Berm	$650	per lf	$550			Baird
Rip Rap	$215	per lf	$250			Baird
Place Treated Material	$2	per cy	$2			pj
Clean Soil Cap	$10	per cy	$10			Baird
Seeding	$1	per sy	$1			Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing

Dewatering - Upland Pond (2 cells)			
Land Lease or Purchase	$1.80	per sf	Ole
Area	644,791	sf	2 days slurry + 13 wk solids * 2 cell
Perimeter	3,212	lf	assume square
Depth of Material in Dewatering Cell	8	feet	based on size at Arrowhead Park
Cell Retention Time	24	hours	Not Used
Cell Depth	10	feet	
Mobilization	$20,000	LS	pj
Clear and Grub	$2,000	per acre	pj
Berm Volume	10.4	cy per lf	2:1 slope, 8-foot top
Berm Construction	$6	per cy	pj
Rough Grading	$0.25	per sf	pj
Alphalt Liner	$1.50	per sf	pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS	pj
Regrade Berm Soils	$6	per cy	pj
Seed/Sod	$1	per sy	Baird
Dewatering - Mechanical			
Mobilization	$100,000		pj
Holding Pond-Centrifuge	$80	per bone dry ton	Global Dewatering

Water Treatment			
Flow Rate (passive dewatering)	395	gpm	assume operate 24/7
Unit, Purchase (passive dewatering)	$691,096	LS	pj
Flow Rate (mechanical dewatering)	484	gpm	
Unit, Purchase (mechanical dewatering)	$781,094	LS	
Water Treatment (Including Operator)	$0.40	per 1,000 gallons	pj
Water Treatment QA	$200	per day	pj, 1 sample/day

Disposal			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Off-site Disposal (Passive Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	625	acre		$10,000,000
Dredging - 12 hour shifts	975	Day	7.5	$5,557,500
Dredge Monitoring (Water Quality)	975	Day		$2,925,000
Sediment Removal QA	975	Day		$1,170,000
Site Restoration	2	Each		$1,200,000
Direct Capital:				$21,222,500
Engineering, Procurement & Construction Management:				2,546,700
Contractor Overhead/Profit:				3,183,375
Total Capital:				**$27,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	776,111,197	gal	$310,444
Water Treatment QA	1,365	day	$273,000
Direct Capital:			$1,274,540
Engineering, Procurement & Construction Management:			152,945
Total Capital:			**$1,400,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	1,221,165	ton		$30,529,125
Lime Purchase	122,117	ton		$7,327,020
Soil Loading	1,221,165	ton		$3,419,262
Soil Hauling	1,221,165	ton		$5,724,211
Tipping Fees (non-TSCA)	1,201,880	ton		$51,680,836
Tipping Fees (TSCA)	19,285	ton		$1,060,680
Direct Capital:				$99,741,134
Engineering, Procurement & Construction Management:				11,968,936
Total Capital:				**$111,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$147,800,000**

ALTERNATIVE C2: Dredge Sediment With Off-site Disposal (Mechanical Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	625	acre		$10,000,000
Dredging - 12 hour shifts	975	Day	7.5	$5,557,500
Dredge Monitoring (Water Quality)	975	Day		$2,925,000
Sediment Removal QA	975	Day		$1,170,000
Site Restoration	2	Each		$1,200,000
Direct Capital:				$21,222,500
Engineering, Procurement & Construction Management:				2,546,700
Contractor Overhead/Profit:				3,183,375
Total Capital:				**$27,000,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	244,233	bdt	$19,538,640
Direct Capital:			$19,638,640
Engineering, Procurement & Construction Management:			2,356,637
Total Capital:			**$22,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	951,771,083	gal	$380,708
Water Treatment QA	1,365	day	$273,000
Direct Capital:			$1,434,802
Engineering, Procurement & Construction Management:			172,176
Total Capital:			**$1,600,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	488,466	ton	$1,367,705
Soil Hauling	488,466	ton	$2,289,684
Tipping Fees (non-TSCA)	480,752	ton	$20,672,334
Tipping Fees (TSCA)	7,714	ton	$424,272
Direct Capital:			$24,753,995
Engineering, Procurement & Construction Management:			2,970,479
Total Capital:			**$27,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$82,800,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Lime Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	625	acre	$10,000,000
Dredging - 12 hour shifts	960	Day	$5,472,000
Dredge Monitoring (Water Quality)	960	Day	$2,880,000
Sediment Removal QA	960	Day	$1,152,000
Site Restoration	1	LS	$600,000
Direct Capital:			$20,474,000
Engineering, Procurement & Construction Management:			2,456,880
Contractor Overhead/Profit:			3,071,100
Total Capital:			**$26,000,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,520,000	sf		$4,536,000
Shot Rock/Rip Rap	8,000	lf		$6,920,000
Sheetpile Placement	240,000	sf		$4,560,000
Clean Soil Cap	190,000	cy		$1,900,000
Seeding	280,000	sy		$280,000
Mitigation	58	acre		$578,512
Direct Capital:				$18,774,512
Engineering, Procurement & Construction Management:				2,252,941
Total Capital:				**$21,027,454**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs				$16,258,262
Total Project Capital and O&M Cost				**$37,300,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	27,778	sf		$50,000
Shot Rock/Rip Rap	9,200	lf		$7,360,000
Sheetpile Placement	276,000	sf		$5,244,000
Clean Soil Cap	170,000	cy		$1,700,000
Seeding	250,000	sy		$250,000
Mitigation	52	acre		$516,529
Direct Capital:				$15,120,529
Engineering, Procurement & Construction Management:				1,814,463
Total Capital:				**$16,934,992**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs				$15,026,734
Total Project Capital and O&M Cost				**$32,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	937,066,839	gal	$374,827
Water Treatment QA	1,365	day	$273,000
Direct Capital:			$1,428,921
Engineering, Procurement & Construction Management:			171,470
Total Capital:			**$1,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$105,100,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	625	acre	$10,000,000
Dredging - 12 hour shifts	975	Day	$5,557,500
Dredge Monitoring (Water Quality)	975	Day	$2,925,000
Sediment Removal QA	975	Day	$1,170,000
Site Restoration	2	Each	$1,200,000
Direct Capital:			$21,222,500
Engineering, Procurement & Construction Management:			2,546,700
Contractor Overhead/Profit:			3,183,375
Total Capital:			**$27,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	776,111,197	gal	$310,444
Water Treatment QA	1,365	day	$273,000
Direct Capital:			$1,274,540
Engineering, Procurement & Construction Management:			152,945
Total Capital:			**$1,400,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	1,221,165	ton	$32,971,455
Soil Loading	1,221,165	ton	$3,419,262
Soil Hauling	1,221,165	ton	$1,431,053
Direct Capital:			$37,821,769
Engineering, Procurement & Construction Management:			$4,538,612
Total Capital:			**$42,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$78,500,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge to CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Cement Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	659,971	tons		$3,959,827
Sand Placement	471,408	cy		$2,828,448
Cobble Purchase and Placement	282,845	cy		$8,485,343
Cap Placement QA	1	LS		$100,000
Direct Capital:				$15,573,617
Engineering, Procurement & Construction Management:				1,868,834
Total Capital:				**$17,442,452**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$348,849	$5,248,886
Total Present Worth, Longer Term O&M Costs				$11,267,405
Total Project Capital and O&M Cost				**$28,700,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	625	acre	$10,000,000
Dredging - 12 hour shifts	720	Day	$4,104,000
Dredge Monitoring (Water Quality)	720	Day	$2,160,000
Sediment Removal QA	720	Day	$864,000
Site Restoration	2	Each	$1,200,000
Direct Capital:			$18,698,000
Engineering, Procurement & Construction Management:			2,243,760
Contractor Overhead/Profit:			2,804,700
Total Capital:			**$23,700,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	702,702,086	gal	$281,081
Water Treatment QA	1,029	Day	$205,800
Direct Capital:			$1,267,975
Engineering, Procurement & Construction Management:			152,157
Total Capital:			**$1,400,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$99,300,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE LAKE BUTTE DES MORTS
Action Level - 1,000 ppb

Material Handling Assumptions:							
Volume > 1000 ppb	784,192	cy	526	ac	598,620	m3	Acres corresponds to dredge
Volume > 125 ppb	1,689,173	cy			1,289,445	m3	footprint area
Volume > 250 ppb	1,322,818	cy			1,009,785	m3	
Volume > 500 ppb	1,023,621	cy			781,390	m3	
Volume > 5,000 ppb	281,689	cy			215,030	m3	
Volume > 50,000 ppb	16,165	cy			12,340	m3	
Solids Specific Gravity	2.51						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.3%	v/v	0.99	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density (passive pond)	20%	w/w	9.1%	v/v	0.96	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	28.5%	v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.8%	w/w	60.0%	v/v	1.35	tons per cy	
Arrowhead/Menasha CDF Capacity	1,406,932	cy	in situ		1,337,963	m3	
HTTD Treatment Capacity	1,099,327	cy	in situ		1,650,000	tons	
Cap Volume	148,646	cy			113,470	m3	
Vitrification Treatment Capacity	4,496,073	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						Not Used
Sales Tax	5.5%						
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
Mechanical - 3 cy bucket							
Dock Construction	$400,000	LS					pj
Mobilization - Equipment	$455,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$9,000	per shift					Ogden Beeman
Dredge Rate	630	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					pj
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Offload Crane Mobilization	$50,000	LS					pj
Site Restoration	$75,000	LS					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Vitrification (unit cost incl Cap and Op Costs)	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	5,884,487	sf	546,700			m2	
Sand Cap Depth	1.7	feet					
Sand Placement	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area	644,791	sf					2 days slurry + 13 wk solids * 2 cell
Perimeter	3,212	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Alphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate (passive dewatering)	395	gpm					assume operate 24/7
Unit, Purchase (passive dewatering)	$691,096	LS					pj
Flow Rate (mechanical dewatering)	484	gpm					
Unit, Purchase (mechanical dewatering)	$781,094	LS					
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample/day
Disposal							
Off-Site Disposal							
Load Soil for Hauling	$2.80	per ton					pj
Round-trip Hauling	2	hours					pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours					pj
Tipping Fee (non-TSCA)	$43	per ton					St. Paul
Tipping Fee (TSCA)	$55	per ton					St. Paul
Truck Rate	$75	per hour					pj
Truck Load	32	tons					pj
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Off-site Disposal (Passive Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	526	acre		$8,416,000
Dredging - 12 hour shifts	747	Day	5.746153846	$4,257,900
Dredge Monitoring (Water Quality)	747	Day		$2,241,000
Sediment Removal QA	747	Day		$896,400
Site Restoration	2	Each		$1,200,000
Direct Capital:				$17,381,300
Engineering, Procurement & Construction Management:				2,085,756
Contractor Overhead/Profit:				2,607,195
Total Capital:				**$22,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	594,575,928	gal	$237,830
Water Treatment QA	1,046	day	$209,200
Direct Capital:			$1,138,126
Engineering, Procurement & Construction Management:			136,575
Total Capital:			**$1,300,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	935,530	ton		$23,388,250
Lime Purchase	93,553	ton		$5,613,180
Soil Loading	935,530	ton		$2,619,484
Soil Hauling	935,530	ton		$4,385,297
Tipping Fees (non-TSCA)	916,245	ton		$39,398,531
Tipping Fees (TSCA)	19,285	ton		$1,060,680
Direct Capital:				$76,465,422
Engineering, Procurement & Construction Management:				9,175,851
Total Capital:				**$85,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$116,700,000**

ALTERNATIVE C2: Dredge Sediment With Off-site Disposal (Mechanical Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	526	acre		$8,416,000
Dredging - 12 hour shifts	747	Day	5.746153846	$4,257,900
Dredge Monitoring (Water Quality)	747	Day		$2,241,000
Sediment Removal QA	747	Day		$896,400
Site Restoration	2	Each		$1,200,000
Direct Capital:				$17,381,300
Engineering, Procurement & Construction Management:				2,085,756
Contractor Overhead/Profit:				2,607,195
Total Capital:				**$22,100,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	187,106	bdt	$14,968,480
Direct Capital:			$15,068,480
Engineering, Procurement & Construction Management:			1,808,218
Total Capital:			**$16,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	729,148,320	gal	$291,659
Water Treatment QA	1,046	day	$209,200
Direct Capital:			$1,281,953
Engineering, Procurement & Construction Management:			153,834
Total Capital:			**$1,400,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	374,212	ton	$1,047,794
Soil Hauling	374,212	ton	$1,754,119
Tipping Fees (non-TSCA)	366,498	ton	$15,759,412
Tipping Fees (TSCA)	7,714	ton	$424,272
Direct Capital:			$18,985,597
Engineering, Procurement & Construction Management:			2,278,272
Total Capital:			**$21,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$66,200,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Lime Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	526	acre	$8,416,000
Dredging - 12 hour shifts	732	Day	$4,172,400
Dredge Monitoring (Water Quality)	732	Day	$2,196,000
Sediment Removal QA	732	Day	$878,400
Site Restoration	1	LS	$600,000
Direct Capital:			$16,632,800
Engineering, Procurement & Construction Management:			1,995,936
Contractor Overhead/Profit:			2,494,920
Total Capital:			**$21,100,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	714,444,075	gal	$285,778
Water Treatment QA	1,046	day	$209,200
Direct Capital:			$1,276,072
Engineering, Procurement & Construction Management:			153,129
Total Capital:			**$1,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$68,000,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	526	acre	$8,416,000
Dredging - 12 hour shifts	747	Day	$4,257,900
Dredge Monitoring (Water Quality)	747	Day	$2,241,000
Sediment Removal QA	747	Day	$896,400
Site Restoration	2	Each	$1,200,000
Direct Capital:			$17,381,300
Engineering, Procurement & Construction Management:			2,085,756
Contractor Overhead/Profit:			2,607,195
Total Capital:			**$22,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	594,575,928	gal	$237,830
Water Treatment QA	1,046	day	$209,200
Direct Capital:			$1,138,126
Engineering, Procurement & Construction Management:			136,575
Total Capital:			**$1,300,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	935,530	ton	$25,259,310
Soil Loading	935,530	ton	$2,619,484
Soil Hauling	935,530	ton	$1,096,324
Direct Capital:			$28,975,118
Engineering, Procurement & Construction Management:			$3,477,014
Total Capital:			**$32,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$63,600,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge to CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Cement Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

CAPPING

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$200,000
Sand Purchase	508,536	tons	$3,051,215
Sand Placement	363,240	cy	$2,179,440
Cobble Purchase and Placement	217,944	cy	$6,538,319
Cap Placement QA	1	LS	$100,000
Direct Capital:			$12,068,973
Engineering, Procurement & Construction Management:			1,448,277
Total Capital:			**$13,517,250**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$270,345	$4,067,691
Total Present Worth, Longer Term O&M Costs			$10,086,210
Total Project Capital and O&M Cost			**$23,600,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	526	acre	$8,416,000
Dredging - 12 hour shifts	590	Day	$3,363,000
Dredge Monitoring (Water Quality)	590	Day	$1,770,000
Sediment Removal QA	590	Day	$708,000
Site Restoration	2	Each	$1,200,000
Direct Capital:			$15,827,000
Engineering, Procurement & Construction Management:			1,899,240
Contractor Overhead/Profit:			2,374,050
Total Capital:			**$20,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	576,232,088	gal	$230,493
Water Treatment QA	848	Day	$169,600
Direct Capital:			$1,181,187
Engineering, Procurement & Construction Management:			141,742
Total Capital:			**$1,300,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$90,500,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE LAKE BUTTE DES MORTS
Action Level - 5,000 ppb

Material Handling Assumptions:								
Volume > 5000 ppb	281,689	cy	174	ac	215,030	m3		Acres corresponds to dredge
Volume > 125 ppb	1,689,173	cy			1,289,445	m3		footprint area
Volume > 250 ppb	1,322,818	cy			1,009,785	m3		
Volume > 500 ppb	1,128,565	cy			781,390	m3		
Volume > 1,000 ppb	784,192	cy			598,620	m3		
Volume > 50,000 ppb	16,165	cy			12,340	m3		
Solids Specific Gravity	2.51							
Fresh Water Density	62.4	lb/ft3						
In Situ Density	24.2%	w/w	11.3%	v/v	0.99	tons per cy		
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy		Ogden Beeman
Dewatered Density (passive pond)	20%	w/w	9.1%	v/v	0.96	tons per cy		Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	28.5%	v/v	1.20	tons per cy		Foth & VanDyke
Treated Density	93.8%	w/w	60.0%	v/v	1.35	tons per cy		
Arrowhead/Menasha CDF Capacity	1,406,932	cy	in situ		1,337,963	m3		
HTTD Treatment Capacity	1,099,327	cy	in situ		1,650,000	tons		
Cap Volume	59,055	cy			45,080	m3		
Vitrification Treatment Capacity	4,496,073	cy	in situ		2145500.00	tons		
Cost Estimating Parameters & Methodology:								
Interest Rate	6.0%							Not Used
Sales Tax	5.5%							
Engineering, Procurement and Construction Mgmt	12.0%							
Contractor Overhead and Profit - Dredging Only	15.0%							
Dredging								
Debris Sweep	$16,000	per acre						Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day						
Sediment Removal QA	$1,200	per day						
Hydraulic - 10-inch Cutterhead								
Site Preparation	$100,000	per dredge launch site						pj
Mobilization - Equipment	$135,000	per dredge						Ogden Beeman
Mobilization - Silt Curtain	$35,000							Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift						Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift						Ogden Beeman
Site Restoration	$600,000	per dredge launch site						pj
Mechanical - 3 cy bucket								
Dock Construction	$400,000	LS						pj
Mobilization - Equipment	$455,000	per dredge						Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS						Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea						Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$9,000	per shift						Ogden Beeman
Dredge Rate	630	cy in situ per 10 hour shift						Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area						pj
Free Water per cy Dredged (10%)	20	gal						Ogden Beeman
Offload Crane Mobilization	$50,000	LS						pj
Site Restoration	$75,000	LS						pj
High Temperature Thermal Desorption								
Setup Staging Area	$50,000							pj
Mobilization/Site Prep	$150,000							Maxymillian
Sediment Treatment QA	$2	per ton						
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1						
Sand Purchase and Deliver	$6	per ton						Ole
Blending	$25	per ton						Ole
HTTD (includes off-gas treatment)	$75	per ton						Maxymillian
Stack Testing	$50,000	LS						Maxymillian
Place Treated Material	$3	per ton						
Vitrification								
Vitrification (unit cost incl Cap and Op Costs)	$27.0	per ton (250 glass ton per day melter unit)						Unit Cost Study- Minergy
Capping								
Mobilization/Site Prep	$200,000							Ogden Beeman
Area	1,791,071	sf		166,400		m2		
Sand Cap Depth	1.7	feet						
Sand Placement	$6	per cy						Ogden Beeman
Sand Purchase	$6	per ton						Ole
Sand Density	1.4	tons per cy						
Armored Cap Depth	1.0	feet						
Cobbles	$30	per cy						Means
Cap Placement QA	$100,000	LS						Ogden Beeman
Long-term O&M	2%	of capital						pj
Long-term Monitoring	$400,000	per year						Anne LTM

	Arrowhead		Menasha			
Nearshore CDF						
Land Lease or Purchase	$1.8	per sf	$1.8			Ole
Length	8,000	lf	9,200			Baird
Capping Volume	190,000	cy	170,000			Baird
Seeding Area	280,000	sy	250,000			Baird
Sheetpile Wall Length	8,000	lf	9,200			Baird
Sheetpile Depth	30	ft	30			based on bathymetry
Sheetpile Cost	$19	per sf	$19			pj
Shot Rock Berm	$650	per lf	$550			Baird
Rip Rap	$215	per lf	$250			Baird
Place Treated Material	$2	per cy	$2			pj
Clean Soil Cap	$10	per cy	$10			Baird
Seeding	$1	per sy	$1			Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area	644,791	sf				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,212	lf				assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				pj
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Alphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Water Treatment						
Flow Rate (passive dewatering)	395	gpm				assume operate 24/7
Unit, Purchase (passive dewatering)	$691,096	LS				pj
Flow Rate (mechanical dewatering)	484	gpm				
Unit, Purchase (mechanical dewatering)	$781,094	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Disposal						
Off-Site Disposal						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Institutional Controls						
Public Education Program	$100,000					pj
O&M Plans	$20,000					pj
Deed Restrictions	$5,000					pj
Annual Costs						
Public Education Program	$30,000					pj
Maintaining O&M Plans	$800					pj
Reporting	$20,000					pj
Long-term Monitoring	$600,000					Anne LTM
Long-term Monitoring (no action)	$300,000					Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Off-site Disposal (Passive Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	174	acre		$2,784,000
Dredging - 12 hour shifts	269	Day	2.069230769	$1,533,300
Dredge Monitoring (Water Quality)	269	Day		$807,000
Sediment Removal QA	269	Day		$322,800
Site Restoration	2	Each		$1,200,000
Direct Capital:				$7,017,100
Engineering, Procurement & Construction Management:				842,052
Contractor Overhead/Profit:				1,052,565
Total Capital:				**$8,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	213,577,331	gal	$85,431
Water Treatment QA	376	day	$75,200
Direct Capital:			$851,727
Engineering, Procurement & Construction Management:			102,207
Total Capital:			**$1,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	336,052	ton		$8,401,300
Lime Purchase	33,606	ton		$2,016,360
Soil Loading	336,052	ton		$940,946
Soil Hauling	336,052	ton		$1,575,244
Tipping Fees (non-TSCA)	316,767	ton		$13,620,975
Tipping Fees (TSCA)	19,285	ton		$1,060,682
Direct Capital:				$27,615,507
Engineering, Procurement & Construction Management:				3,313,861
Total Capital:				**$30,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$48,500,000**

ALTERNATIVE C2: Dredge Sediment With Off-site Disposal (Mechanical Dewatering)

SEDIMENT REMOVAL (CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$200,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	174	acre		$2,784,000
Dredging - 12 hour shifts	269	Day	2.069230769	$1,533,300
Dredge Monitoring (Water Quality)	269	Day		$807,000
Sediment Removal QA	269	Day		$322,800
Site Restoration	2	Each		$1,200,000
Direct Capital:				$7,017,100
Engineering, Procurement & Construction Management:				842,052
Contractor Overhead/Profit:				1,052,565
Total Capital:				**$8,900,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	67,210	bdt	$5,376,820
Direct Capital:			$5,476,820
Engineering, Procurement & Construction Management:			657,218
Total Capital:			**$6,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	261,917,015	gal	$104,767
Water Treatment QA	376	day	$75,200
Direct Capital:			$961,061
Engineering, Procurement & Construction Management:			115,327
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	134,421	ton	$376,377
Soil Hauling	134,421	ton	$630,096
Tipping Fees (non-TSCA)	126,706	ton	$5,448,378
Tipping Fees (TSCA)	7,714	ton	$424,272
Direct Capital:			$6,879,124
Engineering, Procurement & Construction Management:			825,495
Total Capital:			**$7,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$28,300,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Lime Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	174	acre	$2,784,000
Dredging - 12 hour shifts	253	Day	$1,442,100
Dredge Monitoring (Water Quality)	253	Day	$759,000
Sediment Removal QA	253	Day	$303,600
Site Restoration	1	LS	$600,000
Direct Capital:			$6,258,700
Engineering, Procurement & Construction Management:			751,044
Contractor Overhead/Profit:			938,805
Total Capital:			**$7,900,000**

CDF CONSTRUCTION - ARROWHEAD

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,520,000	sf	$4,536,000
Shot Rock/Rip Rap	8,000	lf	$6,920,000
Sheetpile Placement	240,000	sf	$4,560,000
Clean Soil Cap	190,000	cy	$1,900,000
Seeding	280,000	sy	$280,000
Mitigation	58	acre	$578,512
Direct Capital:			$18,774,512
Engineering, Procurement & Construction Management:			2,252,941
Total Capital:			**$21,027,454**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	420,549	$6,327,706
Total Present Worth, Longer Term O&M Costs			$16,258,262
Total Project Capital and O&M Cost			**$37,300,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	484	gpm	$781,094
Water Treatment (Includes Operator)	247,212,770	gal	$98,885
Water Treatment QA	376	day	$75,200
Direct Capital:			$955,179
Engineering, Procurement & Construction Management:			114,621
Total Capital:			**$1,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$54,500,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	174	acre	$2,784,000
Dredging - 12 hour shifts	269	Day	$1,533,300
Dredge Monitoring (Water Quality)	269	Day	$807,000
Sediment Removal QA	269	Day	$322,800
Site Restoration	2	Each	$1,200,000
Direct Capital:			$7,017,100
Engineering, Procurement & Construction Management:			842,052
Contractor Overhead/Profit:			1,052,565
Total Capital:			**$8,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	644,791	sf	$1,160,624
Mobilization	1	LS	$20,000
Clear and Grub	644,791	sf	$29,605
Berm Construction	33,309	cy	$199,855
Rough Grading	644,791	sf	$161,198
Liner Placement	644,791	sf	$967,187
Demob/Disposal	1	LS	$10,000
Regrade	33,309	cy	$199,855
Seed/Sod	71,643	sy	$71,643
Direct Capital:			$2,819,968
Engineering, Procurement & Construction Management:			338,396
Total Capital:			**$3,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,096
Water Treatment (Includes Operator)	213,577,331	gal	$85,431
Water Treatment QA	376	day	$75,200
Direct Capital:			$851,727
Engineering, Procurement & Construction Management:			102,207
Total Capital:			**$1,000,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	336,051	ton	$9,073,384
Soil Loading	336,051	ton	$940,944
Soil Hauling	336,051	ton	$393,810
Direct Capital:			$10,408,138
Engineering, Procurement & Construction Management:			$1,248,977
Total Capital:			**$11,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$29,300,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge to CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$490,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	26	Day	$234,000
Dredge Monitoring (Water Quality)	26	Day	$78,000
Sediment Removal QA	26	Day	$31,200
Offload Crane Mobilization	1	LS	$50,000
Direct Capital:			$1,358,200
Engineering, Procurement & Construction Management:			162,984
Contractor Overhead/Profit:			203,730
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	19,286	ton	$482,150
Cement Purchase	1,929	ton	$115,740
Soil Loading	19,286	ton	$54,001
Soil Hauling	19,286	ton	$90,403
Tipping Fees (TSCA)	19,286	ton	$1,060,730
Direct Capital:			$1,803,024
Engineering, Procurement & Construction Management:			216,363
Total Capital:			**$2,000,000**

CAPPING

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$200,000
Sand Purchase	154,784	tons	$928,704
Sand Placement	110,560	cy	$663,360
Cobble Purchase and Placement	66,336	cy	$1,990,079
Cap Placement QA	1	LS	$100,000
Direct Capital:			$3,882,142
Engineering, Procurement & Construction Management:			465,857
Total Capital:			**$4,347,999**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$86,960	$1,308,426
Total Present Worth, Longer Term O&M Costs			$7,326,945
Total Project Capital and O&M Cost			**$11,700,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	2	Each	$200,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	174	acre	$2,784,000
Dredging - 12 hour shifts	197	Day	$1,122,900
Dredge Monitoring (Water Quality)	197	Day	$591,000
Sediment Removal QA	197	Day	$236,400
Site Restoration	2	Each	$1,200,000
Direct Capital:			$6,304,300
Engineering, Procurement & Construction Management:			756,516
Contractor Overhead/Profit:			945,645
Total Capital:			**$8,000,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	484	gpm		$781,094
Water Treatment (Includes Operator)	192,303,134	gal		$76,921
Water Treatment QA	297	Day		$59,400
Direct Capital:				$917,415
Engineering, Procurement & Construction Management:				110,090
Total Capital:				**$1,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$66,200,000**

Table 7-6 Cost Summary for Remedial Alternatives - Appleton to Little Rapids

125 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	182,450	$10,100,000	---	---	$3,000,000	$900,000	---	---	$19,800,000	$4,500,000	$38,300,000	$7,660,000	$45,960,000
E	182,450	$10,100,000	---	---	$3,000,000	$900,000	$7,700,000	---	---	$4,500,000	$26,200,000	$5,240,000	$31,440,000

250 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	80,611	$8,000,000	---	---	$3,000,000	$800,000	---	---	$8,700,000	$4,500,000	$25,000,000	$5,000,000	$30,000,000
E	80,611	$8,000,000	---	---	$3,000,000	$800,000	$3,400,000	---	---	$4,500,000	$19,700,000	$3,940,000	$23,640,000

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	56,998	$7,200,000	---	---	$3,000,000	$800,000	---	---	$6,200,000	$4,500,000	$21,700,000	$4,340,000	$26,040,000
E	56,998	$7,200,000	---	---	$3,000,000	$800,000	$2,400,000	---	---	$4,500,000	$17,900,000	$3,580,000	$21,480,000

1000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	46,178	$6,800,000	---	---	$3,000,000	$800,000	---	---	$5,000,000	$4,500,000	$20,100,000	$4,020,000	$24,120,000
E	46,178	$6,800,000	---	---	$3,000,000	$800,000	$2,000,000	---	---	$4,500,000	$17,100,000	$3,420,000	$20,520,000

5000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	20,148	$6,000,000	---	---	$3,000,000	$800,000	---	---	$2,200,000	$4,500,000	$16,500,000	$3,300,000	$19,800,000
E	20,148	$6,000,000	---	---	$3,000,000	$800,000	$900,000	---	---	$4,500,000	$15,200,000	$3,040,000	$18,240,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
APPLETON TO LITTLE RAPIDS
Action Level - 125 ppb

Material Handling Assumptions:							
Volume > 125 ppb	182,450	cy	119	ac	139,275	m3	Acres corresponds to dredge
Volume > 250 ppb	80,611	cy			61,535	m3	footprint area
Volume > 500 ppb	56,998	cy			43,510	m3	
Volume > 1,000 ppb	46,178	cy			35,250	m3	
Volume > 5000 ppb	20,148	cy			15,380	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.4						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.7%	v/v	0.98	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density	20%	w/w	9.4%	v/v	0.95	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	29.4%	v/v	1.19	tons per cy	Foth & VanDyke
Treated Density	93.5%	w/w	60.0%	v/v	1.30	tons per cy	
HTTD Treatment Capacity	1,264,377	cy	in situ		1,650,000	tons	
Vitrification Treatment Capacity	1,328,888	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Vitrification							
Vitrification	$27.0	per ton (250 glass ton per dya melter unit)					Unit Cost Study- Minergy
<u>Dewatering - Upland Pond (2 cells)</u>							
Land Lease or Purchase	$1.80	per sf					Ole
Area	608,771	sf	13.97546543				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,121	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
<u>Dewatering - Mechanical</u>							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
<u>Water Treatment</u>							
Flow Rate	395	gpm					assume operate 24/7
Unit, Purchase	$691,235	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					
Water Treatment QA	$200	per day					
Flow Rate (mechanical dewatering)	484	gpm					pj
Unit, Purchase (mechanical dewatering)	$780,778	LS					pj, 1 sample/day

Disposal
Off-Site Disposal

Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj

Institutional Controls

Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge Sediment With Off-site Disposal

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	119	ac		$1,904,000
Dredging - 12 hour shifts	174	Day	1.338461538	$991,800
Dredge Monitoring (Water Quality)	174	Day		$522,000
Sediment Removal QA	174	Day		$208,800
Site Restoration	5	Each		$3,000,000
Direct Capital:				$7,976,600
Engineering, Procurement & Construction Management:				957,192
Contractor Overhead/Profit:				1,196,490
Total Capital:				**$10,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641

Direct Capital:	$2,675,115
Engineering, Procurement & Construction Management:	321,014
Total Capital:	**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	138,380,705	gal	$55,352
Water Treatment QA	244	day	$48,800

Direct Capital:	$795,388
Engineering, Procurement & Construction Management:	95,447
Total Capital:	**$900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	216,541	ton	$5,413,525
Lime Purchase	21,655	ton	$1,299,300
Soil Loading	216,541	ton	$606,315
Soil Hauling	216,541	ton	$1,015,036
Tipping Fees (non-TSCA)	216,541	ton	$9,311,263

Direct Capital:	$17,645,439
Engineering, Procurement & Construction Management:	2,117,453
Total Capital:	**$19,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$38,300,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	119	ac		$1,904,000
Dredging - 12 hour shifts	174	Day	1.338461538	$991,800
Dredge Monitoring (Water Quality)	174	Day		$522,000
Sediment Removal QA	174	Day		$208,800
Site Restoration	5	Each		$3,000,000
Direct Capital:				$7,976,600
Engineering, Procurement & Construction Management:				957,192
Contractor Overhead/Profit:				1,196,490
Total Capital:				**$10,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	138,380,705	gal	$55,352
Water Treatment QA	244	day	$48,800
Direct Capital:			$795,388
Engineering, Procurement & Construction Management:			95,447
Total Capital:			**$900,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	216,541	ton	$5,846,596
Soil Loading	216,541	ton	$606,314
Soil Hauling	216,541	ton	$253,758
Direct Capital:			$6,706,668
Engineering, Procurement & Construction Management:			$1,006,000
Total Capital:			**$7,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$26,200,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
APPLETON TO LITTLE RAPIDS
Action Level - 250 ppb

Material Handling Assumptions:							
Volume > 250 ppb	80,611	cy	73	ac	61,535	m3	Acres corresponds to dredge
Volume > 125 ppb	182,450	cy			139,275	m3	footprint area
Volume > 500 ppb	56,998	cy			43,510	m3	
Volume > 1,000 ppb	46,178	cy			35,250	m3	
Volume > 5000 ppb	20,148	cy			15,380	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.4						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.7%	v/v	0.98	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density	20%	w/w	9.4%	v/v	0.95	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	29.4%	v/v	1.19	tons per cy	Foth & VanDyke
Treated Density	93.5%	w/w	60.0%	v/v	1.30	tons per cy	
HTTD Treatment Capacity	1,264,377	cy	in situ		1,650,000	tons	
Vitrification Treatment Capacity	1,328,888	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Vitrification							
Vitrification	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
<u>Dewatering - Upland Pond (2 cells)</u>							
Land Lease or Purchase	$1.80	per sf					Ole
Area	608,771	sf	13.97546543				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,121	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
<u>Dewatering - Mechanical</u>							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
<u>Water Treatment</u>							
Flow Rate	395	gpm					assume operate 24/7
Unit, Purchase	$691,235	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					
Water Treatment QA	$200	per day					
Flow Rate (mechanical dewatering)	484	gpm					pj
Unit, Purchase (mechanical dewatering)	$780,778	LS					pj, 1 sample/day

Disposal			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge Sediment With Off-site Disposal

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	73	ac		$1,168,000
Dredging - 12 hour shifts	77	Day	0.592307692	$438,900
Dredge Monitoring (Water Quality)	77	Day		$231,000
Sediment Removal QA	77	Day		$92,400
Site Restoration	5	Each		$3,000,000
Direct Capital:				$6,280,300
Engineering, Procurement & Construction Management:				753,636
Contractor Overhead/Profit:				942,045
Total Capital:				**$8,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641

Direct Capital:	$2,675,115
Engineering, Procurement & Construction Management:	321,014
Total Capital:	**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	61,139,879	gal	$24,456
Water Treatment QA	108	day	$21,600

Direct Capital:	$737,291
Engineering, Procurement & Construction Management:	88,475
Total Capital:	**$800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	95,673	ton	$2,391,825
Lime Purchase	9,568	ton	$574,080
Soil Loading	95,673	ton	$267,884
Soil Hauling	95,673	ton	$448,467
Tipping Fees (non-TSCA)	95,673	ton	$4,113,939

Direct Capital:	$7,796,196
Engineering, Procurement & Construction Management:	935,543
Total Capital:	**$8,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$25,000,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	73	ac		$1,168,000
Dredging - 12 hour shifts	77	Day	0.592307692	$438,900
Dredge Monitoring (Water Quality)	77	Day		$231,000
Sediment Removal QA	77	Day		$92,400
Site Restoration	5	Each		$3,000,000
Direct Capital:				$6,280,300
Engineering, Procurement & Construction Management:				753,636
Contractor Overhead/Profit:				942,045
Total Capital:				**$8,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	61,139,879	gal	$24,456
Water Treatment QA	108	day	$21,600
Direct Capital:			$737,291
Engineering, Procurement & Construction Management:			88,475
Total Capital:			**$800,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	95,673	ton	$2,583,165
Soil Loading	95,673	ton	$267,884
Soil Hauling	95,673	ton	$112,117
Direct Capital:			$2,963,165
Engineering, Procurement & Construction Management:			$444,475
Total Capital:			**$3,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$19,700,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
APPLETON TO LITTLE RAPIDS
Action Level - 500 ppb

Material Handling Assumptions:							
Volume > 500 ppb	56,998	cy	48	ac	43,510	m3	Acres corresponds to dredge
Volume > 125 ppb	182,450	cy			139,275	m3	footprint area
Volume > 250 ppb	80,611	cy			61,535	m3	
Volume > 1,000 ppb	46,178	cy			35,250	m3	
Volume > 5000 ppb	20,148	cy			15,380	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.4						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.7%	v/v	0.98	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density	20%	w/w	9.4%	v/v	0.95	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	29.4%	v/v	1.19	tons per cy	Foth & VanDyke
Treated Density	93.5%	w/w	60.0%	v/v	1.30	tons per cy	
HTTD Treatment Capacity	1,264,377	cy	in situ		1,650,000	tons	
Vitrification Treatment Capacity	1,328,888	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Vitrification							
Vitrification	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area	608,771	sf	13.97546543				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,121	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate	395	gpm					assume operate 24/7
Unit, Purchase	$691,235	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					
Water Treatment QA	$200	per day					
Flow Rate (mechanical dewatering)	484	gpm					pj
Unit, Purchase (mechanical dewatering)	$780,778	LS					pj, 1 sample/day

<u>Disposal</u>			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
<u>Institutional Controls</u>			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
<u>Annual Costs</u>			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge Sediment With Off-site Disposal

