UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
GREAT LAKES NATIONAL PROGRAM OFFICE
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

Stephen Galarneau, Director
Office of Great Waters – Great Lakes & Mississippi River
Wisconsin Department of Natural Resources
PO Box 7921
Madison, WI 53707-7921

Dear Mr. Galarneau,

Thank you for your April 13, 2020 request to remove the *Eutrophication or Undesirable Algae* Beneficial Use Impairment (BUI), known in the St. Louis River Area of Concern (AOC) as *Excessive Loading of Sediment and Nutrients*. As you know, we share Wisconsin's desire to restore all the Great Lakes AOCs and to formally delist them.

Based upon a review of your submittal and the supporting data, the U.S. Environmental Protection Agency (EPA) approves Wisconsin's request to remove this BUI from the St. Louis River AOC. EPA will notify the International Joint Commission (IJC) of this significant positive environmental change at this AOC.

We congratulate you and your staff as well as the many federal, state and local partners who have been instrumental in achieving this environmental improvement. Removal of this BUI will benefit not only the people who live and work in the AOC, but all residents of Minnesota and Wisconsin and the Great Lakes basin as well.

We look forward to the continuation of this important and productive relationship with your agency, the Minnesota Pollution Control Agency, and the Minnesota Department of Natural Resources as we work together to delist this AOC in the years to come. If you have any further questions, please contact me at (312) 353-8320 or your staff can contact Leah Medley at (312) 886-1307.

Sincerely,

CHRISTOPHER KORLESKI
Digitally signed by CHRISTOPHER KORLESKI
Date: 2020.04.28 14:51:39 -05'00'

Chris Korleski, Director
Great Lakes National Program Office

cc: Barbara Huberty, MPCA
Matt Steiger, WNDR
Melissa Sjolund, MNDNR
Rick Gitar, Fond du Lac Band of Lake Superior Chippewa
Raj Bejankiwar, IJC

State of Wisconsin
DEPARTMENT OF NATURAL RESOURCES
101 S. Webster Street
Box 7921
Madison WI 53707-7921

Tony Evers, Governor
Preston D. Cole, Secretary
Telephone 608-266-2621
Toll Free 1-888-936-7463
TTY Access via relay - 711

April 13, 2020

Mr. Chris Korleski
Great Lakes National Program Office
U.S. Environmental Protection Agency
77 West Jackson Boulevard (G-17J)
Chicago, IL 60604-3507

Subject: Removal of the *Excessive Loading of Sediment and Nutrients to Lake Superior* Beneficial Use Impairment in the St. Louis River Area of Concern

Dear Mr. Korleski:

I am writing to request the U.S. Environmental Protection Agency (U.S. EPA) Great Lakes National Program Office's (GLNPO's) concurrence with the removal of the *Excessive Loading of Sediment and Nutrients to Lake Superior* Beneficial Use Impairment (BUI) from the St. Louis River AOC (SLRAOC). This BUI removal request is provided as a companion to the request submitted by the Minnesota Pollution Control Agency (MN PCA).

The SLRAOC team has assessed the status of the management actions for the *Excessive Loading of Sediment and Nutrients to Lake Superior* BUI (referred to in the Great Lakes Water Quality Agreement as the *Excessive Nutrients or Undesirable Algae* BUI) as outlined in the Remedial Action Plan. Five management actions have been completed and the current and historical conditions of sediment and nutrients in the St. Louis and Nemadji Rivers have been assessed. All management actions associated with this impairment have been completed and the BUI removal target has been met. A public review of the recommendation was conducted from February 24 through March 24, 2020, and one public comment in support of BUI removal was received. Therefore, we recommend that the *Excessive Loading of Sediment and Nutrients to Lake Superior* BUI be removed from the SLRAOC's impairments list.

Documentation to support this recommendation was transmitted on April 13, 2020 to U.S. EPA via a downloadable zip file provided by MN PCA, including the "Excessive Loading of Sediment and Nutrients to Lake Superior Beneficial Use Impairment Removal Recommendation" document prepared by WDNR and MN PCA staff. A letter of support from the St. Louis River Alliance is included as an appendix to the document.

We value our continuing partnership in the AOC Program and look forward to working closely with the GLNPO in the removal of BUIs and the delisting of Wisconsin's AOCs. If you need additional information, please contact Matt Steiger, WDNR, at 715-395-6904, or you may contact me.

Sincerely,

Stephen Galarneau, Director
Office of Great Waters - Great Lakes & Mississippi River
Wisconsin Department of Natural Resources
608-266-1956
stephen.galarneau@wisconsin.gov

cc: Leah Medley, USEPA
Todd Nettesheim, USEPA
Amy Pelka, USEPA
Marc Tuchman, USEPA
Paul Buszka, USGS
Matt Steiger, WDNR
Cherie Hagen, WDNR
Kendra Axness, WDNR
Melissa Sjolund, MN DNR
Barbara Huberty, MN PCA
Rick Gitar, Fond du Lac Band of Lake Superior Chippewa

MINNESOTA POLLUTION CONTROL AGENCY

520 Lafayette Road North | St. Paul, Minnesota 55155-4194 | 651-296-6300

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April 13, 2020

Mr. Chris Korleski
Director, Great Lakes National Program Office
United States Environmental Protection Agency
77 West Jackson Boulevard
Chicago, IL 60604-3507

RE: Approve the request to remove the Excessive Loading of Sediment and Nutrients Beneficial Use Impairment in the St. Louis River Area of Concern

Dear Mr. Korleski:

The Minnesota Pollution Control Agency and the Wisconsin Department of Natural Resources hereby request the approval of the Environmental Protection Agency's (EPA) Great Lakes National Program Office (GLNPO) staff to remove the Excessive Loading of Sediment and Nutrients Beneficial Use Impairment (BUI) in the St Louis River Area of Concern (SLRAOC).

The SLRAOC team has assessed the status of the management actions for the Excessive Loading of Sediment and Nutrients BUI as outlined in the 2013 SLRAOC Remedial Action Plan and its subsequent annual updates. All of the management actions associated with this impairment have been completed and a public review of the recommendation has been conducted. One comment was received supporting the removal recommendation and no further action was needed. A letter of support was provided by the St. Louis River Alliance, the citizens' action committee for the SLRAOC. We therefore recommend that the Excessive Loading of Sediment and Nutrients BUI be removed from the SLRAOC's impairments list. The documentation to support this recommendation is enclosed.

We value our continuing partnership with the GLNPO staff and the funding support provided to the SLRAOC through the Great Lakes Restoration Initiative. It is through your significant involvement and that of all of our federal, state and local partners that will keep us on the path to delisting the SLRAOC.

If you need further information about this request please contact either Barb Huberty at 218-302-6630 or barbara.huberty@state.mn.us or Matt Steiger at 715-395-6904 or matthew.steiger@wisconsin.gov.

Sincerely,

Laura Bishop
Commissioner

Enclosure: St. Louis River Area of Concern Beneficial Use Impairment Removal Recommendation for Excessive Loading of Sediment and Nutrients

cc: Leah Medley, SLRAOC Task Force Lead
Paul Buszka, USGS Technical Resource Lead
Matt Steiger, WDNR AOC Coordinator
Melissa Sjolund, MN DNR AOC Coordinator
Rick Gitar, Fond du Lac AOC Coordinator

St. Louis River Area of Concern

Beneficial Use Impairment Removal Recommendation for
Excessive Loading of Sediment and Nutrients

April 13, 2020

Submitted to:
U.S. EPA-Region 5
77 W. Jackson Boulevard
Chicago, IL 60604

Prepared by these implementing agencies:

NAH-GAH-CHI-WA-NONG FOND DU LAC RESERVATION

DEPARTMENT OF NATURAL RESOURCES

MINNESOTA POLLUTION CONTROL AGENCY

WISCONSIN DEPT. OF NATURAL RESOURCES

With major funding support from the Great Lakes Restoration Initiative.

Great Lakes RESTORATION

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ACRONYMS

- AOC – Area of Concern
- BUI – beneficial use impairment
- ca. – circa
- CBOD – carbonaceous biological oxygen demand
- chl α – chlorophyll α
- CWA – Clean Water Act
- CWMP – Coastal Wetland Monitoring Program
- DO – dissolved oxygen
- DOP – dissolved orthophosphorus
- EPT – Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies)
- FdL – Fond du Lac Band of Lake Superior Chippewa
- HSPF – Hydrologic Simulation Program—FORTRAN
- IBI – index of biotic integrity
- IEC – index of ecological condition
- MAs – management actions
- µg/L – microgram per liter
- mg/L – milligram per liter
- MNDNR – Minnesota Department of Natural Resources
- MPCA – Minnesota Pollution Control Agency
- N – nitrogen
- NRCS – Natural Resources Conservation Service
- NTU – nephelometric turbidity unit
- RAP – Remedial Action Plan
- SLRAOC – St. Louis River Area of Concern
- SLRE – St. Louis River Estuary
- TN – total nitrogen
- TIN – total inorganic nitrogen
- TMI – trimetric index
- TP – total phosphorus
- TSI – trophic state index
- TSS – total suspended solids
- UMD – University of Minnesota Duluth
- USEPA-GLNPO – U.S. Environmental Protection Agency – Great Lakes National Program Office
- USEPA-GLTED – U.S. Environmental Protection Agency – Great Lakes Toxicology and Ecology Division
- USGS – U.S. Geological Survey
- WDNR – Wisconsin Department of Natural Resources
- WLSSD – Western Lake Superior Sanitary District

COMPARISON OF UNITS USED TO EXPRESS CONCENTRATIONS:

Unit	Symbol	Also Described As	Equals
milligram per litter	mg/L	part per million (ppm)	$1/10^6$ or 0.000001
microgram per liter	µg/L	part per billion (ppb)	$1/10^9$ or 0.000000001

Conversions: 1 µg/L = 0.001 mg/L or 1 mg/L = 1000 µg/L

Within this document, mg/L will be the base unit used. Where scientists have used µg/L in their papers, the mg/L conversion will be shown in brackets to ease comparisons.

Executive Summary

Background

The United State and Canada designated 43 Areas of Concern (AOC) across the Great Lakes in 1987, including the St. Louis River Area of Concern (SLRAOC). The AOCs were designated because significant environmental damage at those locations caused specific types of Beneficial Use Impairments (BUIs). At the time of AOC designation, the International Joint Commission identified 14 BUIs in the Great Lakes Water Quality Agreement that were to be assessed at each AOC to determine their applicability. Only nine BUIs applied to the SLRAOC. Once the BUIs were identified, removal targets for each were established and management actions (MAs) to achieve the targets for each BUI were identified.

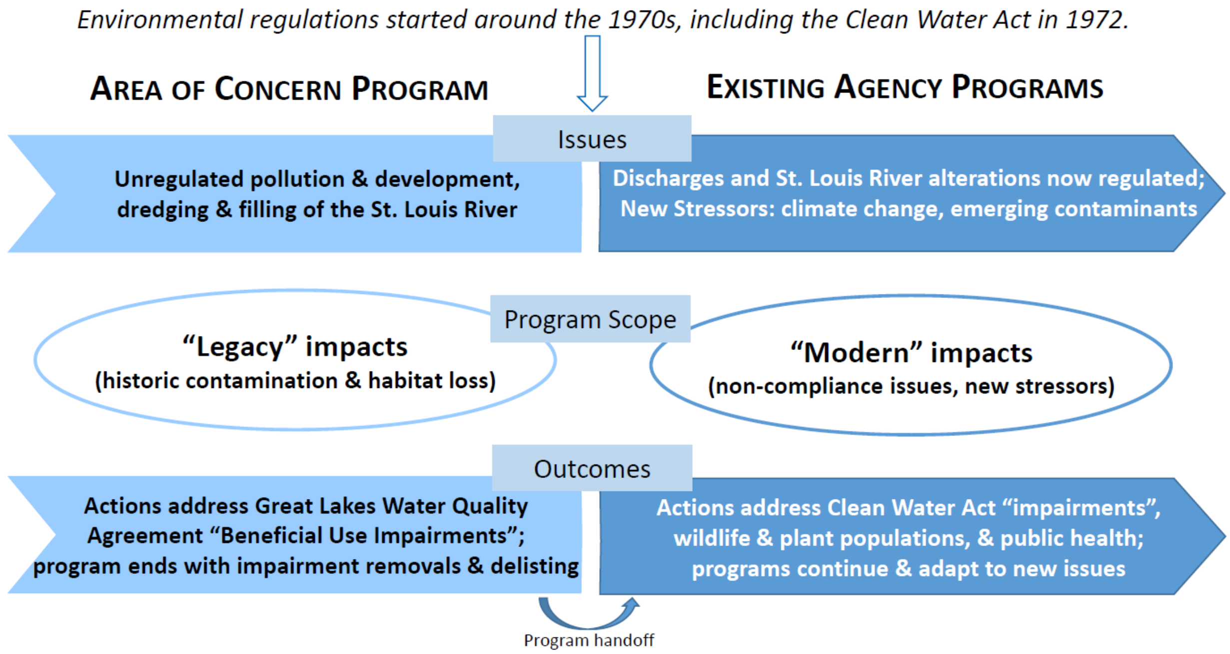
Once the MAs for a BUI are completed, a removal package is prepared for public review and, ultimately, concurrence by the U.S. Environmental Protection Agency.

This document provides the justifications supporting a removal recommendation for the Excessive Loading of Sediments and Nutrients BUI (BUI 6) for the SLRAOC, which is a modification of the "Eutrophication or Undesirable Algae" BUI from the Great Lakes Water Quality Agreement to address the SLRAOC-specific conditions. All five MAs that apply to BUI 6 are complete and the BUI 6 removal target and its four criteria are met. The removal criteria and brief conclusions pertaining to the studies applicable to each are included in this executive summary. Detailed summaries of the studies and findings for each MA are included in the main body of this document, while the study reports prepared for each management action are included in the appendices.

The voluntary AOC program was established to address "legacy" issues. These were environmental problems that caused ecosystem impairments at the time of the AOC designation and largely occurred before modern environmental regulations were in place. Legacy issues significantly impacted geographically-defined sites rather than regional-scale stressors.

For the SLRAOC, examples of legacy issues are: unregulated discharge of industrial and municipal waste, dredging and filling in the estuary, wood waste deposited in the river, and extensive logging – all of which exacerbated erosion and sedimentation problems. Since then, the Clean Water Act (CWA) and other environmental regulations are being implemented to protect the environment and human health from these types of large-scale problems.

The scope of the AOC program does not include "modern" issues that are the responsibility of many state and federal agencies under a variety of natural resources, environmental, and public health program authorities. Some examples of modern issues are: contaminants of emerging concern, water-related climate change impacts, non-compliance of point source permits, and impairments identified and regulated under the CWA. Figure ES-1 depicts the differences between the AOC and existing agency programs.



The same environmental and natural resource agencies that implemented the Area of Concern Program will address ongoing issues after the Program has ended, but under different program authorities. This will include long-term monitoring and maintenance of remediation and habitat projects, species management, and regulatory enforcement.

Figure ES 1: The Program Scope of the St. Louis River Area of Concern

As it relates to the removal of the Excessive Loading of Sediment and Nutrients BUI discussed in this report, consider climate change effects as an example of the difference between legacy and modern impacts. The SLRAOC is experiencing more frequent and intense storm events and these are affecting the intensity of seiche impacts, which are, in turn, impacting sediment and nutrient conditions in western Lake Superior and the St. Louis River Estuary (SLRE). These are modern impacts that fall under the purview of the CWA, not the SLRAOC program. The Future Actions section of this document lists a variety of future needs to be addressed by other agency programs.

It is important to note that the assessments associated with each MA are time limited. Once a MA is completed, there is not an effort to return to the endpoint of the studies to add data gathered by other agency programs since the conclusion of the study. Similarly, many implementation activities pertinent to BUI 6 are already underway by other agency programs that are outside the SLRAOC program. More recent data and activities are not reported here. Additionally, regulatory programs are ever-evolving and terminology in place when the BUI 6 studies were completed have not been substituted by newer terminology (e.g., turbidity impairments under the CWA are now total suspended sediment [TSS] impairments).

The Removal Target and Criteria Have Been Met

The removal target will have been met when:

Nutrient and sediment levels have not been shown to impair water quality and habitat, and do not restrict recreation, including fishing, boating, or body contact in the estuary and within western Lake Superior based on the following criteria:

1. *All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorous), organic matter, and sediment;*

   CONCLUSION: As confirmed by permit compliance staff within the Wisconsin Department of Natural Resources (WDNR), all eight pollutant discharge elimination system permits within the SLRAOC area are in substantial compliance as of December 2019. Also as of December 2019, permit compliance staff from the Minnesota Pollution Control Agency (MPCA) have confirmed that there are 32 pollutant discharge elimination system permits within the SLRAOC area, of which only 21 have nitrogen, phosphorus, TSS and/or carbonaceous biological oxygen demand (CBOD) compliance conditions. Eleven permittees do not have nutrient-related requirements. Only one of the industrial permittee is noncompliant for TSS only and is following MPCA's compliance processes to address the noncompliance issues. The other 20 permittees with nutrient-related requirements are in substantial compliance with their permits.

   Additionally, the Western Lake Superior Sanitary District (WLSSD) and the City of Duluth are working to meet the conditions of a federal Consent Decree to reduce inflow and infiltration into the sanitary sewer system as a means to reduce sanitary sewer overflows.

   Both the City of Superior and the City of Duluth have also invested in stormwater management practices and outreach to reduce the impacts of non-point source, urban runoff.

2. *Total phosphorus concentrations in the Lake Superior portion of the AOC do not exceed 0.010 mg/L (upper limit of oligotrophic range);*

   CONCLUSION: Multiple data sources indicated that the Lake Superior portion of the AOC met this criterion (Table ES-1). The Lake Superior data from the 2012 and 2013 BUI study (MA 6.01) showed that total phosphorus (TP) values were slightly higher than the BUI criterion of 0.010 mg/L for Lake Superior's western arm, with an average of 12.7 µg/L [0.0127 mg/L].[1] Additional water quality parameters sampled during the study show that DO was generally near saturation and the chlorophyll α (chl α) concentrations were consistent with an oligotrophic water body. Paleolimnological study results (MA 6.03) for the Lake Superior sample location concluded that (1) water quality had improved from past periods of higher TP concentrations and (2) current prevailing concentrations of phosphorus did not exceed the TP criterion. Specifically, diatom-inferred TP results for the Lake Superior core indicated that western Lake Superior concentrations of TP were 3 - 6 µg/L (0.003 to 0.006 mg/L). TP results for western Lake Superior were available for 1996-2015 from the U.S. Environmental Protection Agency's (USEPA's) Great Lakes Biology Monitoring Program (USEPA, Great Lakes Biology Monitoring Program, 1983 – present; Central Data Exchange). The TP results (see Appendix 11) showed that from 1996-2015 the mean western Lake Superior TP concentration was 2.6 µg/L [0.0026 mg/L] and the range was 1.0 to 8.0 µg/L [0.001 to 0.008 mg/L] and never exceeded the criterion[2].

[1]Data from this assessment was collected in nearshore conditions, which were likely biased toward St. Louis River conditions due to river water mixing with the lake at the sample sites.
[2] The USEPA's Great Lakes Biology Monitoring Program sampling point is not located within the boundary of the SLRAOC.

3. *There are no exceedances of the most protective water quality standard for either state in the western basin of Lake Superior due to excessive inputs of organic matter or algal growth attributed to loadings from wastewater overflows into the St. Louis River;*

   CONCLUSION: Data used to assess St. Louis River water quality indicate that the BUI removal criteria (MA 6.01-6.04) have been met. Additionally, these data do not indicate any excessive algal growth in or inputs of organic matter to the SLRAOC. Wastewater overflows are prohibited by Wisconsin Administrative Code Chapter NR 210.21 and are administered in Minnesota by State Statute 115.03, Minnesota Rule 7050.0210 and Minnesota Rule 7053.0205.

   Wastewater overflows, including sanitary sewer overflows, treatment facility overflows and combined sewer overflows have been drastically reduced since the time of AOC listing. Wastewater permits administered by the states have included conditions to reduce and report overflow events. In addition, as of August 2016, all facilities in Wisconsin were required to have developed and be actively implementing a Capacity, Management, Operation, and Maintenance program for operation and maintenance of sanitary sewer collection systems with goals to help address issues of inflow and infiltration which are the primary causes of overflow events. Minnesota's wastewater permitees have met similar facility management requirements. Upgrades to wastewater and collection systems in the past decade have resulted in significant reductions in overflow events. The improvements in DO, TSS and nutrients (Bellinger et al., 2016) also support this conclusion.

4. *Total phosphorus concentrations within the St. Louis River portion of AOC do not exceed an interim guide of 0.030 mg/L (upper limit of mesotrophic range) or the most restrictive water quality standards. This ensures that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive productivity and nuisance conditions within the St. Louis River Estuary.*

CONCLUSION: The 5 MA's that have been completed for this BUI indicated that water quality improvements in the SLRE and Nemadji River watershed have resulted in the majority of the AOC meeting the phosphorus criterion (see Table ES-1). In addition, other water quality parameters (TSS, dissolved oxygen [DO] and chl α) indicate nutrients and sediments are not causing an impairment. Data showed a dramatic decline in TP concentrations and sediment loading in the SLRAOC since the time of listing.

Table ES-1: Summary of Water Quality Results for Management Action 6.04

Parameter	SLRE, from Fond du Lac dam to Lake Superior (Bellinger, et al., 2016)	Lake Superior[1] (Bellinger, et al., 2016)	Western Lake Superior[2] (USEPA, Great Lakes Biology Monitoring Program, 1996-2015)
TP	~60% of area below 30 µg/L [0.030 mg/L]	Average = 12.7 µg/L [0.0127 mg/L]	Average = 2.6 µg/L [0.0026 mg/L]
TSS	>85% of area below 15 mg/L	Average = 4.4 mg/L [0.0044 mg/L]	not assessed
DO	>5.5 mg/L; no hypoxia	Average = 12.2 mg/L	not assessed
chl α	>70% of area below 10 µg/L [0.010 mg/L]; oligotrophic to mesotrophic	Average = 2.7 µg/L [0.027 mg/L]; oligotrophic	not assessed

[1] *The interim TP guide for Lake Superior is 0.010 mg/L. Data from this assessment were collected in nearshore conditions, which were likely biased toward SLRE conditions due to seiche mixing.*
[2] *The USEPA's Great Lakes Biology Monitoring Program sampling point (SU 19) is not located within the boundary of the SLRAOC*

A BUI technical team of subject matter experts was established to evaluate the removal strategy and review the findings from each study and offer recommendations to address any deficiencies until the target and criteria were met (see Appendix 12 for the technical team members and their affiliations).

A public information process was conducted to obtain input from interested parties on the information provided in the removal package.

Multiple lines of evidence support a removal recommendation for this BUI. The results of the BUI 6 studies, along with support from the BUI 6 technical team, SLRAOC partners, and stakeholders have resulted in this recommendation by the SLRAOC Coordinators, leaders, and executive managers to remove the Excessive Loading of Sediments and Nutrients BUI from the SLRAOC.

Purpose

The purpose of this document is to provide the information needed to support a recommendation to remove the Excessive Loading of Sediment and Nutrients Beneficial Use Impairment (BUI) in the St. Louis River Area of Concern (SLRAOC).

St. Louis River Area of Concern Background

The 1987 US-Canada Great Lakes Water Quality Agreement designated the SLRAOC as one of 43 areas with significant environmental degradation. The SLRAOC is spatially large and geographically complex, spanning the Minnesota and Wisconsin state line and including tribal interests (see Figure 1).

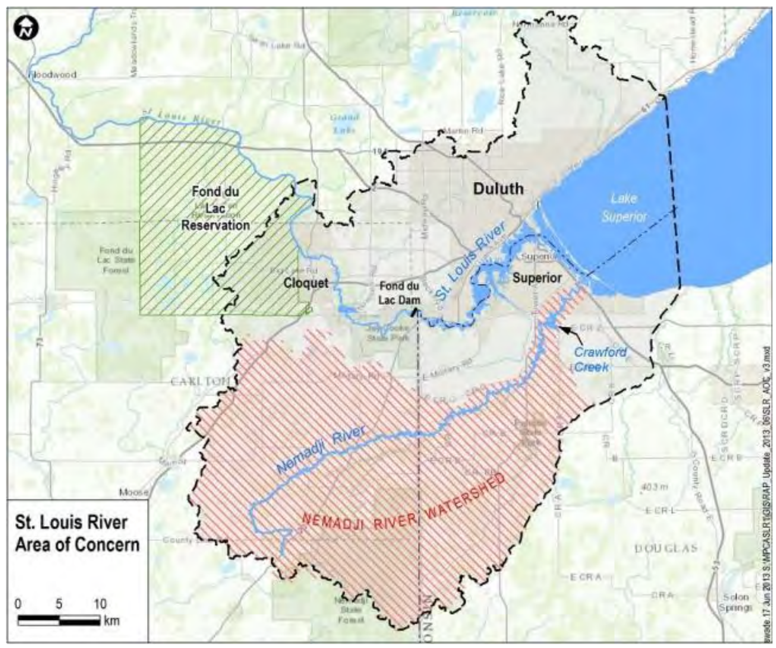


Figure 1: Extent of the St. Louis River Area of Concern

The SLRAOC is jointly managed by four implementing agencies: the Fond du Lac Band of Lake Superior Chippewa (FdL), the Minnesota Department of Natural Resources (MNDNR), the Minnesota Pollution Control Agency (MPCA), and the Wisconsin Department of Natural Resources (WDNR). MPCA and WDNR are the delegated authorities that manage official transactions with the U.S. Environmental Protection Agency - Great Lakes National Program Office (USEPA-GLNPO). Dozens of stakeholder organizations are also involved in activities related to the SLRAOC.

Efforts to reverse the BUIs are located primarily within the 12,000-acre St. Louis River Estuary (SLRE), where water from the St. Louis River and Lake Superior mix. The twin port cities of Duluth, MN and Superior, WI are located on either side of the estuary.

A Stage I Remedial Action Plan (RAP) identified these nine BUIs (MPCA and WDNR, 1992):

1. Restrictions on Fish and Wildlife Consumption
2. Degradation of Fish and Wildlife Populations
3. Fish Tumors or Other Deformities; removed in 2017
4. Degradation of Benthos
5. Restrictions on Dredging Activities
6. Eutrophication or Undesirable Algae (SLRAOC name: Excessive Loading of Sediment and Nutrients)

7. Beach Closings (SLRAOC name: Beach Closing and Body Contact Restrictions)
8. Degradation of Aesthetics; removed in 2014
9. Loss of Fish and Wildlife Habitat

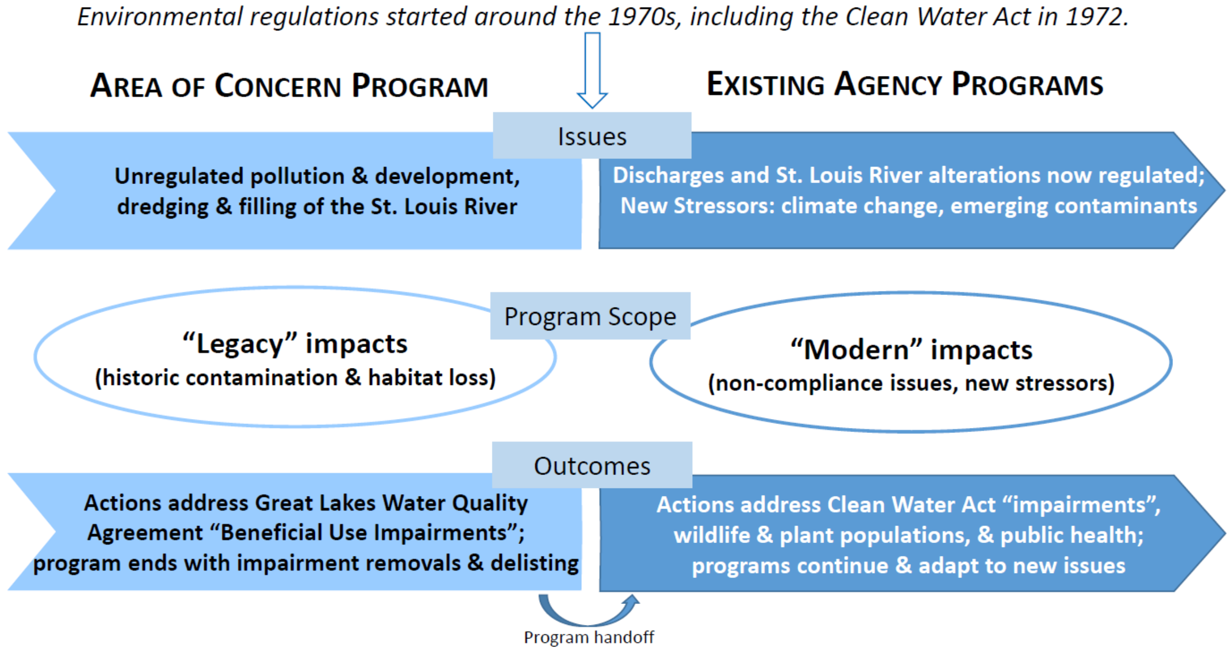
The Great Lakes Water Quality Agreement "Eutrophication or Undesirable Algae" BUI was modified to become the SLRAOC's "Excessive Loading of Sediment and Nutrients" BUI 6 for two reasons. First, with the end of wholesale logging and lumber milling and the improvement of wastewater treatment in the area, the St. Louis River was no longer characterized as eutrophic. Second, undesirable algal blooms were not an identified concern. However, the delivery of excessive loads of sediment and nutrients remained as an important local concern, so BUI 6 was established to ascertain the effects of the estuary's unique turbidity, algae, and nutrient conditions.

A Stage II RAP was completed in 1995 and it was later superseded by the 2013 St. Louis River Area of Concern Implementation Framework: Roadmap to Delisting (MPCA and WDNR, 1995 and 2013, respectively). The 2013 RAP was a comprehensive listing of the BUIs, their removal targets, and the management actions (MAs) needed to achieve those targets. The 2013 RAP has been updated annually thereafter to document progress and changes to the RAP implementation plan and schedule (MPCA and WDNR, 2014-2019).

It is important to understand that the voluntary AOC program was created to address "legacy" issues or environmental problems that caused ecosystem impairments at the time of the AOC designation and largely occurred before modern environmental regulations were in place. Legacy issues significantly impacted geographically-defined sites rather than regional-scale stressors.

For the SLRAOC, examples of legacy issues are unregulated discharge of industrial and municipal waste, dredging and filling in the estuary, wood waste deposited in the river, and extensive logging – all of which exacerbated erosion and sedimentation problems. Since then, the Clean Water Act (CWA) and other environmental regulations are being implemented to protect the environment and human health from these types of large-scale problems.

The scope of the AOC program does not include "modern" issues that are the responsibility of many state and federal agencies under a variety of natural resources, environmental, and public health program authorities. Some examples of modern issues are: contaminants of emerging concern, water-related climate change impacts, non-compliance of point source permits, and impairments identified and regulated under the CWA. Figure 2 depicts the differences between the AOC and existing agency programs.



The same environmental and natural resource agencies that implemented the Area of Concern Program will address ongoing issues after the Program has ended, but under different program authorities. This will include long-term monitoring and maintenance of remediation and habitat projects, species management, and regulatory enforcement.

Figure 2: The Program Scope of the St. Louis River Area of Concern

As it relates to the removal of the Excessive Loading of Sediment and Nutrients BUI discussed in this report, consider climate change effects as an example of the difference between legacy and modern impacts. The SLRAOC is experiencing more frequent and intense storm events and these are affecting the intensity of seiche impacts, which are, in turn, impacting sediment and nutrient conditions in western Lake Superior and the SLRE. These are modern impacts that fall under the purview of the CWA, not the SLRAOC program. The Future Actions section of this document lists a variety of future needs to be addressed by other agency programs.

BUI Information

Rationale for Listing

The SLRAOC's RAP describes the rationale for listing this BUI as follows:

> *Prior to the improvements in wastewater treatment in the late 1970s, water quality and biological investigations characterized the St. Louis River Estuary (SLRE) as low in dissolved oxygen and high in total phosphorus and total suspended solids. At that time, the Western Lake Superior Sanitary District (WLSSD) treatment plant was built and the Superior wastewater treatment plant was upgraded. Since then, many indicators of trophic status have shown improvements. For instance, concentrations of total phosphorus have decreased and dissolved nitrogen has shown variable*

decline in St. Louis Bay. The loading of phosphorus to the estuary from point sources has been reduced substantially. At the time of AOC listing, further work was needed to ascertain the effects of nonpoint source loadings to the system and to Lake Superior. Despite the reductions in point source loadings, phosphorus concentrations in the estuary remained at levels where eutrophic conditions might be expected. Algal biomass was lower than would be expected, however, given these high phosphorus concentrations. Chlorophyll a concentrations measured in the estuary were similar to levels found in mesotrophic or oligotrophic waters. Several investigators proposed that reduced light penetration caused by turbidity and color may be a limiting factor for algal growth in the estuary. Although persistent water quality problems associated with eutrophication were not observed in the estuary, the high levels of nutrients and sediments being delivered to Lake Superior were determined to be an important concern. Therefore, the RAP used a modification of the International Joint Commission eutrophication criterion to reflect local conditions.

The St. Louis River Watershed, which drains to the St. Louis River and the SLRE near Lake Superior, has experienced more than 150 years of urban and industrial development that has altered land use, water quality, and aquatic ecosystems. Prior to the passage of the CWA, discharges from industrial and municipal sources were unregulated. Inadequately treated wastewater discharges, disposal of sawmill and paper mill waste products into the river, and runoff of forest debris in the wake of landscape-scale logging all contributed to low oxygen levels that negatively impacted aquatic life across the food web. The barren, post-logging landscape also contributed excessive loading of sediments, resulting in increased turbidity and nutrient concentrations (e.g., phosphorus, nitrogen) in the river.

The CWA spawned both state and federal laws used to control point source discharges. Because municipalities and industries can no longer discharge directly to the river without treatment to meet effluent standards, improved wastewater treatment and manufacturing processes have helped restore the water quality in the SLRE.

Removal Target

With the involvement of stakeholders, a removal target for the Excessive Loading of Sediments and Nutrients BUI was established (MPCA and WDNR 2011), stating that the removal target will be reached when:

Nutrient and sediment levels have not been shown to impair water quality and habitat, and do not restrict recreation, including fishing, boating, or body contact in the estuary and within western Lake Superior based on the following criteria:

1. *All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorous), organic matter, and sediment; and*
2. *Total phosphorus concentrations in the Lake Superior portion of the AOC do not exceed 0.010 mg/L (upper limit of oligotrophic range); and*
3. *There are no exceedances of the most protective water quality standard for either state in the western basin of Lake Superior due to excessive inputs of organic matter*

or algal growth attributed to loadings from wastewater overflows into the St. Louis River; and,

4. *Total phosphorus concentrations within the St. Louis River portion of AOC do not exceed an interim guide of 0.030 mg/L (upper limit of mesotrophic range) or the most restrictive water quality standards. This ensures that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive productivity and nuisance conditions within the St. Louis River Estuary.*

The interim guides used for the removal criteria are estimations based on existing standards. Although the St. Louis River holds some features in common with other rivers and flow-through lakes, this ecosystem is unique because of the implications of residence time, mixing, and biogeochemistry resulting from landward forcing of lake water (i.e., the result of seiche or storm surge) that mixes the lake and tributary waters. The Interim Status Indicators selected (see Table 1) are part of the BUI 6 Blueprint, (MPCA and WDNR, 2013, Appendix D).

Table 1: Water Quality Interim Status Indicators from the BUI 6 Blueprint Document

Indicator	Target	Location	Source
Water column TSS	15 mg/L	St. Louis River portion of AOC	Draft MN criteria for north river region (MPCA, May 2011)
	10 mg/L	Lake Superior portion of AOC	Draft MN criteria for class 2A waters (MPCA, May 2011)
Water column TP	30 µg/L (1)	St. Louis River portion of AOC	Final Delisting Target: Note the discrepancy between current MN and WI TP criteria that might also be used for the SLR AOC - MN draft TP criterion for the north river region is 55 µg/L (MPCA, 2011); WI TP criterion for St. Louis River is 100 µg/L (WDNR, November 2010; N.R. 102.06(3)(a))
	10 µg/L (2)	Lake Superior portion of AOC	Final Delisting Target: Note WI, but not MN, has a TP criteria that should be considered of 5 µg/L (WI TP standard for Lake Superior of 5 µg/L includes open and nearshore waters- WDNR, November 2010; N.R. 102.06(5))
Chlorophyll *a*	10 µg/L	St. Louis River portion of AOC	Draft MN criteria for north river region (MPCA, November 2010)
	1.3 µg/L	Lake Superior portion of AOC	Number derived from Annex 4 of the Great Lakes Water Quality Agreement target TP loading of 3400 metric tons per year (IJC 1983); corresponding TP is 5 µg/L.
	3 µg/L	MN Class 2A	7050.0222 Specific Water Quality Stds for Class 2; Aquatic Life and Recreation
Dissolved Oxygen	7 mg/L	MN Class 2A	Daily minimum and compliance with the standard 50% of the days at which the flow of receiving water is equal to the $7Q_{10}$
Un-ionized Ammonia (NH_3)			Criteria are many and varied, depending on agency and methodology. Therefore, it is not appropriate at this time to list existing Wisconsin and Minnesota standards as an interim status indicator without further review and historical data analysis.

In addition, the following measurable indicators are applicable to discharge permits and wastewater overflows.

Indicator	Measurement Basis	Target
Federal, state, and local permitted dischargers, including MS4s in the AOC	Determined through review by WDNR and MPCA	All permittees in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorus), organic matter, and sediment
Municipal wastewater collection systems and WWTP permittees within the AOC	Determined through review by WDNR and MPCA	All permittees in compliance with permit conditions with regard to controlling sewage overflows

The SLRAOC RAP interprets this to mean that the removal of the Excessive Loading of Sediment and Nutrients BUI will be justified when:

1. *All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorus), organic matter, and sediment.*
2. *Assessment of current water quality data for the Lake Superior and the SLRE portions of the SLRAOC indicate that water quality meets the water quality goals established by the strategy described below.*
3. *Watershed management objectives for the Nemadji River watershed that are in the Nemadji Basin Plan (NRCS, 1998) are adopted and progress towards implementing the objectives is being made.*

The RAP goes on to explain that:

Total phosphorus data alone will not provide the level of confidence needed to show that nutrient and sediment concentrations do not impair water quality and habitat and do not restrict recreation, including fishing, boating, or body contact in the estuary. Therefore, to protect and restore the condition of the SLRAOC related to the listing of this BUI, a thorough review of historical data and a statistical analysis of the current water quality condition based on the recommended seven status indicators listed below are necessary. These analyses will allow the BUI Technical Team to assess the trends and current condition of the SLRE in relation to BUI removal. The seven status indicators include:

- *Chemical – total phosphorus, un-ionized ammonia, dissolved oxygen*
- *Biological – chlorophyll a*
- *Physical – total suspended solids (TSS) and turbidity or other loading metric based on tons of sediment*
- *Watershed – progress toward meeting management objectives to reduce runoff rates and sediment delivery in the Nemadji River watershed*

The RAP further acknowledges that:

This work is not intended to set or replace State water quality standards, but to develop BUI removal objectives agreeable to both States and FdL that are consistent with the intent of the BUI removal target. The BUI removal objective water quality goals are to: protect the riverine and estuarine portions of the AOC from a eutrophic classification, to protect the Lake Superior portion of the AOC from a mesotrophic *classification, and to achieve desired levels of sediment and nutrient loading to Lake Superior. SLRAOC managers and the BUI Technical Team decided that additional water quality goals were not necessary for BUI removal. Sufficient information is available to justify BUI removal using the parameters in the BUI removal target.*

Removal Strategy

Five management actions were established in the RAP to support the removal of the Excessive Loading of Sediments and Nutrients BUI and all have been completed (see Table 2).

Table 2: Completed Management Actions for BUI 6

Mgmt. Action	Name	Description
6.01	*Perform Area-Wide Water Quality Sampling and Analyses*	*Identify data needs, develop sampling design based on Bellinger et al. (2012) and evaluate results.*
6.02	*Perform Expanded Historical Data Analysis*	*Conduct a thorough review of current and historical data and a statistical analysis of the six water quality indicators (total phosphorus, un-ionized ammonia, dissolved oxygen, chlorophyll a, TSS and turbidity) and evaluate long-term trends in water quality.*
6.03	*Paleolimnological Investigation*	*Perform a paleolimnological investigation of the St. Louis River Estuary to reconstruct the algal and geochemical history and develop models to characterize trends in natural and anthropogenic drivers in water quality.*
6.04	*Develop Water Quality Goals (Compilation of 6.01, 6.02, and 6.03)*	*Assess results of 6.01, 6.02, and 6.03 and determine appropriate water quality goals for the reference condition of biological, chemical and physical indicators of water quality.*
6.05	*Assessment and Implementation Planning in the Nemadji River Basin*	*Assess sediment impairments through biological, water quality, and sediment monitoring, and HSPF modelling of historic sediment loads. Support implementation of the Nemadji Basin project recommendations to reduce sedimentation through stakeholder and landowner planning efforts.*

The strategy outlined in the RAP for each of the management actions is described below.

Strategy for MA 6.01– Perform Area-Wide Water Quality Sampling and Analyses

Perform area-wide water quality analyses in the SLRE based on the 2012 monitoring protocols in Bellinger et al. The objective of this project is to work with SLRAOC program staff and other groups responsible for monitoring and assessing conditions in the SLRE to identify data needs, develop a sampling design to meet those needs, and evaluate the relevancy of the results. Analysis of the water quality indicators will be used to estimate conditions within geographic zones and/or estuary-wide. Results will be used to report whether the SLRE is trending toward or has reached the reference condition or range of conditions considered reasonable for the estuary. Understanding changes in *water quality and associated biological conditions that meet BUI removal objectives is the focus of this work and it will include the six chemical water quality status indicators to:*

a. *Provide a summary of the six chemical water quality indicators for a period of two to three years and*
b. *Assess and verify the relevance of all six status chemical indicators within the SLRE or by geographic zone, if necessary, to determine if the estuary is impaired for these parameters based on agreed-upon reference conditions and accounting for any unique conditions.*

Strategy for MA 6.02 – Perform Expanded Historical Data Analysis

Perform an expanded historical data set analysis based on methodologies used in Hoffman (2011) to evaluate long-term trends in water quality as it relates to the six chemical status indicators. Determine the appropriate water quality goals for the reference condition of any or all of the status indicators appropriate for the SLRE and western portion of Lake Superior that will meet approval by Minnesota and Wisconsin as appropriate for the SLRAOC.

Strategy for MA 6.03 – Paleolimnological Investigation

Perform a paleolimnological investigation of the SLRE to reconstruct the algal and geochemical history for approximately the last 300 years (management action 6.03). Diatom-based (i.e., microfossil algae) models will be applied to identify historical temporal and spatial variations in biological (i.e., chlorophyll, algal load), chemical (i.e., phosphorus, ammonia) and physical (i.e., TSS, turbidity) water quality indicators. Combined with the results of the monitoring data and trend analyses described in the strategies for 6.01 and 6.02, the paleolimnological data will provide quantitative and qualitative reconstructions of the important physical, chemical and biological trends that have resulted from natural and anthropogenic drivers.

Strategy for MA 6.04 – Develop Water Quality Goals (Compilation of 6.01, 6.02, and 6.03)

Determine the appropriate water quality goals for the reference condition of any or all of the status indicators appropriate for the SLRE and western portion of Lake Superior that will meet approval by Minnesota and Wisconsin as appropriate for the SLRAOC.

Strategy for MA 6.05 – Assessment & Implementation Planning in the Nemadji River Basin

Document progress toward meeting watershed management objectives from the Nemadji Basin Plan (NRCS, 1998) as an indicator of sediment loading to the SLRAOC. The Nemadji plan established watershed objectives to reduce runoff rates and sediment delivery from the Nemadji River watershed into SLRAOC.

Once the work for the five management actions is complete, the RAP directs an assessment of the status of the SLRE in relation to BUI removal:

1. *For the water quality indicators:*
    a. *If the assessments show the current conditions are sustained and the water quality has improved to where it meets the water quality goals, then removal targets are met.*
    b. *If the assessments show the current conditions are not sustained and water quality is not meeting the water quality goals, then removal targets are not met. Determine possible sources and develop an action plan to address the source(s). Then, re-evaluate annually until it can be shown that water quality meets applicable water quality goals for two consecutive years.*

2. *For the watershed indicator:*
    a. *If watershed management objectives for the Nemadji watershed are met or progress over time to meet the objectives can be demonstrated, this information will help support removal of the sediment loading aspect of this BUI.*

It is important to note that the assessments associated with each MA are time limited. Once a MA is completed, there is not an effort to return to the endpoint of the studies to add data gathered by other agency programs since the conclusion of the study. Similarly, some implementation activities pertinent to BUI 6 are already underway by other agency program that are outside the SLRAOC program. More recent data and activities are not reported here. Additionally, regulatory programs are ever-evolving and terminology in place at the time BUI 6 studies were completed have not been substituted by newer terminology (e.g., turbidity impairments under the CWA are now TSS impairments).

Management Actions Methods, Findings, and Conclusions

6.01 Area-Wide Water Quality Sampling and Analyses

Historical and current water quality conditions for a variety of parameters were evaluated to compare concentration estimates with BUI removal criteria established by SLRAOC stakeholders. Current water quality condition was assessed both seasonally and spatially using data collected in 2012 and 2013 (MA 6.01). For the historical component, 60 years of water quality data (1953 – 2013) from two fixed stations was used to determine how nutrient and sediment concentrations and loads changed in the SLRE (MA 6.02). These MA's were combined into one scientific paper*, Water quality in the St. Louis River Area of Concern, Lake Superior: Historical and current conditions and delisting implications* (see Appendix 1). This work was completed by the U.S. Environmental Protection Agency – Great Lakes Toxicology and Ecology Division (EPA-GLTED) under the direction of Dr. Joel Hoffman and Dr. Brent Bellinger (Bellinger, et al., 2016) and has been summarized below (see Appendix 1 for the scientific paper).

6.01 Methods

Long-term water quality trends in the SLRE were assessed at both the Highway 23 Bridge (i.e., upper estuary) from 1953 to 2013 and the Interstate 535/US Highway 53 John A. Blatnik Bridge (i.e., lower estuary) from 1973 to 2013 (see Figure 3). Data were available for dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), dissolved nitrate/nitrite-N, ammonium/ammonia-N, and TSS. Chlorophyll α (chl α) was not available as a historical measurement. This summary focused on trends in both concentration and loadings for TSS and TP, in particular, as well as trends in DO concentration. For TSS and TP, a conservative mixing model was used to estimate the concentration in the river, absent a lake effect. The study was intended to better understand how water quality has changed from the industrial era to the present day and whether the levels today meet BUI removal objectives.

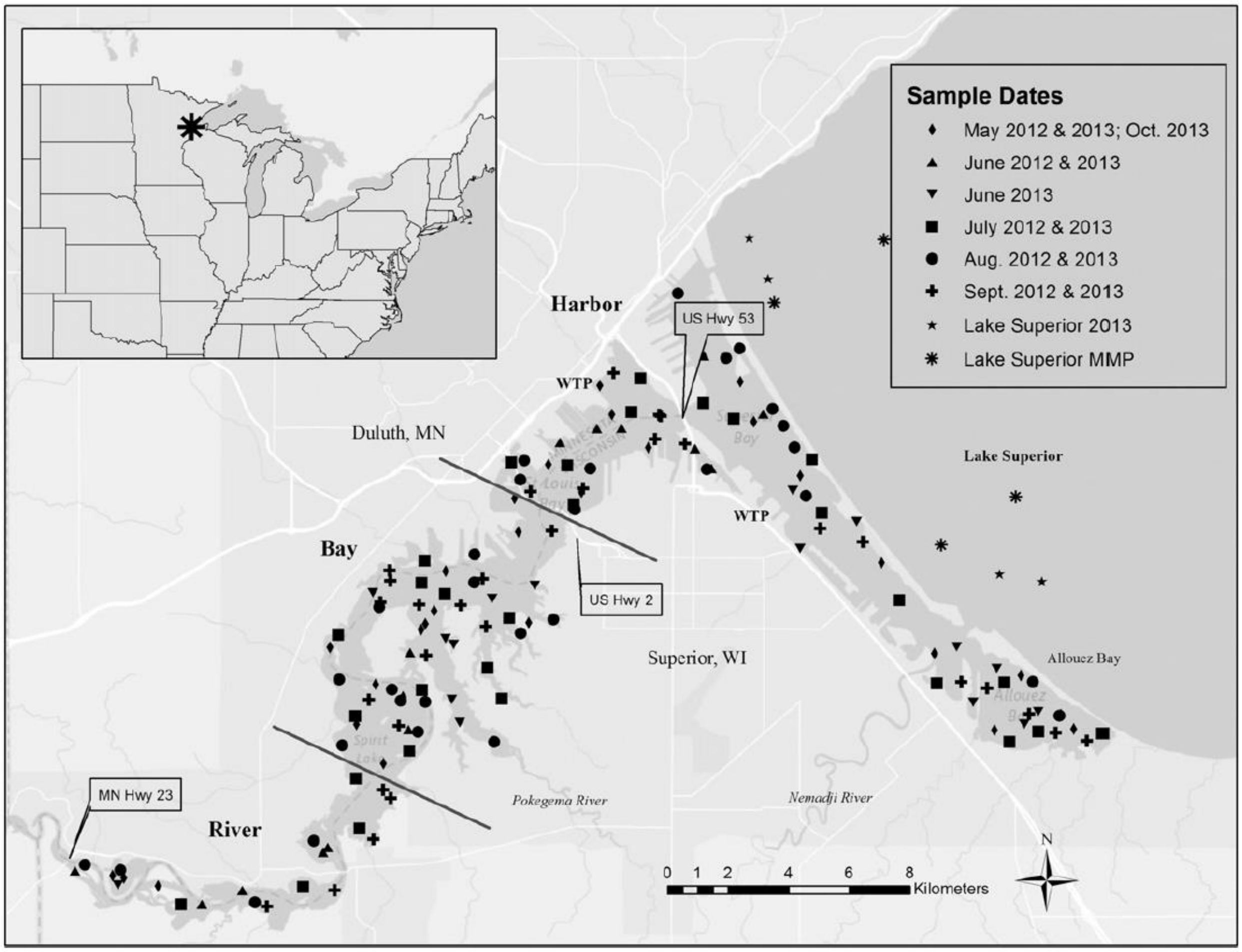


Figure 3 Sampling Locations for Management Action 6.01

Current water quality conditions for the estuary were assessed from 2012-2013 for TP, TSS, DO, and chl α to estimate the proportion of the estuary's surface area below the BUI removal criteria concentrations. A random, spatially balanced sampling design was developed to provide unbiased, area-weighted water quality concentration estimates for DO, TP, and TSS across the SLRAOC (see Figure 3). The design was then used to determine the areal extent of the SLRAOC that either met or was in exceedance of a specific water quality criteria. The sampling event locations were identified and subsequently assigned to three zones with distinct hydrologic and geochemical character: River (i.e., upper estuary), Bay (i.e., central estuary or St. Louis Bay, and the Harbor (i.e., lower estuary or Superior Bay).

6.01 Findings – Historic Water Quality Trends (1953-2013)

Sediment and nutrient loads, as represented by TSS and TP, respectively, declined between 1953 and 2013. See Figure 4, where:

- panels A and C: temporal trends in monthly TP and TSS concentrations
- panels B and D: annual TP and TSS loads
- monitoring stations: upper estuary (closed circles) and lower estuary (open circles)
- dashed lines = BUI removal criteria of 0.030 mg/L TP and 15 mg/L TSS.

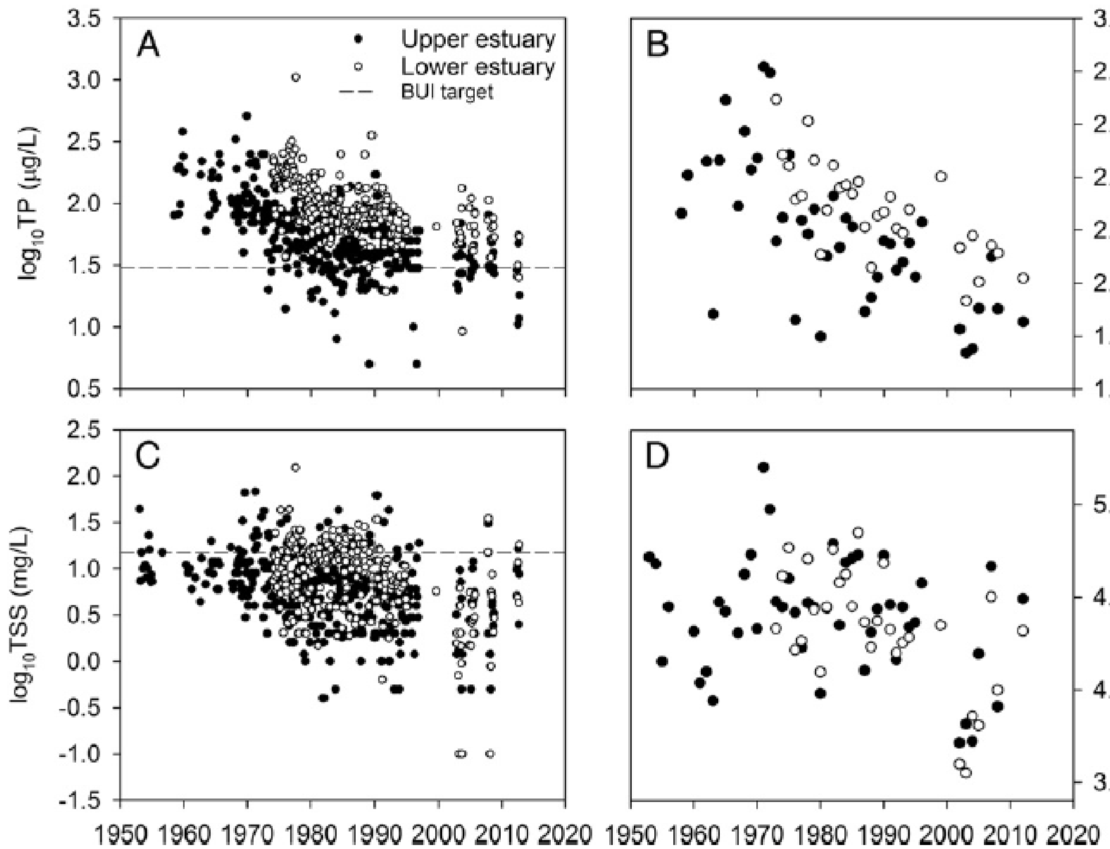


Figure 4: Total Phosphorus and Total Suspended Solids Results from Management Action 6.02

Annual mean TP concentrations and loads to Lake Superior declined significantly over time; the change in concentration was faster at the lower estuary station than the upper estuary station. Since 2000, TP concentrations at the upper estuary stations have generally ranged between 20 and 50 µg/L [0.020 and 0.050 mg/L]. Though concentrations have declined, monthly and annual average TP concentrations frequently exceeded the BUI removal criterion of 30 µg/L [0.030 mg/L] over the period of record; however, the majority of concentrations greater than the criterion precede 1990. The ratio between the mean annual load and river discharge (known as the mean mass per unit discharge), revealed a decline over time, indicating that the decline in TP load was the result of changes in TP concentration rather than discharge. The decline in TP concentration can be attributed to a combination of factors, including reduced TP inputs to the system, improved retention of TP within the watershed, and reduced resuspension of legacy organic matter inputs. Through time, TP concentrations in the lower estuary were higher than in the upper estuary, implying there were internal TP sources (e.g., resuspension of sediment) or tributary additions. From 2002 to 2012, the estimated mean annual TP load was 76 tons at the upper estuary station and 133 tons at the lower estuary station, for an average annual net addition of 57 tons.

Annual mean TSS concentrations significantly declined over time at both stations; as with TP concentrations, the decline was faster at the lower estuary station than the upper estuary station.

Average annual TSS concentrations were above the interim status indicator of 15 mg/L (see Table 1) three times prior to 1978. After 2000, relatively low TSS concentrations (≤5 mg/L) were measured at both stations except for two instances (2007, 2012) in which elevated TSS concentrations (31.0 and 16.3 mg/L, respectively) coincided with large discharge events (354 and 120 m^3/s, respectively).

Annual TSS loads to the SLRE declined over time at both stations, until the 2012 flood. TSS loads to Lake Superior also declined faster at the lower estuary station than the upper estuary station. Notably, at the beginning of the time-series, the estuary between stations was a source of TSS, compared to its current neutral status or that of a TSS sink, which suggested a substantial shift in TSS dynamics within the estuary. As with TP loads, the ratio of the mean annual load and discharge (i.e., the volume-weighted mean TSS) declined over time, indicating that the change in TSS load was due to change in TSS concentration rather than discharge.

A long-standing concern for water quality in the SLRAOC has been low DO (see Appendix 1). Historically, this was strongly influenced by the discharge or dumping of materials with high biological oxygen demand, such as wood waste and sewage. At both monitoring stations, the last recording of summer hypoxia (<2 mg/L DO) was 1964; DO values <5 mg/L were infrequent after 1975. The DO standard (as a daily minimum) in Minnesota and Wisconsin is 5 mg/L for class 2B (warmwater) streams. The period for which hypoxia was present somewhere in the river was likely longer than the time series suggest because the available longitudinal DO concentration data indicated that the lowest DO concentrations in the river were typically located between the upper and lower estuary stations (i.e., between river km 20 and 35). Nevertheless, low DO concentrations have not been observed in the thalweg (i.e., the deepest part of the river channel) since the mid-1970s. At the upper estuary station, late-summer (July–September) DO concentrations increased from 1953 to ca. 1990, after which the concentrations leveled-off and possibly declined slightly (generally, between 7 and 9 mg/L). Data from the lower estuary followed a similar pattern. Since 2000, monthly summer concentrations were always above 5.5 mg/L at both stations.

6.01 Findings – Current Water Quality Conditions (2012-2013)

In both 2012 and 2013, about 60% of SLRE area between Fond du Lac dam and Lake Superior was below the BUI removal criterion for TP of 30 µg/L [0.030 mg/L]; thus, 40% of SLRE area exceeded the TP removal criterion. The spatial distribution of TP is shown in Figure 5 for 2012 and in Figure 6 for 2013. The highest TP exceedances were seen in “hotspots” that had unique characteristics compared to normal SLRE conditions (i.e., primarily near wastewater treatment facility outfalls or in clay-influenced bays). System-wide TP concentrations ranged from 4.7 µg/L [0.0047 mg/L] to 195.4 µg/L [0.1954 mg/L] with a median concentration across years of 28.7 µg/L [0.0287 mg/L]. The weighted mean TP concentration for 2012 (30.9 µg/L [0.0309 mg/L]) and 2013 (30.7 µg/L [0.0307 mg/L]) were not significantly different from the BUI criterion (30 µg/L [0.030 mg/L]). The TP hotspots identified in the Wisconsin clay-influenced bays justified the study included as part of MA 6.04.

The WLSSD hotspot was likely an anomaly, potentially associated with sanitary sewer overflows during the 2012 flood. This conclusion is supported by WLSSD’s publically available records, indicating a later change to load-based TP limits, its permit compliance record, and its operational excellence awards.

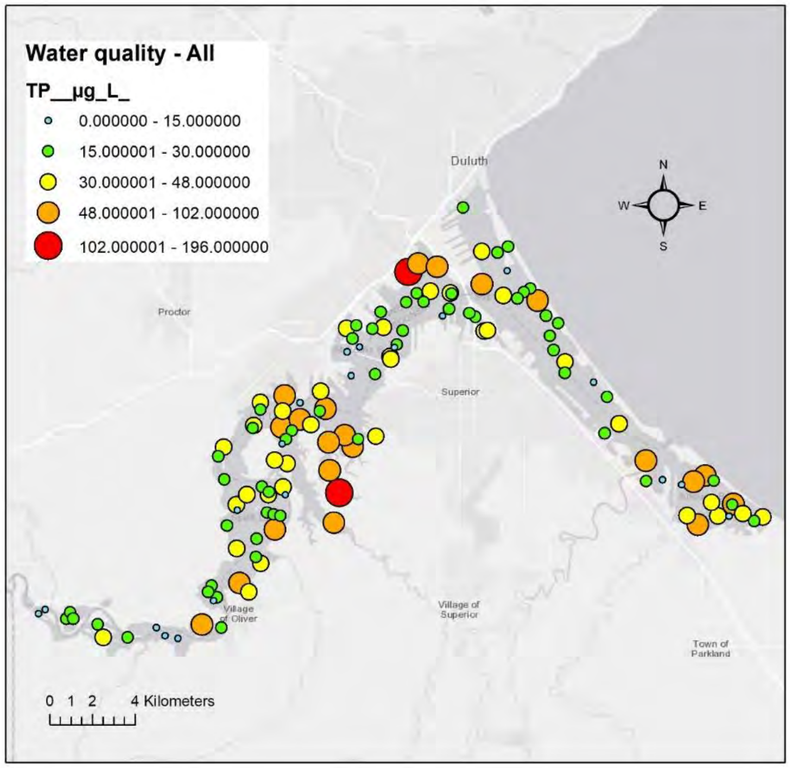


Figure 5: 2012 Total Phosphorus Results from Management Action 6.01

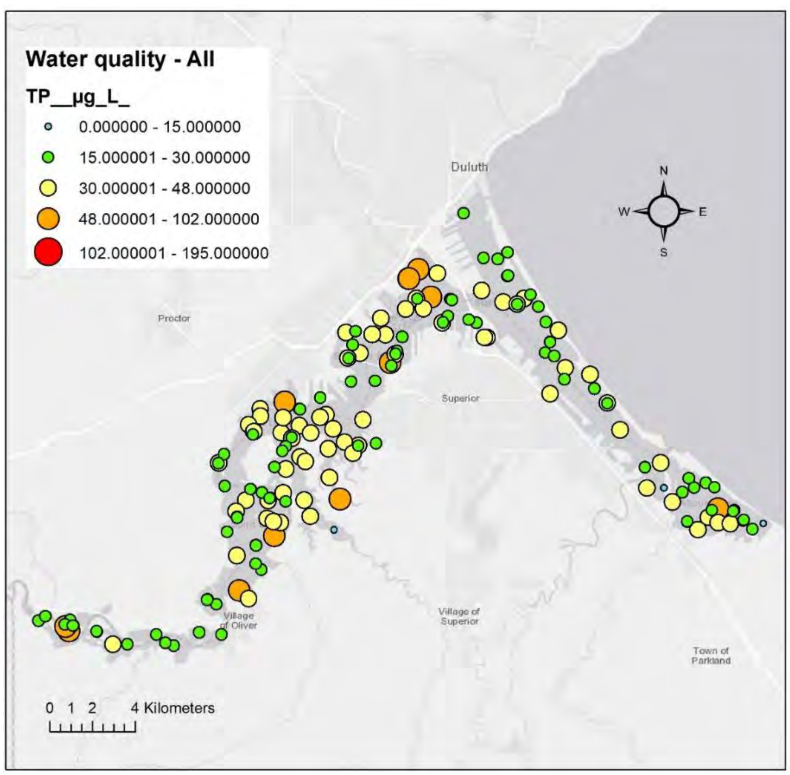


Figure 6: 2013 Total Phosphorus Results from Management Action 6.01

At least 85% of the area of the SLRE between Fond du Lac dam and Lake Superior had TSS concentrations below the 15 mg/L interim status indicator in both years. TSS concentrations varied from 2.3 mg/L to 71.4 mg/L, with a median concentration of 8.6 mg/L. The weighted mean TSS concentrations for 2012 (12.0 mg/L) and 2013 (9.9 mg/L) were significantly below the BUI criterion of 15 mg/L.