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	48	ac		$768,000
Dredging - 12 hour shifts	55	Day	0.423076923	$313,500
Dredge Monitoring (Water Quality)	55	Day		$165,000
Sediment Removal QA	55	Day		$66,000
Site Restoration	5	Each		$3,000,000
Direct Capital:				$5,662,500
Engineering, Procurement & Construction Management:				679,500
Contractor Overhead/Profit:				849,375
Total Capital:				**$7,200,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641

Direct Capital:	$2,675,115
Engineering, Procurement & Construction Management:	321,014
Total Capital:	**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	43,230,619	gal	$17,292
Water Treatment QA	76	day	$15,200

Direct Capital:	$723,728
Engineering, Procurement & Construction Management:	86,847
Total Capital:	**$800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	67,649	ton	$1,691,225
Lime Purchase	6,765	ton	$405,900
Soil Loading	67,649	ton	$189,417
Soil Hauling	67,649	ton	$317,105
Tipping Fees (non-TSCA)	67,649	ton	$2,908,907

Direct Capital:	$5,512,554
Engineering, Procurement & Construction Management:	661,506
Total Capital:	**$6,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$21,700,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	48	ac		$768,000
Dredging - 12 hour shifts	55	Day	0.423076923	$313,500
Dredge Monitoring (Water Quality)	55	Day		$165,000
Sediment Removal QA	55	Day		$66,000
Site Restoration	5	Each		$3,000,000
Direct Capital:				$5,662,500
Engineering, Procurement & Construction Management:				679,500
Contractor Overhead/Profit:				849,375
Total Capital:				**$7,200,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	43,230,619	gal	$17,292
Water Treatment QA	76	day	$15,200
Direct Capital:			$723,728
Engineering, Procurement & Construction Management:			86,847
Total Capital:			**$800,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	67,648	ton	$1,826,497
Soil Loading	67,648	ton	$189,415
Soil Hauling	67,648	ton	$79,275
Direct Capital:			$2,095,187
Engineering, Procurement & Construction Management:			$314,278
Total Capital:			**$2,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$17,900,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
APPLETON TO LITTLE RAPIDS
Action Level - 1,000 ppb

Material Handling Assumptions:							
Volume > 1000 ppb	46,178	cy	34	ac	35,250	m3	Acres corresponds to dredge
Volume > 125 ppb	182,450	cy			139,275	m3	footprint area
Volume > 250 ppb	80,611	cy			61,535	m3	
Volume > 500 ppb	56,998	cy			43,510	m3	
Volume > 5000 ppb	20,148	cy			15,380	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.4						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.7%	v/v	0.98	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density	20%	w/w	9.4%	v/v	0.95	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	29.4%	v/v	1.19	tons per cy	Foth & VanDyke
Treated Density	93.5%	w/w	60.0%	v/v	1.30	tons per cy	
HTTD Treatment Capacity	1,264,377	cy	in situ		1,650,000	tons	
Vitrification Treatment Capacity	1,328,888	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Vitrification							
Vitrification	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
<u>Dewatering - Upland Pond (2 cells)</u>							
Land Lease or Purchase	$1.80	per sf					Ole
Area	608,771	sf	13.97546543				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,121	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
<u>Dewatering - Mechanical</u>							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
<u>Water Treatment</u>							
Flow Rate	395	gpm					assume operate 24/7
Unit, Purchase	$691,235	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					
Water Treatment QA	$200	per day					
Flow Rate (mechanical dewatering)	484	gpm					pj
Unit, Purchase (mechanical dewatering)	$780,778	LS					pj, 1 sample/day

Disposal			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge Sediment With Off-site Disposal

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	34	ac		$544,000
Dredging - 12 hour shifts	44	Day	0.338461538	$250,800
Dredge Monitoring (Water Quality)	44	Day		$132,000
Sediment Removal QA	44	Day		$52,800
Site Restoration	5	Each		$3,000,000
Direct Capital:				$5,329,600
Engineering, Procurement & Construction Management:				639,552
Contractor Overhead/Profit:				799,440
Total Capital:				**$6,800,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	35,023,657	gal	$14,009
Water Treatment QA	62	day	$12,400
Direct Capital:			$717,645
Engineering, Procurement & Construction Management:			86,117
Total Capital:			**$800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	54,806	ton	$1,370,150
Lime Purchase	5,481	ton	$328,860
Soil Loading	54,806	ton	$153,457
Soil Hauling	54,806	ton	$256,903
Tipping Fees (non-TSCA)	54,806	ton	$2,356,658
Direct Capital:			$4,466,028
Engineering, Procurement & Construction Management:			535,923
Total Capital:			**$5,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$20,100,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	34	ac		$544,000
Dredging - 12 hour shifts	44	Day	0.338461538	$250,800
Dredge Monitoring (Water Quality)	44	Day		$132,000
Sediment Removal QA	44	Day		$52,800
Site Restoration	5	Each		$3,000,000
Direct Capital:				$5,329,600
Engineering, Procurement & Construction Management:				639,552
Contractor Overhead/Profit:				799,440
Total Capital:				**$6,800,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	35,023,657	gal	$14,009
Water Treatment QA	62	day	$12,400
Direct Capital:			$717,645
Engineering, Procurement & Construction Management:			86,117
Total Capital:			**$800,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	54,806	ton	$1,479,752
Soil Loading	54,806	ton	$153,456
Soil Hauling	54,806	ton	$64,225
Direct Capital:			$1,697,433
Engineering, Procurement & Construction Management:			$254,615
Total Capital:			**$2,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$17,100,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
APPLETON TO LITTLE RAPIDS
Action Level - 5,000 ppb

Material Handling Assumptions:							
Volume > 5000 ppb	20,148	cy	13	ac	15,380	m3	Acres corresponds to dredge
Volume > 125 ppb	182,450	cy			139,275	m3	footprint area
Volume > 250 ppb	80,611	cy			61,535	m3	
Volume > 500 ppb	56,998	cy			43,510	m3	
Volume > 1000 ppb	46,178	cy			35,250	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.4						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	24.2%	w/w	11.7%	v/v	0.98	tons per cy	
Slurry Density (20% in situ)	5.5%	w/w	2.3%	v/v	0.87	tons per cy	Ogden Beeman
Dewatered Density	20%	w/w	9.4%	v/v	0.95	tons per cy	Montgomery Watson
Dewatered Density (mechanical and CDF)	50%	w/w	29.4%	v/v	1.19	tons per cy	Foth & VanDyke
Treated Density	93.5%	w/w	60.0%	v/v	1.30	tons per cy	
HTTD Treatment Capacity	1,264,377	cy	in situ		1,650,000	tons	
Vitrification Treatment Capacity	1,328,888	cy	in situ		2145500.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Vitrification							
Vitrification	$27.0	per ton (250 glass ton per day melter unit)					Unit Cost Study- Minergy
<u>Dewatering - Upland Pond (2 cells)</u>							
Land Lease or Purchase	$1.80	per sf					Ole
Area	608,771	sf	13.97546543				2 days slurry + 13 wk solids * 2 cell
Perimeter	3,121	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
<u>Dewatering - Mechanical</u>							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
<u>Water Treatment</u>							
Flow Rate	395	gpm					assume operate 24/7
Unit, Purchase	$691,235	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					
Water Treatment QA	$200	per day					
Flow Rate (mechanical dewatering)	484	gpm					pj
Unit, Purchase (mechanical dewatering)	$780,778	LS					pj, 1 sample/day

Disposal			
Off-Site Disposal			
Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge Sediment With Off-site Disposal

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	13	ac		$208,000
Dredging - 12 hour shifts	20	Day	0.153846154	$114,000
Dredge Monitoring (Water Quality)	20	Day		$60,000
Sediment Removal QA	20	Day		$24,000
Site Restoration	5	Each		$3,000,000
Direct Capital:				$4,756,000
Engineering, Procurement & Construction Management:				570,720
Contractor Overhead/Profit:				713,400
Total Capital:				**$6,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641

Direct Capital:	$2,675,115
Engineering, Procurement & Construction Management:	321,014
Total Capital:	**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	15,281,244	gal	$6,112
Water Treatment QA	27	day	$5,400

Direct Capital:	$702,748
Engineering, Procurement & Construction Management:	84,330
Total Capital:	**$800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	23,913	ton	$597,825
Lime Purchase	2,392	ton	$143,520
Soil Loading	23,913	ton	$66,956
Soil Hauling	23,913	ton	$112,092
Tipping Fees (non-TSCA)	23,913	ton	$1,028,259

Direct Capital:	$1,948,653
Engineering, Procurement & Construction Management:	233,838
Total Capital:	**$2,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$16,500,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	5	Each		$500,000
Mobilization - Equipment and Silt Curtain	5	LS		$850,000
Debris Sweep	13	ac		$208,000
Dredging - 12 hour shifts	20	Day	0.153846154	$114,000
Dredge Monitoring (Water Quality)	20	Day		$60,000
Sediment Removal QA	20	Day		$24,000
Site Restoration	5	Each		$3,000,000
Direct Capital:				$4,756,000
Engineering, Procurement & Construction Management:				570,720
Contractor Overhead/Profit:				713,400
Total Capital:				**$6,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	608,771	sf	$1,095,788
Mobilization	1	LS	$20,000
Clear and Grub	608,771	sf	$27,951
Berm Construction	32,365	cy	$194,193
Rough Grading	608,771	sf	$152,193
Liner Placement	608,771	sf	$913,157
Demob/Disposal	1	LS	$10,000
Regrade	32,365	cy	$194,193
Seed/Sod	67,641	sy	$67,641
Direct Capital:			$2,675,115
Engineering, Procurement & Construction Management:			321,014
Total Capital:			**$3,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	395	gpm	$691,235
Water Treatment (Includes Operator)	15,281,244	gal	$6,112
Water Treatment QA	27	day	$5,400
Direct Capital:			$702,748
Engineering, Procurement & Construction Management:			84,330
Total Capital:			**$800,000**

SEDIMENT TREATMENT (VITRIFICATION 1x250 tons Integrated Storage Unit)

Capital Items	Quantity	Units	Cost
Sediment Treatment	23,912	ton	$645,634
Soil Loading	23,912	ton	$66,955
Soil Hauling	23,912	ton	$28,022
Direct Capital:			$740,611
Engineering, Procurement & Construction Management:			$111,092
Total Capital:			**$900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$15,200,000**

Table 7-8 Cost Summary for Remedial Alternatives - Little Rapids to De Pere

125 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,483,156	$33,900,000	---	---	$3,100,000	$1,700,000	---	---	$181,000,000	$4,500,000	$224,200,000	$44,840,000	$269,040,000
C2A	1,483,156	$43,300,000	---	---	---	$5,100,000	---	---	$19,400,000	$4,500,000	$72,300,000	$14,460,000	$86,760,000
C2B	1,483,156	$43,300,000	---	---	$22,100,000	$5,000,000	---	---	$104,900,000	$4,500,000	$179,800,000	$35,960,000	$215,760,000
C3	1,483,156	$33,900,000	---	---	$53,400,000	$2,600,000	---	---	$67,300,000	$4,500,000	$161,700,000	$32,340,000	$194,040,000
D	1,483,156	$33,900,000	---	---	---	$1,900,000	---	$32,000,000	---	$4,500,000	$72,300,000	$14,460,000	$86,760,000
E	1,483,156	$43,300,000	---	---	$22,100,000	$10,700,000	$62,100,000	---	---	$4,500,000	$142,700,000	$28,540,000	$171,240,000
F	585,020	$23,100,000	---	$40,500,000	$3,100,000	$1,100,000	---	---	$71,400,000	$4,500,000	$143,700,000	$28,740,000	$172,440,000

250 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	1,171,585	$28,600,000	---	---	$3,100,000	$1,500,000	---	---	$143,000,000	$4,500,000	$180,700,000	$36,140,000	$216,840,000
C2A	1,171,585	$37,600,000	---	---	---	$4,900,000	---	---	$16,200,000	$4,500,000	$63,200,000	$12,640,000	$75,840,000
C2B	1,171,585	$37,600,000	---	---	$22,100,000	$4,900,000	---	---	$83,700,000	$4,500,000	$152,800,000	$30,560,000	$183,360,000
C3	1,171,585	$28,600,000	---	---	$42,200,000	$2,400,000	---	---	$53,100,000	$4,500,000	$130,800,000	$26,160,000	$156,960,000
D	1,171,585	$28,600,000	---	---	---	$1,700,000	---	$32,000,000	---	$4,500,000	$66,800,000	$13,360,000	$80,160,000
E	1,171,585	$37,600,000	---	---	$22,100,000	$10,500,000	$49,100,000	---	---	$4,500,000	$123,800,000	$24,760,000	$148,560,000
F	411,065	$19,500,000	---	$36,000,000	$3,100,000	$1,000,000	---	---	$50,200,000	$4,500,000	$114,300,000	$22,860,000	$137,160,000

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	776,791	$20,500,000	---	---	$3,100,000	$1,300,000	---	---	$94,800,000	$4,500,000	$124,200,000	$24,840,000	$149,040,000
C2A	776,791	$30,100,000	---	---	---	$4,700,000	---	---	$12,100,000	$4,500,000	$51,400,000	$10,280,000	$61,680,000
C2B	776,791	$30,100,000	---	---	$22,100,000	$4,700,000	---	---	$56,900,000	$4,500,000	$118,300,000	$23,660,000	$141,960,000
C3	776,791	$20,500,000	---	---	$28,000,000	$2,100,000	---	---	$35,200,000	$4,500,000	$90,300,000	$18,060,000	$108,360,000
D	776,791	$20,500,000	---	---	---	$1,400,000	---	$32,000,000	---	$4,500,000	$58,400,000	$11,680,000	$70,080,000
E	776,791	$30,100,000	---	---	$22,100,000	$10,300,000	$32,500,000	---	---	$4,500,000	$99,500,000	$19,900,000	$119,400,000
F	283,812	$14,600,000	---	$30,100,000	$3,100,000	$900,000	---	---	$34,600,000	$4,500,000	$87,800,000	$17,560,000	$105,360,000

1000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	586,788	$14,800,000	---	---	$3,100,000	$1,100,000	---	---	$71,600,000	$4,500,000	$95,100,000	$19,020,000	$114,120,000
C2A	586,788	$24,700,000	---	---	---	$4,600,000	---	---	$10,100,000	$4,500,000	$43,900,000	$8,780,000	$52,680,000
C2B	586,788	$24,700,000	---	---	$22,100,000	$4,600,000	---	---	$44,000,000	$4,500,000	$99,900,000	$19,980,000	$119,880,000
C3	586,788	$14,800,000	---	---	$21,200,000	$2,000,000	---	---	$26,600,000	$4,500,000	$69,100,000	$13,820,000	$82,920,000
D	586,788	$14,800,000	---	---	---	$1,200,000	---	$32,000,000	---	$4,500,000	$52,500,000	$10,500,000	$63,000,000
E	586,788	$24,700,000	---	---	$22,100,000	$10,300,000	$24,600,000	---	---	$4,500,000	$86,200,000	$17,240,000	$103,440,000
F	170,418	$9,800,000	---	$23,800,000	$3,100,000	$900,000	---	---	$20,800,000	$4,500,000	$62,900,000	$12,580,000	$75,480,000

5000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C1	186,348	$6,900,000	---	---	$3,100,000	$900,000	---	---	$22,700,000	$4,500,000	$38,100,000	$7,620,000	$45,720,000
C2A	186,348	$17,400,000	---	---	---	$4,500,000	---	---	$6,000,000	$4,500,000	$32,400,000	$6,480,000	$38,880,000
C2B	186,348	$17,400,000	---	---	$22,100,000	$4,500,000	---	---	$16,800,000	$4,500,000	$65,300,000	$13,060,000	$78,360,000
C3	186,348	$6,900,000	---	---	$6,800,000	$1,700,000	---	---	$8,500,000	$4,500,000	$28,400,000	$5,680,000	$34,080,000
D	186,348	$6,900,000	---	---	---	$1,000,000	---	$32,000,000	---	$4,500,000	$44,400,000	$8,880,000	$53,280,000
E	186,348	$17,400,000	---	---	$22,100,000	$10,100,000	$7,800,000	---	---	$4,500,000	$61,900,000	$12,380,000	$74,280,000
F	50,160	$5,200,000	---	$15,000,000	$3,100,000	$800,000	---	---	$6,100,000	$4,500,000	$34,700,000	$6,940,000	$41,640,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE RAPIDS TO DE PERE
Action Level - 125 ppb

Material Handling Assumptions:							
Volume > 125 ppb	1,483,156	cy	739	ac	1,132,180	m3	Acres corresponds to dredge footprint area
Volume > 250 ppb	1,171,585	cy			894,340	m3	
Volume > 500 ppb	776,791	cy			592,970	m3	
Volume > 1,000 ppb	586,788	cy			447,930	m3	
Volume > 5000 ppb	186,348	cy			142,250	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.47						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	37.1%	w/w	19.3%	v/v	1.08	tons per cy	
Slurry Density (20% in situ)	9.0%	w/w	3.9%	v/v	0.89	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	14.8%	v/v	1.03	tons per cy	Montgomery Watson
Dewatered Density (CDF or landfill)	50%	w/w	28.8%	v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.7%	w/w	60.0%	v/v	1.33	tons per cy	
HTTD Treatment Capacity	2,198,917	cy			1,650,000	tons	
Cap Volume	898,136	cy			685,600	m3	
Vitrification Treatment Capacity	8,028,121	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft	18	mi			Distance to Town of Holland (map provded by Fred Swed) 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	4	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	11,689,322	sf	1,086,000			m2	
Sand Cap Depth	1.7	feet					
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton		pj, pug mill mixing
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area (1050 cy dredge rate)	636,049	sf	14.60168334				2 days slurry + 13 wk solids * 2 cell
Perimeter (1050 cy dredge rate)	3,190	lf					assume square
Area (2885 cy dredge rate)	5,010,182	sf	115.0179519				2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter (2885 cy dredge rate)	8,953	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate (1 10-inch Dredge; settling pond)	389	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; settling pond)	$684,675	LS					pj
Flow Rate (1 10-inch Dredge; CDF)	456	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; CDF)	$752,984	LS					pj
Flow Rate (2 12-inch Dredges)	3,505	gpm					assume operate 24/7
Unit, Purchase (2 12-inch Dredges)	$2,561,265	LS					pj
Flow Rate (2-12-in Dredges; settling pond)	2,991	gpm					assume operate 24/7
Flow Rate (mechanical dewatering)	1,252	gpm					
Unit, Purchase (mechanical dewatering)	$1,380,892	LS					
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet					Distance from town of Holland to river per map provided by Fred Swed
Disposal							
Off-Site Disposal (Existing NR 500 Commercial)							
Load Soil for Hauling	$2.80	per ton					pj
Round-trip Hauling	2	hours					pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours					pj
Tipping Fee (non-TSCA)	$43	per ton					St. Paul
Tipping Fee (TSCA)	$55	per ton					St. Paul
Truck Rate	$75	per hour					pj
Truck Load	32	tons					pj
Conveyer Facility Construction	1,000,000	LS					pj
Dedicated NR 500 Monofill							
Landfill Construction	$5,611,941						
Landfill Area	140	acres					
Local Siting Fee	$5	per cy					
Closure Cap	$100,000	per acre					
Operating Cost	$500,000	per year					
Post-closure Monitoring	$30,000	per year					
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 12 hour shifts	1413	Day	10.86923077	$8,054,100
Dredge Monitoring (Water Quality)	1413	Day		$4,239,000
Sediment Removal QA	1413	Day		$1,695,600
Site Restoration	1	Each		$600,000
Direct Capital:				$26,682,700
Engineering, Procurement & Construction Management:				3,201,924
Contractor Overhead/Profit:				4,002,405
Total Capital:				**$33,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	1,107,174,048	gal		$442,870
Water Treatment QA	1,978	day		$395,600
Direct Capital:				$1,523,145
Engineering, Procurement & Construction Management:				182,777
Total Capital:				**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	1,982,931	ton		$49,573,275
Lime Purchase	198,294	ton		$11,897,640
Soil Loading	1,982,931	ton		$5,552,207
Soil Hauling	1,982,931	ton		$9,294,989
Tipping Fees (non-TSCA)	1,982,931	ton		$85,266,033
Direct Capital:				$161,584,144
Engineering, Procurement & Construction Management:				19,390,097
Total Capital:				**$181,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$224,200,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 2 12-hour shifts	258	Day	1.417582418	$7,327,200
Dredge Monitoring (Water Quality)	258	Day		$1,548,000
Sediment Removal QA	258	Day		$619,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,580,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$34,125,200
Engineering, Procurement & Construction Management:				4,095,024
Contractor Overhead/Profit:				5,118,780
Total Capital:				**$43,300,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,505	gpm		$2,561,265
Water Treatment (Includes Operator)	1,297,331,997	gal		$518,933
Water Treatment QA	258	day		$103,200
Piping	20,000	ft		$1,340,000
Direct Capital:				$4,523,398
Engineering, Procurement & Construction Management:				542,808
Total Capital:				**$5,100,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$5,611,941
Local Siting Fee	992,071	cy		$4,960,355
Closure	31	acres		$3,074,600
Direct Capital:				$13,646,896
Engineering, Procurement & Construction Management:				1,637,628
Total Capital:				**$15,300,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$19,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST **$72,300,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 2 12-hour shifts	258	Day	1.417582418	$7,327,200
Dredge Monitoring (Water Quality)	258	Day		$1,548,000
Sediment Removal QA	258	Day		$619,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,580,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$34,125,200
Engineering, Procurement & Construction Management:				4,095,024
Contractor Overhead/Profit:				5,118,780
Total Capital:				**$43,300,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	1,107,174,048	gal	$442,870
Water Treatment QA	720	day	$144,000
Piping	20,000	ft	$1,340,000
Direct Capital:			$4,488,135
Engineering, Procurement & Construction Management:			538,576
Total Capital:			**$5,000,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Solidification	1,982,931	ton	$49,573,275
Lime Purchase	198,294	ton	$11,897,640
Sediment Loading	1,982,930	ton	$5,552,205
Sediment Hauling	1,982,930	ton	$9,294,987
Landfill Construction	1	LS	$5,611,941
Local Siting Fee	992,071	cy	$4,960,355
Closure	31	acres	$3,074,600
Direct Capital:			$89,965,003
Engineering, Procurement & Construction Management:			10,795,800
Total Capital:			**$100,800,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$104,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$179,800,000**

ALTERNATIVE C3: Dredge with Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 12 hour shifts	1413	Day	10.86923077	$8,054,100
Dredge Monitoring (Water Quality)	1413	Day		$4,239,000
Sediment Removal QA	1413	Day		$1,695,600
Site Restoration	1	Each		$600,000
Direct Capital:				$26,682,700
Engineering, Procurement & Construction Management:				3,201,924
Contractor Overhead/Profit:				4,002,405
Total Capital:				**$33,900,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	594,879	bdt	$47,590,332
Direct Capital:			$47,690,332
Engineering, Procurement & Construction Management:			5,722,840
Total Capital:			**$53,400,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$1,380,892
Water Treatment (Includes Operator)	1,297,331,997	gal	$518,933
Water Treatment QA	1,978	day	$395,600
Direct Capital:			$2,295,425
Engineering, Procurement & Construction Management:			275,451
Total Capital:			**$2,600,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	1,189,758	ton	$3,331,323
Soil Hauling	1,189,758	ton	$5,576,992
Tipping Fees (non-TSCA)	1,189,758	ton	$51,159,607
Tipping Fees (TSCA)	0	ton	$0
Direct Capital:			$60,067,922
Engineering, Procurement & Construction Management:			7,208,151
Total Capital:			**$67,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$161,700,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 12 hour shifts	1413	Day	10.86923077	$8,054,100
Dredge Monitoring (Water Quality)	1413	Day		$4,239,000
Sediment Removal QA	1413	Day		$1,695,600
Site Restoration	1	Each		$600,000
Direct Capital:				$26,682,700
Engineering, Procurement & Construction Management:				3,201,924
Contractor Overhead/Profit:				4,002,405
Total Capital:				**$33,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$752,984
Water Treatment (Includes Operator)	1,297,331,997	gal	$518,933
Water Treatment QA	1,978	day	$395,600
Direct Capital:			$1,667,517
Engineering, Procurement & Construction Management:			200,102
Total Capital:			**$1,900,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$72,300,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	2	Each		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	739	ac		$11,824,000
Dredging - 2 12-hour shifts	258	Day	1.417582418	$7,327,200
Dredge Monitoring (Water Quality)	258	Day		$1,548,000
Sediment Removal QA	258	Day		$619,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,580,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$34,125,200
Engineering, Procurement & Construction Management:				4,095,024
Contractor Overhead/Profit:				5,118,780
Total Capital:				**$43,300,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	1,107,174,048	gal	$442,870
Water Treatment QA	720	day	$144,000
Piping	95,000	ft	$6,365,000
Direct Capital:			$9,513,135
Engineering, Procurement & Construction Management:			1,141,576
Total Capital:			**$10,700,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	1,982,930	ton	$47,590,332
Soil Loading	1,982,930	ton	$5,552,205
Soil Hauling	1,982,930	ton	$2,323,747
Direct Capital:			$55,466,284
Engineering, Procurement & Construction Management:			$6,655,954
Total Capital:			**$62,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$142,700,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge and Off-site Disposal

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,010,188	tons		$6,061,130
Sand Placement	721,563	cy		$4,329,379
Cobble Purchase and Placement	432,938	cy		$12,988,136
Cap Placement QA	1	LS		$100,000
Direct Capital:				$23,678,645
Engineering, Procurement & Construction Management:				2,841,437
Total Capital:				**$26,520,082**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$530,402	$7,980,581
Total Present Worth, Longer Term O&M Costs				$13,999,099
Total Project Capital and O&M Cost				**$40,500,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	1	Each	$100,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	739	ac	$11,824,000
Dredging - 12 hour shifts	558	Day	$3,180,600
Dredge Monitoring (Water Quality)	558	Day	$1,674,000
Sediment Removal QA	558	Day	$669,600
Site Restoration	1	Each	$600,000
Direct Capital:			$18,218,200
Engineering, Procurement & Construction Management:			2,186,184
Contractor Overhead/Profit:			2,732,730
Total Capital:			**$23,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	389	gpm	$684,675
Water Treatment (Includes Operator)	436,716,588	gal	$174,687
Water Treatment QA	781	Day	$156,200

Direct Capital:	$1,015,562
Engineering, Procurement & Construction Management:	121,867
Total Capital:	**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	782,153	ton	$19,553,825
Lime Purchase	78,216	ton	$4,692,960
Soil Loading	782,153	ton	$2,190,028
Soil Hauling	782,153	ton	$3,666,342
Tipping Fees (non-TSCA)	782,153	ton	$33,632,579

Direct Capital:	$63,735,735
Engineering, Procurement & Construction Management:	7,648,288
Total Capital:	**$71,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$143,700,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE RAPIDS TO DE PERE
Action Level - 250 ppb

Material Handling Assumptions:							
Volume > 250 ppb	1,171,585	cy	665	ac	894,340	m3	Acres corresponds to dredge footprint area
Volume > 125 ppb	1,483,156	cy			1,132,180	m3	
Volume > 500 ppb	776,791	cy			592,970	m3	
Volume > 1,000 ppb	586,788	cy			447,930	m3	
Volume > 5000 ppb	186,348	cy			142,250	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.47						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	37.1%	w/w	19.3%	v/v	1.08	tons per cy	
Slurry Density (20% in situ)	9.0%	w/w	3.9%	v/v	0.89	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	14.8%	v/v	1.03	tons per cy	Montgomery Watson
Dewatered Density (CDF or landfill)	50%	w/w	28.8%	v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.7%	w/w	60.0%	v/v	1.33	tons per cy	
HTTD Treatment Capacity	2,198,917	cy			1,650,000	tons	
Cap Volume	760,521	cy			580,550	m3	
Vitrification Treatment Capacity	8,028,121	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft			18	mi	Distance to Town of Holland (map provded by Fred Swed) 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	4	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	10,155,502	sf	943,500			m2	
Sand Cap Depth	1.7	feet					
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area (1050 cy dredge rate)	636,049	sf					2 days slurry + 13 wk solids * 2 cell
Perimeter (1050 cy dredge rate)	3,190	lf					assume square
Area (2885 cy dredge rate)	5,010,182	sf					2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter (2885 cy dredge rate)	8,953	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate (1 10-inch Dredge; settling pond)	389	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; settling pond)	$684,675	LS					pj
Flow Rate (1 10-inch Dredge; CDF)	456	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; CDF)	$752,984	LS					pj
Flow Rate (2 12-inch Dredges)	3,505	gpm					assume operate 24/7
Unit, Purchase (2 12-inch Dredges)	$2,561,265	LS					pj
Flow Rate (2-12-in Dredges; settling pond)	2,991	gpm					assume operate 24/7
Flow Rate (mechanical dewatering)	1,252	gpm					
Unit, Purchase (mechanical dewatering)	$1,380,892	LS					
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet					Distance from town of Holland to river per map provided by Fred Swed
Disposal							
Off-Site Disposal (Existing NR 500 Commercial)							
Load Soil for Hauling	$2.80	per ton					pj
Round-trip Hauling	2	hours					pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours					pj
Tipping Fee (non-TSCA)	$43	per ton					St. Paul
Tipping Fee (TSCA)	$55	per ton					St. Paul
Truck Rate	$75	per hour					pj
Truck Load	32	tons					pj
Conveyer Facility Construction	1,000,000	LS					pj
Dedicated NR 500 Monofill							
Landfill Construction	$4,433,026						
Landfill Area	140	acres					
Local Siting Fee	$5	per cy					
Closure Cap	$100,000	per acre					
Operating Cost	$500,000	per year					
Post-closure Monitoring	$30,000	per year					
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 12 hour shifts	1116	Day	8.584615385	$6,361,200
Dredge Monitoring (Water Quality)	1116	Day		$3,348,000
Sediment Removal QA	1116	Day		$1,339,200
Site Restoration	1	Each		$600,000
Direct Capital:				$22,558,400
Engineering, Procurement & Construction Management:				2,707,008
Contractor Overhead/Profit:				3,383,760
Total Capital:				**$28,600,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	874,587,113	gal		$349,835
Water Treatment QA	1,563	day		$312,600
Direct Capital:				$1,347,110
Engineering, Procurement & Construction Management:				161,653
Total Capital:				**$1,500,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	1,566,372	ton		$39,159,300
Lime Purchase	156,638	ton		$9,398,280
Soil Loading	1,566,372	ton		$4,385,842
Soil Hauling	1,566,372	ton		$7,342,369
Tipping Fees (non-TSCA)	1,566,372	ton		$67,353,996
Direct Capital:				$127,639,786
Engineering, Procurement & Construction Management:				15,316,774
Total Capital:				**$143,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$180,700,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 2 12-hour shifts	204	Day	1.120879121	$5,793,600
Dredge Monitoring (Water Quality)	204	Day		$1,224,000
Sediment Removal QA	204	Day		$489,600
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,040,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$29,610,600
Engineering, Procurement & Construction Management:				3,553,272
Contractor Overhead/Profit:				4,441,590
Total Capital:				**$37,600,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,505	gpm		$2,561,265
Water Treatment (Includes Operator)	1,024,798,087	gal		$409,919
Water Treatment QA	204	day		$81,600
Piping	20,000	ft		$1,340,000
Direct Capital:				$4,392,785
Engineering, Procurement & Construction Management:				527,134
Total Capital:				**$4,900,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$4,433,026
Local Siting Fee	783,664	cy		$3,918,320
Closure	24	acres		$2,428,711
Direct Capital:				$10,780,057
Engineering, Procurement & Construction Management:				1,293,607
Total Capital:				**$12,100,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$16,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$63,200,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 2 12-hour shifts	204	Day	1.120879121	$5,793,600
Dredge Monitoring (Water Quality)	204	Day		$1,224,000
Sediment Removal QA	204	Day		$489,600
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,040,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$29,610,600
Engineering, Procurement & Construction Management:				3,553,272
Contractor Overhead/Profit:				4,441,590
Total Capital:				**$37,600,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687

Direct Capital:	$19,717,067
Engineering, Procurement & Construction Management:	2,366,048
Total Capital:	**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	874,587,113	gal	$349,835
Water Treatment QA	569	day	$113,800
Piping	20,000	ft	$1,340,000

Direct Capital:	$4,364,900
Engineering, Procurement & Construction Management:	523,788
Total Capital:	**$4,900,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Solidification	1,566,372	ton	$39,159,300
Lime Purchase	156,638	ton	$9,398,280
Sediment Loading	1,566,371	ton	$4,385,839
Sediment Hauling	1,566,371	ton	$7,342,365
Landfill Construction	1	LS	$4,433,026
Local Siting Fee	783,664	cy	$3,918,320
Closure	24	acres	$2,428,711

Direct Capital:	$71,065,840
Engineering, Procurement & Construction Management:	8,527,901
Total Capital:	**$79,600,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389

Total Present Worth, Longer Term O&M Costs	$4,131,432
Total Project Capital and O&M Cost	**$83,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**

TOTAL COST	**$152,800,000**

ALTERNATIVE C3: Dredge with Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 12 hour shifts	1116	Day	8.584615385	$6,361,200
Dredge Monitoring (Water Quality)	1116	Day		$3,348,000
Sediment Removal QA	1116	Day		$1,339,200
Site Restoration	1	Each		$600,000
Direct Capital:				$22,558,400
Engineering, Procurement & Construction Management:				2,707,008
Contractor Overhead/Profit:				3,383,760
Total Capital:				**$28,600,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	469,911	bdt	$37,592,907
Direct Capital:			$37,692,907
Engineering, Procurement & Construction Management:			4,523,149
Total Capital:			**$42,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$1,380,892
Water Treatment (Includes Operator)	1,024,798,087	gal	$409,919
Water Treatment QA	1,563	day	$312,600
Direct Capital:			$2,103,411
Engineering, Procurement & Construction Management:			252,409
Total Capital:			**$2,400,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	939,823	ton	$2,631,503
Soil Hauling	939,823	ton	$4,405,419
Tipping Fees (non-TSCA)	939,823	ton	$40,412,375
Tipping Fees (TSCA)	0	ton	$0
Direct Capital:			$47,449,297
Engineering, Procurement & Construction Management:			5,693,916
Total Capital:			**$53,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$130,800,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 12 hour shifts	1116	Day	8.584615385	$6,361,200
Dredge Monitoring (Water Quality)	1116	Day		$3,348,000
Sediment Removal QA	1116	Day		$1,339,200
Site Restoration	1	Each		$600,000
Direct Capital:				$22,558,400
Engineering, Procurement & Construction Management:				2,707,008
Contractor Overhead/Profit:				3,383,760
Total Capital:				**$28,600,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$752,984
Water Treatment (Includes Operator)	1,024,798,087	gal	$409,919
Water Treatment QA	1,563	day	$312,600
Direct Capital:			$1,475,503
Engineering, Procurement & Construction Management:			177,060
Total Capital:			**$1,700,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$66,800,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	665	ac		$10,640,000
Dredging - 2 12-hour shifts	204	Day	1.120879121	$5,793,600
Dredge Monitoring (Water Quality)	204	Day		$1,224,000
Sediment Removal QA	204	Day		$489,600
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$2,040,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$29,610,600
Engineering, Procurement & Construction Management:				3,553,272
Contractor Overhead/Profit:				4,441,590
Total Capital:				**$37,600,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	874,587,113	gal	$349,835
Water Treatment QA	569	day	$113,800
Piping	95,000	ft	$6,365,000
Direct Capital:			$9,389,900
Engineering, Procurement & Construction Management:			1,126,788
Total Capital:			**$10,500,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	1,566,371	ton	$37,592,907
Soil Loading	1,566,371	ton	$4,385,839
Soil Hauling	1,566,371	ton	$1,835,591
Direct Capital:			$43,814,337
Engineering, Procurement & Construction Management:			$5,257,720
Total Capital:			**$49,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$123,800,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge and Off-site Disposal

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	877,636	tons		$5,265,816
Sand Placement	626,883	cy		$3,761,297
Cobble Purchase and Placement	376,130	cy		$11,283,892
Cap Placement QA	1	LS		$100,000
Direct Capital:				$20,611,005
Engineering, Procurement & Construction Management:				2,473,321
Total Capital:				**$23,084,326**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$461,687	$6,946,672
Total Present Worth, Longer Term O&M Costs				$12,965,191
Total Project Capital and O&M Cost				**$36,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	1	Each	$100,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	665	ac	$10,640,000
Dredging - 12 hour shifts	392	Day	$2,234,400
Dredge Monitoring (Water Quality)	392	Day	$1,176,000
Sediment Removal QA	392	Day	$470,400
Site Restoration	1	Each	$600,000
Direct Capital:			$15,390,800
Engineering, Procurement & Construction Management:			1,846,896
Contractor Overhead/Profit:			2,308,620
Total Capital:			**$19,500,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	306,859,461	gal		$122,744
Water Treatment QA	549	Day		$109,800
Direct Capital:				$917,219
Engineering, Procurement & Construction Management:				110,066
Total Capital:				**$1,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units		Cost
Solidification	549,581	ton		$13,739,525
Lime Purchase	54,959	ton		$3,297,540
Soil Loading	549,581	ton		$1,538,827
Soil Hauling	549,581	ton		$2,576,161
Tipping Fees (non-TSCA)	549,581	ton		$23,631,983
Direct Capital:				$44,784,036
Engineering, Procurement & Construction Management:				5,374,084
Total Capital:				**$50,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$114,300,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE RAPIDS TO DE PERE
Action Level - 500 ppb