Chlorophyll α concentration data were not available in the time-series monitoring to assess trophic status. For both years, over 70% of the area of the SLRE between Fond du Lac dam and Lake Superior had chl α concentrations below the interim status indicator of 10 µg/L [0.010 mg/L], as listed in Table 1. Chlorophyll α concentrations ranged from 0.6 µg/L [0.0006 mg/L] (October 2013) to 49.9 µg/L [0.0499 mg/L] (September 2012). The weighted mean chl α concentrations in 2012 and in 2013 were significantly below the BUI criterion.

For the Lake Superior portion of the SLRAOC, TP concentrations were greatest in June and averaged 12.7 µg/L [0.0127 mg/L]. Average TSS concentration was 4.4 mg/L, ranging from 0.4 to 15.1 mg/L. Dissolved oxygen was always at or near 100% saturation; concentration for the season averaged 12.2 mg/L. Chlorophyll α concentration was greatest in June (4.5 mg/L) and averaged 2.7 mg/L.

It should be noted that the Lake Superior sampling locations for this study were just outside of the estuary and were influenced by river water mixing with the lake, which likely contributed to higher results than would have been seen in the open water areas of Lake Superior (Figure 3). Additional data from the USEPA's Great Lakes Biology Monitoring Program and the paleolimnology study (MA 6.03) were used as additional lines of evidence to justify that Lake Superior BUI removal criteria have been met.

6.01 Conclusions – Area-Wide Water Quality Sampling and Analyses

Since the 1950s, there has been a dramatic decline in TP concentrations in the SLRAOC, with concentrations generally ranging from 80-380 µg/L [0.080 – 0.380 mg/L] in the 1950s to 20-50 µg/L [0.020 – 0.050 mg/L] in the 2000s. In 2012 and 2013, about 60% of SLRE area between Fond du Lac dam and Lake Superior was below the BUI removal criterion of 30 µg/L [0.030 mg/L]. Similarly, there has been a dramatic decline in TSS, with concentrations generally ranging from 7-20 mg/L in the 1950s to 1-10 mg/L in the 2000s. At least 85% of the area of the SLRE between Fond du Lac dam and Lake Superior had TSS concentrations below 15 mg/L, the interim status indicator, in 2012 and 2013. Along with these changes, DO concentrations improved and no indications of hypoxia (<2 mg/L) have been observed in the SLRE thalweg since 1964. The current chl α concentrations observed in the SLRE are generally indicative of an oligotrophic to mesotrophic waterbody, ranging from <1 µg/L [0.001 mg/L] to nearly 50 µg/L [0.050 mg/L]. In 2012 and 2013, over 70% of the area of the SLRE between Fond du Lac dam and Lake Superior had chl α concentrations below the interim status indicator of 10 µg/L [0.010 mg/L].

In the Lake Superior portion of the SLRAOC, the DO was generally near 100% saturation and the chl α concentrations were consistent with an oligotrophic water body. Total phosphorus values measured near the estuary entry points (average of 12.7 µg/L [0.0127 mg/L]) were generally higher than typical values measured in offshore waters in the western arm of Lake Superior (generally <5 µg/L [<0.005 mg/L]). Nearshore environments of Lake Superior are expected to be more productive (and closer to the upper limits of the oligotrophic range) than offshore waters, due to riverine and other nearshore inputs. Most of the SLRE area and Lake Superior were below the status indicators for each parameter (See Table 3).

Table 3: Summary of Water Quality Results for Management Action 6.04

Parameter	SLRE, from Fond du Lac dam to Lake Superior (Bellinger, et al., 2016)	Lake Superior[1] (Bellinger, et al., 2016)	Western Lake Superior[2] (USEPA,'Great Lakes Biology Monitoring Program, 1996-2015)
TP	~60% of area below 30 µg/L [0.030 mg/L]	Average = 12.7 µg/L [0.0127 mg/L]	Average = 2.6 µg/L [0.0026 mg/L]
TSS	>85% of area below 15 mg/L	Average = 4.4 mg/L [0.0044 mg/L]	not assessed
DO	>5.5 mg/L; no hypoxia	Average = 12.2 mg/L	not assessed
chl α	>70% of area below 10 µg/L [0.010 mg/L]; oligotrophic to mesotrophic	Average = 2.7 µg/L [0.027 mg/L]; oligotrophic	not assessed

[1] The interim TP guide for Lake Superior is 0.010 mg/L. Data from this assessment were collected in nearshore conditions, which were likely biased toward SLRE conditions due to seiche mixing.
[2] The USEPA's Great Lakes Biology Monitoring Program sampling point (SU 19) is not located within the boundary of the SLRAOC.

6.02 Perform Expanded Historical Data Analysis

Management Action 6.02 was to conduct a thorough review of current and historical data and conduct a statistical analysis of the six water quality indicators (TP, un-ionized ammonia, DO, chl α, TSS and turbidity) and evaluate long-term trends in water quality. To establish long term trends in the portion of the SLRE below the Fond du Lac dam, staff from USEPA-GLTED analyzed data sets from four stations in the lower St. Louis River that were monitored by the MPCA from the early 1950's (for some sites) until 2008 when their Milestone Monitoring Program was discontinued. The collected data were provided by MPCA to USEPA-GLTED and subsequently included in the public STORET database. The milestone stations utilized were the MN Hwy 23 Bridge, the Oliver Bridge, the former Arrowhead Bridge/U.S. Hwy 2 Bong Bridge, and the U.S. Hwy 53 Blatnik Bridge. The length of time for the data series at each location varied.

Dissolved inorganic nitrogen, TP, and TSS data were available from October 1974 and May 1975 from the four locations. Historic data were not available for chl α, soluble reactive phosphorus, or TN for these stations. To characterize current conditions, data collected by USEPA-GLTED researchers were analyzed. Data from April-September 2002-2007 at numerous locations were available, though only one station was sampled regularly within the same year.

Data analyzed for MA 6.02 was merged with the 1953-2013 data evaluated as part of the 6.01 Area-Wide Water Quality Sampling and Analyses effort and published in Bellinger, et al., 2016 (see Appendix 1). Findings and conclusions for the merged data sets were described in MA 6.01, above.

6.03 Paleolimnological Investigation

6.03 Methods and Findings

The historical magnitude and extent of sediment and nutrient impacts had not been well understood for the years preceding water quality improvements due to environmental regulations and systematic long-term monitoring of water quality (pre- 1953-1973, depending on location). Therefore, a paleolimnology study of the SLRE was initiated to close the knowledge gap. To help understand this history, seven cores were taken from SLRE sites believed to have undisturbed sediments and continuous depositional environments (see the red dots on Figure 7). These cores provided good representation of the conditions present in the SLRE; they represent western Lake Superior, the St. Louis River thalweg, and the nearshore portions of the SLRE.

Figure 7: Paleolimnological Core Locations for Management Action 6.03

The cores were evaluated for retrospective analyses by staff from the Natural Resources Research Institute, of the University of Minnesota-Duluth. The primary goal, especially related to the excessive loading of sediment and nutrients BUI, was to determine pre-industrial water quality conditions and to track, through time, the anthropogenic impacts and the extent of loading reductions. In order to do this, sediments in the core samples were dated using isotopic analyses and fossil remains (i.e., diatoms, pigments, pollen, and phytoliths) were identified in concordance with other stratigraphic indicators (i.e., organic and inorganic materials, contaminants, and sedimentation rates) to reconstruct the history of the system from 1850 to the present. That work (Reavie, et al., 2016; Alexson et al. 2018) was summarized here and contained in Appendix 2.

Diatoms in relation to water quality

Diatom assemblages were assessed from sediment intervals and these assemblages were used to infer trophic conditions using a regional diatom-based model for Great Lakes coastlines. Interpretations were based on diatom-based models that contained known species responses to water quality, which were applied to fossil assemblages. The diatom records indicated varying ecological histories and trajectories depending on the location within the SLRE. Deeper core locations (e.g., near the federal navigation channel, Lake Superior) indicated water quality improvement from past periods of higher total phosphorus concentrations and algal productivity, and that current, prevailing concentrations of phosphorus, based on inferred total phosphorus concentrations from core samples, did not exceed the SLRAOC BUI removal phosphorus criterion of 0.030 mg/L. However, the near-coastal (e.g., North Bay, Pokegama Bay, Allouez Bay) reconstructions revealed a recent increase in inferred phosphorus. At these locations, the inferred phosphorus levels based on the diatom species model would have been in exceedance of the BUI removal criterion. It is noteworthy that the earliest dated concentrations (~1850) were also inferred to be above the criterion, reflecting the productivity of these systems at that time.

It should be noted that a later study (Alexson, et al., 2018) determined that there is possible uncertainty in the inferred total phosphorus concentration or diatom-inferred TP data. That study showed a close, but not exact, relationship in the TP and diatom-inferred TP concentration trends. Additionally, the diatom-inferred TP concentrations in that study were found to be lower than those observed by Bellinger, et al., 2016 at the most comparable sampling location, but also provided possible reasons for those differences.

One core was taken in Lake Superior within the AOC boundary. The inferred total phosphorus concentrations from the Lake Superior core showed concentrations of TP that ranged from 3 - 6 µg/L [0.003 to 0.006 mg/L]; these were less than the Lake Superior BUI criterion of 0.010 mg/L.

Geochemistry in relation to water quality and nutrient loading

Algal pigment concentrations in the sediment profiles concurred with diatom-based inferences. Main channel cores did not indicate recent increases in algal abundance, however the increasing presence of cyanobacterial pigments in two bays (North Bay, Billings Park) indicated increases in potentially undesirable algae; an indicator of increasing nutrients in those locations.

Historical sediment accumulation rates (organic and inorganic) indicated that recent sediment loads to the estuary remained higher than loads estimated around 1850. However, three sites (Lake Superior, Allouez Bay and Billings Park) exhibited reduced sediment loads since the peak period of development in the mid-20th century. This finding aligned with the results of other sediment load studies in the Nemadji River watershed.

In addition to water quality information, cores were analyzed for heavy metals and organic contaminants indicative of human activity and industrialization. This work was intended to better understand general trends and to see if the science behind the analysis could provide a line of evidence that supports overall water quality improvement through time. Mercury was included as a marker of human activities such as mining, burning of fossil fuels, and untreated sewage disposal. Sediment mercury concentrations peaked in the mid-1900s, but more recently declined to near pre-impact concentrations, indicating recent decreases in some combination of direct atmospheric deposition, watershed runoff, and point source domestic and industrial discharges. There were distinct mid-1900s peaks in cadmium, zinc, lead, tin, antimony and magnesium, likely resulting from watershed disruptions that exposed materials to erosion and runoff and/or industrial discharges. With improved regulation of these activities, a concurrent reduction in metals was seen. Sedimentary organic contaminants analyzed from the single core from the harbor had concentrations below the detection levels.

6.03 Conclusions – Paleolimnological Investigation

Overall, paleolimnological results from Lake Superior and the main stem of the St. Louis River indicated improvements in nutrient loads or a discontinuation in the enrichment trends that were observed through the 1970s. Since the onset of environmental regulations, there have been clear improvements in TP concentrations in the water column, as inferred from paleo-diatom analyses from three mid-channel cores and one core from western Lake Superior, largely due to wastewater treatment and stormwater management improvements that have occurred in the SLRAOC over the past ~40 years.

Increasing nutrient loads were seen in the three nearshore/bay cores. However, in terms of nearshore phosphorus, the study generated evidence that pre-industrial impact concentrations of phosphorus likely exceeded the BUI removal criterion of 30 mg/L for TP by approximately 10 – 15 µg/L [0.010-0.015 mg/L] for TP. Also, nearshore changes in water quality may have been the result of phenomena outside the rationale for listing this BUI, such as climate change, increasing precipitation, phosphorus recycling, and perhaps other indirect mechanisms. A more detailed paleolimnology investigation, including speciation of phosphorus and development of nutrient (i.e., carbon, nitrogen, and phosphorus) budgets for the system would be needed to determine the factors influencing the nearshore areas.

These data indicated that BUI removal objectives were being met in over fifty percent of the SLRE. The clay-influenced Wisconsin bays were an area where the removal objectives were not being met and was another reason why the clay-influenced bays study was added as a BUI 6 activity (see Section 6.04). It is noteworthy that the earliest dated estuary phosphorus concentrations (~1850) were inferred to be above the BUI criterion, reflecting the productivity of these systems before industrial influence and putting the BUI removal criteria into context with the natural productivity of the nearshore areas.

The inferred phosphorus concentrations from the Lake Superior core did not exceed the removal criteria for TP in water of 0.010 mg/L.

The overall improvement seen is one line of evidence to support BUI 6 removal, given the rationale for listing.

6.04 Develop Water Quality Goals (Compilation of 6.01, 6.02, and 6.03)

The purpose of MA 6.04 was to assess the findings of MAs 6.01, 6.02, and 6.03 and determine appropriate water quality goals for the reference condition of biological, chemical, and physical indicators of water quality in the SLRAOC and to use the MA findings to determine if the SLRAOC met these goals. Since the numeric BUI criteria were recommended based on interim values, the BUI Technical Team was tasked with evaluating those criteria. After reviewing results of four assessments performed under AOC management actions, the BUI Technical Team agreed that the indicators included in the BUI removal target were an appropriate goal to justify BUI removal and additional water quality goals were not needed for BUI removal evaluation. The upper limit of mesotrophic range (0.030 mg/L) was identified as being appropriate for riverine and estuarine portions, while the upper limit of oligotrophic range (0.010 mg/L) was deemed appropriate for the Lake Superior portion of the SLRAOC.

Although these three MAs showed that sediment and nutrient conditions were improving in the SLRE, the improvements were not uniformly distributed throughout the SLRE. In particular, clay-influenced nearshore bays in Wisconsin had higher nutrient levels than the rest of the SLRAOC; however, eutrophication that might be expected under those conditions was absent. Additionally, these same bays had higher sediment loads than the rest of the SLRAOC. No comprehensive dataset existed to determine if these higher nutrient and sediment conditions were having a negative impact on aquatic life. As a result, a study was added to MA 6.04 to assess the clay-influenced bays in the Wisconsin portion of the SLRAOC (Roesler, 2018; Appendix 3) and provide data that could be used to determine if any additional AOC action was needed and whether site-specific water quality goals for these bays would be appropriate.

Background: Saint Louis River Estuary Clay-Influenced Bay Assessment

A BUI removal criterion of 0.030 mg/L for TP was established for the SLRAOC. This criterion was established to ensure that anthropogenic sources and activities in the SLRAOC were not resulting in excessive productivity and nuisance conditions within the SLRE. Diatom-inferred TP concentrations from sediment core analyses (Reavie, et al., 2016) indicated that TP concentrations in some SLRE bays exceeded the BUI removal criterion, but they had been at or above this criterion prior to development in this watershed.

Three bays on the Wisconsin side of the SLRE were selected for monitoring and assessment: Allouez Bay, Pokegama Bay, and Kimball's Bay (Figure 8). These sites were selected because very limited pre-existing water quality data was available for these bays and because they are the major clay-influenced bays within the SLRE. Watersheds for these bays contain clay-rich soils that are highly erodible and prone to high rates of surface runoff.

Figure 8: Clay-Influenced Bays Sampled for Management Action 6.04

The monitoring at these three bays was intended to:

- Document the current water quality and biotic conditions in these SLRE clay-influenced bays.
- Determine if current nutrient and suspended solids concentrations are negatively affecting aquatic life.
- Provide data that could be used to determine if site specific water quality goals are warranted.

Methods

The three bays were monitored twice per month during May – October of 2017 for water quality, algae, sediment chemistry, and benthic invertebrates. Tributary streams for the bays were monitored for water quality. Pre-existing water quality and biotic information was reviewed and summarized (Roesler, 2018). A companion project to assess fish communities in the bays was also conducted in 2017 (Nelson, 2019).

Findings: Clay-Influenced Bay Characteristics and Water Quality

The three bays had some unique characteristics relative to nearby main channel waters that influenced their water quality during the 2017 sampling period, as described below.

- Allouez Bay is the largest (1,011 acres) and shallowest and it is subject to frequent wind-induced mixing. The mouth of the bay is adjacent to the Superior entrance to Lake Superior and seiche-induced backflows of Lake Superior water influence the bay.

- Allouez Bay was mostly well-mixed, with intermittent thermal and DO stratification. There were indications that seiche-induced inputs of cooler Lake Superior water flowed along the bay bottom at times. Mean TP, TSS, and chl α concentrations were 85 µg/l [0.085 mg/L], 21 mg/L, and 7.1 µg/l [0.071 mg/L], respectively. TP and TSS concentrations were highest in May and

October when more runoff and suspended sediment were entering the bay. Chl α concentrations were highest in June and August when runoff and suspended sediment loads were lower and water clarity was higher than the other months.

- Pokegama Bay (441 acres) has the largest watershed area and so its water quality is heavily influenced by Pokegama River inflow. The bay is also affected by wetlands that fringe its narrow upstream end.

- Pokegama Bay also was mostly well-mixed, with intermittent thermal and DO stratification. Lower DO concentrations occurred more frequently at the surface in the upstream end of the bay, likely due to decomposing organic matter and overall high respiration rates in the fringe wetlands. There were likely occasional releases of sediment phosphorus from wind mixing of intermittently anoxic bottom waters in deeper areas of the bay, in addition to runoff-driven pulses of phosphorus from the fringe wetlands. Such intermittent inputs of phosphorus, and nitrogen (mostly as ammonium-N), are a characteristic of shallow lakes, ponds, and embayments. Mean TP, TSS, and chl α concentrations were 121 µg/L [0.121 mg/L], 32 mg/L, and 6.2 µg/L [0.062 mg/L], respectively. TP and TSS concentrations were highest in May and October at the two more downstream monitoring stations when more watershed runoff was entering the bay. TP and TSS concentrations were more variable at the most upstream monitoring station which is most strongly influenced by variability in Pokegama River inflows. Just as occurred in Allouez Bay, chl α concentrations were highest in July and August when watershed runoff was low and water clarity was higher than the other months.

- Kimball's Bay (101 acres) is the smallest of the three bays. Steep sloped, wooded banks line the bay's perimeter. The narrowness of the bay and the high wooded banks, along with its greater mean depth (Table 1) tend to minimize the frequency and extent of wind-induced mixing relative to other bays, although it is still a shallow system. The single water quality monitoring site in the bay is close to the bay mouth and strongly influenced by seiche-induced mixing of main channel and Lake Superior water.

- Kimball's Bay was more frequently stratified (i.e., temperature, DO, and other parameters) than other bays, despite the seiche influence. Phosphorus release from sediment during periods of bottom water anoxia was evident and prolonged during July and August. Inflow from the small tributary stream appeared to be mostly flowing along the bottom of the bay and producing higher turbidity (implying higher TSS) near the bottom. Mean TP, TSS and chl α concentrations were 63 µg/l [0.063 mg/L], 5 mg/L, and 7.6 µg/L [0.076 mg/L], respectively. TP concentrations were somewhat higher in May and October and increased from mid-June to early September, presumably due to sediment phosphorus release. As for the other bays, TSS levels were higher in May and October and chl α levels were higher in July through early September when water clarity was higher.

For the three bays, mean TP concentrations were 2-4 times higher than those found in the rest of the SLRE (Bellinger, et al., 2016). Mean chl α concentrations were lower than those found in the rest of the SLRE. Mean TSS concentrations were lower at the Kimball's Bay site and higher at the Allouez and Pokegama Bay sites compared to the rest of the SLRE (see Table 4).

Table 4. Summary of Mean Total Phosphorus, Total Suspended Solids and Chlorophyll α Concentrations in 2017

	Size (acres)	Mean Depth (ft)	Mean TP (µg/L)	Mean TSS (µg/L)	Mean Chl a (µg/L)
Allouez Bay	1,011	6	**85 [0.085 mg/L]**	**21 [0.021 mg/L]**	7.1 [0.0071 mg/L]
Pokegama Bay	441	5	**121 [0.121 mg/L]**	**32 [0.032 mg/L]**	6.2 [0.0062 mg/L]
Kimball's Bay	101	12	**63 [0.063 mg/L]**	5 [0.005 mg/L]	7.6 [0.0076 mg/L]
Estuary Mean	NA	NA	31 [0.31 mg/L]	11 [0.011 mg/L]	9.4 [0.0094 mg/L]

(Bold #s indicates values higher than the estuary mean)

Water quality monitoring was also conducted in the tributary streams that enter these bays. Stream TP and TSS concentration means ranged from 106-224 µg/L [0.106-0.224 mg/L] and 28-106 mg/L, respectively. Watershed non-point sources of phosphorus include pasture and hayfield runoff (including the influence of manure spreading), barnyards, and septic systems. Streambank and bluff erosion along streams is not believed to be a large phosphorus source (Bahnick, 1977), but is believed to be the largest source of TSS. Additional tributary information is contained in the full report in Appendix 3.

Findings: Bay Chlorophyll α Relationship to Other Trophic State Indices

Chl α concentrations in the three bays were much lower than would be predicted based on TP concentrations using either the Carlson Trophic State Index (TSI; Carlson, 1977, used to measure biological productivity) or the MN and WI statistical modeling of relationships between TP, Secchi depth, and chl α for inland lake assessments (MPCA, 2016 and WDNR, 2020). Chl α concentrations were only 3 -18% of what is typically found at the TP concentrations predicted by the Carlson, 1977 equations. Water clarities (i.e., Secchi depths) were also lower (i.e., poorer) than typical for comparable chl α concentrations.

Total algal cell densities were highest in all bays in July, August, and September. Pokegama Bay had the highest total cell density on July 10th (10,343 cells/ml). All algal phyla occurred in higher densities during those three months. Total suspended solids concentrations and turbidity were lower during these months, which increased light availability for algal growth (see further discussions below). Water temperatures were higher during these months which can also promote algal growth.

Poor light availability due to suspended sediment and dissolved organic carbon (as opposed to nutrients like phosphorus and nitrogen) likely limits algal growth in the bays, as also happens in shallow, turbid lakes. The brown "tea" color of SLRE waters, from dissolved organic matter draining from wetlands, also contributes to lower light availability for algal growth, as well as its high variability. Lack of typical TSI parameter relationships complicates water quality goal setting since it makes it difficult to predict responses to water quality improvements.

Findings: Bay Sediment Characteristics

Mean clay content of sediment in all three bays (40 – 46%) was significantly higher than that found in the remainder of the central and lower SLRE, where clay content averaged about 14.7% (NOAA DIVER 2018); this was not surprising given the clay-rich soils in the watersheds of the bays. Clay content of sediment (% clay) was moderately well correlated with phosphorus concentration (R^2 = 0.75) and iron concentration (R^2 = 0.76); this was also not surprising since iron readily attaches to the extensive bonding surfaces of clay particles and phosphorus attaches to the iron.

Findings: Clay-Influenced Bay Biological Indicators

Multiple biological indicators were assessed to provide a better understanding of how water quality conditions effect the habitat and overall biological health of the bays. Four biological areas were examined and described below: benthic macroinvertebrates, aquatic macrophytes, wetlands, and the fishery. The results for each community, separately and collectively, provided further lines of evidence that an impairment does not exist. The bays were shown to sustain adequate biological health despite TP conditions that exceeded the BUI removal criterion.

Benthic Macroinvertebrates

The trimetric index (TMI) (Angradi, et al., 2016), an index of benthic invertebrate community quality, was developed specifically for the SLRE. Due to their unique clay conditions, Allouez and Pokegama Bays were excluded from the development of the TMI and the accompanying ephemerid density index. This complicated the interpretation of the benthic data conditions reported, however the TMI was the most useful benthic invertebrate indices available for these bays and provided a basis of comparison to the rest of the SLRE.

The median TMI value was poor for Allouez Bay, fair for Pokegama Bay, and poor for Kimball's Bay. The quality of the benthic invertebrate community in all three bays was below average in comparison to the rest of the SLRE. The physical characteristics of sediment with high clay content (and corresponding high-water content) likely provided poor habitat for some benthic invertebrates in these bays. Periods of anoxia at two sites in Kimball's Bay probably also contributed below average benthos.

The median ephemerid (mayflies) density index value (Angradi et al. 2016) was good for Allouez Bay, excellent for Pokegama Bay, and poor for Kimball's Bay, with Allouez and Pokegama Bays above average in comparison to the rest of the SLRE.

Aquatic Macrophytes

Aquatic macrophyte surveys from 2004-2015 were summarized and statistically analyzed (Danz, et al., 2017) to develop the Coefficient of Conservatism (C*) as an index of tolerance to disturbance (see Table 5). Mean C* values for Allouez and Pokegama Bays were similar and somewhat higher than the mean for all SLRE surveys, while Kimball's Bay was substantially poorer, likely due to physical conditions and less littoral zone area in the bay compared to the other Bays and SLRE.

Table 5. 2017 Aquatic Macrophyte Survey Data for Management Action 6.04

	Allouez Bay	Kimball's Bay	Pokegama Bay	All SLRE surveys
Number of species	155	74	148	NC**
Species per plot	8.8	5.0	5.8	NC**
Mean C* value	5.6	3.6	5.4	5.06

C* = coefficient of conservatism, an index of tolerance to disturbance. **NC = not comparable because a number of species and species per plot are influenced by the size of area surveyed and survey methods, and so the data do not offer a simple means of comparison.

Wetlands

Recent wetland monitoring data (2011-2017) was available for all three bays from the Great Lakes Coastal Wetland Monitoring Program (Brady, 2018).

Wetland nutrient, turbidity, and chl α concentrations were generally similar to those found at open water sampling sites in 2017, although Kimball's Bay TP concentrations were higher than in open water.

Daytime DO concentrations in wetlands were low (<3 mg/L) for 5-25% of the measurements, with Kimball's Bay having the most low oxygen periods.
Wetland macroinvertebrate IBI's were taken from the Coastal Wetland Monitoring Program (CWMP) data for Allouez and Pokegama Bays for 2011 and 2012. Most Allouez Bay sites showed moderate impacts, while Pokegama Bay showed moderate impacts to most pristine.

Wetland fish IBI ratings for 2011, 2013, 2015, and 2016 for Allouez Bay ranged from moderate impacts to mild degradation. The rating for the 2017 fish study (Nelson, 2018) was generally similar; Pokegama Bay showed mild impacts and Kimball's Bay showed moderate degradation.

Wetland bird and frog survey results (2012-2013) were also available for Allouez and Pokegama Bays (Tozer 2014) and for one or more years during 2014 -2017 for all three bays (Brady, 2018). A summary of the wetland bird and frog survey assessments were compiled in Table 6 and Table 7.

Table 6: Summary of Bird Survey Data for Management Action 6.04

Year	Allouez Bay	Pokegama Bay	Kimball's Bay	L. Superior Coastal Wetlands
2012	Fair IBI	Fair IBI	NA	Fair for 14 sites
2013	NA	NA	NA	Fair for 14 sites
2014	High quality IEC	NA	NA	NA
2015	NA	NA	NA	NA
2016	High quality IEC	Mildly impacted	Degraded	NA
2017	High quality IEC	NA	NA	NA

Table 7: Summary of Frog Survey Data for Management Action 6.04

Year	Allouez Bay	Pokegama Bay	Kimball's Bay	L. Superior Coastal Wetlands
2012	Good	Very Good	NA	Excellent for 13 sites
2013	Good	Very Good	NA	NA
2014	Excellent	NA	NA	NA
2015	NA	NA	NA	NA
2016	Excellent	Moderately Impacted	Moderately Impacted	NA
2017	Excellent	NA	NA	NA

Fishery

Bay fisheries were monitored during 2017 using gill nets and shoreline electrofishing and compared to 2017 estuary wide gill netting data from MNDNR (Nelson, 2019). Results are summarized in Table 8.

Table 8. Comparison of 2017 St. Louis River Gill Net Data for Management Action 6.04

Gill Net Data	Allouez Bay	Kimballs Bay	Pokegama Bay	21 MN SLRE gill net sites
Total number of species	12	6	9	19
Median number of species/net lift	9	3	9	8
Mean fish/net lift	39.9	3.6	19.3	27.5
Mean kg fish/net lift	21.9	1.3	8.3	13.0
Gill Net plus Electrofishing Data				
Total number of species	22	15	21	not applicable
Number of native species	18	14	16	not applicable
Number of non-native species	4	1	5	not applicable
Number of intolerant species	4	4	3	not applicable

Allouez and Pokegama Bays gill net data was generally similar to data collected by the MNDNR during 2017 from 21 SLRE gill net sites for number of species/net lift, mean fish/net lift, and mean kg of fish/net lift. Data from Kimball's Bay indicated a poorer fish community than the MNDNR data averaged from 21 sites within the SLRE.

The conclusion from the fishery survey report stated: "Despite turbid conditions that may lead to the perception of poor water quality or habitat, locally popular sport fish species like walleye, northern pike, black crappie, and yellow perch were well represented in both Allouez and Pokegama Bays. Other species of interest to anglers and state fisheries management agencies were also found in these bays including lake sturgeon, muskellunge, bluegill, and channel catfish. While increased turbidity in Allouez and Pokegama Bays may influence the presence or abundance of specific species, it has not diminished the fishery value or eliminated desirable gamefish species from these areas." (Nelson, 2019)

Biological Indicators Summary

Although nutrient and sediment loads were higher in the clay-influenced bays than in the other areas of the SLRE, this study showed that biotic health was not limited as a result, as seen in the summary of available biological indicators for the three bays in Table 9.

Table 9: Summary of Biological Indicators for Management Action 6.04

BIOLOGICAL COMMUNITY	INDICATOR	ALLOUEZ BAY	KIMBALLS BAY	POKEGAMA BAY
Benthic invertebrates	Trimetric index[1]	median = poor (poorer than average for SLRE)	median = poor (poorer than average for SLRE)	median = fair (poorer than average for SLRE)
Ephemerid mayflies	Ephemerid density index[1]	median = good (better than average for SLRE)	median = poor (poorer than average for SLRE)	median = excellent (better than average for SLRE)
Aquatic macrophytes	Species richness[2]	155	74	148
Aquatic macrophytes	Species richness per plot[2]	8.8	5.0	5.8
Aquatic macrophytes	Mean C value[2]	5.6; species that tolerate moderate disturbance; better than SLRE mean value of 5.06	3.6; generalist species that are tolerant of disturbance; poorer than SLRE mean value of 5.06	5.4; species that tolerate moderate disturbance; better than SLRE mean value of 5.06
Bay fish	multiple[6,7]; no applicable IBI available	Number fish/gill net lift = 145% of 21 site SLRE mean; kg fish/gill net lift = 168% of 21 site SLRE mean; number species /gill net lift = 112% of 21 site SLRE median; % native species = 92%; number of intolerant species = 4; "...popular sport fish species...are well represented in Allouez ...Bay."	Number fish/gill net lift = 13% of 21 site SLRE mean; kg fish/gill net lift = 10% of 21 site SLRE mean; number species /gill net lift = 38% of 21 site SLRE median; % native species = 99%; number of intolerant species = 4	Number fish/gill net lift = 70% of 21 site SLRE mean; kg fish/gill net lift = 63% of 21 site SLRE mean; number species/gill net lift = 112% of 21 site SLRE median; % native species = 79%; number of intolerant species = 3; "...popular sport fish species ... are well represented in ... Pokegama Bay."

Table 9 (continued): Summary of Biological Indicators for Management Action 6.04

BIOLOGICAL COMMUNITY	INDICATOR	ALLOUEZ BAY	KIMBALLS BAY	POKEGAMA BAY
Wetland Macroinvertebrates	Wetland macroinvertebrate IBI[4]	2011, 2012 = moderately impacted; not enough non-clay influenced SLRE surveys to allow comparison.	IBI not available	2011, 2012 median = mildly impacted; not enough non-clay influenced SLRE surveys to allow comparison.
Wetland Vegetation	Wetland vegetation IBI[4]	2011-2017 median = moderately impacted = median for non-clay influenced SLRE surveys	2014, 2016 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impacted).	2011, 2012, 2016 median = moderately impacted = median for non-clay influenced SLRE surveys
Wetland Fish	Wetland fish IBI[4]	2011-2017 median = moderately impaired to moderately degraded, which is slightly poorer than the median for non-clay influenced SLRE surveys (moderately impaired).	2014 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impaired).	2012 = mildly impacted, which is better than the median for non-clay influenced SLRE surveys (moderately impaired).
Wetland Birds	Bird IBI[3]	31.8; fair - just below median value of 33.3 found for 14 Lake Superior coastal wetlands, mostly outside of SLRE	no data	34.0; fair - just above median value of 33.3 found for 14 Lake Superior coastal wetlands, mostly outside of SLRE
Wetland Birds	Bird IEC[4]	2014 2016, 2017 median = high quality, which is better than the median for non-clay influenced SLRE surveys (moderately impacted)	2016 = degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impacted)	2016 = mildly impacted, which is better than the median for non-clay influenced SLRE surveys (moderately impacted)
Wetland Frogs	Frog IBI[3]	60.0; good - below median value of 86.5 found for 13 Lake Superior coastal wetlands, mostly outside of SLRE	no data	70.3; very good - below median value of 86.5 found for 13 Lake Superior coastal wetlands, mostly outside of SLRE
Wetland Frogs	Frog IEC[4]	2014 2016, 2017 median = reference condition, which is better than the median for non-clay influenced SLRE surveys (mildly impacted)	2016 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (mildly impacted)	2016 = moderately impacted, which is poorer than the median for non-clay influenced SLRE surveys (mildly impacted)

[1]Angradi, TR, Bartsch, WM, Trebitz, AS, Brady, VJ, Launspach, JJ. 2016. A depth-adjusted ambient distribution approach for setting numeric removal targets for a Great Lakes Area of Concern beneficial use impairment: degraded benthos. J Great Lakes Res.
[2]data from Danz, et al. 2017 (get full reference)
[3]Tozer, D. 2014. LSRI nearshore monitoring project: 2012-2013 bird and frog indices of biotic integrity. EPA assistance no. GL00E00500-0.
[4]Uzarski, DG, et al. 2017. Standardized measures of coastal wetland condition: implementation at a Laurentian Great Lakes basin-wide scale. Wetlands (37:15).
[6]Nelson, A. 2018. St. Louis River Bays – Douglas County; 2017 fish community survey. Wisconsin Dept. of Natural Resources, Superior, WI. Unpublished report.
[7]Pinkerton, J. 2018. Personal communication. Minnesota Dept. of Natural Resources fisheries specialist, Duluth, MN.

Conclusions: Clay-Influenced Bays

Considering the findings of the SLRE Clay-Influenced Bay Assessment, members of the BUI Technical Team reached agreement that establishing site specific water quality goals for the Wisconsin bays would not be necessary. Many standard indicators were not tailored to these unique estuary and clay-influenced conditions and best professional judgement was needed to properly interpret these results. Although this study was a comprehensive look at the bays, tributary streams and biota, it was limited to one season of water quality data and only limited conclusions could be made. However, the biological condition in the bays was dependent on water quality and a better long term indicator of bay health was shown to be the condition of aquatic life. Despite some differences seen amongst the bays and between the bays and the remainder of the SLRE, the study did not indicate that the biota in these environments were impaired by higher levels of sediment and nutrients. In fact, the study found that some of these areas contained unique high quality habitats and species assemblages.

Monitoring of aquatic life in the SLRE will continue because aquatic life is one beneficial use addressed under MPCA's and WDNR's 303(d) programs. One goal of these 3030(d) programs is to reverse identified impairments and protect beneficial uses according to the requirements of the CWA.

6.04 Overall Conclusions: Develop Water Quality Goals (Compilation of 6.01, 6.02, & 6.03)

The findings of MAs 6.01, 6.02, 6.03 and the SLRE Clay-Influenced Bay Assessment support BUI removal.

The comprehensive approach used to assess the current status against BUI criteria included studies that detailed historical, current, and site-specific water quality and biologic indicators. The BUI Technical Team was part of the review and discussion of each of the studies. Due to the magnitude of unique conditions and habitats found in the AOC, specific water quality goals were not established in addition to the BUI removal target. BUI criteria for the SLRE (0.030 mg/L) and Lake Superior (0.010 mg/L) remained an appropriate measure of nutrient improvements for the SLRAOC.

Estuary Conditions

The BUI Technical Team and AOC Coordinators concluded that, given that a large percentage of the area in the SLRE is composed of clay-influenced bays that have unique combinations of water quality indicators that are due to natural background conditions, the 60% of the SLRE that met the BUI TP criterion of 0.030 mg/L phosphorus during the study period fulfilled the criteria for BUI removal. Additional water quality indicators were used to support this conclusion, including improving trends in TSS, DO, and chl α (see Table 10). The clay-influenced bay study supported the hypothesis that the SLRE ecosystem was reasonably well adapted to current sediment, nutrient, and other biophysical conditions, and no AOC impairment caused by excessive sediment and nutrients remained.

Lake Superior Conditions

The BUI Technical Team and AOC Coordinators concluded that information from MA 6.01, 6.03 and 6.04 suggested average Lake Superior water quality was not exceeding the BUI criterion of 0.010 mg/L TP; therefore, the BUI removal criterion was met.

Multiple data sources were used to evaluate the Lake Superior-specific BUI criterion. The inferred phosphorus conditions from the paleolimnological core (MA 6.03) showed that Lake Superior conditions had not exceeded the BUI criterion. The core location is within the AOC boundary and showed concentrations of TP ranging from 3 - 6 µg/L [0.003 to 0.006 mg/L].

MA 6.01 also gathered data from Lake Superior sample locations, but the average values were slightly above the criterion (0.0127 mg/L). This is attributed to data from this assessment being collected in nearshore conditions, which were likely biased toward St. Louis River conditions due to river water mixing with the lake at the sample sites. DO and chl α data were consistent with oligotrophic waters.

Additional data for the western Lake Superior sampling point (SU 19), which is part of the USEPA's Great Lakes Biology Monitoring Program (1983- present; https://www.epa.gov/great-lakes-monitoring/great-lakes-biology-monitoring-program), were reviewed to supplement the findings in MA's 6.01 and 6.03. This sampling point was not located within the boundary of the SLRAOC, but still provided a longer-term record of the nutrient conditions in the western portion of Lake Superior compared to the data collected in MA 6.01. Select data available from USEPA's Great Lakes Environmental Database via the Central Data Exchange (https://cdx.epa.gov/) was used for this comparison. Data from 1996-2015 showed the mean western Lake Superior TP concentration was 2.6 µg/L [0.0026 mg/L] and the range was 1.0 to 8.0 µg/L [0.001 to 0.008 mg/L] (Table 10, Figure 9). Data selected for BUI comparison represented upper water column samples including epilimnion (top 10 m) or spring integrated sample designations. Hypolimnetic or deep-water samples were excluded from the BUI comparison.

Table 10: Summary of Water Quality Results for Management Action 6.04

Parameter	SLRE, from Fond du Lac dam to Lake Superior (Bellinger, et al., 2016)	Lake Superior[1] (Bellinger, et al., 2016)	Western Lake Superior[2] (USEPA, Great Lakes Biology Monitoring Program 1996-2015)
TP	~60% of area below 30 µg/L [0.030 mg/L]	Average = 12.7 µg/L [0.0127 mg/L]	Average = 2.6 µg/L [0.0026 mg/L]
TSS	>85% of area below 15 mg/L	Average = 4.4 mg/L [0.0044 mg/L]	not assessed
DO	>5.5 mg/L; no hypoxia	Average = 12.2 mg/L	not assessed
chl α	>70% of area below 10 µg/L [0.010 mg/L]; oligotrophic to mesotrophic	Average = 2.7 µg/L [0.027 mg/L]; oligotrophic	not assessed

[1] The interim TP guide for Lake Superior is 0.010 mg/L. Data from this assessment were collected in nearshore conditions, which were likely biased toward SLRE conditions due to seiche mixing.
[2] The USEPA's Great Lakes Biology Monitoring Program sampling point (SU 19) is not located within the boundary of the SLRAOC.

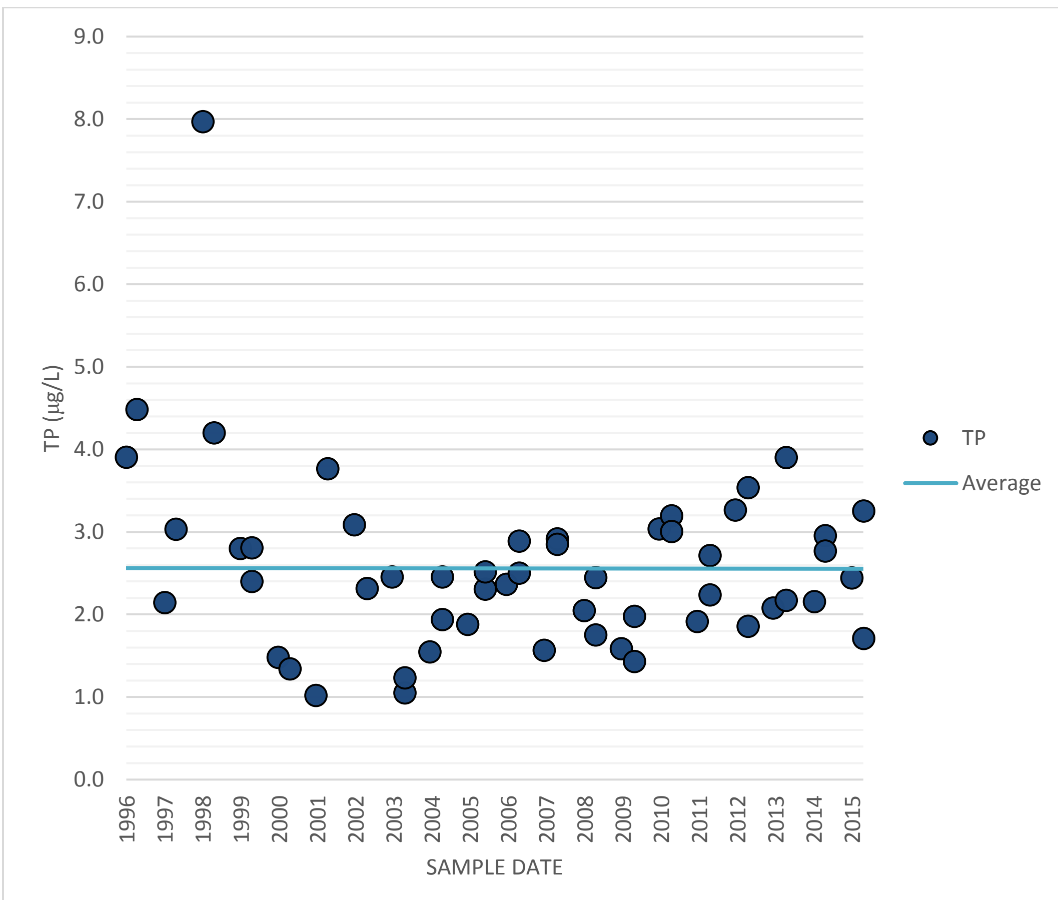


Figure 9: 1996-2015 Lake Superior Upper Water Column Total Phosphorus at SU 19 Great Lakes Biology Monitoring Program

6.05 Nemadji River Basin Studies

The Nemadji River Basin comprises a large portion of the SLRAOC (see Figure 10).

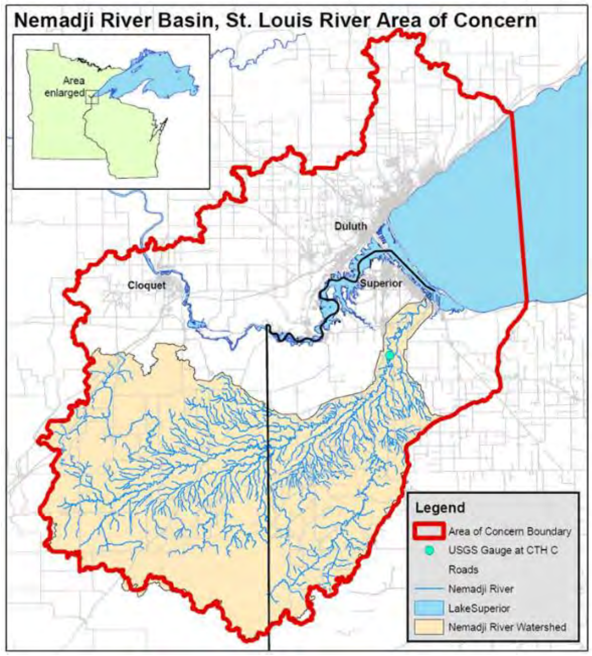


Figure 10: Map of the Nemadji River Basin within the St. Louis River Area Concern

In geologic terms, the Nemadji River Basin is relatively young. The Nemadji River and its tributary streams are still changing to reach slope equilibrium after elevations changed when the Laurentide ice sheet retreated approximately 10,000 years ago. As the river and stream channels adjust, steep valley walls, sloughing clay banks, and high sediment loading to the SLRE and Lake Superior result. Historic logging and agricultural practices have exacerbated the erosion problem in some areas. By removing old growth forest cover and draining wetlands, stormwater runoff to the channel and peak flows are increased. The Nemadji River Basin Project Report (NRCS, 1998) outlines many recommended actions and best management practices to help reduce the impacts of land use on peak flows and sediment loading in the Nemadji River Basin.

As a follow-up to the Natural Resources Conservation Service (NRCS) Report, and to show progress towards implementing the report's objectives has been made, several studies were conducted in the Nemadji River Basin to assess sediment impairments and evaluate the <40% open lands watershed objective that was previously a BUI removal objective. As part of MA 6.05, WDNR (through the Great Lakes Protection Fund) and Carlton County, MN funded a GIS based open lands assessment in the Nemadji River Watershed. A comparison of 2002 data to the 2014 analysis showed that the <40% open land objectives in the Nemadji River Basin Plan had not been met (Appendix 4; Community GIS, 2016).

However, there were several issues with requiring this objective to be met for BUI removal and the <40% open lands objective was removed from the BUI removal strategy in 2014 and MA 6.05 was adapted to assess the biological condition of the Nemadji River and to determine if excessive sediment is an impairment.

The open lands assessment identified small hydrological units within the Nemadji River watershed exceeding 40% open land status by digitizing agricultural and urban land and timber stands ≤15 years in age. The 280,787-acre Nemadji watershed with its 171 sub-watersheds were delineated for this study, of which 26.9% had more than 40% open land.

While land use trends have an impact on peak flows and erosion in the basin, there are several caveats to using the <40% open lands objective in the Nemadji Basin in the RAP. The "open land" classification includes urban, agriculture, grasslands, hay fields, shrublands, and young forest; but each of these land cover types influences peak flows differently (Verry 1976, Verry et al. 1983, Verry 1986). Verry's work found that at moderate percentages (40 -60%) open lands, snowmelt peak flows are desynchronized and thus reduced. Because of this desynchronization and the differences in water uptake among different types of open lands, there is a lack of consensus among resource managers about what the appropriate percent open lands target should be. Also, because "slow the flow" efforts are not limited to reforestation (but also include wetland restoration, ditch plugging, elimination of unused roads, field borders, filter strips, etc.), using the percent of open lands in the basin as the target metric does not accurately assess physical results of efforts that have been implemented to reduce sediment in the Nemadji River. In fact, initial assessments of fish and macroinvertebrates at several sites on the Nemadji in Wisconsin do not indicate there is an impairment due to sediment (Roesler, 2014).

The adapted MA 6.05, described in the following sections, justifies BUI removal based on historical sediment load modeling and biological conditions, and implementation of the Nemadji Basin Plan through stakeholder and landowner planning workshops in the Nemadji River Basin. The planning component included communication of the results of the open lands assessment to stakeholders and landowners in the Nemadji Basin.

SLRAOC managers adopted the strategy to evaluate the Nemadji River through: sediment monitoring and HSPF modelling of historic sediment loads, biological and water quality assessments, and planning efforts to better understand the following conditions.

1. Sediment loading:
    a. During pre-settlement, peak agriculture, and current conditions using an existing HSPF model.
        i. See Appendix 5: Current and Historical Sediment Loading in the Nemadji River Basin (Butcher, 2016)
    b. Comparing current sediment loading to 1970's sediment loads as reported in the Nemadji River Basin Project Report (NRCS, 1998).
        i. See Appendix 6: Sediment Characteristics of Northwestern Wisconsin's Nemadji River, 1973-2016 (Fitzpatrick, 2020)

2. The health of natural biological communities through an assessment of fish, macroinvertebrate, and water quality samples.
    a. See Appendix 7: Lower Nemadji River-Douglas County Fish Community Survey (Nelson, 2015)
    b. See Appendix 8: Nemadji River and Tributaries Water Quality Assessment (Roesler, 2014)
    c. See Appendix 9: Lower Nemadji River Water Quality and Macroinvertebrate Community Assessment (Roesler, 2015)
3. How making progress towards meeting watershed management objectives identified in the Nemadji River Basin Project Report (NRCS 1998) is advanced by completing an implementation planning effort aimed at educating citizens and local government officials in the Nemadji River Basin and identifying landowners to implement best management practices on their property.
    a. See Appendix 10: Nemadji River Watershed Implementation Planning Report (Ostern, 2017)

Each of the listed projects is summarized below and the full reports are contained in the appendices noted above.

Current and Historic Sediment Loading in the Nemadji River Basin

Methods and Findings

As part of their obligation to identify impaired waters and make Total Maximum Daily Load determinations, MPCA developed Hydrologic Simulation Program—FORTRAN (HSPF) models for all eight of the basins in Minnesota. One of the basin models encompasses both the Minnesota and Wisconsin portions of the Nemadji River watershed. These models were developed to better understand water quality and predict how it could change under different land management practices.

Tetra Tech used MPCA's existing HSPF basin model to evaluate and document changes in sediment loading caused by the conversion of land use from old growth evergreen forest to agriculture and new growth forests. The basin-wide HSPF model was calibrated and modified to provide watershed-level detail for the Nemadji River watershed portion of the basin. The model represented sediment loading from both upland and channel sources and provided a credible match to observed suspended sediment concentrations and loads at multiple monitoring points. Due to its relatively coarse spatial scale, the model was not an ideal simulation tool to specifically address loading from bluff slumping, believed to be the major source of sediment loading in the Nemadji. Nonetheless, the Nemadji model provided a useful framework to investigate potential changes in sediment loading over time.

Analyses with the HSPF model were used to compare current conditions to the probable sediment loading patterns under pre-settlement conditions (prior to harvesting of the mature white pine forests that previously covered most of the watershed) and under peak agriculture conditions. A date around 1930 was selected for peak agriculture primarily due to the availability of the Bordner Survey maps that provide a detailed representation of land use and land cover in Wisconsin during the Great Depression. (In fact, peak agriculture in the basin may have occurred somewhat later, during the 1940s and 1950s, but comparable land use surveys are not available for that time period.) Pre-settlement conditions were based on survey notes from the original Land Office grants in the watershed in the 1850s.

Initial settlement of the watershed was followed by harvest of the old-growth evergreen forest, followed by drainage and conversion to agricultural uses. Massive fires further altered the watershed and its sediment generating characteristics at the beginning of the 20th century. The early period of forest harvest included massive disruption to the natural stream network as channels were straightened and de-snagged to promote floating of logs to mills in Superior, WI, including use of splash dams that were used to build up flow and then dynamited to so logs could move downstream. Insufficient records existed to simulate the likely massive impacts on sediment loading that occurred from these events.

By the 1930s almost all of the old growth forest had been cut and areas that were previously in mature white pine had either been replaced by subsistence agriculture (primarily small grains) or reverted to second-growth deciduous aspen forest. These conditions promoted increased sediment loading from the uplands and also increased peak flows in the streams, which likely exacerbated erosion from stream banks and bluffs. Another important change was the drainage of wetlands, which were estimated to have declined from 38% of the watershed during the pre-settlement era to 13% of the watershed ca. 1930. This caused a loss in the wetland functions of mitigating peak erosive flows in streams and trapping sediment eroded from the uplands. Since the 1930s, wetlands have increased to approximately 17% of the watershed, but most of the recovery has been in herbaceous wetlands rather than the pre-settlement dominance of forested wetlands.

A major unknown in the analyses was how channel geometry may have changed from pre-settlement conditions. No data were available for the pre-settlement period, but anecdotal evidence suggests that stream channels may have been more stable, with greater roughness (due to large wood debris), greater sinuosity (and thus smaller slope), and less entrenchment of stream channels.
It must be recognized, however, that the Nemadji watershed is geologically young, with unstable clay soils. The Nemadji River is a highly erosive system influenced by ongoing slope adjustments to post-glaciated conditions, especially the changing base levels in Lake Superior resulting from glacial recession.

Application of the HSPF model suggests that upland sediment loads in the Nemadji watershed increased more than threefold from pre-settlement conditions to ca. 1930, but have since recovered to the point that current upland loads are less than twice pre-settlement loads (see Table 3.3 in Appendix 5). The major sediment source in the Nemadji is from bank and bluff contributions (estimated at about 75% of the total load). The bank and bluff contributions do not change much under model simulations that assume channel geometry pre-settlement is similar to current conditions. However, reasonable assumptions about pre-settlement channels with greater sinuosity and lower gradient prior to logging suggest this component, while still significant, may be about 27% less than under current conditions.

In summary, clear-cut logging during the late 19th century increased sediment loads over three-fold from the pre-settlement era. The end of landscape-scale logging decreased sediment loading. Additional progress in reducing loads has been made since the peak agriculture period, but upland loads were still estimated to be nearly double those that would have occurred under pre-settlement white pine and forested wetland cover.

The total sediment load is primarily derived from channel erosion and bluff slumping where the river intersects the valley walls, a natural characteristic of the watershed. That problem is exacerbated by changes in land use in the watershed that increase peak flows. Therefore, reducing erosive flows in the Nemadji and its tributaries (e.g., through wetland restoration) can help ameliorate, but not eliminate, sediment loads from these sources.

Processes such as evolving head cuts, ongoing expansion of the drainage network, and responses to changing base levels in Lake Superior that affect channel bank and bluff erosion may not be readily amenable to management interventions.

It should be noted that the modeling conducted for this analysis is limited in its predictive power because the HSPF model is constructed at a relatively coarse scale (approximately HUC12 sub-basins) and quantitative data on contributions from bluff and channel bank sources is lacking. Nonetheless, the model provides a credible basin-scale indication of the changes that have likely occurred over time. Use of a finer-scale model informed by detailed stream surveys would help in identifying local hotspots of sediment loading where management intervention might be beneficial. More sophisticated channel evolution models, informed by detailed channel measurements, would also help to better constrain model predictions.

Sediment Characteristics of Northwestern Wisconsin's Nemadji River, 1973-2016 Methods and Findings

Over the last 45 years, a variety of sediment samples were collected and analyzed periodically using different field and analytical techniques by the USGS, the WDNR, and the MPCA at the USGS stream gage on the Nemadji River near South Superior (USGS identification number 04024430). Most of the samples were of suspended sediment concentration. In 1973-86, the USGS collected samples for suspended-sediment concentration analysis and a limited number of bedload samples, including two in 1978. Starting in 2006 and continuing through the present, the WDNR and MPCA have been collecting TSS data.

Three objectives were identified for this study:

1. Develop a calibration curve between suspended sediment-concentration (SSC) and total suspended solids (TSS) data.
2. Compare SSC-based sediment rating curves from the 1973-86 with adjusted TSS-based curves from 2006-15 and determine if there has been a change in suspended sediment discharge.
3. Describe 2015-16 total sediment discharges, comparing USGS and WDNR data, which were determined directly by collecting suspended sediment, bedload and bed material samples and measuring suspended sediment discharge and bedload discharge and indirectly by calculating total sediment discharge using the modified Einstein procedure.

Study methods included:

- Gathering published historical and ongoing sediment concentration, water discharge, and sediment discharge data collected by the USGS, WDNR, and MPCA at the USGS stream gage on the Nemadji River.
- Collecting comparative measurements of suspended sediment, bedload, and bed material in 2015-16.
- Calculating instantaneous total sediment discharges for 2015-16 samples by summing the measured suspended sediment discharge and bedload discharge.
- Calculating the estimated total sediment discharge using the modified Einstein procedure.
- Comparing sediment concentration-water discharge rating curves using analysis of covariance.

Hydrologic conditions were variable over the two periods of historical suspended sediment data collection. Mean annual flows during 2006-15 were about 84% less than during 1973-86. In contrast, two extreme floods in 2011 and 2012 were over 2.5 times larger than any peak flow in the 1973-86 period.

The 2009-16 annual total sediment discharges ranged from a low of 18,000 tons/year in 2015 to almost 180,000 in 2012. Bedload discharges ranged from 20 percent of the total sediment discharge during low mean annual flow years to only 5 to 6% during high flow years. A sediment rating curve for suspended sediment concentration and water discharge for 2006-15 had a similar slope but a lower intercept than its 1973-86 counterpart. Although not statistically significant, the negative offset resulted in a potential reduction of about 15% of the annual suspended sediment discharge for an example data set of annual discharges from 2009-16. Altogether, these various data sets collected over different time periods and using different methods helped to describe present and past sediment characteristics as well as provide a calibration tool for future sediment data collection.

The hydrologic context with what is seeming to have more year-to-year variability will likely become more important than the overall value of annual loading at face value. The 10-fold increase in the size of sediment discharges during extreme floods compared to more average flood condition suggests that restoration done at the mouth of the Nemadji River needs to be resilient to large floods and sporadic, highly variable sediment deposition, even though overall the amount of suspended sediment per unit of water discharge may have been reduced.

6.05 Sediment Loading Assessment Conclusions

Results from both sediment loading assessments document a recovery from higher sediment loading in the past. These results support the efforts of the Nemadji River Basin Plan (NRCS, 1998) and the “slow the flow” initiative as watershed management programs continue making progress toward sediment load reduction and meeting plan objectives.

Lower Nemadji River-Douglas County Fish Community Survey
Methods and Findings

This work was completed to assess the fish community present in the Lower Nemadji River watershed (Nelson, 2015). Electrofishing sampling was conducted at six wadable and non-wadable stations. This method was chosen because it eliminated bias from net locations, mesh sizes or openings on nets or traps, or fish behavior and allowed for standardized Index of Biotic Integrity sampling. All captured fish were identified by species. Gamefish and panfish species were measured to the nearest tenth of an inch and larger individuals were weighed. All other non-gamefish species were counted. All fish captured in the survey were released back to the river, except for voucher species used to confirm species identification.

At the time of the study, the Nemadji River supported a diverse, primarily native, fish assemblage; 24 different fish species were documented in the 6 stations assessed in 2015. Minnows were the most abundant and widely distributed fish species and were represented mainly by common and emerald shiners. Silver redhorse, shorthead redhorse, rock bass, smallmouth bass and walleyes were also widely distributed throughout the Nemadji River, but didn't occur in the higher abundance seen in the minnow species. Muskellunge, largemouth bass, yellow perch, and channel catfish were also present, but in smaller numbers.

The fish communities from each station were scored and rated using the Lake Superior warmwater IBI rating to determine if the site is degraded and to what extent. Despite not being able to incorporate weight data, the non-wadable stations that were assessed scored between 56.25 and 75 points and were minimally rated from "Fair" to "Good". The IBI score for the wadable stations were rated as "Excellent". Despite relatively poor instream and riparian habitat in the Lower Nemadji River and some difficulty sampling fish, the fish communities documented reflected good water quality. In some instances, the lower scores for the IBI metrics reflected lower fish diversity in the Lake Superior basin rather than environmental degradation.

Nemadji River and Tributaries Water Quality Assessment
Methods and Findings

The Nemadji River and five of its tributaries (Crawford Creek, Black River, Balsam Creek, Clear Creek, and Mud Creek) were monitored for fish and macroinvertebrate communities, water chemistry, and stream habitat from 2008-2010 to assess water quality conditions and to determine if these streams should be placed on Wisconsin's 303d list of impaired waters (Roesler, 2014).

Fish communities were assessed by electroshocking and calculating IBI ratings. Macroinvertebrate communities were assessed by collecting kick samples from riffles. Water samples were collected and field parameters were measured following standard WDNR protocols. Stream habitat was assessed based on fish community-temperature relationships.

Fish community IBIs on the Nemadji River, Black River, Balsam Creek, and Mud Creek were rated excellent and the IBI for Clear Creek was rated good. The fish community IBI for Crawford Creek was rated as fair. Macroinvertebrate IBI ratings were excellent or good at all sites except Crawford Creek, which was rated as fair. Hilsenhoff biotic index ratings (mostly influenced by organic matter loading and the resultant dissolved oxygen concentrations) ranged from good to excellent. Streams ranged from cool-cold headwaters to warm mainstems.

Sampling frequency and duration for water chemistry varied by site; no water samples were collected from the Black River. Median concentrations of TP and TN were low to moderate at the two Nemadji River sites, with more than one nutrient sample analysis. These sites had low concentrations of ammonia and nitrate plus nitrite. All sites had fairly high TSS concentrations, fairly high turbidity, and fairly low transparency. Daytime DO concentrations were generally good. Median conductivities ranged from 195 – 520 µmhos/cm and pH median values ranged from 7.5 to 8.0.

Common stream concerns in this area include:

- High peak flows resulting from rapid runoff from clay soils.
- Low base flows resulting from limited groundwater discharge.
- Stream bed scouring and bank erosion resulting from high peak flows.
- High bed loads of sand and silt, reducing the substrate quality for fish and macroinvertebrates.
- High TSS and turbidity, and low transparency resulting from erosion of clay soils.

The Nemadji River was added to Wisconsin's 303d list in 2010 based on the state's narrative standard due to its high sediment load (Wisconsin does not have a standard for turbidity or TSS). The Nemadji River was placed on Minnesota's 303d list in 2004 due to exceedances of Minnesota's turbidity standard. The two states are working together to develop a comprehensive turbidity Total Maximum Daily Load for the entire watershed. Crawford Creek was placed on Wisconsin's 303d list in 1998 due to chronic aquatic toxicity. The data collected from this project did not support 303d listing of any of the other streams monitored.

Lower Nemadji River Water Quality and Macroinvertebrate Community Assessment Methods and Findings

Past water quality monitoring in the lower 8.8 miles of the Nemadji River was affected by Lake Superior's seiche causing partial backflow in the lower river. Previously, the most downstream water quality data was collected at the County Rd C crossing, 11.9 miles above the river mouth. Furthermore, deep water and lack of coarse substrate discouraged macroinvertebrate sampling, with the most downstream macroinvertebrate sample previously collected at County Rd W, 31.2 miles above the river mouth. With higher percentages of urban and agricultural land use in the lower portion of the watershed, inflow from Crawford Creek and discharges from point source outfalls could have been expected to contribute to poorer water quality and macroinvertebrate communities in the lower portion of the watershed, which is only 3.7% of the total watershed area. Therefore, monitoring of water quality and macroinvertebrate sampling were done in 2015 to evaluate lower river conditions (Roesler, 2015).

Water quality monitoring was conducted monthly at three sites from May to October on the second Wednesday of each month to provide a systematic, random distribution of samples. A Kemmerer sampler was used to collect water samples near the river center, where the river continued to move downstream, in an attempt to avoid the seiche effects of observed backflows moving upstream near the stream banks. Water quality samples were collected and field parameters were measured following standard DNR protocols.

Macroinvertebrate communities were assessed by collecting kick samples at six sampling sites. Due to the lack of riffles and scarcity of coarse substrate (gravel/cobble), all but one sample was collected from woody debris draped with leaf packs and other vegetative debris. One sample was collected from cobble substrate to allow a comparison of a nearby sample collected from woody debris/leaf snags. Samples were preserved in 85% ethanol before the macroinvertebrates were counted and identified to the lowest possible taxa. Biotic indices and other statistics were generated.

Water quality results were as follows:

- DO concentrations exceeded the 5 mg/L water quality standard for fish and aquatic life.
- Conductivity ranged from 93 to 275 µmhos/cm; lowest conductivity occurred when flows were higher.
- Transparency ranged from 3 to 65 cm; lowest transparencies occurred during highest flows. Soil erosion was greatest during high flows.
- TP concentrations ranged from 33 to 501 µg/L [0.033 to 0.501 mg/L]; they were highest when flows were highest. Median TP concentrations (49–56.3 µg/l [0.049-0.0563 mg/L]) were below Wisconsin's stream water quality standard of 75 µg/L [0.075 mg/L]. Relatively higher TP concentrations corresponded with relatively higher TSS and turbidity concentrations. (This is comparable to the findings in Roesler 2015 where larger mean daily flows corresponded with larger concentrations of TP, TSS, turbidity and E. coli.
- Dissolved orthophosphorus (DOP) concentrations ranged from <1.7–13 µ/L [<0.0017-0.013 mg/L]. The percent of TP as DOP ranged from 2.2 – 25%, with a tendency for DOP to comprise a smaller percentage of TP when flows were higher and more particulate bound TP was present.
- Total Kjeldahl nitrogen concentrations ranged from 0.56 to 1.62 mg/L; highest concentrations occurred when flows were higher.
- Ammonium-nitrogen and nitrate plus nitrite-nitrogen concentrations were very low (they ranged from <0.0150 – 0.0303 mg/L and <0.0190 – 0.0868 mg/L, respectively).
- TSS concentrations and turbidity ranged from 5.8 – 393 mg/L and turbidity ranged from 7.1 – 729 nephelometric turbidity units (ntu's). Both parameters were much higher during high flows. Median turbidities ranged from 24.9 to 26.9 ntu's. Although all three sites are in Wisconsin, the values are very close to Minnesota's 25 ntu standard.

Other factors that may be impacting water quality:

- During seiche events, the water back-flowing up the lower reach of the Nemadji River is derived mostly from the SLRE, with additional contributions from Lake Superior. In general, backflow of SLRE water is expected to contribute to lower TP, TSS, and DO concentrations, higher nitrate-nitrogen concentrations, and conductivity and temperature increases.
- Water quality conditions are dominated by upstream inputs. Runoff from the lower Nemadji River sub-watershed is expected to increase concentrations or loads of TP less than 3%. Increased concentrations or loads of TN and TSS are also likely to be small.
- Crawford Creek's watershed is about half the area of the Lower Nemadji River sub-watershed and about 1.8% of the total Nemadji River watershed. The creek is contaminated with creosote and PAH's from a former wood preserving facility, contributing a slight increase in downstream Nemadji River conductivities.
- Three point sources have discharges to the lower Nemadji River that may be impacting its water quality.
    - The Superior combined sewer treatment plant discharges intermittently following heavy rainfalls, when Nemadji River flows are usually high, and so considerable dilution capacity is usually available. However, discharges can, at times, have high concentrations of BOD5 (2-60 mg/L), *E. coli* (100-250,000cfu/100ml), ammonia (0.2-5.36 mg/L), TP (40-793 µg/L [0.040-0.793 mg/L]), and TSS (9-189 mg/L).
    - Enbridge Energy had a much larger than usual pipeline pressure test in 2015 that resulted in water discharges during most of October, slightly increasing TP in the river. At that time, average concentrations of BOD5, ammonia, and TSS were unlikely to produce measurable impacts in the Nemadji River. Conductivity of the discharges was not reported, so that was a possible contributor to higher conductivities in the river.
    - The Burlington Northern Sante Fe Railway Company discharge is comprised primarily of runoff from the taconite storage pile plus a small amount of treated maintenance water; both are treated in a retention/settling pond. With the exception of chloride, this point source appears unlikely to produce measurable impacts to the Nemadji River.

There may be other potential influences on temperature and DO. The Nemadji River widens, deepens, and slows between County Rd C and U.S. Highway 2/53. Solar radiation inputs may also be a contributor to the increases. DO decreases may be due to reduced oxygen solubility that is a function of temperature increases and sediment oxygen demand might be higher in the lower river if temporary deposition of organic solids is occurring due to reduced stream velocities.

Macroinvertebrate sampling did not occur at multiple sites as planned due to low discharge rates and inadequate current velocities that did not meet Wisconsin's protocols for applying WDNR macroinvertebrate biotic indices for streams or rivers. Furthermore, the periodic backflows prevented any accumulation of leaf packs or other vegetative debris on a suitable sampling substrate. Despite this, very healthy macroinvertebrate communities were found at all six sites. All samples had high macroinvertebrate IBIs rated as excellent. Hilsenhoff biotic index values ranged from good to excellent, indicating oxygen availability is consistently good and little organic pollution is present (Table 11). Species richness ranged from 19 to 41. Percent EPT individuals (Ephemeroptera-mayflies, Plecoptera-stoneflies, Trichoptera-caddisflies) was high (40-75%), and percent Chironomidae individuals was low (2-21%), which both also suggested good water quality.

Table 11. 2015 Lower Nemadji River Macroinvertebrate Sample Results for Management Action 6.05

Site	SWIMS station #	Date	Macroinvertebrate Index of Biotic Integrity (MIBI)	MIBI Condition Category	Hilsenhoff Biotic Index (HBI)	HBI Condition Category
Nemadji R. 15 m DS Dedham Rd.	10044435	11/02/2015	8.75	excellent	3.99	Very good
Nemadji R. 25 m US Finn Rd.	163233	10/22/2015	9.04	excellent	4.96	Good
Nemadji R. 10 m DS Finn Rd.	163233	10/22/2015	9.32	excellent	2.78	Excellent
Nemadji R. 135 m DS STH 35	163048	11/02/2015	8.69	excellent	3.85	Very good
Nemadji R. 60 m US CTH C	163003	10/22/2015	11.62	excellent	3.73	Very good
Nemadji R. 3 mi. DS CTH C	10044397	10/22/2015	11.34	excellent	3.61	Very good

Two samples were collected at one station from different substrates for comparison. The downstream sample was collected from leaf packs snagged on woody debris, while the upstream sample was collected from cobble. The cobble had fairly heavy coatings of periphyton and silt. The sample from cobble had a similar macrophyte IBI, a poorer Hilsenhoff biotic index, higher species richness, a lower percent EPT, and a higher percent Chironomids. The coatings of periphyton and entrapped silt on the cobble substrate were probably a major reason for these differences.

Overall, the high quality of the macroinvertebrate community found in the lower Nemadji River is consistent with past findings for the Nemadji River, despite higher levels of turbidity and sediment loads.

6.05 Water Quality and Biotic Assessment Conclusions

Results from the three assessments document that the biota in the Nemadji River do not indicate an impaired condition in relation to BUI status. These results show that many sites in the Nemadji River Basin contain high quality species assemblages despite the wide variety of sediment conditions present.

Nemadji River Watershed Implementation Planning
Methods, Findings, and Conclusions

The purpose of this project was to conduct Nemadji River implementation planning activities as an element of the BUI removal strategy. The work was completed in two phases. During the first phase, a Nemadji River Implementation Plan (Plan) was developed that included the following activities:

- Developed a Nemadji Watershed Implementation Strategy
- Compiled a landowner database
- Compiled natural resource information for the watershed
- Compiled watershed maps
- Developed a newsletter and mail to resident landowners (approximately 1600 residents)
- Conducted a watershed informational workshop
- Coordinated with the Carlton County Soil and Water Conservation District

Implementation of the Plan began during the second phase, during which these activities were conducted by Douglas County, WI:

- Convened and coordinated a Wisconsin stakeholder group
- Developed informational workshops to provide information on water quality issues.
- Identified a minimum of 3-5 landowners who agreed to explore cost-share opportunities to implement best management practices on their property.
- Maintained communication with the Carlton County Soil and Water Conservation District and other groups involved with Nemadji Watershed research to identify ways to continue to collaborate on outreach activities.
- Developed supporting documents that included the Implementation Plan, a map of parcels for landowners that scheduled site visits, stakeholder committee contacts and meeting agendas, an open house flyer, a workshop invitation, a landowner site visit form, a newsletter, and photos.

At the close of this grant project, primary considerations for next steps were recommended, as follows:

- Identifying needs for project design assistance, cost share and other support for implementing best management practices for reducing runoff and erosion
- Developing strategies for continuing funding and outreach efforts in the watershed
- Expanding watershed partnerships to include groups such as (for example) Northern Institute of Applied Climate Science, West Wisconsin Land Trust, Wisconsin Towns Association, Wisconsin Farmers Union, Ruffed Grouse and American Woodcock Society. This will form the foundation for a coalition with the capacity to further develop and implement watershed protection, restoration and participation into the future and beyond any one grant-funded project.

As a result of this work, Douglas County, Wisconsin increased the local capacity for addressing watershed issues in the Nemadji River through the engagement of landowners, community leaders, and local decision-makers. Educational workshops have increased stakeholder knowledge of water resource problems and provided information on best management practices to reduce runoff and facilitate the implementation of projects that will improve watershed health. These accomplishments documented important progress in the effort to promote and implement the Nemadji River Basin Plan (NRCS, 1998) objectives and fulfilled the intent of the Nemadji River Watershed BUI removal strategy.

6.05 Overall Conclusions

The comprehensive assessments and planning effort included in MA 6.05 document Nemadji River Basin water quality, sediment loading, and biological conditions. Results do not indicate that an impairment exists in relation to the SLRAOC BUI removal. Watershed level management and implementation of best management practices identified by MA 6.05 will continue outside of the AOC program.

Future Actions

Sediment and nutrient management in relation to water quality and habitat is an ongoing effort needed on a watershed scale. Following the completion of the management actions for BUI 6, a variety of future actions outside of the AOC program still exist, including: planning, monitoring, and research needs. Additionally, there are a number of programs that are already implementing actions related to modern issues. The following descriptions portray a sampling of the ongoing programs and additional needs, but it is not intended to be a fully inclusive list.

Planning and Program Implementation

The MPCA has completed a Watershed Restoration and Protection Strategy for the upper portion of the Nemadji River Watershed located in Minnesota (MPCA, 2017). This includes a compilation of slump inventories, which show locations that may be contributing to erosion-based P.
Implementation planning for the Minnesota portion of the Nemadji River Watershed is being led by the Carlton County Soil and Water Conservation District following Minnesota's One Watershed One Plan process (https://carltonswcd.org/nemadji-1w1p). The plan is expected to be ready in late 2020.

The cities of Duluth and Superior are implementing Municipal Separate Storm Sewer System Permit programs to manage stormwater in their communities. Implementation of these ongoing programs helps manage runoff and its resultant erosion.

The MNDNR, MPCA, and WDNR websites that contain SLRAOC information will be maintained as information repositories from which stakeholders will be able to obtain information generated to complete this BUI. Although it contains some SLRAOC project information, the St. Louis River Stories and Science website (www.stlouisriverestuary.org) goes beyond the goals of the SLRAOC. It is currently being maintained by the University of Wisconsin-Extension staff and its continuance will depend on future communication needs identified by the broader SLRE community and the ability to obtain continued funding.

Water Quality and Biological Monitoring

The MPCA currently completes high-resolution stream monitoring at major tributaries to the SLRE. This tributary monitoring approach is in place and will continue in the future. TSS, TP, dissolved orthophosphate, nitrogen and total Kjeldahl nitrogen are sampled 35 times per year and are paired with USGS flow data. This allows the MPCA to determine concentrations and loadings specific to the main tributaries to the estuary on an annual basis. The St. Louis River sampling location is at Scanlon, MN and the Nemadji River sampling site is near South Superior, WI (see Figure 11). The St. Louis River sampling location has consistently low levels of TP and TSS. In general, the Nemadji River carries higher sediment and phosphorus loads to the estuary. This monitoring effort will continue into the future and drives the modeling used to develop Watershed Restoration and Protection Strategies for these two watersheds. MPCA is prepared to ensure that activities are managed so that water quality standards are met at the outlets of these major watersheds.

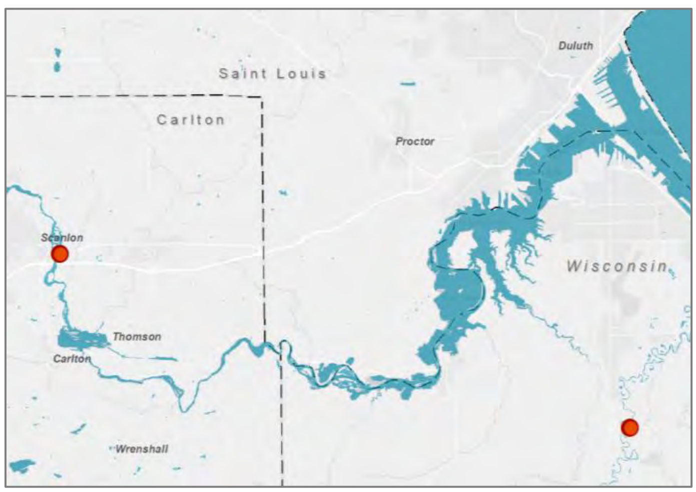


Figure 11: Location of USGS Gaging Stations on the St. Louis and Nemadji Rivers

Moving forward, MPCA and WDNR monitoring staff are conversing to determine what approach and frequency of surface water monitoring in the estuary is appropriate under existing state monitoring programs to determine ambient conditions for aquatic recreation and aquatic life uses.

As these conversations ensue, evaluating whether to use constituent-specific probes or continuous constituent-based surrogate statistic models of nutrient and sediment concentrations at strategic stream locations should be considered as a way to improve concentration monitoring and load estimates for the St. Louis River and the Nemadji River sites. These techniques can help identify real time water quality patterns between sampling events to indicate nutrient fluxes and, in places, the possibility of best management practice-related improvements. The USGS, MPCA and WDNR data from these sites may be appropriate for surrogate model computation. Additionally, historical water quality data collected by state and federal agencies from the SLRE should be assessed. This could include comparing USGS's Scanlon station nutrient and sediment concentration and load data to MPCA's comparable data, taking into account storm-event flows and utilizing continuous nutrient or sediment surrogate models to improve concentration monitoring, detection of concentration peaks between samples, and load estimates. Such a comparison could also help validate future efforts and identify potential differences in nutrient loads based on sampling methods and how hydrologic conditions are represented in the two data sets.

MPCA and WDNR also have ongoing programs to monitor surface waters and identify impairments under Section 303(d) of the Clean Water Act. Additionally, each agency administers permit programs to address impairments if found in the future. Three tributaries to the St. Louis River are considered impaired for total phosphorus: Bear Creek, Bluff Creek and the Pokegama River; however, these tributaries are located in the clay plain and assessing these waters based on statewide water quality standards may not be appropriate. At this time, there are no 303(d) nutrient impairments in the St. Louis River within Minnesota's portion of the SLRAOC. The Nemadji River is listed as impaired for turbidity in both Minnesota and Wisconsin and is being managed jointly under Total Maximum Daily Load rules.

The Lake Superior National Estuarine Research Reserve routinely monitors water quality under its System-Wide Monitoring Program, which began in 2013. This program perpetuates the long-term data series collected by MPCA under the Milestone Monitoring Program. The Reserve collects and analyzes TSS and nutrients (i.e., TP, TN, dissolved nitrate-N, ammonium/ammonia-N), as well as chl α and DO at both upper river (Oliver Bridge) and lower river (Blatnik Bridge) sites. The sampling locations and collection methodology allow for direct comparison of results to historic MPCA data. Current and future (i.e., post-2013) data can thus be added to the historic sediment and nutrient annual load estimates (using methods of Bellinger et al., 2016) to evaluate long-term water quality trends post BUI 6 removal. This congruence will allow for critical assessment of sediment and nutrient dynamics as the SLRE exits an historic period strongly affected by unregulated discharges and poor land use practices to an era of recovery. The Reserve will continue monitoring water quality to assess impacts from current and future stressors such as precipitation regimes, flood events, and warming temperatures. Additionally, the continuation of chl α and DO monitoring will help assess how future changes impact SLRE's productivity.

There are many other monitoring programs that may also continue to generate SLRE data in the future, such as:

- USEPA's Biology Monitoring Program
- USEPA GLTED's mission-oriented research, including the Cooperative Science and Monitoring Initiative program, as well as remedy and restoration effectiveness monitoring for the AOC program
- CWMP's coastal wetland monitoring

Continuation of USGS cooperative stream flow monitoring is recommended to provide flow context for individual samples collected by state and federal agencies. Hydrologic data from those programs should be mentioned if they are part of future research and watershed improvements.
There is a need to determine how to integrate all these monitoring efforts to develop a collaborative and comprehensive SLRE monitoring program by assessing current monitoring efforts, identifying future monitoring needs and funding sources, and creating a structure to collaboratively administer a comprehensive monitoring program for the SLRE.

Research

Sediment and nutrient cycling and predictors of harmful algal blooms in the SLRE are poorly understood. In particular, there is a need to understand whether recent water temperature changes and shifts to cyanobacterial populations are a factor in TP increases in the SLRE and how those factors are related to sediment cycling. Based on similar observations in degrading systems in western Lake Erie and southern Lake of the Woods (Ontario and Minnesota, respectively), the nearshore eutrophication observed in the SLRE may be due to factors such as periodic recycling of stored sedimentary phosphorus (regulated by the extent and duration of oxygen depletion during warm months coupled with intermittent wind mixing events). These conditions may be further aggravated by climate change related to increased winds and stormwater runoff, more frequent and larger storms, stronger thermal stratification in the ice-free season, or other indirect mechanisms, such as water clarity, light penetration, and nutrient availability. As described above, comprehensive, long-term water quality monitoring with periodic data evaluation and public reporting is needed, including a more detailed paleolimnology investigation of the nearshore environment coupled with a speciation of phosphorous study, development of a nutrient budget, long-term chl α data collection, and a comprehensive food web study. This knowledge will help develop an understanding of factors that may be contributing to nearshore eutrophication in the SLRE, identify vulnerabilities, and provide anticipatory and cost-effective management of the SLRE.

More frequent and intense storms and flood events cause peak flows that generate outliers in data sets that skew background data. An evaluation of peak flows over time is needed to identify how TP and TSS correlate with high flows and at what point higher loads cause nutrient resuspension. These analyses, supported with additional long-term streamflow data and watershed-specific precipitation data, are needed throughout the estuary, including in the clay-influenced bays. Potentially, analyses of nutrient and sediment sources and loads from the smaller, clay-influenced tributaries discharging to the SLRE may require automated streamflow and storm-based water quality sampling to represent rapidly developing conditions leading to nutrient and sediment mobility into the clay-influenced bays. An assessment of the 2012 flood is also needed to determine its effect on post-2013 conditions. Further, a cumulative frequency analysis for both base flow and peak flow regimes is needed to determine the effects of each.

UMD is conducting multiple research efforts related to nutrients and sediments, including evaluating the effect of nutrient and water clarity changes on algal productivity and erosion risk in the Nemadji River Watershed.

Pursuit of the actions described above will be the responsibility of individual organizations, or collaborations of organizations, acting under authorities outside of the AOC program that will exist after BUI 6 has been removed.

BUI Assessment Conclusions

With the completion of the five MA's and their review and interpretation by the BUI Technical Team, the BUI Target has been reached for each of the BUI criteria, as summarized below (see Table 12).

Table 12: Summary of Water Quality Results for Management Action 6.04

Parameter	SLRE, from Fond du Lac dam to Lake Superior (Bellinger, et al., 2016)	Lake Superior[1] (Bellinger, et al., 2016)	Western Lake Superior[2] (USEPA, Great Lakes Biology Monitoring Program 1996-2015)
TP	~60% of area below 30 µg/L [0.030 mg/L]	Average = 12.7 µg/L [0.0127 mg/L]	Average = 2.6 µg/L [0.0026 mg/L]
TSS	>85% of area below 15 mg/L	Average = 4.4 mg/L [0.0044 mg/L]	not assessed
DO	>5.5 mg/L; no hypoxia	Average = 12.2 mg/L	not assessed
chl α	>70% of area below 10 µg/L [0.010 mg/L]; oligotrophic to mesotrophic	Average = 2.7 µg/L [0.027 mg/L]; oligotrophic	not assessed

[1] The interim TP guide for Lake Superior is 0.010 mg/L. Data from this assessment were collected in nearshore conditions, which were likely biased toward SLRE conditions due to seiche mixing.
[2] The USEPA's Great Lakes Biology Monitoring Program sampling point (SU 19) is not located within the boundary of the SLRAOC

The Removal Target and Criteria Have Been Met

Nutrient and sediment levels have not been shown to impair water quality and habitat, and do not restrict recreation, including fishing, boating, or body contact in the estuary and within western Lake Superior based on the following criteria:

1. *All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorous), organic matter, and sediment;*

   CONCLUSION: As confirmed by permit compliance staff within the WDNR, all eight pollutant discharge elimination system permits within the SLRAOC area are in substantial compliance as of December 2019. Also as of December 2019, permit compliance staff from the MPCA have confirmed that there are 32 pollutant discharge elimination system permits within the SLRAOC area, of which only 21 have nitrogen, phosphorus, TSS and/or CBOD compliance conditions,   Eleven permittees do not have nutrient-related requirements. Only one of the industrial permittee with nutrient-related requirements is noncompliant for TSS only and is following MPCA's compliance processes to address the noncompliance issues. The other 20 permittees with nutrient-related requirements are in substantial compliance with their permits.

Additionally, WLSSD and the City of Duluth are working to meet the conditions of a federal Consent Decree to reduce inflow and infiltration into the sanitary sewer system as a means to reduce sanitary sewer overflows.

Both the City of Superior and the City of Duluth have also invested in stormwater management practices and outreach to reduce the impacts of non-point source, urban runoff.

2. *Total phosphorus concentrations in the Lake Superior portion of the AOC do not exceed 0.010 mg/L (upper limit of oligotrophic range);*

   CONCLUSION: Multiple data sources indicated that the Lake Superior portion of the AOC met this criterion (Table ES-1). The Lake Superior data from the 2012 and 2013 BUI study (MA 6.01) showed that TP values were slightly higher than the BUI criterion of 0.010 mg/L for Lake Superior's western arm, with an average of 12.7 µg/L [0.0127 mg/L].[1] Additional water quality parameters sampled during the study show that DO was generally near saturation and the chl α concentrations were consistent with an oligotrophic water body. Paleolimnological study results (MA 6.03) for the Lake Superior sample location concluded that (1) water quality had improvemed from past periods of higher TP concentrations and (2) current prevailing concentrations of phosphorus did not exceed the TP criterion. Specifically, diatom-inferred TP results for the Lake Superior core indicated that western Lake Superior concentrations of TP were 3 - 6 µg/L (0.003 to 0.006 mg/L). TP results for western Lake Superior were available for 1996-2015 from the USEPA's Great Lakes Biology Monitoring Program (USEPA, Great Lakes Biology Monitoring Program, 1983-present; Central Data Exchange). The TP results (see Appendix 11) showed that from 1996-2015 the mean western Lake Superior TP concentration was 2.6 µg/L [0.0026 mg/L] and the range was 1.0 to 8.0 µg/L [0.001 to 0.008 mg/L] and never exceeded the criterion[2].

   [1] Data from this assessment was collected in nearshore conditions, which were likely biased toward St. Louis River conditions due to river water mixing with the lake at the sample sites.
   [2] The USEPA's Great Lakes Biology Monitoring Program sampling point is not located within the boundary of the SLRAOC.

3. *There are no exceedances of the most protective water quality standard for either state in the western basin of Lake Superior due to excessive inputs of organic matter or algal growth attributed to loadings from wastewater overflows into the St. Louis River;*

   CONCLUSION: Data used to assess St. Louis River water quality indicate that the BUI removal criteria (MA 6.01-6.04) have been met. Additionally, these data do not indicate any excessive algal growth in or inputs of organic matter to the SLRAOC. Wastewater

overflows are prohibited by Wisconsin Administrative Code Chapter NR 210.21 and are administered in Minnesota by State Statute 115.03, Minnesota Rule 7050.0210 and Minnesota Rule 7053.0205.
Wastewater overflows, including sanitary sewer overflows, treatment facility overflows and combined sewer overflows have been drastically reduced since the time of AOC listing. Wastewater permits administered by the states have included conditions to reduce and report overflow events. In addition, as of August 2016, all facilities in Wisconsin were required to have developed and be actively implementing a Capacity, Management, Operation, and Maintenance program for operation and maintenance of sanitary sewer collection systems with goals to help address issues of inflow and infiltration which are the primary causes of overflow events. Minnesota's wastewater permitees have met similar facility management requirements. Upgrades to wastewater and collection systems in the past decade have resulted in significant reductions in overflow events. The improvement in DO, TSS and nutrients (Bellinger, et al,, 2016) also support this conclusion.

4. *Total phosphorus concentrations within the St. Louis River portion of AOC do not exceed an interim guide of 0.030 mg/L (upper limit of mesotrophic range) or the most restrictive water quality standards. This ensures that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive productivity and nuisance conditions within the St. Louis River Estuary.*

   CONCLUSION: The 5 MA's that have been completed for this BUI indicated that water quality improvements in the SLRE and Nemadji River watershed have resulted in the majority of the AOC meeting the phosphorus criterion. In addition, other water quality parameters (TSS, DO and chl α) indicate nutrients and sediments are not causing an impairment. Data showed a dramatic decline in TP concentrations and sediment loading in the SLRAOC since the time of listing.

Public Involvement Process

Many types of public involvement activities are conducted as part of the SLRAOC program. Some are specific to projects and BUIs and others are related to the SLRAOC program more broadly and they are too numerous to be mentioned here. Three specific activities fall in the public involvement realm for this BUI:

1. <u>The activities associated with the BUI 6 technical team</u> (see Appendix 12 for the members and their affiliations). The technical team members assisted the SLRAOC Coordinators with activities associated with reaching the RAP's BUI 6 removal target, including: making recommendations on data collection and analyses, reviewing the findings, and providing input on the removal package.
2. <u>The process to obtain public input on the BUI removal package</u>. A thirty-day public comment period about the BUI 6 removal recommendation was held from February 24, 2020 through March 24, 2020. The draft removal document was placed on MPCA's SLRAOC web site and, over the course of the public comment period, there were 110 unique visitors. A public meeting was

scheduled for March 19, 2020, but had to be cancelled due to the need for social distancing due to the coronavirus pandemic. A cancellation notice was sent to the approximately 400 recipients on the SLRAOC's master contacts list and the notice was also shared by the St. Louis River Alliance on their Twitter and Facebook accounts. As an alternative to the meeting, the posters and presentation prepared for the meeting were posted on the MPCA SLRAOC web site and their availability was promoted in the cancellation notice. Only one comment was received during the comment period (see Appendix 12). Since it was in support of the removal recommendation, no changes to the removal document were needed.

3. Additional outreach. A presentation about the BUI 6 removal recommendation was made at the St. Louis River Summit on March 3, 2020 and to the Harbor Technical Advisory Committee on March 4, 2020. About 270 people attended the Summit and 35 people attended the Committee meeting.
4. SLRA Letter of Support. The St. Louis River Alliance is the designated citizens' action committee for the SLRAOC. Information about the BUI 6 removal recommendation was made available to the members of the Alliance's External Affairs/Issues Committee. This information included the BUI 6 removal document and the posters and presentation prepared for the public meeting. As a result of their review, a letter of support for the removal of BUI 6 was submitted on behalf of the St. Louis River Alliance (see Appendix 12).

Removal Recommendation

The results of the BUI 6 studies show multiple lines of evidence that, taken together, demonstrate improved conditions warranting a removal recommendation for BUI 6. Such a recommendation is supported by the BUI 6 technical team; the SLRAOC partners; and the SLRAOC Coordinators, leaders, and executive managers who collectively request that the Excessive Loading of Sediments and Nutrients BUI be removed from the SLRAOC. Feedback received as a result of the public involvement efforts also supports this removal request.

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Appendix 1

Water quality in the St. Louis River Area of Concern, Lake Superior: Historical and current conditions and delisting implications (Pertaining to management actions 6.01 and 6.02.)

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Water quality in the St. Louis River Area of Concern, Lake Superior: Historical and current conditions and delisting implications

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ABSTRACT

Water quality in the St. Louis River Area of Concern (AOC) was assessed at two stations over a 60 year period (1953–2013) and system-wide for 2012–2013 to determine if the AOC beneficial use impairment (BUI) of "Excessive loading of sediment and nutrients" should be considered for removal. Based on the time-series analysis, concentration and loading of total suspended solids and total phosphorus to Lake Superior from the St. Louis River have decreased over time, and episodic hypoxia in the mainstem of the estuary was eliminated after 1975. Detection of temporal patterns in nitrogen concentration and loading, particularly in the lower estuary, were complicated by Lake Superior nitrogen inputs and changes in wastewater treatment practices. For the system-wide assessment, sample locations were based on a probabilistic survey design. In 2012 and 2013, there was significant monthly (May–October) variability in water quality constituents. Based on area-weighted estimates, 60–85% of the estuary surface area was below BUI criterion for total phosphorus, total suspended solids, and chlorophyll *a*. Water quality in the western arm of Lake Superior in 2013 was indicative of oligotrophic conditions, satisfying delisting requirements. The long-term improvements in water quality followed improvements in watershed land-use practices and treatment of wastewater. The stratified system-wide survey provided unbiased estimates of spatial and temporal condition and identified some outlier sites. The data from this study supports the BUI removal process for the St. Louis River AOC.

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Introduction

The St. Louis River Estuary (SLRE), located at the western end of Lake Superior, is the largest estuary of the Great Lakes (50 km^2; Fig. 1). The SLRE is bordered by the port cities of Duluth, MN, and Superior, WI. The Duluth–Superior area developed rapidly during the late 1800s and early 1900s, a period of widespread deforestation throughout the watershed that increased sediment and nutrient loading to surface waters (Hartig and Thomas, 1988; Meyers, 2003). Industrial and urban development resulted in uncontrolled discharges of sewage, industrial waste, organic contaminants (e.g., polychlorinated biphenyls, polyaromatic hydrocarbons, and dioxins), and heavy metals into the estuary (Dole and Wesbrook, 1907; MPCA and WDNR, 1992). Early water quality surveys reported sediment contamination from sawmill waste, tar substances, and organic matter, and episodic anoxia during summer (MSBH et al., 1929). These conditions virtually eliminated aquatic life in some areas of the estuary. Tertiary treatment of municipal and industrial wastewater began in 1978 with the establishment of the Western Lake Superior Sanitary District (WLSSD; MPCA and WDNR, 1992).

The Great Lakes Water Quality Agreement between the United States and Canada (http://epa.gov/grtlakes/glwqa/1978/annex.html#annex 2; site accessed 1/2015) designated 43 coastal ecosystems across the Great Lakes as areas of concern (AOC), defined as locations having significantly degraded chemical, physical, and biological attributes (referred to as beneficial use impairments, or BUIs). Nine BUIs were identified for the SLRE: restrictions on fish and wildlife consumption; degraded fish and wildlife populations; fish tumors and other deformities; degradation of benthos; restrictions on dredging; excessive loading of sediment and nutrients to Lake Superior; beach closings/body contact; degradation of

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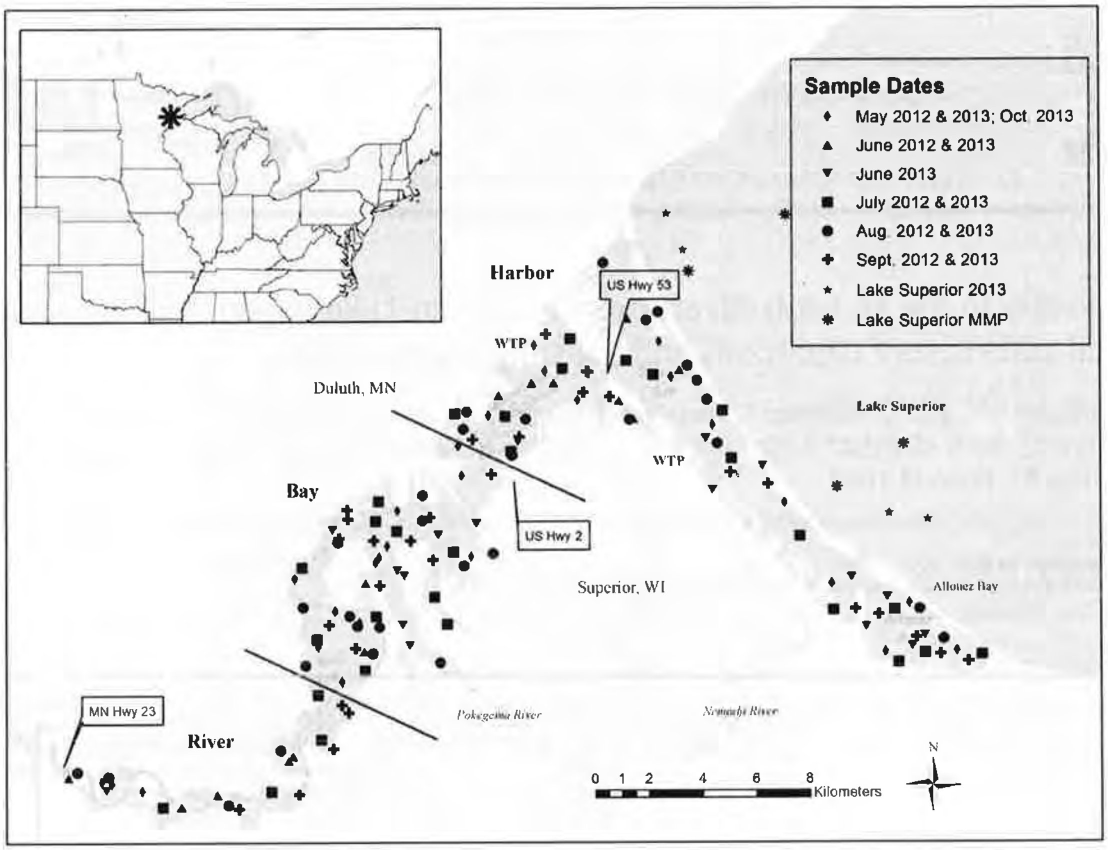

Fig. 1. Extent of the St. Louis River Estuary (SLRE) from the Fond du Lac Dam (upriver) to the western arm of Lake Superior. Milestone Monitoring Program (MMP) historic monitoring sites were at MN Hwy 23 ("Upper Estuary"), US Hwy 53 ("Lower Estuary"), and Lake Superior. Approximate zone delineations for the probabilistic sampling design applied in 2012 and 2013 are the head of Spirit Lake (River-Bay) and the US Highway 2 Bridge (Bay-Harbor). Lake Superior sites sampled in 2013 were randomly selected but meant to be near the MMP stations. Abbreviations: WTP = water treatment plant.

esthetics; and loss of fish and wildlife habitat (MPCA and WDNR, 1992; MPCA, 2013). To remove BUIs and delist an AOC, the U.S. Environmental Protection Agency (EPA) requires that condition indicators and delisting targets be established by local advisory groups through a remedial action plan (RAP) (Hartig and Thomas, 1988; US Policy Committee, 2001). Goals of the RAP include making recommendations of necessary remediation and restoration actions and developing BUI removal indicators and targets (MPCA and WDNR, 1992; US Policy Committee, 2001; MPCA, 2013).

One of the most significant developments toward water quality improvement in the SLRE that occurred before AOC listing was the establishment of the WLSSD in Duluth in 1978 (MPCA and WDNR, 1992). Phosphorus loadings from municipal treatment plants were reduced 80%, after which nuisance algal blooms became infrequent. However, there was still concern about water quality and nutrient loadings to Lake Superior, necessitating the water quality BUI listing (MPCA and WDNR, 1992). Following the Water Quality Agreement and RAP development, efforts to identify and remove impairments included: controlling storm water overflows, protection of existing forest and riparian areas, enhanced erosion control efforts, and implementation of agriculture and construction best management practices (MPCA and WDNR, 1992; MPCA, 2013). These efforts have improved water quality to the extent that nutrient and sediment loadings may have been reduced to concentrations consistent with removal of the excessive sediment and nutrient BUI. Loading of phosphorus has only been quantified from its major source, the WLSSD treatment plant (Fig. 1). However, the cumulative effect of the improvements and actions through time and on current conditions has yet to be assessed. The SLRE benefits from having a long history of water quality monitoring. In this paper, we analyze 60 years of water-quality data (1953–2013) from two fixed stations to determine whether nutrient and sediment concentrations and loads have changed in the SLRE.

We also describe current water quality conditions, compare concentration estimates with BUI removal criteria established by stakeholders, and estimate the proportion of the SLRE surface area below threshold (criterion) concentration. To estimate current conditions, we applied a probabilistic system-wide sample design that allowed us to assess seasonal as well as spatial variability in 2012 and 2013 (Crane et al., 2005; Messer et al., 1991). This study documents changes in BUI indicator values over time and it shows the utility of a spatially-balanced monitoring design for whole-system characterization necessary for BUI removal and AOC delisting.

Materials and methods

Study area

The 288-km long St. Louis River (9412-km^2 watershed) has an estimated mean daily discharge of 73 m^3 s^{-1} at the U.S. Highway 53 Bridge (Fig. 1). Our study area comprised the estuarine portion of the river (i.e., the reach of river subject to seiche-induced bi-directional flow; Stortz and Sydor, 1980), which extends from below the Minnesota Highway 23 Bridge, near the Fond du Lac Dam, to Lake Superior (including the Duluth–Superior Harbor), and the Lake Superior portion of the AOC, which extends approximately 16 km into the lake. The SLRE is situated behind a natural sand bar that restricts river-lake exchange to inlets at Duluth, MN, and Superior, WI. The upper SLRE ("river" section; Fig. 1) has a lotic character with generally intact riparian and floodplain habitat. In contrast, the lower 20 km of the SLRE ("bay" and "harbor" sections; Fig. 1) has a lentic character and has been deepened by dredging, shoreline stabilization and hardening are extensive, and the riparian zone is highly developed. The SLRE is mostly shallow (mean depth ≈ 3.0 m) outside of the navigation channels (>7 m deep), and is generally well mixed. Estuarine waters have a slightly basic pH (ca. 7–8) and low transparency owing to high concentrations of dissolved organic carbon (DOC = 10–35 mg/L). Periodic seiche flows of about 8 h duration and weak semi-diurnal tides cause daily variation in water height in the SLRE of about 13 cm (Trebitz, 2006).

Historical water quality data

Long-term monitoring in the SLRE was conducted by the Minnesota Pollution Control Agency (MPCA) under the Milestone Monitoring Program (MMP). We accessed MMP data from the STORET database (www.epa.gov/storet; site accessed 1/2015). We analyzed data from the two fixed MMP stations within the SLRE with the longest periods of record: the Highway 23 Bridge ("upper estuary station") (1953–2008) and downriver at the Interstate 535/US Highway 53 John A. Blatnik Bridge ("lower estuary station") (1973–2008) (Table 1; Fig. 1). These two stations essentially bound the SLRE, providing data on nutrients and sediments imported from upriver and exported to Lake Superior via the harbor. The MMP generally included one surface sampling effort per month when the river was ice-free; if more than one sample was collected in a month, we averaged the data. For values below detection limits, we used one-half the minimum detection level as reported by MMP (TSS: 0.1 mg/L, nutrients: 0.01 mg/L; Table 1). We focused on status indicators for the St. Louis River BUI "Excessive loading of sediment and nutrients", which include concentrations of dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), dissolved nitrate-N (NO_3^-), ammonium/ammonia-N (NH_4^+), and total suspended solids (TSS) (MPCA, 2013). Chlorophyll *a* (chl *a*) is also a status indicator for this BUI, but was not historically measured. To estimate loadings, we obtained mean daily discharge for the sampling dates from the nearest stream gage (Scanlon, MN; USGS gage #04024000), located 17 km upriver of the Fond du Lac Dam. To account for tributary inputs between the gage and MMP monitoring locations, we estimated cumulative downstream discharge to each station using the National Hydrography Dataset Plus (NHD Plus) unit runoff method (Research Triangle Institute, 2001). We calculated an associated discharge index for the upper and lower estuary monitoring stations (i.e., the estimated cumulative discharge at the station relative to the Scanlon stream gauge; 1.04 and 1.08, respectively), and corrected daily discharge values for each monitoring station by multiplying the Scanlon discharge by the respective index value. In addition, some along-thalweg DO data were available to depict historical changes in hypoxia (Hoffman et al., 2012; MDH, 1961; MSBH et al., 1929).

To characterize historical conditions in the Lake Superior portion of the AOC and compare them to present-day measures, we summarized MMP data from four stations in Lake Superior sampled between October 1974 and May 1975. The Lake Superior data are few, but they represent a period prior to improved wastewater treatment (Table 2; Fig. 1).

Current conditions survey sample design

Sites sampled in 2012 and 2013 were selected using a generalized random-tessellation stratified (GRTS) design which is based on the Environmental Monitoring and Assessment Program (EMAP; http://www.epa.gov/emap/; site accessed 1/2015; Crane et al., 2005; Messer et al., 1991). The site designation design provides unbiased area-weighted parameter estimates of condition across a defined sample "frame" (e.g., a region, watershed, or estuary) by generating random sample locations (Stevens and Olsen, 2003, 2004). The SLRE sample frame represented 4376 hectares (ha), or 90%, of the total surface area from the Fond du Lac Dam to Lake Superior. Across the sample frame, 150 unique sites (i.e., locations to conduct a sampling event) were identified and subsequently assigned to one of three zones with distinct hydrologic and geochemical character: the St. Louis River ("river" zone; 403 ha; n = 19), the central estuary ("bay" zone; 1482 ha; n = 57), and the lower estuary ("harbor" zone; 2491 ha; n = 74; Fig. 1). Sample site weights, in hectares, were determined by dividing the total number of sites within a zone by that zone's area (Stevens and Olsen, 2003). Thirty of the 150 sites were randomly selected and assigned to one of five months (May–September) and sampled (Fig. 1). Because we added a sixth sampling month in 2013, in October we resampled the 30 sites from May. Sampling typically occurred during the third week of each month. One sample was lost from the May 2012 sampling, and only 14 sites were sampled in June 2012 due to unsafe conditions following a 500-year recurrence interval flood (Czuba et al., 2012). Site weights were adjusted to ensure the entire sample frame was represented.

In 2013, we sampled the Lake Superior portion of the AOC at four haphazardly-selected sites near two of the MMP sites from the 1974–1975 survey (Fig. 1).

Table 1
Available historic data from the Minnesota Milestone Monitoring Program for the upper and lower estuary stations (Minnesota Highway 23 and US Highway 53, respectively; Fig. 1), and sample sizes for the Mann Kendall (M–K) test applied to both monthly concentration (conc.) data and annual load estimates with associated *p*-values (corrected for serial autocorrelation; see text for details). Abbreviations: TP = total phosphorus; NO_3^- = nitrate; NH_4^+ = ammonium; TSS = total suspended solids; DO = dissolved oxygen.

Station	Parameter	Available (missing)	n (non-detects)	Mean n/yr (range)	M–K test n, conc./load	M–K test*p*-value,conc./ oad
Minnesota Highway 23	TP	1958–2008 (1960–1961, 1966, 1997–2001, 2006)	571 (4)	14 (2–44)	369/43	<0.0001/<0.0001
	NO_3^-	1958–1996 (1961–1967)	334 (52)	7 (1–12)		
	NH_4^+	1960–2008 (1966, 1996, 2001, 2006)	548 (159)	12 (1–28)		
	TSS	1953–2008 (1957–1959, 1966, 1997–2001, 2006)	549 (11)	12 (1–22)	379/47	<0.0001/0.101
	DO	1953–2008(1960–1961, 1966, 1997, 1999, 2001–2002, 2004, 2007)	206 (0)	8 (2–12)		
US Highway 53	TP	1973–2008 (1995–1998, 2000–2001, 2006)	241 (1)	8 (1–15)	240/30	<0.0001/<0.0001
	NO_3^-	1976–2008 (1996, 2001, 2006)	228 (6)	7 (2–12)		
	NH_4^+	1973–2008 (1996, 2001, 2006)	267 (160)	8 (1–15)		
	TSS	1973–2008 (1995–1998, 2000–2001, 2006)	241 (0)	8 (1–15)	240/30	0.006/0.005
	DO	1973–2008(1996, 2001)	265 (0)	8 (1–12)		

Table 2
Mean water quality concentrations from the MPCA's Milestone Monitoring Program at four stations located in Lake Superior within the St. Louis River Area of Concern (Fig. 1). For all samples, data were available from three dates (12 October 1974, 24 October 1974, 13 May 1975) for multiple (generally three) depths at each station. Values shown are the daily means averaged across depths. Abbreviations: TP = total phosphorus; NO_3^- = nitrate; NH_4^+ = ammonium; TSS = total suspended solids.

Latitude (N)	Longitude (W)	TP (μg/L)	NO_3^- (μg/L)	NH_4^+ (μg/L)	TSS (mg/L)
46.7233	−92.0244	10.9	285.6	46.1	4.9
46.7331	−92.0022	13.7	382.8	55.6	4.6
46.7725	−92.0739	12.3	332.8	34.4	4.1
46.7853	−92.0414	9.2	317.8	62.2	2.5

Water sample collection and chemistry

At each site, we measured DO with a Hydrolab DataSonde (Hach Hydromet, Loveland, CO, USA). A 4-L surface water sample was collected and kept on ice for transport to the lab. Samples were stored at 4 °C and processed within 24 h. Water samples were analyzed for TSS by gravimetric analysis (APHA, 1998; method 2130B), and for chl *a* by flourometry (TD-700 Turner Designs, Sunnyvale, CA, USA) after extraction with magnesium saturated acetone (Welschmeyer, 1994). Total N, NO_x, NH_4^+, and TP were measured on a Lachat 8000 flow-injection analyzer (APHA, 1998; Lachat Quickchem methods, Lachat Instruments, Loveland, CO, USA). Unfiltered subsamples were digested by persulfate digestion for TP and TN (APHA, 1998). Total phosphorus was determined by the molybdate-ascorbic acid method (APHA, 1998; Lachat Quickchem method 10-115-01-1-B). Total N and dissolved NO_x (0.45-μm membrane filtered) were analyzed by the cadmium reduction method (APHA, 1998; Lachat Quickchem method 10-107-04-1-O). Ammonium was determined on filtered (0.45-μm pore membrane) samples on the Lachat analyzer with the phenolate method (APHA, 1998; Lachat Quickchem method 10-107-06-1-F; 2012 samples only) and salicylate method (Lachat Quickchem method 10-107-06-2-C; 2013 samples only). The methods were changed to reduce hazardous waste generation but were compared to ensure similar results. One NH_4^+ sample from July 2013, a TN and TP sample from August 2013, and a TP sample from September 2013 were lost or did not meet lab quality criteria and were not used in the final analyses.

Data analysis

We used the Mann–Kendall test to determine whether there was evidence for a monotonic decrease in TSS or TP monthly concentrations and annual loads over time. We used a one-tailed test with a continuity correction and the Hamed and Rao method (1998) to correct for serial autocorrelation. We used this non-parametric test because there were long periods for which data were unavailable (Table 1). We $\log_{10}$-transformed TSS and TP before analysis. Because TSS and TP concentrations demonstrate seasonality, we used a seasonal Mann–Kendall test using monthly data (Electronic Supplementary Material (ESM) Fig. S1). To compare trends between stations, we used the nonparametric Sen's slope estimator.

Annual TSS and TP loads were estimated using the ratio method (Preston et al., 1989): $L = (l / q_m)Q$, where L is the estimated annual load in metric tons (t), l is the average of daily loads, q_m is the average daily discharge on sample dates, and Q is the total annual discharge. The method is appropriate because we have a nearly complete discharge record, but only monthly nutrient and sediment concentration records (Quilbé et al., 2006). To account for the influence of lake water mixing at the lower estuary station due to seiches, we used a conservative mixing model to normalize lower estuary historical TSS and TP concentrations to 100% river water (i.e., $[TSS]_{river}$, where $[TSS]_{mixed} = f_{lake} \times [TSS]_{lake} + f_{river} \times [TSS]_{river}$, and $1 = f_{lake} + f_{river}$); we assumed a constant $[TSS]_{lake}$ of 1.93 mg/L and $[TP]_{lake}$ of 7 μg/L (Hoffman et al., 2012). The fraction river water (f_{river}) was estimated from mean daily discharge (q_d) using logistic regression ($f_{river} = a / (1 + (q_d / X_0)^b)$) to estimate f_{river} at the U.S. Highway 53 bridge at a given daily discharge level (ESM Fig. S2). The data for the logistic regression came from the 2012 and 2013 sampling; q_d data were from the Scanlon gage and f_{river} was estimated using measured magnesium (Mg) as a conservative tracer in a conservative mixing model ($[Mg]_{lake}$ was 2.9 mg/L, and $[Mg]_{river}$ was the value measured at the upper estuary station, which is above the mixing zone; Hoffman et al., 2012; Morrice et al., 2009). The regression met statistical assumptions of normality (Shapiro–Wilk test, $p = 0.3$) and constant variance ($p = 0.5$) and was significant ($p = 0.001$, $r^2 = 0.81$; $a = 1.07 \pm$ standard error [SE] 0.22, $b = -1.13 \pm$ SE 0.69, $X_0 = 16.63 \pm$ SE 7.59). Based on the regression, when Scanlon discharge is at 15 $m^3 s^{-1}$, water at the lower estuary station is of half lake and half river origin, whereas at a Scanlon discharge ≥130 $m^3 s^{-1}$, all the water is of river origin.

Temporal trends in DO (upper estuary only), NO_3^- ($\log_{10}(x + 1)$-transformed) and NH_4^+ ($\log_{10}(x + 1)$-transformed) concentrations were examined using local regression (LOESS; SigmaPlot 13.0, Systat Software, Inc., San Jose, CA, USA) because the time-series were not monotonic (i.e., entirely increasing or decreasing) and thus not suitable for the Mann–Kendall test. The local regressions were fit iteratively by varying the polynomial order (1–3) and sampling proportion (0.1–0.9) to generalize the data over a 5–10 year period. Monthly DO data were from late summer (July–September), when the annual seasonal low typically occurs; NO_3^- and NH_4^+ data were monthly data. For the lower estuary station, monthly NO_x and NH_4^+ concentrations were seiche-corrected, using the combined conservative mixing model and logistic regression approach previously described. At the lower estuary station this approach resulted in some negative concentration values, indicating the estuary was acting as a net N-sink relative to the inputs. For the mixing model, Lake Superior NO_3^- concentration increased through time, ranging from 0.28 to 0.36 mg/L (Finlay et al., 2007), and NH_4^+ concentration was constant, 0.1 mg/L, based on MMP data. Along-estuary thalweg DO data from summer months were compared among years when data were available (noted above: 1929, 1961, and 2007) to identify along-estuary changes.

For the 2012 and 2013 survey sampling, area-weighted mean TSS, TP, and chl *a* concentration estimates for each month, longitudinal zone, and summarized within a year across months and zones were compared with draft BUI targets derived for waters of Northern Minnesota (15 mg/L TSS, 30 μg/L TP, and 10 μg/L chl *a*; Heiskary et al., 2013; MPCA, 2013) using a one sample Z-test calculated as: $Z_{score} = (\overline{X}_w - T) / SE_w$, where $\overline{X}_w$ is the area-weighted mean, T is the BUI criteria, and SE_w is the area-weighted standard error. We differentiated monthly and zone water quality concentration differences by overlap in 95th percentile confidence intervals (CI). While the annual system-wide average concentration is most important for BUI removal, the other estimates revealed temporal changes and potential longitudinal variations in water quality across the SLRE. Lake Superior data were not based on a probability design and so monthly averages were compared using one-way ANOVA. Data were tested for normality using the Shapiro–Wilk test and were $\log_{10}$ transformed to approximate a normal distribution. Statistical analyses were conducted using Systat v.11.00.01 (Systat Software, Inc., San Jose, CA, USA).

Results

Long-term water quality trends

Annual mean TP concentrations and load to Lake Superior declined significantly and at similar rates at both stations over time (Table 1, Fig. 2A, B). For TP concentration, the decline (Sen's slope) was −0.017

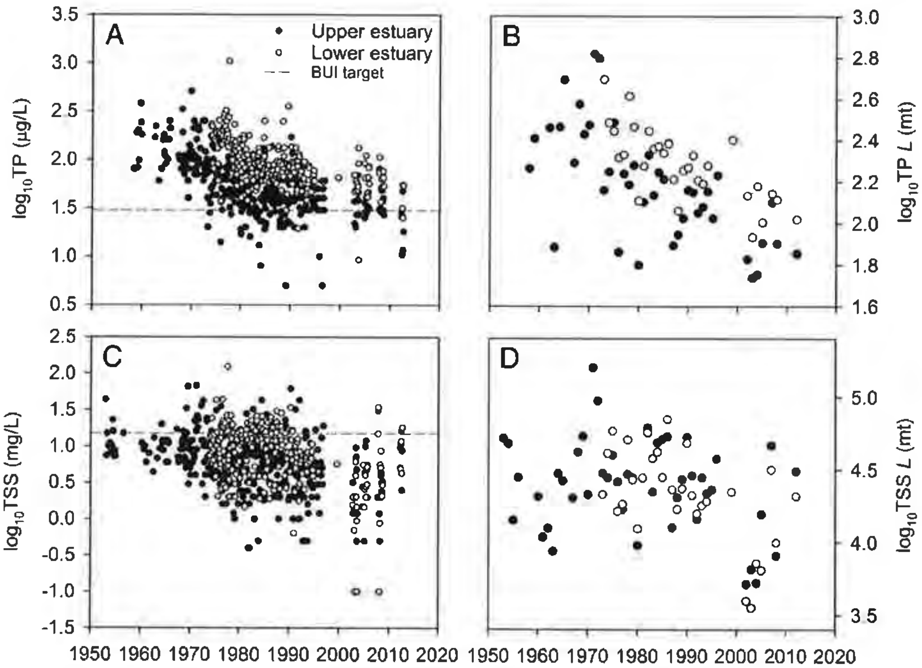

Fig. 2. Temporal trends in monthly total phosphorus (TP) and total suspended solids (TSS) concentrations panels A, C), and annual TP and TSS loads (panels B, D) measured at the upper (closed circle) and lower (open circle) estuary monitoring stations. There was a significant decline in all parameters except TSS loading at the upper estuary station (Mann Kendall test, $\alpha = 0.05$; see text for details). The dashed lines indicate the targets for Beneficial Use Impairment removal (30 μg/L TP, 15 mg/L TSS).

$\log_{10}$(TP, μg/L) yr^{-1} at the upper estuary station and -0.023 $\log_{10}$(TP, μg/L) yr^{-1} at the lower station. Though concentrations have declined, monthly and annual average TP concentrations for the two stations have exceeded the BUI criterion over the period of record at the two stations. For TP load, however, the declines (Sen's slope) were the same, ≈ -0.014 $\log_{10}$(TP *L*, t) yr^{-1}. The ratio between the mean annual load (l) and discharge (q_m), the mean mass per unit discharge, revealed a decline over time, indicating that the decline in TP load was the result of changes in TP concentration rather than discharge. Total P concentrations in the lower estuary were higher than in the upper estuary, implying there were internal TP sources (e.g., resuspension of sediment) or tributary additions. From 2002 to 2012, the estimated mean annual TP load was 76 t at the upper estuary station and 133 t at the lower estuary station, for an average annual net addition of 56 t.

Annual mean TSS concentrations significantly declined over time at both stations (Table 1, Fig. 2C and D). The decline (Sen's slope) was -0.016 $\log_{10}$(TSS, mg/L) yr^{-1} at the upper estuary station and -0.022 $\log_{10}$(TSS, mg/L) yr^{-1} at the lower station. Average annual TSS concentrations were above the BUI criterion three times prior to 1978, and monthly exceedances through 2008 were rare. After 2000, relatively low TSS concentrations (≤5 mg/L) were measured at both stations except for two instances (2007, 2012) in which elevated TSS concentrations (31.0 and 16.3 mg/L, respectively) coincided with large discharge events (354 and 120 $m^3 s^{-1}$, respectively). Loading of TSS significantly declined at the lower estuary station, but not at the upper station (Table 1); and TSS loads to Lake Superior declined faster at the lower estuary station (Sen's slope -0.018 $\log_{10}$(TSS *L*, t) yr^{-1}) than the upper estuary station (-0.003 $\log_{10}$(TSS *L*, t) yr^{-1}; Fig. 2D). At the beginning of the time-series the estuary between stations was a source of TSS, whereas it is currently similar between stations (Fig. 2). As with TP loads, the ratio between the mean annual load (l) and discharge (q_m) declined over time, indicating that the change in TSS load was due to change in TSS concentration.

At the upper estuary station, late-summer (July–September) DO concentrations increased from 1953 to ca. 1990, after which it leveled-off and possibly declined slightly (Fig. 3A). Data from the lower estuary followed a similar pattern. Since 2000, monthly summer concentrations were always above 5.5 mg/L at both stations. At both monitoring stations, the last year of summer hypoxia (<2 mg/L) was 1964; values <5 mg/L were infrequent after 1975. The period for which hypoxia was present somewhere in the river was likely longer than the time-series suggest, however, because the available longitudinal DO concentration data indicate that the lowest DO concentrations in the river were typically located between the upper and lower estuary stations (i.e., between river km 20 and 35; Fig. 4).

Nitrate concentrations in the upper estuary were highest in the 1950s and declined until about 1970, after which they have been relatively constant (Fig. 3B). At the lower estuary station, for which we have a shorter record, NO_x concentrations have been more variable, possibly due to seiche-dominated inputs of NO_x from Lake Superior (Sterner, 2011), with sporadic low concentrations measured for 1988–2003. Ammonium concentrations were generally higher in the lower estuary than the upper estuary except from 1987 to 1997 when concentrations were similar (i.e., LOESS fits) between stations (Fig. 3C). There were numerous non-detections in the early part of the time-series, but there are no independent data to verify these observations.

2012 and 2013 survey summaries

System-wide TP concentrations ranged from 4.7 μg/L (May 2012 in the bay) to 195.4 μg/L (May 2012 in the harbor) with a median concentration across years of 28.7 μg/L (Table 3). The weighted mean TP concentration for 2012 (30.9 μg/L) and 2013 (30.7 μg/L) were not significantly different from the BUI criterion (30 μg/L; Tables 3 and 4). In July 2012 and in June and July 2013, weighted mean TP concentrations were significantly above the BUI criterion. May and August of 2012 and 2013 had TP concentrations significantly less than the BUI criterion (Tables 3 and 4). Total P concentrations in the bay in 2012 were significantly above 30 μg/L; the river in 2012 was significantly below the criterion.

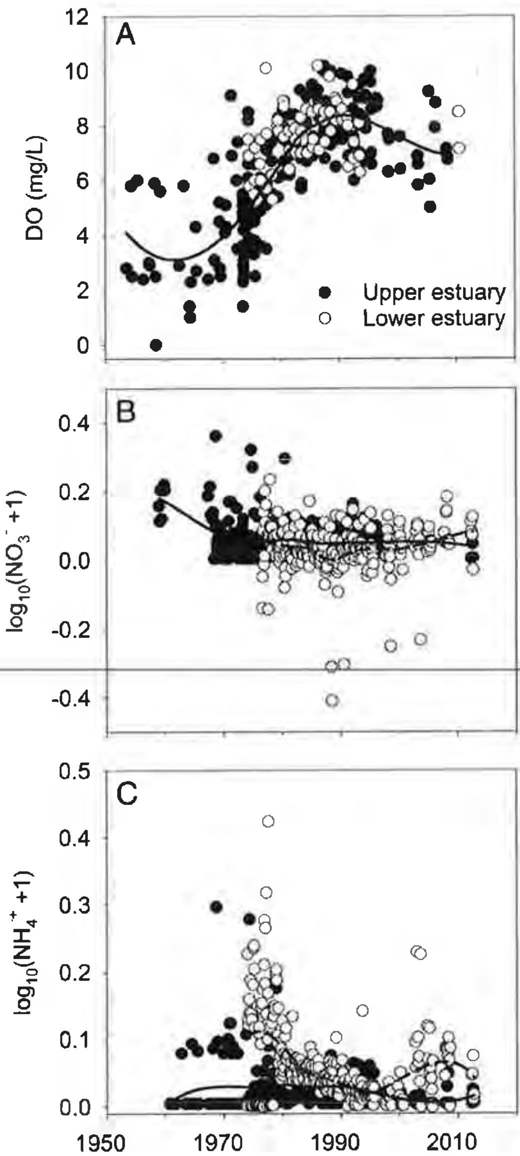

Fig. 3. Temporal trends in dissolved oxygen (DO; A), nitrate (NO_3^-; B) and ammonium (NH_4^+; C) measured in the upper (closed circle) and lower estuary (open circle) monitoring stations and LOESS regressions (lines). For A, the solid line is the LOESS fit to the upper estuary station only (3rd order, proportion = 0.8); lower estuary station data are added for a visual comparison. For B, the solid line is the LOESS fit to the upper estuary station (3rd order, proportion = 0.7) and the dashed line is the LOESS fit to the lower estuary station (3rd order, proportion = 0.6). For C, the solid line is the LOESS fit to the upper estuary station (3rd order, proportion = 0.6) and the dashed line is the LOESS fit to the lower estuary station (3rd order, proportion = 0.7).

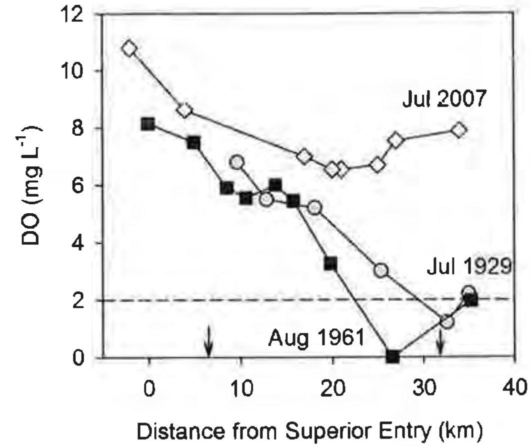

Fig. 4. Historical late-summer thalweg dissolved oxygen (DO) concentrations (MSBH et al., 1929 [closed circles], MDH, 1961 [closed squares]) compared to a 2007 survey (open diamonds; J. Hoffman, unpublished data). Arrows indicate locations of upper estuary and lower estuary monitoring stations. Where the River flows into Lake Superior (inlet near Allouez Bay) is at km 0.

In both years, about 60% of SLRE area was below the BUI removal criterion (Fig. 5A).

Dissolved oxygen concentration in the SLRE ranged from 4.5 mg/L (July 2012 in the bay) to 13.3 mg/L (October 2013 in the river), with a median of 8.3 and 9.5 mg/L in 2012 and 2013, respectively (Table 3). Lowest weighted mean DO concentration (6.4 mg/L) was measured in July 2012. Concentrations differed among months in both years. In 2013, there were significant differences among zones (Table 3).

Total N concentrations ranged from 399 to nearly 4300 μg/L (Table 3), and had a median concentration across years of 990 μg/L. Lowest concentrations were measured in August and September (Table 3). Total N did not differ among zones in either year. Between years, NO_x ranged from 1.6 to 418.7 mg/L. Median concentrations for the SLRE were 153.4 and 135.4 μg/L in 2012 and 2013, respectively. In both years, greater NO_x concentrations were measured in the harbor than elsewhere. Total NH_4^+ ranged from 7.0 to 3645.0 μg/L (Table 3). Greatest NH_4^+ concentrations were measured in June and July, at sites nearest the WTPs (Fig. 1), and differed among zones.

Total suspended solid concentrations varied from 2.3 mg/L (October 2013 in the bay) to 71.4 mg/L (September 2012 in the harbor) (Table 3) with a median concentration across years of 8.6 mg/L. The weighted mean TSS concentration for 2012 (12.0 mg/L) and 2013 (9.9 mg/L) was significantly below the BUI criterion of 15 mg/L (Tables 3 and 4). Total suspended solid concentration was above the BUI criterion in July and September 2012 and June 2013 (Tables 3 and 4). Weighted means within zones were significantly below the BUI criterion in both years. In 2013, there were significant differences among zones. At least 85% of the area of the SLRE had TSS concentrations below 15 mg/L in both years (Fig. 5B).

Chlorophyll *a* concentrations ranged from 0.6 μg/L (October 2013 in the harbor) to 49.9 μg/L (September 2012 in the harbor) (Table 3). The weighted mean chl *a* concentrations in 2012 and in 2013 were significantly below the BUI criterion of 10 μg/L (Tables 3 and 4). In both years, chl *a* concentrations were greatest in August and September (Table 3). Chlorophyll *a* concentrations exceeded the BUI criterion in September 2012 and August 2013. Between zones across all months, chl *a* concentrations in the bay and river were significantly below the BUI removal criterion (Tables 3 and 4). For both years, over 70% of the area of the SLRE had chl *a* concentrations below the criterion (Fig. 5C).