Material Handling Assumptions:							
Volume > 500 ppb	776,791	cy	498 ac		592,970	m3	Acres corresponds to dredge footprint area
Volume > 125 ppb	1,483,156	cy			1,132,180	m3	
Volume > 250 ppb	1,171,585	cy			894,340	m3	
Volume > 1,000 ppb	586,788	cy			447,930	m3	
Volume > 5000 ppb	186,348	cy			142,250	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.47						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	37.1%	w/w	19.3% v/v		1.08	tons per cy	
Slurry Density (20% in situ)	9.0%	w/w	3.9% v/v		0.89	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	14.8% v/v		1.03	tons per cy	Montgomery Watson
Dewatered Density (CDF or landfill)	50%	w/w	28.8% v/v		1.20	tons per cy	Foth & VanDyke
Treated Density	93.7%	w/w	60.0% v/v		1.33	tons per cy	
HTTD Treatment Capacity	2,198,917	cy			1,650,000	tons	
Cap Volume	492,979	cy			376,320	m3	
Vitrification Treatment Capacity	8,028,121	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft		18 mi			Distance to Town of Holland (map provded by Fred Swed) 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	4	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	8,117,944	sf		754,200		m2	
Sand Cap Depth	1.7	feet					
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF	Arrowhead		Menasha				
Land Lease or Purchase	$1.8	per sf	$1.8				Ole
Length	8,000	lf	9,200				Baird
Capping Volume	190,000	cy	170,000				Baird
Seeding Area	280,000	sy	250,000				Baird
Sheetpile Wall Length	8,000	lf	9,200				Baird
Sheetpile Depth	30	ft	30				based on bathymetry
Sheetpile Cost	$19	per sf	$19				pj
Shot Rock Berm	$650	per lf	$550				Baird
Rip Rap	$215	per lf	$250				Baird
Place Treated Material	$2	per cy	$2				pj
Clean Soil Cap	$10	per cy	$10				Baird
Seeding	$1	per sy	$1				Baird
Mitigation	$10,000	per acre					Tim
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					Anne LTM
Long-term O&M	2%	of capital					pj
Solidification							
Percent Lime	10.0%	(w/w)					Montgomery Watson
Lime	$60	per ton	Mixing		$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)							
Land Lease or Purchase	$1.80	per sf					Ole
Area (1050 cy dredge rate)	636,049	sf					2 days slurry + 13 wk solids * 2 cell
Perimeter (1050 cy dredge rate)	3,190	lf					assume square
Area (2885 cy dredge rate)	5,010,182	sf					2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter (2885 cy dredge rate)	8,953	lf					assume square
Depth of Material in Dewatering Cell	8	feet					based on size at Arrowhead Park
Cell Retention Time	24	hours					Not Used
Cell Depth	10	feet					
Mobilization	$20,000	LS					pj
Clear and Grub	$2,000	per acre					pj
Berm Volume	10.4	cy per lf					2:1 slope, 8-foot top
Berm Construction	$6	per cy					pj
Rough Grading	$0.25	per sf					pj
Asphalt Liner	$1.50	per sf					pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS					pj
Regrade Berm Soils	$6	per cy					pj
Seed/Sod	$1	per sy					Baird
Dewatering - Mechanical							
Mobilization	$100,000						pj
Holding Pond-Centrifuge	$80	per bone dry ton					Global Dewatering
Water Treatment							
Flow Rate (1 10-inch Dredge; settling pond)	389	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; settling pond)	$684,675	LS					pj
Flow Rate (1 10-inch Dredge; CDF)	456	gpm					assume operate 24/7
Unit, Purchase (1 10-inch Dredge; CDF)	$752,984	LS					pj
Flow Rate (2 12-inch Dredges)	3,505	gpm					assume operate 24/7
Unit, Purchase (2 12-inch Dredges)	$2,561,265	LS					pj
Flow Rate (2-12-in Dredges; settling pond)	2,991	gpm					assume operate 24/7
Flow Rate (mechanical dewatering)	1,252	gpm					
Unit, Purchase (mechanical dewatering)	$1,380,892	LS					
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet					Distance from town of Holland to river per map provided by Fred Swed
Disposal							
Off-Site Disposal (Existing NR 500 Commercial)							
Load Soil for Hauling	$2.80	per ton					pj
Round-trip Hauling	2	hours					pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours					pj
Tipping Fee (non-TSCA)	$43	per ton					St. Paul
Tipping Fee (TSCA)	$55	per ton					St. Paul
Truck Rate	$75	per hour					pj
Truck Load	32	tons					pj
Conveyer Facility Construction	1,000,000	LS					pj
Dedicated NR 500 Monofill							
Landfill Construction	$2,939,208						
Landfill Area	140	acres					
Local Siting Fee	$5	per cy					
Closure Cap	$100,000	per acre					
Operating Cost	$500,000	per year					
Post-closure Monitoring	$30,000	per year					
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 12 hour shifts	740	Day	5.692307692	$4,218,000
Dredge Monitoring (Water Quality)	740	Day		$2,220,000
Sediment Removal QA	740	Day		$888,000
Site Restoration	1	Each		$600,000
Direct Capital:				$16,164,000
Engineering, Procurement & Construction Management:				1,939,680
Contractor Overhead/Profit:				2,424,600
Total Capital:				**$20,500,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	579,873,337	gal		$231,949
Water Treatment QA	1,036	day		$207,200
Direct Capital:				$1,123,825
Engineering, Procurement & Construction Management:				134,859
Total Capital:				**$1,300,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	1,038,544	ton		$25,963,600
Lime Purchase	103,855	ton		$6,231,300
Soil Loading	1,038,544	ton		$2,907,923
Soil Hauling	1,038,544	ton		$4,868,175
Tipping Fees (non-TSCA)	1,038,544	ton		$44,657,392
Direct Capital:				$84,628,390
Engineering, Procurement & Construction Management:				10,155,407
Total Capital:				**$94,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$124,200,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 2 12-hour shifts	135	Day	0.741758242	$3,834,000
Dredge Monitoring (Water Quality)	135	Day		$810,000
Sediment Removal QA	135	Day		$324,000
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,350,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$23,709,400
Engineering, Procurement & Construction Management:				2,845,128
Contractor Overhead/Profit:				3,556,410
Total Capital:				**$30,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,505	gpm		$2,561,265
Water Treatment (Includes Operator)	679,467,005	gal		$271,787
Water Treatment QA	135	day		$54,000
Piping	20,000	ft		$1,340,000
Direct Capital:				$4,227,052
Engineering, Procurement & Construction Management:				507,246
Total Capital:				**$4,700,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$2,939,208
Local Siting Fee	519,589	cy		$2,597,945
Closure	16	acres		$1,610,296
Direct Capital:				$7,147,450
Engineering, Procurement & Construction Management:				857,694
Total Capital:				**$8,000,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$12,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST **$51,400,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 2 12-hour shifts	135	Day	0.741758242	$3,834,000
Dredge Monitoring (Water Quality)	135	Day		$810,000
Sediment Removal QA	135	Day		$324,000
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,350,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$23,709,400
Engineering, Procurement & Construction Management:				2,845,128
Contractor Overhead/Profit:				3,556,410
Total Capital:				**$30,100,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	579,873,337	gal	$231,949
Water Treatment QA	377	day	$75,400
Piping	20,000	ft	$1,340,000
Direct Capital:			$4,208,615
Engineering, Procurement & Construction Management:			505,034
Total Capital:			**$4,700,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Solidification	1,038,544	ton	$25,963,600
Lime Purchase	103,855	ton	$6,231,300
Sediment Loading	1,038,544	ton	$2,907,922
Sediment Hauling	1,038,544	ton	$4,868,173
Landfill Construction	1	LS	$2,939,208
Local Siting Fee	519,589	cy	$2,597,945
Closure	16	acres	$1,610,296
Direct Capital:			$47,118,445
Engineering, Procurement & Construction Management:			5,654,213
Total Capital:			**$52,800,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$56,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$118,300,000**

ALTERNATIVE C3: Dredge with Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 12 hour shifts	740	Day	5.692307692	$4,218,000
Dredge Monitoring (Water Quality)	740	Day		$2,220,000
Sediment Removal QA	740	Day		$888,000
Site Restoration	1	Each		$600,000
Direct Capital:				$16,164,000
Engineering, Procurement & Construction Management:				1,939,680
Contractor Overhead/Profit:				2,424,600
Total Capital:				**$20,500,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	311,563	bdt	$24,925,046
Direct Capital:			$25,025,046
Engineering, Procurement & Construction Management:			3,003,006
Total Capital:			**$28,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$1,380,892
Water Treatment (Includes Operator)	679,467,005	gal	$271,787
Water Treatment QA	1,036	day	$207,200
Direct Capital:			$1,859,879
Engineering, Procurement & Construction Management:			223,185
Total Capital:			**$2,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	623,126	ton	$1,744,753
Soil Hauling	623,126	ton	$2,920,904
Tipping Fees (non-TSCA)	623,126	ton	$26,794,425
Tipping Fees (TSCA)	0	ton	$0
Direct Capital:			$31,460,082
Engineering, Procurement & Construction Management:			3,775,210
Total Capital:			**$35,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$90,300,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 12 hour shifts	740	Day	5.692307692	$4,218,000
Dredge Monitoring (Water Quality)	740	Day		$2,220,000
Sediment Removal QA	740	Day		$888,000
Site Restoration	1	Each		$600,000
Direct Capital:				$16,164,000
Engineering, Procurement & Construction Management:				1,939,680
Contractor Overhead/Profit:				2,424,600
Total Capital:				**$20,500,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$752,984
Water Treatment (Includes Operator)	679,467,005	gal	$271,787
Water Treatment QA	1,036	day	$207,200
Direct Capital:			$1,231,971
Engineering, Procurement & Construction Management:			147,837
Total Capital:			**$1,400,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$58,400,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 2 12-hour shifts	135	Day	0.741758242	$3,834,000
Dredge Monitoring (Water Quality)	135	Day		$810,000
Sediment Removal QA	135	Day		$324,000
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,350,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$23,709,400
Engineering, Procurement & Construction Management:				2,845,128
Contractor Overhead/Profit:				3,556,410
Total Capital:				**$30,100,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	579,873,337	gal	$231,949
Water Treatment QA	377	day	$75,400
Piping	95,000	ft	$6,365,000
Direct Capital:			$9,233,615
Engineering, Procurement & Construction Management:			1,108,034
Total Capital:			**$10,300,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	1,038,544	ton	$24,925,046
Soil Loading	1,038,544	ton	$2,907,922
Soil Hauling	1,038,544	ton	$1,217,043
Direct Capital:			$29,050,012
Engineering, Procurement & Construction Management:			$3,486,001
Total Capital:			**$32,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$99,500,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge and Off-site Disposal

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	701,551	tons		$4,209,304
Sand Placement	501,108	cy		$3,006,646
Cobble Purchase and Placement	300,665	cy		$9,019,938
Cap Placement QA	1	LS		$100,000
Direct Capital:				$16,535,888
Engineering, Procurement & Construction Management:				1,984,307
Total Capital:				**$18,520,194**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$370,404	$5,573,207
Total Present Worth, Longer Term O&M Costs				$11,591,726
Total Project Capital and O&M Cost				**$30,100,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	498	ac		$7,968,000
Dredging - 12 hour shifts	271	Day		$1,544,700
Dredge Monitoring (Water Quality)	271	Day		$813,000
Sediment Removal QA	271	Day		$325,200
Site Restoration	1	Each		$600,000
Direct Capital:				$11,520,900
Engineering, Procurement & Construction Management:				1,382,508
Contractor Overhead/Profit:				1,728,135
Total Capital:				**$14,600,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672

Direct Capital:	$2,784,842
Engineering, Procurement & Construction Management:	334,181
Total Capital:	**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	389	gpm	$684,675
Water Treatment (Includes Operator)	211,864,949	gal	$84,746
Water Treatment QA	379	Day	$75,800

Direct Capital:	$845,221
Engineering, Procurement & Construction Management:	101,427
Total Capital:	**$900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units	Cost
Solidification	379,447	ton	$9,486,175
Lime Purchase	37,945	ton	$2,276,700
Soil Loading	379,447	ton	$1,062,452
Soil Hauling	379,447	ton	$1,778,658
Tipping Fees (non-TSCA)	379,447	ton	$16,316,221

Direct Capital:	$30,920,205
Engineering, Procurement & Construction Management:	3,710,425
Total Capital:	**$34,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$87,800,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE RAPIDS TO DE PERE
Action Level - 1,000 ppb

Material Handling Assumptions:							
Volume > 1000 ppb	586,788	cy	328 ac		447,930	m3	Acres corresponds to dredge
Volume > 125 ppb	1,483,156	cy			1,132,180	m3	footprint area
Volume > 250 ppb	1,171,585	cy			894,340	m3	
Volume > 500 ppb	776,791	cy			592,970	m3	
Volume > 5000 ppb	186,348	cy			142,250	m3	
Volume > 50,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.47						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	37.1%	w/w	19.3%	v/v	1.08	tons per cy	
Slurry Density (20% in situ)	9.0%	w/w	3.9%	v/v	0.89	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	14.8%	v/v	1.03	tons per cy	Montgomery Watson
Dewatered Density (CDF or landfill)	50%	w/w	28.8%	v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.7%	w/w	60.0%	v/v	1.33	tons per cy	
HTTD Treatment Capacity	2,198,917	cy			1,650,000	tons	
Cap Volume	416,370	cy			317,840	m3	
Vitrification Treatment Capacity	8,028,121	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Debris Sweep	$16,000	per acre					Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Hydraulic - 10-inch Cutterhead							
Site Preparation	$100,000	per dredge launch site					pj
Mobilization - Equipment	$135,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift					Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					pj
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft		18 mi			Distance to Town of Holland (map provded by Fred Swed) 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	4	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	5,945,840	sf		552,400		m2	
Sand Cap Depth	1.7	feet					
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

	Arrowhead		Menasha			Source
Nearshore CDF						
Land Lease or Purchase	$1.8	per sf	$1.8			Ole
Length	8,000	lf	9,200			Baird
Capping Volume	190,000	cy	170,000			Baird
Seeding Area	280,000	sy	250,000			Baird
Sheetpile Wall Length	8,000	lf	9,200			Baird
Sheetpile Depth	30	ft	30			based on bathymetry
Sheetpile Cost	$19	per sf	$19			pj
Shot Rock Berm	$650	per lf	$550			Baird
Rip Rap	$215	per lf	$250			Baird
Place Treated Material	$2	per cy	$2			pj
Clean Soil Cap	$10	per cy	$10			Baird
Seeding	$1	per sy	$1			Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area (1050 cy dredge rate)	636,049	sf				2 days slurry + 13 wk solids * 2 cell
Perimeter (1050 cy dredge rate)	3,190	lf				assume square
Area (2885 cy dredge rate)	5,010,182	sf				2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter (2885 cy dredge rate)	8,953	lf				assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				pj
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Asphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Water Treatment						
Flow Rate (1 10-inch Dredge; settling pond)	389	gpm				assume operate 24/7
Unit, Purchase (1 10-inch Dredge; settling pond)	$684,675	LS				pj
Flow Rate (1 10-inch Dredge; CDF)	456	gpm				assume operate 24/7
Unit, Purchase (1 10-inch Dredge; CDF)	$752,984	LS				pj
Flow Rate (2 12-inch Dredges)	3,505	gpm				assume operate 24/7
Unit, Purchase (2 12-inch Dredges)	$2,561,265	LS				pj
Flow Rate (2-12-in Dredges; settling pond)	2,991	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	1,252	gpm				
Unit, Purchase (mechanical dewatering)	$1,380,892	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Off-Site Disposal (Existing NR 500 Commercial)						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer Facility Construction	1,000,000	LS				pj
Dedicated NR 500 Monofill						
Landfill Construction	$2,220,280					
Landfill Area	140	acres				
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				
Institutional Controls						
Public Education Program	$100,000					pj
O&M Plans	$20,000					pj
Deed Restrictions	$5,000					pj
Annual Costs						
Public Education Program	$30,000					pj
Maintaining O&M Plans	$800					pj
Reporting	$20,000					pj
Long-term Monitoring	$600,000					Anne LTM
Long-term Monitoring (no action)	$300,000					Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 12 hour shifts	559	Day	4.3	$3,186,300
Dredge Monitoring (Water Quality)	559	Day		$1,677,000
Sediment Removal QA	559	Day		$670,800
Site Restoration	1	Each		$600,000
Direct Capital:				$11,652,100
Engineering, Procurement & Construction Management:				1,398,252
Contractor Overhead/Profit:				1,747,815
Total Capital:				**$14,800,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	438,036,771	gal		$175,215
Water Treatment QA	783	day		$156,600
Direct Capital:				$1,016,490
Engineering, Procurement & Construction Management:				121,979
Total Capital:				**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	784,517	ton		$19,612,925
Lime Purchase	78,452	ton		$4,707,120
Soil Loading	784,517	ton		$2,196,648
Soil Hauling	784,517	ton		$3,677,423
Tipping Fees (non-TSCA)	784,517	ton		$33,734,231
Direct Capital:				$63,928,347
Engineering, Procurement & Construction Management:				7,671,402
Total Capital:				**$71,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$95,100,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 2 12-hour shifts	102	Day	0.56043956	$2,896,800
Dredge Monitoring (Water Quality)	102	Day		$612,000
Sediment Removal QA	102	Day		$244,800
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,020,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$19,445,000
Engineering, Procurement & Construction Management:				2,333,400
Contractor Overhead/Profit:				2,916,750
Total Capital:				**$24,700,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,505	gpm		$2,561,265
Water Treatment (Includes Operator)	513,269,905	gal		$205,308
Water Treatment QA	102	day		$40,800
Piping	20,000	ft		$1,340,000
Direct Capital:				$4,147,373
Engineering, Procurement & Construction Management:				497,685
Total Capital:				**$4,600,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$2,220,280
Local Siting Fee	392,498	cy		$1,962,490
Closure	12	acres		$1,216,419
Direct Capital:				$5,399,189
Engineering, Procurement & Construction Management:				647,903
Total Capital:				**$6,000,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$10,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST **$43,900,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 2 12-hour shifts	102	Day	0.56043956	$2,896,800
Dredge Monitoring (Water Quality)	102	Day		$612,000
Sediment Removal QA	102	Day		$244,800
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,020,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$19,445,000
Engineering, Procurement & Construction Management:				2,333,400
Contractor Overhead/Profit:				2,916,750
Total Capital:				**$24,700,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	5,010,182	sf		$9,018,328
Mobilization	1	LS		$20,000
Clear and Grub	5,010,182	sf		$230,036
Berm Construction	92,850	cy		$557,099
Rough Grading	5,010,182	sf		$1,252,545
Liner Placement	5,010,182	sf		$7,515,273
Demob/Disposal	1	LS		$10,000
Regrade	92,850	cy		$557,099
Seed/Sod	556,687	sy		$556,687
Direct Capital:				$19,717,067
Engineering, Procurement & Construction Management:				2,366,048
Total Capital:				**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	2,991	gpm		$2,561,265
Water Treatment (Includes Operator)	438,036,771	gal		$175,215
Water Treatment QA	285	day		$57,000
Piping	20,000	ft		$1,340,000
Direct Capital:				$4,133,480
Engineering, Procurement & Construction Management:				496,018
Total Capital:				**$4,600,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	784,517	ton		$19,612,925
Lime Purchase	78,452	ton		$4,707,120
Sediment Loading	784,517	ton		$2,196,647
Sediment Hauling	784,517	ton		$3,677,422
Landfill Construction	1	LS		$2,220,280
Local Siting Fee	392,498	cy		$1,962,490
Closure	12	acres		$1,216,419
Direct Capital:				$35,593,303
Engineering, Procurement & Construction Management:				4,271,196
Total Capital:				**$39,900,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$44,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$99,900,000**

ALTERNATIVE C3: Dredge with Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 12 hour shifts	559	Day	4.3	$3,186,300
Dredge Monitoring (Water Quality)	559	Day		$1,677,000
Sediment Removal QA	559	Day		$670,800
Site Restoration	1	Each		$600,000
Direct Capital:				$11,652,100
Engineering, Procurement & Construction Management:				1,398,252
Contractor Overhead/Profit:				1,747,815
Total Capital:				**$14,800,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	235,355	bdt	$18,828,399
Direct Capital:			$18,928,399
Engineering, Procurement & Construction Management:			2,271,408
Total Capital:			**$21,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$1,380,892
Water Treatment (Includes Operator)	513,269,905	gal	$205,308
Water Treatment QA	783	day	$156,600
Direct Capital:			$1,742,800
Engineering, Procurement & Construction Management:			209,136
Total Capital:			**$2,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	470,710	ton	$1,317,988
Soil Hauling	470,710	ton	$2,206,453
Tipping Fees (non-TSCA)	470,710	ton	$20,240,529
Tipping Fees (TSCA)	0	ton	$0
Direct Capital:			$23,764,970
Engineering, Procurement & Construction Management:			2,851,796
Total Capital:			**$26,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$69,100,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 12 hour shifts	559	Day	4.3	$3,186,300
Dredge Monitoring (Water Quality)	559	Day		$1,677,000
Sediment Removal QA	559	Day		$670,800
Site Restoration	1	Each		$600,000
Direct Capital:				$11,652,100
Engineering, Procurement & Construction Management:				1,398,252
Contractor Overhead/Profit:				1,747,815
Total Capital:				**$14,800,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$752,984
Water Treatment (Includes Operator)	513,269,905	gal	$205,308
Water Treatment QA	783	day	$156,600
Direct Capital:			$1,114,892
Engineering, Procurement & Construction Management:			133,787
Total Capital:			**$1,200,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$52,500,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	328	ac		$5,248,000
Dredging - 2 12-hour shifts	102	Day	0.56043956	$2,896,800
Dredge Monitoring (Water Quality)	102	Day		$612,000
Sediment Removal QA	102	Day		$244,800
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$1,020,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$19,445,000
Engineering, Procurement & Construction Management:				2,333,400
Contractor Overhead/Profit:				2,916,750
Total Capital:				**$24,700,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	438,036,771	gal	$175,215
Water Treatment QA	285	day	$57,000
Piping	95,000	ft	$6,365,000
Direct Capital:			$9,158,480
Engineering, Procurement & Construction Management:			1,099,018
Total Capital:			**$10,300,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	784,517	ton	$18,828,399
Soil Loading	784,517	ton	$2,196,647
Soil Hauling	784,517	ton	$919,355
Direct Capital:			$21,944,401
Engineering, Procurement & Construction Management:			$2,633,328
Total Capital:			**$24,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$86,200,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge and Off-site Disposal

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	513,838	tons		$3,083,028
Sand Placement	367,027	cy		$2,202,163
Cobble Purchase and Placement	220,216	cy		$6,606,488
Cap Placement QA	1	LS		$100,000
Direct Capital:				$12,191,679
Engineering, Procurement & Construction Management:				1,463,001
Total Capital:				**$13,654,680**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$273,094	$4,109,048
Total Present Worth, Longer Term O&M Costs				$10,127,566
Total Project Capital and O&M Cost				**$23,800,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	1	Each	$100,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	328	ac	$5,248,000
Dredging - 12 hour shifts	163	Day	$929,100
Dredge Monitoring (Water Quality)	163	Day	$489,000
Sediment Removal QA	163	Day	$195,600
Site Restoration	1	Each	$600,000
Direct Capital:			$7,731,700
Engineering, Procurement & Construction Management:			927,804
Contractor Overhead/Profit:			1,159,755
Total Capital:			**$9,800,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672

Direct Capital:	$2,784,842
Engineering, Procurement & Construction Management:	334,181
Total Capital:	**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	389	gpm	$684,675
Water Treatment (Includes Operator)	127,216,760	gal	$50,887
Water Treatment QA	228	Day	$45,600

Direct Capital:	$781,162
Engineering, Procurement & Construction Management:	93,739
Total Capital:	**$900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units	Cost
Solidification	227,844	ton	$5,696,100
Lime Purchase	22,785	ton	$1,367,100
Soil Loading	227,844	ton	$637,963
Soil Hauling	227,844	ton	$1,068,019
Tipping Fees (non-TSCA)	227,844	ton	$9,797,292

Direct Capital:	$18,566,474
Engineering, Procurement & Construction Management:	2,227,977
Total Capital:	**$20,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$62,900,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
LITTLE RAPIDS TO DE PERE
Action Level - 5,000 ppb

Material Handling Assumptions:						
Volume > 5000 ppb	186,348	cy	173 ac	142,250	m3	Acres corresponds to dredge
Volume > 125 ppb	1,483,156	cy		1,132,180	m3	footprint area
Volume > 250 ppb	1,171,585	cy		894,340	m3	
Volume > 500 ppb	776,791	cy		592,970	m3	
Volume > 1000 ppb	586,788	cy		447,930	m3	
Volume > 50,000 ppb	0	cy		0	m3	
Solids Specific Gravity	2.47					
Fresh Water Density	62.4	lb/ft3				
In Situ Density	37.1%	w/w	19.3% v/v	1.08	tons per cy	
Slurry Density (20% in situ)	9.0%	w/w	3.9% v/v	0.89	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	14.8% v/v	1.03	tons per cy	Montgomery Watson
Dewatered Density (CDF or landfill)	50%	w/w	28.8% v/v	1.20	tons per cy	Foth & VanDyke
Treated Density	93.7%	w/w	60.0% v/v	1.33	tons per cy	
HTTD Treatment Capacity	2,198,917	cy		1,650,000	tons	
Cap Volume	136,188	cy		103,960	m3	
Vitrification Treatment Capacity	8,028,121	cy	in situ	6440000.00	tons	
Cost Estimating Parameters & Methodology:						
Interest Rate	6.0%					
Sales Tax	5.5%					Not Used
Engineering, Procurement and Construction Mgmt	12.0%					
Contractor Overhead and Profit - Dredging Only	15.0%					
<u>Dredging</u>						
Debris Sweep	$16,000	per acre				Ogden Beeman
Dredge Monitoring (Water Quality)	$3,000	per day				
Sediment Removal QA	$1,200	per day				
Hydraulic - 10-inch Cutterhead						
Site Preparation	$100,000	per dredge launch site				pj
Mobilization - Equipment	$135,000	per dredge				Ogden Beeman
Mobilization - Silt Curtain	$35,000					Ogden Beeman
Shift Rate (10 hours)	$5,700	per shift				Ogden Beeman
Dredge Rate	1050	cy in situ per 10 hour shift				Ogden Beeman
Site Restoration	$600,000	per dredge launch site				pj
Hydraulic - 2 12-inch Cutterheads						
Site Preparation	$803,400	LS				Ogden Beeman
Mobilization - Equipment	$1,135,000	LS				Ogden Beeman
Mobilization - Silt Curtain	$35,000					Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift				Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift				Ogden Beeman
Winter Over Equipment	$285,000	per year				Ogden Beeman
Site Restoration	$600,000	per dredge launch site				
Length of Piping	95,000	ft	18 mi			Distance to Town of Holland (map provded by Fred Swed) 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft				Ogden Beeman
Number of Road Crossings	4	each				pj, review map
Cost per Road Crossing	$50,000	per crossing				pj, review map
Number of Booster Pumps	4	each				Ogden Beeman
Booster Pump Cost	$2,500	per day				Ogden Beeman
High Temperature Thermal Desorption						
Setup Staging Area	$50,000					pj
Mobilization/Site Prep	$150,000					Maxymillian
Sediment Treatment QA	$2	per ton				
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1				
Sand Purchase and Deliver	$6	per ton				Ole
Blending	$25	per ton				Ole
HTTD (includes off-gas treatment)	$75	per ton				Maxymillian
Stack Testing	$50,000	LS				Maxymillian
Place Treated Material	$3	per ton				
Vitrification						
Capital Costs	$36,000,000	LS				Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year				Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton				Unit Cost Study- Minergy
Capping						
Mobilization/Site Prep	$200,000					Ogden Beeman
Area	2,943,858	sf	273,500		m2	
Sand Cap Depth	1.7	feet				
Placement Rate	$6	per cy				Ogden Beeman
Sand Purchase	$6	per ton				Ole
Sand Density	1.4	tons per cy				
Armored Cap Depth	1.0	feet				
Cobbles	$30	per cy				Means
Cap Placement QA	$100,000	LS				Ogden Beeman
Long-term O&M	2%	of capital				pj
Long-term Monitoring	$400,000	per year				Anne LTM

Nearshore CDF	Arrowhead		Menasha			
Land Lease or Purchase	$1.8	per sf	$1.8			Ole
Length	8,000	lf	9,200			Baird
Capping Volume	190,000	cy	170,000			Baird
Seeding Area	280,000	sy	250,000			Baird
Sheetpile Wall Length	8,000	lf	9,200			Baird
Sheetpile Depth	30	ft	30			based on bathymetry
Sheetpile Cost	$19	per sf	$19			pj
Shot Rock Berm	$650	per lf	$550			Baird
Rip Rap	$215	per lf	$250			Baird
Place Treated Material	$2	per cy	$2			pj
Clean Soil Cap	$10	per cy	$10			Baird
Seeding	$1	per sy	$1			Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area (1050 cy dredge rate)	636,049	sf				2 days slurry + 13 wk solids * 2 cell
Perimeter (1050 cy dredge rate)	3,190	lf				assume square
Area (2885 cy dredge rate)	5,010,182	sf				2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter (2885 cy dredge rate)	8,953	lf				assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				pj
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Asphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Water Treatment						
Flow Rate (1 10-inch Dredge; settling pond)	389	gpm				assume operate 24/7
Unit, Purchase (1 10-inch Dredge; settling pond)	$684,675	LS				pj
Flow Rate (1 10-inch Dredge; CDF)	456	gpm				assume operate 24/7
Unit, Purchase (1 10-inch Dredge; CDF)	$752,984	LS				pj
Flow Rate (2 12-inch Dredges)	3,505	gpm				assume operate 24/7
Unit, Purchase (2 12-inch Dredges)	$2,561,265	LS				pj
Flow Rate (2-12-in Dredges; settling pond)	2,991	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	1,252	gpm				
Unit, Purchase (mechanical dewatering)	$1,380,892	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Off-Site Disposal (Existing NR 500 Commercial)						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer Facility Construction	1,000,000	LS				pj
Dedicated NR 500 Monofill						
Landfill Construction	$705,099					
Landfill Area	140	acres				
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				
Institutional Controls						
Public Education Program	$100,000					pj
O&M Plans	$20,000					pj
Deed Restrictions	$5,000					pj
Annual Costs						
Public Education Program	$30,000					pj
Maintaining O&M Plans	$800					pj
Reporting	$20,000					pj
Long-term Monitoring	$600,000					Anne LTM
Long-term Monitoring (no action)	$300,000					Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs	**Years**	**Annual Cost**		
Long-term Monitoring (no action)	40	$300,000		$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs	**Years**	**Annual Cost**		
Long-term Monitoring	40	$600,000		$9,027,778
Public Education Program	40	$30,000		$451,389
Maintaining O&M Plans	40	$800		$12,037
Reporting	40	$20,000		$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 12 hour shifts	178	Day	1.369230769	$1,014,600
Dredge Monitoring (Water Quality)	178	Day		$534,000
Sediment Removal QA	178	Day		$213,600
Site Restoration	1	Each		$600,000
Direct Capital:				$5,400,200
Engineering, Procurement & Construction Management:				648,024
Contractor Overhead/Profit:				810,030
Total Capital:				**$6,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672
Direct Capital:			$2,784,842
Engineering, Procurement & Construction Management:			334,181
Total Capital:			**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	389	gpm		$684,675
Water Treatment (Includes Operator)	139,108,188	gal		$55,643
Water Treatment QA	249	day		$49,800
Direct Capital:				$790,119
Engineering, Procurement & Construction Management:				94,814
Total Capital:				**$900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	249,141	ton		$6,228,525
Lime Purchase	24,915	ton		$1,494,900
Soil Loading	249,141	ton		$697,595
Soil Hauling	249,141	ton		$1,167,848
Tipping Fees (non-TSCA)	249,141	ton		$10,713,063
Direct Capital:				$20,301,931
Engineering, Procurement & Construction Management:				2,436,232
Total Capital:				**$22,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$38,100,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 2 12-hour shifts	33	Day	0.181318681	$937,200
Dredge Monitoring (Water Quality)	33	Day		$198,000
Sediment Removal QA	33	Day		$79,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$330,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$13,735,800
Engineering, Procurement & Construction Management:				1,648,296
Contractor Overhead/Profit:				2,060,370
Total Capital:				**$17,400,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,505	gpm		$2,561,265
Water Treatment (Includes Operator)	163,000,121	gal		$65,200
Water Treatment QA	33	day		$13,200
Piping	20,000	ft		$1,340,000
Direct Capital:				$3,979,666
Engineering, Procurement & Construction Management:				477,560
Total Capital:				**$4,500,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$705,099
Local Siting Fee	124,646	cy		$623,230
Closure	4	acres		$386,300
Direct Capital:				$1,714,628
Engineering, Procurement & Construction Management:				205,755
Total Capital:				**$1,900,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$6,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST **$32,400,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facility

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 2 12-hour shifts	33	Day	0.181318681	$937,200
Dredge Monitoring (Water Quality)	33	Day		$198,000
Sediment Removal QA	33	Day		$79,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$330,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$13,735,800
Engineering, Procurement & Construction Management:				1,648,296
Contractor Overhead/Profit:				2,060,370
Total Capital:				**$17,400,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	5,010,182	sf		$9,018,328
Mobilization	1	LS		$20,000
Clear and Grub	5,010,182	sf		$230,036
Berm Construction	92,850	cy		$557,099
Rough Grading	5,010,182	sf		$1,252,545
Liner Placement	5,010,182	sf		$7,515,273
Demob/Disposal	1	LS		$10,000
Regrade	92,850	cy		$557,099
Seed/Sod	556,687	sy		$556,687
Direct Capital:				$19,717,067
Engineering, Procurement & Construction Management:				2,366,048
Total Capital:				**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	2,991	gpm		$2,561,265
Water Treatment (Includes Operator)	139,108,188	gal		$55,643
Water Treatment QA	91	day		$18,200
Piping	20,000	ft		$1,340,000
Direct Capital:				$3,975,109
Engineering, Procurement & Construction Management:				477,013
Total Capital:				**$4,500,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	249,141	ton		$6,228,525
Lime Purchase	24,915	ton		$1,494,900
Sediment Loading	249,140	ton		$697,593
Sediment Hauling	249,140	ton		$1,167,846
Landfill Construction	1	LS		$705,099
Local Siting Fee	124,646	cy		$623,230
Closure	4	acres		$386,300
Direct Capital:				$11,303,493
Engineering, Procurement & Construction Management:				1,356,419
Total Capital:				**$12,700,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$451,389
Total Present Worth, Longer Term O&M Costs			$4,131,432
Total Project Capital and O&M Cost			**$16,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$65,300,000**

ALTERNATIVE C3: Dredge with Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 12 hour shifts	178	Day	1.369230769	$1,014,600
Dredge Monitoring (Water Quality)	178	Day		$534,000
Sediment Removal QA	178	Day		$213,600
Site Restoration	1	Each		$600,000
Direct Capital:				$5,400,200
Engineering, Procurement & Construction Management:				648,024
Contractor Overhead/Profit:				810,030
Total Capital:				**$6,900,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	74,742	bdt	$5,979,371
Direct Capital:			$6,079,371
Engineering, Procurement & Construction Management:			729,525
Total Capital:			**$6,800,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$1,380,892
Water Treatment (Includes Operator)	163,000,121	gal	$65,200
Water Treatment QA	249	day	$49,800
Direct Capital:			$1,495,892
Engineering, Procurement & Construction Management:			179,507
Total Capital:			**$1,700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	149,484	ton	$418,556
Soil Hauling	149,484	ton	$700,708
Tipping Fees (non-TSCA)	149,484	ton	$6,427,824
Tipping Fees (TSCA)	0	ton	$0
Direct Capital:			$7,547,088
Engineering, Procurement & Construction Management:			905,651
Total Capital:			**$8,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$28,400,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$100,000
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 12 hour shifts	178	Day	1.369230769	$1,014,600
Dredge Monitoring (Water Quality)	178	Day		$534,000
Sediment Removal QA	178	Day		$213,600
Site Restoration	1	Each		$600,000
Direct Capital:				$5,400,200
Engineering, Procurement & Construction Management:				648,024
Contractor Overhead/Profit:				810,030
Total Capital:				**$6,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	456	gpm	$752,984
Water Treatment (Includes Operator)	163,000,121	gal	$65,200
Water Treatment QA	249	day	$49,800
Direct Capital:			$867,984
Engineering, Procurement & Construction Management:			104,158
Total Capital:			**$1,000,000**

CDF CONSTRUCTION - MENASHA

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	27,778	sf	$50,000
Shot Rock/Rip Rap	9,200	lf	$7,360,000
Sheetpile Placement	276,000	sf	$5,244,000
Clean Soil Cap	170,000	cy	$1,700,000
Seeding	250,000	sy	$250,000
Mitigation	52	acre	$516,529
Direct Capital:			$15,120,529
Engineering, Procurement & Construction Management:			1,814,463
Total Capital:			**$16,934,992**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	338,700	$5,096,178
Total Present Worth, Longer Term O&M Costs			$15,026,734
Total Project Capital and O&M Cost			**$32,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

TOTAL COST	**$44,400,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (12-INCH CUTTERHEAD)

Capital Items	Quantity	Units		Cost
Site Preparation	1	Each		$803,400
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	173	ac		$2,768,000
Dredging - 2 12-hour shifts	33	Day	0.181318681	$937,200
Dredge Monitoring (Water Quality)	33	Day		$198,000
Sediment Removal QA	33	Day		$79,200
Piping	95,000	ft		$6,365,000
Road Crossings	4	Each		$200,000
Booster Pumps	4	Each		$330,000
Winter Over All Equipment	1	year		$285,000
Site Restoration	1	Each		$600,000
Direct Capital:				$13,735,800
Engineering, Procurement & Construction Management:				1,648,296
Contractor Overhead/Profit:				2,060,370
Total Capital:				**$17,400,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	5,010,182	sf	$9,018,328
Mobilization	1	LS	$20,000
Clear and Grub	5,010,182	sf	$230,036
Berm Construction	92,850	cy	$557,099
Rough Grading	5,010,182	sf	$1,252,545
Liner Placement	5,010,182	sf	$7,515,273
Demob/Disposal	1	LS	$10,000
Regrade	92,850	cy	$557,099
Seed/Sod	556,687	sy	$556,687
Direct Capital:			$19,717,067
Engineering, Procurement & Construction Management:			2,366,048
Total Capital:			**$22,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	2,991	gpm	$2,561,265
Water Treatment (Includes Operator)	139,108,188	gal	$55,643
Water Treatment QA	91	day	$18,200
Piping	95,000	ft	$6,365,000
Direct Capital:			$9,000,109
Engineering, Procurement & Construction Management:			1,080,013
Total Capital:			**$10,100,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	249,140	ton	$5,979,371
Soil Loading	249,140	ton	$697,593
Soil Hauling	249,140	ton	$291,961
Direct Capital:			$6,968,926
Engineering, Procurement & Construction Management:			$836,271
Total Capital:			**$7,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$61,900,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible, Dredge and Off-site Disposal

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	254,407	tons		$1,526,445
Sand Placement	181,720	cy		$1,090,318
Cobble Purchase and Placement	109,032	cy		$3,270,953
Cap Placement QA	1	LS		$100,000
Direct Capital:				$6,187,716
Engineering, Procurement & Construction Management:				742,526
Total Capital:				**$6,930,242**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$138,605	$2,085,489
Total Present Worth, Longer Term O&M Costs				$8,104,008
Total Project Capital and O&M Cost				**$15,000,000**

SEDIMENT REMOVAL (10-INCH CUTTERHEAD)

Capital Items	Quantity	Units	Cost
Site Preparation	1	Each	$100,000
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Debris Sweep	173	ac	$2,768,000
Dredging - 12 hour shifts	48	Day	$273,600
Dredge Monitoring (Water Quality)	48	Day	$144,000
Sediment Removal QA	48	Day	$57,600
Site Restoration	1	Each	$600,000
Direct Capital:			$4,113,200
Engineering, Procurement & Construction Management:			493,584
Contractor Overhead/Profit:			616,980
Total Capital:			**$5,200,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	636,049	sf	$1,144,889
Mobilization	1	LS	$20,000
Clear and Grub	636,049	sf	$29,203
Berm Construction	33,083	cy	$198,496
Rough Grading	636,049	sf	$159,012
Liner Placement	636,049	sf	$954,074
Demob/Disposal	1	LS	$10,000
Regrade	33,083	cy	$198,496
Seed/Sod	70,672	sy	$70,672

Direct Capital:	$2,784,842
Engineering, Procurement & Construction Management:	334,181
Total Capital:	**$3,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	389	gpm	$684,675
Water Treatment (Includes Operator)	37,444,306	gal	$14,978
Water Treatment QA	67	Day	$13,400

Direct Capital:	$713,053
Engineering, Procurement & Construction Management:	85,566
Total Capital:	**$800,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units	Cost
Solidification	67,063	ton	$1,676,575
Lime Purchase	6,707	ton	$402,420
Soil Loading	67,063	ton	$187,776
Soil Hauling	67,063	ton	$314,358
Tipping Fees (non-TSCA)	67,063	ton	$2,883,709

Direct Capital:	$5,464,838
Engineering, Procurement & Construction Management:	655,781
Total Capital:	**$6,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**
TOTAL COST	**$34,700,000**

Table 7-10 Cost Summary for Remedial Alternatives - De Pere to Green Bay

125 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,868,500	240,778	---	$100,500,000	---	---	$700,000	---	---	$659,200,000	$4,500,000	$4,200,000	$769,100,000	$153,820,000	$922,920,000
C2A	6,868,500	240,778	$109,400,000	---	---	---	$7,700,000	---	---	$70,200,000	$4,500,000	$4,200,000	$196,000,000	$39,200,000	$235,200,000
C2B	6,868,500	240,778	$109,400,000	---	---	$19,900,000	$7,300,000	---	---	$419,200,000	$4,500,000	$4,200,000	$564,500,000	$112,900,000	$677,400,000
C3	6,868,500	240,778	$85,400,000	---	---	$217,700,000	$6,400,000	---	---	$277,000,000	$4,500,000	$4,200,000	$595,200,000	$119,040,000	$714,240,000
D	6,868,500	240,778	---	$100,500,000	---	---	$1,200,000	---	$39,200,000	$462,200,000	$4,500,000	$4,200,000	$611,800,000	$122,360,000	$734,160,000
E	6,868,500	240,778	$109,400,000	---	---	$19,900,000	$12,900,000	$253,600,000	---	---	$4,500,000	$4,200,000	$404,500,000	$80,900,000	$485,400,000
F	4,680,565	240,778	---	$69,500,000	$67,800,000	---	$1,100,000	---	$39,200,000	$246,300,000	$4,500,000	$4,200,000	$432,600,000	$86,520,000	$519,120,000

250 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,449,065	240,778	---	$94,600,000	---	---	$700,000	---	---	$619,100,000	$4,500,000	$4,200,000	$723,100,000	$144,620,000	$867,720,000
C2A	6,449,065	240,778	$104,500,000	---	---	---	$7,500,000	---	---	$66,200,000	$4,500,000	$4,200,000	$186,900,000	$37,380,000	$224,280,000
C2B	6,449,065	240,778	$104,500,000	---	---	$19,900,000	$7,100,000	---	---	$393,900,000	$4,500,000	$4,200,000	$534,100,000	$106,820,000	$640,920,000
C3	6,449,065	240,778	$81,500,000	---	---	$204,400,000	$6,200,000	---	---	$260,200,000	$4,500,000	$4,200,000	$561,000,000	$112,200,000	$673,200,000
D	6,449,065	240,778	---	$94,600,000	---	---	$1,100,000	---	$39,200,000	$422,800,000	$4,500,000	$4,200,000	$566,400,000	$113,280,000	$679,680,000
E	6,449,065	240,778	$104,500,000	---	---	$19,900,000	$12,800,000	$238,100,000	---	---	$4,500,000	$4,200,000	$384,000,000	$76,800,000	$460,800,000
F	4,433,446	240,778	---	$66,000,000	$66,200,000	---	$1,100,000	---	$39,200,000	$222,700,000	$4,500,000	$4,200,000	$403,900,000	$80,780,000	$484,680,000

500 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	6,169,458	240,778	---	$90,600,000	---	---	$600,000	---	---	$592,400,000	$4,500,000	$4,200,000	$692,300,000	$138,460,000	$830,760,000
C2A	6,169,458	240,778	$100,900,000	---	---	---	$7,300,000	---	---	$63,500,000	$4,500,000	$4,200,000	$180,400,000	$36,080,000	$216,480,000
C2B	6,169,458	240,778	$100,900,000	---	---	$19,900,000	$7,000,000	---	---	$377,000,000	$4,500,000	$4,200,000	$513,500,000	$102,700,000	$616,200,000
C3	6,169,458	240,778	$78,500,000	---	---	$195,600,000	$6,000,000	---	---	$249,000,000	$4,500,000	$4,200,000	$537,800,000	$107,560,000	$645,360,000
D	6,169,458	240,778	---	$90,600,000	---	---	$1,100,000	---	$39,200,000	$396,600,000	$4,500,000	$4,200,000	$536,200,000	$107,240,000	$643,440,000
E	6,169,458	240,778	$100,900,000	---	---	$19,900,000	$12,700,000	$227,800,000	---	---	$4,500,000	$4,200,000	$370,000,000	$74,000,000	$444,000,000
F	4,242,710	240,778	---	$63,300,000	$65,100,000	---	$1,100,000	---	$39,200,000	$204,500,000	$4,500,000	$4,200,000	$381,900,000	$76,380,000	$458,280,000

1000 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	5,879,529	240,778	---	$86,500,000	---	---	$600,000	---	---	$564,800,000	$4,500,000	$4,200,000	$660,600,000	$132,120,000	$792,720,000
C2A	5,879,529	240,778	$96,900,000	---	---	---	$7,200,000	---	---	$60,700,000	$4,500,000	$4,200,000	$173,500,000	$34,700,000	$208,200,000
C2B	5,879,529	240,778	$96,900,000	---	---	$19,900,000	$6,900,000	---	---	$359,400,000	$4,500,000	$4,200,000	$491,800,000	$98,360,000	$590,160,000
C3	5,879,529	240,778	$75,100,000	---	---	$186,400,000	$5,900,000	---	---	$237,400,000	$4,500,000	$4,200,000	$513,500,000	$102,700,000	$616,200,000
D	5,879,529	240,778	---	$86,500,000	---	---	$1,100,000	---	$39,200,000	$369,600,000	$4,500,000	$4,200,000	$505,100,000	$101,020,000	$606,120,000
E	5,879,529	240,778	$96,900,000	---	---	$19,900,000	$12,500,000	$217,100,000	---	---	$4,500,000	$4,200,000	$355,100,000	$71,020,000	$426,120,000
F	4,046,276	240,778	---	$60,500,000	$61,900,000	---	$1,100,000	---	$39,200,000	$185,700,000	$4,500,000	$4,200,000	$357,100,000	$71,420,000	$428,520,000

5000 ppb

Alternative	Dredge Volume (cy)	TSCA Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Capping	Dewatering	Water Treatment	Thermal Treatment	CDF Construction	Off-site Disposal	Institutional Controls	Bayport Closure[1]	Subtotal	20% Contingency	TOTAL
A	0	0	---	---	---	---	---	---	---	---	$4,500,000	---	$4,500,000	$900,000	$5,400,000
B	0	0	---	---	---	---	---	---	---	---	$9,900,000	---	$9,900,000	$1,980,000	$11,880,000
C1	4,517,391	240,778	---	$67,200,000	---	---	$500,000	---	---	$434,700,000	$4,500,000	$4,200,000	$511,100,000	$102,220,000	$613,320,000
C2A	4,517,391	240,778	$76,000,000	---	---	---	$6,500,000	---	---	$47,500,000	$4,500,000	$4,200,000	$138,700,000	$27,740,000	$166,440,000
C2B	4,517,391	240,778	$76,000,000	---	---	$19,900,000	$6,300,000	---	---	$277,100,000	$4,500,000	$4,200,000	$388,000,000	$77,600,000	$465,600,000
C3	4,517,391	240,778	$57,200,000	---	---	$143,200,000	$5,200,000	---	---	$182,900,000	$4,500,000	$4,200,000	$397,200,000	$79,440,000	$476,640,000
D	4,517,391	240,778	---	$67,200,000	---	---	$1,000,000	---	$39,200,000	$244,600,000	$4,500,000	$4,200,000	$360,700,000	$72,140,000	$432,840,000
E	4,517,391	240,778	$76,000,000	---	---	$19,900,000	$11,900,000	$166,800,000	---	---	$4,500,000	$4,200,000	$283,300,000	$56,660,000	$339,960,000
F	3,102,041	240,778	---	$47,100,000	$42,900,000	---	$1,000,000	---	$39,200,000	$95,500,000	$4,500,000	$4,200,000	$234,400,000	$46,880,000	$281,280,000

[1] Bayport closure costs are present value costs based on closure 40 years from the present.

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
DE PERE TO GREEN BAY
Action Level - 125 ppb

Material Handling Assumptions:							
Volume > 125 ppb	6,868,500	cy	1130 ac		5,243,130	m3	Acres corresponds to dredge footprint area
Volume > 250 ppb	6,449,065	cy			4,922,950	m3	
Volume > 500 ppb	6,169,458	cy			4,709,510	m3	
Volume > 1,000 ppb	5,879,529	cy			4,488,190	m3	
Volume > 5000 ppb	4,517,391	cy			3,448,390	m3	
Volume > 50,000 ppb	240,778	cy			183,800	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	33.8%	w/w	17.8%	v/v	1.05	tons per cy	
Slurry Density (20% in situ)	8.0%	w/w	3.6%	v/v	0.88	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	15.4%	v/v	1.02	tons per cy	Montgomery Watson
Dewatered Density (Hydraulic Dredging and CDF)	50.0%	w/w	29.8%	v/v	1.18	tons per cy	Foth & VanDyke
Dewatered Density (Mechanical Dredging)	33.8%	w/w	17.8%	v/v	1.05	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	2,136,771	cy	in situ		974,801	m3	
HTTD Treatment Capacity	1,577,177	cy	in situ		1,650,000	tons	
Cap Volume	2,187,936	cy			1,670,180	m3	
Vitrification Treatment Capacity	9,106,166	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Debris Sweep	$16,000	per acre					Ogden Beeman
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft			18	mi	Distance to Town of Holland (map provided by Fred Swed). 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	12	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
Mechanical - 8 cy bucket							
Dock Construction	$400,000	LS					pj
Mobilization - Equipment	$455,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$17,000	per shift					Ogden Beeman
Dredge Rate	1900	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					pj
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Offload Crane Mobilization	$50,000	LS					pj
Site Restoration	$500,000	LS					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy

Capping						
Mobilization/Site Prep	$200,000					Ogden Beeman
Area	21,055,849	sf	1,956,200	m2		
Sand Cap Depth	1.7	feet				
Sand Purchase	$6	per ton				Ole
Placement Rate	$6	per cy				Ogden Beeman
Sand Density	1.4	tons per cy				
Armored Cap Depth	1.0	feet				
Cobbles	$30	per cy				Means
Sand Density	1.4	tons per cy				
Cap Placement QA	$100,000	LS				Ogden Beeman
Long-term O&M	2%	of capital				pj
Long-term Monitoring	$400,000	per year				Anne LTM
Nearshore CDF			Bayport			
Land Lease or Purchase	$1.80	per sf				Baird
Length	9,600	lf				Baird
Capping Volume	205,000	cy	2,178,000			Baird
Seeding Area	300,000	sy	2,178,000			Baird
Sheetpile Wall Length	9,600	lf				based on bathymetry
Sheetpile Depth	30	ft				pj
Sheetpile Cost	$19	per sf				Baird
Shot Rock Berm	$500	per lf				Baird
Rip Rap	$210	per lf				pj
Clean Soil Cap	$10	per cy				Baird
Seeding	$1	per sy				Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area	4,491,228	sf	103.10			2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter	8,477	lf	2119.251741			assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Alphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Water Treatment						
Flow Rate (3 Mechanical Dredges)	57	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges)	$216,590	LS				pj
Flow Rate (3 Mechanical Dredges to CDF)	287	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges to CDF)	$570,498	LS				pj
Flow Rate (2 Hydraulic Dredges)	3,563	gpm				assume operate 24/7
Unit, Purchase (Hydraulic Dredge)	$2,586,470	LS				pj
Flow Rate (2 Hydraulic Dredges; settling pond)	3,110	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	3,563	gpm				
Unit, Purchase (mechanical dewatering)	$2,586,470	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Existing NR 500 Commercial Disposal Facility						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer System Construction	1,000,000	LS				pj
New Landfill Disposal (Dedicated NR 500 Monofill)						
Landfill Construction	$25,988,920					
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				

Institutional Controls		
Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	3	LS		$1,470,000
Watertight Barges	4	ea		$400,000
Offload Stockpile Area Prep.	1	LS		$75,000
Dredging - 12 hour shifts	3,615	Day	27.80769231	$61,455,000
Dredge Monitoring (Water Quality)	3,615	Day		$10,845,000
Sediment Removal QA	3,615	Day		$4,338,000
Offload Crane Mobilization	1	LS		$50,000
Site Restoration	1	ea		$500,000
Direct Capital:				$79,133,000
Engineering, Procurement & Construction Management:				9,495,960
Contractor Overhead/Profit:				11,869,950
Total Capital:				**$100,500,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	57	gpm		$216,590
Water Treatment (Includes Operator)	138,716,232	gal		$55,486
Water Treatment QA	1,687	day		$337,400
Direct Capital:				$609,476
Engineering, Procurement & Construction Management:				73,137
Total Capital:				**$700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	7,185,641	ton		$179,641,037
Lime Purchase	718,565	ton		$43,113,900
Soil Loading	7,185,641	ton		$20,119,796
Soil Hauling	7,185,641	ton		$33,682,694
Tipping Fees (non-TSCA)	6,933,746	ton		$298,151,076
Tipping Fees (TSCA)	251,896	ton		$13,854,253
Direct Capital:				$588,562,756
Engineering, Procurement & Construction Management:				70,627,531
Total Capital:				**$659,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**

TOTAL COST **$769,100,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1130	acre		$18,080,000
Dredging - 2 12 hour shifts/day	1191	Day	6.543956044	$33,824,400
Dredge Monitoring (Water Quality)	1191	Day		$7,146,000
Sediment Removal QA	1191	Day		$2,858,400
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,910,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$86,155,600
Engineering, Procurement & Construction Management:				10,338,672
Contractor Overhead/Profit:				12,923,340
Total Capital:				**$109,400,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Including Operator)	6,106,807,801	gal	$2,442,723
Water Treatment QA	1,191	Day	$476,400
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,845,593
Engineering, Procurement & Construction Management:			821,471
Total Capital:			**$7,700,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$25,988,920
Local Siting Fee	4,104,792	cy		$20,523,960
Closure	127	acres		$12,721,463
Direct Capital:				$59,234,343
Engineering, Procurement & Construction Management:				7,108,121
Total Capital:				**$66,300,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Operations		10	$500,000	$3,680,044
Post Closure Monitoring		40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs				$3,932,097
Total Project Capital and O&M Cost				**$70,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$192,100,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facilities

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1130	acre		$18,080,000
Dredging - 2 12 hour shifts/day	1191	Day	6.543956044	$33,824,400
Dredge Monitoring (Water Quality)	1191	Day		$7,146,000
Sediment Removal QA	1191	Day		$2,858,400
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,910,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$86,155,600
Engineering, Procurement & Construction Management:				10,338,672
Contractor Overhead/Profit:				12,923,340
Total Capital:				**$109,400,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	5,330,439,162	gal	$2,132,176
Water Treatment QA	1,191	Day	$476,400
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,535,045
Engineering, Procurement & Construction Management:			784,205
Total Capital:			**$7,300,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	8,095,823	ton		$202,395,568
Lime Purchase	809,583	ton		$48,574,980
Sediment Loading	8,095,823	ton		$22,668,304
Sediment Hauling	8,095,823	ton		$37,949,169
Landfill Construction	1	LS		$25,988,920
Local Siting Fee	4,104,792	cy		$20,523,960
Closure	127	acres		$12,721,463
Direct Capital:				$370,822,364
Engineering, Procurement & Construction Management:				44,498,684
Total Capital:				**$415,300,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Operations		10	$500,000	$3,680,044
Post Closure Monitoring		40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs				$3,932,097
Total Project Capital and O&M Cost				**$419,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST **$564,500,000**

ALTERNATIVE C3: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1130	acre		$18,080,000
Dredging - 2 12 hour shifts/day	1191	Day	6.543956044	$33,824,400
Dredge Monitoring (Water Quality)	1191	Day		$7,146,000
Sediment Removal QA	1191	Day		$2,858,400
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$67,280,600
Engineering, Procurement & Construction Management:				8,073,672
Contractor Overhead/Profit:				10,092,090
Total Capital:				**$85,400,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	2,428,747	bdt	$194,299,745
Direct Capital:			$194,399,745
Engineering, Procurement & Construction Management:			23,327,969
Total Capital:			**$217,700,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Includes Operator)	6,106,807,801	gal	$2,442,723
Water Treatment QA	3,334	day	$666,800
Direct Capital:			$5,695,993
Engineering, Procurement & Construction Management:			683,519
Total Capital:			**$6,400,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	4,857,494	ton	$13,600,982
Soil Hauling	4,857,494	ton	$22,769,501
Tipping Fees (non-TSCA)	4,687,212	ton	$201,550,127
Tipping Fees (TSCA)	170,281	ton	$9,365,475
Direct Capital:			$247,286,086
Engineering, Procurement & Construction Management:			29,674,330
Total Capital:			**$277,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$595,200,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	3,615	Day	$61,455,000
Dredge Monitoring (Water Quality)	3,615	Day	$10,845,000
Sediment Removal QA	3,615	Day	$4,338,000
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$79,133,000
Engineering, Procurement & Construction Management:			9,495,960
Contractor Overhead/Profit:			11,869,950
Total Capital:			**$100,500,000**

CDF CONSTRUCTION

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,700,000	sf	$4,860,000
Shot Rock/Rip Rap	9,600	lf	$6,816,000
Sheetpile Placement	288,000	sf	$5,472,000
Clean Soil Cap	205,000	cy	$2,050,000
Seeding	300,000	sy	$300,000
Mitigation	62	acre	$619,835
Direct Capital:			$20,117,835
Engineering, Procurement & Construction Management:			$2,414,140
Total Capital:			**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs			**$16,711,012**
Total Project Capital and O&M Cost			**$39,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	312,357,784	gal	$124,943
Water Treatment QA	1,687	day	$337,400
Direct Capital:			$1,032,841
Engineering, Procurement & Construction Management:			123,941
Total Capital:			**$1,200,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	4,950,209	ton		$123,755,225
Lime Purchase	495,021	ton		$29,701,260
Soil Loading	4,950,209	ton		$13,860,585
Soil Hauling	4,950,209	ton		$23,204,105
Tipping Fees (non-TSCA)	4,698,313	ton		$202,027,479
Tipping Fees (TSCA)	365,647	ton		$20,110,606
Direct Capital:				$412,659,260
Engineering, Procurement & Construction Management:				49,519,111
Total Capital:				**$462,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST **$611,800,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEAD'S)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1130	acre		$18,080,000
Dredging - 2 12 hour shifts/day	1191	Day	6.543956044	$33,824,400
Dredge Monitoring (Water Quality)	1191	Day		$7,146,000
Sediment Removal QA	1191	Day		$2,858,400
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,910,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$86,155,600
Engineering, Procurement & Construction Management:				10,338,672
Contractor Overhead/Profit:				12,923,340
Total Capital:				**$109,400,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	5,330,439,162	gal	$2,132,176
Water Treatment QA	1,191	Day	$476,400
Piping	95,000	ft	$6,365,000
Direct Capital:			$11,560,045
Engineering, Procurement & Construction Management:			1,387,205
Total Capital:			**$12,900,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	8,095,823	ton	$194,299,745
Soil Loading	8,095,823	ton	$22,668,304
Soil Hauling	8,095,823	ton	$9,487,292
Direct Capital:			$226,455,341
Engineering, Procurement & Construction Management:			$27,174,641
Total Capital:			**$253,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$404,500,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible,Dredge to CDF and Off-site Disposal

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs				**$16,711,012**
Total Project Capital and O&M Cost				**$39,200,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,819,641	tons		$10,917,848
Sand Placement	1,299,744	cy		$7,798,463
Cobble Purchase and Placement	779,846	cy		$23,395,388
Cap Placement QA	1	LS		$100,000
Direct Capital:				$42,411,699
Engineering, Procurement & Construction Management:				5,089,404
Total Capital:				**$47,501,103**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$950,022	$14,294,314
Total Present Worth, Longer Term O&M Costs				$20,312,833
Total Project Capital and O&M Cost				**$67,800,000**

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	2,464	Day	$41,888,000
Dredge Monitoring (Water Quality)	2,464	Day	$7,392,000
Sediment Removal QA	2,464	Day	$2,956,800
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$54,731,800
Engineering, Procurement & Construction Management:			6,567,816
Contractor Overhead/Profit:			8,209,770
Total Capital:			**$69,500,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	268,170,233	gal	$107,268
Water Treatment QA	1,687	day	$337,400
Direct Capital:			$1,015,166
Engineering, Procurement & Construction Management:			121,820
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	2,661,249	ton	$66,531,225
Lime Purchase	266,125	ton	$15,967,500
Soil Loading	2,661,249	ton	$7,451,497
Soil Hauling	2,661,249	ton	$12,474,605
Tipping Fees (non-TSCA)	2,409,353	ton	$103,602,198
Tipping Fees (TSCA)	251,896	ton	$13,854,255
Direct Capital:			$219,881,280
Engineering, Procurement & Construction Management:			26,385,754
Total Capital:			**$246,300,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			**$4,513,889**
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$432,600,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
DE PERE TO GREEN BAY
Action Level - 250 ppb

Material Handling Assumptions:							
Volume > 250 ppb	6,449,065	cy	1103	ac	4,922,950	m3	Acres corresponds to dredge footprint area
Volume > 125 ppb	6,868,500	cy			5,243,130	m3	
Volume > 500 ppb	6,169,458	cy			4,709,510	m3	
Volume > 1,000 ppb	5,879,529	cy			4,488,190	m3	
Volume > 5000 ppb	4,517,391	cy			3,448,390	m3	
Volume > 50,000 ppb	240,778	cy			183,800	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	33.8%	w/w	17.8%	v/v	1.05	tons per cy	
Slurry Density (20% in situ)	8.0%	w/w	3.6%	v/v	0.88	tons per cy	Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	15.4%	v/v	1.02	tons per cy	Montgomery Watson
Dewatered Density (Hydraulic Dredging and CDF)	50.0%	w/w	29.8%	v/v	1.18	tons per cy	Foth & VanDyke
Dewatered Density (Mechanical Dredging)	33.8%	w/w	17.8%	v/v	1.05	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	2,136,771	cy	in situ		974,801	m3	
HTTD Treatment Capacity	1,577,177	cy	in situ		1,650,000	tons	
Cap Volume	2,015,618	cy			1,538,640	m3	
Vitrification Treatment Capacity	9,106,166	cy	in situ		6440000.00	tons	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Debris Sweep	$16,000	per acre					Ogden Beeman
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft			18	mi	Distance to Town of Holland (map provided by Fred Swed). 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	12	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
Mechanical - 8 cy bucket							
Dock Construction	$400,000	LS					pj
Mobilization - Equipment	$455,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$17,000	per shift					Ogden Beeman
Dredge Rate	1900	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					pj
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Offload Crane Mobilization	$50,000	LS					pj
Site Restoration	$500,000	LS					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy
Capping							
Mobilization/Site Prep	$200,000						Ogden Beeman
Area	20,514,438	sf	1,905,900		m2		
Sand Cap Depth	1.7	feet					
Sand Purchase	$6	per ton					Ole
Placement Rate	$6	per cy					Ogden Beeman
Sand Density	1.4	tons per cy					
Armored Cap Depth	1.0	feet					
Cobbles	$30	per cy					Means
Sand Density	1.4	tons per cy					
Cap Placement QA	$100,000	LS					Ogden Beeman
Long-term O&M	2%	of capital					pj
Long-term Monitoring	$400,000	per year					Anne LTM

Nearshore CDF			Bayport			
Land Lease or Purchase	$1.80	per sf				Baird
Length	9,600	lf				Baird
Capping Volume	205,000	cy	2,178,000			Baird
Seeding Area	300,000	sy	2,178,000			Baird
Sheetpile Wall Length	9,600	lf				based on bathymetry
Sheetpile Depth	30	ft				pj
Sheetpile Cost	$19	per sf				Baird
Shot Rock Berm	$500	per lf				Baird
Rip Rap	$210	per lf				pj
Clean Soil Cap	$10	per cy				Baird
Seeding	$1	per sy				Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area	4,491,228	sf	103.10			2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter	8,477	lf	2119.251741			assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Alphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Water Treatment						
Flow Rate (3 Mechanical Dredges)	57	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges)	$216,590	LS				pj
Flow Rate (3 Mechanical Dredges to CDF)	287	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges to CDF)	$570,498	LS				pj
Flow Rate (2 Hydraulic Dredges)	3,563	gpm				assume operate 24/7
Unit, Purchase (Hydraulic Dredge)	$2,586,470	LS				pj
Flow Rate (2 Hydraulic Dredges; settling pond)	3,110	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	3,563	gpm				
Unit, Purchase (mechanical dewatering)	$2,586,470	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Existing NR 500 Commercial Disposal Facility						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer System Construction	1,000,000	LS				pj
New Landfill Disposal (Dedicated NR 500 Monofill)						
Landfill Construction	$24,401,866					
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				
Institutional Controls						
Public Education Program	$100,000					pj
O&M Plans	$20,000					pj
Deed Restrictions	$5,000					pj
Annual Costs						
Public Education Program	$30,000					pj
Maintaining O&M Plans	$800					pj
Reporting	$20,000					pj
Long-term Monitoring	$600,000					Anne LTM
Long-term Monitoring (no action)	$300,000					Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	**Quantity**	**Units**		**Cost**
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	**Quantity**	**Units**		**Cost**
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	**Quantity**	**Units**		**Cost**
Mobilization - Equipment and Silt Curtain	3	LS		$1,470,000
Watertight Barges	4	ea		$400,000
Offload Stockpile Area Prep.	1	LS		$75,000
Dredging - 12 hour shifts	3,395	Day	26.11538462	$57,715,000
Dredge Monitoring (Water Quality)	3,395	Day		$10,185,000
Sediment Removal QA	3,395	Day		$4,074,000
Offload Crane Mobilization	1	LS		$50,000
Site Restoration	1	ea		$500,000
Direct Capital:				$74,469,000
Engineering, Procurement & Construction Management:				8,936,280
Contractor Overhead/Profit:				11,170,350
Total Capital:				**$94,600,000**

WATER TREATMENT

Capital Items	**Quantity**	**Units**	**Cost**
Unit Purchase	57	gpm	$216,590
Water Treatment (Includes Operator)	130,245,307	gal	$52,098
Water Treatment QA	1,584	day	$316,800
Direct Capital:			$585,488
Engineering, Procurement & Construction Management:			70,259
Total Capital:			**$700,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost	
Solidification	6,746,839	ton		$168,670,973	
Lime Purchase	674,684	ton		$40,481,040	
Soil Loading	6,746,839	ton		$18,891,149	
Soil Hauling	6,746,839	ton		$31,625,808	
Tipping Fees (non-TSCA)	6,494,943	ton		$279,282,567	$293,136,820
Tipping Fees (TSCA)	251,896	ton		$13,854,253	
Direct Capital:				$552,805,790	
Engineering, Procurement & Construction Management:				66,336,695	
Total Capital:				**$619,100,000**	

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$723,100,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1103	acre		$17,648,000
Dredging - 2 12 hour shifts/day	1118	Day	6.142857143	$31,751,200
Dredge Monitoring (Water Quality)	1118	Day		$6,708,000
Sediment Removal QA	1118	Day		$2,683,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,180,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$82,307,200
Engineering, Procurement & Construction Management:				9,876,864
Contractor Overhead/Profit:				12,346,080
Total Capital:				**$104,500,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,563	gpm		$2,586,470
Water Treatment (Including Operator)	5,733,885,955	gal		$2,293,554
Water Treatment QA	1,118	Day		$447,200
Piping	20,000	ft		$1,340,000
Direct Capital:				$6,667,224
Engineering, Procurement & Construction Management:				800,067
Total Capital:				**$7,500,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Landfill Construction	1	LS		$24,401,866
Local Siting Fee	3,854,126	cy		$19,270,632
Closure	119	acres		$11,944,607
Direct Capital:				$55,617,105
Engineering, Procurement & Construction Management:				6,674,053
Total Capital:				**$62,300,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Operations		10	$500,000	$3,680,044
Post Closure Monitoring		40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs				$3,932,097
Total Project Capital and O&M Cost				**$66,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$183,000,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facilities

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1103	acre		$17,648,000
Dredging - 2 12 hour shifts/day	1118	Day	6.142857143	$31,751,200
Dredge Monitoring (Water Quality)	1118	Day		$6,708,000
Sediment Removal QA	1118	Day		$2,683,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,180,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$82,307,200
Engineering, Procurement & Construction Management:				9,876,864
Contractor Overhead/Profit:				12,346,080
Total Capital:				**$104,500,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	5,004,927,490	gal	$2,001,971
Water Treatment QA	1,118	Day	$447,200
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,375,641
Engineering, Procurement & Construction Management:			765,077
Total Capital:			**$7,100,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Solidification	7,601,439	ton	$190,035,963
Lime Purchase	760,144	ton	$45,608,640
Sediment Loading	7,601,439	ton	$21,284,028
Sediment Hauling	7,601,439	ton	$35,631,743
Landfill Construction	1	LS	$24,401,866
Local Siting Fee	3,854,126	cy	$19,270,632
Closure	119	acres	$11,944,607
Direct Capital:			$348,177,479
Engineering, Procurement & Construction Management:			41,781,297
Total Capital:			**$390,000,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs			$3,932,097
Total Project Capital and O&M Cost			**$393,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST **$534,100,000**

ALTERNATIVE C3: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1103	acre		$17,648,000
Dredging - 2 12 hour shifts/day	1118	Day	6.142857143	$31,751,200
Dredge Monitoring (Water Quality)	1118	Day		$6,708,000
Sediment Removal QA	1118	Day		$2,683,200
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$64,162,200
Engineering, Procurement & Construction Management:				7,699,464
Contractor Overhead/Profit:				9,624,330
Total Capital:				**$81,500,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	2,280,432	bdt	$182,434,525
Direct Capital:			$182,534,525
Engineering, Procurement & Construction Management:			21,904,143
Total Capital:			**$204,400,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,563	gpm		$2,586,470
Water Treatment (Includes Operator)	5,733,885,955	gal		$2,293,554
Water Treatment QA	3,130	day		$626,000
Direct Capital:				$5,506,024
Engineering, Procurement & Construction Management:				660,723
Total Capital:				**$6,200,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Soil Loading	4,560,863	ton		$12,770,417
Soil Hauling	4,560,863	ton		$21,379,046
Tipping Fees (non-TSCA)	4,390,582	ton		$188,795,016
Tipping Fees (TSCA)	170,281	ton		$9,365,475
Direct Capital:				$232,309,953
Engineering, Procurement & Construction Management:				27,877,194
Total Capital:				**$260,200,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$561,000,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	3,395	Day	$57,715,000
Dredge Monitoring (Water Quality)	3,395	Day	$10,185,000
Sediment Removal QA	3,395	Day	$4,074,000
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$74,469,000
Engineering, Procurement & Construction Management:			8,936,280
Contractor Overhead/Profit:			11,170,350
Total Capital:			**$94,600,000**

CDF CONSTRUCTION

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,700,000	sf	$4,860,000
Shot Rock/Rip Rap	9,600	lf	$6,816,000
Sheetpile Placement	288,000	sf	$5,472,000
Clean Soil Cap	205,000	cy	$2,050,000
Seeding	300,000	sy	$300,000
Mitigation	62	acre	$619,835
Direct Capital:			$20,117,835
Engineering, Procurement & Construction Management:			$2,414,140
Total Capital:			**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs			**$16,711,012**
Total Project Capital and O&M Cost			**$39,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	303,886,859	gal	$121,555
Water Treatment QA	1,584	day	$316,800
Direct Capital:			$1,008,853
Engineering, Procurement & Construction Management:			121,062
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	4,511,406	ton	$112,785,150
Lime Purchase	451,141	ton	$27,068,460
Soil Loading	4,511,406	ton	$12,631,937
Soil Hauling	4,511,406	ton	$21,147,216
Tipping Fees (non-TSCA)	4,259,510	ton	$183,158,951
Tipping Fees (TSCA)	376,711	ton	$20,719,131
Direct Capital:			$377,510,845
Engineering, Procurement & Construction Management:			45,301,301
Total Capital:			**$422,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$566,400,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEAD'S)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1103	acre		$17,648,000
Dredging - 2 12 hour shifts/day	1118	Day	6.142857143	$31,751,200
Dredge Monitoring (Water Quality)	1118	Day		$6,708,000
Sediment Removal QA	1118	Day		$2,683,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$11,180,000
Winter Over All Equipment	7	yr		$1,995,000
Site Restoration	1	LS		$600,000
Direct Capital:				$82,307,200
Engineering, Procurement & Construction Management:				9,876,864
Contractor Overhead/Profit:				12,346,080
Total Capital:				**$104,500,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	4,491,228	sf		$8,084,210
Mobilization	1	LS		$20,000
Clear and Grub	4,491,228	sf		$206,209
Berm Construction	87,910	cy		$527,458
Rough Grading	4,491,228	sf		$1,122,807
Liner Placement	4,491,228	sf		$6,736,842
Demob/Disposal	1	LS		$10,000
Regrade	87,910	cy		$527,458
Seed/Sod	499,025	sy		$499,025
Direct Capital:				$17,734,010
Engineering, Procurement & Construction Management:				2,128,081
Total Capital:				**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	3,110	gpm		$2,586,470
Water Treatment (Including Operator)	5,004,927,490	gal		$2,001,971
Water Treatment QA	1,118	Day		$447,200
Piping	95,000	ft		$6,365,000
Direct Capital:				$11,400,641
Engineering, Procurement & Construction Management:				1,368,077
Total Capital:				**$12,800,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units		Cost
Sediment Treatment	7,601,439	ton		$182,434,525
Soil Loading	7,601,439	ton		$21,284,028
Soil Hauling	7,601,439	ton		$8,907,936
Direct Capital:				$212,626,488
Engineering, Procurement & Construction Management:				$25,515,179
Total Capital:				**$238,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$384,000,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible,Dredge to CDF and Off-site Disposal

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs				**$16,711,012**
Total Project Capital and O&M Cost				**$39,200,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,772,853	tons		$10,637,116
Sand Placement	1,266,323	cy		$7,597,940
Cobble Purchase and Placement	759,794	cy		$22,793,820
Cap Placement QA	1	LS		$100,000
Direct Capital:				$41,328,876
Engineering, Procurement & Construction Management:				4,959,465
Total Capital:				**$46,288,341**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$925,767	$13,929,362
Total Present Worth, Longer Term O&M Costs				$19,947,881
Total Project Capital and O&M Cost				**$66,200,000**