In 2013, average TSS concentration at Lake Superior sites was 4.4 mg L, ranging from 0.4 to 15.1 mg/L (Table 5). Chlorophyll *a* concentration was greatest in June (4.5 mg/L) and averaged 2.7 mg/L. Total phosphorus concentrations were greatest in June and averaged 12.7 μg/L. Dissolved oxygen was always at or near saturation; concentration for the season averaged 12.2 mg/L. Total N concentration averaged 606.9 μg/L with 2–5% as NH_4^+ and 35–65% as NO_x (Table 5).

Discussion

Documentation of system recovery is required for BUI removal and AOC delisting. In this study, we utilized long-term fixed station data

(1953–2008) and data from a system-wide monitoring study (2012–2013) to show the remarkable improvement in water quality in the St. Louis River estuary over the past 60 years, driven primarily by changes in land-use practices within the watershed and improved wastewater treatment. The system-wide surveys provide area-weighted estimates of system condition relative to BUI criterion, and detail spatial variability in water quality across the SLRE. The condition estimates derived from the probability design show that most of the area of the SLRE was similar in condition or better than conditions defined by BUI removal criteria, and that the other parameters measured were not indicative of eutrophic conditions.

Long-term change in water quality

Data from the two fixed monitoring stations demonstrate that sediment and nutrient inputs to Lake Superior have declined over time. In the Laurentian Great Lakes region, eutrophication of coastal systems from increased delivery of soil-derived phosphorus began in the mid-1800s, and anthropogenic eutrophication from soil- and wastewater-derived nutrients increased until 1965–1975, after which changes to nutrient management were implemented basin-wide (Meyers, 2003). In Minnesota, logging activity was greatest from 1860 to 1931 (White and Mladenoff, 1994). These timelines are consistent with changes in the SLRE, particularly the gradual improvements in DO concentration and declines in TSS and TP concentrations during 1960–1970. As logging declined throughout the first half of the 20th century, loading of TSS (and associated TP) from the watershed and the discharge of sawmill waste to the SLRE declined (Smith and Moyle, 1944). The relative difference between the two monitoring stations in the change in annual TSS load suggests that changes in organic waste inputs were more influential than changes in watershed-based inputs. Lower loadings of organic waste likely contributed to a reduction in biological oxygen demand and hypoxic conditions, with recovery of DO beginning around 1966; by 1976 hypoxia was rare. Improved wastewater treatment since the 1970s are estimated to have contributed to an 80% reduction in TP loadings to the estuary compared to the years before the WLSSD (MPCA and WDNR, 1992).

Nitrate concentration at the upper SLRE station was relatively stable over time; variability in NO_x was greater at the lower estuary station. Low NO_x values measured during summer months from 1987 to 2004 suggest periods of high primary production, which is consistent with declines in NH_4^+ at both stations. Corroborating estimates of primary productivity or chl *a* are lacking, however. The increase in NH_4^+ after 2001 at the lower estuary station was coincident with the implementation of a biosolids program at WLSSD (http://www.wlssd.com/wastewater_biosolids.php), the result of which was increased ammonium concentration in plant discharge necessary to manage the quality of the biosolid product. Lake Superior is also a substantial source of NO_x to the lower SLRE (Bellinger et al., 2014; Sterner, 2011). Because of lake inputs of NO_x, the highest denitrification rates in the system occur in the harbor (Bellinger et al., 2014). Algal biomass was greater in the harbor than elsewhere (Table 3), presumably owing to higher N-availability. Nitrogen concentrations in the lower SLRE should continue to be monitored because elevated NH_3/NH_4^+ and NO_x concentrations can negatively affect aquatic organisms and are expensive to remove through wastewater treatment (Compton et al., 2011).

Current conditions

The 2012–2013 surveys document that most of the SLRE water quality was at or below impairment criteria designated in the AOC RAP (MPCA, 2013). Between sample years, we found agreement in our system-wide seasonal and monthly water quality parameter estimates. Spatial and seasonal variation of water quality was evident in the SLRE, as it is in other Great Lakes coastal embayments (Hiriart-Baer et al., 2009; Steinman et al., 2008). In light of the monthly and longitudinal differences in water quality parameter concentrations, consideration must be given to sampling frequency as well as site selection as part of a system-monitoring plan.

The size and location of the SLRE present unique challenges for monitoring because of the extent of the mixing zone with Lake Superior water, the variability in tributary watershed geology (Bartsch et al., 2015), and the uneven distribution of riparian development (Crane et al., 2005; MPCA, 2013). The GRTS design was spatially stratified *a priori* in an effort to capture the longitudinal heterogeneity of the SLRE and to identify potential outliers. For example, Allouez Bay and the adjacent Nemadji River are naturally turbid because of the clay-dominated soils of their watersheds. By weighting sites, which decreased the influence of Allouez Bay on the mean, estimated mean TSS concentration across all months was 28% lower in the harbor zone than the unweighted arithmetic mean. The sample design provides flexibility as it can be modified to increase monitoring intensity or frequency in specific zones (e.g., those consistently above a criterion or being in the highest 5% of all parameter concentrations).

Although most of the SLRE area (>50%) was below criterion values for each parameter (Fig. 5), whether or not this is sufficient justification for BUI removal is up to local stakeholders and EPA. We have shown how a probability site selection process enables estimation of the proportion of a system above or below target condition criteria (Jackson et al., 2000; Messer et al., 1991); this is information that cannot be derived from repeated measures at fixed stations. A similar probabilistic survey has been used in the SLRE for characterization of sediment contaminants and invertebrate communities (Crane et al., 2005). The authors concluded that the EMAP survey design is an effective means of tracking system health and condition.

Total P concentrations in 2012–2013 were lowest in the river zone, and increased in the zones downriver. The spatially-comprehensive survey corroborated the long-term trends observed between the upper estuary station (MN Highway 23) and lower estuary station (Highway 53 Bridge). Greater TP concentrations in the central and lower estuary could be due to internal loading by sediment resuspension or tributary sources. For example, the Pokegama River is a naturally turbid system, with average TP and TSS concentrations of 60 μg/L and 18 mg/L, respectively (B.J. Bellinger, unpublished data). Non-point sources of phosphorus to the lower SLRE have been estimated to represent 50–90% of total inputs (MPCA and WDNR, 1992). Watershed management efforts and benchmarks continue to be pursued and prioritized by local agencies in order to reduce TP and TSS loads (MPCA, 2013).

Dissolved oxygen concentrations from the 2012–2013 survey corroborated observations at the long-term monitoring stations, indicating that hypoxia (DO < 5 mg L^{-1}) was not wide-spread in the SLRE (<1% of all stations were hypoxic at time of sampling). However, we did not sample all sites early in the morning to capture lowest possible concentrations. Periodic, localized hypoxia is also known to occur in small embayments along the Wisconsin shoreline of the SLRE (R. Garono, personal communication). Those small embayments and other similar backwaters comprise a relatively small area of the SLRE, and therefore had a low probability of sampling under the probabilistic sampling design. However, they have physicochemical characteristics important to aquatic organisms and nutrient cycling functions of the SLRE (Johnston et al., 2001). Their absence in our dataset highlights the difficulty of monitoring complex coastal systems and in the application of a randomized probability design (Crane et al., 2005).

The elevated concentration of most water quality parameters (TP, TSS, TN, and NH_4^+) and the decrease in DO in July 2012 were most likely due to a 500-year-recurrence flood that struck the lower St. Louis River watershed in mid-June (Czuba et al., 2012; Minor et al., 2014). However, TP and TSS concentrations in June and July 2013 were also elevated

Table 3
Summary statistics of water quality parameters identified in the original Remedial Action Plan (RAP) and in the RAP update (MPCA, 2013) as being impaired, measured in the St. Louis River Estuary (SLRE) in 2012 and 2013. Abbreviations: TP = total phosphorus; DO = dissolved oxygen; TN = total nitrogen; NO_x-N = nitrate/nitrite-N; NH_4-N = ammonium-N; TSS = total suspended solids; Chl *a* = chlorophyll *a*; CI = confidence interval; SE = standard error; na = not available.

Parameter	Year	Statistic	Month						Zone			All observations
			May	June	July	August	September	October	Harbor	Bay	River	
TP (μg/L)	2012	Range	4.7–195.4	6.0–31.0	23.6–102.5	11.0–66.2	6.1–93.7	na	6.1–195.4	4.7–102.5	6.0–54.0	4.7–195.4
		Median	20.2	24.8	45.4	24.2	28.5	na	26.3	31.0	18.5	26.9
		Weighted Mean ± SE	26.5 ± 4.1	23.1 ± 1.8	46.1 ± 2.0	26.3 ± 1.7	27.3 ± 2.2	na	30.1 ± 2.1	35.0 ± 2.4	21.0 ± 2.3	30.9 ± 1.5
		Weighted 95th CI	18.5–34.5	19.6–26.7	42.2–50.0	23.0–29.6	23.1–31.5	na	26.0–34.2	30.4–39.6	16.5–25.6	28.1–33.8
	2013	Range	15.1–52.9	15.5–66.5	10.0–66.6	20.1–37.6	22.9–65.7	23.9–58.5	10.0–65.7	16.4–66.6	15.5–66.5	10.0–66.6
		Median	21.2	32.5	40.2	24.2	29.6	29	28.1	31.8	26.0	29.0
		Weighted Mean ± SE	24.6 ± 1.9	34.3 ± 1.3	39.2 ± 1.5	25.2 ± 0.6	32.9 ± 1.2	31.1 ± 1.3	30.3 ± 0.8	32.0 ± 1.2	28.1 ± 1.6	30.7 ± 0.6
		Weighted 95th CI	20.9–28.2	31.7–36.8	36.2–42.2	24.1–26.3	30.6–35.2	28.6–33.6	28.7–32.0	29.8–34.2	25.0–31.2	29.4–31.9
DO (mg/L)	2012	Range	6.6–11.9	7.0–10.0	4.5–8.5	6.0–9.0	8.2–12.0	na	4.8–12.0	4.5–11.3	6.8–11.9	4.5–12.0
		Median	11.1	8.0	6.5	7.5	10.6	na	8.2	7.9	8.6	8.3
		Weighted Mean ± SE	10.9 ± 0.1	8.1 ± 0.1	6.4 ± 0.1	7.6 ± 0.1	10.4 ± 0.1	na	8.9 ± 0.3	8.4 ± 0.3	9.1 ± 0.3	8.7 ± 0.2
		Weighted 95th CI	10.7–11.2	7.8–8.4	6.2–6.7	7.4–7.8	10.1–10.7	na	8.3–9.4	7.9–8.9	8.5–9.8	8.4–9.1
	2013	Range	7.1–12.9	7.6–11.0	7.7–10.8	7.3–9.8	6.4–9.6	8.7–13.3	6.4–12.7	7.3–12.9	7.8–13.3	6.4–13.3
		Median	11.9	9.5	9.2	8.9	8	11.6	9.5	9.0	10.3	9.5
		Weighted Mean ± SE	11.7 ± 0.2	9.5 ± 0.1	9.2 ± 0.1	9.0 ± 0.1	8.4 ± 0.1	11.5 ± 0.1	10.0 ± 0.1	9.6 ± 0.2	10.2 ± 0.4	9.9 ± 0.1
		Weighted 95th CI	11.3–12.1	9.2–9.8	9.0–9.3	8.9–9.1	8.2–8.5	11.2–11.7	9.7–10.2	9.3–10.0	9.5–10.9	9.7–10.1
TN (μg/L)	2012	Range	746–4274	1036–1222	798–1580	399–1213	449–1358	na	399–4274	612–1580	491–1381	399–4274
		Median	1004	1142	1285	799	739	na	922	970	1004	963
		Weighted Mean ± SE	1104 ± 70	1138 ± 12	1273 ± 25	787 ± 19	746 ± 20	na	1006 ± 43	996 ± 34	943 ± 75	997 ± 28
		Weighted 95th CI	968–1240	1114–1163	1224–1322	751–824	707–785	na	922–1091	928–1062	795–1092	943–1051
	2013	Range	655–4390	436.0–2057	760–1515	406–918	467–4149	691–379	466–4390	666–1277	406–1800	406–4390
		Median	919	1193	1035	57	711	919	903	907	912	905
		Weighted Mean ± SE	1066 ± 113	1202 ± 34	1018 ± 16	765 ± 15	853 ± 80	1035 ± 97	1019 ± 37	900 ± 14	867 ± 43	965 ± 22

(continued on next page)

Table 3 (*continued*)

Parameter	Year	Statistic	Month						Zone			
			May	June	July	August	September	October	Harbor	Bay	River	All observations
		Weighted 95th C.I.	844–1289	1136–1268	987–1049	735–794	696–1009	846–1224	946–1091	873–927	782–952	922–1008
NO_x-N (μg/L)	2012	Range	8.5–418.7	143.8–212.7	44.6–275.9	3.8–387.5	1.6–238.3	na	1.6–418.7	2.3–180.5	4.0–180.5	1.6–418.7
		Median	134.7	173.5	177.7	137.9	12.0	na	193.8	121.0	113.9	153.4
		Weighted Mean ± SE	183.2 ± 14.3	178.7 ± 5.3	173.1 ± 7.6	213.5 ± 14.5	78.8 ± 11.4	na	214.1 ± 8.7	98.2 ± 8.5	96.7 ± 22.7	164.0 ± 6.0
		Weighted 95th CI	155.2–211.2	168.2–189.1	158.2–187.9	185.0–242.0	56.5–101.1	na	197.0–231.1	81.6–114.8	52.3–141.1	152.3–175.7
	2013	Range	87.0–351.4	41.6–261.9	25.7–311.8	4.7–309.7	4.0–255.9	59.4–251.9	23.0–351.4	4.0–261.9	4.7–225.3	4.0–351.4
		Median	143.7	133.9	190.8	89.6	24.0	108.5	169.8	101	87.3	135.4
		Weighted Mean ± SE	177.4 ± 6.1	142.6 ± 4.8	201.3 ± 11.4	147.5 ± 15.4	96.5 ± 7.7	150.9 ± 8.5	189.4 ± 6.3	97.0 ± 7.3	91.1 ± 11.1	149.0 ± 4.4
		Weighted 95th C.I.	165.5–189.3	133.2–152.1	178.9–223.7	117.4–177.7	81.4–111.5	134.2–167.6	177.0–201.7	82.8–111.3	69.1–112.8	140.4–157.7
NH_4-N (μg/L)	2012	Range	9.7–110.9	34.3–142.9	30.8–180.3	11.0–52.7	7.0–78.5	na	7.0–180.3	8.2–89.2	10.3–67.1	7.0–180.3
		Median	22.6	68.9	73.7	22.8	12.4	na	34.8	25.2	18.6	29.5
		Weighted Mean ± SE	42.5 ± 5.2	80.9 ± 11.3	85.1 ± 6.6	24.3 ± 1.5	15.2 ± 1.5	na	56.7 ± 6.4	35.0 ± 3.5	26.8 ± 4.2	46.6 ± 3.9
		Weighted 95th CI	32.3–52.8	58.7–103.1	72.1–98.1	21.5–27.2	12.4–18.0	na	44.2–69.3	28.1–41.9	18.5–35.1	39.1–54.2
	2013	Range	5.0–3629.0	16.5–174.8	10.0–123.9	4.9–129.6	2.0–3645.0	2.02–2875.0	2.0–3645.0	4.5–77.4	9.1–207.9	2.0–3645.0
		Median	17.4	47.1	33.2	17.2	10.6	51.8	35.5	23.7	24.7	26.6
		Weighted Mean ± SE	170.2 ± 117.7	79.7 ± 6.8	50.3 ± 5.2	30.7 ± 7.2	126.0 ± 76.8	194.5 ± 92.9	134.3 ± 28.8	25.8 ± 1.7	36.4 ± 7.5	88.7 ± 16.5
		Weighted 95th CI	0.0–400.9	66.4–93.0	40.1–60.5	16.6–44.8	0.0–276.6	12.5–376.6	77.9–190.6	22.5–29.2	21.7–51.1	56.4–121.0
TSS (mg/L)	2012	Range	3.7–51.3	3.6–13.7	7.7–62.7	2.5–18.5	6.0–71.4	na	3.3–71.4	4.2–28.8	2.5–33.3	2.5–71.4
		Median	6.5	10.1	13.4	6.4	13.6	na	10.5	10.8	9.7	10.1
		Weighted Mean ± SE	11.1 ± 1.3	8.7 ± 1.0	16.3 ± 1.3	7.0 ± 0.5	15.1 ± 1.3	na	13.0 ± 0.8	10.9 ± 0.6	10.2 ± 1.4	12.0 ± 0.5
		Weighted 95th CI	8.6–13.6	6.8–10.6	13.8–18.8	6.0–8.0	12.5–17.7	na	11.3–14.6	9.7–12.2	7.4–13.0	11.0–13.1
	2013	Range	3.2–55.6	5.0–40.5	2.7–26.5	3.7–19.3	2.7–17.3	2.3–31.7	4.3–55.6	2.3–36.7	1.8–17.3	2.3–55.6
		Median	7.9	12.8	10.3	6.6	7.7	6.0	9.3	7.3	6.5	8.0
		Weighted Mean ± SE	14.1 ± 1.8	15.1 ± 1.2	12.4 ± 0.6	7.0 ± 0.4	7.4 ± 0.4	8.9 ± 1.0	11.0 ± 0.5	8.6 ± 0.6	7.9 ± 1.3	9.9 ± 0.4
		Weighted 95th CI	24.9–41.4	22.8–33.8	24.2–31.6	11.3–13.8	15.0–18.2	26.2–37.1	10.0–12.1	7.3–9.8	5.3–10.4	9.2–10.7
Chl *a* (μg/L)	2012	Range	2.3–13.5	1.1–5.5	1.4–41.6	2.6–19.4	4.3–49.9	na	1.1–49.9	1.4–41.6	2.1–21.3	1.1–49.9
		Median	4.6	3.2	4.9	6.3	15.9	na	6.3	5.5	5.5	6.0
		Weighted Mean ± SE	5.0 ± 0.3	3.0 ± 0.3	7.5 ± 1.3	8.4 ± 0.7	17.2 ± 1.3	na	9.6 ± 1.0	8.1 ± 0.8	6.4 ± 1.1	8.8 ± 0.7
		Weighted 95th CI	4.3–5.6	2.4–3.6	5.0–10.0	7.1–9.7	14.6–19.8	na	7.6–11.7	6.5–9.8	4.3–8.5	7.5–10.1
	2013	Range	3.0–8.9	3.5–19.5	3.9–28.1	5.1–23.1	2.3–21.4	0.6–6.7	0.6–26.0	1.5–28.1	1.8–17.3	0.6–28.1
		Median	5.2	7.1	7.8	13.6	7.4	2.5	7.1	6.3	5.10	6.3
		Weighted Mean ± SE	5.4 ± 0.2	8.2 ± 0.5	9.0 ± 0.8	14.6 ± 0.6	10.0 ± 0.8	2.7 ± 0.2	9.1 ± 0.6	7.2 ± 0.5	5.7 ± 0.6	8.1 ± 0.4
		Weighted 95th CI	5.0–5.8	7.4–9.1	7.4–10.6	13.4–15.7	8.4–11.5	2.4–3.0	7.9–10.3	6.3–8.2	4.5–7.0	7.4–8.9

Table 4
Summary statistics comparing BUI criterion concentrations with weighted means (Z-test) for each month, zone, and for all observations within a sampling year. Arrows indicate whether the mean was above (↑) or below (↓) the BUI criterion. Abbreviations: TP = total phosphorus; TSS = total suspended solids; Chl *a* = chlorophyll *a*; NS = not significantly different from criterion.

		Month						Zone			
Year	Parameter	May	June	July	August	September	October	Harbor	Bay	River	All observations
2012	TP	NS	↓ −3.8***	↑ 8.1***	↓ −2.2*	NS	na	NS	↑ 2.1*	↓ −3.9***	NS
	TSS	↓ −3.0***	↓ −6.3***	NS	↓ −16.0***	NS	na	↓ −2.5*	↓ −6.8***	↓ −3.2**	↓ −6.0***
	Chl *a*	↓ −16.7***	↓ −23.3***	NS	↓ −2.3*	↑ 5.5***	na	NS	↓ −2.4*	↓ −3.3**	NS
2013	TP	↓ −2.8***	↑ 3.3***	↑ 6.1***	↓ −8.0***	↑ 2.4*	NS	NS	NS	NS	NS
	TSS	NS	NS	↓ −4.3***	↓ −20.0***	↓ −19.0***	↓ −6.1***	↓ −8.0***	↓ −10.7***	↓ −5.5***	↓ −12.8***
	Chl *a*	↓ −23.0***	↓ −3.6***	NS	↑ 7.7***	NS	↓ −36.5***	NS	↓ −5.6***	↓ −7.2***	↓ −4.8***

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

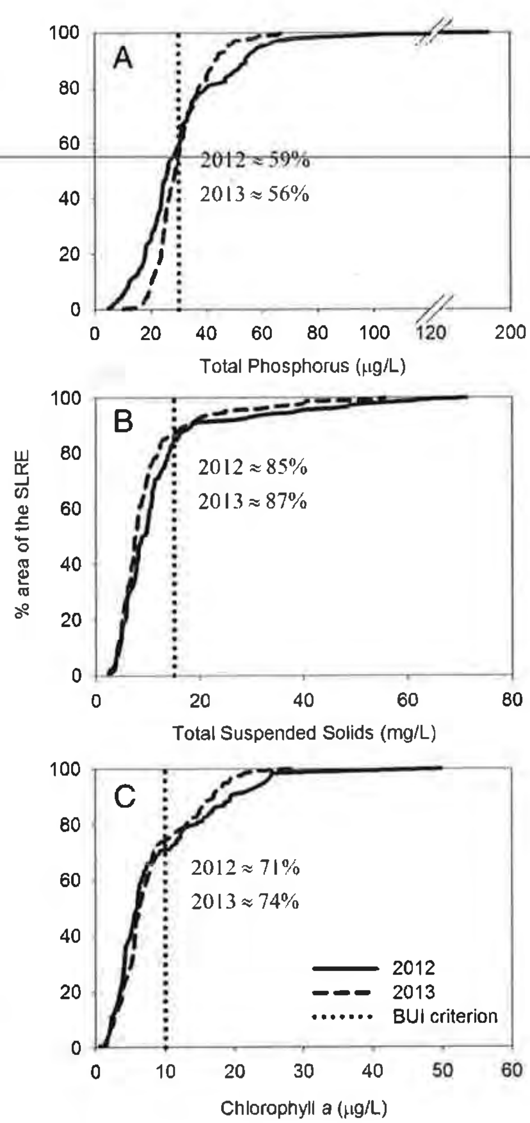

Fig. 5. Cumulative area functions for A) total suspended solids; B) total phosphorus; and C) Chlorophyll *a*. The x-axis is the analyte concentration versus the y-axis which is the cumulative percentage of area-weighted sites sampled in 2012 (solid line) and 2013 (dashed line) with 100% being the total surface area of the St. Louis River Estuary (i.e., 4376 ha). Vertical dotted lines are BUI criterion concentrations; percentages in each figure indicate the proportion of the system surface area below the criterion concentration.

relative to other months, indicating a recurring seasonal pattern. Factors include coupled rainfall mobilization of sediments and nutrients from the watershed and a lack of robust aquatic vegetation early in the season. Phytoplankton biomass and sediment-adsorbed P contribute to TP concentrations, and most P in the SLRE is particulate rather than dissolved (e.g., as orthophosphate; B.J. Bellinger, unpublished data). Additionally, vegetation coverage in the SLRE was reduced after the flood (Angradi et al., 2013). Resuspension of flood-transported sediment may still be elevating TSS and nutrient concentrations in the SLRE over pre-flood concentrations.

St. Louis River flood-pulse effects on water quality in the western arm of Lake Superior were apparently short-lived (Minor et al., 2014). The lake portion of the AOC had water quality conditions in 2013 consistent with oligotrophic conditions, satisfying the established BUI criteria (MPCA, 2013). Comparing findings from the 1974–1975 surveys with 2013, the water quality of western Lake Superior has remained consistently oligotrophic suggesting no enrichment from the estuary. Rather, Lake Superior is an N source to the estuary, especially of nitrate (Hiriart-Baer et al., 2009; Sterner, 2011). Elevated mean NH_4^+ concentrations in the harbor zone (Table 5) reflect samples collected near municipal wastewater treatment facilities (Fig. 1). Despite loadings of NH_4^+ and TP to Lake Superior, low concentrations in the open lake are maintained by phytoplankton and microbial processes (e.g., nitrification; Finlay et al., 2007; MPCA and WDNR, 1992; Munawar and Munawar, 1978).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jglr.2015.11.008.

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Table 5
Lake Superior water quality summary statistics data collected in 2013. Arithmetic means were compared between months and zones with one-way ANOVA. Significant pair-wise differences were identified with Scheffe's post hoc test and are indicated by different letters. Abbreviations: TP = total phosphorus; DO = dissolved oxygen; TN = total nitrogen; NO_x-N = nitrate/nitrite-N; NH_4-N = ammonium-N; TSS = total suspended solids; Chl *a* = Chlorophyll *a*; SE = standard error; NS = not significantly different.

Parameter	Year	Statistic	Month						ANOVA ($F_{5,18}$)	All Observations
			May	June	July	August	September	October		
TP (μg/L)	2013	Range	11.4–13.9	21.6–25.7	17.1–22.5	4.4–19.1	3.4–23.5	4.0–5.7		3.4–25.7
		Unweighted mean ± SE	12.2 ± 0.6	24.4 ± 0.9	19.0 ± 1.3	9.8 ± 4.7	8.6 ± 5.0	4.7 ± 0.4	5.2**	12.7 ± 1.7
DO (mg/L)	2013	Range	14.4–15.9	11.3–13.1	12.1–12.5	10.7–14.2	9.7–10.3	11.1–11.2		9.7–15.9
		Unweighted mean ± SE	15.1 ± 0.3^{c}	12.3 ± 0.4^{ab}	12.2 ± 0.1^{ab}	12.5 ± 0.9^{a}	10.1 ± 0.1^{b}	11.1 ± 0.1^{ab}	15.3***	12.2 ± 0.4
TN (μg/L)	2013	Range	467.1–742.4	531.4–887.2	523.8–576.7	309.3–651.1	493.8–714.1	513.4–824.3		309.3–887.2
		Unweighted mean ± SE	594.3 ± 56.6	784.0 ± 84.9	556.6 ± 11.5	526.6 ± 77.2	573.5 ± 48.8	606.1 ± 73.2	NS	606.9 ± 28.8
NO_x-N (μg/L)	2013	Range	304.1–358.9	268.5–283.0	315.9–326.0	325.0–351.4	307.4–337.3	311.1–364.1		268.5–364.1
		Unweighted mean ± SE	339.6 ± 12.2^{a}	274.5 ± 3.2^{b}	322.7 ± 2.3^{a}	333.0 ± 6.2^{a}	324.9 ± 7.2^{a}	334.3 ± 11.1^{a}	9.0***	321.5 ± 5.4
NH_4-N (μg/L)	2013	Range	2.0–42.1	28.1–47.7	13.5–26.1	2.0–30.6	6.2–17.8	2.0–30.7		2.0–47.7
		Unweighted mean ± SE	18.9 ± 9.0	39.3 ± 4.3	21.6 ± 2.9	10.3 ± 6.9	13.3 ± 2.6	14.0 ± 6.8	3.2*	19.6 ± 2.9
TSS (mg/L)	2013	Range	2.1–15.1	1.1–6.0	2.8–3.8	0.4–3.0	4.0–7.7	2.8–6.0		0.4–15.1
		Unweighted mean ± SE	6.6 ± 3.0	4.1 ± 1.2	3.1 ± 0.2	1.7 ± 0.6	6.2 ± 0.9	4.6 ± 0.8	NS	4.4 ± 0.6
Chl *a* (μg/L)	2013	Range	1.8–2.6	3.7–4.8	2.1–3.5	1.7–6.7	1.2–3.7	1.2–1.6		1.2–6.7
		Unweighted mean ± SE	2.1 ± 0.2^{ab}	4.5 ± 0.3^{a}	3.1 ± 0.3^{ab}	3.0 ± 1.2^{ab}	2.4 ± 0.5^{ab}	1.4 ± 0.1^{b}	4.4**	2.7 ± 0.3

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

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Appendix 2

Paleolimnology of the St. Louis River Estuary
And
Paleolimnology of a freshwater estuary to inform Area of Concern nutrient delisting efforts
(Pertaining to management action 6.03.)

This appendix is abbreviated due to file size. The full appendix is available upon request from the Wisconsin DNR St. Louis River Area of Concern Coordinator. For contact information, visit dnr.wi.gov and search "St. Louis River AOC."

Paleolimnology of the St. Louis River Estuary

May 2016
The Minnesota Pollution Control Agency

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Driven to Discover

Minnesota Pollution Control Agency

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Executive Summary to the Beneficial Use Impairment Actions
Associated with Investigations of
Paleolimnology and Historic and Current Water Quality Condition
in the St. Louis River Area of Concern

Introduction

This executive summary provides an overview of the following investigations in relation to the St. Louis River Area of Concern's (SLRAOC) excessive loading of sediment and nutrients Beneficial Use Impairment (BUI) removal objectives:

Paleolimnology research results are organized into three attached reports structured for submission to peer-reviewed literature:

- Attachment A - Paleolimnology of the St. Louis River Area of Concern using algal microfossils including diatoms, pigments and basic sediment composition;
- Attachment B - Paleolimnology of wild rice and other plants in the St. Louis River Area of Concern using phytoliths and pollen;
- Attachment C - Historic Analysis of Various Chemical Constituents in Sediment Cores from the St. Louis River Area of Concern.

Purpose

The St. Louis River Watershed which drains to the St. Louis River and its associated estuary near Lake Superior has more than 150 years of human development history since Euro-Americans first settled there, resulting in critical water quality impacts. In 1987, the U.S. Environmental Protection Agency designated the St. Louis River as an Area of Concern primarily due to that history which entailed inappropriate discharge of untreated wastewater and debris from poor industrial and community practices. The organic matter loading from inadequate treatment of sewage and paper mill products along with the dumping of woody debris from sawmills contributed to low oxygen levels in the river. The result included devastating impacts to the entire food web from the bacteria to vegetation to invertebrates to fish. Concurrently, poorly managed stormwater runoff from this post-logged, barren landscape contributed excessive loading of suspended sediments resulting in increased turbidity and nutrient concentrations (e.g., phosphorus, nitrogen) to the river. Since then, government and private entities have taken action to restore the water quality in the St. Louis River Estuary, and to eventually remove the eight remaining SLRAOC BUIs. This summary focuses on the research documenting water quality changes over time associated with the excessive loading of sediment and nutrients BUI.

The historical magnitude and extent of sediment and nutrient impacts during the years preceding systematic long-term monitoring of water quality (pre-1953-1973, depending on location) is not well understood, and therefore, a paleolimnology study of the St. Louis River Estuary (SLRE) was initiated to close the knowledge gap. To help understand this history seven cores from the SLRE were evaluated for retrospective analyses by the Natural Resources Research Institute under Dr. Euan Reavie. The primary goal especially related to the excessive loading of sediment and nutrients BUI was to determine pre-

European settlement water quality conditions and to track through time the anthropogenic impacts followed by the extent of remedial progress. In order to do this, sediments in the core samples were dated using isotopic analyses and fossil remains (diatoms, pigments, pollen, phytoliths) were identified in concordance with other stratigraphic indicators (organic and inorganic materials, contaminants, sedimentation rates) to reconstruct the history of the system from 1850 to the present.

Historic and current water quality conditions were also evaluated to compare concentration estimates with BUI removal targets established by SLRAOC stakeholders. For the historic component, 60 years of water quality data (1953 – 2013) from two fixed stations were used to determine whether nutrient and sediment concentrations and loads have changed in the SLRE. In addition, current water quality condition was assessed both seasonally and spatially using data collected in 2012 and 2013. This work was supported by U.S. Environmental Protection Agency – Office of Research and Development under Dr. Joel Hoffman and Dr. Brent Bellinger.

SLRAOC BUI Overview

This summary is intended to assist Minnesota, Wisconsin, and the Fond du Lac Band of Lake Superior Chippewa in assessing the BUI targets for this particular action and determine if the BUI removal objectives are being met. The SLRAOC's Remedial Action Plan (RAP, 2015) describes the 1992 rationale for listing this BUI as follows:

> *Prior to the improvements in wastewater treatment in the late 1970s, water quality and biological investigations characterized the St. Louis River estuary (SLRE) as low in dissolved oxygen and high in total phosphorus and total suspended solids. At that time, the Western Lake Superior Sanitary District (WLSSD) treatment plant was built and the Superior wastewater treatment plant was upgraded. Since then, many indicators of trophic status have shown improvements. For instance, concentrations of total phosphorus have decreased and dissolved nitrogen has shown variable decline in St. Louis Bay. The loading of phosphorus to the estuary from point sources has been reduced substantially. At the time of AOC listing, further work was needed to ascertain the effects of nonpoint source loadings to the system and to Lake Superior. Despite the reductions in point source loadings, phosphorus concentrations in the estuary remained at levels where eutrophic conditions might be expected. Algal biomass was lower than would be expected, however, given these high phosphorus concentrations. Chlorophyll α concentrations measured in the estuary were similar to levels found in mesotrophic or oligotrophic waters. Several investigators proposed that reduced light penetration caused by turbidity and color may be a limiting factor for algal growth in the estuary. Although persistent water quality problems associated with eutrophication were not observed in the estuary, the high levels of nutrients and sediments being delivered to Lake Superior were determined to be an important concern. Therefore, the RAP used a modification of the International Joint Commission eutrophication criterion to reflect local conditions.*

BUI removal target

The BUI removal target, as established by stakeholders in 2008, is:

Nutrient and sediment levels have not been shown to impair water quality and habitat, and do not restrict recreation, including fishing, boating, or body contact in the estuary and within western Lake Superior based on the following criteria:

1. *All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorous), organic matter, and sediment; and*
2. *Total phosphorus concentrations in the Lake Superior portion of the AOC do not exceed 0.010 mg/l (upper limit of oligotrophic range); and*
3. *There are no exceedances of the most protective water quality standard for either state in the western basin of Lake Superior due to excessive inputs of organic matter or algal growth attributed to loadings from wastewater overflows into the St. Louis River; and,*
4. *Total phosphorus concentrations within the St. Louis River portion of AOC do not exceed an interim guide of 0.030 mg/l (upper limit of mesotrophic range) or the most restrictive water quality standards. This ensures that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive productivity and nuisance conditions within the St. Louis River Estuary.*

The removal of this BUI (RAP, 2015) will be justified when:

1. All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorus), organic matter, and sediment.
2. <u>Assessment of current water quality data for the Lake Superior and the St. Louis River estuary portions of the AOC indicate that water quality meets the water quality goals for a mesotrophic estuary and an oligotrophic lake</u>.
3. Watershed management objectives for the Nemadji River watershed, as established by the Nemadji Basin Plan (NRCS, 1998), have been adopted and progress towards implementing the objectives is being made.

This work addresses the removal justification for #2 underlined above. It is important to keep in mind that there were fewer data to rely on when these targets were established. Therefore, the partners and stakeholders used the state established phosphorus criteria for inland lakes and rivers; these water bodies are very different than the western arm of Lake Superior and the St. Louis River Estuary. This work reviewed a suite of water quality parameters as specified in the RAP (2015) to determine whether legacy related impairments are influencing a eutrophic classification in the St. Louis River Estuary or a mesotrophic classification in Lake Superior. The parameters include:

- <u>Chemical</u> - total phosphorus, un-ionized ammonia, dissolved oxygen
- <u>Biological</u> – chlorophyll α
- <u>Physical</u> - total suspended solids (TSS) and turbidity or other loading metric based on tons of sediment

Paleolimnology study as a component of the BUI removal strategy

The BUI removal target contains several actions which should be completed in order to evaluate and document if the SLRAOC meets the objectives necessary to remove the BUI. Past efforts, particularly in regard to improved treatment of point source discharges and the construction of the Western Lake Superior Wastewater Sanitary District facilities in the late 1970s resulted in substantial water quality improvements in the estuary. This paleolimnological investigation report was completed in order to better understand historical water quality conditions prior, during, and following Euro-American settlement and development of the harbor. This study was designed to help clarify long-term nutrient trends prior to water quality monitoring in the estuary and to better understand the status of primary producers (e.g., phytoplankton, algae) and the potential for eutrophication in the estuary.

Paleolimnology Findings in relation to the BUI

Diatoms in relation to water quality

Diatom assemblages were assessed from sediment intervals and these assemblages were used to infer trophic conditions using a regional diatom-based model for Great Lakes coastlines. Interpretations were based on diatom-based models that contain known species responses to water quality, which are applied to fossil assemblages. The diatom records indicate varying ecological histories and trajectories depending on the location within the estuary. Deeper core locations (e.g., within or close to the federal navigation channel, Lake Superior) indicate water quality improvement from past periods of higher total phosphorus concentrations and algal productivity, and that current, prevailing concentrations of phosphorus do not exceed the SLRAOC BUI removal phosphorus target. However, the near-coastal (e.g., North Bay, Pokegama Bay, Allouez Bay) reconstructions reveal a recent increase in inferred phosphorus. At these locations, the inferred phosphorus levels based on the diatom species model would be in exceedance of the BUI removal target (see BUI Removal Target above). It is noteworthy that the earliest dated concentrations (~1850) are also inferred to be above the target, reflecting the natural productivity of these systems at that time.

Geochemistry in relation to water quality and nutrient loading

Algal pigment concentrations in the sediment profiles concur with diatom-based inferences. Main channel cores do not indicate recent increases in algal abundance, however the increasing presence of cyanobacterial pigments in two bays (North Bay, Billings Park – the only bays characterized for pigments) indicate increases in potentially undesirable algae, which are an indicator of increasing nutrients in those locations.

Historical sediment accumulation rates (organic and inorganic) indicate that recent sediment loads to the estuary remain higher than loads estimated around 1850. However, three sites (Lake Superior, Allouez Bay and Billings Park) exhibit reduced sediment loads since the peak period of development in the mid-20th century.

Paleolimnology Findings in relation to the overall history of the St. Louis River and its impairments

Diatoms and water quality

Overall, paleolimnological results from Lake Superior and the main stem of the estuary indicate improvements in nutrient loads or discontinuation in the enrichment trends that were observed through the 1970s. Based on similar observations in degrading systems (e.g., western Lake Erie, southern Lake of the Woods [Minnesota-Ontario]), the nearshore eutrophication observed in the estuary may be due to factors such as periodic recycling of stored sedimentary phosphorus (regulated by the extent and duration of oxygen depletion coupled with intermittent wind mixing events). These conditions may be further aggravated by climate change related to increased winds and stormwater runoff and stronger thermal stratification in the ice-free season. These factors are poorly understood and require further studies based, in part, on comprehensive long-term water quality monitoring.

Geochemistry

This work was intended to better understand general trends of sediment contaminants and to see if the science behind the analysis can provide a line of evidence that supports improvement of these historic contaminations through time. Mercury is a marker of human activities such as mining, burning of fossil fuels, and untreated sewage disposal. Sediment mercury concentrations peaked in the mid-1900s but more recently declined to near pre-impact concentrations, indicating recent decreases in some combination of direct atmospheric deposition, watershed runoff, and point source domestic and industrial discharges. There were distinct mid-1900s peaks in cadmium, zinc, lead, tin, antimony and magnesium, likely resulting from watershed disruptions that exposed materials to erosion and runoff and/or industrial discharges. With improved regulation of these activities there has been a concurrent reduction in sedimentary concentrations. Sedimentary organic contaminants (PCBs, VOCs, PAHs) analyzed from a single core from the harbor had concentrations below the detection levels.

Wild Rice/Vegetation Historical Patterns

Pollen distributions in the cores generally reflected the historical reduction in conifers due to deforestation through the late 1800s and early 1900s and the more recent increase in birch trees. Sedimentary remains of wild rice (phytoliths and pollen) do not indicate a reduction in wild rice abundance in the SLRAOC in modern times relative to pre-industrialization of the harbor, but it was clear the core locations were not optimal for assessing historical wild rice communities. Wild rice restoration is occurring in the estuary and future work outside of the SLRAOC program is recommended at core locations within or close to known or past wild rice beds to help better understand expectations for restoration.

Conclusions in Relation to BUI Status

Paleolimnology Investigation

Clear improvements in TP concentrations in the water column, as inferred from paleo-diatom analyses from mid-channel cores, have resulted from remedial efforts (largely wastewater treatment and stormwater management) in the SLRAOC over the past ~40 years. Increasing nutrient loads are inferred in the three nearshore locations. In terms of nearshore phosphorus, the study generated evidence that pre-European impact concentrations of phosphorus likely exceeded the BUI removal target criteria by approximately 10 – 15 µg TP/L. Also, it is likely nearshore changes in water quality are a result of phenomena (such as climate change, sediment phosphorus recycling, and perhaps other indirect mechanisms) that were not included in the rationale for listing this BUI. A more detailed paleolimnology investigation, including speciation of phosphorous and development of a nutrient budget for the system would be needed to determine the factors influencing the nearshore areas.

These data indicate BUI removal objectives are being met in over fifty percent of the estuary. It is interesting to note the BUI target is lower than some of the earliest inferred phosphorus conditions. It may be appropriate to support BUI removal based on overall improvement. As we move forward from legacy to present issues, studies are recommended to better understand the main drivers of algal production (i.e., a direct cause of eutrophication) in nearshore areas of the SLRE and portions of the St. Louis and Nemadji watersheds. Efforts to minimize pollutant loads should continue and a comprehensive monitoring program with periodic re-evaluation of these data should be established.

Appendix 3

Saint Louis River Estuary Clay-Influenced Bay Assessment 2018
And
St. Louis River Bays – Douglas County 2017 Fish Community Survey
(Pertains to management action 6.04)

This appendix is abbreviated due to file size. The full appendix is available upon request from the Wisconsin DNR St. Louis River Area of Concern Coordinator. For contact information, visit dnr.wi.gov and search "St. Louis River AOC."

Saint Louis River Estuary
Clay-Influenced Bay Assessment

Pokegama Bay on a fall day. Photo by Craig Roesler, Wisconsin DNR

Craig Roesler, Madeline Roberts, Chang Vang
Wisconsin Department of Natural Resources
Funded by The U.S. Environmental Protection Agency

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About

The Saint Louis River Estuary (SLRE) is a Great Lakes Area of Concern where efforts to improve water quality, including nutrient and sediment loading reductions, have been ongoing. Some bays in the estuary were known to have substantially higher total phosphorus concentrations than the remainder of the estuary. Three bays, Allouez, Pokegama, and Kimballs, were extensively monitored for water quality and biological condition in 2017. Objectives of the monitoring were to:

- Document the current water quality and biotic conditions in these SLRE clay-influenced bays
- Determine if current nutrient and suspended solids concentrations are negatively affecting aquatic life
- Provide data that could be used to determine if site specific water quality goals are warranted

Funding

This study was funded in part through a grant from the U.S. EPA's Great Lakes Restoration Initiative and the Wisconsin Department of Natural Resources.

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Summary

Introduction

The lower St. Louis River (SLR) is part of a Great Lakes Area of Concern (AOC) (Figure 1). The SLR AOC has nine beneficial use impairments (BUI's) listed in the Remedial Action Plan (MPCA and WDNR 2017). One of the BUI's is "Excessive Loading of Sediment and Nutrients."

Diatom-inferred (DI) total phosphorus concentrations (TP's) from sediment core analyses (Reavie 2016) indicated that TP's in some SLRE bays (including Allouez and Pokegama Bays) currently exceed the TP goal (30 ug/l) for the SLRE and were at or above this goal prior to watershed development. Therefore, site specific water quality goals for these bays may be appropriate.

Three clay-influenced bays on the Wisconsin side of the SLRE were selected for monitoring: Allouez Bay, Pokegema Bay, and Kimballs Bay (Figure 2). These areas are the largest clay-influenced bays in the estuary. Limited pre-existing water quality data was available for these bays. Direct watersheds for these bays contain clay-rich soils that are highly erodible, and prone to high rates of surface runoff.

> *Beneficial Use Impairment Target*
>
> *BUI removal target of 30 ug/l for total phosphorus has been established for the St. Louis River portion of the AOC.*
>
> *This target was established to ensure that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive phytoplankton productivity and nuisance algal conditions within the St. Louis River Estuary (SLRE).*

The monitoring was intended to:

- Document the current water quality and biotic conditions in these SLRE clay-influenced bays.
- Determine if current nutrient and suspended solids concentrations are negatively affecting aquatic life.
- Provide data that could be used to determine if site specific water quality goals are warranted.

The three bays were monitored during May – October of 2017 for water quality, algae, sediment chemistry, and benthic invertebrates. Tributary streams for the bays were monitored for water quality. Pre-existing water quality and biotic information was reviewed and summarized. A companion project to assess fish communities in the bays was also conducted in 2017 (Nelson 2017). A summary of that assessment is included in this report.

Bay Characteristics and Water Quality

The three bays have some unique characteristics that influence their water quality. Allouez Bay is large (1,011 acres), shallow, and subject to frequent wind-induced mixing. The mouth of the bay is adjacent to the Superior entrance to Lake Superior. Seiche-induced backflows of Lake Superior water influence the bay.

Allouez Bay had minimal thermal and dissolved oxygen stratification. There were indications that seiche-induced inputs of cooler Lake Superior water flowed along the bay bottom at times. Mean total phosphorus concentration was 85 ug/l. Mean total suspended solids concentration was 21 mg/l. Mean chlorophyll a concentration was 7.1 ug/l. Total phosphorus and total suspended solids concentrations were higher in May and October when more watershed runoff was entering the bay. Chlorophyll a concentrations were highest in June and August when watershed runoff was low and water clarity was higher.

Pokegama Bay (441 acres) has the largest direct watershed area and so is heavily influenced by Pokegama River inflow. The bay is also affected by wetlands that fringe its narrow upstream end. Pokegama Bay also had minimal thermal and dissolved oxygen stratification. Lower dissolved oxygen concentrations occurred more frequently at the surface in the upstream end of the bay, probably due largely to decomposition of organic matter in the fringe wetlands.

There may have been occasional releases of sediment phosphorus from the deeper areas in the bay. Phosphorus release from the fringe wetlands may also have occurred. Mean total phosphorus concentration was 121 ug/l. Mean total suspended solids concentration was 32 mg/l. Mean chlorophyll a concentration was 6.2 ug/l. Total phosphorus and total suspended solids concentrations were higher in May and October at the two more downstream monitoring stations when more watershed runoff was entering the bay. Total phosphorus and total suspended solids concentrations were more variable at the most upstream monitoring station which is most strongly influenced by Pokegama River inflow. Chlorophyll a concentrations were highest in July and August when watershed runoff was low and water clarity was higher.

Kimballs Bay (101 acres) is the smallest of the three bays. Steep sloped, wooded banks line the bay's perimeter. The narrowness of the bay and the high wooded banks tend to minimize wind-induced mixing. The greater mean depth (12 ft) also helps minimize mixing. The single water quality monitoring site in the bay was close to the bay mouth and strongly influenced by seiche-induced mixing of SLRE water.

Kimballs Bay had substantial thermal and dissolved oxygen stratification despite the influence of seiche-induced mixing. Sediment phosphorus release was also substantial and prolonged during July and August. Inflow from the small tributary stream appeared to be mostly flowing along the bottom of the bay and producing higher turbidities near the bottom. Mean total phosphorus concentration was 63 ug/l. Mean total suspended solids concentration was 5 mg/l. Mean chlorophyll a concentration was 7.6 ug/l. Total phosphorus concentrations were somewhat higher in May and October, and there was also a pattern of increasing total phosphorus concentrations from mid-June to early September, probably due to sediment phosphorus release. Total suspended solids concentrations were higher in May and October like the other bays. Chlorophyll a concentrations were higher in July through early September when water clarity was higher.

For the three bays, mean total phosphorus concentrations were 2-4 times higher than those found in the rest of the SLRE (Bellinger et al 2015). Mean chlorophyll a concentrations were lower than those found in the rest of the SLRE. Mean total suspended solids concentrations were lower at the Kimballs Bay site and higher at the Allouez and Pokegama Bay sites compared to the rest of the SLRE. The data is summarized below in Table 1.

Table 1. Summary of Mean Total Phosphorus, Total Suspended Solids and Chlorophyll a Concentrations

	Size (acres)	Mean Depth (ft)	Mean TP (ug/L)	Mean TSS (ug/L)	Mean Chl a (ug/L)
Allouez Bay	1,011	6	**85**	**21**	7.1
Pokegama Bay	441	5	**121**	**32**	6.2
Kimball's Bay	101	12	**63**	5	7.6
Estuary Mean	NA	NA	31	11	9.4

(bold #s indicate values higher than the estuary mean)

Bay Chlorophyll a Relationship to Other Trophic State Indices

Chlorophyll a concentrations in the three bays showed non-standard relationships to other trophic state indices (TSI) (trophic state is a water body's level of biological productivity). Chlorophyll a concentrations were only 3 -18% of what is typically found at the total phosphorus concentrations present (Carlson 1977). Water clarities (Secchi depths) are also lower than what is typically found. The poor water clarity due to suspended clay and silt is the probable reason for these altered relationships. Suspended clay and silt is controlling water clarity and the resultant lack of light availability is limiting algal growth. Lack of typical TSI parameter relationships complicate water quality goal setting since it makes it difficult to predict responses to water quality improvements.

Bay Tributary Stream Characteristics and Monitoring Results

Land use in bay tributary stream watersheds is mostly undeveloped, with 77-94% of the watersheds comprised of forest and wetland. Agricultural row crops are absent in four of the watersheds, and only account for 1.2% of the land use in the Bear Creek watershed. Grassland (pasture and hayfield) is the largest agricultural land use and comprises 1.4-20.6% of the watersheds. Streambank and bluff erosion along streams has been identified as the dominant source of fine sediment to clay plain streams. Most runoff and streamflow occurred in May, late September, and October. Total May-October 2017 precipitation was 15% above normal.

Stream dissolved oxygen concentrations were nearly all above 5 mg/l (the WI water quality standard), except for the small tributary to Kimballs Bay that had dissolved oxygen concentrations less than 5 mg/l on two dates. That site was influenced by fringe wetlands and seiche-induced backflows, which likely accounted for the higher dissolved oxygen variability.

Stream total phosphorus concentration means ranged from 106-224 ug/l. Orthophosphate concentration means ranged from 12-33 ug/l. Total suspended solids concentration means ranged from 28-106 mg/l. Watershed non-point sources of phosphorus include pasture and hayfield runoff (including the influence of manure spreading), barnyards, and septic systems. Streambank and bluff erosion along streams is not believed to be a large phosphorus source (Bahnick 1977) but is believed to be the largest source of total suspended solids.

Effluent discharged to the Pokegama River from the Village of Superior wastewater lagoons was the only point source affecting bay tributary streams. During May-October lagoon effluent was estimated to provide about 5.7% of the Pokegama River total phosphorus load and 2.8% of the river's biochemical oxygen demand load. Elevated orthophosphate concentrations in the Pokegama River were seen when stream flow was low and lagoon discharge was occurring.

Elevated concentrations of orthophosphate, ammonia, and nitrate plus nitrite concentrations occurred during low flows in Bear Creek. This may be due to residential septic system discharges. Problems with failing septic systems have been previously documented in the Bear Creek watershed.
Unusually red water was observed in Bluff Creek on one date. Runoff from the rail yard at the taconite storage facility appeared to be the likely source of the color.

Bay Sediment Characteristics

Mean clay content of sediment in all three bays (40 – 46%) was significantly higher than that found in the remainder of the central and lower SLRE, where clay content averages about 14.7% (NOAA DIVER 2018); this is not surprising given the clay rich soils in the watersheds of the bays. Additional findings are summarized below.

- Clay content of sediment (% Clay) was moderately well correlated with phosphorus concentration (R^2 = 0.75) and iron concentration (R^2 = 0.76). Iron readily attaches to the extensive bonding surfaces of clay particles and phosphorus will attach to the iron.
- Clay content was also moderately inversely correlated with % solids (R^2 = 0.43). Clay sediment tends to have a higher water content than coarser grained sediment.
- Allouez Bay sites had the highest mean, median and maximum % sand. There was an inverse correlation between site depth and % sand for the bay (R^2 = 0.73). Sediment scouring by wave action is probably removing finer sediments at shallow sites and leaving more sand.
- Soft sediment thickness ranged from 0.9 to 12.9 feet. Water depth and soft sediment thickness showed moderate correlations for individual bays (Allouez Bay (less site ASD), R^2 = 0.42; Pokegama Bay, R^2 = 0.70). Deeper sites tend to favor long term sediment deposition.

Algae

Total algal cell densities were highest in all bays in July, August, and September. Pokegama Bay had the highest total cell density on July 10th (10,343 cells/ml). All algal phyla occurred in higher densities during those three months. Total suspended solids concentrations and turbidity were lower during these months which increased light availability for algal growth. Water temperatures were higher during these months which can also promote algal growth.

Benthic Invertebrates

The trimetric index (TMI) (Angradi et al 2016) is an index of benthic invertebrate community quality and was developed specifically for the SLRE. Allouez and Pokegama Bays were excluded from the SLRE for the development of the TMI and the accompanying ephemerid density index. However, they are still the most useful benthic invertebrate indices to apply to these bays and provide a basis of comparison to the rest of the SLRE.

The median TMI value for Allouez Bay was poor, for Pokegama Bay was fair, and for Kimballs Bay was poor. The quality of the benthic invertebrate community in all three bays was below average in comparison to the rest of the SLRE. The physical characteristics of sediment with high clay content (and corresponding high-water content) may be restrictive to some benthic invertebrates in all three of the bays, and possibly account for the low TMI values. Periods of anoxia at two sites in Kimballs Bay probably also contributed to the poor median TMI there.

The median ephemerid (mayflies) density index value (Angradi et al. 2016) for Allouez Bay was good, for Pokegama Bay was excellent, and for Kimballs Bay was poor. Median values for Allouez and Pokegama Bays were above average in comparison to the rest of the SLRE. High clay content of sediment does not appear to negatively affect ephemerid species. Periods of anoxia at two sites in Kimballs Bay may have again accounted for the poor median value there.

Aquatic Macrophytes

Results from recent aquatic macrophyte surveys (2004-2015) are available for the three bays (Danz et al. 2017) and are summarized below in Table 2:

Table 2. Aquatic Macrophyte Survey Data for the Bays

	Allouez Bay	Kimballs Bay	Pokegama Bay	All SLRE surveys
Number of species	155	74	148	NC**
Species per plot	8.8	5.0	5.8	NC**
Mean C* value	5.6	3.6	5.4	5.06

*C = coefficient of conservatism, an index of tolerance to disturbance. **NC = not comparable; number of species and species per plot are influenced by size of area surveyed and survey methods, so do not offer a simple means of comparison.

Mean C values for Allouez and Pokegama Bays are better than the mean C value for all SLRE aquatic macrophyte surveys, while the mean C value for Kimballs Bay is poorer. Allouez Bay appears to have the best aquatic plant community, while Kimballs Bay has the poorest.

Wetlands[1]

Recent wetland monitoring data (2011-2017) is available for all three bays from the Great Lakes Coastal Wetland Monitoring Program (Brady 2018).

Wetland nutrient, turbidity, and chlorophyll concentrations were generally similar to those found at open water sampling sites in 2017, although Kimballs Bay total phosphorus concentrations were higher than open water concentrations, suggesting wetland phosphorus release may be occurring at higher rates there.

Daytime dissolved oxygen concentrations in wetlands were below 3 mg/l for a significant percentage of measurements (5-25%), with Kimballs Bay having the highest percentage of such measurements. Less water mixing in Kimballs Bay due to its sheltered nature may account for these differences. Wetland macroinvertebrate IBI's are available for Allouez and Pokegama Bays for 2011 and 2012. Allouez Bay scores were rated as moderately impacted. Pokegama Bay scores were rated as moderately impacted to most pristine.

Wetland fish IBI ratings for the four years monitored for Allouez Bay ranged from moderately impacted to mildly degraded. The rating for the one year monitored for Kimballs Bay was moderately degraded. The rating for the one year monitored for Pokegama Bay was mildly impacted.

Wetland bird and frog survey results (2012-2013) are available for Allouez and Pokegama Bays (Tozer 2014). Additional wetland bird and frog survey result are available for one or more years during 2014 - 2017 for all three bays (Brady 2018).

For the 2012-2013 bird surveys, Allouez Bay had an index of biotic integrity (IBI) score of 31.8 (fair) which is slightly below the median score of 33.3 found for 14 Lake Superior coastal wetlands (mostly outside of the SLRE). Pokegama Bay had a score of 34.0 (fair) which is slightly above that median score. For Allouez Bay, three wetland bird surveys (2014, 2016, 2017) had a median index of ecological condition (IEC) rating of high quality. A Kimballs Bay survey (2016) had an IEC rating of degraded. A Pokegama Bay survey (2016) had an IEC of mildly impacted.

For the 2012-2013 frog surveys, Allouez Bay had an IBI score of 60.0 (rated good) which is below the median score of 86.5 found for 13 Lake Superior coastal wetlands (mostly outside of the SLRE). Pokegama Bay had a score of 70.3 (rated very good) which is also below that median score. For Allouez Bay, three wetland frog surveys (2014, 2016, 2017) had a median IEC rating of reference condition. A Kimballs Bay survey (2016) had an IEC rating of moderately degraded. A Pokegama Bay survey (2016) had an EIC rating of moderately impacted.

Fishery

Bay fisheries were monitored during 2017 using gill nets and shoreline electrofishing (Nelson 2018). Results are summarized in Table 3 below.

[1] also see Biological Indicators Summary, below

Table 3. Bay Fish Data Summary with Comparison to MN DNR Gill Net Data

Gill Net Data	Alllouez Bay	Kimballs Bay	Pokegama Bay	21 MN SLRE gill net sites
Total number of species	12	6	9	19
Median number of species/net lift	9	3	9	8
Mean fish/net lift	39.9	3.6	19.3	27.5
Mean kg fish/net lift	21.9	1.3	8.3	13.0
Gill Net plus Electrofishing Data				
Total number of species	22	15	21	not applicable
Number of native species	18	14	16	not applicable
Number of non-native species	4	1	5	not applicable
Number of intolerant species	4	4	3	not applicable

Allouez and Pokegama Bays gill net data is generally similar to data collected by the Minnesota DNR during 2017 from 21 SLRE gill net sites for median number of species/net lift, mean fish/net lift, and mean kg of fish/net lift. Kimballs Bay gill net data is substantially lower than the Minnesota DNR data for those parameters.

Conclusions of the fishery survey report included, "Despite turbid conditions that may lead to the perception of poor water quality or habitat, locally popular sport fish species like walleye, northern pike, black crappie, and yellow perch were well represented in both Allouez and Pokegama Bays. Other species of interest to anglers and state fisheries management agencies were also found in these bays including lake sturgeon, muskellunge, bluegill, and channel catfish. While Increased turbidity in Allouez and Pokegama Bays may influence the presence or abundance of specific species, it has not diminished the fishery value or eliminated desirable gamefish species from these areas." (Nelson 2018)

Biological Indicators Summary

The available biological indicators for the three bays are summarized below in Table 4.

Table 4. SLRE Bays Biological Indicators

BIOLOGICAL COMMUNITY	INDICATOR	ALLOUEZ BAY	KIMBALLS BAY	POKEGAMA BAY
Benthic invertebrates	Trimetric index[1]	median = poor (poorer than average for SLRE)	median = poor (poorer than average for SLRE)	median = fair (poorer than average for SLRE)
Ephemerid mayflies	Ephemerid density index[1]	median = good (better than average for SLRE)	median = poor (poorer than average for SLRE)	median = excellent (better than average for SLRE)
Aquatic macrophytes	Species richness[2]	155	74	148
Aquatic macrophytes	Species richness per plot[2]	8.8	5.0	5.8
Aquatic macrophytes	Mean C value[2]	5.6; species that tolerate moderate disturbance; better than SLRE mean value of 5.06	3.6; generalist species that are tolerant of disturbance; poorer than SLRE mean value of 5.06	5.4; species that tolerate moderate disturbance; better than SLRE mean value of 5.06
Bay fish	multiple[5,7]; no applicable IBI available	Number fish/gill net lift = 145% of 21 site SLRE mean; kg fish/gill net lift = 168% of 21 site SLRE mean; number species /gill net lift = 112% of 21 site SLRE median; % native species = 92%; number of intolerant species = 4; "...popular sport fish species...are well represented in Allouez ...Bay."	Number fish/gill net lift = 13% of 21 site SLRE mean; kg fish/gill net lift = 10% of 21 site SLRE mean; number species /gill net lift = 38% of 21 site SLRE median; % native species = 99%; number of intolerant species = 4	Number fish/gill net lift = 70% of 21 site SLRE mean; kg fish/gill net lift = 63% of 21 site SLRE mean; number species/gill net lift = 112% of 21 site SLRE median; % native species = 79%; number of intolerant species = 3; "...popular sport fish species ... are well represented in ... Pokegama Bay."

Table 4. SLRE Bays Biological Indicators (Cont.)

BIOLOGICAL COMMUNITY	INDICATOR	ALLOUEZ BAY	KIMBALLS BAY	POKEGAMA BAY
Wetland Macroinvertebrates	Wetland macroinvertebrate IBI[4]	2011, 2012 = moderately impacted; not enough non-clay influenced SLRE surveys to allow comparison.	IBI not available	2011, 2012 median = mildly impacted; not enough non-clay influenced SLRE surveys to allow comparison.
Wetland Vegetation	Wetland vegetation IBI[4]	2011-2017 median = moderately impacted = median for non-clay influenced SLRE surveys	2014, 2016 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impacted).	2011, 2012, 2016 median = moderately impacted = median for non-clay influenced SLRE surveys
Wetland Fish	Wetland fish IBI[4]	2011-2017 median = moderately impaired to moderately degraded, which is slightly poorer than the median for non-clay influenced SLRE surveys (moderately impaired).	2014 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impaired).	2012 = mildly impacted, which is better than the median for non-clay influenced SLRE surveys (moderately impaired).
Wetland Birds	Bird IBI[3]	31.8; fair - just below median value of 33.3 found for 14 Lake Superior coastal wetlands, mostly outside of SLRE	no data	34.0; fair - just above median value of 33.3 found for 14 Lake Superior coastal wetlands, mostly outside of SLRE
Wetland Birds	Bird IEC[4]	2014 2016, 2017 median = high quality, which is better than the median for non-clay influenced SLRE surveys (moderately impacted)	2016 = degraded, which is poorer than the median for non-clay influenced SLRE surveys (moderately impacted)	2016 = mildly impacted, which is better than the median for non-clay influenced SLRE surveys (moderately impacted)
Wetland Frogs	Frog IBI[3]	60.0; good - below median value of 86.5 found for 13 Lake Superior coastal wetlands, mostly outside of SLRE	no data	70.3; very good - below median value of 86.5 found for 13 Lake Superior coastal wetlands, mostly outside of SLRE
Wetland Frogs	Frog IEC[4]	2014 2016, 2017 median = reference condition, which is better than the median for non-clay influenced SLRE surveys (mildly impacted)	2016 = moderately degraded, which is poorer than the median for non-clay influenced SLRE surveys (mildly impacted)	2016 = moderately impacted, which is poorer than the median for non-clay influenced SLRE surveys (mildly impacted)

[1]Angradi, TR, Bartsch, WM, Trebitz, AS, Brady, VJ, Launspach, JJ. 2016. A depth-adjusted ambient distribution approach for setting numeric removal targets for a Great Lakes Area of Concern beneficial use impairment: degraded benthos. J Great Lakes Res.
[2]data from Danz, et al. 2017 (get full reference)
[3]Tozer, D. 2014. LSRI nearshore monitoring project: 2012-2013 bird and frog indices of biotic integrity. EPA assistance no. GL00E00500-0.
[4]Uzarski, DG, et al. 2017. Standardized measures of coastal wetland condition: implementation at a Laurentian Great Lakes basin-wide scale. Wetlands (37:15).