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	2,334	Day	$39,678,000
Dredge Monitoring (Water Quality)	2,334	Day	$7,002,000
Sediment Removal QA	2,334	Day	$2,800,800
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$51,975,800
Engineering, Procurement & Construction Management:			6,237,096
Contractor Overhead/Profit:			7,796,370
Total Capital:			**$66,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	263,179,430	gal	$105,272
Water Treatment QA	1,584	day	$316,800
Direct Capital:			$992,570
Engineering, Procurement & Construction Management:			119,108
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	2,402,720	ton		$60,068,000
Lime Purchase	240,272	ton		$14,416,320
Soil Loading	2,402,720	ton		$6,727,616
Soil Hauling	2,402,720	ton		$11,262,750
Tipping Fees (non-TSCA)	2,150,824	ton		$92,485,453
Tipping Fees (TSCA)	251,896	ton		$13,854,254
Direct Capital:				$198,814,392
Engineering, Procurement & Construction Management:				23,857,727
Total Capital:				**$222,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$403,900,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
DE PERE TO GREEN BAY
Action Level - 500 ppb

Material Handling Assumptions:								
Volume > 500 ppb	6,169,458	cy	1083	ac	4,709,510	m3		Acres corresponds to dredge footprint area
Volume > 125 ppb	6,868,500	cy			5,243,130	m3		
Volume > 250 ppb	6,449,065	cy			4,922,950	m3		
Volume > 1,000 ppb	5,879,529	cy			4,488,190	m3		
Volume > 5000 ppb	4,517,391	cy			3,448,390	m3		
Volume > 50,000 ppb	240,778	cy			183,800	m3		
Solids Specific Gravity	2.36							
Fresh Water Density	62.4	lb/ft3						
In Situ Density	33.8%	w/w	17.8%	v/v	1.05	tons per cy		
Slurry Density (20% in situ)	8.0%	w/w	3.6%	v/v	0.88	tons per cy		Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	15.4%	v/v	1.02	tons per cy		Montgomery Watson
Dewatered Density (Hydraulic Dredging and CDF)	50.0%	w/w	29.8%	v/v	1.18	tons per cy		Foth & VanDyke
Dewatered Density (Mechanical Dredging)	33.8%	w/w	17.8%	v/v	1.05	tons per cy		
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy		
CDF Capacity	2,136,771	cy	in situ		974,801	m3		
HTTD Treatment Capacity	1,577,177	cy	in situ		1,650,000	tons		
Cap Volume	1,926,748	cy			1,470,800	m3		
Vitrification Treatment Capacity	9,106,166	cy	in situ		6440000.00	tons		
Cost Estimating Parameters & Methodology:								
Interest Rate	6.0%							
Sales Tax	5.5%							Not Used
Engineering, Procurement and Construction Mgmt	12.0%							
Contractor Overhead and Profit - Dredging Only	15.0%							
<u>Dredging</u>								
Dredge Monitoring (Water Quality)	$3,000	per day						
Sediment Removal QA	$1,200	per day						
Debris Sweep	$16,000	per acre						Ogden Beeman
Hydraulic - 2 12-inch Cutterheads								
Site Preparation	$803,400	LS						Ogden Beeman
Mobilization - Equipment	$1,135,000	LS						Ogden Beeman
Mobilization - Silt Curtain	$35,000							Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift						Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift						Ogden Beeman
Winter Over Equipment	$285,000	per year						Ogden Beeman
Site Restoration	$600,000	per dredge launch site						
Length of Piping	95,000	ft			18	mi		Distance to Town of Holland (map provided by Fred Swed). 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft						Ogden Beeman
Number of Road Crossings	12	each						pj, review map
Cost per Road Crossing	$50,000	per crossing						pj, review map
Number of Booster Pumps	4	each						Ogden Beeman
Booster Pump Cost	$2,500	per day						Ogden Beeman
Mechanical - 8 cy bucket								
Dock Construction	$400,000	LS						pj
Mobilization - Equipment	$455,000	per dredge						Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS						Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea						Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$17,000	per shift						Ogden Beeman
Dredge Rate	1900	cy in situ per 10 hour shift						Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area						pj
Free Water per cy Dredged (10%)	20	gal						Ogden Beeman
Offload Crane Mobilization	$50,000	LS						pj
Site Restoration	$500,000	LS						pj
High Temperature Thermal Desorption								
Setup Staging Area	$50,000							pj
Mobilization/Site Prep	$150,000							Maxymillian
Sediment Treatment QA	$2	per ton						
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1						
Sand Purchase and Deliver	$6	per ton						Ole
Blending	$25	per ton						Ole
HTTD (includes off-gas treatment)	$75	per ton						Maxymillian
Stack Testing	$50,000	LS						Maxymillian
Place Treated Material	$3	per ton						
Vitrification								
Capital Costs	$36,000,000	LS						Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year						Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton						Unit Cost Study- Minergy

Capping						
Mobilization/Site Prep	$200,000					Ogden Beeman
Area	20,132,328	sf	1,870,400	m2		
Sand Cap Depth	1.7	feet				
Sand Purchase	$6	per ton				Ole
Placement Rate	$6	per cy				Ogden Beeman
Sand Density	1.4	tons per cy				
Armored Cap Depth	1.0	feet				
Cobbles	$30	per cy				Means
Sand Density	1.4	tons per cy				
Cap Placement QA	$100,000	LS				Ogden Beeman
Long-term O&M	2%	of capital				pj
Long-term Monitoring	$400,000	per year				Anne LTM
Nearshore CDF			Bayport			
Land Lease or Purchase	$1.80	per sf				Baird
Length	9,600	lf				Baird
Capping Volume	205,000	cy	2,178,000			Baird
Seeding Area	300,000	sy	2,178,000			Baird
Sheetpile Wall Length	9,600	lf				based on bathymetry
Sheetpile Depth	30	ft				pj
Sheetpile Cost	$19	per sf				Baird
Shot Rock Berm	$500	per lf				Baird
Rip Rap	$210	per lf				pj
Clean Soil Cap	$10	per cy				Baird
Seeding	$1	per sy				Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area	4,491,228	sf	103.10			2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter	8,477	lf	2119.251741			assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Alphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Water Treatment						
Flow Rate (3 Mechanical Dredges)	57	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges)	$216,590	LS				pj
Flow Rate (3 Mechanical Dredges to CDF)	287	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges to CDF)	$570,498	LS				pj
Flow Rate (2 Hydraulic Dredges)	3,563	gpm				assume operate 24/7
Unit, Purchase (Hydraulic Dredge)	$2,586,470	LS				pj
Flow Rate (2 Hydraulic Dredges; settling pond)	3,110	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	3,563	gpm				
Unit, Purchase (mechanical dewatering)	$2,586,470	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Existing NR 500 Commercial Disposal Facility						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer System Construction	1,000,000	LS				pj
New Landfill Disposal (Dedicated NR 500 Monofill)						
Landfill Construction	$23,343,896					
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				

Institutional Controls		
Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	3	LS		$1,470,000
Watertight Barges	4	ea		$400,000
Offload Stockpile Area Prep.	1	LS		$75,000
Dredging - 12 hour shifts	3,248	Day	24.98461538	$55,216,000
Dredge Monitoring (Water Quality)	3,248	Day		$9,744,000
Sediment Removal QA	3,248	Day		$3,897,600
Offload Crane Mobilization	1	LS		$50,000
Site Restoration	1	ea		$500,000
Direct Capital:				$71,352,600
Engineering, Procurement & Construction Management:				8,562,312
Contractor Overhead/Profit:				10,702,890
Total Capital:				**$90,600,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	57	gpm		$216,590
Water Treatment (Includes Operator)	124,598,376	gal		$49,839
Water Treatment QA	1,516	day		$303,200
Direct Capital:				$569,629
Engineering, Procurement & Construction Management:				68,355
Total Capital:				**$600,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	6,454,322	ton		$161,358,055
Lime Purchase	645,433	ton		$38,725,980
Soil Loading	6,454,322	ton		$18,072,102
Soil Hauling	6,454,322	ton		$30,254,635
Tipping Fees (non-TSCA)	6,202,427	ton		$266,704,347
Tipping Fees (TSCA)	251,896	ton		$13,854,253
Direct Capital:				$528,969,373
Engineering, Procurement & Construction Management:				63,476,325
Total Capital:				**$592,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$692,300,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1083	acre		$17,328,000
Dredging - 2 12 hour shifts/day	1070	Day	5.879120879	$30,388,000
Dredge Monitoring (Water Quality)	1070	Day		$6,420,000
Sediment Removal QA	1070	Day		$2,568,000
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,700,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$79,455,800
Engineering, Procurement & Construction Management:				9,534,696
Contractor Overhead/Profit:				11,918,370
Total Capital:				**$100,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Including Operator)	5,485,286,920	gal	$2,194,115
Water Treatment QA	1,070	Day	$428,000
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,548,584
Engineering, Procurement & Construction Management:			785,830
Total Capital:			**$7,300,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Landfill Construction	1	LS	$23,343,896
Local Siting Fee	3,687,026	cy	$18,435,132
Closure	114	acres	$11,426,735
Direct Capital:			$53,205,763
Engineering, Procurement & Construction Management:			6,384,692
Total Capital:			**$59,600,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs			$3,932,097
Total Project Capital and O&M Cost			**$63,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$176,500,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facilities

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1083	acre		$17,328,000
Dredging - 2 12 hour shifts/day	1070	Day	5.879120879	$30,388,000
Dredge Monitoring (Water Quality)	1070	Day		$6,420,000
Sediment Removal QA	1070	Day		$2,568,000
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,700,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$79,455,800
Engineering, Procurement & Construction Management:				9,534,696
Contractor Overhead/Profit:				11,918,370
Total Capital:				**$100,900,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	4,787,933,264	gal	$1,915,173
Water Treatment QA	1,070	Day	$428,000
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,269,643
Engineering, Procurement & Construction Management:			752,357
Total Capital:			**$7,000,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	7,271,870	ton		$181,796,742
Lime Purchase	727,187	ton		$43,631,220
Sediment Loading	7,271,870	ton		$20,361,235
Sediment Hauling	7,271,870	ton		$34,086,889
Landfill Construction	1	LS		$23,343,896
Local Siting Fee	3,687,026	cy		$18,435,132
Closure	114	acres		$11,426,735
Direct Capital:				$333,081,849
Engineering, Procurement & Construction Management:				39,969,822
Total Capital:				**$373,100,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Operations		10	$500,000	$3,680,044
Post Closure Monitoring		40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs				$3,932,097
Total Project Capital and O&M Cost				**$377,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$513,500,000**

ALTERNATIVE C3: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1083	acre		$17,328,000
Dredging - 2 12 hour shifts/day	1070	Day	5.879120879	$30,388,000
Dredge Monitoring (Water Quality)	1070	Day		$6,420,000
Sediment Removal QA	1070	Day		$2,568,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$61,790,800
Engineering, Procurement & Construction Management:				7,414,896
Contractor Overhead/Profit:				9,268,620
Total Capital:				**$78,500,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	2,181,561	bdt	$174,524,872
Direct Capital:			$174,624,872
Engineering, Procurement & Construction Management:			20,954,985
Total Capital:			**$195,600,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Includes Operator)	5,485,286,920	gal	$2,194,115
Water Treatment QA	2,994	day	$598,800
Direct Capital:			$5,379,384
Engineering, Procurement & Construction Management:			645,526
Total Capital:			**$6,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	4,363,122	ton	$12,216,741
Soil Hauling	4,363,122	ton	$20,452,133
Tipping Fees (non-TSCA)	4,192,840	ton	$180,292,139
Tipping Fees (TSCA)	170,281	ton	$9,365,475
Direct Capital:			$222,326,488
Engineering, Procurement & Construction Management:			26,679,179
Total Capital:			**$249,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	2,178,000	cy	$21,780,000
Seeding	2,178,000	sy	$2,178,000
Mitigation	450	acre	$4,500,000

Present Worth of Direct Capital:	$2,766,749
Engineering, Procurement & Construction Management:	$332,010
Total Capital:	**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659

Total Present Worth, Longer Term O&M Costs	**$1,056,130**
Total Project Capital and O&M Cost	**$4,200,000**
TOTAL COST	**$537,800,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	3,248	Day	$55,216,000
Dredge Monitoring (Water Quality)	3,248	Day	$9,744,000
Sediment Removal QA	3,248	Day	$3,897,600
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000

Direct Capital:	$71,352,600
Engineering, Procurement & Construction Management:	8,562,312
Contractor Overhead/Profit:	10,702,890
Total Capital:	**$90,600,000**

CDF CONSTRUCTION

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,700,000	sf	$4,860,000
Shot Rock/Rip Rap	9,600	lf	$6,816,000
Sheetpile Placement	288,000	sf	$5,472,000
Clean Soil Cap	205,000	cy	$2,050,000
Seeding	300,000	sy	$300,000
Mitigation	62	acre	$619,835

Direct Capital:	$20,117,835
Engineering, Procurement & Construction Management:	$2,414,140
Total Capital:	**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456

Total Present Worth, Longer Term O&M Costs	**$16,711,012**
Total Project Capital and O&M Cost	**$39,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	298,239,928	gal	$119,296
Water Treatment QA	1,516	day	$303,200

Direct Capital:	$992,994
Engineering, Procurement & Construction Management:	119,159
Total Capital:	**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	4,218,890	ton		$105,472,250
Lime Purchase	421,889	ton		$25,313,340
Soil Loading	4,218,890	ton		$11,812,892
Soil Hauling	4,218,890	ton		$19,776,047
Tipping Fees (non-TSCA)	3,966,994	ton		$170,580,761
Tipping Fees (TSCA)	385,366	ton		$21,195,108
Direct Capital:				$354,150,398
Engineering, Procurement & Construction Management:				42,498,048
Total Capital:				**$396,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$536,200,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEAD'S)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1083	acre		$17,328,000
Dredging - 2 12 hour shifts/day	1070	Day	5.879120879	$30,388,000
Dredge Monitoring (Water Quality)	1070	Day		$6,420,000
Sediment Removal QA	1070	Day		$2,568,000
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,700,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$79,455,800
Engineering, Procurement & Construction Management:				9,534,696
Contractor Overhead/Profit:				11,918,370
Total Capital:				**$100,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	4,787,933,264	gal	$1,915,173
Water Treatment QA	1,070	Day	$428,000
Piping	95,000	ft	$6,365,000
Direct Capital:			$11,294,643
Engineering, Procurement & Construction Management:			1,355,357
Total Capital:			**$12,700,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	7,271,870	ton	$174,524,872
Soil Loading	7,271,870	ton	$20,361,235
Soil Hauling	7,271,870	ton	$8,521,722
Direct Capital:			$203,407,829
Engineering, Procurement & Construction Management:			$24,408,940
Total Capital:			**$227,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$370,000,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible,Dredge to CDF and Off-site Disposal

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs			**$16,711,012**
Total Project Capital and O&M Cost			**$39,200,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,739,831	tons		$10,438,985
Sand Placement	1,242,736	cy		$7,456,418
Cobble Purchase and Placement	745,642	cy		$22,369,254
Cap Placement QA	1	LS		$100,000
Direct Capital:				$40,564,657
Engineering, Procurement & Construction Management:				4,867,759
Total Capital:				**$45,432,416**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$908,648	$13,671,792
Total Present Worth, Longer Term O&M Costs			$19,690,311
Total Project Capital and O&M Cost			**$65,100,000**

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	2,233	Day	$37,961,000
Dredge Monitoring (Water Quality)	2,233	Day	$6,699,000
Sediment Removal QA	2,233	Day	$2,679,600
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$49,834,600
Engineering, Procurement & Construction Management:			5,980,152
Contractor Overhead/Profit:			7,475,190
Total Capital:			**$63,300,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	259,327,325	gal	$103,731
Water Treatment QA	1,516	day	$303,200
Direct Capital:			$977,429
Engineering, Procurement & Construction Management:			117,291
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	2,203,177	ton	$55,079,425
Lime Purchase	220,318	ton	$13,219,080
Soil Loading	2,203,177	ton	$6,168,896
Soil Hauling	2,203,177	ton	$10,327,392
Tipping Fees (non-TSCA)	1,951,281	ton	$83,905,104
Tipping Fees (TSCA)	251,896	ton	$13,854,253
Direct Capital:			$182,554,150
Engineering, Procurement & Construction Management:			21,906,498
Total Capital:			**$204,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			**$4,513,889**
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**

TOTAL COST	**$381,900,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
DE PERE TO GREEN BAY
Action Level - 1,000 ppb

Material Handling Assumptions:								
Volume > 1000 ppb	5,879,529	cy	1034 ac		4,488,190	m3		Acres corresponds to dredge footprint area
Volume > 125 ppb	6,868,500	cy			5,243,130	m3		
Volume > 250 ppb	6,449,065	cy			4,922,950	m3		
Volume > 500 ppb	6,169,458	cy			4,709,510	m3		
Volume > 5000 ppb	4,517,391	cy			3,448,390	m3		
Volume > 50,000 ppb	240,778	cy			183,800	m3		
Solids Specific Gravity	2.36							
Fresh Water Density	62.4	lb/ft3						
In Situ Density	33.8%	w/w	17.8%	v/v	1.05	tons per cy		
Slurry Density (20% in situ)	8.0%	w/w	3.6%	v/v	0.88	tons per cy		Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	15.4%	v/v	1.02	tons per cy		Montgomery Watson
Dewatered Density (Hydraulic Dredging and CDF)	50.0%	w/w	29.8%	v/v	1.18	tons per cy		Foth & VanDyke
Dewatered Density (Mechanical Dredging)	33.8%	w/w	17.8%	v/v	1.05	tons per cy		
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy		
CDF Capacity	2,136,771	cy	in situ		974,801	m3		
HTTD Treatment Capacity	1,577,177	cy	in situ		1,650,000	tons		
Cap Volume	1,833,253	cy			1,399,430	m3		
Vitrification Treatment Capacity	9,106,166	cy	in situ		6440000.00	tons		
Cost Estimating Parameters & Methodology:								
Interest Rate	6.0%							
Sales Tax	5.5%							Not Used
Engineering, Procurement and Construction Mgmt	12.0%							
Contractor Overhead and Profit - Dredging Only	15.0%							
Dredging								
Dredge Monitoring (Water Quality)	$3,000	per day						
Sediment Removal QA	$1,200	per day						
Debris Sweep	$16,000	per acre						Ogden Beeman
Hydraulic - 2 12-inch Cutterheads								
Site Preparation	$803,400	LS						Ogden Beeman
Mobilization - Equipment	$1,135,000	LS						Ogden Beeman
Mobilization - Silt Curtain	$35,000							Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift						Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift						Ogden Beeman
Winter Over Equipment	$285,000	per year						Ogden Beeman
Site Restoration	$600,000	per dredge launch site						
Length of Piping	95,000	ft			18	mi		Distance to Town of Holland (map provided by Fred Swed). 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft						Ogden Beeman
Number of Road Crossings	12	each						pj, review map
Cost per Road Crossing	$50,000	per crossing						pj, review map
Number of Booster Pumps	4	each						Ogden Beeman
Booster Pump Cost	$2,500	per day						Ogden Beeman
Mechanical - 8 cy bucket								
Dock Construction	$400,000	LS						pj
Mobilization - Equipment	$455,000	per dredge						Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS						Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea						Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$17,000	per shift						Ogden Beeman
Dredge Rate	1900	cy in situ per 10 hour shift						Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area						pj
Free Water per cy Dredged (10%)	20	gal						Ogden Beeman
Offload Crane Mobilization	$50,000	LS						pj
Site Restoration	$500,000	LS						pj
High Temperature Thermal Desorption								
Setup Staging Area	$50,000							pj
Mobilization/Site Prep	$150,000							Maxymillian
Sediment Treatment QA	$2	per ton						
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1						
Sand Purchase and Deliver	$6	per ton						Ole
Blending	$25	per ton						Ole
HTTD (includes off-gas treatment)	$75	per ton						Maxymillian
Stack Testing	$50,000	LS						Maxymillian
Place Treated Material	$3	per ton						
Vitrification								
Capital Costs	$36,000,000	LS						Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year						Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton						Unit Cost Study- Minergy

Capping					
Mobilization/Site Prep	$200,000				Ogden Beeman
Area	19,041,971	sf	1,769,100	m2	
Sand Cap Depth	1.7	feet			
Sand Purchase	$6	per ton			Ole
Placement Rate	$6	per cy			Ogden Beeman
Sand Density	1.4	tons per cy			
Armored Cap Depth	1.0	feet			
Cobbles	$30	per cy			Means
Sand Density	1.4	tons per cy			
Cap Placement QA	$100,000	LS			Ogden Beeman
Long-term O&M	2%	of capital			pj
Long-term Monitoring	$400,000	per year			Anne LTM
Nearshore CDF			<u>Bayport</u>		
Land Lease or Purchase	$1.80	per sf			Baird
Length	9,600	lf			Baird
Capping Volume	205,000	cy	2,178,000		Baird
Seeding Area	300,000	sy	2,178,000		Baird
Sheetpile Wall Length	9,600	lf			based on bathymetry
Sheetpile Depth	30	ft			pj
Sheetpile Cost	$19	per sf			Baird
Shot Rock Berm	$500	per lf			Baird
Rip Rap	$210	per lf			pj
Clean Soil Cap	$10	per cy			Baird
Seeding	$1	per sy			Baird
Mitigation	$10,000	per acre			Tim
	$10,000	per year			Tim
Long-term Monitoring	$650,000	per year			Anne LTM
Long-term O&M	2%	of capital			pj
Solidification					
Percent Lime	10.0%	(w/w)			Montgomery Watson
Lime	$60	per ton	Mixing	$25 per ton	pj, pug mill mixing
<u>Dewatering - Mechanical</u>					
Mobilization	$100,000				pj
Holding Pond-Centrifuge	$80	per bone dry ton			Global Dewatering
<u>Dewatering - Upland Pond (2 cells)</u>					
Land Lease or Purchase	$1.80	per sf			Ole
Area	4,491,228	sf	103.10		2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter	8,477	lf	2119.251741		assume square
Depth of Material in Dewatering Cell	8	feet			based on size at Arrowhead Park
Cell Retention Time	24	hours			Not Used
Cell Depth	10	feet			
Mobilization	$20,000	LS			
Clear and Grub	$2,000	per acre			pj
Berm Volume	10.4	cy per lf			2:1 slope, 8-foot top
Berm Construction	$6	per cy			pj
Rough Grading	$0.25	per sf			pj
Alphalt Liner	$1.50	per sf			pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS			pj
Regrade Berm Soils	$6	per cy			pj
Seed/Sod	$1	per sy			Baird
<u>Water Treatment</u>					
Flow Rate (3 Mechanical Dredges)	57	gpm			assume operate 24/7
Unit, Purchase (3 Mechanical Dredges)	$216,590	LS			pj
Flow Rate (3 Mechanical Dredges to CDF)	287	gpm			assume operate 24/7
Unit, Purchase (3 Mechanical Dredges to CDF)	$570,498	LS			pj
Flow Rate (2 Hydraulic Dredges)	3,563	gpm			assume operate 24/7
Unit, Purchase (Hydraulic Dredge)	$2,586,470	LS			pj
Flow Rate (2 Hydraulic Dredges; settling pond)	3,110	gpm			assume operate 24/7
Flow Rate (mechanical dewatering)	3,563	gpm			
Unit, Purchase (mechanical dewatering)	$2,586,470	LS			
Water Treatment (Including Operator)	$0.40	per 1,000 gallons			pj
Water Treatment QA	$200	per day			pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet			Distance from town of Holland to river per map provided by Fred Swed
<u>Disposal</u>					
Existing NR 500 Commercial Disposal Facility					
Load Soil for Hauling	$2.80	per ton			pj
Round-trip Hauling	2	hours			pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours			pj
Tipping Fee (non-TSCA)	$43	per ton			St. Paul
Tipping Fee (TSCA)	$55	per ton			St. Paul
Truck Rate	$75	per hour			pj
Truck Load	32	tons			pj
Conveyer System Construction	1,000,000	LS			pj
New Landfill Disposal (Dedicated NR 500 Monofill)					
Landfill Construction	$22,246,866				
Local Siting Fee	$5	per cy			
Closure Cap	$100,000	per acre			
Operating Cost	$500,000	per year			
Post-closure Monitoring	$30,000	per year			

Institutional Controls		
Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	3	LS		$1,470,000
Watertight Barges	4	ea		$400,000
Offload Stockpile Area Prep.	1	LS		$75,000
Dredging - 12 hour shifts	3,095	Day	23.80769231	$52,615,000
Dredge Monitoring (Water Quality)	3,095	Day		$9,285,000
Sediment Removal QA	3,095	Day		$3,714,000
Offload Crane Mobilization	1	LS		$50,000
Site Restoration	1	ea		$500,000
Direct Capital:				$68,109,000
Engineering, Procurement & Construction Management:				8,173,080
Contractor Overhead/Profit:				10,216,350
Total Capital:				**$86,500,000**

WATER TREATMENT

Capital Items	Quantity	Units		Cost
Unit Purchase	57	gpm		$216,590
Water Treatment (Includes Operator)	118,742,966	gal		$47,497
Water Treatment QA	1,445	day		$289,000
Direct Capital:				$553,087
Engineering, Procurement & Construction Management:				66,370
Total Capital:				**$600,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	6,151,006	ton		$153,775,150
Lime Purchase	615,101	ton		$36,906,060
Soil Loading	6,151,006	ton		$17,222,817
Soil Hauling	6,151,006	ton		$28,832,841
Tipping Fees (non-TSCA)	5,899,111	ton		$253,661,752
Tipping Fees (TSCA)	251,896	ton		$13,854,253
Direct Capital:				$504,252,872
Engineering, Procurement & Construction Management:				60,510,345
Total Capital:				**$564,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST **$660,600,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1034	acre		$16,544,000
Dredging - 2 12 hour shifts/day	1019	Day	5.598901099	$28,939,600
Dredge Monitoring (Water Quality)	1019	Day		$6,114,000
Sediment Removal QA	1019	Day		$2,445,600
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,190,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$76,285,000
Engineering, Procurement & Construction Management:				9,154,200
Contractor Overhead/Profit:				11,442,750
Total Capital:				**$96,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Including Operator)	5,227,509,847	gal	$2,091,004
Water Treatment QA	1,019	Day	$407,600
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,425,074
Engineering, Procurement & Construction Management:			771,009
Total Capital:			**$7,200,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Landfill Construction	1	LS	$22,246,866
Local Siting Fee	3,513,757	cy	$17,568,787
Closure	109	acres	$10,889,744
Direct Capital:			$50,705,397
Engineering, Procurement & Construction Management:			6,084,648
Total Capital:			**$56,800,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs			$3,932,097
Total Project Capital and O&M Cost			**$60,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$169,600,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facilities

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1034	acre		$16,544,000
Dredging - 2 12 hour shifts/day	1019	Day	5.598901099	$28,939,600
Dredge Monitoring (Water Quality)	1019	Day		$6,114,000
Sediment Removal QA	1019	Day		$2,445,600
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,190,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$76,285,000
Engineering, Procurement & Construction Management:				9,154,200
Contractor Overhead/Profit:				11,442,750
Total Capital:				**$96,900,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	4,562,927,820	gal	$1,825,171
Water Treatment QA	1,019	Day	$407,600
Piping	20,000	ft	$1,340,000
Direct Capital:			$6,159,241
Engineering, Procurement & Construction Management:			739,109
Total Capital:			**$6,900,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	6,930,133	ton		$173,253,336
Lime Purchase	693,014	ton		$41,580,840
Sediment Loading	6,930,133	ton		$19,404,374
Sediment Hauling	6,930,133	ton		$32,485,000
Landfill Construction	1	LS		$22,246,866
Local Siting Fee	3,513,757	cy		$17,568,787
Closure	109	acres		$10,889,744
Direct Capital:				$317,428,947
Engineering, Procurement & Construction Management:				38,091,474
Total Capital:				**$355,500,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Operations		10	$500,000	$3,680,044
Post Closure Monitoring		40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs				$3,932,097
Total Project Capital and O&M Cost				**$359,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST	**$491,800,000**

ALTERNATIVE C3: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1034	acre		$16,544,000
Dredging - 2 12 hour shifts/day	1019	Day	5.598901099	$28,939,600
Dredge Monitoring (Water Quality)	1019	Day		$6,114,000
Sediment Removal QA	1019	Day		$2,445,600
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$59,130,000
Engineering, Procurement & Construction Management:				7,095,600
Contractor Overhead/Profit:				8,869,500
Total Capital:				**$75,100,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	2,079,040	bdt	$166,323,203
Direct Capital:			$166,423,203
Engineering, Procurement & Construction Management:			19,970,784
Total Capital:			**$186,400,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Includes Operator)	5,227,509,847	gal	$2,091,004
Water Treatment QA	2,854	day	$570,800
Direct Capital:			$5,248,274
Engineering, Procurement & Construction Management:			629,793
Total Capital:			**$5,900,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	4,158,080	ton	$11,642,624
Soil Hauling	4,158,080	ton	$19,491,000
Tipping Fees (non-TSCA)	3,987,799	ton	$171,475,344
Tipping Fees (TSCA)	170,281	ton	$9,365,475
Direct Capital:			$211,974,444
Engineering, Procurement & Construction Management:			25,436,933
Total Capital:			**$237,400,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$513,500,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	3,095	Day	$52,615,000
Dredge Monitoring (Water Quality)	3,095	Day	$9,285,000
Sediment Removal QA	3,095	Day	$3,714,000
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$68,109,000
Engineering, Procurement & Construction Management:			8,173,080
Contractor Overhead/Profit:			10,216,350
Total Capital:			**$86,500,000**

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs				**$16,711,012**
Total Project Capital and O&M Cost				**$39,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	292,384,518	gal	$116,954
Water Treatment QA	1,445	day	$289,000
Direct Capital:			$976,452
Engineering, Procurement & Construction Management:			117,174
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	3,915,574	ton		$97,889,350
Lime Purchase	391,558	ton		$23,493,480
Soil Loading	3,915,574	ton		$10,963,607
Soil Hauling	3,915,574	ton		$18,354,253
Tipping Fees (non-TSCA)	3,663,678	ton		$157,538,173
Tipping Fees (TSCA)	395,705	ton		$21,763,760
Direct Capital:				$330,002,623
Engineering, Procurement & Construction Management:				39,600,315
Total Capital:				**$369,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$505,100,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEAD'S)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	1034	acre		$16,544,000
Dredging - 2 12 hour shifts/day	1019	Day	5.598901099	$28,939,600
Dredge Monitoring (Water Quality)	1019	Day		$6,114,000
Sediment Removal QA	1019	Day		$2,445,600
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$10,190,000
Winter Over All Equipment	6	yr		$1,710,000
Site Restoration	1	LS		$600,000
Direct Capital:				$76,285,000
Engineering, Procurement & Construction Management:				9,154,200
Contractor Overhead/Profit:				11,442,750
Total Capital:				**$96,900,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	4,562,927,820	gal	$1,825,171
Water Treatment QA	1,019	Day	$407,600
Piping	95,000	ft	$6,365,000
Direct Capital:			$11,184,241
Engineering, Procurement & Construction Management:			1,342,109
Total Capital:			**$12,500,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	6,930,133	ton	$166,323,203
Soil Loading	6,930,133	ton	$19,404,374
Soil Hauling	6,930,133	ton	$8,121,250
Direct Capital:			$193,848,826
Engineering, Procurement & Construction Management:			$23,261,859
Total Capital:			**$217,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$355,100,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible,Dredge to CDF and Off-site Disposal

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs				**$16,711,012**
Total Project Capital and O&M Cost				**$39,200,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,645,602	tons		$9,873,614
Sand Placement	1,175,430	cy		$7,052,582
Cobble Purchase and Placement	705,258	cy		$21,157,745
Cap Placement QA	1	LS		$100,000
Direct Capital:				$38,383,942
Engineering, Procurement & Construction Management:				4,606,073
Total Capital:				**$42,990,015**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$859,800	$12,936,810
Total Present Worth, Longer Term O&M Costs				$18,955,329
Total Project Capital and O&M Cost				**$61,900,000**

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	2,130	Day	$36,210,000
Dredge Monitoring (Water Quality)	2,130	Day	$6,390,000
Sediment Removal QA	2,130	Day	$2,556,000
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$47,651,000
Engineering, Procurement & Construction Management:			5,718,120
Contractor Overhead/Profit:			7,147,650
Total Capital:			**$60,500,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	255,360,134	gal	$102,144
Water Treatment QA	1,445	day	$289,000
Direct Capital:			$961,642
Engineering, Procurement & Construction Management:			115,397
Total Capital:			**$1,100,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	1,997,673	ton	$49,941,825
Lime Purchase	199,768	ton	$11,986,080
Soil Loading	1,997,673	ton	$5,593,484
Soil Hauling	1,997,673	ton	$9,364,092
Tipping Fees (non-TSCA)	1,745,777	ton	$75,068,429
Tipping Fees (TSCA)	251,896	ton	$13,854,257
Direct Capital:			$165,808,168
Engineering, Procurement & Construction Management:			19,896,980
Total Capital:			**$185,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			**$4,513,889**
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	2,178,000	cy	$21,780,000
Seeding	2,178,000	sy	$2,178,000
Mitigation	450	acre	$4,500,000
Present Worth of Direct Capital:			$2,766,749
Engineering, Procurement & Construction Management:			$332,010
Total Capital:			**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$357,100,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
DE PERE TO GREEN BAY
Action Level - 5,000 ppb

Material Handling Assumptions:							
Volume > 5000 ppb	4,517,391	cy	715 ac	3,448,390	m3		Acres corresponds to dredge footprint area
Volume > 125 ppb	6,868,500	cy		5,243,130	m3		
Volume > 250 ppb	6,449,065	cy		4,922,950	m3		
Volume > 500 ppb	6,169,458	cy		4,709,510	m3		
Volume > 1000 ppb	5,879,529	cy		4,488,190	m3		
Volume > 50,000 ppb	240,778	cy		183,800	m3		
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	33.8%	w/w	17.8% v/v	1.05	tons per cy		
Slurry Density (20% in situ)	8.0%	w/w	3.6% v/v	0.88	tons per cy		Ogden Beeman
Dewatered Density (settling pond)	30%	w/w	15.4% v/v	1.02	tons per cy		Montgomery Watson
Dewatered Density (Hydraulic Dredging and CDF)	50.0%	w/w	29.8% v/v	1.18	tons per cy		Foth & VanDyke
Dewatered Density (Mechanical Dredging)	33.8%	w/w	17.8% v/v	1.05	tons per cy		
Treated Density	93.4%	w/w	60.0% v/v	1.28	tons per cy		
CDF Capacity	2,136,771	cy	in situ	974,801	m3		
HTTD Treatment Capacity	1,577,177	cy	in situ	1,650,000	tons		
Cap Volume	1,415,350	cy		1,080,420	m3		
Vitrification Treatment Capacity	9,106,166	cy	in situ	6440000.00	tons		
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Debris Sweep	$16,000	per acre					Ogden Beeman
Hydraulic - 2 12-inch Cutterheads							
Site Preparation	$803,400	LS					Ogden Beeman
Mobilization - Equipment	$1,135,000	LS					Ogden Beeman
Mobilization - Silt Curtain	$35,000						Ogden Beeman
Shift Rate (12 hours)	$14,200	per shift					Ogden Beeman
Dredge Rate	2885	cy in situ per 12 hour shift					Ogden Beeman
Winter Over Equipment	$285,000	per year					Ogden Beeman
Site Restoration	$600,000	per dredge launch site					
Length of Piping	95,000	ft		18	mi		Distance to Town of Holland (map provided by Fred Swed). 11 mi of hard piping plus 7 mi of floating pipe
Piping Purchase/Installation	$67	per ft					Ogden Beeman
Number of Road Crossings	12	each					pj, review map
Cost per Road Crossing	$50,000	per crossing					pj, review map
Number of Booster Pumps	4	each					Ogden Beeman
Booster Pump Cost	$2,500	per day					Ogden Beeman
Mechanical - 8 cy bucket							
Dock Construction	$400,000	LS					pj
Mobilization - Equipment	$455,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman - JAG estimate
Shift Rate (10 hours)	$17,000	per shift					Ogden Beeman
Dredge Rate	1900	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					pj
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Offload Crane Mobilization	$50,000	LS					pj
Site Restoration	$500,000	LS					pj
High Temperature Thermal Desorption							
Setup Staging Area	$50,000						pj
Mobilization/Site Prep	$150,000						Maxymillian
Sediment Treatment QA	$2	per ton					
Ratio of Amending Sand Volume to Dredge Vol.	0.25	:1					
Sand Purchase and Deliver	$6	per ton					Ole
Blending	$25	per ton					Ole
HTTD (includes off-gas treatment)	$75	per ton					Maxymillian
Stack Testing	$50,000	LS					Maxymillian
Place Treated Material	$3	per ton					
Vitrification							
Capital Costs	$36,000,000	LS					Unit Cost Study- Minergy
Operating Costs	$6,800,000	per year					Unit Cost Study- Minergy
Vitrification (Unit Cost includes Cap and Oper Costs)	$24.0	per ton					Unit Cost Study- Minergy

Capping						
Mobilization/Site Prep	$200,000					Ogden Beeman
Area	12,497,672	sf	1,161,100	m2		
Sand Cap Depth	1.7	feet				
Sand Purchase	$6	per ton				Ole
Placement Rate	$6	per cy				Ogden Beeman
Sand Density	1.4	tons per cy				
Armored Cap Depth	1.0	feet				
Cobbles	$30	per cy				Means
Sand Density	1.4	tons per cy				
Cap Placement QA	$100,000	LS				Ogden Beeman
Long-term O&M	2%	of capital				pj
Long-term Monitoring	$400,000	per year				Anne LTM
Nearshore CDF			Bayport			
Land Lease or Purchase	$1.80	per sf				Baird
Length	9,600	lf				Baird
Capping Volume	205,000	cy	2,178,000			Baird
Seeding Area	300,000	sy	2,178,000			Baird
Sheetpile Wall Length	9,600	lf				based on bathymetry
Sheetpile Depth	30	ft				pj
Sheetpile Cost	$19	per sf				Baird
Shot Rock Berm	$500	per lf				Baird
Rip Rap	$210	per lf				pj
Clean Soil Cap	$10	per cy				Baird
Seeding	$1	per sy				Baird
Mitigation	$10,000	per acre				Tim
	$10,000	per year				Tim
Long-term Monitoring	$650,000	per year				Anne LTM
Long-term O&M	2%	of capital				pj
Solidification						
Percent Lime	10.0%	(w/w)				Montgomery Watson
Lime	$60	per ton	Mixing	$25	per ton	pj, pug mill mixing
Dewatering - Mechanical						
Mobilization	$100,000					pj
Holding Pond-Centrifuge	$80	per bone dry ton				Global Dewatering
Dewatering - Upland Pond (2 cells)						
Land Lease or Purchase	$1.80	per sf				Ole
Area	4,491,228	sf	103.10			2 days slurry + 13 wk solids * 2 cells * 2 shifts per day
Perimeter	8,477	lf	2119.251741			assume square
Depth of Material in Dewatering Cell	8	feet				based on size at Arrowhead Park
Cell Retention Time	24	hours				Not Used
Cell Depth	10	feet				
Mobilization	$20,000	LS				
Clear and Grub	$2,000	per acre				pj
Berm Volume	10.4	cy per lf				2:1 slope, 8-foot top
Berm Construction	$6	per cy				pj
Rough Grading	$0.25	per sf				pj
Alphalt Liner	$1.50	per sf				pj, 2 2-inch lifts
Demob/Disposal	$10,000	LS				pj
Regrade Berm Soils	$6	per cy				pj
Seed/Sod	$1	per sy				Baird
Water Treatment						
Flow Rate (3 Mechanical Dredges)	57	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges)	$216,590	LS				pj
Flow Rate (3 Mechanical Dredges to CDF)	287	gpm				assume operate 24/7
Unit, Purchase (3 Mechanical Dredges to CDF)	$570,498	LS				pj
Flow Rate (2 Hydraulic Dredges)	3,563	gpm				assume operate 24/7
Unit, Purchase (Hydraulic Dredge)	$2,586,470	LS				pj
Flow Rate (2 Hydraulic Dredges; settling pond)	3,110	gpm				assume operate 24/7
Flow Rate (mechanical dewatering)	3,563	gpm				
Unit, Purchase (mechanical dewatering)	$2,586,470	LS				
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample/day
Length of piping for treated water discharge	20,000	feet				Distance from town of Holland to river per map provided by Fred Swed
Disposal						
Existing NR 500 Commercial Disposal Facility						
Load Soil for Hauling	$2.80	per ton				pj
Round-trip Hauling	2	hours				pj
Round-trip Hauling (to Vitrification Facility)	0.5	hours				pj
Tipping Fee (non-TSCA)	$43	per ton				St. Paul
Tipping Fee (TSCA)	$55	per ton				St. Paul
Truck Rate	$75	per hour				pj
Truck Load	32	tons				pj
Conveyer System Construction	1,000,000	LS				pj
New Landfill Disposal (Dedicated NR 500 Monofill)						
Landfill Construction	$17,092,830					
Local Siting Fee	$5	per cy				
Closure Cap	$100,000	per acre				
Operating Cost	$500,000	per year				
Post-closure Monitoring	$30,000	per year				

Institutional Controls		
Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE C1: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Passive Dewatering)

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	3	LS		$1,470,000
Watertight Barges	4	ea		$400,000
Offload Stockpile Area Prep.	1	LS		$75,000
Dredging - 12 hour shifts	2,378	Day	18.29230769	$40,426,000
Dredge Monitoring (Water Quality)	2,378	Day		$7,134,000
Sediment Removal QA	2,378	Day		$2,853,600
Offload Crane Mobilization	1	LS		$50,000
Site Restoration	1	ea		$500,000
Direct Capital:				$52,908,600
Engineering, Procurement & Construction Management:				6,349,032
Contractor Overhead/Profit:				7,936,290
Total Capital:				**$67,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	57	gpm	$216,590
Water Treatment (Includes Operator)	91,233,227	gal	$36,493
Water Treatment QA	1,110	day	$222,000
Direct Capital:			$475,083
Engineering, Procurement & Construction Management:			57,010
Total Capital:			**$500,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	4,725,974	ton	$118,149,341
Lime Purchase	472,598	ton	$28,355,880
Soil Loading	4,725,974	ton	$13,232,726
Soil Hauling	4,725,974	ton	$22,153,001
Tipping Fees (non-TSCA)	4,474,078	ton	$192,385,360
Tipping Fees (TSCA)	251,896	ton	$13,854,253
Direct Capital:			$388,130,561
Engineering, Procurement & Construction Management:			46,575,667
Total Capital:			**$434,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	2,178,000	cy	$21,780,000
Seeding	2,178,000	sy	$2,178,000
Mitigation	450	acre	$4,500,000
Present Worth of Direct Capital:			$2,766,749
Engineering, Procurement & Construction Management:			$332,010
Total Capital:			**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**

TOTAL COST **$511,100,000**

ALTERNATIVE C2A: Dredge Sediment with Combined Dewatering and Disposal Facility

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	715	acre		$11,440,000
Dredging - 2 12 hour shifts/day	783	Day	4.302197802	$22,237,200
Dredge Monitoring (Water Quality)	783	Day		$4,698,000
Sediment Removal QA	783	Day		$1,879,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$7,830,000
Winter Over All Equipment	5	yr		$1,425,000
Site Restoration	1	LS		$600,000
Direct Capital:				$59,851,200
Engineering, Procurement & Construction Management:				7,182,144
Contractor Overhead/Profit:				8,977,680
Total Capital:				**$76,000,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Including Operator)	4,016,428,155	gal	$1,606,571
Water Treatment QA	783	Day	$313,200
Piping	20,000	ft	$1,340,000
Direct Capital:			$5,846,241
Engineering, Procurement & Construction Management:			701,549
Total Capital:			**$6,500,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units	Cost
Landfill Construction	1	LS	$17,092,830
Local Siting Fee	2,699,709	cy	$13,498,544
Closure	84	acres	$8,366,866
Direct Capital:			$38,958,240
Engineering, Procurement & Construction Management:			4,674,989
Total Capital:			**$43,600,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs			$3,932,097
Total Project Capital and O&M Cost			**$47,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$138,700,000**

ALTERNATIVE C2B: Dredge Sediment with Separate Dewatering and Disposal Facilities

SEDIMENT REMOVAL (2 12-INCH CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	715	acre		$11,440,000
Dredging - 2 12 hour shifts/day	783	Day	4.302197802	$22,237,200
Dredge Monitoring (Water Quality)	783	Day		$4,698,000
Sediment Removal QA	783	Day		$1,879,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$7,830,000
Winter Over All Equipment	5	yr		$1,425,000
Site Restoration	1	LS		$600,000
Direct Capital:				$59,851,200
Engineering, Procurement & Construction Management:				7,182,144
Contractor Overhead/Profit:				8,977,680
Total Capital:				**$76,000,000**

SEDIMENT DEWATERING (GRAVITY - NR 213)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025
Direct Capital:			$17,734,010
Engineering, Procurement & Construction Management:			2,128,081
Total Capital:			**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	3,505,812,959	gal	$1,402,325
Water Treatment QA	783	Day	$313,200
Piping	20,000	ft	$1,340,000
Direct Capital:			$5,641,995
Engineering, Procurement & Construction Management:			677,039
Total Capital:			**$6,300,000**

SEDIMENT DISPOSAL (Dedicated NR 500 Monofill)

Capital Items	Quantity	Units		Cost
Solidification	5,324,597	ton		$133,114,924
Lime Purchase	532,460	ton		$31,947,600
Sediment Loading	5,324,597	ton		$14,908,872
Sediment Hauling	5,324,597	ton		$24,959,048
Landfill Construction	1	LS		$17,092,830
Local Siting Fee	2,699,709	cy		$13,498,544
Closure	84	acres		$8,366,866
Direct Capital:				$243,888,684
Engineering, Procurement & Construction Management:				29,266,642
Total Capital:				**$273,200,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Operations	10	$500,000	$3,680,044
Post Closure Monitoring	40	$30,000	$252,053
Total Present Worth, Longer Term O&M Costs			$3,932,097
Total Project Capital and O&M Cost			**$277,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	2,178,000	cy	$21,780,000
Seeding	2,178,000	sy	$2,178,000
Mitigation	450	acre	$4,500,000
Present Worth of Direct Capital:			$2,766,749
Engineering, Procurement & Construction Management:			$332,010
Total Capital:			**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**

TOTAL COST **$388,000,000**

ALTERNATIVE C3: Dredge Sediment With Disposal at Existing NR 500 Commercial Disposal Facility (Mechanical Dewatering)

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEADS)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	715	acre		$11,440,000
Dredging - 2 12 hour shifts/day	783	Day	4.302197802	$22,237,200
Dredge Monitoring (Water Quality)	783	Day		$4,698,000
Sediment Removal QA	783	Day		$1,879,200
Winter Over All Equipment	5	yr		$1,425,000
Site Restoration	1	LS		$600,000
Direct Capital:				$45,056,200
Engineering, Procurement & Construction Management:				5,406,744
Contractor Overhead/Profit:				6,758,430
Total Capital:				**$57,200,000**

SEDIMENT DEWATERING (MECHANICAL)

Capital Items	Quantity	Units	Cost
Mobilization/Site Prep	1	LS	$100,000
Dewatering	1,597,379	bdt	$127,790,327
Direct Capital:			$127,890,327
Engineering, Procurement & Construction Management:			15,346,839
Total Capital:			**$143,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,563	gpm	$2,586,470
Water Treatment (Includes Operator)	4,016,428,155	gal	$1,606,571
Water Treatment QA	2,193	day	$438,600
Direct Capital:			$4,631,641
Engineering, Procurement & Construction Management:			555,797
Total Capital:			**$5,200,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Soil Loading	3,194,758	ton	$8,945,323
Soil Hauling	3,194,758	ton	$14,975,429
Tipping Fees (non-TSCA)	3,024,477	ton	$130,052,503
Tipping Fees (TSCA)	170,281	ton	$9,365,475
Direct Capital:			$163,338,730
Engineering, Procurement & Construction Management:			19,600,648
Total Capital:			**$182,900,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**

TOTAL COST **$397,200,000**

ALTERNATIVE D: Dredge Sediment, CDF and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	2,378	Day	$40,426,000
Dredge Monitoring (Water Quality)	2,378	Day	$7,134,000
Sediment Removal QA	2,378	Day	$2,853,600
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$52,908,600
Engineering, Procurement & Construction Management:			6,349,032
Contractor Overhead/Profit:			7,936,290
Total Capital:			**$67,200,000**

CDF CONSTRUCTION

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	2,700,000	sf	$4,860,000
Shot Rock/Rip Rap	9,600	lf	$6,816,000
Sheetpile Placement	288,000	sf	$5,472,000
Clean Soil Cap	205,000	cy	$2,050,000
Seeding	300,000	sy	$300,000
Mitigation	62	acre	$619,835
Direct Capital:			$20,117,835
Engineering, Procurement & Construction Management:			$2,414,140
Total Capital:			**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs			**$16,711,012**
Total Project Capital and O&M Cost			**$39,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	264,874,779	gal	$105,950
Water Treatment QA	1,110	day	$222,000
Direct Capital:			$898,448
Engineering, Procurement & Construction Management:			107,814
Total Capital:			**$1,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units		Cost
Solidification	2,490,541	ton		$62,263,525
Lime Purchase	249,055	ton		$14,943,300
Soil Loading	2,490,541	ton		$6,973,515
Soil Hauling	2,490,541	ton		$11,674,411
Tipping Fees (non-TSCA)	2,238,645	ton		$96,261,755
Tipping Fees (TSCA)	477,989	ton		$26,289,406
Direct Capital:				$218,405,911
Engineering, Procurement & Construction Management:				26,208,709
Total Capital:				**$244,600,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**

TOTAL COST **$360,700,000**

ALTERNATIVE E: Dredge Sediment and Thermal Treatment

SEDIMENT REMOVAL (2 - 12-inch CUTTERHEAD'S)

Capital Items	Quantity	Units		Cost
Site Preparation	2	LS		$1,606,800
Mobilization - Equipment and Silt Curtain	1	LS		$1,170,000
Debris Sweep	715	acre		$11,440,000
Dredging - 2 12 hour shifts/day	783	Day	4.302197802	$22,237,200
Dredge Monitoring (Water Quality)	783	Day		$4,698,000
Sediment Removal QA	783	Day		$1,879,200
Piping	95,000	ft		$6,365,000
Road Crossings	12	ea		$600,000
Booster Pumps	4	ea		$7,830,000
Winter Over All Equipment	5	yr		$1,425,000
Site Restoration	1	LS		$600,000
Direct Capital:				$59,851,200
Engineering, Procurement & Construction Management:				7,182,144
Contractor Overhead/Profit:				8,977,680
Total Capital:				**$76,000,000**

SEDIMENT DEWATERING (GRAVITY)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,491,228	sf	$8,084,210
Mobilization	1	LS	$20,000
Clear and Grub	4,491,228	sf	$206,209
Berm Construction	87,910	cy	$527,458
Rough Grading	4,491,228	sf	$1,122,807
Liner Placement	4,491,228	sf	$6,736,842
Demob/Disposal	1	LS	$10,000
Regrade	87,910	cy	$527,458
Seed/Sod	499,025	sy	$499,025

Direct Capital:	$17,734,010
Engineering, Procurement & Construction Management:	2,128,081
Total Capital:	**$19,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	3,110	gpm	$2,586,470
Water Treatment (Including Operator)	3,505,812,959	gal	$1,402,325
Water Treatment QA	783	Day	$313,200
Piping	95,000	ft	$6,365,000

Direct Capital:	$10,666,995
Engineering, Procurement & Construction Management:	1,280,039
Total Capital:	**$11,900,000**

SEDIMENT TREATMENT (VITRIFICATION 2x375 t Standalone Storage Units)

Capital Items	Quantity	Units	Cost
Sediment Treatment	5,324,597	ton	$127,790,327
Soil Loading	5,324,597	ton	$14,908,872
Soil Hauling	5,324,597	ton	$6,239,762

Direct Capital:	$148,938,961
Engineering, Procurement & Construction Management:	$17,872,675
Total Capital:	**$166,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000

Direct Capital:	$5,000
Engineering, Procurement & Construction Management:	600
Total Capital:	**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889

Total Present Worth, Longer Term O&M Costs	$4,513,889
Total Project Capital and O&M Cost	**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	972	$14,628
Long-term Monitoring	40	63,194	$950,842
Long-term O&M	40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs			**$1,056,130**
Total Project Capital and O&M Cost			**$4,200,000**
TOTAL COST			**$283,300,000**

ALTERNATIVE F: Cap Sediment to Maximum Extent Possible,Dredge to CDF and Off-site Disposal

CDF CONSTRUCTION

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	2,700,000	sf		$4,860,000
Shot Rock/Rip Rap	9,600	lf		$6,816,000
Sheetpile Placement	288,000	sf		$5,472,000
Clean Soil Cap	205,000	cy		$2,050,000
Seeding	300,000	sy		$300,000
Mitigation	62	acre		$619,835
Direct Capital:				$20,117,835
Engineering, Procurement & Construction Management:				$2,414,140
Total Capital:				**$22,531,975**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	450,639	$6,780,456
Total Present Worth, Longer Term O&M Costs			**$16,711,012**
Total Project Capital and O&M Cost			**$39,200,000**

CAPPING

Capital Items	Quantity	Units		Cost
Mobilization/Site Prep	1	LS		$200,000
Sand Purchase	1,080,046	tons		$6,480,275
Sand Placement	771,461	cy		$4,628,768
Cobble Purchase and Placement	462,877	cy		$13,886,303
Cap Placement QA	1	LS		$100,000
Direct Capital:				$25,295,345
Engineering, Procurement & Construction Management:				3,035,441
Total Capital:				**$28,330,786**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	Cost
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$566,616	$8,525,468
Total Present Worth, Longer Term O&M Costs			$14,543,987
Total Project Capital and O&M Cost			**$42,900,000**

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	3	LS	$1,470,000
Watertight Barges	4	ea	$400,000
Offload Stockpile Area Prep.	1	LS	$75,000
Dredging - 12 hour shifts	1,633	Day	$27,761,000
Dredge Monitoring (Water Quality)	1,633	Day	$4,899,000
Sediment Removal QA	1,633	Day	$1,959,600
Offload Crane Mobilization	1	LS	$50,000
Site Restoration	1	ea	$500,000
Direct Capital:			$37,114,600
Engineering, Procurement & Construction Management:			4,453,752
Contractor Overhead/Profit:			5,567,190
Total Capital:			**$47,100,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	287	gpm	$570,498
Water Treatment (Includes Operator)	236,290,366	gal	$94,516
Water Treatment QA	1,110	day	$222,000
Direct Capital:			$887,014
Engineering, Procurement & Construction Management:			106,442
Total Capital:			**$1,000,000**

SEDIMENT DISPOSAL (Existing NR 500 Commercial Disposal Facility)

Capital Items	Quantity	Units	Cost
Solidification	1,009,840	ton	$25,246,000
Lime Purchase	100,984	ton	$6,059,040
Soil Loading	1,009,840	ton	$2,827,552
Soil Hauling	1,009,840	ton	$4,733,625
Tipping Fees (non-TSCA)	757,944	ton	$32,591,604
Tipping Fees (TSCA)	251,896	ton	$13,854,265
Direct Capital:			$85,312,086
Engineering, Procurement & Construction Management:			10,237,450
Total Capital:			**$95,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units	Cost
Deed Restrictions	1	LS	$5,000
Direct Capital:			$5,000
Engineering, Procurement & Construction Management:			600
Total Capital:			**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			**$4,513,889**
Total Project Capital and O&M Cost			**$4,500,000**

BAYPORT CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	2,178,000	cy		$21,780,000
Seeding	2,178,000	sy		$2,178,000
Mitigation	450	acre		$4,500,000
Present Worth of Direct Capital:				$2,766,749
Engineering, Procurement & Construction Management:				$332,010
Total Capital:				**$3,098,759**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	972	$14,628
Long-term Monitoring		40	63,194	$950,842
Long-term O&M		40	6,025	$90,659
Total Present Worth, Longer Term O&M Costs				**$1,056,130**
Total Project Capital and O&M Cost				**$4,200,000**
TOTAL COST				**$234,400,000**

Table 7-3 Cost Summary for Remedial Alternatives - Zone 2

500 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	29,748,004	$327,500,000	$1,200,000	---	$476,000,000	$15,500,000	---	$4,500,000	$824,700,000	$164,940,000	$989,640,000
G	29,748,004	$327,500,000	$1,200,000	$358,700,000	---	$15,500,000	---	$4,500,000	$707,400,000	$141,480,000	$848,880,000

1000 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	29,322,254	$322,900,000	$1,200,000	---	$470,000,000	$15,500,000	---	$4,500,000	$814,100,000	$162,820,000	$976,920,000
G	29,322,254	$322,900,000	$1,200,000	$353,700,000	---	$15,500,000	---	$4,500,000	$697,800,000	$139,560,000	$837,360,000

5000 ppb

Alternative	Dredge Volume (cy)	Mechanical Dredging	Water Treatment	CAD Construction	CDF Construction	Renard Island Closure	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	4,070,170	$48,700,000	$700,000	---	---	$15,500,000	$437,800,000	$4,500,000	$507,200,000	$101,440,000	$608,640,000
D	4,070,170	$48,700,000	$700,000	---	$97,100,000	$15,500,000	---	$4,500,000	$166,500,000	$33,300,000	$199,800,000
G	4,070,170	$48,700,000	$700,000	$54,600,000	---	$15,500,000	---	$4,500,000	$124,000,000	$24,800,000	$148,800,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 2
Action Level - 500 ppb

Material Handling Assumptions:							
Volume > 500 ppb	29,748,004	cy			22,708,400	m3	
Volume > 1,000 ppb	29,322,254	cy			22,383,400	m3	
Volume > 5,000 ppb	4,070,170	cy			3,107,000	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Slurry Density (20% in situ)	12.8%	w/w	5.9%	v/v	0.91	tons per cy	
Dewatered Density (settling pond)	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	29,336,664	cy			22,394,400	m3	
CAD Capacity	29,336,664	cy			22,394,400	m3	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
Dredging							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Mechanical - 12 cy bucket							
Dock Construction	$400,000	LS					Ogden Beeman
Mobilization - Equipment	$315,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift					Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Site Restoration	$670,000	LS					
Nearshore CDF			Renard Island				
Land Lease or Purchase	$1.80	per sf					Ole
Length	20,948	lf					Baird
Capping Volume	3,880,174	cy	290,400				Baird
Area	34,921,570	sf	2,613,600				Baird
Ground Treatment Volume	117,777	cy					
Ground Treatment	$25	per cy					
Dredge Volume	3,880,174	cy					
Fill Purchase/Placement	$30	per cy					
Sheetpile Area	2,513,814	sf					Baird
Sheetpile Cost	$19	per sf					Grant
Shot Rock Berm	$650	per lf					Baird
Rip Rap	$215	per lf					Baird
Place Treated Material	$2	per cy					
Clean Soil Cap	$10	per cy					Baird
Seeding	$1	per sy					Baird
Mitigation	$10,000	per acre					
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					
Long-term O&M	2%	of capital					
CAD							
Removal Volume	29,748,004	cy					
Area	50,199,757	sf					
Sand Cap Thickness	3	ft					
Mobilization/Site Prep	$200,000						
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Cap Placement QA	$100,000	LS					
Long-term O&M	2%	of capital					
Long-term Monitoring	$400,000	per year					
Water Treatment							
Flow Rate (7 dredges)	281	gpm					assume operate 24/7
Unit, Purchase	$562,869	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample per day
Institutional Controls							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
Annual Costs							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	7	LS		$2,450,000
Watertight Barges	4	ea		$400,000
Dredging - 12 hour shifts	7,437	Day	57.20769231	$223,110,000
Dredge Monitoring (Water Quality)	7,437	Day		$22,311,000
Sediment Removal QA	7,437	Day		$8,924,400
Site Restoration	1	ea		$670,000
Direct Capital:				$257,865,400
Engineering, Procurement & Construction Management:				30,943,848
Contractor Overhead/Profit:				38,679,810
Total Capital:				**$327,500,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	600,790,689	gal	$240,316
Water Treatment QA	1,488	day	$297,600
Direct Capital:			$1,100,786
Engineering, Procurement & Construction Management:			132,094
Total Capital:			**$1,200,000**

CDF CONSTRUCTION (Cellular Cofferdam Design)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	34,921,570	sf		$62,858,826
Ground Treatment	117,777	cy		$2,944,420
Dredging	3,695	day		$21,063,804
Fill Purchase/Placement	3,880,174	cy		$116,405,233
Shot Rock/Rip Rap	20,948	lf		$18,120,406
Sheetpile Placement	2,513,814	sf		$47,762,457
Clean Soil Cap	3,880,174	cy		$38,801,744
Seeding	3,880,174	sy		$3,880,174
Mitigation	802	acre		$8,016,889
Direct Capital:				$319,853,954
Engineering, Procurement & Construction Management:				$38,382,475
Total Capital:				**$358,236,429**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	7,164,729	$107,802,633
Total Present Worth, Longer Term O&M Costs				**$117,733,189**
Total Project Capital and O&M Cost				**$476,000,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	290,400	cy		$2,904,000
Seeding	290,400	sy		$290,400
Mitigation	60	acre		$600,000
Direct Capital:				$3,794,400
Engineering, Procurement & Construction Management:				$455,328
Total Capital:				**$4,249,728**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs				**$11,209,409**
Total Project Capital and O&M Cost				**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$824,700,000**

ALTERNATIVE G: Dredge Sediment to CAD

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	7,437	Day	$223,110,000
Dredge Monitoring (Water Quality)	7,437	Day	$22,311,000
Sediment Removal QA	7,437	Day	$8,924,400
Site Restoration	1	ea	$670,000
Direct Capital:			$257,865,400
Engineering, Procurement & Construction Management:			30,943,848
Contractor Overhead/Profit:			38,679,810
Total Capital:			**$327,500,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	600,790,689	gal	$240,316
Water Treatment QA	1,488	day	$297,600
Direct Capital:			$1,100,786
Engineering, Procurement & Construction Management:			132,094
Total Capital:			**$1,200,000**

CAD CONSTRUCTION

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Dredging - 12 hour shifts	28,332	Day		$161,492,400
Sand Purchase	7,808,851	tons		$46,853,106
Placement	5,577,751	cy		$33,466,505
Cap Placement QA	1	LS		$100,000
Direct Capital:				$242,082,011
Engineering, Procurement & Construction Management:				29,049,841
Total Capital:				**$271,131,852**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$5,422,637	$81,590,607
Total Present Worth, Longer Term O&M Costs				$87,609,126
Total Project Capital and O&M Cost				**$358,700,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	290,400	cy		$2,904,000
Seeding	290,400	sy		$290,400
Mitigation	60	acre		$600,000
Direct Capital:				$3,794,400
Engineering, Procurement & Construction Management:				$455,328
Total Capital:				**$4,249,728**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs				**$11,209,409**
Total Project Capital and O&M Cost				**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$707,400,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 2
Action Level - 1,000 ppb

Material Handling Assumptions:

Volume > 1,000 ppb	29,322,254	cy			22,383,400	m3	
Volume > 500 ppb	29,748,004	cy			22,708,400	m3	
Volume > 5,000 ppb	4,070,170	cy			3,107,000	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Slurry Density (20% in situ)	12.8%	w/w	5.9%	v/v	0.91	tons per cy	
Dewatered Density (settling pond)	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	26,394,060	cy			22,394,400	m3	
CAD Capacity	29,336,664	cy			22,394,400	m3	

Cost Estimating Parameters & Methodology:

Interest Rate	6.0%			
Sales Tax	5.5%			Not Used
Engineering, Procurement and Construction Mgmt	12.0%			
Contractor Overhead and Profit - Dredging Only	15.0%			
Dredging				
Dredge Monitoring (Water Quality)	$3,000	per day		
Sediment Removal QA	$1,200	per day		
Mechanical - 12 cy bucket				
Dock Construction	$400,000	LS		Ogden Beeman
Mobilization - Equipment	$315,000	per dredge		Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS		Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea		Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift		Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift		Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area		
Free Water per cy Dredged (10%)	20	gal		Ogden Beeman
Site Restoration	$670,000	LS		
Nearshore CDF			Renard Island	
Land Lease or Purchase	$1.80	per sf		Ole
Length	20,798	lf		Baird
Capping Volume	3,824,642	cy	290,400	Baird
Area	34,421,776	sf	2,613,600	Baird
Ground Treatment Volume	116,931	cy		
Ground Treatment	$25	per cy		
Dredge Volume	3,824,642	cy		
Fill Purchase/Placement	$30	per cy		
Sheetpile Area	2,495,760	sf		Baird
Sheetpile Cost	$19	per sf		Grant
Shot Rock Berm	$650	per lf		Baird
Rip Rap	$215	per lf		Baird
Place Treated Material	$2	per cy		
Clean Soil Cap	$10	per cy		Baird
Seeding	$1	per sy		Baird
Mitigation	$10,000	per acre		
	$10,000	per year		Tim
Long-term Monitoring	$650,000	per year		
Long-term O&M	2%	of capital		
CAD				
Removal Volume	29,322,254	cy		
Area	49,481,304	sf		
Sand Cap Thickness	3	ft		
Mobilization/Site Prep	$200,000			
Placement Rate	$6	per cy		Ogden Beeman
Sand Purchase	$6	per ton		Ole
Sand Density	1.4	tons per cy		
Cap Placement QA	$100,000	LS		
Long-term O&M	2%	of capital		
Long-term Monitoring	$400,000	per year		
Water Treatment				
Flow Rate (7 dredges)	281	gpm		assume operate 24/7
Unit, Purchase	$562,869	LS		pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons		pj
Water Treatment QA	$200	per day		pj, 1 sample per day
Institutional Controls				
Public Education Program	$100,000			pj
O&M Plans	$20,000			pj
Deed Restrictions	$5,000			pj
Annual Costs				
Public Education Program	$30,000			pj
Maintaining O&M Plans	$800			pj
Reporting	$20,000			pj
Long-term Monitoring	$600,000			Anne LTM
Long-term Monitoring (no action)	$300,000			Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	7	LS		$2,450,000
Watertight Barges	4	ea		$400,000
Dredging - 12 hour shifts	7,331	Day	56.39230769	$219,930,000
Dredge Monitoring (Water Quality)	7,331	Day		$21,993,000
Sediment Removal QA	7,331	Day		$8,797,200
Site Restoration	1	ea		$670,000
Direct Capital:				$254,240,200
Engineering, Procurement & Construction Management:				30,508,824
Contractor Overhead/Profit:				38,136,030
Total Capital:				**$322,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	592,192,242	gal	$236,877
Water Treatment QA	1,467	day	$293,400
Direct Capital:			$1,093,146
Engineering, Procurement & Construction Management:			131,178
Total Capital:			**$1,200,000**

CDF CONSTRUCTION (Cellular Cofferdam Design)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	34,421,776	sf		$61,959,198
Ground Treatment	116,931	cy		$2,923,274
Dredging	3,643	day		$20,762,341
Fill Purchase/Placement	3,824,642	cy		$114,739,255
Shot Rock/Rip Rap	20,798	lf		$17,990,270
Sheetpile Placement	2,495,760	sf		$47,419,440
Clean Soil Cap	3,824,642	cy		$38,246,418
Seeding	3,824,642	sy		$3,824,642
Mitigation	790	acre		$7,902,153
Direct Capital:				$315,766,990
Engineering, Procurement & Construction Management:				$37,892,039
Total Capital:				**$353,659,029**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	7,073,181	$106,425,175
Total Present Worth, Longer Term O&M Costs				**$116,355,731**
Total Project Capital and O&M Cost				**$470,000,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	290,400	cy		$2,904,000
Seeding	290,400	sy		$290,400
Mitigation	60	acre		$600,000
Direct Capital:				$3,794,400
Engineering, Procurement & Construction Management:				$455,328
Total Capital:				**$4,249,728**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs				**$11,209,409**
Total Project Capital and O&M Cost				**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$814,100,000**

ALTERNATIVE G: Dredge Sediment to CAD

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	7,331	Day	$219,930,000
Dredge Monitoring (Water Quality)	7,331	Day	$21,993,000
Sediment Removal QA	7,331	Day	$8,797,200
Site Restoration	1	ea	$670,000
Direct Capital:			$254,240,200
Engineering, Procurement & Construction Management:			30,508,824
Contractor Overhead/Profit:			38,136,030
Total Capital:			**$322,900,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	592,192,242	gal	$236,877
Water Treatment QA	1,467	day	$293,400
Direct Capital:			$1,093,146
Engineering, Procurement & Construction Management:			131,178
Total Capital:			**$1,200,000**

CAD CONSTRUCTION

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	1	LS	$170,000
Dredging - 12 hour shifts	27,926	Day	$159,178,200
Sand Purchase	7,697,092	tons	$46,182,550
Placement	5,497,923	cy	$32,987,536
Cap Placement QA	1	LS	$100,000
Direct Capital:			$238,618,286
Engineering, Procurement & Construction Management:			28,634,194
Total Capital:			**$267,252,480**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$5,345,050	$80,423,203
Total Present Worth, Longer Term O&M Costs			$86,441,722
Total Project Capital and O&M Cost			**$353,700,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	290,400	cy	$2,904,000
Seeding	290,400	sy	$290,400
Mitigation	60	acre	$600,000
Direct Capital:			$3,794,400
Engineering, Procurement & Construction Management:			$455,328
Total Capital:			**$4,249,728**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs			**$11,209,409**
Total Project Capital and O&M Cost			**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$697,800,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 2
Action Level - 5,000 ppb

Material Handling Assumptions:							
Volume > 5,000 ppb	4,070,170	cy			3,107,000	m3	
Volume > 500 ppb	29,322,254	cy			22,383,400	m3	
Volume > 1,000 ppb	29,748,004	cy			22,708,400	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Slurry Density (20% in situ)	12.8%	w/w	5.9%	v/v	0.91	tons per cy	
Dewatered Density (settling pond)	49.5%	w/w	29.3%	v/v	1.18	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	26,394,060	cy			22,394,400	m3	
CAD Capacity	29,336,664	cy			22,394,400	m3	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Mechanical - 12 cy bucket							
Dock Construction	$400,000	LS					Ogden Beeman
Mobilization - Equipment	$315,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift					Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Site Restoration	$670,000	LS					
Nearshore CDF			<u>Renard Island</u>				
Land Lease or Purchase	$1.80	per sf					Ole
Length	7,749	lf					Baird
Capping Volume	530,892	cy	290,400				Baird
Area	4,778,026	sf	2,613,600				Baird
Ground Treatment Volume	43,565	cy					
Ground Treatment	$25	per cy					
Dredge Volume	530,892	cy					
Fill Purchase/Placement	$30	per cy					
Sheetpile Area	929,845	sf					Baird
Sheetpile Cost	$19	per sf					Grant
Shot Rock Berm	$650	per lf					Baird
Rip Rap	$215	per lf					Baird
Place Treated Material	$2	per cy					
Clean Soil Cap	$10	per cy					Baird
Seeding	$1	per sy					Baird
Mitigation	$10,000	per acre					
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					
Long-term O&M	2%	of capital					
Solidification							Tim
Percent Lime	10.0%	(w/w)					
Lime	$60	per ton	Mixing		$25	per ton	Ole
<u>CAD</u>							
Removal Volume	4,070,170	cy					
Area	6,868,412	sf					
Sand Cap Thickness	3	ft					
Mobilization/Site Prep	$200,000						
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Cap Placement QA	$100,000	LS					
Long-term O&M	2%	of capital					
Long-term Monitoring	$400,000	per year					
<u>Water Treatment</u>							
Flow Rate (7 dredges)	281	gpm					assume operate 24/7
Unit, Purchase	$562,869	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample per day

Disposal
Off-Site Disposal

Load Soil for Hauling	$2.80	per ton	pj
Round-trip Hauling	2	hours	pj
Tipping Fee (non-TSCA)	$43	per ton	St. Paul
Tipping Fee (TSCA)	$55	per ton	St. Paul
Truck Rate	$75	per hour	pj
Truck Load	32	tons	pj

Institutional Controls

Public Education Program	$100,000	pj
O&M Plans	$20,000	pj
Deed Restrictions	$5,000	pj
Annual Costs		
Public Education Program	$30,000	pj
Maintaining O&M Plans	$800	pj
Reporting	$20,000	pj
Long-term Monitoring	$600,000	Anne LTM
Long-term Monitoring (no action)	$300,000	Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**
TOTAL COST				**$9,900,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	1,018	Day	$30,540,000
Dredge Monitoring (Water Quality)	1,018	Day	$3,054,000
Sediment Removal QA	1,018	Day	$1,221,600
Site Restoration	1	ea	$670,000
Direct Capital:			$38,335,600
Engineering, Procurement & Construction Management:			4,600,272
Contractor Overhead/Profit:			5,750,340
Total Capital:			**$48,700,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	82,201,153	gal	$32,880
Water Treatment QA	204	day	$40,800
Direct Capital:			$636,550
Engineering, Procurement & Construction Management:			76,386
Total Capital:			**$700,000**

CDF CONSTRUCTION (Cellular Cofferdam Design)

Capital Items	Quantity	Units	Cost
Land Lease or Purchase	4,778,026	sf	$8,600,446
Ground Treatment	43,565	cy	$1,089,124
Dredging	506	day	$2,881,984
Fill Purchase/Placement	530,892	cy	$15,926,752
Shot Rock/Rip Rap	7,749	lf	$6,702,630
Sheetpile Placement	929,845	sf	$17,667,049
Clean Soil Cap	530,892	cy	$5,308,917
Seeding	530,892	sy	$530,892
Mitigation	110	acre	$1,096,884
Direct Capital:			$59,804,678
Engineering, Procurement & Construction Management:			$7,176,561
Total Capital:			**$66,981,240**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	1,339,625	$20,156,392
Total Present Worth, Longer Term O&M Costs			**$30,086,948**
Total Project Capital and O&M Cost			**$97,100,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units	Cost
Clean Soil Cap	290,400	cy	$2,904,000
Seeding	290,400	sy	$290,400
Mitigation	60	acre	$600,000
Direct Capital:			$3,794,400
Engineering, Procurement & Construction Management:			$455,328
Total Capital:			**$4,249,728**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Mitigation	40	10,000	$150,463
Long-term Monitoring	40	650,000	$9,780,093
Long-term O&M	40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs			**$11,209,409**
Total Project Capital and O&M Cost			**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$166,500,000**

ALTERNATIVE G: Dredge Sediment to CAD

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	1,018	Day	$30,540,000
Dredge Monitoring (Water Quality)	1,018	Day	$3,054,000
Sediment Removal QA	1,018	Day	$1,221,600
Site Restoration	1	ea	$670,000
Direct Capital:			$38,335,600
Engineering, Procurement & Construction Management:			4,600,272
Contractor Overhead/Profit:			5,750,340
Total Capital:			**$48,700,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	82,201,153	gal	$32,880
Water Treatment QA	204	day	$40,800
Direct Capital:			$636,550
Engineering, Procurement & Construction Management:			76,386
Total Capital:			**$700,000**