[6]Nelson, A. 2018. St. Louis River Bays – Douglas County; 2017 fish community survey. Wisconsin Dept. of Natural Resources, Superior, WI. Unpublished report.

[7]Pinkerton, J. 2018. Personal communication. Minnesota Dept. of Natural Resources fisheries specialist, Duluth, MN.

Allouez and Pokegama Bays both had high turbidities and total phosphorus concentrations. However, biological indicators for these bays tended to have moderate values that were often close to average, and in some cases above average ((ephemerid mayflies, aquatic macrophyte mean C, wetland birds, wetland fish (Pokegama only), wetland frogs (Allouez only)) for the SLRE or other comparable sites. Current water quality conditions do not appear to be having any strong negative effect on biological communities in these two bays. This finding is similar to that of the Red Clay Project conducted during the 1970's (EPA 1980). A conclusion of that project was, "Analysis of areas of Lake Superior and the Nemadji River system which are turbid throughout the year due to erosion of unconsolidated glacial lake deposits indicated that any direct physical effects of this turbidity and resultant low-level sedimentation (on aquatic life) are minimal."

The trimetric index for benthic invertebrates is one biological indicator that is below the SLRE average for Allouez and Pokegama Bays. This may be due to the high clay and water content of the bay sediment, which could be physically restrictive to some benthic organisms.

Kimballs Bay consistently has the poorest values for the biological indicators. Kimballs Bay has the lowest turbidities and total phosphorus concentrations of the three bays. It has a very small direct clay rich soil watershed and no known legacy contaminants. The poorer biological conditions were probably naturally occurring and resulted from the bay's physical characteristics. The bay is narrow and has tall, steep wooded banks that minimize wind-induced mixing. The bay also has steeper bottom contours and greater average depth. The limited mixing results in low summer dissolved oxygen concentrations occurring at depth in the bay. Low summer dissolved oxygen concentrations have also been observed to occur more frequently in the wetlands of this bay than in Allouez and Pokegama Bays, probably also due to the limited mixing.

Low dissolved oxygen concentrations could be impairing the benthic invertebrate, ephemerid mayfly, wetland macroinvertebrate, wetland and bay fish, and possibly frog communities in Kimballs Bay. It is unclear what may be causing the poor biological indicator values for aquatic macrophytes, wetland vegetation, and wetland birds.

Appendix 4

Comparative Analysis of the Nemadji River Watershed
In the Lake Superior Basin
(Pertains to management action 6.05)

Final Report Community GIS Services, Inc.
Comparative Analysis of The Nemadji River Watershed in the
Lake Superior Basin

Our goal of the project was to deliver a product that local, state, and federal governmental entities could use to identify small hydrological units within the Nemadji River Watershed that are exceeding forty percent open land status. For this project our definition of open land class was timber that is 15 years or less in age, agricultural land, and urban land types.

Our first task was to digitize the 0 – 15 year timber age class within the watershed. We accomplished this task by obtaining 16 years of USGS Landsat 5 and Landsat 8 satellite imagery covering the entire watershed. Covering the entire Nemadji River Watershed with Landsat scenes often took two adjacent image scenes (Row 27, Path 28 and Row 26, Path 27). For gathering 16 years of these images, Community GIS Services needed to obtain 32 images or scenes of Landsat data that were acquired or captured between the months of May and September. Scenes captured within this time period revealed peak leaf chlorophyll amounts. Community GIS Services checked for proper spatial control of the Landsat scenes by matching them with previously rectified scenes. In ArcGIS software the technician imported the native Landsat format to tif file format and clipped the imagery to the watershed bounds. The clipped Landsat images were given a band combination of 4 (Near Infrared),5 (Short-wave Infrared),3 (visual red) for Landsat 5 scenes and for Landsat 8 scenes a band combination of 5 (Near Infrared), 6 (Short Wave Infrared 1), 3 (visual red). These band combinations along with the use of high resolution aerial imagery, 1:24,000 scale digital USGS Topographic maps and wetland inventory data allowed us to distinguish between timber harvests / agricultural lands and wetlands.

Community GIS Services digitized each timber harvest occurring within the watershed by utilizing ArcGIS software with the 16 years of layered Landsat scenes as a basis and watershed boundaries and section line boundaries as secondary layers. The GIS technician would start on one side of the watershed and turn each year of the Landsat imagery on for each section and looked for changes to the landscape that indicated a timber harvest. If a harvest was found, it was digitized and attributed with the year in which it occurred. This process continued for the entire watershed on a section-by-section basis.

The next task was to digitize the urban and agricultural lands within the watershed. Since the timber harvests were already digitized, the technician could use 2013 aerial imagery from USDA and Douglas County Wisconsin to identify and digitize the boundaries of these land features on-screen using ArcGIS software.

Our third task was to digitize the small hydrological units that would be used to calculate the percentage of open land. Community GIS Services had previously contracted hydrologist Dr. E. Sandy Verry to determine the extents of the hydrological units. This was completed by Community GIS Services printing in large format the 1:24,000 USGS digital topographic maps with USFS HUC-12 watershed boundaries of the Nemadji River Watershed and Dr. Verry cutting the HUC-12 delineations into smaller hydrological units with pencil. His criteria for cutting the watersheds were stream sinuosity, stream slope, watershed contour, and personal knowledge of the region. Community GIS Services delineated the outlines of the hydrological units on the maps and digitized onscreen using ArcGIS software. These digitized hydrological units were attributed and printed again for Dr. Verry to verify. Finally, Community GIS Services combined the harvests, agriculture, and urban land features into one GIS layer and performed an Identity function on the open land class layer and the digitized hydrological units. The identity function combined both the polygon features of the land classes and the hydrological units with the attribute records of both GIS layers. Community GIS Services was then able to calculate total percent open based on 0 – 15 year timber harvests, agriculture and urban land, and a combination of both land classes per hydrological units within the Nemadji River Watershed. Additionally, we incorporated the previous open land study data of 2003 and 2008 to measure the amount of increase or decrease of cumulative open lands within each subwatershed.

After checking and rechecking our data for accuracy and completeness Community GIS services created small format map layouts in digital map formats for replication. All data created and used for this project along with map images were copied to our web server and are available to local, state, tribal, and federal governmental entities that requested a copy.

A Summary of results:
Watershed Size: 280,787 Acres
Number of subwatersheds delineated for the study: 171

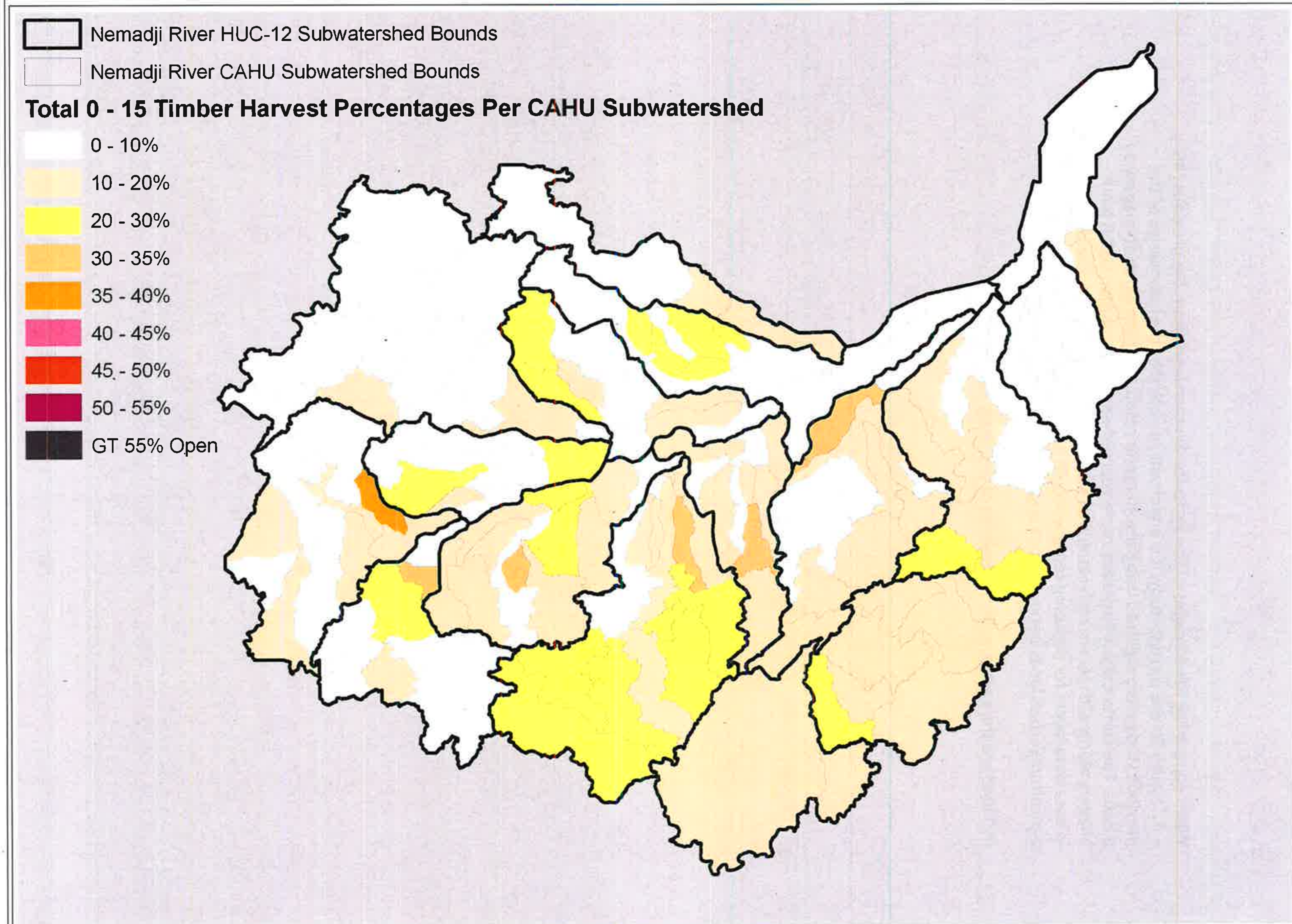
Number of subwatersheds below 40% open for current study: 125
Number of subwatersheds between 40 – 50% open for current study: 23
Number of subwatersheds between 50 – 60% open for current study: 18
Number of subwatersheds above 60% open for current study: 5

Number of subwatersheds below 40% open for previous (86' – 02') study: 136
Number of subwatersheds between 40 – 50% open for previous (86' – 02') study: 20
Number of subwatersheds between 50 – 60% open for previous (86' – 02')study: 12
Number of subwatersheds above 60% open for previous (86' – 02') study: 3

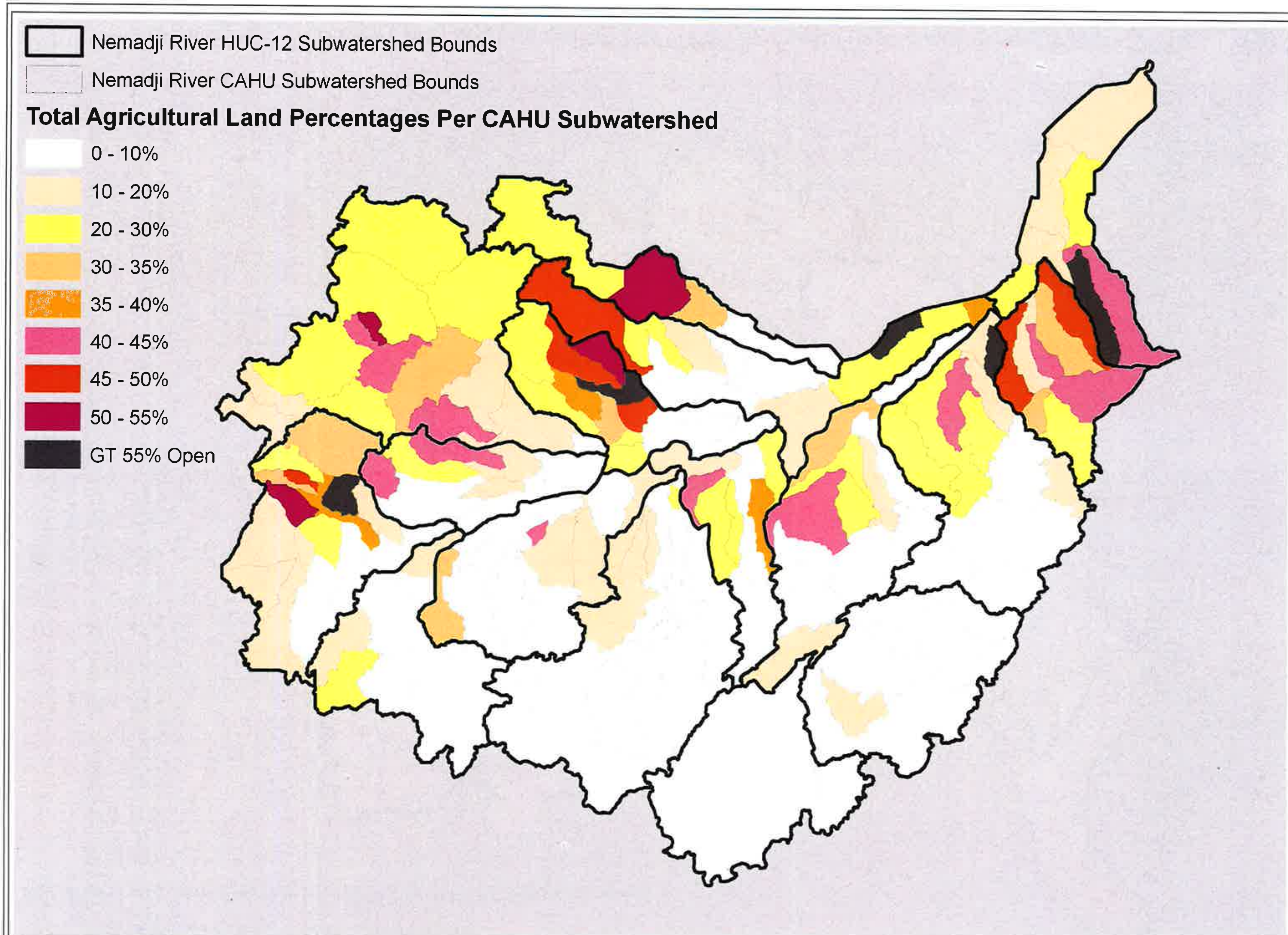
Total acres of 0 – 15 year timber age class for current study: 35,444
Total acres of agricultural/urban lands for current study: 55,825
Total acres of 0 – 15 year timber age class for previous (86' - 02') study: 27,898
Total acres of agricultural/urban lands for previous (86' - 02') study: 44,184

When comparing the acreages of the agricultural/urban lands from the previous (86' – 02') study to the current study, it is important to note that the boundaries of the previous study were digitized using the 30-meter resolution 2002 Landsat imagery as a basis. The current study had many more years of 1-meter resolution USDA NAIP imagery along with recent high resolution state and county imagery. The differences in base data layers for digitizing features could be one factor for the 26% increase in agricultural/urban lands between 2002 and 2014 studies.

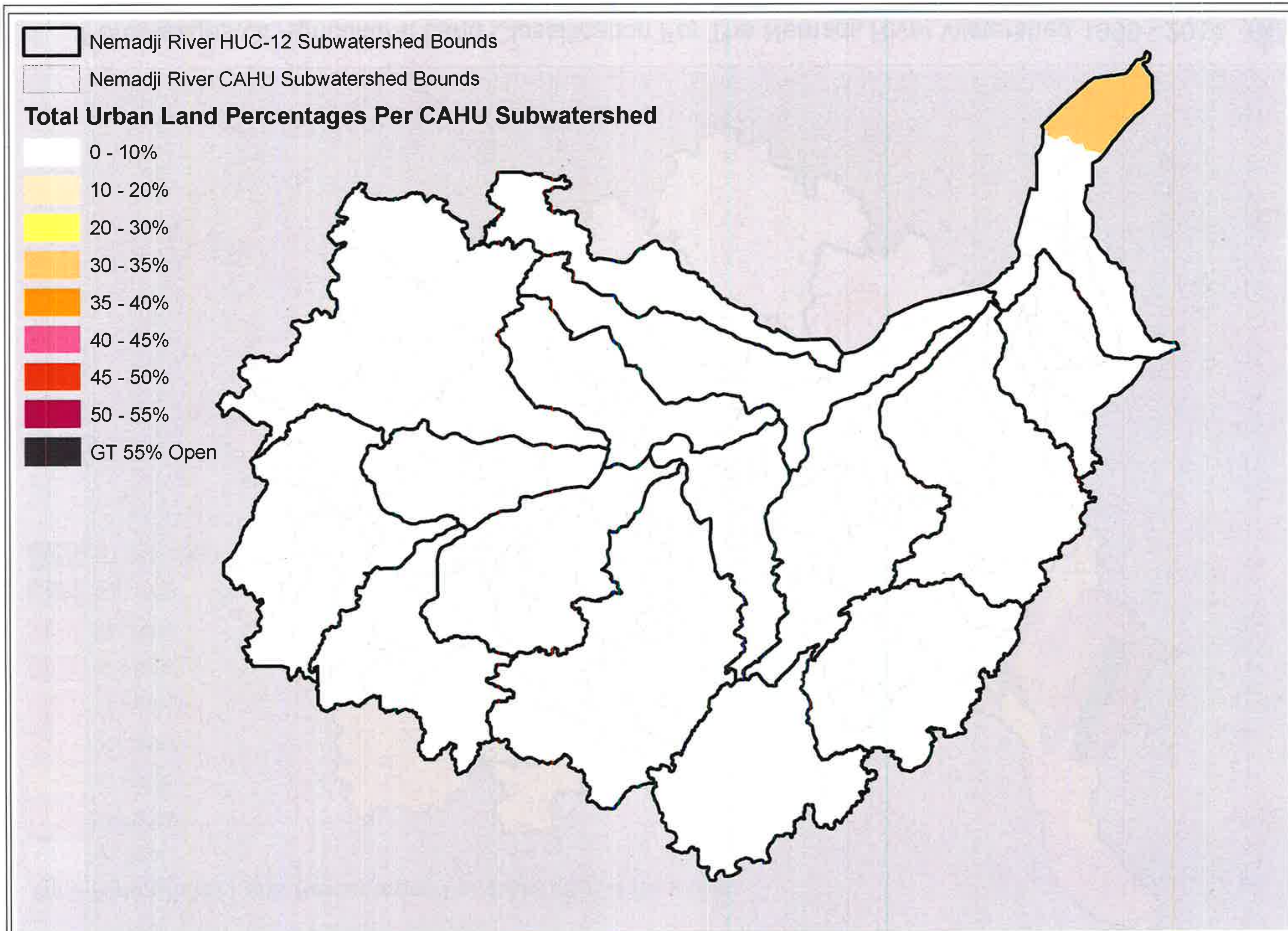
Included are the cartographic summaries of the study's analysis.



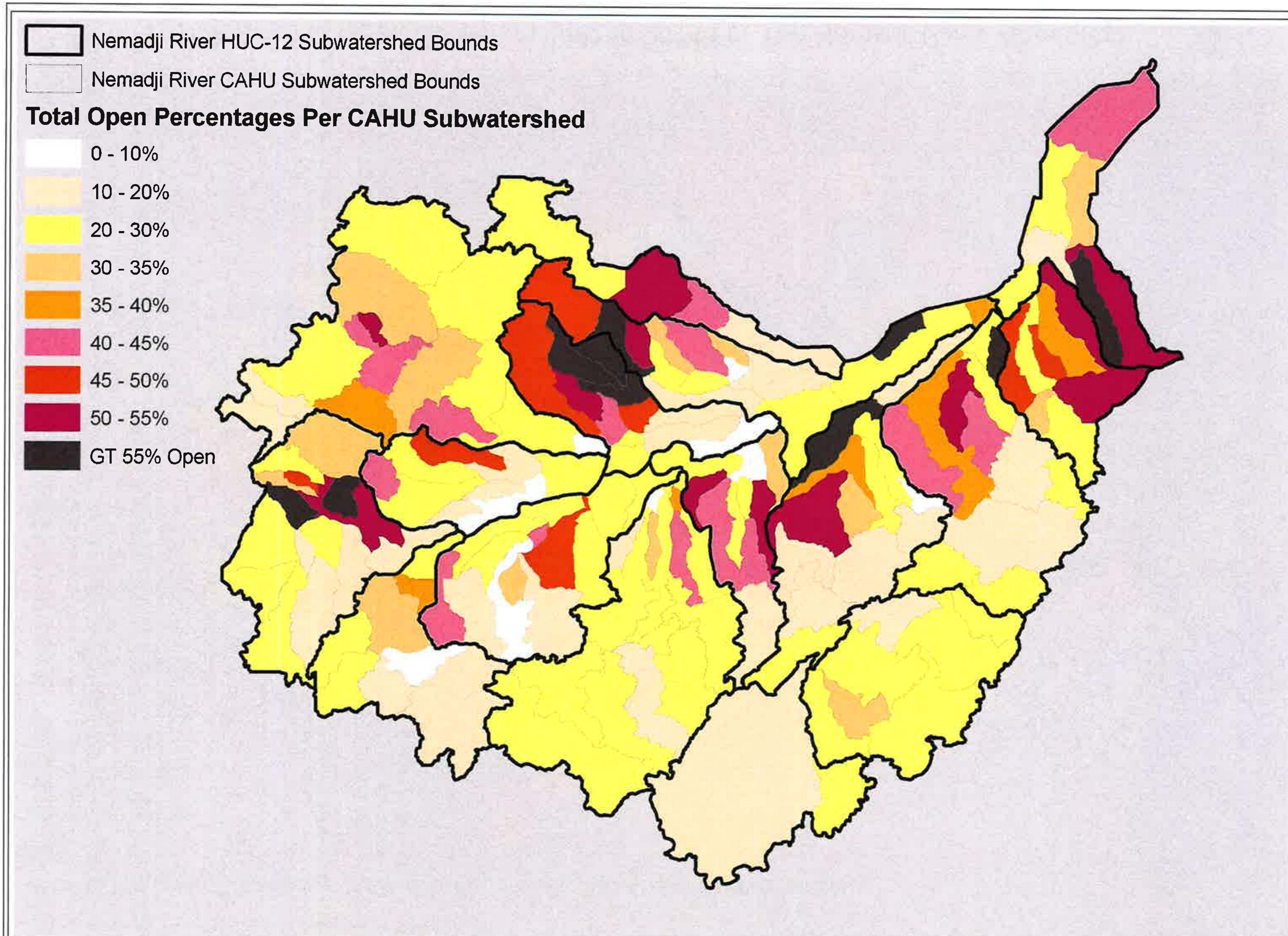
Percentages Of 0 - 15 Year Timber Age Class For The Nemadji River Watershed 1999 - 2014



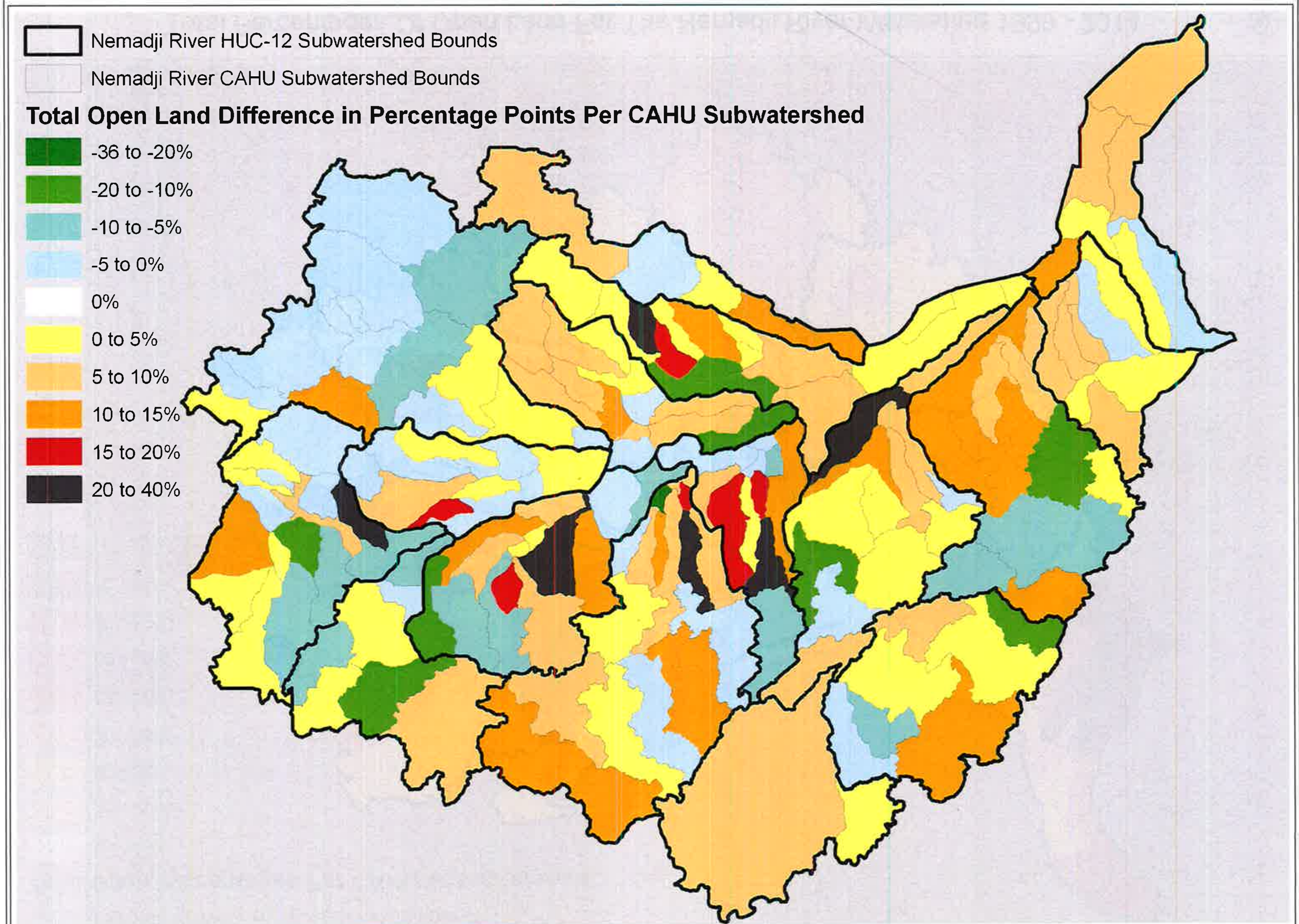
Percentages Of Agricultural Land Classification For The Nemadji River Watershed 1999 - 2014



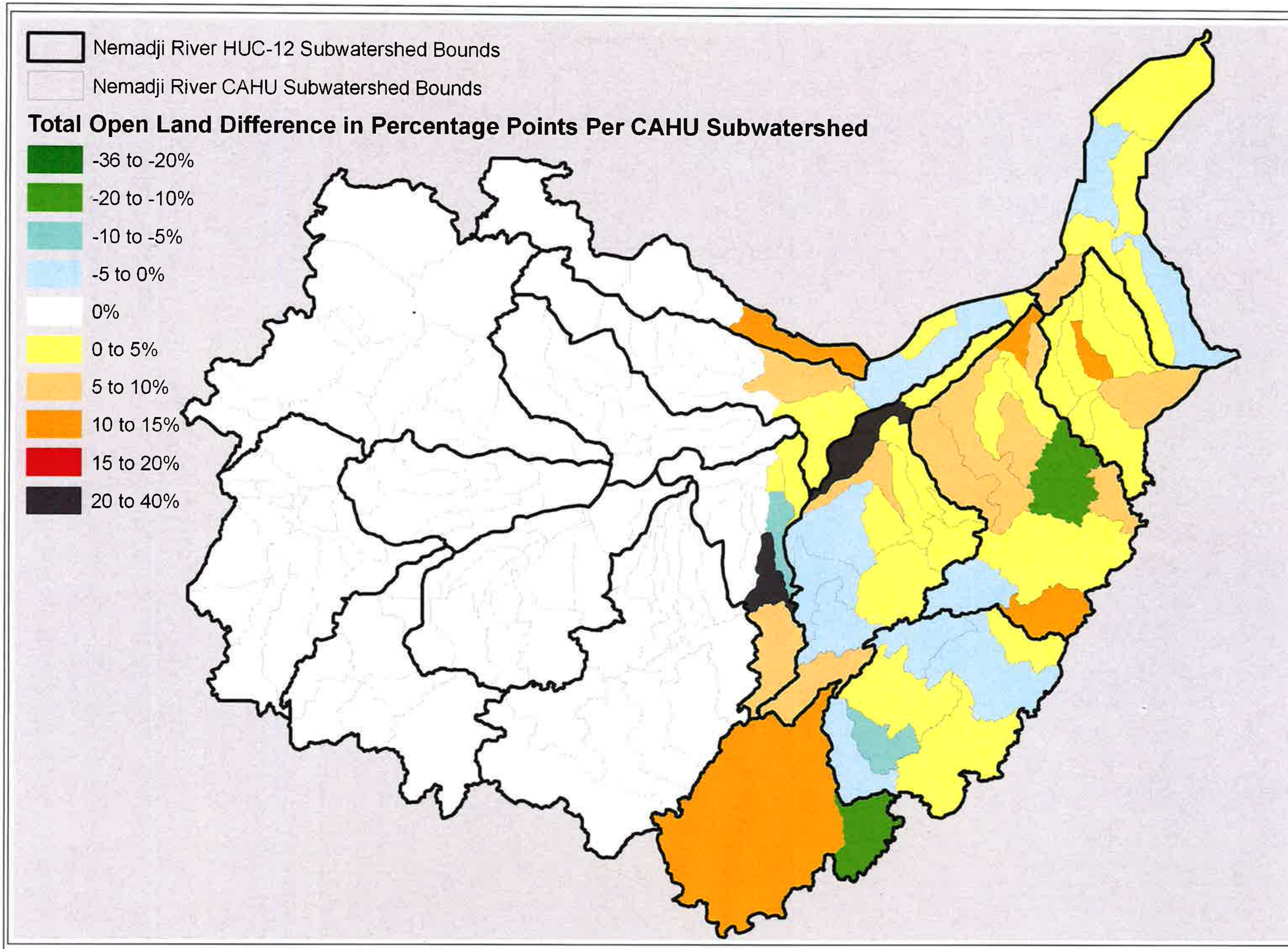
Percentages Of Urban Land Classification For The Nemadji River Watershed 1999 - 2014



Total Percentages Of Open Land For The Nemadji River Watershed 1999 - 2014



Difference in Open Land from 2002 to 2014 For The Nemadji River Watershed



Difference in Wisconsin Open Land from 2008 to 2014 For The Nemadji River Watershed

Appendix 5

Current and Historic Sediment Loading in the Nemadji River Basin
(Pertains to management action 6.05)

Current and Historic Sediment Loading in the Nemadji River Basin

August 1, 2016

PREPARED FOR

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1.0 INTRODUCTION

The overall project goal was to simulate historical conditions for sediment loading in the Nemadji River watershed and compare current to estimates of historic conditions in an effort to understand how sediment loads have changed over time. The project makes use of an existing Hydrological Simulation Program-Fortran (HSPF, version 12.4; Bicknell et al., 2014) watershed model developed under contract with the MPCA (Tetra Tech 2016). The HSPF model was developed for MPCA's general basin planning and permit development purposes and addresses flow, sediment, dissolved oxygen, temperature, nutrient loads, and algae within the Nemadji River basin. It is a tool of opportunity for use in evaluating historic sediment loading scenarios that provides a reasonable representation of sediment loading, from both upland and channel sources, under current conditions and can be efficiently modified to address historic conditions. It is not, however, an ideal tool for sediment loading simulation because it was created at a fairly coarse spatial scale and provides a one-dimensional channel simulation that cannot resolve the details of bank stability throughout the planform of the Nemadji River and its tributaries. More detailed high-resolution channel models would be preferable for conducting analysis of sediment scour and deposition processes; however, such models require a high level of effort and detailed survey information that is not feasible under the currently available funding. Nonetheless, we believe that the HSPF model scenarios provide a reasonable first-cut estimate of the likely differences between current and historic conditions for sediment loading and transport in the Nemadji River watershed and can provide a basis for planning future, more detailed modeling studies.

The project area includes the Nemadji River's 1,130 km^2 watershed that drains to the St. Louis River Estuary on Lake Superior. The entire Nemadji watershed is included in the St. Louis River Area of Concern due to excessive sedimentation observed in the river. The lower portion of the Nemadji watershed is situated in extremely clay-rich glaciolacustrine soils (Lake Superior Red Clay Plain) that are naturally prone to erosion and sedimentation. The upper third of the basin is situated in interbedded glacial tills and beach and outwash sands and gravels. Sedimentation issues related to historic land use changes are very difficult to distinguish from natural processes in this naturally sediment-rich system. The Nemadji is a young watershed and is affected by a continuous change in base levels in Lake Superior, so equilibrium assumptions regarding channel form are likely not appropriate. An apparent increase in precipitation event intensity due to a changing climate compounds the problem further.

Changes in sediment loading since European settlement of the area are difficult to quantify. The estimated average annual suspended sediment load at the mouth of the Nemadji was 130,000 tons/yr based on sediment data collected in the 1970s and flow data through the late 1990s (NRCS 1998 and Robertson, 1996). As a check on model performance, we used the USACE FLUX program to estimate sediment loading in the Nemadji at South Superior directly from monitoring and flow gaging data for 1997-2012, obtaining an estimate of 80,107 tons/yr. This estimate is matched within 2 percent by the HSPF model (after revisions described below in Section 2.3.2): Using 2008 land cover, the HSPF model predicts an average annual suspended sediment load at South Superior of 78,751 tons/yr – both confirming model performance and indicating improvement in sediment loading conditions since the 1970s. Note that all estimates of sediment load are based on suspended sediment monitoring, which is likely to under-estimate the total sediment load because sediment moving as bedload has not been sampled.

Land use changes in the past two centuries have resulted in hydrologic alterations and accelerated erosion rates in similar rivers in Wisconsin situated in the Red Clay Plain (e.g., Fitzpatrick et al., 1999; Fitzpatrick and Knox, 2000). The Nemadji watershed was logged extensively in the late 1800s and early 1900s, and subsequently many upland wetlands and depressions were drained and converted to agriculture. Many channels were straightened, steepened, and cleared in order to raise water levels and facilitate the transport of logs downstream (Rector, 1951). These manipulations likely accelerated down-cutting and widening of streams in the basin. Trapping of beaver may also have had important effects, as beaver dams trap sediment and increase the extent of wetlands. In the 1930s, agriculture (crops, hay, pasture) is said to have occupied nearly half of the land area in the Wisconsin portion of the basin. Increased water yields during peak agriculture resulted in increased incision and entrenchment of Nemadji and its tributaries, and disconnection from the floodplain (Riedel et al., 2001). Since the mid-1900s, many acres have been converted back to forests. Today, the watershed is approximately 68% forested 11% agriculture (crop, pasture, hay), and 18% wetlands and lakes; however, the second-growth aspen/birch forest cover is not functionally equivalent to the native old growth, white pine forest cover prior to logging. Wetland area, which mitigates peak flows, has also been substantially reduced relative to pre-settlement conditions, from about 38 percent of the watershed under pre-settlement conditions to about 17 percent of the watershed under current conditions.

A better understanding of the influence of historic land use change on sediment loading will help resource managers address key areas where sedimentation is excessive by working with landowners and stakeholders to make improvements. This will also meet the actions required under the Excessive Loading of Sediment and Nutrients beneficial use impairment (RAP, 2015) for the St. Louis River Area of Concern. As a means to assess this, HSPF modeling scenarios were developed to evaluate sediment loads for the following time periods that encompass the range of upland land conditions experienced in the watershed:

- Prior to European settlement in the watershed
- During the time period with the highest percentage of agriculture and logged lands (ca. 1930)
- Under current land use conditions

Representation of current conditions uses the calibrated HSPF model previously developed by Tetra Tech (2016) for MPCA (with additional updates documented below in Section 2.3.2). The model is constructed at approximately the HUC-12 spatial scale (Figure 1-1). It uses land use information from the 2006 National Land Cover Database, the 2008 LANDFIRE coverage from the U.S. Forest Service, and the 2013 Cropland Data Layer from USDA. Channel dimensions and hydraulic behavior are based on analysis of available cross sections and regional hydraulic geometry relationships developed by Magner and Brooks (2008). Model calibration and validation demonstrate that the model provides a reasonable representation of recent sediment loads in the Nemadji River watershed, although the relatively coarse segmentation of the model limits the ability to describe conditions within individual source areas. The HSPF model provides an available platform with which to examine relative changes in sediment load over time.

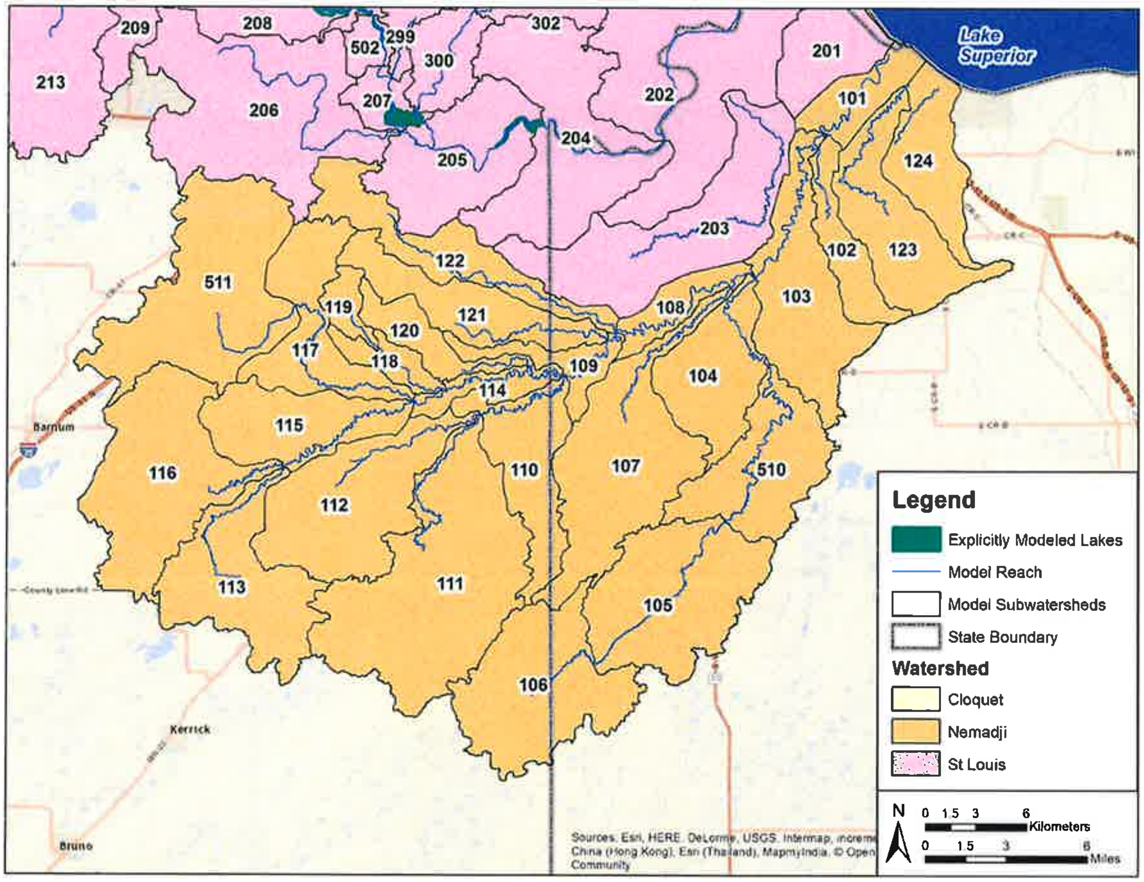

Figure 1-1. Model Subbasins in the Nemadji River HSPF Model

The existing model uses a hydrologic response unit (HRU) approach in which the landscape is simulated based on unit-area components that reflect a combination of land use, land cover, and soil properties summarized by hydrologic soil group (HSG). HSG is a measure of infiltration potential, ranging from A soils (high infiltration capacity) to D soils (very low infiltration capacity). The HRUs described in the model are listed in Table 1-1. The developed and road categories are further sub-divided into pervious and hydrologically connected impervious areas, as described in Tetra Tech (2012).

Table 1-1. Hydrologic Response Units in the Nemadji River HSPF Model

Land Use	HSG
Forest, Deciduous	AB
Forest, Deciduous	CD
Forest, Evergreen	AB
Forest, Evergreen	CD
Wetlands, Forested	CD
Wetlands, Herbaceous	CD
Grassland/Shrubland	AB
Grassland/Shrubland	CD
Pasture/Hay	AB
Pasture/Hay	CD
Row Crops	AB
Row Crops	CD
Row Crops	Drained
Developed, Open Space	All
Developed, Medium Intensity	All
Developed, High Intensity	All
Water	CD
Barren/Strip Mines	CD
Roads	All

2.0 METHODS

2.1 LAND USE/ LAND COVER

An evaluation of historical sediment dynamics was conducted by applying the existing model to land use/land cover conditions or previous time periods. To apply the model to historical time periods it is first necessary to estimate appropriate land use/land cover in the watershed. The approach and relevant information sources are provided below for each of the scenarios. An evaluation of the uncertainties associated with the available and utilized datasets is provided in the Results (Section Results3.0).

2.1.1 Current Conditions

As noted above, current conditions simulation relies on the previously developed and calibrated HSPF watershed model (Tetra Tech, 2016). Land use/land cover components of this model are described below.

Base Land Use and Land Cover: The base land use and land cover representation is as developed for the existing Nemadji River basin model for MPCA. This uses the 2008 LANDFIRE coverage (which is based on the same 2006 Landsat imagery as the 2006 NLCD) combined with 2006 NLCD and SSURGO soils.

A more detailed study of open lands in the Nemadji basin was recently completed by Community GIS Services ([2014], *Comparative Analysis of The Nemadji River Watershed in the Lake Superior Basin).* Among other things, this study used year-by-year analysis of Landsat imagery to estimate the 0-15 year timber age class, allowing identification of rates of forest harvest. The HSPF model represents a static land use and is developed at a coarser scale than the open lands analysis, so this information cannot be incorporated directly. The HSPF model does include shrub and barren land classifications into which recently timbered land (as of 2006) will fall. The open lands study suggests that the fraction of forest classified as shrubland is consistent with recent long-term average forest harvest rates in the watershed.

Surface Drainage: Surface drainage is enhanced relative to natural conditions due to ditching and the construction of roads. The natural watershed is believed to have included many internally drained depressions which were leveled and/or drained during peak agriculture. Although much of the agricultural land has reverted to forest since that time, the enhanced surface drainage remains (NRCS, 1998). The current conditions model hydrologic calibration implicitly incorporates the current enhanced surface drainage.

Wetlands: As identified in the base land use and land cover for the existing model.

Lakes: The lakes that are present in the watershed are generally small and disconnected from the main stream network. They are represented in the existing model as water land uses.

Rural Development: As identified in the base land use and land cover.

Roads/Railways: As identified in the base land use and land cover using the Tiger Census roads and local county roads coverages.

2.1.2 Peak Agriculture (ca. 1930)

Peak agriculture in the watershed was assumed to be approximately 1930 (although the agricultural census suggests that additional conversion of land to agriculture may have continued after 1930.) Satellite-based estimates of land use/land cover conditions are obviously not available for 1930. The data sources and assumptions used to describe ca. 1930 land use and land cover are described below.

Base Land Use/Land Cover: Topographic maps of the whole watershed are not available until the late 1940s. There is aerial imagery from 1939, but resources are not currently available to process this imagery. For the Wisconsin portion of the watershed, detailed information on land use in Douglas Co. as of 1933 is provided in the Wisconsin Land Economic Survey maps ("Bordner surveys"; https://uwdc.library.wisc.edu/collections/EcoNatRes/WILandInv/). The Bordner surveys have been digitized and merged to form a seamless map. The digitizing was for land use only, and does not include buildings and roads. As buildings and roads can have an important impact on hydrology they must be addressed separately, as described below. The Bordner surveys, after subtracting the road impervious area, provide the base land use/land cover for ca. 1930 conditions in the Wisconsin portion of the watershed.

The Bordner surveys do not cover the City of Superior, WI – except insofar as to show it as an urban area. Superior is at the very mouth of the Nemadji and has only a small impact on delivered sediment loads associated with the river. Therefore, we initially assumed that the land use distribution within the 1930 city limits was approximately the same as under current conditions. Population Census data are used to determine if a density-based adjustment to the impervious cover fraction in the City of Superior relative to current conditions is warranted.

There is not a spatial coverage comparable to the Bordner surveys for the Minnesota portion of the watershed (in Carlton County and a small part of Pine County). Therefore, more approximate methods must be used. Specifically, we use county level information for Carlton Co. from the 1929 and 1934 tabulations provided in the 1935 Agricultural Census (Bureau of the Census, 1936) compared to the average in the 2007-2012 Agricultural Census (USDA, 2014) to determine the relative change in cultivated, fallow, and hay/pasture land uses. We use a two-census average because these reports are based on statistical samples of farms and thus subject to uncertainty. This relative change is applied to the 2008 land cover currently in the model to estimate the area present ca. 1930. The agricultural census also contains county-level statistics on the fraction of farms that was in forest or forest-pasture that were used to make some rough estimates as to changes in forest cover.

The type of agriculture conducted around 1930 was also different from modern practices as it included moldboard plowing and much more acreage of oats, barley, and rye (with some corn as well) than are currently grown. Under current conditions there is much less production of small grains, and tillage practices involve much less soil disturbance. We use the crop acreage shown in the agricultural census to estimate likely tillage and cover conditions ca. 1930 and adjust the seasonal pattern of detached sediment on farm land accordingly. In HSPF this is done through the use of the SPECIAL ACTIONS routine to reset the amount of detached sediment on the land surface after spring plowing, seed planting and tillage, and at harvest.

Logging is not expected to have been a major factor in sediment dynamics ca. 1930. Most of the old growth forest had been long since cut and the massive fire of 1918 further degraded forest cover, such that there was likely little mature forest available for timber production in 1930. The first Forest Service Forest Inventory and Analyses for Wisconsin as well as for Minnesota were conducted in 1936 and for the area around Lake Superior show mostly young forest with lots of aspen. Given this history, the model is not adjusted to represent differences in logging for this period relative to current conditions.

Surface Drainage: Much of the modern surface drainage network was already in place by 1930, although additional drainage of wetlands occurred after World War II, due in part to the ready availability of dynamite in that period. We use the extent of wetlands in 1930 as the primary indicator of differences in surface drainage present in 1930 as areas in wetlands are by definition not effectively drained.

Wetlands: The Bordner surveys are the primary source for the extent of wetlands in Douglas Co. ca. 1930. For Minnesota we do not have a 1930 wetlands coverage and it is believed that additional drainage occurred after this period. Lacking other information, we assume that any fraction of additional wetland loss after 1930 identified in the Douglas Co. portion of the watershed would also apply to the Minnesota portion of the watershed.

Rural Development: As noted above, the digitization of the Bordner surveys did not include buildings, driveways, and other impervious areas that are important to hydrology. Only small changes in developed area are expected. The decennial Census, however, gives counts of population on a township basis. We evaluated the change in population statistics between 1930 and 2000 by township as a basis for deciding whether changes in developed impervious area (other than transportation) are needed.

Roads/Railways: The impervious surface in roads and railways plays an important role in storm event hydrology. Unfortunately, the available digitized version of the Bordner survey does not include the roads. Tetra Tech therefore digitized the road and rail lines from the Bordner survey. We were able to obtain an image of a 1935 transportation map of Carlton Co., MN, which is used for the same purpose. For Pine Co., MN the area that is in the Nemadji watershed is sparsely developed. The best available coverage for peak agriculture roads in this small area is provided by the road lines contained on the 1941 county soil survey map.

The amount of impervious area associated with road lines depends on the lane width. The travel lanes on paved roads, gravel roads, and unimproved dirt roads can all be considered as essentially impervious for storm response modeling. However, lane width ca. 1930 was generally less than under today's engineering guidelines. An FHWA (1994) survey discusses the presence of many older rural roads that have only an 8 or 9 foot lane width. Roads present in 1930 were generally two lane, and interstate highways had not yet been built. The following assumptions are made for road impervious area:

- Improved numbered route: 2 lanes, total 20' paved width.
- Rural road: 2 lanes, total 16' paved width
- Unimproved dirt/gravel road: 1 lane, 8' paved width
- Railroad corridor: 12' effective impervious width (gravel, compacted earth)

2.1.3 Pre-Settlement / Intact Forest (ca. 1850)

Base Land Use and Land Cover: The pre-settlement land use is simpler to describe, but harder to observe. In both Wisconsin (Finley, 1976) and Minnesota (Marschner, 1974) the notes and descriptions of lines and corners in the original land plats have been used to reconstruct the pre-settlement vegetation. Both are available in digital form. Tabulations obtained from these maps were checked for consistency against the focused analysis of original vegetation in the Nemadji of Koch et al. (1977).

Much of the watershed prior to settlement was covered with mature pine forest, although fire was also a natural part of the landscape and, along with disease and blowdowns, resulting in a patchwork of ages and types of stands in the pre-settlement forest (NRCS, 1998). This differed in both quantity and quality from current second growth forest. It was not feasible to incorporate all the potential effects of mature forest, such as impacts on the seasonal evapotranspiration cycle or higher amounts of soil piping in undisturbed forest land; however, the shift to evergreen forest for pre-settlement conditions automatically incorporates a greater degree of shading (for snowmelt), higher rates of rainfall interception, and greater cover relative to erosion.

Surface Drainage: Prior to settlement there were no ditches or roads, which reduced the hydrologic connectivity of the uplands to streams. This is approximated in two ways. First, we use the wetland studies described in the next paragraph to approximate areas that were either true wetlands or internally drained depressions with hydric soil characteristics prior to settlement. Second, we modified the model to include longer average overland flow path lengths to better reflect a roadless and unditched situation.

Wetlands: The original vegetation maps (Finley, 1976; Marschner and Heinselman, 1974) provide a rough representation of the extent of pre-settlement wetlands in the Nemadji watershed through comparison to the potentially restorable wetland coverages (National Wetlands Inventory (http://www.fws.gov/wetlands/), Minnesota Restorable Wetlands coverage (http://mnwetlandrestlore.org), and work on restorable wetlands in Douglas Co. (Stark and Robertson, 2013)). Wetlands present in 1930 or shown on the National Wetlands Inventory (see Section 3.1). In addition to drainage of upland wetlands, it is speculated that reduction in riparian wetland area along the middle and lower reaches of the Nemadji may have occurred due to overbank sedimentation and entrenchment of channels.

Rural Development: None.

Roads/Railways: None

2.2 WEATHER

All model simulations for both current and historic land use employ the same weather series, covering the period 1/1/1993 – 12/31/2012. Climate ca. 1930 and ca. 1850 may well have been different from the weather of 1993 - 2012; however, there are not detailed observations available and use of the same weather series for all time periods enables comparison of differences due only to changes in the landscape and channel form.

The model operates on an hourly time step, but hourly precipitation data are not available for the Nemadji watershed. Instead, records from summary-of-the day stations are used, with temporal disaggregation against the hourly pattern at Duluth International Airport. Only four precipitation stations with sufficient periods of record were available for the Nemadji watershed: WI478349 (Superior, WI), WI476413 (Pattison State Park, WI), MN213863 (Holyoke, MN), and MN211630 (Cloquet, MN, used only for the northeast edge of the watershed). Unfortunately, three of these stations had incomplete records and needed to be filled from nearby stations using the normal ratio method: Records for WI478349 end on 12/31/2005 and later dates were filled from WI476413, records for WI476413 commence on 4/30/1998 and earlier dates were filled from WI478349), and records of MN213863 end on 12/31/2006 and later dates were filled from WI476413. There is thus considerable uncertainty in the precipitation record, which propagates into the hydrologic simulation. Air temperature was also taken from local stations, while the third major driver of the energy balance, potential evapotranspiration, was calculated using the Penman Pan energy balance method. The Penman Pan calculations combine local air temperature with inputs for cloud cover, dew point, solar radiation, and wind taken from Duluth International Airport, and are thus also subject to uncertainty.

It is worth noting that gridded meteorological data products have become more widely available since the original development of the Nemadji model, including PRISM daily precipitation and hourly energy balance components from NLDAS. Use of these gridded weather inputs would likely improve the performance of the Nemadji model, particularly as there can be strong gradients in weather over short distances due to lake effects.

2.3 CHANNEL PROCESSES

2.3.1 Channel Hydraulics

Land use changes over the past 150 years have resulted in hydrologic alterations and accelerated erosion rates in similar rivers in Wisconsin situated in the Red Clay Plain (e.g., Fitzpatrick et al., 1999; Fitzpatrick and Knox 2000). The Nemadji watershed was logged extensively in the late 1800s and early 1900s. Many channels were straightened, steepened, and cleared in order to raise water levels and facilitate the transport of logs downstream (Rector, 1951). These manipulations likely caused down-cutting and widening of streams in the basin, as is evident from abandoned terraces. Increased water yields during peak agriculture (largely associated with loss of wetlands) are believed to have resulted in incision and entrenchment of the Nemadji and its tributaries, and disconnection from the floodplain (Riedel et al., 2001).

Studies of the Nemadji and similar watersheds such as Knife River and Fish Creek that are dominated by lacustrine clay at the western end of Lake Superior conclude that the soils are generally resistant to erosion under natural land cover (NRCS, 1998; Stone et al., 2010), but that activities within the watershed that expose soils, concentrate flows, or disturb banks can increase fluvial erosion and destabilize channels (Riedel et al., 2005; Riedel et al., 2002).

The existing HSPF model is developed at a relatively coarse scale and does not provide a detailed hydraulic simulation because it is a one-dimensional approximation. Channel/bank scour and deposition processes are simulated as a function of flow velocity (for sand) and average boundary shear stress (for silt and clay). An important source of sediment load in the Nemadji is mass wasting from bluffs where the river impinges on valley walls. The existing HSPF model does not explicitly represent bluff mass wasting, but approximates this process (to the extent that information and monitoring data are available) by increasing the maximum potential scour rate in reaches where these processes occur. Simulation performance could likely be improved through development of a finer scale model that explicitly represents areas where bluff mass wasting contributes sediment loads to the channel.

Both flow velocity and boundary shear depend on the channel cross-sectional area as a function of volume. HSPF uses "Functional Tables" (FTables) to describe the relationships between channel dimensions, volume, and discharge. The channel dimensions in the current model are not based on detailed cross-section surveys, but are developed in one of two ways: There are eight model reaches where the Minnesota Department of Natural Resources (MNDNR) or the U.S. Geological Survey (USGS) has developed rating curves with cross sections (the cross sections generally go only to bank full, but have been extended with LiDAR). These enable a direct estimate of volume-flow-cross sectional area-hydraulic radius and velocity relationships, albeit truly appropriate only to the immediate locale of the rating curve. Most of these are at or near road crossing. For other reaches, we used the regional geometry regressions that Magner and Brooks (2008) developed for bankfull cross-sectional area and bankfull flow, together with measured slope and some assumptions about entrenchment ratio and roughness to calculate hydraulics.

The regional regression equations are available in Magner and Brooks (2008) and accompanying files provided by Tim Larson of MPCA and describe bankfull cross-sectional area A_{bank} (ft^2) and flow Q_{bank} (cfs) as a function of drainage area DA (mi^2).

The following inputs are obtained from GIS:

DA	drainage area	mi^2
L	reach length	ft
W_m	stream width	ft
m_F	floodplain slope (inverse – expressed as run over rise)	
s	reach slope	

We also assume the following based in part on the standard method for FTables in BASINS Technical Note 2 (USEPA, 2007):

$W_F = W_{bank} = W_m$ (i.e., the bankfull width is the same as the observed width and the floodplain side width is assumed equal to the channel width)

$m_C = 1.5$ (channel side slope is assumed 1:1.5 due to somewhat incised nature of many streams in this area)

We then calculate:

A_{bank} (bankfull cross-sectional area in ft^2) = $5.5209 \times DA^{0.7744}$ (Magner 15-sites equation, $R^2 = 0.9744$)

Q_{bank} (bankfull flow in cfs) = $41.913 \times DA^{0.7946}$ (Magner regression, $R^2 = 0.9001$)

Y_c (bankfull depth, ft) = A_{bank}/W_m

$Y_m = Y_c/1.25$ (standard method assumption)

We can use Q_{bank} to back-solve for the channel Manning's coefficient (n) (roughness or friction parameter applied to the flow):

P_{bank} (bankfull wetted perimeter) = $W_m - 2\ m_c\ Y_c + 2\ Y_m\ (m_c^2 + 1)^{0.5} = b + 2\ Y_m\ (m_c^2 + 1)^{0.5}$,

$n = A_{bank}/Q_{bank} \times 1.486 \times (A_{bank}/P_{bank})^{2/3} \times s^{0.5}$

A separate Manning's coefficient is assigned to overbank flow (0.06 in the absence of other information.) We then calculate discharge using Manning's equation, assuming no friction loss between the channel and overbank segments, as is done in WinXSPro (Hardy et al., 2005).

HSPF simulates channel sediment transport, scour, and deposition as a function of the channel hydraulics. Three generalized size classes are represented (sand, silt, and clay). Potential transport of non-cohesive sediment (represented by the sand fraction) is simulated as a power function of the flow velocity (as an average across the cross-section width) and sand scours or deposits depending on the difference between potential and actual mass transport. The behavior of cohesive sediments in HSPF is a function of cross-sectional average shear stress (τ; mass per area). The shear stress at any given flow rate is simulated as the product of slope, the unit mass of water, and the hydraulic radius of the channel, which is defined as the ratio of the cross-sectional area of the channel to the wetted perimeter, and thus depends on the hydraulic geometry described above. Silt and clay both have a critical shear stress below which deposition may occur (τ_{CD}) and a critical shear stress above which scour may occur (τ_{CS}). When $\tau > \tau_{CS}$ the scour rate of the relevant class of cohesive bed material (if available) is simulated as M x (τ/τ_{CS} – 1), where M is an erodibility coefficient (mass per area per hour).

Because HSPF uses a one-dimensional representation of stream channels, scour and deposition from channel banks and the channel bed are not explicitly distinguished. For the Nemadji the largest source of sediment loads is associated with bank and bluff failures, especially where the stream channel impinges on valley-edge bluffs. Detailed surveys of the location and recession rates of bluffs are not available for the Nemadji, so only an approximate representation of these contributions is available at this time. Specifically, contributions from banks and bluffs in reaches where such contributions are believed to be important (based largely on anecdotal and qualitative information) are represented in the model primarily by assigning increased values of the erodibility coefficient (M) to the reach, and both M and τ_{CS} were adjusted on a reach-by-reach basis during the model calibration process to provide a better fit to observed suspended sediment concentrations. This representation could be refined and improved through the collection of survey data, use of a finer-scale spatial resolution, and through application of more sophisticated channel sediment scour and deposition models.

2.3.2 Model Revisions

The upland simulation for current conditions is unchanged from that reported in Tetra Tech (2016). During the course of this work we did, however, identify an error in the implementation of the Magner regional geometry equations for the Nemadji. This prompted us to re-estimate the model FTables that relied on this method, which in turn causes minor changes to the hydrograph shape and larger changes to the simulation of sediment scour and deposition. These changes required recalibration of the model to observed total suspended solids concentrations by adjusting the channel sediment parameters.

The recalibration effort was successful and yields results that are similar to those reported in Tetra Tech (2016). For the downstream station, Nemadji River near South Superior, WI, the recalibrated model has an average error on paired simulated and observed TSS concentrations of 0.83% and an average error on paired simulated and observed TSS daily loads (where "observed" load is calculated from concentration and flow) of -12.17%, both within the relative error performance target of ±30% that is recommended as indicative of a good quality sediment calibration by Donigian (2000) and Duda et al. (2012). Note that the apparent error on load is highly leveraged by one outlier on 4/16/2012 when an observed concentration of 3,500 mg/L TSS was reported.

Observed and simulated TSS time series are compared for the South Superior monitoring station are compared in Figure 2-1 (note the logarithmic scale). The model generally replicates the trend in observed data, although the lowest observed concentrations are over-predicted due to assumptions of a minimum background concentration during low flow conditions. These assumptions reflect non-flow related processes such as disturbances by human and animal activity and have little impact on annual load estimates. A small number of high flow observations are substantially under-estimated. This is commonly observed in water quality simulation models and reflects a number of factors: (1) the observations are point-in-time measurements, whereas the model predicts averages over time, (2) the observations are also point-in-space measurements that may not be representative of the average concentration across the entire cross-sectional area, and (3) individual observations may be affected by stochastic events, such as sudden bank failure, that are not predictable within the model. Figure 2-2 is a power plot that compares the relationship of TSS load to flow at this station and demonstrates general consistency in the relationship to flow between observed and simulated values.