CAD CONSTRUCTION

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Dredging - 12 hour shifts	3,877	Day		$22,098,900
Sand Purchase	1,068,420	tons		$6,410,518
Placement	763,157	cy		$4,578,941
Cap Placement QA	1	LS		$100,000
Direct Capital:				$33,358,359
Engineering, Procurement & Construction Management:				4,003,003
Total Capital:				**$37,361,362**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$747,227	$11,243,003
Total Present Worth, Longer Term O&M Costs				$17,261,522
Total Project Capital and O&M Cost				**$54,600,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	290,400	cy		$2,904,000
Seeding	290,400	sy		$290,400
Mitigation	60	acre		$600,000
Direct Capital:				$3,794,400
Engineering, Procurement & Construction Management:				$455,328
Total Capital:				**$4,249,728**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs				**$11,209,409**
Total Project Capital and O&M Cost				**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$124,000,000**

ALTERNATIVE C: Dredge and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	1,018	Day	$30,540,000
Dredge Monitoring (Water Quality)	1,018	Day	$3,054,000
Sediment Removal QA	1,018	Day	$1,221,600
Site Restoration	1	ea	$670,000
Direct Capital:			$38,335,600
Engineering, Procurement & Construction Management:			4,600,272
Contractor Overhead/Profit:			5,750,340
Total Capital:			**$48,700,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	281	gpm	$562,869
Water Treatment (Includes Operator)	82,201,153	gal	$32,880
Water Treatment QA	204	day	$40,800
Direct Capital:			$636,550
Engineering, Procurement & Construction Management:			76,386
Total Capital:			**$700,000**

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units	Cost
Solidification	4,797,107	ton	$119,927,675
Lime Purchase	479,711	ton	$28,782,660
Soil Loading	4,797,107	ton	$13,431,900
Soil Hauling	4,797,107	ton	$22,486,439
Tipping Fees (non-TSCA)	4,797,107	ton	$206,275,594
Direct Capital:			$390,904,268
Engineering, Procurement & Construction Management:			46,908,512
Total Capital:			**$437,800,000**

RENARD ISLAND CLOSURE

Capital Items	Quantity	Units		Cost
Clean Soil Cap	290,400	cy		$2,904,000
Seeding	290,400	sy		$290,400
Mitigation	60	acre		$600,000
Direct Capital:				$3,794,400
Engineering, Procurement & Construction Management:				$455,328
Total Capital:				**$4,249,728**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	84,995	$1,278,853
Total Present Worth, Longer Term O&M Costs				**$11,209,409**
Total Project Capital and O&M Cost				**$15,500,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$507,200,000**

Table 7-3 Cost Summary for Remedial Alternatives - Zone 3A

500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	16,328,102	---	$181,800,000	---	$3,000,000	---	$285,000,000	---	$4,500,000	$474,300,000	$94,860,000	$569,160,000
G	16,328,102	---	$181,800,000	---	$3,000,000	$199,800,000	---	---	$4,500,000	$389,100,000	$77,820,000	$466,920,000

1000 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
C	14,410	---	$4,600,000	---	$600,000	---	---	$1,300,000	$4,500,000	$11,000,000	$2,200,000	$13,200,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 3A
Action Level - 500 ppb

Material Handling Assumptions:

Volume > 500 ppb	16,328,102	cy			12,464,200	m3	
Volume > 1,000 ppb	14,410	cy			11,000	m3	
Volume > 5,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	28.5%	w/w	14.4%	v/v	1.01	tons per cy	
Slurry Density (20% in situ)	6.5%	w/w	2.9%	v/v	0.88	tons per cy	
Dewatered Density	50.0%	w/w	29.8%	v/v	1.18	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	26,500,893	cy			22,394,400	m3	
CAD Capacity	29,336,664	cy			22,394,400	m3	

Cost Estimating Parameters & Methodology:

Interest Rate	6.0%		
Sales Tax	5.5%		Not Used
Engineering, Procurement and Construction Mgmt	12.0%		
Contractor Overhead and Profit - Dredging Only	15.0%		
Dredging			
Dredge Monitoring (Water Quality)	$3,000	per day	
Sediment Removal QA	$1,200	per day	
Mechanical - 12 cy bucket			
Dock Construction	$400,000	LS	Ogden Beeman
Mobilization - Equipment	$315,000	per dredge	Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS	Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea	Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift	Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift	Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area	
Free Water per cy Dredged (10%)	20	gal	Ogden Beeman
Site Restoration	$670,000	LS	
Nearshore CDF			
Land Lease or Purchase	$1.80	per sf	Ole
Length	15,520	lf	Baird
Capping Volume	2,129,752	cy	Baird
Area	19,167,772	sy	Baird
Ground Treatment Volume	87,257	cy	
Ground Treatment	$25	per cy	
Dredge Volume	2,129,752	cy	
Fill Purchase/Placement	$30	per cy	
Sheetpile Area	1,862,396	sf	Baird
Sheetpile Cost	$19	per sf	Grant
Shot Rock Berm	$650	per lf	Baird
Rip Rap	$215	per lf	Baird
Place Treated Material	$2	per cy	
Clean Soil Cap	$10	per cy	Baird
Seeding	$1	per sy	Baird
Mitigation	$10,000	per acre	
	$10,000	per year	Tim
Long-term Monitoring	$650,000	per year	
Long-term O&M	2%	of capital	
CAD			
Removal Volume	16,328,102	cy	
Area	27,553,672	sf	
Sand Cap Thickness	3	ft	
Mobilization/Site Prep	$200,000		
Placement Rate	$6	per cy	Ogden Beeman
Sand Purchase	$6	per ton	Ole
Sand Density	1.4	tons per cy	
Cap Placement QA	$100,000	LS	
Long-term O&M	2%	of capital	
Long-term Monitoring	$400,000	per year	
Water Treatment			
Flow Rate (7 dredges)	1,727	gpm	assume operate 24/7
Unit, Purchase	$1,674,760	LS	pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons	pj
Water Treatment QA	$200	per day	pj, 1 sample per day
Institutional Controls			
Public Education Program	$100,000		pj
O&M Plans	$20,000		pj
Deed Restrictions	$5,000		pj
Annual Costs			
Public Education Program	$30,000		pj
Maintaining O&M Plans	$800		pj
Reporting	$20,000		pj
Long-term Monitoring	$600,000		Anne LTM
Long-term Monitoring (no action)	$300,000		Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	7	LS		$2,450,000
Watertight Barges	4	ea		$400,000
Dredging - 12 hour shifts	4,083	Day	31.40769231	$122,490,000
Dredge Monitoring (Water Quality)	4,083	Day		$12,249,000
Sediment Removal QA	4,083	Day		$4,899,600
Site Restoration	1	ea		$670,000
Direct Capital:				$143,158,600
Engineering, Procurement & Construction Management:				17,179,032
Contractor Overhead/Profit:				21,473,790
Total Capital:				**$181,800,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	1,727	gpm	$1,674,760
Water Treatment (Includes Operator)	2,029,749,525	gal	$811,900
Water Treatment QA	817	day	$163,400
Direct Capital:			$2,650,060
Engineering, Procurement & Construction Management:			318,007
Total Capital:			**$3,000,000**

CDF CONSTRUCTION (Cellular Cofferdam Design)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	19,167,772	sf		$34,501,989
Ground Treatment	87,257	cy		$2,181,417
Dredging	2,028	day		$11,561,513
Fill Purchase/Placement	2,129,752	cy		$63,892,573
Shot Rock/Rip Rap	15,520	lf		$13,424,770
Sheetpile Placement	1,862,396	sf		$35,385,521
Clean Soil Cap	2,129,752	cy		$21,297,524
Seeding	2,129,752	sy		$2,129,752
Mitigation	440	acre		$4,400,315
Direct Capital:				$188,775,376
Engineering, Procurement & Construction Management:				$22,653,045
Total Capital:				**$211,428,421**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	4,228,568	$63,624,296
Total Present Worth, Longer Term O&M Costs				**$73,554,852**
Total Project Capital and O&M Cost				**$285,000,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$474,300,000**

ALTERNATIVE G: Dredge Sediment to CAD

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	4,083	Day	$122,490,000
Dredge Monitoring (Water Quality)	4,083	Day	$12,249,000
Sediment Removal QA	4,083	Day	$4,899,600
Site Restoration	1	ea	$670,000
Direct Capital:			$143,158,600
Engineering, Procurement & Construction Management:			17,179,032
Contractor Overhead/Profit:			21,473,790
Total Capital:			**$181,800,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	1,727	gpm	$1,674,760
Water Treatment (Includes Operator)	2,029,749,525	gal	$811,900
Water Treatment QA	817	day	$163,400
Direct Capital:			$2,650,060
Engineering, Procurement & Construction Management:			318,007
Total Capital:			**$3,000,000**

CAD CONSTRUCTION

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Dredging - 12 hour shifts	15,551	Day		$88,640,700
Sand Purchase	4,286,127	tons		$25,716,761
Placement	3,061,519	cy		$18,369,115
Cap Placement QA	1	LS		$100,000
Direct Capital:				$132,996,575
Engineering, Procurement & Construction Management:				15,959,589
Total Capital:				**$148,956,164**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Monitoring/O&M				
Long-term Monitoring		40	$400,000	$6,018,519
Long-term O&M		40	$2,979,123	$44,824,773
Total Present Worth, Longer Term O&M Costs				$50,843,292
Total Project Capital and O&M Cost				**$199,800,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$389,100,000**

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 3A
Action Level - 1,000 ppb

Material Handling Assumptions:						
Volume > 1,000 ppb	14,410	cy		11,000	m3	
Volume > 500 ppb	16,328,102	cy		12,464,200	m3	
Volume > 5,000 ppb	0	cy		0	m3	
Solids Specific Gravity	2.36					
Fresh Water Density	62.4	lb/ft3				
In Situ Density	28.5%	w/w	14.4% v/v	1.01	tons per cy	
Slurry Density (20% in situ)	6.5%	w/w	2.9% v/v	0.88	tons per cy	
Dewatered Density	28.5%	w/w	14.4% v/v	1.01	tons per cy	
Treated Density	93.4%	w/w	60.0% v/v	1.28	tons per cy	
Cost Estimating Parameters & Methodology:						
Interest Rate	6.0%					
Sales Tax	5.5%					Not Used
Engineering, Procurement and Construction Mgmt	12.0%					
Contractor Overhead and Profit - Dredging Only	15.0%					
Dredging						
Dredge Monitoring (Water Quality)	$3,000	per day				
Sediment Removal QA	$1,200	per day				
Mechanical - 12 cy bucket						
Dock Construction	$400,000	LS				Ogden Beeman
Mobilization - Equipment	$315,000	per dredge				Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS				Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea				Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift				Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift				Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area				
Free Water per cy Dredged (10%)	20	gal				Ogden Beeman
Site Restoration	$670,000	LS				
Solidification						Tim
Percent Lime	10.0%	(w/w)				
Lime	$60	per ton	Mixing	$25	per ton	Ole
Water Treatment						
Flow Rate	286	gpm				assume operate 24/7
Unit, Purchase	$569,927	LS				pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons				pj
Water Treatment QA	$200	per day				pj, 1 sample per day
Disposal						
Off-Site Disposal						
Load Soil for Hauling	$2.80	per ton				
Round-trip Hauling	2	hours				
Tipping Fee (non-TSCA)	$43	per ton				
Tipping Fee (TSCA)	$55	per ton				
Truck Rate	$75	per hour				
Truck Load	32	tons				
Institutional Controls						
Public Education Program	$100,000					pj
O&M Plans	$20,000					pj
Deed Restrictions	$5,000					pj
Annual Costs						
Public Education Program	$30,000					pj
Maintaining O&M Plans	$800					pj
Reporting	$20,000					pj
Long-term Monitoring	$600,000					Anne LTM
Long-term Monitoring (no action)	$300,000					Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	**Quantity**	**Units**		**Cost**
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				$4,513,889
Total Project Capital and O&M Cost				**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring		40	$600,000	$9,027,778
Public Education Program		40	$30,000	$451,389
Maintaining O&M Plans		40	$800	$12,037
Reporting		40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs				$9,792,130
Total Project Capital and O&M Cost				**$9,900,000**

ALTERNATIVE C: Dredge and Off-site Disposal

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	7	LS	$2,450,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	4	Day	$120,000
Dredge Monitoring (Water Quality)	4	Day	$12,000
Sediment Removal QA	4	Day	$4,800
Site Restoration	1	ea	$670,000
Direct Capital:			$3,656,800
Engineering, Procurement & Construction Management:			438,816
Contractor Overhead/Profit:			548,520
Total Capital:			**$4,600,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit Purchase	286	gpm	$569,927
Water Treatment (Includes Operator)	297,131	gal	$119
Water Treatment QA	1	day	$200
Direct Capital:			$570,246
Engineering, Procurement & Construction Management:			68,429
Total Capital:			**$600,000**

SEDIMENT DISPOSAL (OFF-SITE)

Capital Items	Quantity	Units	Cost
Solidification	14,494	ton	$362,350
Lime Purchase	1,450	ton	$87,000
Soil Loading	14,494	ton	$40,583
Soil Hauling	14,494	ton	$67,941
Tipping Fees (non-TSCA)	14,494	ton	$623,239
Direct Capital:			$1,181,113
Engineering, Procurement & Construction Management:			141,734
Total Capital:			**$1,300,000**

INSTITUTIONAL CONTROLS

Capital Items		Quantity	Units		Cost
Deed Restrictions		1	LS		$5,000
	Direct Capital:				$5,000
	Engineering, Procurement & Construction Management:				600
	Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs			**Years**	**Annual Cost**	
Long-term Monitoring (no action)			40	$300,000	$4,513,889
	Total Present Worth, Longer Term O&M Costs				**$4,513,889**
	Total Project Capital and O&M Cost				**$4,500,000**
	TOTAL COST				**$11,000,000**

Table 7-3 Cost Summary for Remedial Alternatives - Zone 3B
500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000
D	43,625,096	---	$478,200,000	---	$4,700,000	---	$667,700,000	---	$4,500,000	$1,155,100,000	$231,020,000	$1,386,120,000
G	43,625,096	---	$478,600,000	---	$4,700,000	$523,100,000	---	---	$4,500,000	$1,010,900,000	$202,180,000	$1,213,080,000

BASIS FOR PRELIMINARY COST ESTIMATES
SEDIMENT REMEDIATION
FOX RIVER, WISCONSIN
Zone 3B
Action Level - 500 ppb

Material Handling Assumptions:							
Volume > 500 ppb	43,625,096	cy			33,301,600	m3	
Volume > 1,000 ppb	0	cy			0	m3	
Volume > 5,000 ppb	0	cy			0	m3	
Solids Specific Gravity	2.36						
Fresh Water Density	62.4	lb/ft3					
In Situ Density	28.4%	w/w	14.4%	v/v	1.01	tons per cy	
Slurry Density (20% in situ)	6.5%	w/w	2.9%	v/v	0.88	tons per cy	
Dewatered Density	50.0%	w/w	29.8%	v/v	1.18	tons per cy	
Treated Density	93.4%	w/w	60.0%	v/v	1.28	tons per cy	
CDF Capacity	26,500,893	cy			22,394,400	m3	
CAD Capacity	29,336,664	cy			22,394,400	m3	
Cost Estimating Parameters & Methodology:							
Interest Rate	6.0%						
Sales Tax	5.5%						Not Used
Engineering, Procurement and Construction Mgmt	12.0%						
Contractor Overhead and Profit - Dredging Only	15.0%						
<u>Dredging</u>							
Dredge Monitoring (Water Quality)	$3,000	per day					
Sediment Removal QA	$1,200	per day					
Mechanical - 7 dredges							
Dock Construction	$400,000	LS					Ogden Beeman
Mobilization - Equipment	$315,000	per dredge					Ogden Beeman
Mobilization - Silt Curtain	$35,000	LS					Ogden Beeman
Mobilization - Watertight Barge	$100,000	ea					Ogden Beeman (JAG estimate)
Shift Rate (10 hours)	$30,000	per shift					Ogden Beeman
Dredge Rate	4000	cy in situ per 10 hour shift					Ogden Beeman
Offload Stockpile Area Prep.	$75,000	per area					
Free Water per cy Dredged (10%)	20	gal					Ogden Beeman
Site Restoration	$670,000	LS					
Nearshore CDF							
Land Lease or Purchase	$1.80	per sf					Ole
Length	25,368	lf					Baird
Capping Volume	5,690,230	cy					Baird
Area	51,212,069	sy					Baird
Ground Treatment Volume	142,626	cy					
Ground Treatment	$25	per cy					
Dredge Volume	5,690,230	cy					
Fill Purchase/Placement	$30	per cy					
Sheetpile Area	3,044,194	sf					Baird
Sheetpile Cost	$19	per sf					Grant
Shot Rock Berm	$650	per lf					Baird
Rip Rap	$215	per lf					Baird
Place Treated Material	$2	per cy					
Clean Soil Cap	$10	per cy					Baird
Seeding	$1	per sy					Baird
Mitigation	$10,000	per acre					
	$10,000	per year					Tim
Long-term Monitoring	$650,000	per year					
Long-term O&M	2%	of capital					
<u>CAD</u>							
Removal Volume	43,625,096	cy					
Area	73,617,350	sf					
Sand Cap Thickness	3	ft					
Mobilization/Site Prep	$200,000						
Placement Rate	$6	per cy					Ogden Beeman
Sand Purchase	$6	per ton					Ole
Sand Density	1.4	tons per cy					
Cap Placement QA	$100,000	LS					
Long-term O&M	2%	of capital					
Long-term Monitoring	$400,000	per year					
<u>Water Treatment</u>							
Flow Rate (7 dredges)	1,729	gpm					assume operate 24/7
Unit, Purchase	$1,676,421	LS					pj
Water Treatment (Including Operator)	$0.40	per 1,000 gallons					pj
Water Treatment QA	$200	per day					pj, 1 sample per day
<u>Institutional Controls</u>							
Public Education Program	$100,000						pj
O&M Plans	$20,000						pj
Deed Restrictions	$5,000						pj
<u>Annual Costs</u>							
Public Education Program	$30,000						pj
Maintaining O&M Plans	$800						pj
Reporting	$20,000						pj
Long-term Monitoring	$600,000						Anne LTM
Long-term Monitoring (no action)	$300,000						Anne LTM

ALTERNATIVE A: No Action

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**

ALTERNATIVE B: Monitored Natural Recovery

MONITORING/INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Public Education Program	1	LS		$100,000
O&M Plans	1	LS		$20,000
Deed Restrictions	1	LS		$5,000
Direct Capital:				$125,000
Engineering, Procurement & Construction Management:				15,000
Total Capital:				**$140,000**

Present Worth of Longer Term Operating Costs	Years	Annual Cost	
Long-term Monitoring	40	$600,000	$9,027,778
Public Education Program	40	$30,000	$451,389
Maintaining O&M Plans	40	$800	$12,037
Reporting	40	$20,000	$300,926
Total Present Worth, Longer Term O&M Costs			$9,792,130
Total Project Capital and O&M Cost			**$9,900,000**

ALTERNATIVE D: Dredge Sediment to CDF

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	7	LS		$2,450,000
Watertight Barges	4	ea		$400,000
Dredging - 12 hour shifts	10,907	Day	83.9	$327,210,000
Dredge Monitoring (Water Quality)	10,907	Day		$32,721,000
Sediment Removal QA	10,907	Day		$13,088,400
Site Restoration	1	ea		$670,000
Direct Capital:				$376,539,400
Engineering, Procurement & Construction Management:				45,184,728
Contractor Overhead/Profit:				56,480,910
Total Capital:				**$478,200,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
Unit, Purchase	1,729	LS	$1,676,421
Water Treatment (Includes Operator)	5,432,013,966	gal	$2,172,806
Water Treatment QA	1,909	day	$381,800
Direct Capital:			$4,231,027
Engineering, Procurement & Construction Management:			507,723
Total Capital:			**$4,700,000**

CDF CONSTRUCTION (Cellular Cofferdam Design)

Capital Items	Quantity	Units		Cost
Land Lease or Purchase	51,212,069	sf		$92,181,725
Ground Treatment	142,626	cy		$3,565,653
Dredging	5,419	day		$30,889,820
Fill Purchase/Placement	5,690,230	cy		$170,706,897
Shot Rock/Rip Rap	25,368	lf		$21,943,566
Sheetpile Placement	3,044,194	sf		$57,839,688
Clean Soil Cap	5,690,230	cy		$56,902,299
Seeding	5,690,230	sy		$5,690,230
Mitigation	1,176	acre		$11,756,673
Direct Capital:				$451,476,551
Engineering, Procurement & Construction Management:				$54,177,186
Total Capital:				**$505,653,737**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Mitigation		40	10,000	$150,463
Long-term Monitoring		40	650,000	$9,780,093
Long-term O&M		40	10,113,075	$152,164,325
Total Present Worth, Longer Term O&M Costs				**$162,094,881**
Total Project Capital and O&M Cost				**$667,700,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**
Present Worth of Longer Term Operating Costs		**Years**	**Annual Cost**	
Long-term Monitoring (no action)		40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs				**$4,513,889**
Total Project Capital and O&M Cost				**$4,500,000**
TOTAL COST				**$1,155,100,000**

ALTERNATIVE G: Dredge Sediment to CAD

SEDIMENT REMOVAL (MECHANICAL DREDGING)

Capital Items	Quantity	Units	Cost
Mobilization - Equipment and Silt Curtain	8	LS	$2,800,000
Watertight Barges	4	ea	$400,000
Dredging - 12 hour shifts	10,907	Day	$327,210,000
Dredge Monitoring (Water Quality)	10,907	Day	$32,721,000
Sediment Removal QA	10,907	Day	$13,088,400
Site Restoration	1	ea	$670,000
Direct Capital:			$376,889,400
Engineering, Procurement & Construction Management:			45,226,728
Contractor Overhead/Profit:			56,533,410
Total Capital:			**$478,600,000**

WATER TREATMENT

Capital Items	Quantity	Units	Cost
820 gpm unit, Purchase	1	LS	$1,676,421
Water Treatment (Includes Operator)	5,432,013,966	gal	$2,172,806
Water Treatment QA	1,909	day	$381,800
Direct Capital:			$4,231,027
Engineering, Procurement & Construction Management:			507,723
Total Capital:			**$4,700,000**

CAD CONSTRUCTION

Capital Items	Quantity	Units		Cost
Mobilization - Equipment and Silt Curtain	1	LS		$170,000
Dredging - 12 hour shifts	41,548	Day		$236,823,600
Sand Purchase	11,451,588	tons		$68,709,526
Placement	8,179,706	cy		$49,078,233
Cap Placement QA	1	LS		$100,000
Direct Capital:				$354,881,359
Engineering, Procurement & Construction Management:				42,585,763
Total Capital:				**$397,467,122**

Present Worth of Longer Term Operating Costs	**Years**	**Annual Cost**	
Monitoring/O&M			
Long-term Monitoring	40	$400,000	$6,018,519
Long-term O&M	40	$7,949,342	$119,608,166
Total Present Worth, Longer Term O&M Costs			$125,626,685
Total Project Capital and O&M Cost			**$523,100,000**

INSTITUTIONAL CONTROLS

Capital Items	Quantity	Units		Cost
Deed Restrictions	1	LS		$5,000
Direct Capital:				$5,000
Engineering, Procurement & Construction Management:				600
Total Capital:				**$5,600**

Present Worth of Longer Term Operating Costs	**Years**	**Annual Cost**	
Long-term Monitoring (no action)	40	$300,000	$4,513,889
Total Present Worth, Longer Term O&M Costs			$4,513,889
Total Project Capital and O&M Cost			**$4,500,000**
TOTAL COST			**$1,010,900,000**

Table 7-3 Cost Summary for Remedial Alternatives - Zone 4
500 ppb

Alternative	Dredge Volume (cy)	Hydraulic Dredging	Mechanical Dredging	Dewatering	Water Treatment	CAD Construction	CDF Construction	Off-site Disposal	Institutional Controls	Subtotal	20% Contingency	TOTAL
A	0	---	---	---	---	---	---	---	$4,500,000	$4,500,000	$900,000	$5,400,000
B	0	---	---	---	---	---	---	---	$9,900,000	$9,900,000	$1,980,000	$11,880,000

Draft Studies Completed on Cleanup of PCBs in Lower Fox River Sediments

March 1999

Draft Remedial Investigation, Risk Assessment and Feasibility Study Available for Public Review

The Wisconsin Department of Natural Resources (DNR) has been studying the Lower Fox River for many years to gather information to clean up polychlorinated biphenyls (PCBs) in river sediments. Since March 1998, DNR has been working closely with the U.S. Environmental Protection Agency (EPA) and other agencies to develop cleanup plans following the steps in federal Superfund law. The EPA is funding the studies.

At this time the DNR is not recommending any one plan for cleanup of the Lower Fox River. We are releasing for public comment, a series of scientific draft reports. However, before these reports are completed, the DNR is releasing the drafts of them so that the pubic and other interested parties have the opportunity to provide input into them. Since the content and judgements in these reports will be the basis for all future decisions we thought it important to provide this opportunity. Once DNR has received your comments on the drafts, we will proceed with further development of these documents and the selection of a proposed cleanup plan. Information received from the public will be used to help finalize a cleanup solution. The public will again be given an opportunity to comment on the proposed plan in the future.

The remedial investigation (RI) determines the types, levels and locations of the contaminants. The risk assessment (RA) explores health effects on people and wildlife. Finally, the feasibility study (FS) evaluates possible cleanup methods.

Information from both pilot dredging projects (Deposit N and Sediment Management Unit 56/57) has been added to these draft studies. As more information is available from the projects, it will be added to the final studies.

The DNR, the EPA or responsible parties may carry out a cleanup of PCBs in the Lower Fox River. Regardless of who cleans up the river, the three studies will be used to determine a cleanup alternative for the Lower Fox River.

Public input and acceptance is a key factor before making a final decision on the best cleanup plan for the Lower Fox River. The draft feasibility study includes many choices with benefits, potential risks and drawbacks. The Department of Natural Resources invites interested Fox Valley residents to review the studies and provide comments on all elements of the studies and cleanup alternatives. The DNR will review all public comments before proposing a cleanup plan for the whole river.

This fact sheet provides:

1. a summary of the three studies,
2. the schedule and next steps in the evaluation process,
3. ways the public may comment on this preliminary cleanup plan. These three draft reports will be finalized later this year once public comments are considered.

Public comment period

DNR will accept written comments on these draft studies during a 45-day comment period from Feb. 26-April 12, 1999. The full reports are available for review in area libraries listed on page 16 and posted on the DNR's Web page at < http://www.dnr.state.wi.us/org/water/wm/lowerfox/> .

Send written comments on the draft evaluations to **Lower Fox River Cleanup, RR/3, Wisconsin Department of Natural Resources, 101 S. Webster. P.O. Box 7921, Madison, WI 53707.** Comments must be postmarked by April 12, 1999.

Copies of comments should also be sent to: **Fox River RI/FS, U.S. EPA - SR/6J, 77 W. Jackson Blvd., Chicago, IL 60604.**

WISCONSIN DEPT. OF NATURAL RESOURCES
Department of Natural Resources
PUB-CE - 255

Remedial Investigation

The main purpose of the remedial investigation is to locate and measure PCBs found in sediments of the Lower Fox River. This investigation forms the foundation to evaluate risks to people and the environment in the risk assessment and also cleanup options in the feasibility study.

In large part, the investigation summarizes numerous studies conducted during the 1980s and '90s. It added results from work conducted during 1998 to fill in gaps of existing information. The present database includes 24 separate studies and more than 360,000 analyses of contaminants in sediment, water, fish and wildlife.

As many as 360 different chemicals have been found in the water, sediments, fish and wildlife of the Lower Fox River. These chemicals include PCBs, dioxins, furans, mercury, ammonia, DDT and other pesticides (see table on page 6 for more information on these chemicals). The Lower Fox River, which flows northeast for about 39 miles from Lake Winnebago at Neenah-Menasha to the river's mouth at Green Bay, contributes more PCBs to Green Bay and Lake Michigan than any other source.

What and where are PCBs?

PCBs are stable, man-made compounds. They absorb heat and do not easily break down. Because of these properties, they have been widely used in electrical equipment, hydraulic fluids, fire retardants, and many other commercial and industrial processes. In the Fox Valley, PCBs were used in the manufacturing and recycling of carbonless copy paper. As a result, PCBs were released to the river in wastewater discharges.

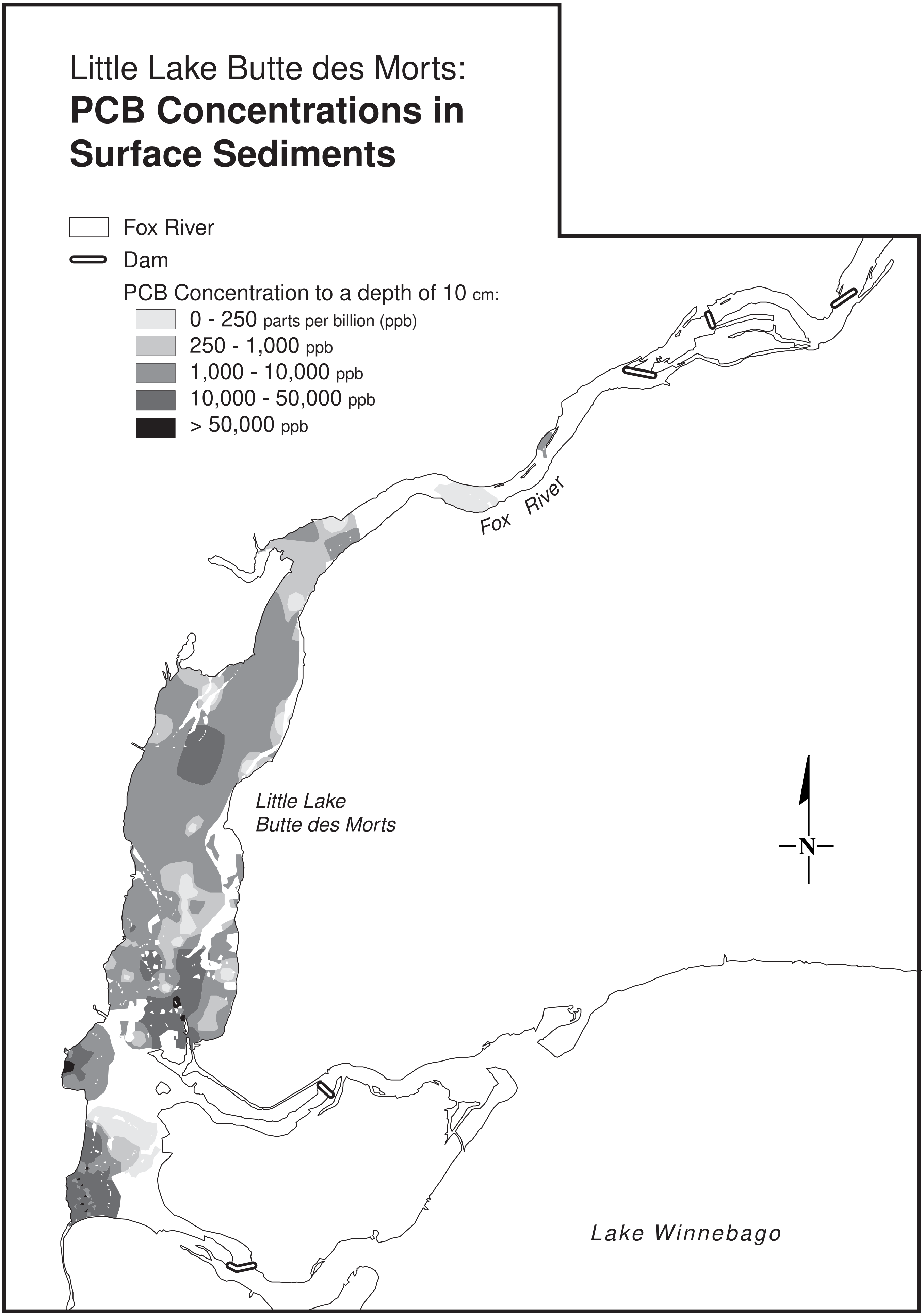
The manufacture and use of PCBs ended in the early 1970s. However, estimates show that more than 98 percent of the PCBs were discharged to the river before this time. Many of these PCBs settled into the river's bottom. Active discharges from industry and wastewater treatment plants to the Lower Fox River were virtually eliminated in the early 1980s.

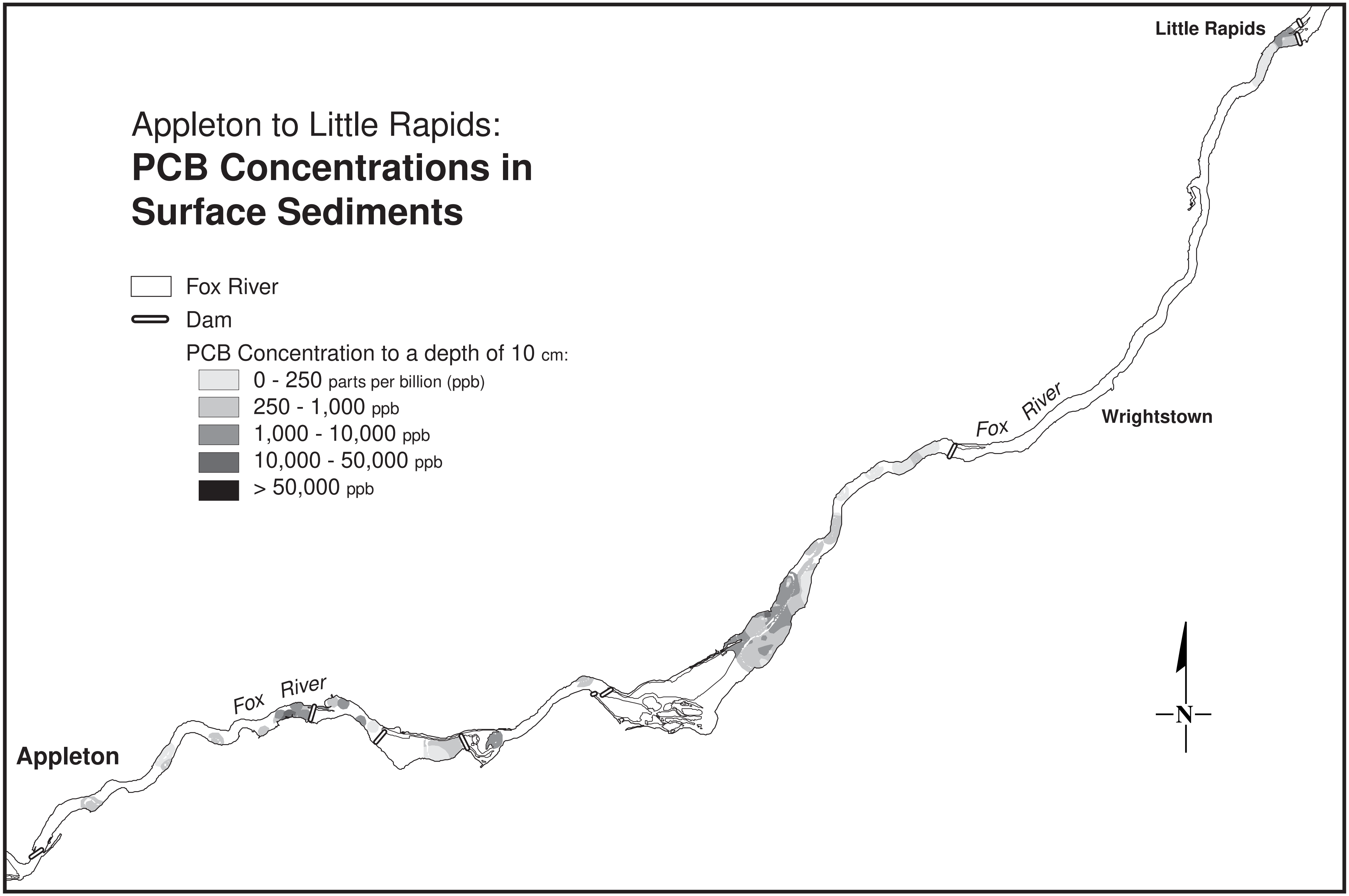
The draft investigation confirmed the presence of 35 individual contaminated sediment deposits in the Lower Fox River between Lake Winnebago and De Pere. Sediments in these deposits have an estimated total volume around 2 million cubic yards and contain about 8,600 pounds of PCBs. From the De Pere dam downstream to the mouth of the river at Green Bay, there is a continuous layer of contaminated sediment. This large deposit has an estimated volume of 8 million cubic yards and contains around 55,000 pounds of PCBs. (See figures on pages 3-6.)

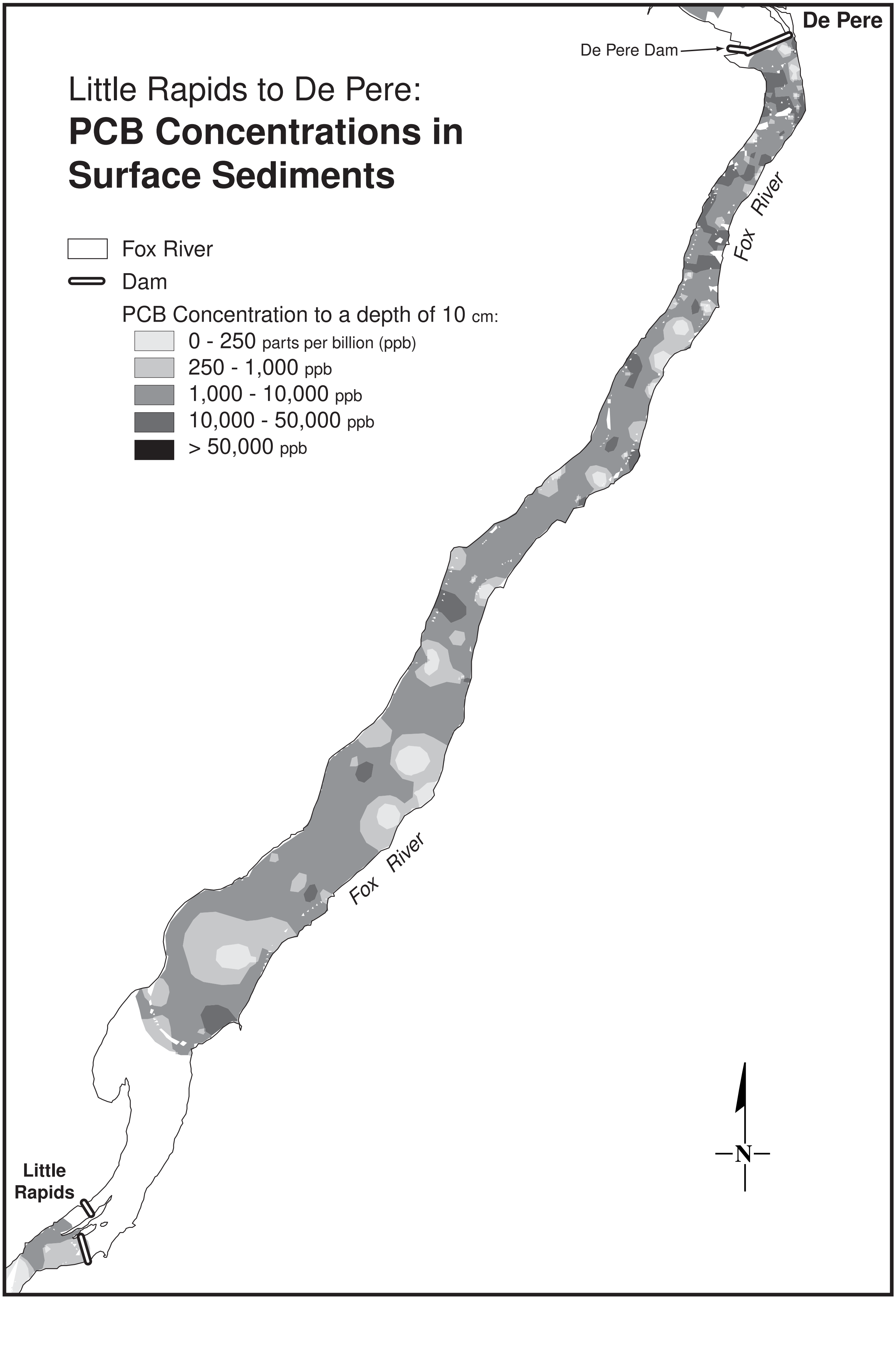
An estimated 63,000 pounds of the PCBs previously discharged remain in the Lower Fox River. Most of them are downstream of the De Pere dam. An even larger quantity has passed through the Lower Fox River to Green Bay, Lake Michigan and beyond. Results of the intensive "Mass Balance" study conducted by the DNR and EPA in 1989 showed that about 160,000 pounds of PCBs have already found their way into Green Bay from the Lower Fox. It also showed that about 620 pounds of PCBs enter the bay from the river each year.

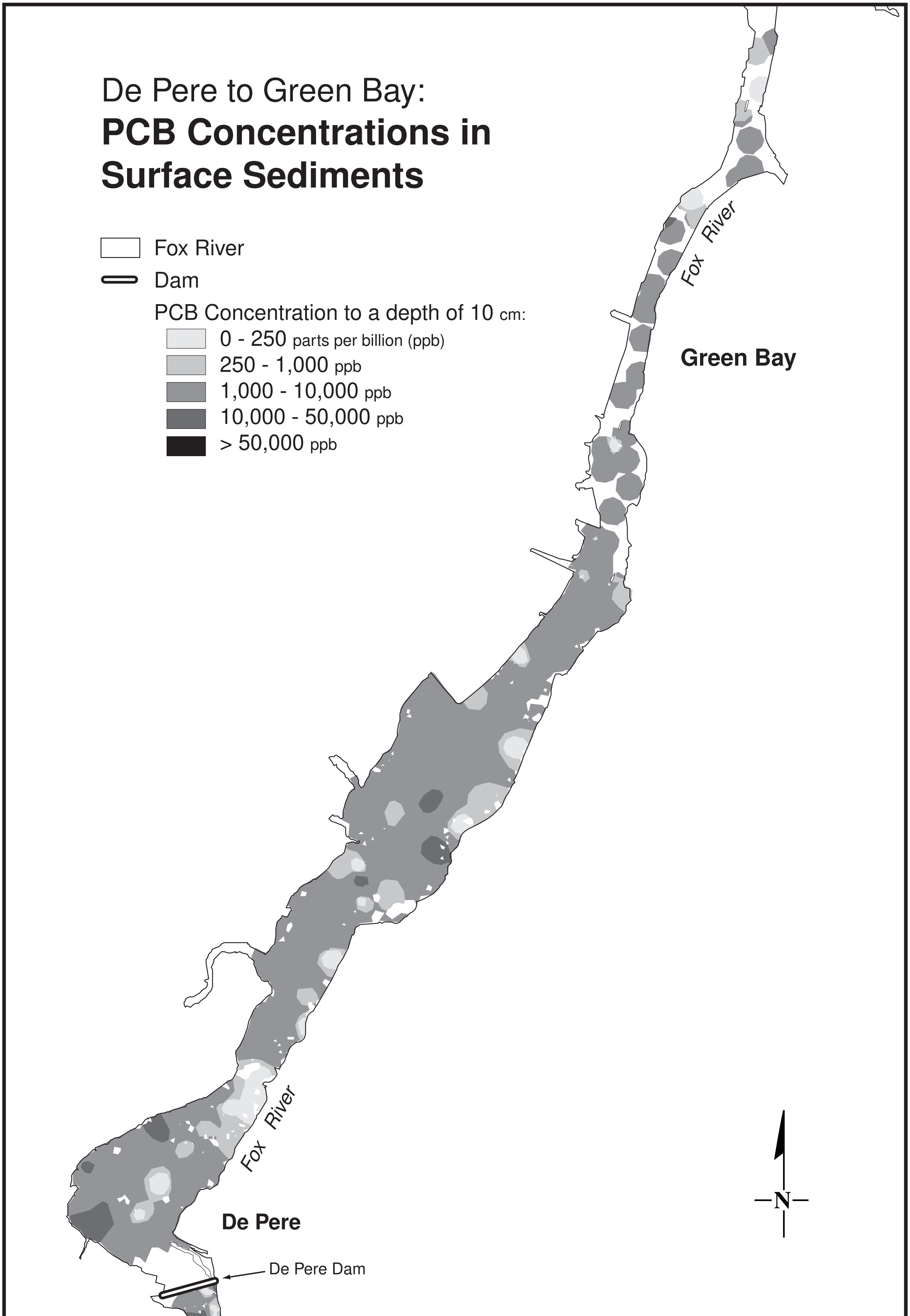
PCBs from the sediments continue to get into the food chain of the river because of the activities of small plants and animals and erosion of sediments by the river's current.

For this reason, cleaning up PCBs is a high priority of the Fox River Intergovernmental Partners. This group includes DNR, EPA, the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, the Menominee Indian Tribe of Wisconsin, and the Oneida Tribe of Indians of Wisconsin, with assistance from the Wisconsin Department of Health and Family Services.


Little Lake Butte des Morts:
PCB Concentrations in Surface Sediments
Fox River
Dam
PCB Concentration to a depth of 10 cm:
0 - 250 parts per billion (ppb)
250 - 1,000 ppb
1,000 - 10,000 ppb
10,000 - 50,000 ppb
> 50,000 ppb
Fox River
Little Lake
Butte des Morts
N
Lake Winnebago


Appleton to Little Rapids:
PCB Concentrations in Surface Sediments
Fox River
Dam
PCB Concentration to a depth of 10 cm:
0 - 250 parts per billion (ppb)
250 - 1,000 ppb
1,000 - 10,000 ppb
10,000 - 50,000 ppb
> 50,000 ppb
Little Rapids
Wrightstown
Fox River
Fox River
Appleton
N


Little Rapids to De Pere:
PCB Concentrations in Surface Sediments
Fox River
Dam
PCB Concentration to a depth of 10 cm:
0 - 250 parts per billion (ppb)
250 - 1,000 ppb
1,000 - 10,000 ppb
10,000 - 50,000 ppb
> 50,000 ppb
De Pere
De Pere Dam
Fox River
Fox River
Little Rapids
N


De Pere to Green Bay:
PCB Concentrations in Surface Sediments
Fox River
Dam
PCB Concentration to a depth of 10 cm:
0 - 250 parts per billion (ppb)
250 - 1,000 ppb
1,000 - 10,000 ppb
10,000 - 50,000 ppb
> 50,000 ppb
Fox River
Green Bay
Fox River
De Pere
De Pere Dam
N

Risk Assessment

The risk assessment estimates which chemicals in the Lower Fox River could harm people, fish, wildlife and the environment. The risk assessment:

- Identifies chemicals found in the river that could cause health problems for people or animals;
- Considers how people, fish and wildlife might be exposed to those chemicals;
- Assesses the health effects of the chemicals; and
- Proposes levels of the chemicals that would protect people's health and the environment.

Results from the risk assessment will not only help state and federal agencies decide whether to clean up the Lower Fox River, but will help in determining how much cleanup is needed. The agencies will also use the risk assessment as a guide when selecting cleanup alternatives — ones that effectively reduce or eliminate risk to people, wildlife and the environment.

Risk findings

When compared to any other chemical found in the Lower Fox River, PCBs in sediments pose the greatest risks to both human and ecological health.

- Almost all of the risk to human health is from exposure to PCBs.
- Eating fish caught in the river and bay is the main way that PCBs can affect people's health. People who regularly eat fish and waterfowl from the river are particularly at risk.
- A small portion of the risk to people's health is from exposure to pesticides and dioxins that are found with the PCBs in sediments and fish tissue.
- Waterfowl hunters and consumers may also have elevated risk, although their risk is about 10 times lower than risks to people who regularly eat fish.
- Cancer risks from exposure to PCBs by eating fish or birds are 100 to 1000 times higher than standards set to protect people's health.
- Noncancer risks (like neurological impacts to infants and children) for people who eat contaminated fish is 56 times higher than state and federal health standards.
- PCBs in fish pose the greatest risks to fish-eating birds and mammals.
- From De Pere to Green Bay, PCB risks to animals were 100 to 1,000 times greater than risks from any other contaminant in that section of the river.

Risk assessors found that reducing the levels of PCBs in river sediments would be the most effective way to reduce health risks to people and animals who depend on the Lower Fox River and Green Bay. The risk assessment includes a focused look at risks related to PCBs. Most importantly, the risk assessment — combined with the models used in the feasibility study — helped scientists understand the amount of risk reduction each cleanup alternative will provide.

How the human risk assessment is done

The first step in a risk assessment is to find out the levels of contaminants and where people are expected to come in contact with them. For the Lower Fox River, risk assessors looked at fish and waterfowl tissue, river water, sediments and air. Sampling information provided a good understanding of the contaminant levels in most of these areas. Very complete information is available about contaminant levels in fish from years of sampling for DNR studies.

The second step is to find out how people are exposed to the contaminants. It is estimated that 47,000 sport anglers and from 2,000 to 5,000 Hmong and Native American anglers and their families are potentially exposed to PCBs. No two people have the same daily routines, habits or diets. For this reason, everyone can have different levels of exposure. Scientists estimate the level of exposure for people likely to have the greatest exposure. Scientists often have to assume quite a bit about these exposures because they do not know the habits of everyone who could be exposed. However, for fish consumption, good information is available about how much fish from the Fox River people eat. Studies have improved understanding of the potential health effects associated with fish consumption. Both cancer and noncancer health effects are considered.

The final step is to consider what is known about the contaminants to determine if they are likely to cause health problems. Information from human studies is considered to be the strongest evidence, but scientists also consider studies done on laboratory animals. Because it is difficult to find large groups of people who have been similarly exposed to a chemical, scientists usually rely on animal studies.

Assessors found that the remaining exposure scenarios for people — from wading, swimming, breathing air and drinking water — are not likely to cause illness.

Health risks from eating PCB-contaminated fish

PCBs build up in people's bodies over time and are stored in fat. It may take months or years of regularly eating contaminated fish to build up enough PCBs to affect people's health. Human and animal studies on exposure to PCBs found: 1) developmental problems and reduced mental abilities in infants and children born to women who were exposed to PCBs; 2) problems with the nervous, immune, circulatory and hormonal systems; 3) liver, brain and skin problems; and 4) increased risk of cancer. Health studies have linked PCBs to reproductive problems in wildlife and fish species living in the Lower Fox River and Green Bay area.

Since 1976, Wisconsin has issued fish consumption advisories for most species of fish caught in the Lower Fox River because of PCB contamination in fish. The advisories warn residents to limit the amount of fish they eat. They provide tips on how to properly clean and cook fish to reduce the amount of PCBs. Despite these fish advisories, many anglers are unaware of the risks and many choose to ignore them.

Ecological health risks

Similar to the human health assessment, the first step in the ecological risk assessment is to find out which species of fish and wildlife are exposed to contaminants and how they are exposed. Researchers evaluated various insects, fish, birds and mammals. They found that animals are exposed to PCBs in three ways: 1) they absorb dissolved chemicals in surface water; 2) they ingest contaminated sediments; and 3) they eat contaminated prey – mainly fish and insects.

Next, researchers compared levels of chemicals in water, sediment and animal tissues with levels set to protect animals' health. Certain animals are more susceptible to effects from PCBs because of their place in the food chain, their sensitivity to contaminants, or because they live in direct contact with contaminated sediments.

Researchers found the chemicals of concern could harm wildlife in the Lower Fox River and Green Bay in a number of ways. Health effects from these chemicals threaten reproduction, growth and survival. As with people, PCBs pose the greatest risks to animals in the Lower Fox River and Green Bay. Sediment-dwelling organisms and fish are at greatest risk. Between Appleton and Little Rapids, PCBs were found in eagle eggs and adult eagle tissues at levels known to cause deformities in birds.

PCB cleanup levels

The risk assessment proposes safe levels of PCBs in sediments that would protect human and ecological health. These concentrations are called "sediment quality thresholds." To evaluate cleanup technologies and alternatives in the feasibility study, the risk assessment proposes to clean up PCBs in river sediments until concentrations measure or average 250 parts per billion (ppb). This level would protect both human and ecological health.

To determine safe levels of PCBs that would protect people's health, the risk assessment used limits set in the Great Lakes Sport Fish Consumption Advisory (GLSFCA). For unlimited fish consumption, the GLSFCA advisory assumes that PCB concentrations in fish will be no higher than 50 ppb.

The cleanup level of 250 ppb would allow people to eat an unlimited amount of sport fish from the Fox River. Cleanup to this level is protective to fish, birds and mammals.

Chemicals of concern identified in the Lower Fox River

PCBs were used in several industrial processes from 1957 to 1972. PCBs were banned in 1976. They are linked to reproductive problems, poor mental development in children, liver damage, skin irritation, hormone problems and cancer.

Dioxins and Furans are byproducts of the wood treatment and bleaching processes often associated with pulp and paper industries. Dioxins can cause cancer in people. Both dioxins and furans can damage the liver, the pancreas, and the circulatory and respiratory systems.

DDT/DDE/DDD are pesticides that were commonly used in the Fox Valley before being banned in the early 1970s. They are known to cause cancer in people.

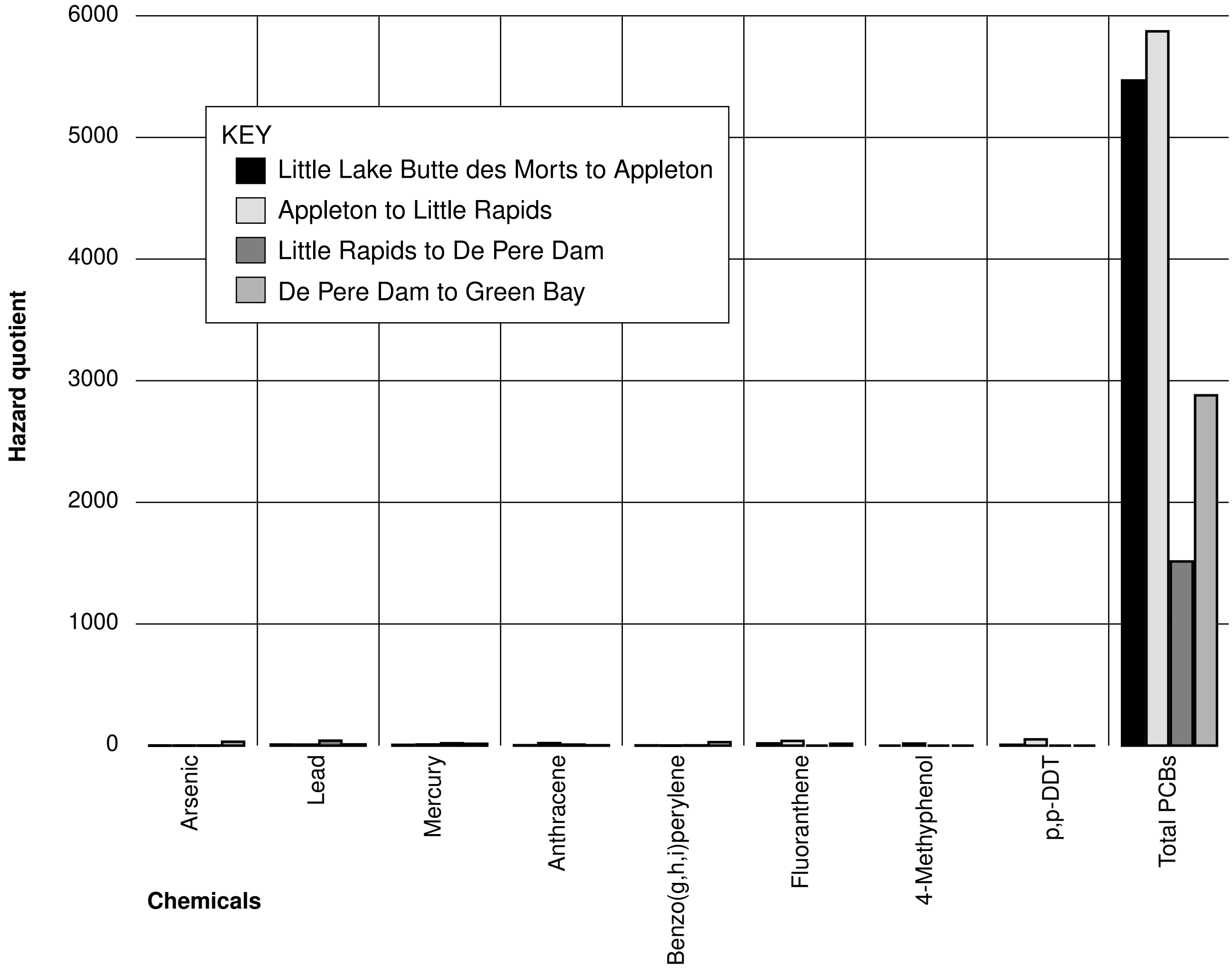
Dieldrin is a pesticide that can cause cancer in people.

Mercury in the Lower Fox River was used in the papermaking process until 1971 when its use was discontinued. It can cause severe damage to the nervous system.

Lead in the river is not associated with a specific source or use. It is known to cause developmental problems in children.

Arsenic in the river is not associated with a specific source or use. It is known to cause skin cancer in people.

Comparing risks from chemicals of concern



Calculated risk from PCB-contaminated river sediments is approximately 100 times higher than from any other chemical pollutant found in the Lower Fox River. Hazard quotient is the ratio of measured PCBs to the concentration at which PCBs are toxic in the environment.

Feasibility Study

The feasibility study identified and evaluated various options for cleaning up PCBs in the Lower Fox River. It set cleanup objectives and then screened technologies that met those objectives. The study breaks the river into four reaches and includes many alternatives to clean up PCBs in sediments within each reach.

To help develop cleanup alternatives, DNR and EPA used computer models developed by national experts. These models helped determine how PCBs move through the river and bay over time.

Based on findings from the remedial investigation and risk assessment, the feasibility study proposes solutions that reduce risks to people and wildlife who eat fish. Before proposing cleanup options for each of the four river reaches, scientists: 1) considered physical characteristics of each reach, 2) estimated human-health and ecological risks, and 3) considered other information specific to each river reach.

The following factors are considered in developing and evaluating cleanup options. (These are known as Superfund's nine cleanup criteria.)

1. Overall protection of human health and the environment
2. Compliance with state and federal laws. Do alternatives meet local, state or federal standards?
3. Reduction of toxicity, mobility and volume of contamination. Does the technology effectively reduce contamination?
4. Implementability. How easy is it to construct a technology?
5. Long-term effectiveness. Is an alternative permanent and effective at reducing contamination and risk over time?
6. Short-term effectiveness. Does the alternative protect the community and workers during cleanup?
7. Cost. How much does the option cost? This includes incremental cost — how much it costs to remove contaminants to certain levels in order to protect human and ecological health. Most options have a threshold where trying to clean up every last trace of PCBs becomes less cost-effective and potentially prohibits cleanup elsewhere.
8. Community acceptance. Which alternative does the community prefer?
9. State acceptance. Does the state agree with the cleanup plan?

Cleaning up the river by reaches

Next the study developed a series of cleanup plans for each of the four reaches. They generally include a combination of capping, dredging, treatment and disposal.

The four Lower Fox River reaches are:

- Little Lake Butte des Morts to Appleton
- Appleton to Little Rapids (just downstream of Wrightstown)
- Little Rapids to De Pere Dam
- De Pere Dam to Green Bay

The alternatives for each river reach are identified in the following tables. These tables identify preliminary information and costs for each alternative within the reach. Costs are preliminary and are used for comparative purposes only. Once a final cleanup plan is chosen, more information on the cost to clean up the Lower Fox River will be available.

Comparing cleanup alternatives

The study evaluates each alternative against a series of questions before forwarding an alternative for further consideration in the feasibility study:

- What are the remaining risks after cleanup?
- What is the level of disruption to local communities during construction?
- What is the level of administrative effort necessary to implement each alternative?
- What is the volume of contaminated sediments cleaned up from the Lower Fox River?
- What is the cost of implementing each alternative?

Appleton to Little Rapids river reach

	Alternative A		Alternative B	Alternative C
	Low* Level	High* Level	Institutional Controls	No Action
Sediment Removal Volume (cubic yards)	338,000	0	0	0
Mass of PCBs (pounds)	660	0	0	0
Removal				
Hydraulic	✔			
Dewatering				
Settling ponds	✔			
Disposal				
Off-site (licensed landfill)	✔			
Institutional Controls			4	
Estimated Cost **	$23,660,000		$1,200,000	$0
Estimated Time to Implement	5 years		—	—

*Low Level = < 50 parts per million (ppm) High Level = > 50 ppm
**Costs are preliminary and are used for comparison purposes only.

Little Lake Butte des Morts river reach

	Alternative A		Alternative B		Alternative C		Alternative D		Alternative E		Alter. F	Alter. G
	Low* Level	High* Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Institutional Controls	No Action
Sediment Removal Volume (cubic yards)	1,563,000	63,000	1,066,000	63,000	805,000	63,000	805,000	63,000	679,000	63,000	0	0
Mass of PCBs (pounds)	3,421	557	3,399	557	1,575	557	1,575	557	977	557	0	0
Removal												
Hydraulic	✔	✔	✔	✔	✔		✔	✔	✔	✔		
Mechanical						✔				✔ (8,000 cu. yds.)		
Dewatering												
Mechanical								✔				
Settling ponds on Arrowhead Park	✔	✔	✔	✔					✔	✔		
Settling on barge						✔				✔		
Settling ponds in on-site Confined Disposal Facilities					✔		✔					
Treatment												
High-temperature Thermal Destruction						✔						
Disposal												
Off-site (licensed landfill)	✔	✔	✔	✔				✔	✔	✔		
On-site Confined Disposal Facility					✔	✔	✔					
Capping												
Armored									✔ (6,000,000 sq. ft)			
Institutional Controls			✔		✔		✔		✔		✔	
Estimated Cost**	$93,500,000		$67,000,000		$58,200,000		$51,500,000		$56,600,000		$1,200,000	$0
Estimated Time to Implement	5 years		4 years		3 years		3 years		1 year		—	—

*Low Level = < 50 (ppm)   High Level = > 50 ppm   **Costs are preliminary and are used for comparison purposes only.

Little Rapids to De Pere Dam river reach

	Alternative A		Alternative B		Alternative C		Alternative D		Alternative E		Alternative F		Alt. G	Alt. H
	Low* Level	High* Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Institut. Controls	No Action
Sediment Removal Volume (cubic yards)	1,188,000	0	1,188,000	0	1,065,000	0	1,065,000	0	593,000	0	0	0	0	0
Mass of PCBs (pounds)	3,144	0	3,144	0	2,361	0	2,361	0	1,540	0	0	0	0	0
Removal														
Hydraulic	✔		✔		✔		✔		✔					
Mechanical														
Dewatering														
Settling ponds	✔				✔									
Settling ponds in new landfill			✔											
Treatment														
High-temperature Thermal Destruction														
Disposal														
Off-site (licensed landfill)	✔				✔									
Off-site (newly constructed landfill)			✔											
On-site Confined Disposal Facility							✔		✔					
Capping														
Sand									✔ (8,000,000 sq. ft)		✔ (12,000,000 sq. ft)			
Institutional Controls					✔		✔		✔		✔		✔	
Estimated Cost **	$113,800,000		$22,200,000		$103,200,000		$29,300,000		$42,100,000		$22,000,000		$1,200,000	$0
Estimated Time to Implement	4 years		4 years		4 years		4 years		4 years		ongoing monitoring		—	—

*Low Level = < 50 ppm High Level = > 50 ppm **Costs are preliminary and are used for comparison purposes only.

De Pere Dam to Green Bay river reach

	Alternative A		Alternative B		Alternative C		Alternative D		Alternative E		Alternative F		Alt. G	Alt. H
	Low* Level	High* Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Institut. Controls	No Action
Sediment Removal Volume (cubic yards)	5,440,000	250,000	5,440,000	250,000	4,815,000	250,000	4,471,000	250,000	4,471,000	250,000	4,011,000	250,000	0	0
Mass of PCBs (pounds)	48,358	3,159	48,358	3,159	43,353	3,159	40,297	3,159	40,297	3,159	38,804	3,159	0	0
Removal														
Hydraulic			✔	✔										
Mechanical	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔		
Dewatering														
Settling on barge	✔	✔			✔	✔	✔	✔	✔	✔	✔	✔		
Settling ponds in landfill			✔	✔										
Settling ponds in on-site Confined Disposal Facilities							✔		✔		✔			
Treatment														
High-temperature Thermal Destruction								✔						
Disposal														
Off-site (licensed landfill)	✔	✔			✔	✔				✔		✔		
Off-site (newly constructed landfill)			✔	✔										
On-site Confined Disposal Facility							✔	✔	✔		✔			
Capping														
Sand											✔ (6,000,000 sq. ft)			
Institutional Controls					✔		✔		✔		✔		✔	
Estimated Cost**	$490,000,000		$45,900,000		$437,600,000		$131,000,000		$122,700,000		$130,500,000		$1,200,000	$0
Estimated Time to Implement	10 years		8 years		7 years		7 years		7 years		ongoing monitoring		—	—

*Low Level = < 50 ppm High Level = > 50 ppm **Costs are preliminary and are used for comparison purposes only.

Sediment cleanup option glossary

A number of technologies can be used to clean up sediment contaminated with PCBs. The following list includes technologies that work both in and out of the river. Over 200 technologies were considered before settling on the following list of choices:

No action

No action is the status quo with continuing fish and waterfowl consumption advisories. It is used as a starting point of comparison per federal guidance.

Institutional controls

Examples include continued fish and waterfowl consumption advisories or possible restrictions on navigational dredging and other water use activities.

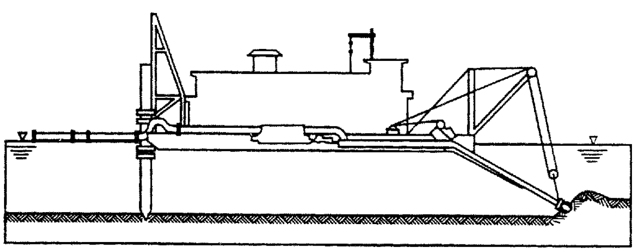
Dewatering

This involves separating water from sediment before disposal or treatment. Mechanical dewatering uses a press to squeeze the water out of the sediments. Passive dewatering such as settling ponds or in-barge dewatering are also used to remove water from sediments. In passive dewatering, sediments gradually accumulate on the bottom so water on top can be removed and treated.

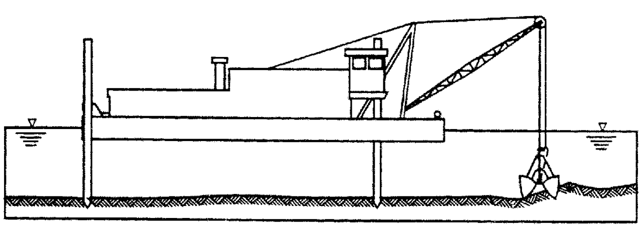
Mechanical presses can be used to separate water from contaminated sediments before disposal.

Removal

Hydraulic dredging involves excavating sediments from the river using a vacuum-like device. Mechanical dredging uses scooping devices like a backhoe, clamshell or closed-bucket clamshell to remove sediments. Removal is usually followed by dewatering, treatment if PCB concentrations are high, and disposal.



Hydraulic dredges suck contaminated sediments off the river bottom.



Mechanical dredges scoop materials off the river bottom.

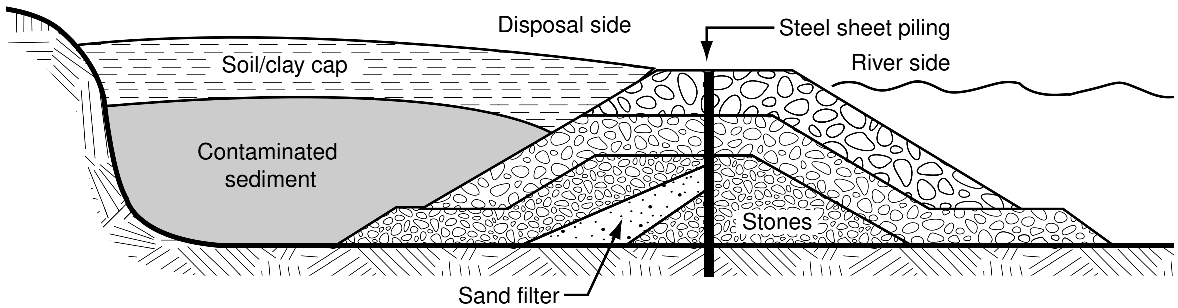
Treatment

Off-site ("ex situ") treatment may immobilize or breaks down PCBs. High-temperature thermal destruction is an example of a technology that can destroy PCBs using heat. In-river ("in situ") treatment immobilizes or breaks down PCBs when different agents are injected into contaminated sediments while still on the river bottom. The feasibility study considers treatment for PCB concentrations greater than 50 parts per million. There are many other forms of treatment.

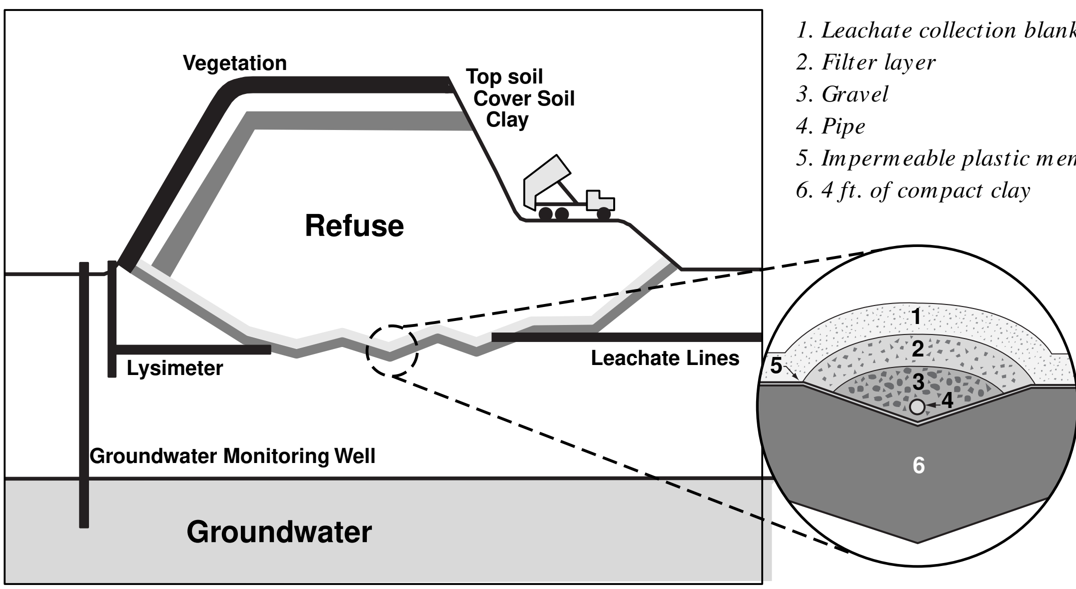
Disposal

Contaminated sediments can be disposed of in a licensed solid-waste landfill that meets state and federal requirements or in a confined disposal facility (CDF). A confined disposal facility is an engineered structure in or close to the river. In-river CDFs are surrounded by walls made of sheet piling, rock and rubble that isolate contaminated sediments. These confined facilities are common in the Great Lakes.

A confined disposal facility with a filter layer and steel barrier that will isolate contaminated sediment and provide for disposal adjacent to the river.



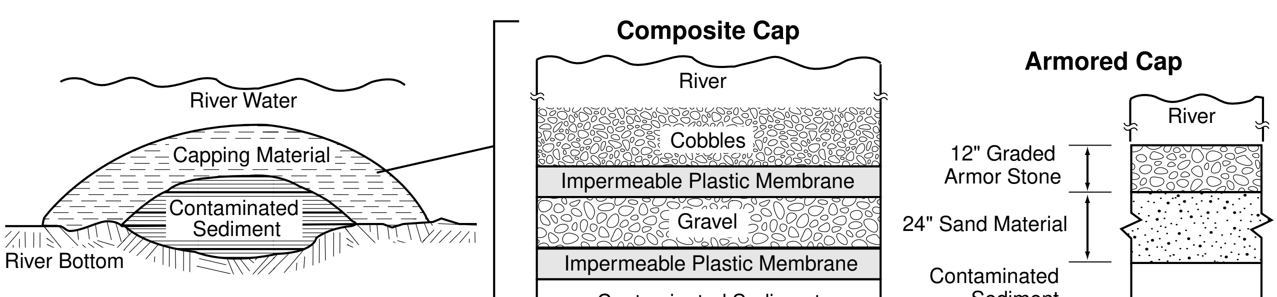
Modern landfills are built with multiple protective layers to prevent leaking.



1. Leachate collection blanket
2. Filter layer
3. Gravel
4. Pipe
5. Impermeable plastic membrane
6. 4 ft. of compact clay

Capping

This involves placing sand, gravel, an impermeable plastic membrane, and/or stones over the contaminated sediment. These materials, or a combination of them, isolate contaminated sediment from river water.



Drawings are not to scale

Next steps

Public comments needed

These draft documents are now available for public review and comment. Citizens have the opportunity to read the studies at information repositories set up at local libraries and on the DNR's Web site (see addresses below). Written comments will be accepted during the public comment period, which runs from Feb. 26 - April 12, 1999. People may also provide comments at public meetings scheduled for March 22 in Green Bay and March 23 in Appleton.

The DNR staff leading these studies will review all comments from the public as well as input from the EPA, other agencies and the companies potentially responsible for contamination. DNR will respond to comments in a document called a responsiveness summary. This summary will be available later this year, both at information repositories set up at Fox Valley libraries and on the Web.

The final reports, particularly the feasibility study, will provide the basis to develop the final recommended cleanup plan to include in the document known as the Record of Decision. The Record of Decision is the whole-river cleanup plan recommended by state and federal agencies. Once the department issues the proposed cleanup plan, people will have another opportunity to share their comments and concerns before the plan is finalized.

The proposed plan will include more detailed information on cleanup costs and time frames for implementing the cleanup.

Schedule of upcoming activities

- Final studies - Summer 1999
- Proposed cleanup plan - Summer/Fall 1999
- Public comment period - Summer/Fall 1999
- Record of Decision - Fall/winter 1999/2000
- Public comment period - Fall/winter 1999/2000

Where to send comments:

- Send written comments on the draft evaluations to **Lower Fox River Cleanup, RR/3, Wisconsin Department of Natural Resources, 101 S. Webster. P.O. Box 7921, Madison, WI 53707**. Comments must be postmarked by **April 12, 1999**.
- Copies of comments should also be sent to **Fox River RI/FS, U.S. EPA - SR/6J, 77 W. Jackson Blvd., Chicago, IL 60604.**

For more information:

- Visit DNR's Web site at < http://www.dnr.state.wi.us/org/water/wm/lowerfox/> . The text of the reports and some tables and figures will be posted on DNR's Web site during the week of March 1.
- Contact Irene Sadowski, DNR public affairs, at (608) 264-8952.
- Visit one of the information repositories set up at libraries in the Fox Valley. The full reports will be available at the following libraries:

Appleton Public Library
225 N. Oneida St.

Wrightstown Public Library
529 Main St.

Neenah Public Library
P.O. Box 569

DePere Public Library
380 Main Ave.

Oshkosh Public Library
106 Washington Ave.

Kaukauna Public Library
111 Main Ave.

Brown County Library
515 Pine St., Green Bay

Door County Library
104 S. Fourth Ave., Sturgeon Bay

Little Chute Public Library
625 Grand Ave.

Oneida Community Library
201 Elm St., Oneida

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