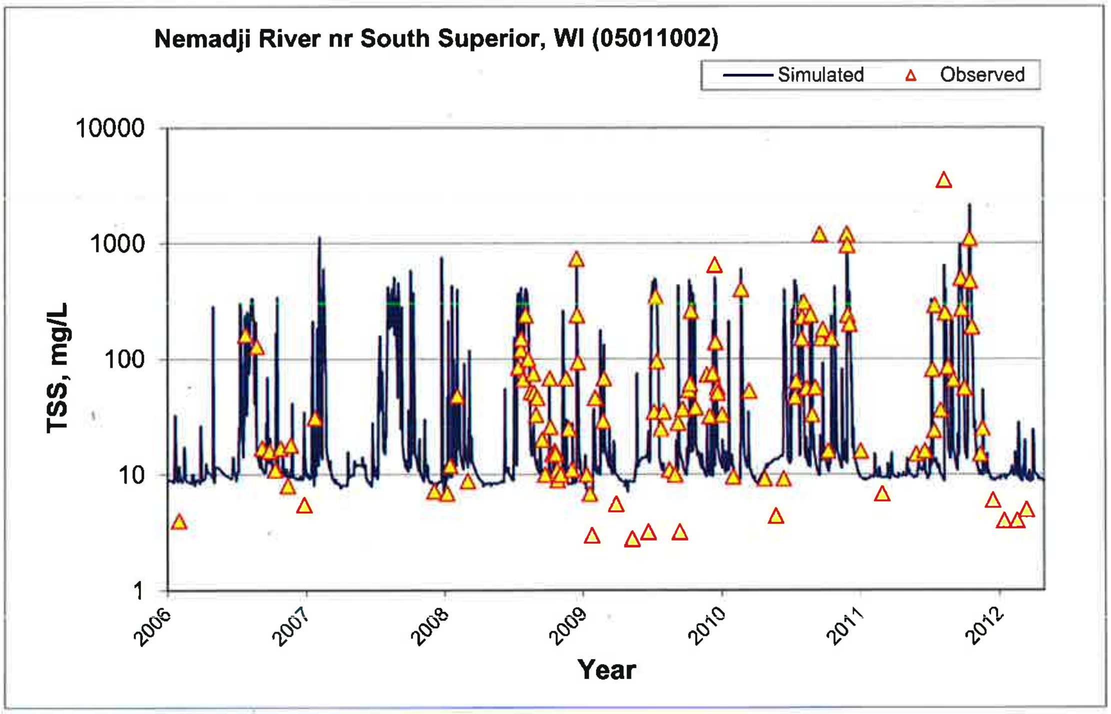

Figure 2-1. TSS Concentration Times Series, Nemadji River near South Superior, WI (05011002)

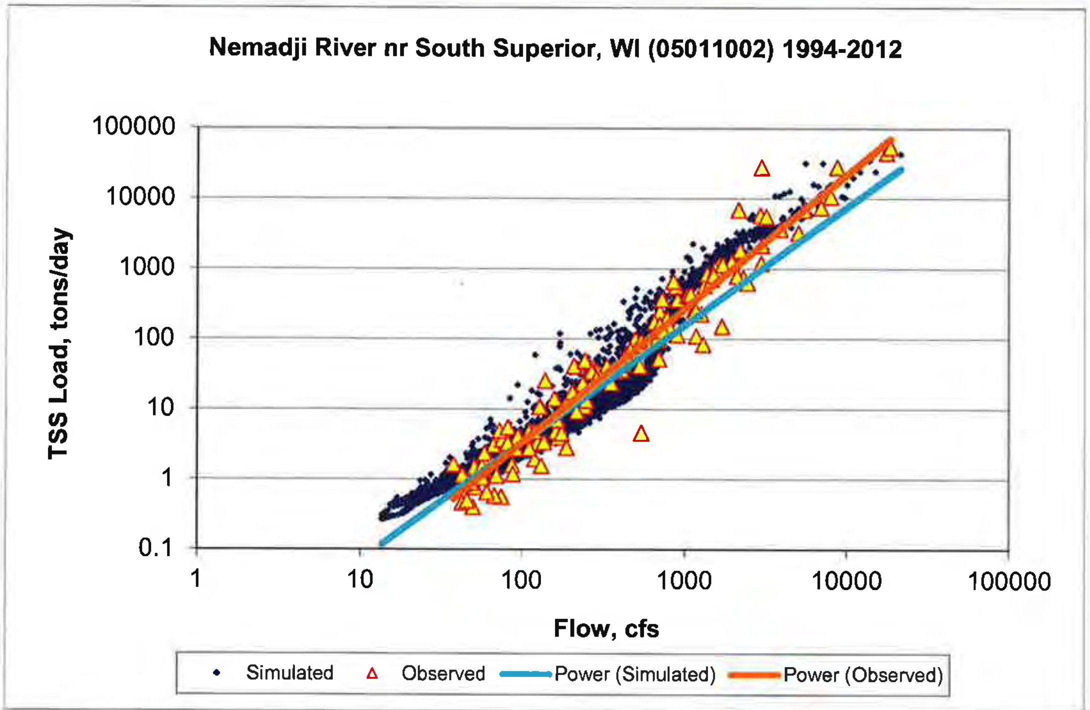

Figure 2-2. TSS Load Power Plot, Nemadji River near South Superior, WI

As an additional check on model performance we compared model predictions of suspended sediment load to estimates derived directly from the monitoring data at the South Superior monitoring station. Suspended sediment load is not observed directly and can only be estimated with uncertainty, using statistical methods, due to the strong correlation between flow and load. The "observed" monthly loads are estimated using the USACE FLUX32 program (a Windows-based update of the FLUX program developed by Walker, 1996; available at https://www.pca.state.mn.us/water/watershed-pollutant-load-monitoring-network#flux32-8f1620f5), and are themselves subject to significant uncertainty. FLUX provides a variety of methods for estimating load, but the estimates with the lowest relative uncertainty are obtained using FLUX method 6 without stratification against flow or season. Method 6 is a bias-corrected regression method based on establishing a relationship between observed flow and concentration and using this relationship to extrapolate to a complete loading time series. For the period 1997 – 2012, FLUX estimates the average suspended sediment load passing the South Superior Station as 80,107 tons/yr, with a coefficient of variation of 0.13 (indicating 95% confidence limits of from 59,696 to 100,518 tons/yr). Over the same time period, the revised HSPF calibration estimates average loading of 76,680 tons/yr, which is only 2 percent lower than the FLUX estimate and near the center of the 95% confidence limit boundaries. Alternative estimation methods in FLUX yield similar results, suggesting that the HSPF model provides a good match to suspended sediment loads on an average annual basis.

2.3.3 Historic Channel Conditions

Anthropogenic changes in land use and land cover are likely to have induced changes in hydrology that induced changes in channel morphology, which in turn would affect the transport, scour, and deposition of sediment. Humans may also have induced geomorphic changes indirectly through trapping and reduction of beaver populations, as beaver dams slow the flow of water and encourage sedimentation, but can also be a cause of episodic scour events during dam failure (Butler and Malanson, 2005). Dramatic changes in channel conditions over time have been documented through the examination of relict channels in detailed studies of Fish Creek (Fitzpatrick et a., 1999; Fitzpatrick and Knox, 2000), which borders the Nemadji to the south. While there are ample grounds for speculation about how channels in the Nemadji basin may have changed in response to human activities there is a lack of hard data to constrain the simulation for this basin. The HSPF model can provide a reasonable representation of how hydrology has changed, which in turn drives erosive stresses on channels, but we do not have a strong basis for assigning pre-settlement channel morphology. We discussed these issues with Dr. Joe Magner and Dr. Mark Riedel, and the consensus seems to be that the Nemadji has never been in geomorphic equilibrium, in part due to changing base levels in Lake Superior and the recent geologic time since the end of glaciation, and that the basin is attempting to continue expansion. The Nemadji likely always generated large sediment loads where the channel impinged on valley walls and there have likely been progressive headcuts in the system even prior to settlement due to natural conditions such as ongoing base level change, wildfires, and so on. While we think channel condition may have been somewhat worse around 1930 (due to a history of logging, damming, straightening, and removal of large woody debris accompanied by clearing and drainage of the uplands) and somewhat better pre-settlement, that is mostly speculative and we do not have a good basis for describing morphology for these periods.

As a result of these uncertainties, this analysis begins by simulating pre-settlement conditions with present morphological/channel geometry relationships, but with the simulation applying different hydraulic stresses associated with changes in land use. This enables a direct examination of the probable effects of changes in land use and cover independent of channel morphology. For this run the only change to channel form is to back out (partially) the effects of road crossings. This is done by assuming that the hydraulic geometry relationships developed by Magner and Brooks (2008) apply to all stream segments and removing the altered hydraulic geometries obtained from the gage rating tables/cross sections (most of which are located at road bridges/culverts).

After this initial pre-settlement run we present a sensitivity analysis to speculate about the additional impacts on sediment loading associated with possible differences in pre-settlement channel form. This includes sensitivity to potentially reduced bankfull cross-sectional area, potential reductions in the maximum channel erosion (due to better root and riparian cover development, plus lower groundwater pore pressure), channels that were somewhat less entrenched, and channels with greater sinuosity prior to de-snagging and use of splash dams to float logs. Increasing sinuosity increases channel length, resulting in a net reduction in the energy grade and thalweg slope. While it is likely that channel roughness may also have been different under pre-settlement conditions (e.g., greater roughness associated with large woody debris) this cannot be investigated as an independent variable in this study because roughness is implicitly defined as a function of channel geometry, slope, and bankfull flow through use of the Magner hydraulic geometry relationships described in Section 2.3.1.

3.0 RESULTS

3.1 HISTORIC LAND USE

Base Land Use/Land Cover: As described in Section 2.1.pre-settlement land use was estimated based on Finley (1976) and Marschner (1974). Land use ca. 1930 was based largely on the Bordner surveys for rural Douglas Co. The Bordner surveys do not cover the City of Superior or the Minnesota portion of the watershed.

For the City of Superior, the U.S. Census for 1930 and 2000 (reported in Bureau of the Census, 1932b, and U.S. Census Bureau, 2012b) show a small net decline in population (within the same boundaries), from 30,113 in 1930 to 27,368 in 2000. Given the lack of growth, land use within the City of Superior (exclusive of state and county roads) is assumed to be unchanged between 1930 and the present.

For the Minnesota portions of the watershed, the change in agricultural land uses within the watershed is approximated by county-level statistics from the agricultural Census for Carlton Co. Total plowed land ca. 1930 was 1.694 times that present ca. 2008, while open pasture land ca. 1930 was about 1.8 times that present ca. 2008. Accordingly, current crop acreage was increased by this ratio on a model subbasin by subbasin basis to create the 1930 scenario for the Minnesota portion of the watershed, with a corresponding reduction in deciduous forest. This approximation likely introduces some error but has the advantage of associating the additional agricultural land proportional to current agricultural use, thus focusing the gain on the locations likely most suitable for cropping. The agricultural Census also indicates that a large portion of the forest area present in 1930 was used for woodland pasture, a practice that has declined substantially (from about 63,000 acres to under 8,000 acres in Carlton Co.) The effects of pasturing in woodlands on hydrology and sediment yield have not been incorporated into the model.

Agricultural practices for the ca. 1930 scenario are believed to have been more intensive than those in use today. The agricultural Census for Douglas Co., WI, and Carlton Co., MN (Bureau of the Census, 1936) shows that the dominant crops were oats, barley, and potatoes, with smaller amounts of corn. Old-style tillage for oats and barley would involve spring moldboard plowing followed by a cultivator on planting. These crops have slightly different timing, with later harvest for potatoes and corn, and we have no spatial coverage of crop types in 1930. Based on local characteristics for oats and barley, we assume spring plowing occurs on April 24, followed by planting on May 1 and harvesting around August 20 (typical oat harvest date would be August 15, but a slightly later date is assumed due to the mix of other crops). The model represents the effects of tillage on sediment availability by increasing the detached sediment store to 2.5 tons/ac consistent with older tillage practices. (In most years the model is not very sensitive to the exact value of this assumption because sediment load from flatter fields with fair or better drainage is primarily limited by overland sediment transport capacity of runoff.)

Surface Drainage and Wetlands: The Bordner surveys are the primary source for the extent of wetlands in Douglas Co. ca. 1930. We also consulted the Douglas Co. Restorable Wetlands spatial analysis of Stark and Robertson (2013) and discussed this coverage with one of the authors who agreed that the Bordner survey provides a good source for 1930 and matches well with their results (personal communication from Andy Robertson, St. Mary's University, 1/28/2016). Comparison of current conditions to 1930 conditions reveals almost no change in forested wetlands, while herbaceous wetland acreage in 1930 is less than that under current conditions. Therefore, contrary to expectation, there does not appear to have been a significant additional loss of wetlands after 1930 and the extent of wetlands in the Minnesota portion of the watershed is not adjusted for the ca. 1930 scenario.

For pre-settlement conditions, all wetlands identified in 1930 and under current land use, plus those in the National Wetlands Inventory (http://www.fws.gov/wetlands/), were combined with the pre-settlement land use coverages to create the wetlands layer. Areas identified on the Minnesota Restorable Wetlands coverage (http://mnwetlandrestlore.org) are generally included within these boundaries. The Douglas Co. Restorable Wetlands work of Stark and Robertson (2013) appear to be of limited use in establishing the extent of pre-settlement wetlands. The authors noted that there were problems in their approach for the Nemadji clay plains because the soils coverages do not clearly distinguish between hydric and non-hydric soils and their analysis for this area is primarily an evaluation of which soil areas are most likely to contain hydric soils. They noted that there has been substantial land leveling to improve agricultural conditions that complicates the topographic analysis, and that the effort does not yield a reliable estimate of the extent of pre-development wetlands (personal communication from Kevin Stark and Andy Robertson, St. Mary's University, 1/28/2016). Based on that discussion we relied on the original vegetation coverage for pre-settlement wetland extent (beyond currently existing wetlands). Stark and Robertson noted that a refined estimate might be obtained from a more detailed analysis of the original land survey notes, but that was beyond the scope of this project.

The major difference in wetland extent over time is between pre-settlement conditions and current conditions for forested wetlands, which declined from over 100,000 acres to about 19,000 acres. Apparently, much of the loss of wetlands had occurred prior to 1930. In contrast to forested wetlands, area in herbaceous wetlands appears to show an increase over time. This likely represents regrowth on a fraction of forested wetlands that were cut but not ditched for agriculture.

We do anticipate that there may have been some increases in drainage efficiency and ditch density from 1930 to present. This is roughly approximated in the model (which is lumped at the subbasin scale) by assuming an increase in the overland flow path length (which defines average travel distance to a simulated stream reach) by 50% to 750' for the ca. 1930 and pre-settlement scenarios. In addition, the small amount of crop land estimated to have tile drainage under current conditions was converted to crop land without artificial sub-surface drainage.

Rural Development: As noted above, the digitization of the Bordner surveys did not include buildings, driveways, and other impervious areas that are important to hydrology. We examined changes in population by census enumeration district (primarily township) between 1930 and present with mixed results (housing data were not available by enumeration district, just at the county level, for 1930). Within the rural townships (Summit and Superior townships, exclusive of the City of Superior) that intersect the watershed in Douglas Co., WI population increased from 2,033 to 3,229; however, agriculture has also declined so the amount of building area, including barns and outbuildings, has not necessarily increased. In enumeration districts intersecting the Minnesota portion of the watershed (Blackhoof, Clear Creek, Holyoke, and Wrenshall townships in Carlton Co. and Nickerson Township in Pine Co.) the total population increased from 2,058 to 2,508, with net decreases in two of the five townships. As the enumeration district boundaries do not line up very well with watershed boundaries and considering the uncertainty in the ratio of total building area to population we decided there was not sufficient evidence to justify changing the acreage of developed area between 1930 and current conditions.

Roads/Railways: The extent of transportation land uses ca. 1930 was analyzed using the approach described in Section 2.1. The total area in these land uses ca. 1930 appears to have been slightly greater than current conditions due to the subsequent abandonment of many minor roads. Note that road construction and maintenance prior to 1930 was more variable than current practices and may have produced greater sediment loading rates than modern roads, although this is not included in the simulations.

The net results of the land use analysis are summarized in Table 3-1 and Figure 3-1 through Figure 3-3. A much larger percentage of the watershed was in crops and pasture ca. 1930 compared to current conditions, although the percentage of the landscape in agricultural land uses (excluding woodland pasture) was still only about 20% based on available data on a whole watershed basis. (Note that the agricultural census shows that cropland area may have been significantly greater in 1934 than in 1929, which is the basis used here). Relative to pre-settlement conditions there are two major changes: a shift from evergreen forest to second-growth deciduous forest and a reduction in the area of forested wetlands. The assignments of land uses to hydrologic soil groups, as well as the average slope for land use class, were re-calculated based on the spatial distribution of land use types for each time period.

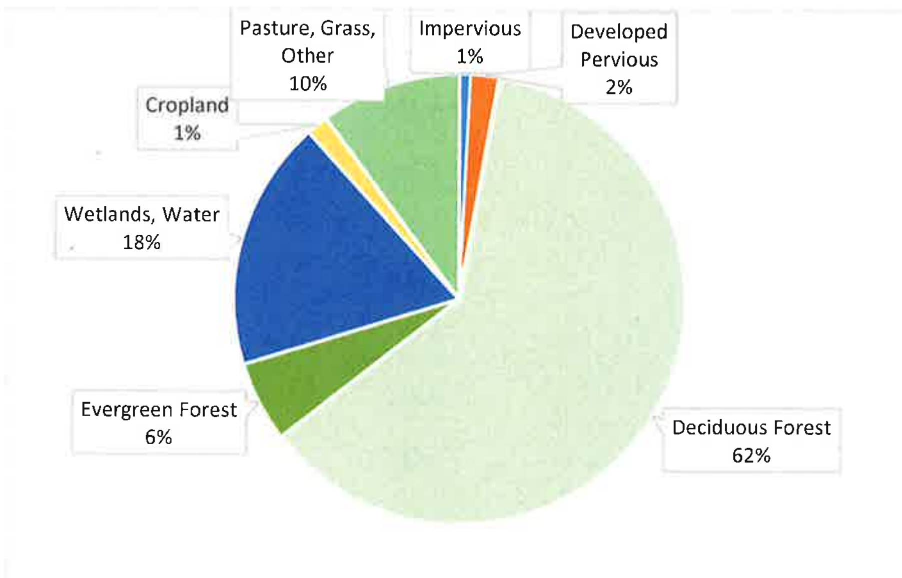

Figure 3-1. Land Use Distribution, 2006

Table 3-1. Historic Land Use Summary (acres)

Land Use/Land Cover (plus HSG)	2006	1930s	Pre-settlement
Dev OS Impervious	392	255	0
Dev MD Impervious	109	74	0
Dev HD Impervious	26	17	0
Road Impervious	1,879	1,936	0
Deciduous Forest (A,B)	47,981	40,323	23,719
Deciduous Forest (C,D)	138,165	136,380	34,051
Evergreen Forest (A,B)	6,933	6,591	33,930
Evergreen Forest (C,D)	10,489	8,777	91,141
Wetlands, Forested	18,856	18,559	107,201
Wetlands, Herbaceous	32,632	21,713	8,665
Grass/Shrub (A,B)	478	345	7
Grass/Shrub (C,D)	2,216	1,224	1,901
Pasture/Hay (A,B)	8,897	15,255	0
Pasture/Hay (C,D)	19,084	19,946	0
Row Crops (A,B)	1,279	4,195	0
Row Crops (C,D)	3,224	17,978	0
Row Crops w/ tile drains	324	0	0
Developed Open Space Pervious	5,925	3,821	0
Developed Medium Density Pervious	132	87	0
Dev High Density Pervious	11	7	0
Water (excluding simulated reaches)	2,643	2,452	1,390
Barren	330	2,070	0
Total	***302,005***	***302,005***	***302,005***

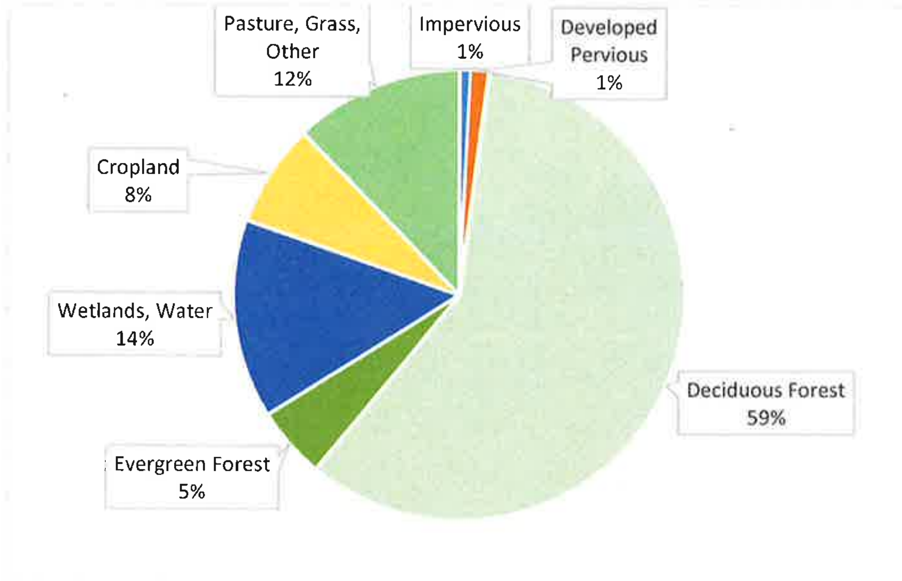

Figure 3-2. Land Use Distribution, ca. 1930

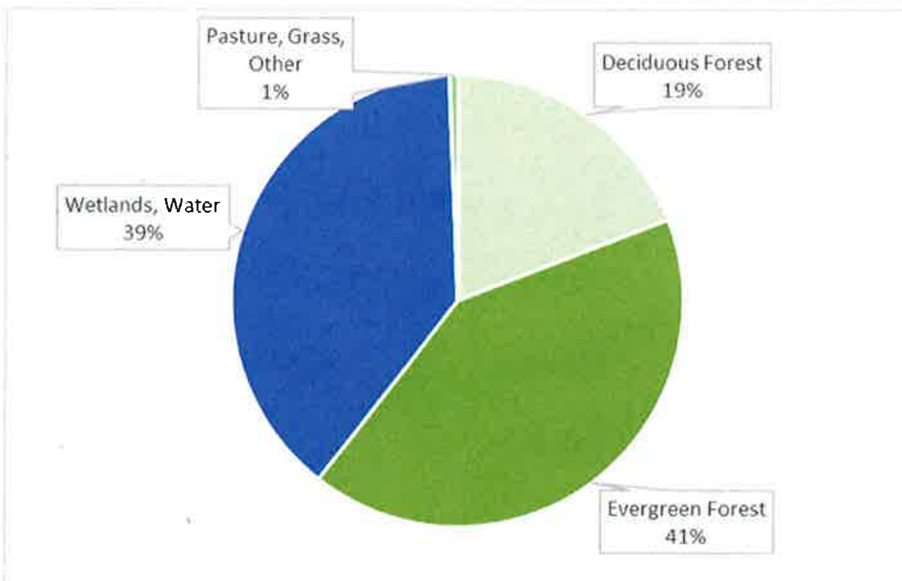

Figure 3-3. Land Use Distribution, Pre-Settlement

Pre-settlement and 2006 land use/land cover extents are mapped in Figure 3-4. A map is not provided for conditions ca. 1930 as these are inferred from a variety of spatial and non-spatial data sources as described above.

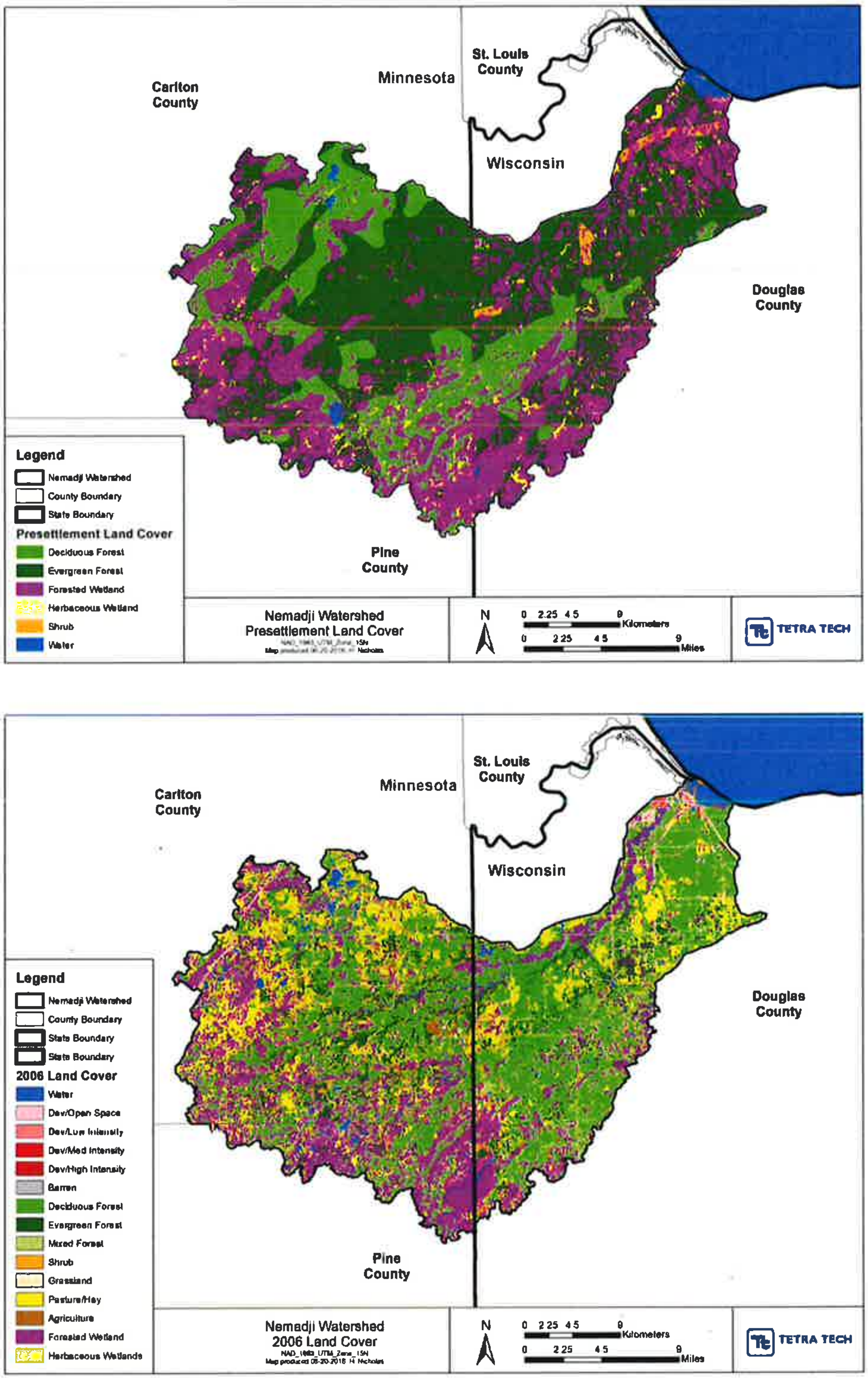

Figure 3-4. Pre-Settlement and 2006 Land Cover for the Nemadji River Watershed

3.2 HYDROLOGY

Changes in land use lead to changes in simulated hydrology, some expected and some not anticipated. In general, greater open space and greater impervious area after development would be expected to increase surface runoff and decrease evapotranspiration, which the model indeed shows. The pre-settlement average water yield across the watershed was 10.9 in/yr, while that for current conditions is 11.1 in/yr over the simulation period. For 1930 conditions, the total water yield is 11.3 in/yr. The differences are relatively small on an annual basis because of the importance of snowmelt volume. During the summer growing season the direct surface runoff, which drives upland sediment erosion, is noticeably higher for current conditions (Figure 3-5).

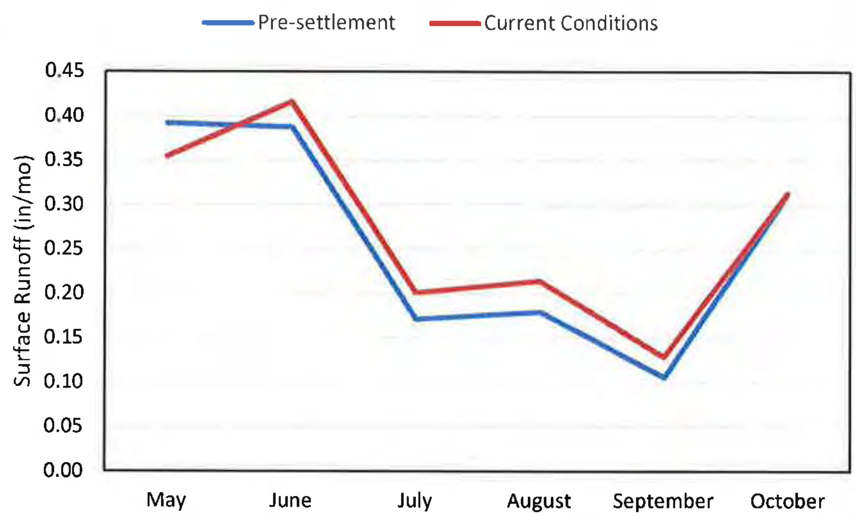

Figure 3-5. Comparison of Growing Season Direct Surface Runoff for Current and Pre-Settlement Conditions

The largest land use differences between pre-settlement and post-settlement conditions is a shift from mature evergreen forest to second-growth deciduous forest, along with a loss of forested wetlands and increase in cleared areas. The shift from evergreen to deciduous (or no) tree cover has a significant effect on the dynamics of snow melt as an evergreen canopy provides shade (and insulation) year round while a deciduous canopy does not. The denser canopy results in less solar energy reaching the snowpack, as well as less longwave energy exchange with the atmosphere, causing spring snow melt to be delayed. (There are many other differences in snowmelt dynamics between evergreen and other cover that are not discussed here, but the later spring snow melt is a key factor.) Under the right weather conditions this can allow more snowpack to persist until warm spring rains cause a sudden melt (see example in Figure 3-6). Higher soil moisture in spring due to later snowmelt can also increase the response to storms, although conifer stands in northern Minnesota are expected to have greater net evapotranspiration losses than deciduous forest on an annual average basis (Verry, 1986).

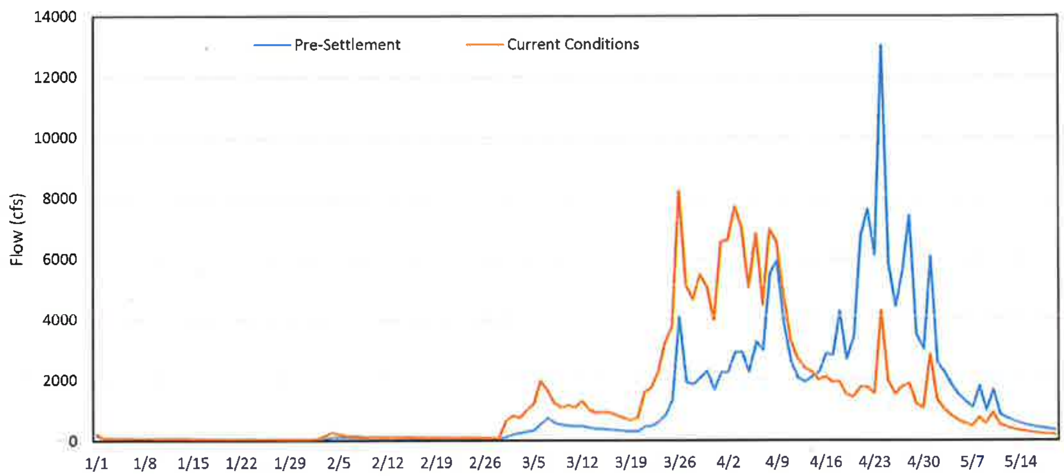

Figure 3-6. Example of Delayed Snowmelt under Pre-Settlement Evergreen Cover (Flow at Watershed Outlet, 1993 Weather)

3.3 UPLAND SEDIMENT LOADS

Upland sediment yield rates (tons/ac/yr) from the baseline model are summarized in Table 3-2. The highest per-acre loads are for cropland, followed by barren and shrub land uses, which primarily represent recent forest harvest and regrowth of timbered areas. The lowest sediment yield rates (excluding water) are for forest land uses (both evergreen and deciduous forest are averaged here), while the highest loading rates are for crops. These changes suggest that the total upland sediment load should be lower for pre-settlement conditions and likely higher around 1930, compared to current conditions, due to the decline in agricultural acreage in the watershed.

Table 3-2. Average Sediment Loading Rates by Land Use, Baseline Model

Land Use	Avg (tons/ac/yr)	Area	% area
Forest	0.031	204,573	67.5%
Wetland	0.045	51,488	17.0%
Shrub	0.339	2,699	0.9%
Pasture	0.133	28,030	9.2%
Crop	0.665	4,856	1.6%
Developed (pervious plus impervious)	0.208	6,595	2.2%
Water	0.000	2,645	0.9%
Barren	0.554	330	0.1%
Roads	0.135	1,879	0.6%

Consistent with these expectations, and despite other factors, such as changes in hydrology, the watershed model predicts dramatic changes in upland sediment load. Under current conditions, the average upland loading rate across the whole watershed is 22,120 tons/yr (based on weather inputs for 1993 – 2012). For pre-settlement conditions, the estimated upland loading is 12,263 tons/yr or 45% less than current conditions, based on the same weather time series. For conditions ca. 1930 the estimated upland loading to streams is 41,929 tons/yr or 90% greater than present conditions. While these changes are dramatic, upland loading represents only about one quarter of the sediment load delivered by the Nemadji River under current conditions, with the remainder coming from channel degradation processes.

3.4 CHANNEL, BANK, BLUFF, AND TOTAL SEDIMENT LOADS

In contrast to upland sediment loads, the model predicts relatively little change in sediment loads derived from the channel, banks, and bluffs over time (Table 3-2). Indeed, the net loading from channel/bank/bluff sources is estimated to be slightly higher under current conditions than during the ca. 1930 period, and there is little predicted reduction in channel sources for the pre-settlement period under the initial pre-development scenario. This reflects the assumption in the initial pre-settlement scenario that channel morphometry was not significantly different pre-settlement; alternative assumptions are investigated in Section 3.5. Under the assumptions of no significant change in channel morphometry the total sediment load delivered to the St. Louis River Estuary under conditions ca. 1930 is predicted to be 21% higher than under current conditions (using the same weather forcing), while the pre-settlement delivered load is predicted to be 15% less than the load under current conditions.

Table 3-3. Total Sediment Loads for Primary Scenarios

Time Period	Upland Load Delivered to Stream (tons/yr)	Net Channel, Bank, and Bluff Sources (tons/yr)	Total Load (tons/yr)
Current Conditions	22,120	66,276	88,396
ca. 1930	41,929	65,197	107,126
Pre-settlement (with current hydraulics)	12,263	63,066	75,329

These estimates are subject to considerable uncertainty. Of particular importance may be the contribution from bluff loads, which are roughly approximated in the model, as described in Section 2.3.1. Bluff load is expected to be a major component of the total sediment load in most tributaries to western Lake Superior. For instance, 67 percent of the sediment load in North Fish Creek is attributed to bluffs (Fitzpatrick et al., 1999), while Nieber et al. (2008) conclude that approximately 90% of the sediment load in the Knife River watershed originates from bank erosion and bluff slumping. NRCS (1998), based on a limited monitoring record, estimated that bluffs contributed 89% of the fine sediment source load and 98% of the delivered load from the Nemadji River. This study suggests that about 75 percent of the sediment load in the Nemadji River derives from bank erosion and bluff sources under current conditions, but how the loads associated with bluff slumping may have differed under historical conditions is not clearly known at this time. Riedel et al. (2005) found that mass wasting appeared to increase exponentially with rate of bankfull discharge normalized to watershed area in this basin. Riedel et al. also show that the rate of bankfull discharge is greater where cover has changed from coniferous to deciduous forest and in watersheds with reduced amounts of wetland area. These findings suggest that mass wasting contributions to the Nemadji were likely lower under pre-settlement conditions dominated by coniferous forests and with larger wetland areas.

Model predictions of change in channel sediment balance by reach over the 20-year simulation period are shown in Figure 3-7 through Figure 3-9. Because HSPF has a one-dimensional representation of stream reaches, both bed scour (incision) and bank scour/bluff contributions (widening) are represented as an equivalent net change in bed elevation by the model. The differences in simulated outcomes by reach are small, and most reaches in the lacustrine core of the Nemadji are predicted to be net sources of sediment under both current and historical conditions, consistent with the hypothesis that the Nemadji is a naturally unstable system that was experiencing channel degradation even under pre-settlement conditions.

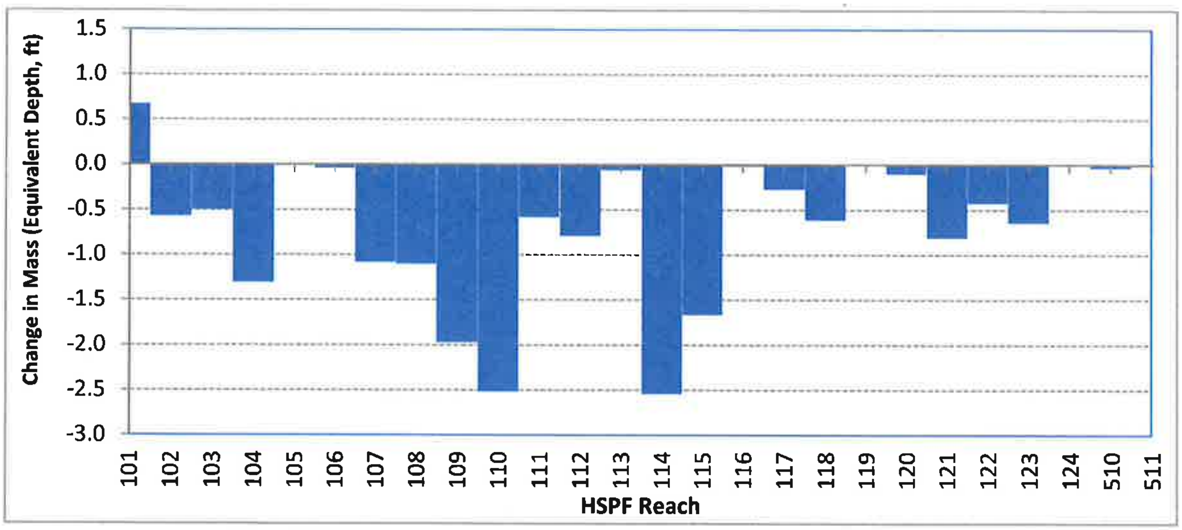

Figure 3-7. Predicted Change in Channel Sediment Balance over 20 years, Current Conditions

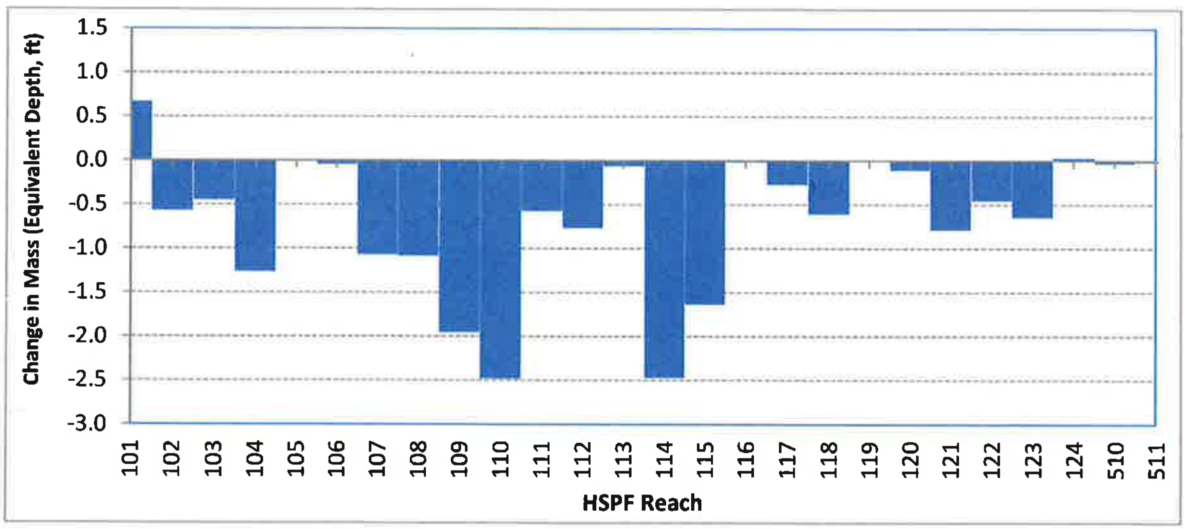

Figure 3-8. Predicted Change in Channel Sediment Balance over 20 years, ca. 1930 Conditions

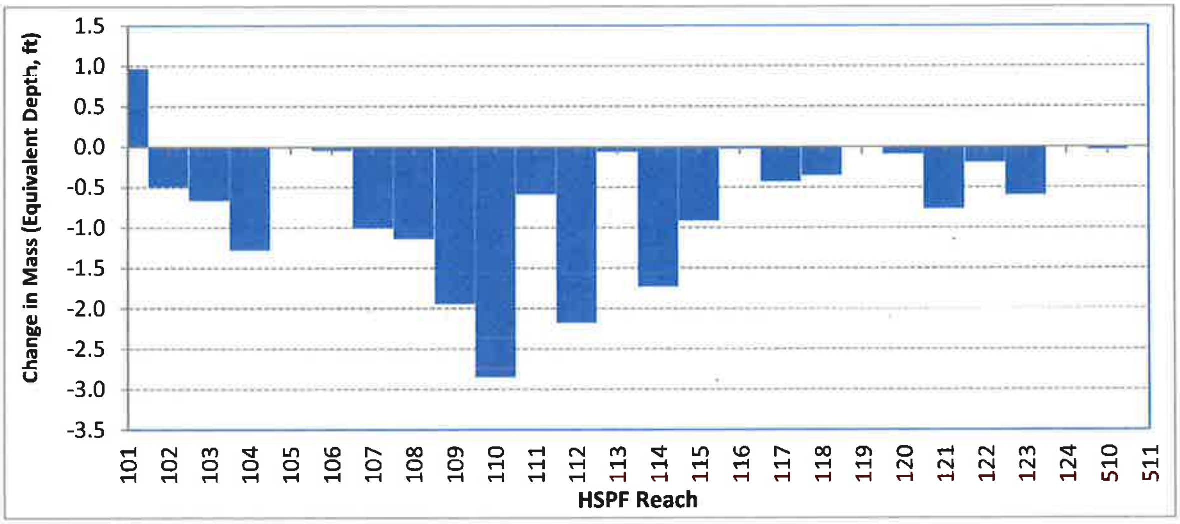

Figure 3-9. Predicted Change in Channel Sediment Balance over 20 years, Pre-Settlement

3.5 SENSITIVITY ANALYSIS FOR PRE-SETTLEMENT CONDITIONS

The results provided in Section 3.4 for pre-settlement conditions assume no change in channel geometry. As noted in Section 2.3.3, it is possible, but not certain, that somewhat different channel geometry conditions applied prior to human activity during the initial logging of the watershed. To test the sensitivity of results to assumptions regarding channel form a second, speculative version of the pre-settlement run was constructed. The major change for this run was an assumption of increased channel sinuosity, resulting in smaller effective slope and greater reach length. In many parts of the Nemadji, the river belt width is constrained by valley walls, so this increase in sinuosity, if it applied, would likely not be great. The scenario assumes a 20% increase in sinuosity. In addition, channels are assumed to have been somewhat less incised through specification of a channel bank width to depth ratio of 2, rather than 1.5. Both assumptions are speculative, but thought to be physically reasonable based on best professional judgment. Finally, the Manning's roughness coefficient for the floodplain was increased from 0.06 to 0.12 to reflect heavily wooded conditions, consistent with values cited in Arcement and Schneider (1989). The revised channel conditions were then used to regenerate the HSPF FTables for the simulation. Channel slopes (which influence the calculation of shear stress) and lengths were also modified in the HSPF input file. The upland simulation is unchanged from the pre-settlement run.

Under these conditions, the total net sediment loading generated from bank and bed scour is predicted to average 48,139 tons/yr, or about 24 percent less than the amount generated under the pre-settlement scenario without hydraulic modifications (see Table 3-4, which repeats Table 3-3 with the addition of the alternate pre-settlement scenario). Even so, the sediment load generated from the channel is still predicted to be much larger than the upland load (12,263 tons/yr). Under these modified pre-settlement conditions the total sediment load delivered to the St. Louis River Estuary was 60,402 tons/yr, 32% less than the load under current conditions, and 44 % less than when the watershed was most degraded (ca 1930)

Table 3-4. Total Sediment Loads for Primary and Alternate Scenarios

Time Period	Upland Load Delivered to Stream (tons/yr)	Net Channel, Bank, and Bluff Sources (tons/yr)	Total Load (tons/yr)
Current Conditions	22,120	66,276	88,396
ca. 1930	41,929	65,197	107,126
Pre-settlement (with current hydraulics)	12,263	63,066	75,329
Pre-settlement modified hydraulics	12,263	48,139	60,402

Changes in channel sediment balance by reach under this alternative scenario are shown in Figure 3-10. Comparing to the pre-settlement run without modifications to channel geometry (Figure 3-9), the pattern remains similar, but the amounts of predicted degradation are less.

As with the results presented earlier, all these results are reasonable, but uncertain, and depend on the accuracy of the existing coarse-resolution model and the assumptions made to describe historical conditions. The true magnitude of change, for which direct evidence is not available, could differ significantly from these projections; however, the qualitative differences between scenarios are believed to be reasonable.

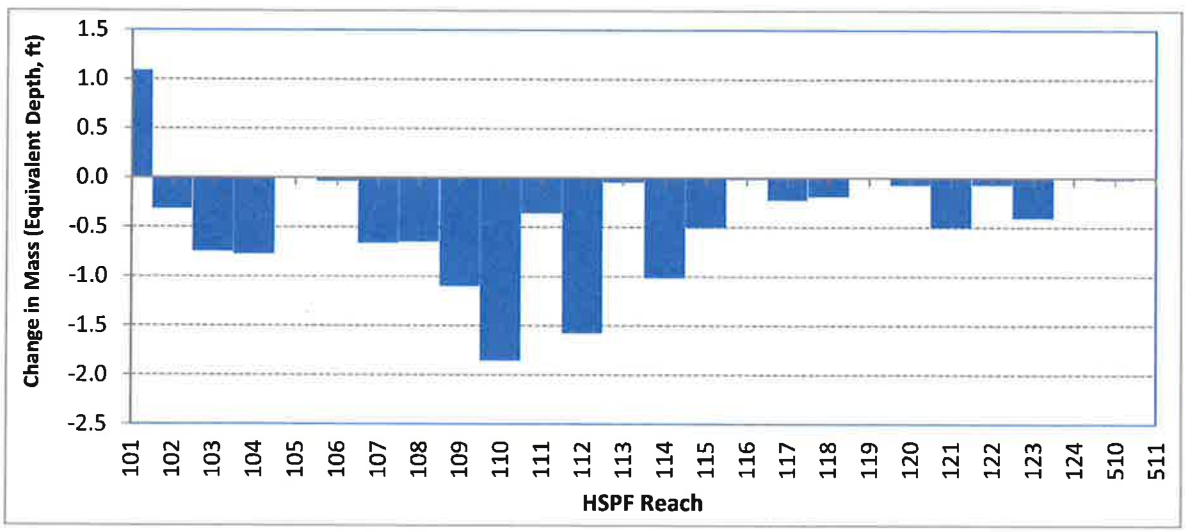

Figure 3-10. Predicted Change in Channel Sediment Balance over 20 Years, Pre-settlement Conditions with Modified Reach Hydraulics

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4.0 SUMMARY

An existing HSPF watershed model was used to examine likely changes in sediment load in the Nemadji River for current conditions relative to pre-settlement conditions and conditions ca. 1930, soon after harvest of the virgin forest had had ceased and when agriculture was more extensive than at present. HSPF is a well-established and widely used tool for dynamic simulation of hydrology and upland sediment loading. The model also provides predictions of scour and deposition of sediment from and to the channel bed and banks as a function of channel geometry and simulated flows. This aspect of the model is perhaps weaker, as the channel is represented as a one-dimensional approximation. Also, in absence of adequate data on changes in channel morphology since pre-settlement times, a sensitivity analysis was conducted to identify the likely range of possible pre-settlement channel conditions. Further, the model is developed at a relatively coarse spatial scale without the benefit of detailed field measurements of channel dimensions, relying instead on regional hydraulic geometry relationships developed for the Nemadji by Magner and Brooks (2008), and thus cannot resolve the fine-scale details of reach erosion processes. Nonetheless, the model provides a credible fit to observed TSS concentrations in the Nemadji and is believed to provide a useful basis for historical comparisons.

Figure 4-1 summarizes the results of the simulation of sediment load delivered from the Nemadji River to the St. Louis River Estuary, based on consistent 20-year weather forcing. The upland sediment loading is predicted to have increased substantially from pre-settlement conditions to the 1930s, and to have subsequently declined; however, the predicted net load generated from bank, bluff, and channel processes shows only small changes when current hydraulic geometry relationships are assumed to apply. The sensitivity analysis of pre-settlement conditions with greater channel sinuosity (and several other changes) does predict a substantial reduction in bank, bluff, and channel-associated sediment load; however, those results are again speculative as direct information is not available on the pre-settlement channel form.

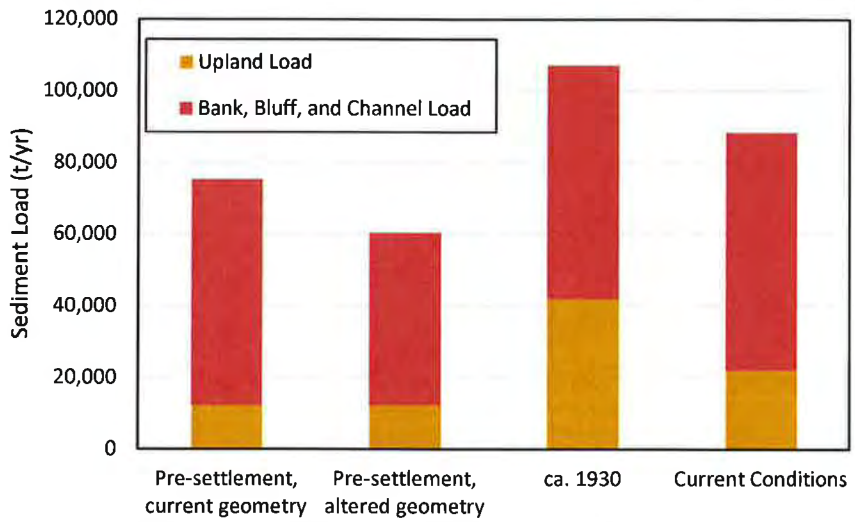

Figure 4-1. Summary of Current and Historic Simulations of Annual Average Sediment Load Delivered from the Nemadji River to the St. Louis River Estuary

It should be noted that conditions ca. 1930 were selected to represent peak agriculture, in part because of the availability of the Bordner surveys at about this time. A comparison of harvested cropland acres by county from the agricultural census (Figure 4-2) suggests that peak agricultural activity may actually have occurred between 1934 and 1945; possibly accompanied by even greater upland sediment loads, although the increased acreage may have been offset to some extent by better tillage practices.

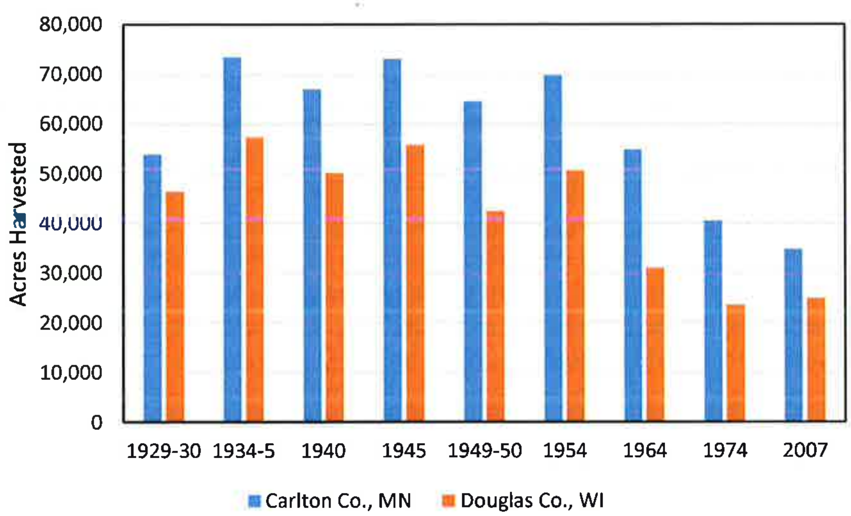

Figure 4-2. County-Level Trends in Harvested Cropland over Time

Finally, the analysis is based on a consistent set of weather data (1993 – 2012 observations) and does not account for any changes in climate over time.

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Appendix 6

Sediment Characteristics of Northwestern Wisconsin's Nemadji River, 1973-2016
(Pertains to management action 6.05)

USGS
science for a changing world

Prepared in Cooperation with the Wisconsin Department of Natural Resources

Sediment Characteristics of Northwestern Wisconsin's Nemadji River, 1973-2016

By Faith A. Fitzpatrick

Open-File Report

13 January 2020

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
Jim Reilly, Director

U.S. Geological Survey, Reston, Virginia: 2020

Cover photograph of the Nemadji River near County Highway C, on July 12, 2016, by Molly Wick, formerly of the Wisconsin Department of Natural Resources

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Technical field assistance was provided by Josef Schuler, Lucas Weegman, and Scott Hagar of the USGS Upper Midwest Water Science Center (UMidWSC) for the collection and processing of suspended sediment, bedload, and bed material samples. Troy Rutter, also of the UMidWSC compiled the data needed for the modified Einstein procedure for calculation of total sediment loads.

The modified Einstein procedure results were reviewed by Christopher Ellison (formerly with the U.S. Geological Survey, Wyoming Water Science Center). Colleague reviews were provided by Joel Groten (U.S. Geological Survey, UMidWSC) and Molly Wood (U.S. Geological Survey, Idaho Water Science Center).

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton, short (2,000 lb)	0.9072	metric ton (t)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Abbreviations

USGS U.S. Geological Survey

WDNR Wisconsin Department of Natural Resources

UMidWSC Upper Midwest Water Science Center

SSC Suspended sediment concentration

TSS Total suspended solids

Sediment Characteristics of Northwestern Wisconsin's Nemadji River, 1973-2016

By Faith A. Fitzpatrick

Abstract

The Nemadji River is part of the U.S. Environmental Protection Agency's St. Louis River Area of Concern (AOC). One of the goals of the AOC cleanup is to reduce sediment loads from the Nemadji River into the estuary of the St. Louis River. The goal of this study was to determine if there was a reduction in sediment loads over the last 45 years due to land use improvements. A change in suspended sediment sampling and analytical methods over the period of interest necessitated a comparison the two types of data before any conclusions could be drawn. Suspended sediment samples from the Nemadji River near South Superior (USGS identification number 04024430) were collected by the U.S. Geological Survey (USGS) from 1973 through 1986 using isokinetic samplers with width- and depth-integrated procedures and suspended sediment concentration (EWI SSC) laboratory analyses. From 2006 through 2016 the Wisconsin Department of Natural Resources and the Minnesota Pollution Control Agency collected grab samples and conducted total suspended solids (grab TSS) laboratory analyses. Previous studies in the region had shown that TSS concentration may be much less than SSC, and for this study

regression equations were developed to provide an adjustment factor to the grab TSS data before they could be compared to the EWI SSC data.

In 2015-16, the USGS, in cooperation with the Wisconsin Department of Natural Resources, conducted a comparison study of the USGS and State methods for collection and laboratory analyses of suspended sediment concentration and loads. From this comparison, regression equations were generated between the EWI SSC and grab TSS data. In addition to suspended sediment, bedload and bed material samples also were collected. The modified Einstein procedure was used to estimate total sediment discharge of the 2015-16 period. Thus, the relations among suspended sediment load, bedload, and total sediment load could also be examined.

As part of the 2015-16 study, historical streamflow data were examined over the two periods of suspended sediment data collection. Mean annual flows during 2006-16 were about 84 percent less than during 1973-86. In contrast, two extreme floods in 2011 and 2012 were over 2.5 times larger than any peak flow in the 1973-86 period. The 2009-16 annual total sediment loads ranged from a low of 18,000 tons per year for a relatively dry year in 2015 to almost 180,000 tons per year in 2012 that included a peak of record. Bedload ranged from 20 percent of the total sediment load during low mean annual flow years and dropped to 5 to 6 percent of the total load during high flow years.

Using adjusted TSS concentrations (TSSadj), the TSSadj curve for 2006 through 2015 had a similar slope but a lower intercept than its 1973-86 SSC-based counterpart. Although not statistically significant, the negative offset resulted in a potential reduction of about 15 percent of the annual suspended sediment loads for an example data set from 2009-16. These results suggest that land use management has started to influence suspended sediment loads. Altogether, these various data sets collected over different periods and using different methods helped to describe the Nemadji River's sediment characteristics as well as provide a calibration tool for future sediment data collections.

Introduction

The Nemadji River (fig. 1) is part of the U.S. Environmental Protection Agency's (EPA) St. Louis River Area of Concern (AOC). One of the Beneficial Use Impairments (BUI) is excessive loading of sediment and nutrients (St. Louis River Alliance, 2015). A major goal of the AOC cleanup is to reduce sediment loads in the Nemadji River, which is one of the largest contributors of sediment to Lake Superior (Robertson, 1996). The Nemadji Basin Plan (Natural Resources Conservation Service, 1998) estimated the average annual suspended sediment discharge at the mouth of the Nemadji to be about 130,000 tons per year (tons/year).

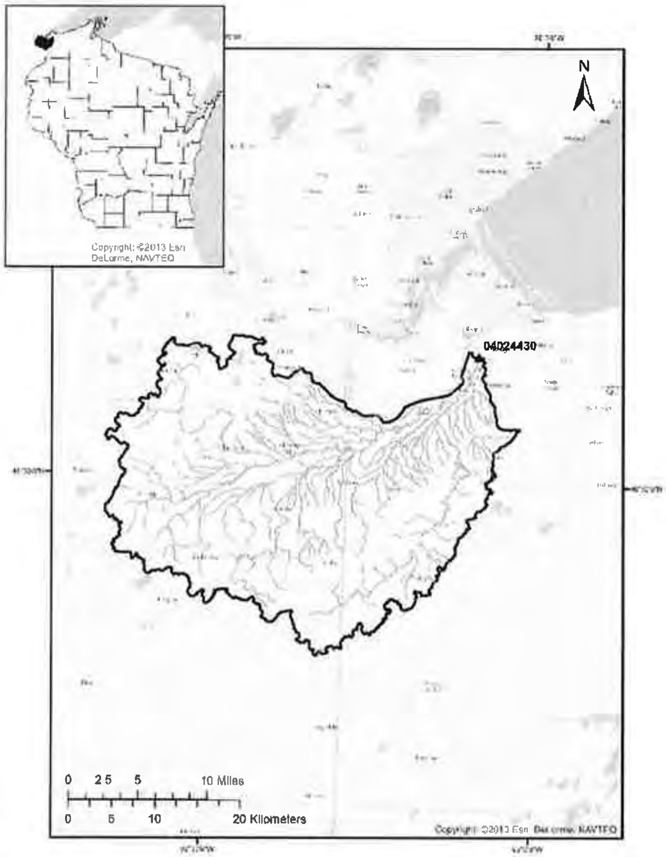

Figure 1. Location of the Nemadji River streamgage (U.S. Geological Survey identification number 04024430).

A U.S. Geological Survey (USGS) streamgage has been operating on the Nemadji River near South Superior, Wisconsin (USGS identification number 04024430) since 1970 (fig. 1). Over the last 45 years, sediment samples were collected and analyzed with two different sets of standard sampling and laboratory methods used by the USGS and state agencies. The USGS used an isokinetic sampler with width- and depth- integrated procedures (EWI) (Edwards and Glysson, 1999; Gray and Landers, 2014) and suspended-sediment concentration (SSC) laboratory methods and sampled from 1973-86. The Wisconsin Department of Natural Resources

(WDNR) and Minnesota Pollution Control Agency (MPCA) used the grab sampling and total suspended solids (TSS) laboratory methods, starting in about 2006. State agencies adopted the grab TSS procedure over the EWI SSC procedure because it is faster and less expensive and it was thought to be adequate for assessing sediment-related impairments as well as other water quality issues (Ellison and others, 2014). Comparison studies of grab TSS and EWI SSC have shown that grab TSS samples are biased negatively compared to EWI SSC samples, especially when the samples had more than 20 percent sand (Gray and others, 2000; Ellison and others, 2014). The negative bias could be caused by the sampling, laboratory procedure, or both.

For the Nemadji River, the gaps in the sediment data collection record combined with the different types of data for the two time periods required the development of a calibration between the two data types. Additionally, it commonly difficult to separate upstream changes in suspended sediment supply from year-to-year hydrologic variability and thus a method comparing sediment concentration to water discharge curves used by Warrick (2014) was adopted for helping to distinguish whether there were changes in the suspended sediment supply potentially associated with land management practices.

In 2015-16, the USGS, in cooperation with the WDNR, conducted a methods and laboratory comparison study for suspended sediment collected at the Nemadji River streamgage. In addition to suspended sediment, bedload and bed material samples also were collected. These data were used to help describe present sediment conditions as well as provide a calibration relation to be able to compare historical suspended sediment data sets. The results from the comparison will be used by the WDNR to identify if sediment loading is increasing, decreasing, or staying the same. This study was part of a larger assessment of the Excessive Loading of Sediment and Nutrients BUI in the Nemadji watershed, funded by the EPA in 2015, which also included evaluation of macroinvertebrate and fish communities in the Lower Nemadji River and modeling historic sediment loads (Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources, 2015).

Purpose and Scope

This report describes three main study objectives related to sediment data collected at the USGS Nemadji River streamgage near Superior, Wisconsin. The first objective was to develop a calibration curve between EWI SSC and grab TSS data. The second objective was to compare the EWI SSC suspended sediment rating curves from 1973-86 data with adjusted TSS-based curves from 2006-15 data and determine if there was a potential change in suspended sediment loads. The third objective was to describe 2015-16 total sediment loads, which were determined directly by measuring suspended sediment loads and bedload and indirectly by estimating total sediment discharge using the modified Einstein procedure.

The USGS collected 12 sets of suspended, bedload, and bed material samples at the Nemadji River streamgage for 11 sampling events from July 2015 through July 2016. For each event, two types of suspended sediment samples were collected including a grab sample from the middle of the river and a composite EWI depth-integrated sample from a representative cross section of the river. Both types of suspended sediment samples were submitted for both SSC and TSS laboratory analyses. The resulting four types of concentration data were used to develop log 10 based regression relations between EWI SSC and grab TSS. Bedload and bed material samples also were collected during the sampling events and submitted to the laboratory for particle size analyses. The modern (2006-15) suspended sediment concentrations relations were used to compare historical (1973-86) sediment curves and discharges. Lastly, a modern 6-yr TSS dataset collected by the MPCA was available for calculation of suspended and total sediment discharges.

Physical Setting

The Nemadji River drains 430 square miles and empties into Lake Superior in Superior, Wisconsin (fig. 1). The watershed straddles eastern Minnesota and northwestern Wisconsin. The USGS streamgage is 2 miles south of Superior, Wisconsin and the river has a drainage area of 420 square miles at the streamgage. The streamgage has operated continuously from 1973 to present.

The steep, mainly forested Nemadji River basin is known for problems with flashy runoff and large sediment discharges (Robertson, 1996; Natural Resources Conservation Service, 1998). The average slope of the river is 2 ft per mile but the thick clayey glacio-lacustrine deposits that cover much of the watershed promote rapid runoff during rainfall events (Natural Resources Conservation Service, 1998; Reidel and others, 2001; 2005). Mass wasting and channel incision along deeply incised stream valleys contribute a large portion of the load (Natural Resources Conservation Service, 1998; Reidel and others, 2001; 2005).

Methods

Methods first included gathering published historical and ongoing sediment concentration, water discharge, and sediment load data collected by the USGS, WDNR, and the MPCA at the Nemadji River streamgage. Additional comparative measurements of suspended sediment, bedload, and bed material were collected by the USGS from July 2015 through July 2016 and analyzed by the USGS Kentucky Sediment Laboratory and Wisconsin State Laboratory of Hygiene (WSLH). Instantaneous total sediment discharges for 2015-16 were calculated from summing the measured suspended sediment discharge and bedload discharge. Estimations of total sediment discharge were calculated with the modified Einstein procedure. Sediment data processing followed four main steps – tabulation, evaluation, editing, and verification, following guidelines in Porterfield (1972), Guy (1969) and the USGS Office of Surface Water Memorandum 91.15. Lastly, analysis of covariance (ANCOVA) was used to for comparing sediment concentration-water discharge rating curves.

Historical Suspended Sediment Data Mining and Sediment Rating Curves

Historical sediment data at the Nemadji River streamgage included SSC collected and analyzed by the USGS from 1973 through 1986 and TSS collected and analyzed by the WDNR and MPCA from 2006 through 2015. Data were gathered from the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2017) and the WDNR Surface Water Integrated Monitoring System (SWIMS) and included SSC, instantaneous water discharge, and suspended sediment loads. The TSS data were collected by either the WDNR or MPCA on a monthly plus events basis for a total of about 30 to 40 samples per year.

The continuous-record streamgage on the Nemadji River has operated by the USGS since 1973 with streamflow data consisting of instantaneous, mean daily, mean annual, and annual instantaneous peak flows. These data were retrieved, along with the historical sediment data, from the NWIS (U.S. Geological Survey, 2017).

TSS mean daily and annual sediment load computations for 2009-16 were made using USGS methods and the Graphical Constituent Loading Analysis System (GCLAS) (Porterfield, 1972; Koltun and others, 2006). The monthly plus events sampling frequency of 30 to 40 samples per year at a variety of water discharges were used to calculate mean daily suspended sediment load. The data sets were sparser than the daily sampling frequency recommended for

GCLAS and the suspended sediment loads are considered estimates. TSS data from 2006-08 were too few to calculate mean daily or annual discharges using this method.

2015-16 Sediment Data Collection, Laboratory Analyses, and Discharge Calculations

From July 2015 through July 2016, 12 sets of sediment samples were collected by USGS at the Nemadji River streamgage along with ongoing water discharge measurements during 11 sampling events from July 2015 through September 2016 (table 1, fig. 2). Water discharge measurements are routinely collected as part of existing funding from WDNR and the USGS Cooperative Water Program to run the realtime continuous-record streamgage (http://waterdata.usgs.gov/usa/nwis/uv?site_no=04024430). A range of water discharges from 300 to over 12,000 cubic feet per second (ft^3/s) were sampled for sediment. The sampling was spread among seasons, except for the winter months of December through March when the river was frozen. The July 2016 flood had an exceedance probability of less than 0.002 (Fitzpatrick et al., 2017).

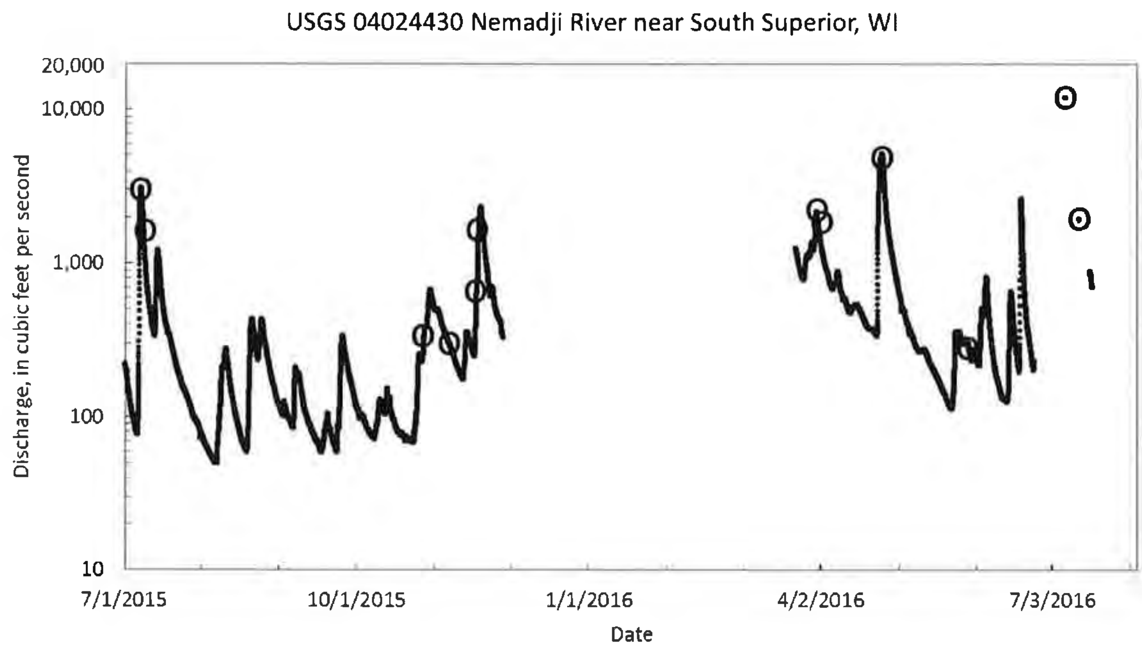

Figure 2. Hydrograph of instantaneous discharge for the Nemadji River streamgage near South Superior, Wisconsin during the study period from July 2015 to July 2016 (U.S. Geological Survey identification number 04024430). Sediment sampling dates shown in circle symbols. Instantaneous discharge data are not available for winter months and for a short time during the July 2016 flood. Data from the National Water Information System.

Table 1. Date and discharge associated with suspended sediment and bedload samples collected by the U.S. Geological Survey at the Nemadji River near Superior, Wis. (identification number 04024430) from July 2015 through July 2016.

Date	Time	Discharge (cubic feet per second)	Comments
7/7/2015	10:29	2,960	None
7/8/2015	10:23	1,540	None
10/28/2015	09:15	385	None
11/6/2015	9:25	300	None
11/17/2015	10:59	654	None
11/18/2015	10:43	1,870	None
3/31/2016	10:16	2,090	None
3/31/2016	15:58	1,950	None
4/25/2016	12:09	4,790	None
5/31/2016	12:08	250	None
7/12/2016	20:29	12,800	Suspended sediment grab sample only
7/15/2016	10:07	1,920	No bedload sample

Suspended Sediment

Cross-sectional composite samples of suspended sediment were collected with a depth-integrating model D-74 sampler using standard USGS methods, including EWI and equal transit rate (ETR) (Edwards and Glysson, 1999; Gray and Landers, 2014). Stream water was collected at 15-20 verticals across the channel cross section with a distance between verticals of about 5 ft. The resulting composite sample, abbreviated in the report as EWI SSC, includes the horizontal and vertical variability in flowing water. These samples were collected followed similar techniques used by the USGS to collect suspended sediment data at the streamgage in 1973-86. The exact depth integrating sampler used in 1973 is not known.

A grab sample of suspended sediment was collected during cross-sectional sampling using a weighted open-bottle sampler, replicating sampling methods used by WDNR and MPCA for the TSS sampling. The grab sample, abbreviated as grab TSS, was collected from approximately 0.3 to 1 m below the water surface in the centroid of flow. The WDNR was able to get a grab sample on 7/12/2016 close to the peak of flooding when the EWI sample was not able to be transported to the site as quickly as needed.

The EWI and the grab sample were each split into two samples using a churn splitter. One set of samples was analyzed for SSC and particle-size determinations at the Kentucky Water Science Center Sediment Laboratory using standard filtration methods (Guy, 1969) and under a quality assurance plan (Shreve and Downs, 2005). The exact particle size determination used depended on the concentration of the sediment and the minimum amount needed for analyses. The second set of samples were analyzed for TSS at the Wisconsin State Laboratory of Hygiene using standard method for the examination of water and waste-water method 2540D (American

Water Works Association, 2012). In hindsight, the churn splitter added another possible source of error to the sediment concentration results, since biases have been documented, both positive and negative, associated with the particular settling velocity of the particles and the amount of sand (Barr, 2018).

The instantaneous water discharge at the time of sampling was used with the results from the concentration analyses to compute an instantaneous suspended sediment load using the equation:

$$Q_s = Q_w \times C_s \times K$$

where Q_s is the suspended sediment load, in tons (English short tons) per day (tons/day), Q_w is the instantaneous streamflow (water discharge), in cubic feet per second (ft^3/s), C_s is suspended sediment concentration (SSC or TSS), in milligrams per liter (mg/L), and K is a coefficient (0.0027) to convert the units of measurement of water discharge and SSC or TSS into loads of tons/day and assumes a specific gravity of 2.65 (Porterfield, 1972). Sometimes the water discharge for the EWI samples was different than the grab sample if the flow conditions were changing between the two types of sampling. The EWI samples generally took about 45 minutes to collect, whereas the grab sample represents more or less a minute of time.

Bedload and Bed Material

Bedload samples were collected with a BL-84 sampler using the single equal-width-increment (SEWI) method (Edwards and Glysson, 1999). Bedload samples were collected at the same verticals as the suspended sediment samples. A sample bag mesh size of 0.125 mm was employed for all events. The more standard 0.250-mm mesh bag was used for the first event for the two out four cross sectional passes, otherwise two traverses of the channel cross section were completed. The sampler was held on the bottom for usually 30 seconds at each vertical. The composited bedload samples were dried at 105 deg C, weighed, and sieved for sand and gravel sizes at the preparatory laboratory at the Wisconsin Water Science Center to obtain bedload mass and sand and larger particle sizes.

For computing bedload discharge, the "total cross-section method" was used (Edwards and Glysson, 1999). This method requires that (1) the sample times at each vertical are equal, (2) the verticals were evenly spaced across the cross section, and (3) the first sample was collected at half the sample width from the starting bank or edge with active bedload transport. The bedload discharge was calculated as:

$$Q_b = K \times (W/t) \times M$$

where Q_b = bedload discharge, in tons per day; K is a conversion factor of 0.381 for the type of sampler (the BL-84 has a 3-inch wide opening); W = total width of the channel from where the bedload samples were collected, in feet; t = total time the sampler was on the bed, in seconds; and M = total mass of sample collected from all verticals sampled in the cross section, in grams.

The measured bedload discharge (Q_b) and suspended-sediment discharge (Q_s) were summed to get measured total sediment discharge (Q_{Mts}):

$$Q_{Mts} = Q_b + Q_s$$

This simple addition of the two loads assumes 100 percent efficiency of the BL-84 bedload samples and that the bedload sampler is sampling the approximately 3-inch unsampled zone near the bed not reached by the suspended sediment sampler (Edwards and Glysson, 1999).

Bed material samples were collected at each of the verticals using methods described in Edwards and Glysson (1999). Particle size determinations were done using standard sieve methods at the Kentucky Water Science Center Sediment Laboratory using standard sieving methods (Guy, 1969).

Modified Einstein Procedure

The USGS program MODEIN for the modified Einstein procedure was used to estimate a total sediment load (Einstein, 1950; Colby and Hembree, 1955; Colby and Hubbell, 1961; Stephens, 1985). This procedure is appropriate for alluvial channels that have mixed sand and gravel beds finer than 16 mm. Additional field data needed for the procedure included water discharge, average water depth, top width of channel, water temperature, particle size of suspended sediment, particle size of bed material, and suspended sediment concentration. Bedload discharge (Q_b) was estimated by subtracting the calculated suspended sediment discharge (Q_s) from the calculated total sediment discharge (Q_{Cts}):

$$Q_b = Q_{Cts} - Q_s$$

The Einstein procedure for calculated estimates of total sediment load and bedload were compared to load estimates based on the sum of the measured suspended sediment and bedload.

Suspended Sediment Rating Curves

Sediment rating curves for SSC and TSS data were constructed by use of standard procedures in Glysson (1987). The graphical based curves represent the fit of the relation between water discharge (Q_w) and sediment concentration (C_s) and were used for both SSC and TSS. Ordinary least squares regression analyses were applied in Excel to the base-10 logarithm transformed concentration and discharge data following methods used in Gray and others (2000) and Warrick (2014). The rating curves used in this study are of the power-law form

$$C_s = a \times Q_w{}^b$$

where a and b are fitted values for the intercept and slope, respectively, of the least squares regression line.

The regression technique was also used for comparison of base-10 logarithm pairs of SSC and TSS data collected in 2015-16. The regression was used to adjust the historical TSS data before it could be compared with the historical SSC data.

Historical data sets of log-transformed SSC and TSS (adjusted by the paired data) data were compared for statistically significant differences using analysis of covariance (ANCOVA) (Clausen and Spooner, 1993). This technique was used in the R Data Analysis and Graphics Program (R Core Team, 2016) to determine if there was a statistical difference in the log-transformed suspended sediment rating curves from 1973-86 compared to the 2006-2015 data. The ANCOVA ($\alpha = 0.05$) determines if there is a significant difference between the slopes and the intercepts of the regressions for the two time periods.

Hydrologic Conditions 1973-2015

For the Nemadji River, mean annual flow from 2006-15 during the TSS sampling was on average 84 percent of mean annual flow from 1973-86 during SSC sampling (fig. 3). During the SSC sampling mean annual flows were highly variable. The highest mean annul flow was measured in 1986. In contrast, the lowest mean annual flow on record was in 2007 during the TSS sampling, with the 10-year moving centered average in mean annual flow increasing from about 2010 to present.

Instaneous peak flows are also helpful for distinguishing years with large floods, even when annual mean flows may be lower than usual (fig. 4). Peak flows during the TSS data collection were higher compared to the SSC data collection. Two large floods in 2011 and 2012 were more than double any previous flood from 1980 onward. The July 2016 flood of 15,600 ft^3/s also had a probability of less than 0.2 percent (Fitzpatrick and others, 2017).

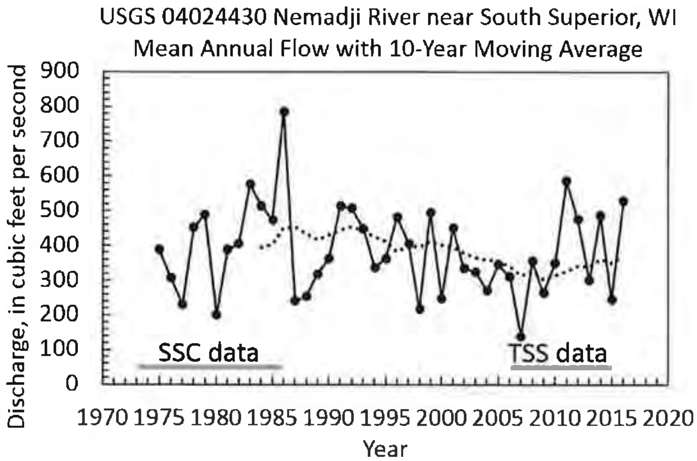

Figure 3. Mean annual flow for Nemadji River streamgage near South Superior, Wisconsin, 1973-2016 (U.S. Geological Survey identification number 04024430). The dotted line represents the 10-year moving average. Suspended-sediment concentration (SSC) data were collected 1973-86 and total suspended solids (TSS) were collected 2006-2015.

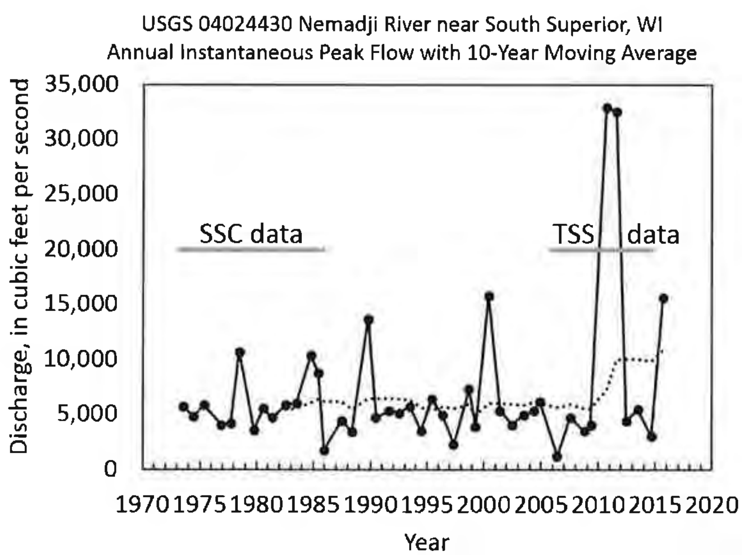

Figure 4. Instantaneous peak flows for the Nemadji River streamgage near South Superior, Wisconsin during the study period from 1973-2016 (U.S. Geological Survey identification number 04024430). The dotted line represents the 10-year moving average. Suspended-sediment concentration (SSC) data were collected 1973-86 and total suspended solids (TSS) were collected 2006-2015.

Flood-frequency characteristics, calculated using the USGS PEAKFQ program (Flynn and others, 2006; Interagency Committee on Water Data, 1982) for three consecutive 30-year periods of streamgage record, indicate a potential decrease in the size of low magnitude frequent floods (95 percent probability of occurring in any given year) and an increase in high magnitude floods (1 percent probability of occurring in any given year) during the data collection period for TSS (fig. 5). The decrease in the size of small frequent floods for 1980-1999 and 1985-2014 periods compared to previous periods is complementary to the decrease in mean annual flows over a similar time period (fig. 3), reflective of the region-wide decade-long drought. The increase in the size of floods with a 1 percent probability for the same period is in part affected by the large floods in 2011 and 2012 (Czuba et al., 2012). The non-stationarity in mean annual flows and instantaneous peak flows over the same period with differing collection methods for suspended sediment preclude any direct interpretations from increasing or decreasing annual sediment loads without considering flow variability.

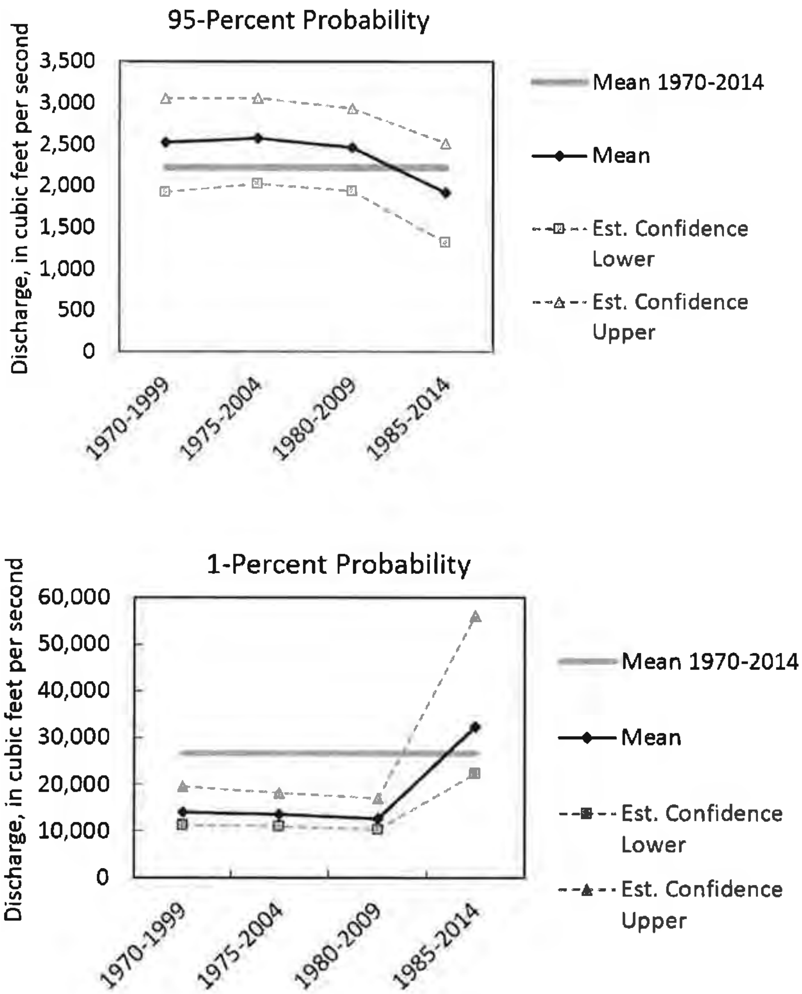

Figure 5. Trends in 30-year moving averages of flood frequency characteristics for Nemadji River near South Superior, WI USGS ID 04024430 for frequent small floods (95-percent probability) and infrequent large floods (1-percent probability). Peak flow data from the National Water Information System. Flood frequency statistics calculated using the PEAKFQ program (Flynn and others, 2006) and confidence limits set at 95 percent.

Sediment Characteristics 2015-16

The 2015-16 sediment sampling at the Nemadji River streamgage was mainly done to develop a calibration curve that could be used for comparing the historical suspended sediment data sets collected with different methods. In addition, bedload and bed material sampling was done to better characterize the proportion of bedload to suspended sediment discharge and ultimately the total amount of sediment discharged to the St. Louis River estuary and AOC.

Suspended Sediment

Suspended sediment samples from 2015-16 were collected during a wide range of flow conditions, from a low flow of 250 cfs to flood flows of 12,800 cfs (table 2). Concentrations based on EWI SSC covered three orders of magnitude from less than 25 to greater than 2,000 mg/L. Concentrations of TSS were lower than SSC in all except four pairs. Concentrations of TSS were on average 84 percent of SSC concentrations. Gray and others (2000) also concluded that TSS was almost always lower than SSC for a 1993-94 data set from three tributaries to Lake Michigan. Moreover, Ellison and others (2014) found SSC concentrations to be on average two times larger than TSS concentrations for Minnesota streams.

Table 2. Suspended sediment concentration (SSC) and total suspended solids (TSS) data collected in 2015-16 at the Nemadji River near South Superior, Wisconsin using two field sampling methods. A composite sample from an equal width increment equal depth interval was collected as well as a grab sample from the centroid of flow.

[EWI, Equal-width-increment; SSC, suspended sediment concentration; TSS, total suspended solids; ns, no sample]

Date and Time	Sampling method, 10 = EWI and 60 = grab	Discharge, instantaneous, cubic feet per second	SSC, milligrams per liter	TSS, water, unfiltered, milligrams per liter	TSS/SSC	Percent greater than 0.063 mm in SSC sample
7/07/2015 18:33	10	2590	297	271	0.91	7
07/07/2015 18:54	60	2560	269	344	1.28	ns
07/08/2015 15:45	10	1350	135	150	1.11	3
07/08/2015 16:20	60	1330	128	161	1.26	ns
10/28/2015 11:10	60	385	34	27	0.79	ns
10/28/2015 13:30	10	388	61	13	* 0.21	15
11/06/2015 11:40	60	298	25	23	0.92	16
11/06/2015 12:54	10	298	33	27	0.82	ns
11/17/2015 14:22	10	698	139	11	* 0.08	14
11/17/2015 14:50	60	704	121	111	0.92	ns
11/18/2015 12:12	60	1980	482	298	0.62	ns
11/18/2015 13:26	10	1990	419	282	0.67	6
03/31/2016 14:21	60	2010	286	262	0.92	ns
03/31/2016 14:41	10	1990	298	270	0.91	8
04/25/2016 15:15	60	4750	2000	1790	0.90	ns
04/25/2016 17:02	10	4820	1550	1320	0.85	6
04/25/2016 17:03	10	4820	1450	1240	0.86	4
04/26/2016 13:25	10	4830	461	372	0.81	12
05/31/2016 15:31	60	248	32	33	1.03	ns
05/31/2016 15:58	10	247	33	29	0.88	2
07/12/2016 17:10	60	15300	1970	1840	0.93	ns
07/13/2016 16:10	10	5930	510	458	0.90	4

*Outliers

The proportion of sand in the SSC samples ranged from 2 to 16 percent, with most of the sand in very fine to medium sand categories (0.063 to 0.500 mm). The proportion of sand greater than 10 percent generally happened during low water discharges, except for a sample on April

26, 2016 that had relatively high discharge and low suspended sediment concentration (table 2). This sample was taken on the receding limb of a spring rainfall event.

The paired samples of SSC and TSS collected from July 2015 through July 2016 were plotted in four ways to illustrate how the sampling and laboratory methods affected the relations between TSS and SSC (fig. 6). The comparison of EWI SSC with grab TSS (fig. 6*A*) has the most variability for multiple potential reasons, including differences between getting a full cross section representation compared to a grab sample and analyzing the entire sample compared to an aliquot in the lab. There may also be a sample difference because of the time offset between the EWI sample, which takes about 45 minutes to collect, compared to the instantaneous grab. For EWI TSS and EWI SSC, concentrations of TSS were particularly low compared to SSC from two pairs (fig. 6*B*). Differences between EWI SSC and grab SSC were present but not as noticeable as the first two comparisons (fig. 6*C)*, and the grab only paired samples had close to a 1:1 relation (fig. 6*D*). The regression equation for the relation between EWI SSC and grab TSS (fig 6*A*) was used to adjust the historical grab TSS data to be comparable to the historical EWI SSC data.

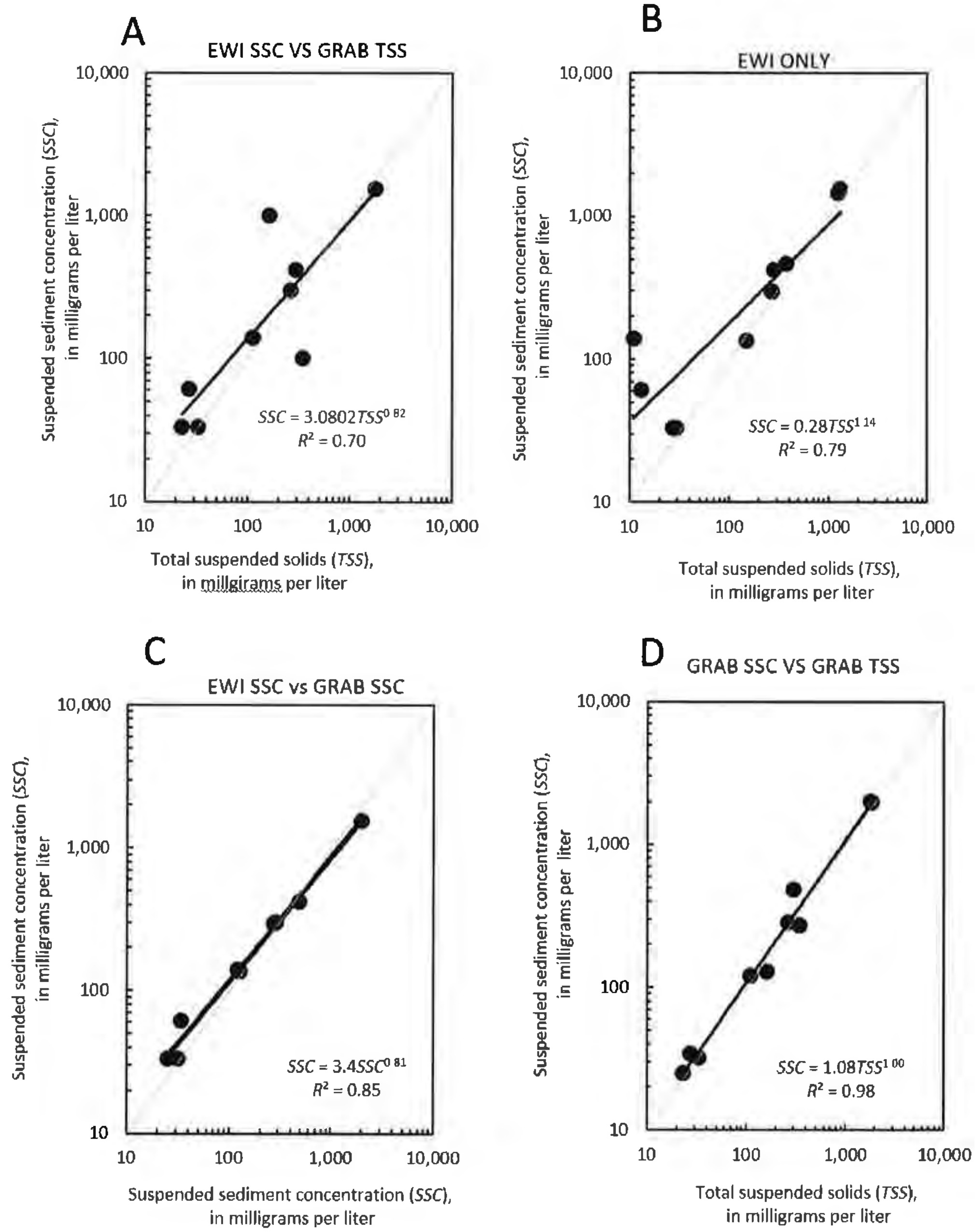

Figure 6. Comparison of paired suspended-sediment concentration (*SSC*) and total suspended solids (*TSS*) data from 2015-16 for the Nemadji River near South Superior, WI USGS ID 04024430. Black lines are power functions fit through log-10 normalized data. A) equal-width-increment (EWI) SSC and grab TSS B) EWI SSC and EWI TSS, C) EWI SSC and grab SSC, and D) grab SSC grab and grab TSS. The line for a 1:1 relation is shown in gray.

The proportion of TSS to SSC was between about 80 and 90 percent for most pairs (fig. 7). Two outliers had particularly low proportions but also had low suspended sediment concentrations of which sand made up 14 and 15 percent (table 2). This suggests that some of the sand portion was likely lost from the TSS sample, either from splitting using the churn sampler or the aliquot sampling during the TSS laboratory analyses. The grab only plot (fig. 6*D*) had an almost 1:1 relation between SSC and TSS and very little variability, indicating that the EWI sampling, more so than the laboratory analytical methods, resulted in higher concentrations for SSC than TSS, especially for concentrations below about 600 mg/L.

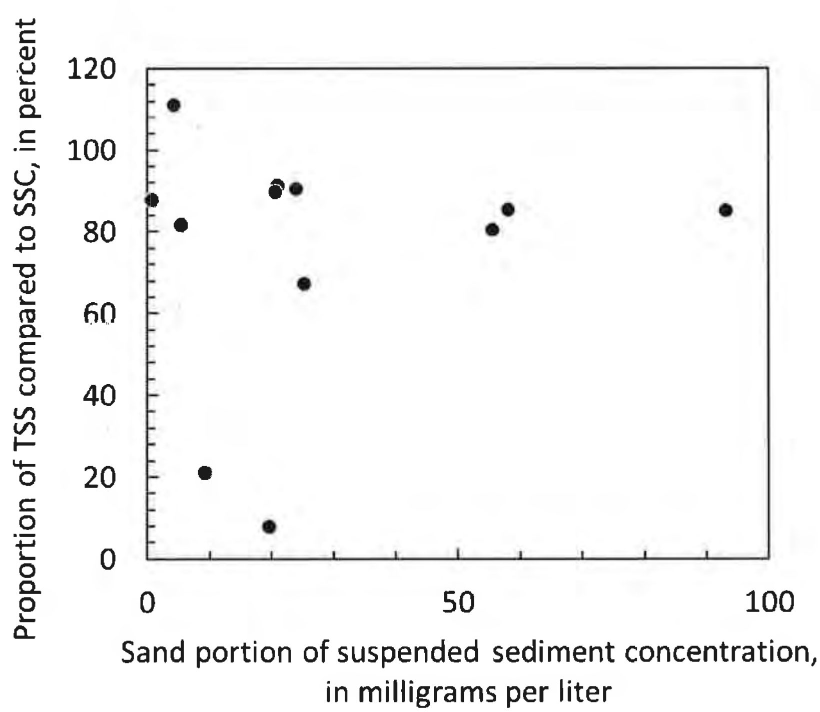

Figure 7. Proportion of total suspended solids (TSS) compared to suspended-sediment concentration (*SSC*) compared with sand concentration in the SSC samples for Nemadji River near South Superior, WI USGS ID 04024430, 2015-16.

Bedload and Bed Material

During the 2015-16 sampling sediment sampling activities, 9 of the 12 suspended sediment sampling events had collection of bedload and bed material samples (table 3). Over the nine events sampled the measured bedload ranged from 5 to 62 tons/day, and less than 1 to 47 percent of the total load. The highest proportions of bedload (and lowest proportions of suspended sediment load) were during low water discharges (fig. 8).

The particle size distribution of the measured bedload was mainly sand (fig. 9). The sampled bed material and calculated bedload component from the modified Einstein procedure also was mainly composed of sand (table 3). The greater than 2 mm fraction was less than 10 percent in all but 1 sample. The mesh size used for the bedload sampler was 0.125 mm except the first two passes on July 7 when the more traditional 0.250 mm mesh was used. The mesh size was changed to 0.125 mm because sediment could be seen evacuating from the bag during retrieval. Whereas silt- and clay-sized particles tend to have a uniform vertical distribution through the water column, the sand sized particles may be more prevalent in the lower part of the water column, especially for the 0.125 to 0.25 mm sizes (Colby, 1963). Most of the bedload was composed of three sand sizes of greater than 0.5 to 1.0 mm, greater than 0.25 to 0.5 mm, and greater than 0.125 to 0.25 mm (fig. 9).

Table 3. Results from 2015-16 sediment load measurements and modified Einstein calculations for Nemadji River near South Superior, WI USGS ID 04024430.

Date of sediment sampling	7/7/15	7/8/16	10/28/15	11/6/15	11/17/15	11/18/15	3/31/16	4/25/16	5/31/16
Measurements									
Channel wetted width (ft^2)	110.0	98.8	70.6	75.4	79.4	88.6	68.0	203.0	71.4
Average water depth (ft)	10.0	7.6	3.4	3.3	4.7	8.1	7.2	9.3	3.1
Channel wetted area (ft^2)	1,100	747	240	245	373	720	489	1,890	222
Average velocity (ft/s)	2.7	2.1	1.6	1.2	1.8	2.6	4.0	2.5	1.1
Average discharge for suspended sediment (ft^3/s)	2,960	1,540	385	300	654	1,870	1,950	4,790	250
Average discharge for bedload (ft^3/s)	2,750	1,490	385	300	689	1,970	2,030	4,755	248
Suspended sediment concentration (mg/L)	297	135	61	33	139	419	298	1,550	33
Suspended sediment load (t/d)	2,374	561	63	27	245	2,116	1,569	20,046	22
Bedload (t/d)	62	25	42	24	58	28	32	41	5
Measured total sediment load (t/d)	2,436	586	105	50	303	2,143	1,601	20,087	28
Percent of measured suspended sediment to total sediment load	97	96	60	53	81	99	98	100	80
Modified Einstein calculated suspended sediment load (t/d)									
0.0020 - 0.0625 mm size range	2,159	529	50	21	202	1,942	1,400	19,008	20
0.0625 - 0.1250 mm size range	77	6	4	2	14	62	76	396	0
0.1250 - 0.2500 mm size range	53	6	3	1	12	41	30	198	0
0.2500 - 0.5000 mm size range	28	6	1	1	5	21	15	198	-
0.5000 - 1.0000 mm size range	5	-	1	0	2	-	-	-	-
1.0000 - 2.0000 mm size range	-	-	-	-	-	-	-	-	-
2.0000 - 4.0000 mm size range	-	-	-			-	-	-	-
Calculated suspended sediment load (t/d)	2,322	545	59	24	234	2,066	1,522	19,800	21
Modified Einstein calculated total sediment load (t/d)									
0.0020 - 0.0625 mm size range	2,230	546	55	26	216	2,057	1,532	19,258	22
0.0625 - 0.1250 mm size range	93	6	5	3	18	90	146	411	0
0.1250 - 0.2500 mm size range	101	10	5	3	18	103	169	234	0
0.2500 - 0.5000 mm size range	140	38	5	4	18	149	304	440	0
0.5000 - 1.0000 mm size range	84	7	5	1	13	55	127	111	-
1.0000 - 2.0000 mm size range	5	0	-	-	-	2	34	4	-
2.0000 - 4.0000 mm size range	0	-	-			-	4	-	-
Calculated total sediment load (t/d)	2,653	607	75	36	282	2,456	2,316	20,459	23
Comparison of calculated and measured results									
Difference betwteen calculated and measurement for total sediment load (t/d)	217	21	-30	-14	-21	313	715	371	-5
Percent difference between calculated and measured	9	4	-29	-29	-7	15	45	2	-18

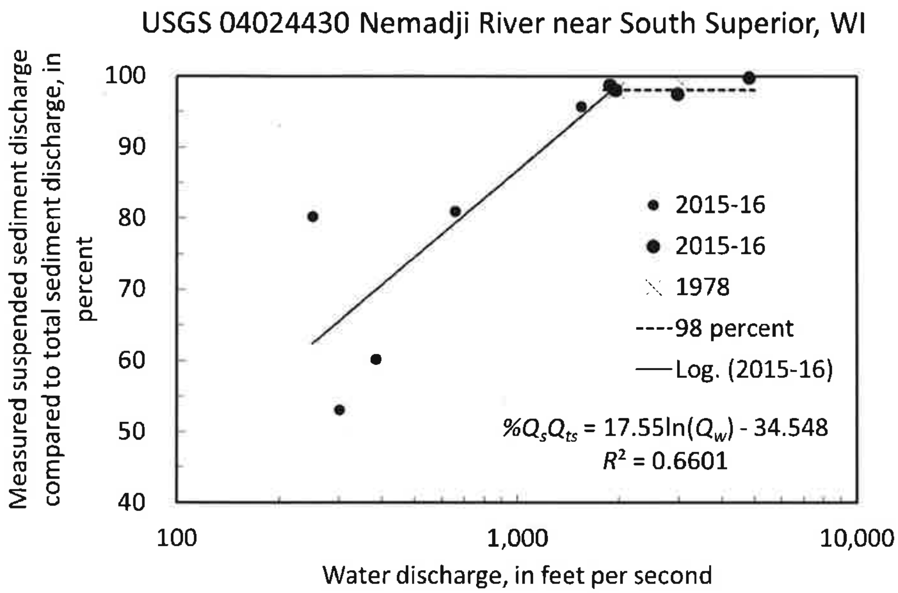

Figure 8. Comparison of the proportion of measured suspended sediment discharge to total sediment discharge with water discharge for nine events sampled in 2015-16 and two events in 1978 with measured bedload at the Nemadji River streamgage near South Superior, Wisconsin, 1973-2016 (U.S. Geological Survey identification number 04024430). The fitted linear regression (solid line) extends to a water discharge of about 1,800 cubic feet per second. Above 1,800 cubic feet per second the percentage of suspended sediment discharge was assumed to be 98 percent (dashed line). Data from 1978 from Rose (1980).

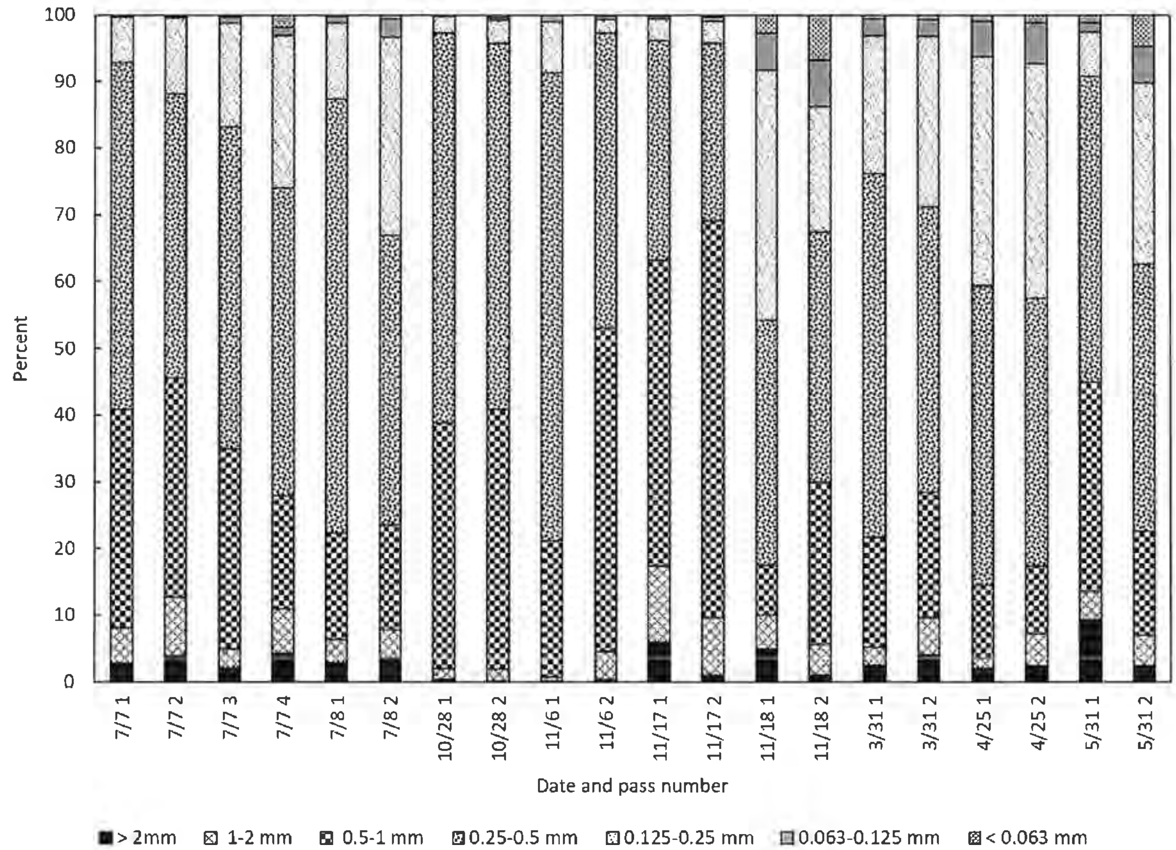

Figure 9. Particle size distribution of bedload from multiple passes from 2015-16 sampling events at the Nemadji River streamgage near South Superior, Wisconsin, 1973-2016 (U.S. Geological Survey identification number 04024430).

Total Sediment Loads

Total sediment loads for the 2015-16 event samples were computed from summing the measured suspended sediment and bedload and compared to loads calculated by the modified Einstein procedure (table 3). Total sediment loads calculated from the modified Einstein procedure varied from being less than the measured for streamflows below about 1,500 ft^3/s to more than the measured for streamflows above 1,500 ft^3/s (table 3, fig. 10). Data for two events sampled in 1978 by Rose (1980) were similar. One potential reason for the modified Einstein procedure calculating more load during high flows than the measured may be from how well the 0.125- to 0.25-mm sand portion was distributed in the water column relative to its possible higher concentrations closer to the bed.

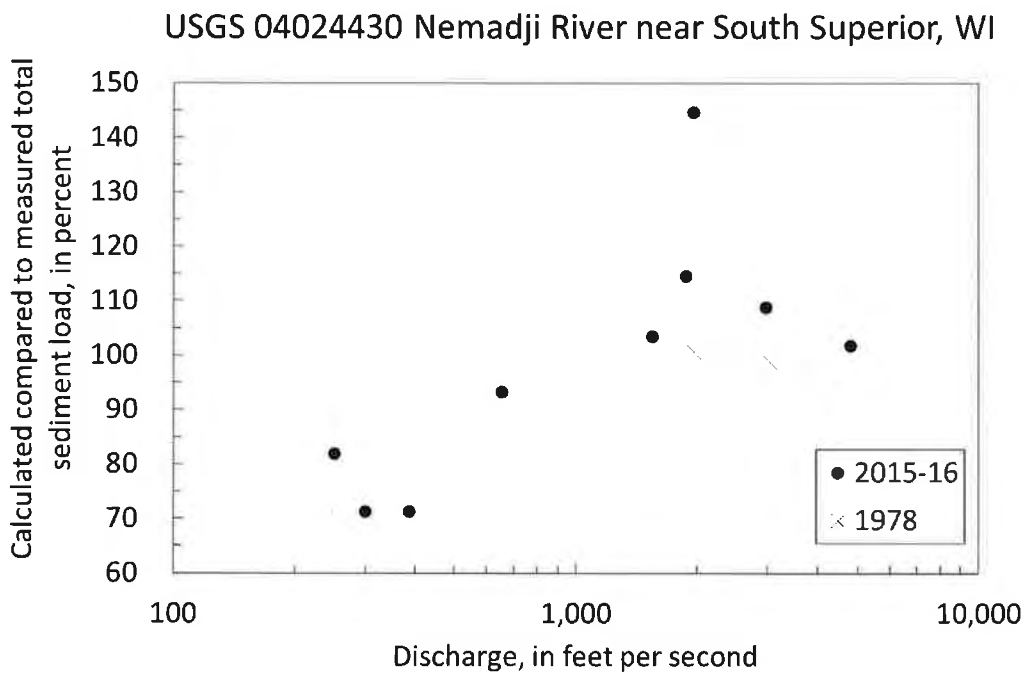

Figure 10. Comparison of percentage of calculated and measured total sediment discharge with water discharge for 2015-16 and 1978 at the Nemadji River streamgage near South Superior, Wisconsin, 1973-2016 (U.S. Geological Survey identification number 04024430). The 1978 data are from Rose (1980).

Estimates of Annual Suspended and Total Sediment Loads 2009-16

The 2009-16 period covered a range of hydrologic conditions and annual suspended and total sediment loads reflected the wide range water discharges (table 4). Estimates were lowest TSS-based annual suspended sediment load of just over 18,000 tons in 2015 in contrast with the almost order of magnitude higher 180,000 tons in 2012 (table 4) which included the flood of record (Czuba and others, 2012).

Table 4. Annual suspended and total sediment loads for 2009-16 based on TSS, *AdjTSS*, and the $\%Q_sQ_{ts}$ relation developed with 2015-16 data. Mean daily values computed with GCLAS.

[TSS, total suspended solids; adjTSS, adjusted total suspended solids; % percent; Qs, suspended sediment discharge; Qts, total sediment discharge; cfs, cubic feet per second]

Year	Water discharge (cfs-days)	TSS annual suspended sediment load (tons)	*AdjTSS* annual suspended sediment load (tons)	$\%Q_sQ_{ts}$-based annual total sediment load (tons)	Suspended sediment load as a percentage of total sediment load
2009	96,168	19,886	26,715	32,566	82
2010	127,869	32,942	42,509	48,484	88
2011	213,770	142,015	153,084	163,018	94
2012	173,792	177,484	180,990	190,233	95
2013	109,599	27,579	36,366	40,379	90
2014	177,284	158,380	166,137	175,048	95
2015	89,125	18,682	24,422	30,354	80
2016	192,926	130,515	134,853	143,308	94

The TSS-based mean daily suspended sediment concentration was updated with the power-function established between the 2015-16 EWI SSC and grab TSS data (fig. 6*A*):

$$AdjTSS = 3.0802 \times TSS^{0.82}$$

Likewise, the mean daily suspended sediment loads calculated from GCLAS were updated using *AdjTSS* concentrations. The resulting annual suspended sediment loads based on *AdjTSS* concentrations are larger than their TSS counterparts (table 4; fig. 11).

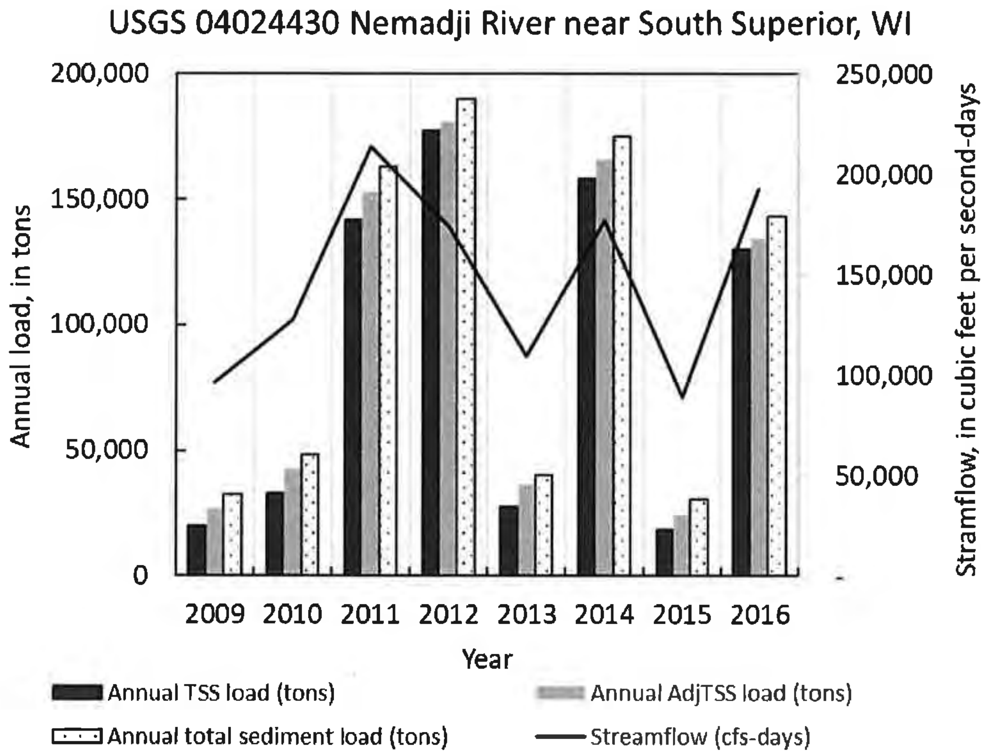

Figure 11. Annual streamflow, suspended sediment load and total sediment load for Nemadji River streamgage near South Superior, Wisconsin, 2009-2016 (U.S. Geological Survey (USGS) identification number 04024430). Suspended sediment load calculated for total suspended solids (TSS) and adjusted total suspended solids (*AdjTSS*). Total sediment load calculated from *AdjTSS* mean daily loads and relation of the percentage of suspended sediment with streamflow.

Rough estimates of annual total sediment load for 2009-16 were calculated by applying the 2015-16 regression relation for suspended sediment loads as a percentage of total sediment loads ($\%Q_sQ_{ts}$) compared to water discharge (Q_w) (fig. 8) to the mean daily data:

$$\%Q_sQ_{ts} = 17.55\ln(Q_w) - 34.548$$

This log-normal regression relation was used for the 2009-16 mean daily water discharges of less than or equal to 1,800 ft*3*/s. For mean daily water discharges over 1,800 ft*3*/s the suspended sediment load was assumed to be 98 percent of the total sediment load. Using this rough estimate indicated that during dry years the annual bedload is probably about 20 percent of the total sediment load whereas in years with large floods the bedload is 5-6 percent (table 4).

Comparison of Suspended Sediment Rating Curves 1973-86 and 2006-15

Trend analyses requires continuous data sets. Having historical data grouped into two data sets with different collection and analytical methods and a gap of 20 years in between required an alternative approach. Another technique can be used that involves suspended sediment concentration and water discharge rating curves. This technique has been used in other studies to determine if there has been a difference in sediment loading in a watershed from land use changes. The assumption for this method is that the sediment relations are supply limited and not transport limited (Warrick, 2014). Using the side-by-side sampling procedures and paired sample linear regression analyses, a calibration coefficient was established between the EWI SSC and the grab TSS data using 2015-16 data (previous section). The sediment rating curve for the adjusted TSS was compared to SSC data for the final determination if there was a change in sediment discharge in the Nemadji River from 1973-86 to 2006-16.

The WDNR and MPCA both collected TSS samples at the Nemadji River gaging station from 2006-2015 through coordinated efforts. Both agencies used the weighted bottle grab technique. A check on suspended sediment rating curves with data grouped by state agency indicates the relation between suspended sediment concentration and water discharge for the two state agencies are virtually the same, indicating no difference in their sampling or analytical methods (fig. 12). The MPCA data cover a higher range of water discharges and also have about double the number of samples. The similarity of the data sets confirm that it is appropriate to combine the data sets into one for comparison with the historical 1973-86 SSC data.

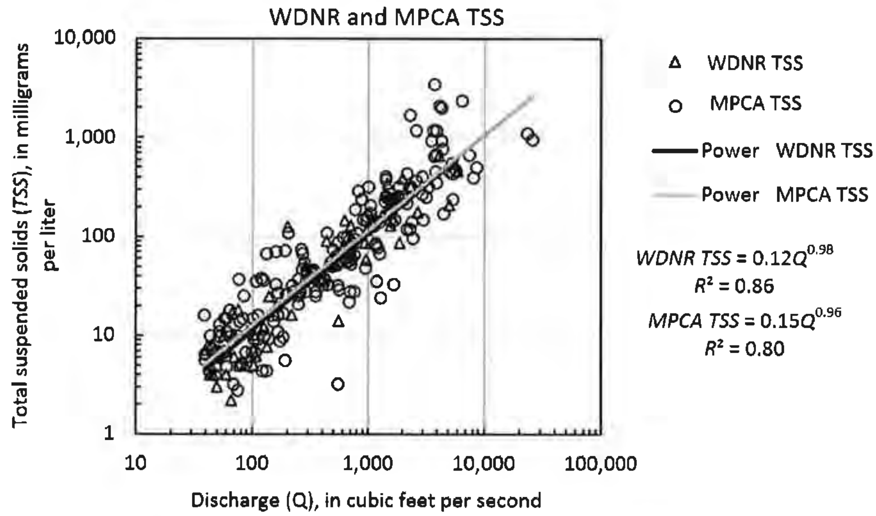

Figure 12. Total suspended solids (TSS) concentrations collected by the Wisconsin Department of Natural Resources (WI) and the Minnesota Pollution Control Agency (MN) from 2006-2015 for Nemadji River near South Superior, WI USGS ID 04024430. Lines are power functions fit through log-10 normalized data from each state agency.

Determination of the presence of a difference in the 1973-86 EWI SSC and 2006-16 grab TSS data required adjusting the TSS data to SSC equivalent data before any comparison technique could be performed. Sediment concentration and water discharge rating curves for 1973-86 SSC and 2006-15 TSS data illustrate how the rating between suspended-sediment concentration and discharge appear lower (less suspended sediment) for the later period covered by grab TSS sampling compared to the earlier period covered by the EWI SSC sampling (fig. 13*A*). There were more samples for SSC (330) than TSS (230), but the two data sets covered a similar range of water discharges and sediment concentrations. Water discharges ranged from about 50 to almost 10,000 cubic feet per second. Sediment concentrations ranged from less than 10 mg/L to over 1,000 mg/L. Power law functions for sediment rating curves fit to each data set in relation to water discharge indicate that the TSS samples had lower concentrations than SSC samples, especially at lower water discharges (fig. 13*A*). This relation is like the relation between EWI SSC and EWI TSS concentrations in the 2015-16 paired comparison sampling (fig. 6*C*).

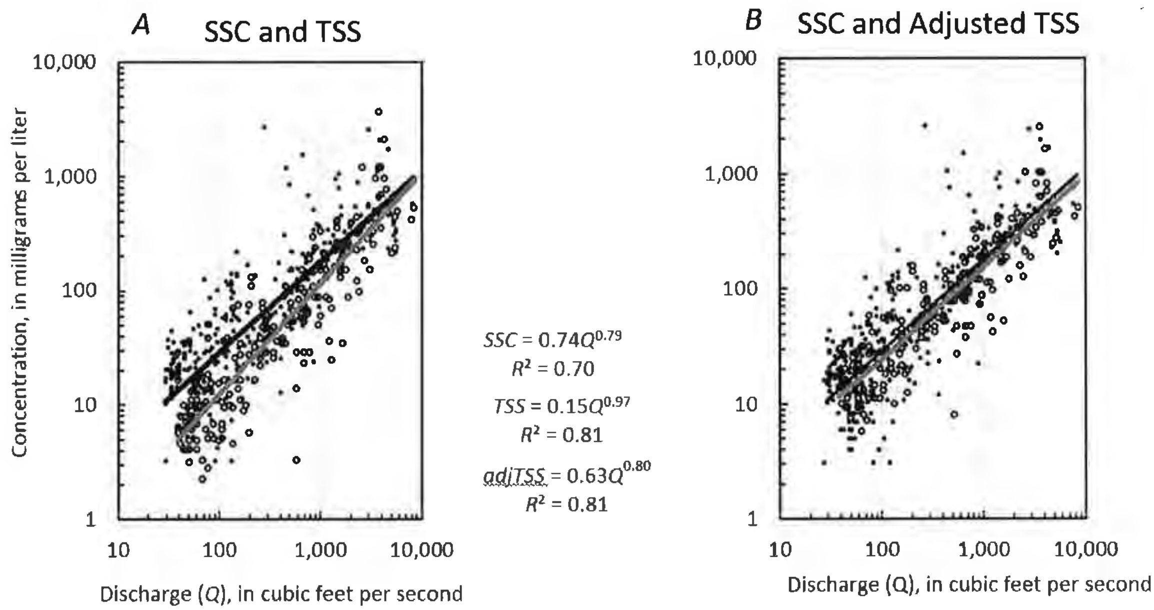

Figure 13. Suspended sediment rating curves for base-10 logarithms of suspended-sediment concentration (*SSC*) from 1973-86 and (*A*) total suspended solids (*TSS*) from 2006-15, and (B) adjusted total suspended solids (*Adj1TSS*) from 2006-15 for Nemadji River near South Superior, WI USGS ID 04024430.

After the 2006-16 TSS concentrations were adjusted (*AdjTSS*), the offset of the rating curves for the two time periods disappeared (fig. 13*B*). The 2006-16 adjusted TSS (*Adj1TSS*) rating curve had similar slope but a small negative offset of the intercept compared to the 1973-86 SSC rating curve. Results from the ANCOVA analyses indicate that the negative offset between the two regressions is not statistically significant (table 5).

Table 5. Analysis of covariance results for suspended sediment rating curves from 1973-86 and 2006-16, using adjusted total suspended solids data for Nemadji River near South Superior, WI USGS ID 04024430.

Coefficients	Estimate	Standard error	t value	Probability (greater than absolute value of t)
Intercept	-0.131	0.060	-2.177	0.030*
Log10(Q)	0.795	0.026	30.951	<2e-16***
Group	-0.111	0.102	-1.086	0.278
Log10(Q)	0.015	0.040	0.382	0.702
Residual standard error	0.3038			
F-statistic	585.2 on 3 and 571 degrees of freedom			
Degrees of freedom	3 and 571			
p-value	<2.2e-16			
Multiple R-squared	0.755			
Adjusted R-squared	0.753			

Although statistical significance remains elusive, annual total sediment loads calculated in GCLAS were compared to the two sediment rating curves for an example time period of 2009-16. Using the same set of mean daily water discharges over the 8-year period, the negative offset between the two curves resulted in the 2006-15 annual total sediment discharges being 86 percent of the 1973-85 sediment discharges. This decrease of 14 percent is not statistically significant, yet it does however give an indication that perhaps sediment discharges are heading toward decreasing. The 2006-15 sediment rating curve derived discharges were higher compared to the GCLAS calculated in six out of eight years, with the highest year in 2013 which had up to almost 170 percent of the GCLAS derived discharge (table 6). The GCLAS method takes into account seasonal and runoff hydrograph (hysteresis) variations that are not possible for with the sediment rating curve method.

Table 6. Comparison of 2009-16 annual total sediment discharges for 2009-2016 using multiple methods.

[TSS, total suspended solids; adjTSS, adjusted total suspended solids; % percent; Qs, suspended sediment discharge; Qts, total sediment discharge; cfs, cubic feet per second]

Year	Water discharge (cfs-days)	Annual total sediment discharge from GCLAS (tons)	Annual total sediment discharge using 2006-15 sediment rating curve (tons)	Annual total sediment discharge using 1973-85 sediment rating curve (tons)	Annual total sediment discharge from the 2006-15 rating curve as a percentage of discharge from the 1973-85 rating curve	Annual total sediment discharge from 2006-15 rating curve as a percentage of discharge from GCLAS
2009	96,168	32,566	32,378	37,741	86	116
2010	127,869	48,484	57,925	67,489	86	139
2011	213,770	163,018	196,812	229,022	86	140
2012	173,792	190,233	230,069	267,613	86	141
2013	109,599	40,379	58,176	67,773	86	168
2014	177,284	175,048	133,692	155,681	86	89
2015	89,125	30,354	22,848	26,644	86	88
2016	192,926	143,308	135,430	157,686	86	110

Summary and Conclusions

A variety of sediment characteristics were examined at the USGS Nemadji River streamgage in northwestern Wisconsin (USGS 04024430), which has flow and sediment data starting in 1973 and continuing through the present. Even though the available sediment data was collected sporadically with different methods and analytical techniques by the USGS and state agencies, some innovative techniques were used to describe differences in suspended sediment collection methods as well as compare historical data sets.

Before any comparisons of historical sediment data sets were done, the hydrologic context was examined in terms of mean annual discharges and annual peak floods. A range of mean annual discharges were covered in an earlier historical data set collected by the USGS in 1973-86 as well as a later data set collected by the Wisconsin DNR and MPCA in 2006-15. However mean annual flows in 2006-15 were about 84 percent of 1973-86 mean annual flows and extreme floods in 2011 and 2012 punctuated the latter period.

From 2009-16, estimated annual total sediment discharges ranges from a low of about 18,000 tons per day in 2015 to a high of almost 180,000 tons in 2012. The percentage of bedload depended on water discharge, with about 20 percent in years with relatively low annual water discharge compared to only 5-6 percent in years with extreme floods.

The sediment rating curve approach was employed to determine if there was a change in annual suspended sediment loads from 1973-86 and 2006-15. An ANCOVA analyses indicated that the suspended sediment rating curves for the two periods were not statistically significantly different after the TSS data were adjusted to be equivalent to SSC data. However, a very rough, although not statistically significant offset in the curves resulted in a reduction of possibly 15 percent when the two curves were applied to 2009-16 annual sediment discharges. This value is not statistically sound, it should be used with caution.

The hydrologic context with what is seeming to have more year-to-year variability will likely become more important than the overall value of annual loading at face value. It is unknown if the extreme floods will become more or less frequent over the coming years. The 10-fold increase in the size of sediment discharges during extreme floods compared to more average flood condition suggest that restoration done at the mouth of the Nemadji River needs to be resilient to large floods and sporadic, highly variable sediment deposition, even though overall the amount of suspended sediment per unit of water discharge may have been reduced.

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Glossary

The following definitions, except where otherwise noted, are from Colby (1963), Edwards and Glysson (1999), and are repeated from Rose (1980) and Czuba and others (2012).

Annual exceedance probability The probability that a given event magnitude will be exceeded or equaled in any given year. The annual exceedance probability is directly related to the recurrence interval. For example, the chance that the 100-year peak flow will be exceeded or equaled in any given year is 1 percent. A flood probability of 0.01 has a recurrence interval of 100 years. The recurrence interval corresponding to a particular flood probability is equal to 1 divided by the flood probability (Holmes and Dinicola, 2010).

Bedload discharge The sediment that moves by rolling, sliding, and bouncing along the streambed.

Bed material Material that constitutes the streambed.

Bed-material discharge Part of the total sediment discharge having particle sizes in the same range as the bed material. In an alluvial stream, bed-material discharge is related to the hydraulic properties of the flow.

Continuous-record streamgage A site where stage, discharge, and other hydrologic data are collected with sufficient frequency to define daily mean values and variations within a day (U.S. Geological Survey, 2011).

Flood peak The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. "Flood crest" has nearly the same meaning, but because it connotes the top of the flood wave, flood crest is properly used only in referring to stage—thus, "crest stage," but not "crest discharge."

Recurrence interval (return period) The average interval of time within which the given flood will be equaled or exceeded once. The recurrence interval is directly related to the flood probability. The recurrence interval corresponding to a particular flood probability is equal to 1 divided by the flood probability. For example, a 100-year recurrence interval has a flood probability of 0.01.

Sediment concentration Ration of dry weight of sediment to the total weight of the water-sediment mixture.

Streamflow The discharge of water in a natural channel. Although the term “discharge” can be applied to the flow of a canal, the word “streamflow” uniquely describes the discharge in a surface stream course.

Streamgage A site on a stream, canal, lake, or reservoir where systematic observations of stage, discharge, or other hydrologic data are obtained (U.S. Geological Survey, 2011).

Suspended-sediment discharge Sediment that is supported by upward components of turbulent currents.

Total sediment discharge All sediment moving downstream, bedload discharge plus suspended-sediment discharge.

Wash-load discharge Part of the total sediment load that is comprised of the particle sizes finer than those in the bed material. Unlike bed-material discharge, there is not a functional relation between wash-load discharge and the hydraulic properties of the flow. Wash load is normally delivered to the stream by overland flow or bank sloughing and is transported at the rate that is made available to the stream.

Water discharge The discharge of water in a natural channel or canal.

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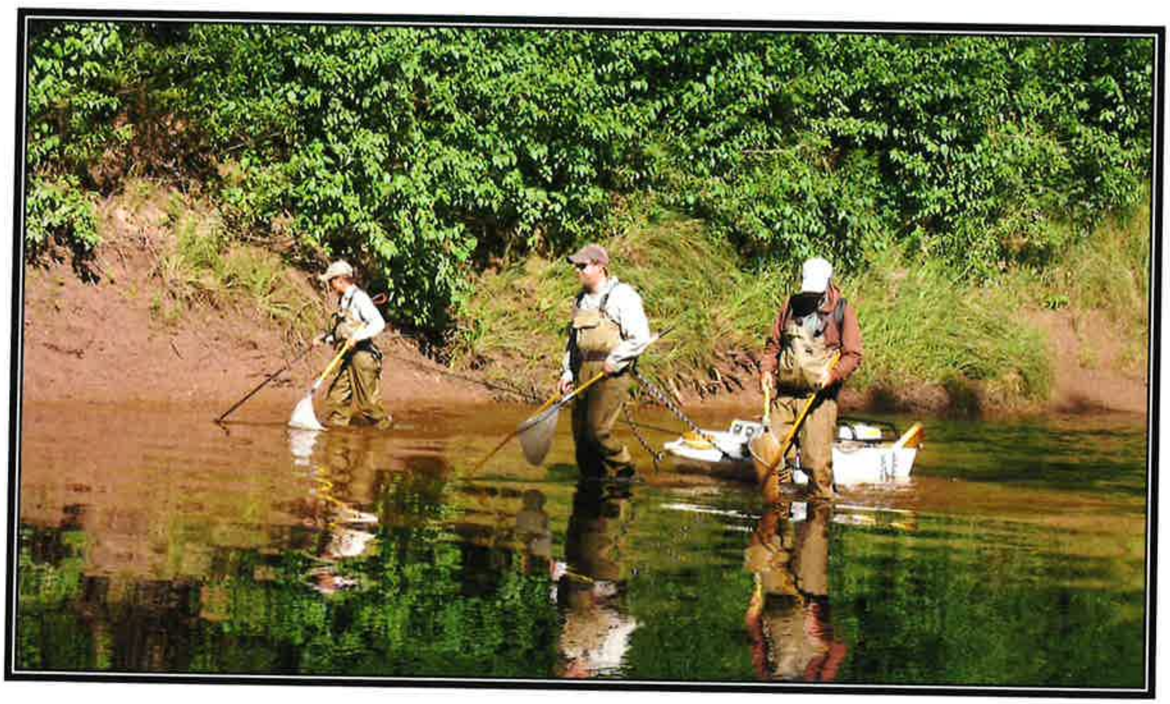
Appendix 7

Lower River Nemadji River - Douglas County Fish Community Survey
(Pertains to management action 6.05)

This appendix is abbreviated due to file size. The full appendix is available upon request from the Wisconsin DNR St. Louis River Area of Concern Coordinator. For contact information, visit dnr.wi.gov and search "St. Louis River AOC."

Lower Nemadji River – Douglas County
2015 Fish Community Survey Summary



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2015
Lower Nemadji River – Douglas County
Fish Community Survey
Aaron Nelson

1. Introduction

The Nemadji River is the second largest tributary to the Duluth/Superior Harbor located at the western end of Lake Superior. The total length of the Nemadji River is 65 miles from its origin in Pine County, Minnesota to its terminus when it reaches Superior Bay in the eastern end of the Duluth/Superior Harbor. The entire Nemadji River watershed was included in the St. Louis River Area of Concern due to Beneficial Use Impairments from Excessive Loading of Sediments and Nutrients; it is also listed on the Wisconsin and Minnesota 303d Impaired Waters List for Sediment/Total Suspended Solids as a Pollutant and Degraded Habitat as an Impairment. This report will summarize survey work completed by Wisconsin DNR Fisheries Management staff to assess the fish community present in the Wisconsin portion of the Nemadji River, specifically the Lower Nemadji River watershed, from the confluence with the Black River to its terminus.

2. Site Description

The project boundary for this survey spanned from the mouth of the Nemadji River upstream to County Highway C. The current Douglas County land-use zoning along the immediate riparian area of the Nemadji River is resource conservation meaning there is no human development permitted along the banks in these zoned areas. Away from the river's edge, county land use and zoning is dominated by agricultural use with minor residential development. Within the City of Superior, the land-use and zoning along the river and within the watershed is primarily suburban or family residential with a few areas of manufacturing or industrial land-use present, most notably the Enbridge Energy refinery on the west side of the river and Burlington Northern rail yard on the east side.

The project area was measured off in one-mile segments to assign one-mile non-wadable river stations. The segment from County Highway C upstream to Finn Rd was also included to allow for additional sampling with the mini-boom if the river channel was navigable and sufficient access was available to launch the mini-boom. This segment included two previous wadable stream stations that were surveyed at Finn Road and Highway 35. Stations numbers were assigned as Station 1, at the upstream most station, continuing downstream to Station 6, the last station selected. Any stations surveyed after the original stations were designated were assigned the number of the station upstream and a letter designation; for example Station 3A was sampled after Stations 3 and 4 had been sampled.

The only sufficient access to launch the mini-boom was at Grand Avenue, and due to low water levels during the sampling period, Mile-14 was assigned Station 3 as it was the furthest upstream that navigation with the mini-boom shocker was possible. Field reconnaissance downstream from County Highway C to the Duluth, Missabe & Iron Range railroad trestle crossing revealed that in low-flow conditions the majority of the stream channel width was wadable with water depths of 1.5 feet or less, however there were deep, non-wadable pools and bends that prevented sampling with the tow barge. The prolonged low-flow conditions prior to the sampling period may have limited areas where sampling with the mini-boom could occur, however it also led to significantly improved visibility of normally very turbid water. Secchi depths taken during the sampling period ranged from 1.8 to 2.25 feet.

3. Methods

The Quality Assurance Project Plan (QAPP) developed for the Lower Nemadji River Biological and Water Quality Monitoring project mentioned use of several types of gear for sampling the fish community of the Nemadji River based on judgement of Fisheries Management staff. Ultimately, electrofishing was chosen over several types of passive net gear (fyke net, minnow trap, gill net) because electrofishing would have less selectivity by eliminating bias from chosen net locations, mesh sizes or openings on nets or traps, or fish behavior and would allow for standardized Index of Biotic Integrity sampling. Using netting gear to sample fish in the Nemadji River could be considered in the future as a means of targeting specific groups of fish or areas, but isn't an unbiased means of gauging the health of the fish community present.

Wadable Stations

The wadable station sampled at County Highway C was surveyed with a tow barge stream electrofishing unit consisting of a Whitney fiberglass sled with three anodes (see report cover). A 240-volt AC generator supplied electrical current to the cathode and anodes via a SDC rectifier control box that transformed AC current to DC. A stainless steel plate affixed to the bottom of the sled acts as the cathode and the anodes are diamond shaped stainless steel hoops epoxied into the end of a fiberglass poles; the anodes then are connected to the SDC control box with power cable by series of connectors and a retractable cable reel. Each of the anodes is deployed by personnel carrying fiberglass handle dip nets and electrofishing commenced from the station start upstream with one crew member towing the barge behind them. Fish were captured as personnel swept the anodes over or around habitat features in the stream channel; any fish captured were transferred to an aerated tub onboard the tow barge.

Water Resources has the option to use best professional judgment and sample a maximum 400-meter station if the habitat, morphology, and substrate are relatively uniform within the 35xMSW station. Based on the mean stream width of 19 meters, a station of 665 meters would have been sampled at County Highway C, however a truncated station of 400 meters was sampled at County Highway C based on available habitat types (deep meanders, shallow inside bends), substrate (sand and clay mix), and morphology (run). While sampling the additional length of the station would have yielded more fish, the extra effort typically results in catching more of the same fish species that have already been captured. Another survey of a station at State Highway 35 was scheduled to be sampled this year, but this area was last sampled in 2011 and IBI scores are considered current for 5 years from the last sampling effort. The station at County Highway C was surveyed as single run fish community (all species collected) catch-per-effort only.

Non-Wadable Stations

The non-wadable stations downstream of County Highway C were surveyed with a mini-boom shocker comprised of an outboard motor propelled aluminum johnboat with a pulsed DC electrofishing unit powered by a 3500 watt AC generator (see report cover). An anode consisting of a standard aluminum "Wisconsin ring" with 16 cylindrical, 17-mm diameter stainless steel droppers was used to deliver electrical current to the water. Pulsed DC settings were set at a pulse rate of 60-hertz and 25% duty cycle; the voltage and amperage were set to maintain electrical output to the anode as close to 3000 watts as possible. This electrofishing unit requires a two person crew consisting of a driver/operator at the stern to run the outboard, generator and electrofishing system and a "dipper" is seated at the bow of the boat with a fiberglass long-handled dip net to capture fish as they are stunned. Electrofishing commenced at the upstream end of the station and the mini-boom shocker drifted with the current or, in slower current areas, run at idle speed downstream along the bank. Fish were drawn to the anode end of the electrical field and any fish captured were transferred to an aerated stock tank on board the mini-boom. Extra sampling effort beyond a simple downstream pass was used to capture additional fish near log jams, snags, or other habitat features as they occurred in the stream channel. All of the 1-mile non-wadable stations were surveyed as single run fish community (all species collected) catch-per-effort only. The distance shocked reflects the distance the mini-boom shocker travelled along the bank and around obstacles or other structure within the 1-mile station.

Fish Processing / Data Collection
All fish captured were identified by species. Gamefish and panfish species were measured to the nearest tenth of an inch and larger individuals were weighed. All other non-gamefish species were counted. All fish captured in the survey were released back to the river with the exception of any voucher species that were retained to confirm species identification.

4. Results/Discussion

Fish Community
The Nemadji River supports a fairly diverse fish assemblage; 24 different fish species were documented in the 6 stations assessed in 2015. (Table 1, Table 3) Based on relative abundance from the electrofishing surveys, cyprinids (minnows) were the most abundant and widely distributed fish species in the Nemadji River and were represented mainly by common shiners and emerald shiners. Silver redhorse, shorthead redhorse, rock bass, smallmouth bass and walleyes were also widely distributed throughout the Nemadji River, but didn't occur in the higher abundance seen in the minnow species.

Based on the gear and sampling methodology used, the fish communities from each station were scored and rated using the Lake Superior Warmwater IBI rating to determine if the site is degraded and to what extent. The summer thermal regime of the Nemadji River is too warm to support salmonids, so based on that criteria, the Warmwater IBI was selected instead of the Coolwater IBI for wadable stations (Lyons et al., 2001). Furthermore, the thermal preferences of the species captured reflect a warmwater system. Muskellunge were the only stenothermal primary coolwater fish species captured in the 2015 surveys. The remaining species captured include a number of secondary coolwater species that occur in both coolwater and warmwater streams, but they are classified as eurythermic meaning they have no thermal requirement or preference. If more primary coolwater or primary coldwater stenothermal species were present, the case could be made for using the Coolwater IBI to determine if the Nemadji River is a degraded coolwater system.

The wadable and non-wadable Lake Superior Warmwater IBI ratings also have scoring criteria calibrated for Lake Superior basin streams that have lower sucker, darter, and centrarchid panfish species richness relative to the other basins in the state (Lyons, 1992, Lyons et al., 2001). For each respective IBI rating system, the fish community receives a score from 0 to 100 points and the score is then assigned a corresponding qualitative rating from "Very Poor" to "Excellent". There is some variation between the two different IBI rating systems for the number of points required to receive the various qualitative ratings, but generally speaking, higher IBI scores receive better qualitative ratings.

Non-Wadable Stations
The IBI scores and ratings for the non-wadable stations are not complete because weight information was not collected for all of the fish captured. Personnel on the crew were unfamiliar with the non-wadable IBI procedures and mandatory requirement for weighing all fish to compute two of the metrics. Despite missing information for two of the metrics, using the scoring metrics with the available data, the sites that were assessed scored between 56.25 and 75 points and were rated from "Fair" to "Good". These scores and ratings should be considered minimum values; if weights had been collected, it's likely all of the sites would be rated "Good", with the possibility of some sites rating "Excellent".

Fish abundance based on the catches may seem low however there are a few factors that may have influenced our ability to capture fish. The first is turbid water conditions; at its best visibility was around 2 feet, so fish had to come up into the field to be visible for dippers to capture. Another factor was the depth of the bends and pools that were sampled, some bends and pools were estimated to be up to 15 feet deep based on readings from the fish finder on board one of the boats used. Capturing fish from these deeper areas of the stream channel with the mini-boom was difficult, if not impossible. Lastly was the efficiency of the mini-boom compared to the stream shocker. The stream shocker is a more efficient means of capturing fish because multiple anodes and dippers can be used with one electrofishing unit to cover a shallow, wadable stream channel compared to one electrofishing unit with one dipper trying to cover the immediate area along one bank of a large, non-wadable stream channel with variable water depths.

Two scoring metrics required weights and they focused on the weight per unit effort and percent insectivore weight. As mentioned above, no scores for these metrics can be computed without weights collected from all fish captured. Lengths were only taken on gamefish species, so it isn't possible to extrapolate approximate weights for non-gamefish species. Based on the information collected, it is doubtful that any station would have received 10 points for >25kg of fish biomass; some of the stations may have received 5 points for falling into the range of 10 to 25kg of fish biomass. All of the stations would have likely met the criteria of 11 to 60-percent of the fish biomass being classified insectivores and thus would have received 5 points for this metric; it's highly unlikely that any site would have exceeded 60-percent insectivore biomass to receive 10 points.

The second metric that was scored was the number of native species; all but one station received a score of 10 points. The only station that didn't score 10 points had 9 native species present, one short of the 10 or more native species present required to receive the full score of 10 points.

The third metric scored was the number of intolerant species present; Stations 3A and 6 received scores of 10 points, while the remaining stations only received 5 points. The lower score for the stations and low abundance of intolerant species may be somewhat misleading. Lake Superior basin streams lack many of the intolerant sucker and darter species found in other basins in the state; out of 25 species listed as intolerant in Appendix A.1 of Lyons, et al. 2001, only 6 have been documented in the Nemadji River watershed and 1 of them is a coldwater species that would not be expected to be present in the mainstem river.

The one noticeable difference between the stations receiving 10 points and those receiving 5 points was the capture of muskellunge, and in stations where muskellunge were captured, only a single individual was captured. The ability to catch muskellunge with the mini-boom relies on effectively stunning them so the dipper could capture them. In particular, adult muskellunge are able to feel the electrical field earlier than smaller fish due to their larger body size, so they are able to evade the mini-boom or are partially stunned, but still manage to swim away. During the electrofishing some larger fish splashed near the boat, but weren't readily identified, so muskellunge could have been present in the station, but not captured. Station 6 had also had spottail shiner present as a fourth intolerant species. Spottail shiners are considered a large river species rather than a riverine species and were likely migrants from the Superior Bay harbor area.

The fourth metric was the number of obligate riverine species present; three stations scored 10 points and the remaining two scored 5 points. Four or more riverine species were required to obtain a score of 10 points and the stations that received 10 points had the minimum number required, the stations that didn't receive 10 points had 2 or 3 riverine species present. As with the intolerant species, the low abundance of riverine species may be misleading because many of the darter, sucker, and minnow species commonly found in other Wisconsin drainages that fit the criteria of riverine species are not found in Lake Superior basin streams. Out of 90 species listed in Appendix A.1 of Lyons, et al. 2001, 37 are known to be present in the Nemadji River watershed and only 10 are considered riverine or large river species.

The fifth metric was the percentage of fish with deformities, erosions, lesions and/or tumors (DELT); no fish at any sites had exhibited deformities, open sores or other abnormalities. The percent of fish with signs or symptoms of DELT are often attributed to industrial or sewage discharge, however most point source pollution from industrial or municipal sources in the state of Wisconsin was eliminated or heavily treated since passage of the Clean Water Act in the 1970's. This metric was left in the scoring criteria as an extra sensitive measure to detect potential future discharge from point source polluters.

The percent obligate riverine species was the sixth metric; four of the five stations received 10 points and the remaining site, Station 3A, received 5 points. The percent riverine species in Station 3A was 29-percent, only 7-percentage points below the lower threshold of 36-percent to receive 10 points. Out of the 23 fish species captured in the surveys, only 6 were considered riverine species and the most prevalent riverine species were emerald shiner and silver redhorse. These species were present in the station and if a few more individuals were captured, this would have raised the percentage and score.

The percent simple lithophilic spawners was the last remaining metric that could be scored and four of five stations received 10 points, the remaining station received 5 points. Station 5 received 5 points, but was only 8-percentage points away from the lower threshold of 69% to receive 10 points. Capture of additional emerald or common shiners in this station would have improved the percentage and score for this metric.

Wadable Stations

The two wadable sites used were County Highway C and the 2011 survey at State Highway 35. The IBI score for County Highway C was 87 points and rated as "Excellent"; the IBI score for State Highway 35 was 70 points and was also rated as "Excellent". Out of the 10 metrics used for scoring the fish community, both IBI scores had 5 metrics that received the highest score of 10 points. Overall, the score reflects excellent water quality, but the metrics that didn't receive scores of 10 points may reflect some of the issues with habitat in both stations.

The first metric where both IBI scores missed points was the number of sunfish plus yellow perch. None of the wadable stream stations sampled between 2006 through 2011 (Table 3) have had more than 2 species in this metric and beyond rock bass, the only other species of sunfish captured in any of the four previous surveys was one bluegill. Downstream in the five non-wadable stations (Table 1), the only sunfish species found were rock bass and two black crappies. The moderate current and lack of deep pools in both wadable stations may be limiting preferred habitat for sunfish species other than rock bass. There was also a noticeable lack of aquatic vegetation in the both the County Highway C and State Highway 35 stations that would serve as suitable sunfish habitat.

The 2011 survey at State Highway 35 also missed points for number of intolerant species and the percent of top carnivore species. The capture of two additional intolerant fish species found in other segments of the Nemadji River would have raised the score up to 10 instead of 5. As mentioned in the discussion of the non-wadable scores and ratings, Lake Superior basin streams lack many of the intolerant sucker and darter species that are prevalent in the warmwater streams in other Wisconsin basins.

At the County Highway C station, 20-percent of the fish captured were considered tolerant of degraded habitat and were represented by creek chub and white sucker. While the station at County Highway C didn't receive a score of 10 points, the lower score isn't cause for alarm. The percentage tolerant species was 1-percentage point over the upper threshold of 19 to receive 10 points and three intolerant species were found in this survey.

In the 2011 survey at State Highway 35, tolerant species comprised 37-percent of the fish community and were represented mainly by creek chubs with white sucker and fathead minnows present. Five years prior to the 2011 survey, a survey of this station yielded only 13 percent of the fish community considered tolerant and 2 intolerant fish species were present. The variation in these scores may reflect migration because of the timing of the surveys; the 2011 survey took place in mid-September, while the 2006 survey was conducted in early July.

Smallmouth bass and muskellunge are two intolerant species that were present in other stations assessed on the Nemadji River, but not captured in this station. Low quality habitat may be the reason they were not present; notes from previous surveys indicate most of the stream channel was shallow, sandy, and generally lacking cover.

The absence of smallmouth bass and muskellunge also resulted in a low top carnivore percentage of only 5 percent and a score of 0 for the State Highway 35 station. In spite of the low percentage and score, this metric was only 2 percentage points away from a score of 2 and 3 percentage points away from the lower threshold for 5 points. If rock bass and smallmouth bass were present at the same level of abundance as the 2006 survey at State Highway 35, the percentage of top carnivore score could have been better. The lower percentage top carnivore may also reflect fish migration because of the mid-September timing of the 2011 survey.

The third metric that both IBI scores didn't receive 10 points for was the percent of simple lithophil spawners (species that lay their eggs on clean gravel or cobble substrate without building a nest or providing parental care). The fish community at both County Highway C and State Highway 35 were comprised of 49-percent simple lithophil spawners and received 5 points, but were only 2 percentage points below the lower threshold of 51-percent for receiving 10 points; 50-percent would have received a score of 7 points. The vast majority of the substrate in both stations was sand or clay and the lack of suitable rock or gravel in the station limits the amount of spawning habitat for simple lithophil species and, in some cases, preferred habitat for several simple lithophil species like suckers, darters and certain minnow species. Previous surveys at other locations have typically received 5 points with the percent simple lithophil spawners ranging from 37 to 49-percent; however the station at County Highway W is an exception. This area of the Nemadji River is higher gradient and has rock and gravel riffle habitat and those features are reflected by the percent of simple lithophil species present as well as presence of species like longnose dace, hornyhead chub, stonecat and log perch that tend to live in areas with gravel and cobble habitats.

IBI Rating Summary

Despite relatively poor instream and riparian habitat in the Lower Nemadji River and some difficulty sampling fish, the fish communities documented reflect good water quality. In some instances, the lower scores for the IBI metrics reflect lower fish diversity in the Lake Superior basin rather than environmental degradation. Intolerant fish species were found in all of the stations and there was little change in species composition between the stations surveyed. Based on the information collected, the wadable stations were all scored as "Excellent". The scores for the non-wadable stations assessed this year can only be considered minimum estimates due to missing weight information for two of the metrics, however available information for each station gives ratings between "Good" and "Fair". If weight information was collected, it's likely that the non-wadable stations would have rate between "Good" and "Excellent".

5. Gamefish Resource Management Considerations

The survey work in the Lower Nemadji River watershed revealed this segment of the river supports several warmwater and coolwater gamefish species, but may be an overlooked fishery because access to the river is limited to carry-in or road-side access for anglers fishing from a canoe or similar watercraft. The Nemadji River does receive some angling pressure in the upper reaches based on observations of lures and fishing line snagged in over-hanging trees and electrical cables at bridge crossings, but most of the recreational fishing effort probably occurs within the last two to three miles; during survey work our crew encountered a pair of anglers fishing from shore at the Grand Avenue launch and two boats with fishermen trolling for walleyes and muskellunge. Future survey work could be considered to better define the gamefish resource present in the Nemadji River and what functions it might serve within the Duluth/Superior Harbor and Lake Superior.

Northern Pike and Muskellunge

Northern pike or muskellunge were found at the wadable station and 4 of 5 non-wadable stations this year as well as previous wadable stream survey work upstream from County Highway C which suggests both species are relatively common in the Nemadji River.

There are some discrepancies with the muskellunge water classification for the Nemadji River. The current version of DNR Wisconsin Muskellunge Waters lists the Nemadji River downstream from CTH C as road only access, Class A1 (lower abundance, higher trophy potential) and Category 2 (combination of natural reproduction and stocking) muskellunge water. The Surface Water Data Viewer Muskellunge Waters layer shows the Nemadji River from the WI-MN border downstream to Lake Superior is Category 0 muskellunge water (unknown reproductive status, stocking occurs). These discrepancies should be clarified to represent the muskellunge fishery present; a Class A1 designation is appropriate and Category 2 would be appropriate based on the current known reproductive status of the musky population. Future survey work could be considered to better document the muskellunge fishery present and extent of natural reproduction in the lower Nemadji River. One young-of-year muskellunge was captured in Station 6, which could indicate adult muskellunge use the floodplain marshes near the mouth of the river for spawning.

There are no state classifications or designations for northern pike waters, but the Nemadji River has the potential to produce quality size (21"+) fish and the population appears to be sustained by natural reproduction.

Muskellunge angling regulations for the Nemadji River are now consistent with the St. Louis River regulation of an open season from the Saturday nearest Memorial Day through November 30th, with a 1 fish daily bag limit and a 50-inch minimum. The current angling regulation for northern pike in the Nemadji River is an open season from the Saturday 2 weeks prior to the Saturday nearest Memorial Day through March 1st the following year, with a 26-inch minimum and 2 fish daily bag limit. These regulations are appropriate as they maintain consistency with the same opportunities for harvest that are available in the adjoining waters of the St. Louis Estuary and Lake Superior.

Walleye

Walleye were found at the wadable station and 4 out of the 5 non-wadable stations this year, as well as previous wadable stream survey work upstream from County Highway C which suggests they are also relatively common in the Nemadji River. There were multiple year classes of walleyes present in the 2015 sampling, but it is unknown if there is natural reproduction occurring in the Nemadji River or if these fish are migrants from the St. Louis River; two tagged walleyes from the spring 2015 survey work on the St. Louis River were captured in the lower Nemadji River and reported by anglers. Additional survey work could be undertaken to determine the status of the walleye fishery in the Nemadji River.

The current set of regulations for walleye, sauger, and their hybrids is an open season from the Saturday 2 weeks prior to the Saturday nearest Memorial Day to March 1st with a 15-inch minimum and a daily bag limit of 2 fish. This regulation maintains consistency with the regulations for the St. Louis River and Superior Bay as well as the same length limit for Lake Superior and Lake Superior tributaries and sloughs; Lake Superior and the tributary streams and sloughs have different season structure and a daily bag limit of 5 walleyes, but only 1 fish over 20-inches is allowed.

Smallmouth and Largemouth Bass

Smallmouth bass are also very prevalent in the Lower Nemadji River, every site sampled this year had smallmouth bass present, however most individuals captured were young-of-year and juvenile fish less than 12-inches. The Lower Nemadji River could be added to the current state list of smallmouth bass waters as a non-wadable fine substrate smallmouth bass stream. This designation does not afford any additional environmental protection to the river, but serves to confirm the presence of smallmouth bass in the river and this segment of the river would appear in Smallmouth Bass Stream layer in the Surface Water Data Viewer that is accessible to department staff and the public.

Largemouth bass abundance in the Nemadji River appears to be very low; only one largemouth bass was captured in Station 6, near the confluence with Superior Bay.

There is no catch are release season for bass applied to the Nemadji River, the current set of regulations for smallmouth and largemouth bass is an open (harvest) season from the last Saturday in May through March 1st the following year, with a five fish daily bag limit and a minimum length limit of 12-inches. The length limit on bass could be increased to 14-inches for the sake of consistency with the length limit on the St. Louis River and Superior Bay.

Other notable species

Based on the electrofishing catch, panfish species occurred in relatively low abundance at all of the stations sampled this year. Rock bass and yellow perch were the most prevalent of the panfish species documented, but few of the individuals captured were large enough to be of interest to anglers.

One channel catfish was captured, no other catfish were observed or collected, but electrofishing with the mini-boom shocker is not the most efficient means of capturing catfish or other benthic species. If there is management interest in channel catfish in the St. Louis River estuary, a survey including the lower Nemadji River could be considered and hoop or trap nets or hook-and-line gear like a trot line or set line could be a more efficient means of capturing catfish.

Lake sturgeon are present in the St. Louis River and estuary, but sturgeon were not observed or collected during this survey work, so there remains no information to suggest sturgeon use any portion of the Nemadji River.

6. Literature and Data Cited

John Lyons, Randal R. Piette & Kent W. Niermeyer (2001) Development,
Validation, and Application of a Fish-Based Index of Biotic Integrity for Wisconsin's Large Warmwater Rivers, Transactions of the American Fisheries Society, 130:6, 1077-1094

Lyons, John 1992. Using the index of biotic integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. General Technical Report NC-149. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station

Wisconsin Department of Natural Resources. 2015. Wisconsin Muskellunge Waters. PUB-FH-515(2015).

NON-WADABLE RIVER FISH COMMUNITY SUMMARY

		STATION:	DISTANCE SHOCKED (miles):	RIVER MILE AT STATION START:
STREAM:	Nemadji River			
WBIC:	2835300	3	1.08	14
COUNTY:	Douglas	3A	1.30	12
GEAR:	240V 3000W DCP Mini-Boom	4	1.10	10
	16 Droppers, 1 Dipper	5	1.22	3
		6	1.44	1

TAXONOMIC FAMILY / FISH SPECIES	Origin / Thermal Guild	Tolerance	Feeding	Habitat	Spawning Type	STATION NUMBERS 3	3A	4	5	6	Total Captured
Esocidae											8
MUSKELLUNGE	NCL	I	TC	O	O		1			1	2
NORTHERN PIKE	NEU	M	TC	O	O	1	1		4		6
Percidae											39
WALLEYE	NEU	M	TC	O	SL	1		2	1	6	10
YELLOW PERCH	NEU	M	IN	O	O	1	4	1	5	6	17
JOHNNY DARTER	NEU	M	IN	O	O		2				2
LOG PERCH	NEU	M	IN	O	SL	6	4				10
Centrarchidae											35
SM BASS	NEU	I	TC	O	O	3	9	1	1	3	17
LM BASS	NEU	M	TC	O	O					1	1
BLACK CRAPPIE	NEU	M	TC	O	O					2	2
ROCK BASS	NEU	I	TC	O	O	1	7	2	4	2	16
Cyprinidae											225
EMERALD SHINER	NEU	M	IN	L	SL	51	12	12	1	32	108
COMMON SHINER	NEU	M	IN	O	SL	15	30	8	5	1	59
SAND SHINER	NEU	M	IN	R	O	3	8		10	29	50
SPOTTAIL SHINER	NEU	I	IN	L	O					6	6
BLUNTNOSE MINNOW	NEU	T	OM	O	O				1		1
HORNYHEAD CHUB	NEU	M	IN	R	O		1				1
Ictaluridae											1
CHANNEL CATFISH	NEU	M	TC	O	O			1			1
Catostomidae											45
WHITE SUCKER	NEU	T	OM	O	SL	6					6
SILVER REDHORSE	NEU	M	IN	R	SL	5	3	4	7	6	25
SHORTHEAD REDHORSE	NEU	M	IN	O	SL	7	1	1	1	4	14
Moronidae											6
WHITE PERCH	EEU	M	TC	O	O				2	4	6
Percopsidae											1
TROUT-PERCH	NEU	M	IN	O	O	1					1
Sciaenidae											1
FRESHWATER DRUM*	EEU	M	IN	L	O	1					1
*Native to WI, but not Lake Superior Basin											
Station Total						102	83	32	42	103	

COMMENTS:

Origin / Thermal Guild - N - Native, E - Exotic / EU - Eurythermic, CL - Stenothermal Coolwater, CD - Stenothermal Coldwater

Tolerance - I-Intolerant, M-Moderately Intolerant, T-Tolerant

Feeding - Fi-Filter Feeder, Ge-Genral Feeder, He-Herbivore, Pa-Parasitic, O-Omnivore, I-Insectivore, TC-Top Carnivore,

Habitat - L-Large River, R-Riverine, O-Other, Spawning Habitat - SL-Simple Lithophilous, O-Other

Table 1. Catch-per-effort summary and species characteristics for all non-wadable stations surveyed on Nemadji River in 2015.

NON-WADABLE RIVER FISH COMMUNITY SUMMARY

	STATION:	DISTANCE SHOCKED (miles):	RIVER MILE AT STATION START:
STREAM: **Nemadji River**	3	1.08	14
WBIC: **2835300**	3A	1.30	12
COUNTY: **Douglas**	4	1.10	10
GEAR: **240V 3500W DCP Mini-Boom**	5	1.22	3
16 Droppers, 1 Dipper	6	1.44	1

Station Name	3	3A	4	5	6
Survey Year	2015	2015	2015	2015	2015
Survey Date	8/3/15	8/4/15	8/3/15	8/5/15	8/5/15
Primary Survey Purpose	Fish Community Survey	Fish Community Survey	Fish Community Survey	Fish Community Survey	Fish Community Survey
Total Fish Collected:	102	83	32	40	98
WPUE (kg):	Minnows, suckers, and darters were counted but not weighed				
WPUE (kg) Score:	**Unable to compute scores without aggregate weights**				
Number Native Species:	14	13	9	11	13
Number Native Species Score:	**10**	**10**	**5**	**10**	**10**
Number Intolerant Species:	2	3	2	2	4
Number Intolerant Species Score:	**5**	**10**	**5**	**5**	**10**
Riverine Species:	4	4	2	3	4
Riverine Species Score:	**10**	**10**	**5**	**5**	**10**
% DELT (Deformity, Erosion, Lesion, Tumor):	0	0	0	0	0
% DELT (Deformity, Erosion, Lesion, Tumor) Score:	**10**	**10**	**10**	**10**	**10**
% Riverine Species (n):	59%	29%	50%	42%	74%
% Riverine Species Score	**10**	**5**	**10**	**10**	**10**
% Lithophils (n):	92%	70%	84%	61%	79%
% Lithophils (n) Score:	**10**	**10**	**10**	**5**	**10**
%Insectivore (wt):	Minnows, suckers, and darters were counted but not weighed				
%Insectivore (wt) Score:	**Unable to compute scores without aggregate weights**				
Score Subtotal	**55**	**55**	**45**	**45**	**60**
Correction Factor For Lower Sucker Richness in Lake Superior Basin Streams (Subtotal X 1.25)	1.25	1.25	1.25	1.25	1.25
Non-Wadable River Warmwater IBI Score	**≥68.75**	**≥68.75**	**≥56.25**	**≥56.25**	**≥75**
Non-Wadable River Warmwater IBI Integrity Rating	**Good**	**Good**	**Fair**	**Fair**	**Good**

Table 2. IBI scores and ratings for all non-wadable stations surveyed on Nemadji River in 2015. Ratings and scores for all of the stations are not complete due to missing weight information and should be considered minimum estimates.

WADABLE RIVER FISH COMMUNITY SUMMARY

STREAM: Nemadji River	YEAR:	STATION:	DISTANCE SHOCKED (meters):	RIVER MILE AT STATION START:
WBIC: 2835300	2006	STH 35	645	18.4
COUNTY: Douglas	2008	Finn Rd	425	20
GEAR: 240V Tow Barge	2009	CTH W	440	31.2
	2011	STH 35	855	18.4
	2015	CTH C	400	11.75

TAXONOMIC FAMILY / FISH SPECIES	Origin / Thermal Guild	Tolerance	Feeding	Spawning Type	STATION NUMBERS / SURVEY YEAR STH 35 2006	Finn Rd 2008	CTH W 2009	STH 35 2011	CTH C 2015
Esocidae									
MUSKELLUNGE	NCL	I	TC	O			1		1
NORTHERN PIKE	NEU	M	TC	O				2	
Percidae									
WALLEYE	NEU	M	TC	SL	1	1	3	1	1
YELLOW PERCH	NEU	M	IN	O					2
JOHNNY DARTER	NEU	M	IN	O	2	1	11	3	6
LOG PERCH	NEU	M	IN	SL	3	1	70	8	1
Centrarchidae									
SM BASS	NEU	I	TC	O	4	2	3		6
ROCK BASS	NEU	I	TC	O	39	29	25	16	12
BLUEGILL	NEU	M	IN	O				1	
Cyprinidae									
EMERALD SHINER	NEU	M	IN	SL					4
COMMON SHINER	NEU	M	IN	SL	53	29	54	150	36
SAND SHINER	NEU	M	IN	O		11	1	4	1
HORNYHEAD CHUB	NEU	M	IN	O	27	22	78	8	7
LONGNOSE DACE	NEU	M	IN	SL			38		
CREEK CHUB	NEU	T	GE	O	23	4	3	78	21
FATHEAD MINNOW	NEU	T	O	O				14	
BRASSY MINNOW	NCL	M	HE	O	3				
Ictaluridae									
STONECAT	NEU	M	IN	O	5	2	7	2	
Catostomidae									
WHITE SUCKER	NEU	T	O	SL		2	18	8	1
SILVER REDHORSE	NEU	M	IN	SL	2	6	38	2	
SHORTHEAD REDHORSE	NEU	M	IN	SL	22	7		5	13
Percopsidae									
TROUT-PERCH	NEU	M	IN	O		7	4	22	1
Umbridae									
CENTRAL MUDMINNOW	NEU	M	IN	O				12	1
Petromyzonidae									
LAMPREYS No indication of life stage or species - can't assign origin, thermal guild or feeding	UNKNOWN	I	FI / PA	O		1			
Station Total					184	125	354	336	114

COMMENTS:

Origin / Thermal Guild - N - Native, E - Exotic / EU - Eurythermic, CL - Stenothermal Coolwater, CD - Stenothermal Coldwater

Tolerance - I-Intolerant, M-Moderately Intolerant, T-Tolerant

Feeding - Fi-Filter Feeder, Ge-Genral Feeder, He-Herbivore, Pa-Parasitic, O-Omnivore, I-Insectivore, TC-Top Carnivore,

Spawning Habitat - SL-Simple Lithophilous, O-Other

Table 3. Catch-per-effort summary and species characteristics for all wadable stations surveyed on Nemadji River.

WADABLE RIVER FISH COMMUNITY SUMMARY

STREAM: **Nemadji River**
WBIC: **2835300**
COUNTY: **Douglas**
GEAR: **240V Tow Barge**

YEAR:	STATION:	DISTANCE SHOCKED (meters):	RIVER MILE AT STATION START:
2006	STH 35	645	18.4
2008	Finn Rd	425	20
2009	CTH W	440	31.2
2011	STH 35	855	18.4
2015	CTH C	400	11.75

Station Name	STH 35	Finn Rd	CTH W	STH 35	CTH C
Survey Year	2006	2008	2009	2011	2015
Survey Begin Date	7/7/06	7/29/08	8/19/09	9/15/11	8/4/15
Survey End Date	7/7/06	7/31/08	9/11/09	9/15/11	8/4/15
Primary Survey Purpose	WATERSHED CLEAN WATER ACT	NATURAL COMMUNITY REFERENCE	SPECIAL STUDY	NATURAL COMMUNITY REFERENCE	FISH COMMUNITY SURVEY
Mean Stream Width (meters)	18.4	13.8	17.5	24.4	19
Total Fish Count Sum	184	124	354	355	114
Number Native Species	12	14	15	18	16
Number of Native Species Score Lake Superior	5	5	10	10	10
Number Darter Madtom Sculpin Species	2	2	2	2	2
umber Darter Madtom Sculpin Species Lake Superior Score	10	10	10	10	10
Number Sucker Species	2	3	2	3	2
Number Sucker Species Score Lake Superior	10	10	10	10	10
Number Sunfish Yellow Perch Species	1	1	1	2	2
Number Sunfish Yellow Perch Species Score Lake Superior	5	5	5	5	5
Number Intolerant Species	2	2	3	1	3
Number Intolerant Species Score Lake Superior	5	5	10	5	10
Percent Tolerant	13	5	6	37	20
Percent Tolerant Score	10	10	10	5	7
Percent Omnivore	0	2	5	6	1
Percent Omnivore Score	10	10	10	10	10
Percent Insectivores	62	69	85	66	63
Percent Insectivore Score	10	10	10	10	10
Percent Top Carnivore	24	26	9	5	18
Percent Top Carnivore Score	10	10	5	0	10
Percent Simple Lithophile	44	37	62	49	49
Percent Simple Lithophile Score	5	5	10	5	5
Abundance Correction Factor	75	83	227	79	68
Percent DELT	-	-	-	-	-
Warmwater IBI Score Lake Superior	80	80	90	70	87
Warmwater IBI Score Lake Superior Corrected	80	80	90	70	87
Warmwater IBI Integrity Rating Lake Superior	Excellent	Excellent	Excellent	Excellent	Excellent

Table 4. IBI scores and ratings for all wadable stations surveyed on Nemadji River.

Appendix I.
Electrofishing Station Maps

Appendix 8

Nemadji River and Tributaries Water Quality Assessment
(Pertains to management action 6.05)

Nemadji River and Tributaries
Water Quality Assessment

Craig Roesler – DNR, Spooner (3/24/14)

Introduction

Monitoring of the Nemadji River and several of its tributaries was conducted during 2008 to 2010 by Superior office staff to assess water quality conditions, and to help determine if these streams should be placed on Wisconsin's 303d list of impaired waters. Sites monitored are shown in figures 1 and 2. Streams monitored were the Nemadji River, Crawford Creek, Black River, Balsam Creek, Clear Creek, and Mud Creek.

The Wisconsin portion of the Nemadji River watershed is located in Douglas County in the northwest corner of the state. The upstream half of the watershed is located in Minnesota. The Nemadji River flows into Superior Bay on the south side of the City of Superior.

Crawford Creek was previously placed on the 303d list in 1998. The impairment identified is chronic aquatic toxicity. Pollutants identified at that time were creosote and PAH's. Dioxins are also present. Koppers Industries operated a wood treatment facility that discharged to the creek and contaminated sediments in the creek and its floodplain. The Department is working with the responsible party to better define the degree and extent of sediment contamination and to work toward the clean-up of the creek and flood plain soils.

Erodible clay soils interspersed with sands and silts are present in the Crawford Creek watershed. Flows are "flashy" with high peak flows during runoff events, and low base flows between runoff events. Eroding stream banks, high turbidity, high suspended solids concentrations, and fine sediment bed load are other concerns for this stream.

Much of the Nemadji River watershed also has erodible clay soils interspersed with sands and silts. Erosion of stream banks and drainageways to streams provides most of the sediment load to the Nemadji River. The river carries a large load of both suspended sediment and bed load sediment. The Nemadji River is estimated to deliver 127,000 tons of sediment per year to Superior Bay and Lake Superior. The Army Corps of Engineers removes about 33,000 tons of sediment (mostly sand) per year near the mouth of the river to maintain the navigation channel. The river has high turbidity and high suspended solids concentrations.

The Nemadji River was added to the 303d list in 2010. The high sediment load was judged to exceed the narrative water quality standard found in NR102.04 (a) of the Wisconsin Administrative Code, which states "Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state." Minnesota placed the Nemadji River on its 303d list in 2004 due to exceedences of their turbidity standard (25 ntu), and began developing a TMDL in 2008. Wisconsin's listing in 2010 was based in large part on Minnesota's listing since conditions in the Minnesota and Wisconsin reaches are similar, although Wisconsin does not have a standard for turbidity or total suspended solids. The median turbidity measured in the Nemadji River at CTH C (Wisconsin) is 27.5 ntu (2006-2012), which exceeds Minnesota's turbidity standard. Including the Nemadji River on Wisconsin's 303d list would allow the two states to work together to develop a comprehensive TMDL that would benefit the entire watershed.

The other consideration that contributed to the listing decision was that creosote and PAH's from Crawford Creek are a continuing source of pollutants to the Nemadji River.

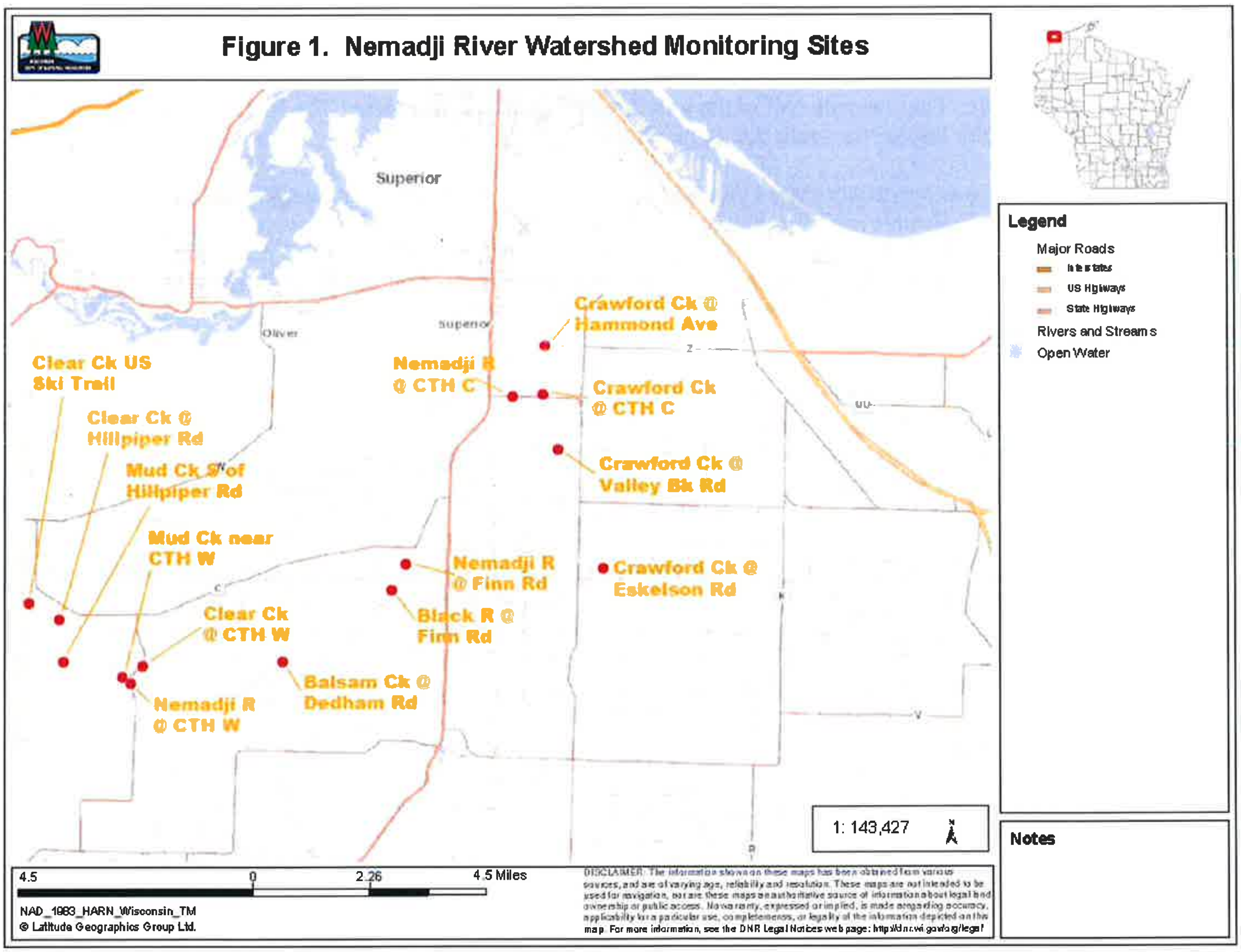
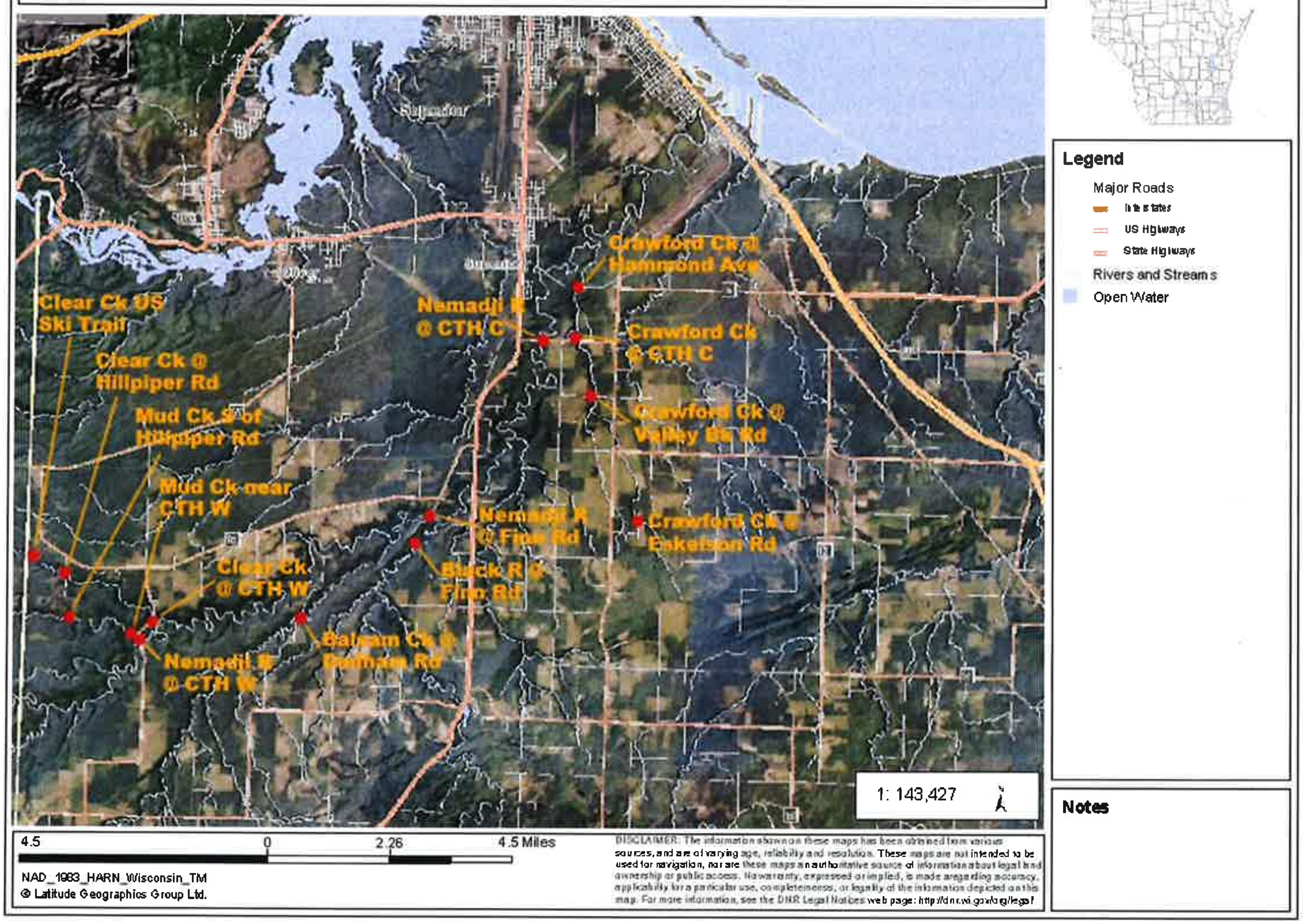


Figure 1. Nemadji River Watershed Monitoring Sites

Figure 2. Nemadji River Watershed Monitoring Sites with 2008 Airphoto Background



There are four point source discharges going directly or indirectly to the Nemadji River:

- Burlington Northern R.R. Co.; a taconite loading and storage facility (direct)
- Lakehead Pipeline Co.; oil storage tanks (direct)
- Superior Sewage Disposal System; municipal wastewater (direct)
- Four Corners School; school wastewater (indirect via unnamed tributary and Copper Creek to the Nemadji River)

The three direct discharges all enter the Nemadji River downstream of the Nemadji River monitoring site at CTH C. Monitoring the Nemadji River downstream of CTH C is difficult due to lack of access points and periodic backflows caused by Lake Superior seiches. The Four Corners School discharge is very small and located far upstream.

The data collected from this monitoring project does not support 303d listing of any of the other streams monitored (see discussion on p. 18).

Methods

One or more sites were monitored on each of the six streams:

- Nemadji River – 3 sites
- Crawford Creek – 3 sites
- Black River – 1 site
- Balsam Creek – 1 site
- Clear Creek – 3 sites
- Mud Creek – 2 sites

Monitoring was done for fish and macroinvertebrate communities, water chemistry, and stream habitat. The range of monitoring at each site varied (table 1).

Fish communities were assessed by electrofishing with a single anode backpack shocker on small stream sites, and a double anode tow barge stream shocker on larger stream sites. As many fish as possible were captured with a single upstream pass. Station lengths were 35 times the mean stream width, with a minimum length of 100 meters. Fish captured were counted and identified to species. Fish community data was used to determine the natural community of the stream, and to calculate potentially appropriate biotic indices.

Macroinvertebrate communities were assessed by collecting kick samples from riffles, using a 500 um mesh D-frame net. Samples were preserved in 85% ethanol and were processed by UW – Stevens Point's Aquatic Biomonitoring Lab. Macroinvertebrates were counted and identified to the lowest possible taxa. Biotic indices and other statistics were generated.

Water samples were collected and field parameters were measured following standard DNR protocols. Water samples were preserved, as needed, and shipped on ice to the Wisconsin State Lab of Hygiene for analysis. Field parameters measured were:

- Temperature
- pH
- Dissolved Oxygen
- Conductivity
- Transparency (using a transparency tube)

Table 1. Nemadji River Watershed Monitoring Site Information

Site					Types of Monitoring Done			
Nemadji River	Swims ID	WBIC	Latitude	Longitude	Water	Macroinvertebrates	Fish	Habitat
Nemadji R @ CTH C	163003	2835300	46.63327	-92.09419	x			
Nemadji R @ Finn Rd	163233	2835300	46.58611	-92.13708	x		x	x
Nemadji R @ CTH W	163047	2835300	46.55017	-92.24740	x	x	x	x
Crawford Creek								
Crawford Ck @ Hammond Ave	10015464	2835500	46.64780	-92.08208	x		x	x
Crawford Ck @ CTH C	10031796	2835500	46.63416	-92.08542		x		
Crawford Ck @ Vally Brook Rd	10032010	2835500	46.61938	-92.07584		x		
Crawford Ck @ Eskelson Rd	10031826	2835800	46.58692	-92.05675		x	x	x
Black River								
Black R @ Finn Rd	10030272	2836900	46.57887	-92.14029		x	x	x
Balsam Creek								
Balsam Ck @ Dedham Rd	10007599	2841400	46.55773	-92.18507	x	x	x	x
Clear Creek								
Clear Ck @ CTH W	10030271	2842800	46.55563	92.24165	x	x	x	x
Clear Ck @ Hillpiper Rd	10031879	2842800	46.56770	-92.27605		x		x
Clear Ck US Ski Trail	10031940	2842800	46.57161	-92.28800	x	x	x	x
Mud Creek								
Mud Ck near CTH W	10030270	2843000	46.55028	-92.24752	x	x	x	x
Mud Ck South of Hillpiper Rd	10031880	2843000	46.55594	-92.27283		x		

Lab parameters were:

- Total Phosphorus
- Ammonia – N
- Total Kjeldahl N
- Nitrate plus Nitrite – N
- Total Suspended Solids
- Turbidity
- Chlorophyll a
- Dissolved phosphorus

Findings and Discussion

Fish Communities

Complete fish survey results are contained in appendix A. Fish survey IBI's (index of biotic integrity) are summarized in table 2.

Fish community indices of biotic integrity (IBI) ranged from excellent to fair. Sites on the Nemadji River, Black River, Balsam Creek, and Mud Creek had IBI ratings of excellent. Clear Creek had IBI ratings of good.

The Crawford Creek sites had the lowest IBI ratings of fair. The percent of fish that are tolerant of environmental disturbances exceeded 75% at these sites (92-100%; table 2). Seventy-five percent tolerant fish is the maximum typically expected in a Cool-Cold Headwater stream. The high percentages of intolerant fish at the Crawford Creek sites probably reflects the influence of erodible clay soils in a small watershed with moderate development, limited fish habitat, and very low base flows.

The stream sites varied in size and natural stream community types (table 2-2), from Cool-Cold Headwaters to Warm Mainstems. Clear Creek upstream of the ski trail was the only site where a coldwater species was found (mottled sculpin; appendix A).

Macroinvertebrate Communities

Macroinvertebrate IBI (MIBI) ratings were excellent or good at all but one site (table 3). The MIBI for Crawford Creek at CTH C was rated as fair. MIBI ratings were generally similar to the IBI's for the fish communities. One exception was the Crawford Creek site at Eskelson Road, where the MIBI was excellent, while the fish IBI was only fair.

Hilsenhoff biotic index (HBI) ratings ranged from good to excellent. HBI's are mostly influenced by organic matter loading and the resultant dissolved oxygen concentrations. The HBI's suggest dissolved oxygen stress to macroinvertebrates is minimal.

Table 2. Nemadji River and Tributaries Fish IBI Summary

Stream Site	Date	Small Stream IBI	Small Stream IBI Rating	Cool - Warm IBI	Cool - Warm IBI Rating	Warmwater L. Superior IBI	Warmwater L. Superior IBI Rating	% Tolerant	> 25 Fish?
Nemadji R @ Finn Rd	06/31/2008					80	excellent	30	yes
Nemadji R @ CTH W	09/11/2009					90	excellent	21	yes
Crawford Ck @ Hammond Ave	07/07/2006	40	fair					92	no, 23
Crawford Ck @ Eskelson Rd	08/23/2010	40	fair					100	yes
Black R @ Finn Rd	09/11/2009			80	excellent			30	yes
Balsam Ck @ Dedham Rd	09/21/2010			90	excellent			38	yes
Clear Ck @ CTH W	08/05/2009	60	fair	60	good			59	yes
Clear Ck US Ski Trail	08/24/2010	90	good					77	yes
Mud Ck near CTH W	09/01/2009	90	good	100	excellent			35	yes

TABLE 2-2. NEMADJI RIVER AND TRIBUTARIES NATURAL STREAM COMMUNITIES

Stream Site	Natural Stream Community*
Nemadji R @ Finn Rd	Warm Mainstem
Nemadji R @ CTH W	Warm Mainstem
Crawford Ck @ Hammond Ave	Cool-Cold or Cool-Warm Headwater
Crawford Ck @ Eskelson Rd	Cool-Cold or Cool-Warm Headwater
Black R @ Finn Rd	Cool-Warm Mainstem
Balsam Ck @ Dedham Rd	Cool-Warm Mainstem
Clear Ck @ CTH W	Cool-Warm Mainstem
Clear Ck US Ski Trail	Cool-Cold or Cool Warm Headwater
Mud Ck near CTH W	Cool-Warm Mainstem

*as indicated by sampled fish populations

Table 3. Nemadji River Watershed Macroinvertebrate Sample Summary*

Site	Station No.	Date	MIBI	MIBI Rating	HBI	HBI Rating	Species Richness (No. species)	% EPT (genera/individuals)
Nemadji R @ CTH W	163047	11/05/2009	8.64	excellent	3.83	very good	47	43/63
Crawford Ck @ CTH C	10031796	10/19/2010	3.84	fair	4.12	very good	20	30/55
Crawford Ck @ Valley Brook Rd	10032010	11/04/2010	6.03	good	5.36	good	28	18/33
Crawford Ck @ Eskelson Rd	10031826	10/19/2010	9.03	excellent	4.48	very good	25	40/73
Black R @ Finn Rd	10030272	11/12/2009	9.55	excellent	4.39	very good	46	41/65
Balsam Ck @ Dedham Rd	10007599	11/12/2009	8.27	excellent	3.23	excellent	40	49/79
Clear Ck @ CTH W	10030271	11/05/2009	5.88	good	3.27	excellent	27	44/62
Clear Ck @ Hillpiper Rd	10031879	10/07/2010	9.27	excellent	3.62	very good	44	39/70
Clear Ck US Ski Trail	10031940	10/25/2010	8.58	excellent	3.31	excellent	25	58/72
Mud Ck near CTH W	10030270	11/12/2009	5.13	good	2.28	excellent	28	46/84
		10/25/2010	5.25	good	2.66	excellent	23	57/89
Mud Ck South of Hillpiper Rd	10031880	10/07/2010	6.61	good	3.69	very good	37	40/60

*MIBI = macroinvertebrate index of biotic integrity
HBI = Hilsenhoff biotic index
% EPT = percent Ephemeroptera, Plecoptera, Trichoptera
US = upstream

Water Chemistry

Water chemistry data for the Nemadji River and sampled tributaries is shown in table 4. Sampling frequency and duration varied by site making comparisons between sites tentative. No water samples were collected from the Black River.

Only the two Nemadji River sites had more than one sample collected for nutrients. Median concentrations of total phosphorus (TP) and total nitrogen (TN)(total Kjeldahl nitrogen plus nitrate and nitrite nitrogen) were low to moderate at these sites (table 4-2). TP concentration medians ranged from 30 – 46 ug/l. The percent of total phosphorus present in the dissolved form was low, with a median concentration of 3 ug/l. TN concentration medians ranged from 0.59 – 0.63 mg/l. More than 92% of the total nitrogen was present in an organic form.

The Nemadji River sites had low concentrations of ammonia and nitrate plus nitrite. Ammonia concentration medians were less than 0.015 mg/l. Nitrate plus nitrite concentration medians ranged from 0.029 – 0.038 mg/l.

All sites had fairly high total suspended solids (TSS) concentrations, fairly high turbidity, and fairly low transparency. The three Nemadji River sites and the Clear Creek site had the lowest turbidity medians (19-35 ntu), and the highest transparency medians (25-42 cm). The Mud Creek site had the highest turbidity median (57 ntu), and the lowest transparency median (17 cm).

Daytime dissolved oxygen (D.O.) concentrations were generally good. Only two concentrations were less than 5 mg/l. The Nemadji River at CTH C had a D.O. concentration of 4.5 mg/l on one date. Crawford Creek at Hammond Avenue had a D.O. concentration of 2.4 mg/l on one date.

Median conductivities ranged from 195 – 520 umhos/cm. Conductivity was highest in Clear Creek (median 520 umhos/cm), probably as a result of more groundwater discharge to this stream. pH median values ranged from 7.5 to 8.0

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA

Nemadji R. @ CTH C Station 163004

	Lab parameters								Field parameters					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Chl. A	DP	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(ug/l)	(ug/l)	(C)	(mg/l)	(%)	(SU)	umhos/cm	(cm)
10/03/2006		ND		20	4	8.2	0.62	ND	12.2	8.5		7.8		
03/27/2007	0.09	0.172	1.13	234	162				0.1	4.5			83	7
04/25/2007	0.026	0.207	0.97	132	129				8	11.4			128	9
05/10/2007		0.031		47	17	27.5	2.54	6						
05/29/2007	ND	0.02	0.8	46	16				15.3	8.8		7.2		36.6
06/13/2007		ND	0.91	49	11		1.61	8						
06/27/2007	ND	0.036	0.624	38	17				23	9.8		7.9	255	30
07/16/2007		ND	0.51	22	8		1.81	ND						
07/24/2007	ND	0.031	0.41	40	18				24.3	7.6		7.8	292	23
08/30/2007	ND	ND	0.35	22	7			4	20.1	8.7		8		56
09/26/2007	ND	ND	0.61	54	31				14.1	10.3		7.9	237	21
09/18/2008		0.031	0.99	56	12		1.47	9						
05/20/2009		ND	0.81	47*	20		0.73	3						
06/23/2009	ND	ND	0.62	34*	16	17.2			18.7	8.7	93	7.8	227	38
06/30/2009		0.028	0.5	30	9		1.66	2						
07/29/2009					25	37.3			20.8	9.2	102.8	8.1	230	27
08/20/2009					548	1070			14.6	8.4	82.4	7.6	133	1.5
09/14/2009					10	15			21.7	8.4	95.4	8	274	64
09/29/2009					3	8.3			10.9	11	99.8	7.9	315	107
10/07/2009					46	45.3			8.6	13.2	112.7	7.6	200	20.5
10/30/2009					68	89.2			6.4	12.3	99.6	7.3	148	12
08/26/2010		0.055	1.42	79	51		1.19	10	17.9	7.9		7.7		20
07/18/2012		0.073	0.57	139*	15			17						
08/20/2012		0.029	0.4	36*	6			2						
09/18/2012		ND	0.22	30*	4			ND						
10/22/2012		0.035	ND	22*	4			ND	8.6	12.1	104	8.3	185	80
11/15/2012		0.097	0.26	19	5			3						

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Nemadji R. @ CTH C (cont.) Station 163004

	Lab parameters								Field parameters					
	NH3 (mg/l)	NO3+2 (mg/l)	TKN (mg/l)	TP (ug/l)	TSS (mg/l)	Turbidity (NTU)	Chl. A (ug/l)	DP (ug/l)	Temp (C)	D.O. (mg/l)	D.O.sat. (%)	pH (SU)	Cond. umhos/cm	Transp. (cm)
Range =	ND-.09	ND-.207	ND-1.42	19-234	3-548	8-1,070	0.6-2.5	ND-17		4.5-13.2		7.2-8.3	83-315	1.5-107
Median =	ND	0.029	0.62	46	16	27.5	1.54	3		8.8		7.8	227	25
May-Oct* TP range =				22-139										

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Nemadji R. @ Finn Rd. Station 163234

	Lab parameters						Field parameters					
Date	NH3 (mg/l)	NO3+2 (mg/l)	TKN (mg/l)	TP (ug/l)	TSS (mg/l)	Turbidity (NTU)	Temp (C)	D.O. (mg/l)	D.O.sat. (%)	pH (SU)	Cond. (umhos/cm)	Transp. (cm)
10/09/2007	0.029	0.06	2.24	292*	326		12.3	10.3		7.9	162	5
11/06/2007	ND	0.075	0.76	36	15		3.7	13.7		7.9	197	42
12/04/2007	0.049	0.182	0.55	33	8		0	15.8		7.8	271	53
01/03/2008	ND	0.206	0.45	30	6		0	15.1		7.7	251	60
02/06/2008	ND	0.272	0.15	25	7		0	15		7.6	304	47
03/05/2008	0.033	0.313	0.2	25	6		0.6	13.2		7.7	298	55
04/03/2008	0.081	0.281	0.64	90	28		0.6	15.2		7.8	181	20
05/07/2008	0.022	ND	0.85	93*	89		10.5	11.1		7.6	124	13
06/04/2008	0.017	ND	0.78	61*	12		11.8	10.3		7.8	197	30
07/09/2008	ND	ND	0.51	28*	9		25.6	7.8		7.9		50
08/11/2008	ND	ND	0.19	23*	4		21	8.7		8		66
09/10/2008	ND	ND	0.32	27*	6		15.4	10.2		8	274	55
06/23/2009	ND	ND	0.61	29	16	17	20.8	8.5	95.2	8	265	41
07/29/2009					21	34.6	20.6	9.6	106.5	8.1	238	29
08/20/2009					592	935	14.5	8.9	86.8	7.5	141	2.5
09/14/2009					7	11.4	21	8.7	99.8	7.9	232	65
09/29/2009					4	9.3	11.4	11.1	101.7	7.9	319	96
10/07/2009					48	54.8	8.4	13.7	116.9	7.7	227	18
10/30/2009					93	106	6.1	12.6	101.7	7.4	159	10
Range =	ND-.081	ND-.313	.15-2.24	23-292	4-592	9.3-935		7.8-15.8		7.4-8.1	124-319	2.5-66
Median =	ND	0.038	0.55	30	12	34.6		11.1		7.8	232	42
May-Oct*												
TP range =				23-292								

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Nemadji R. @ CTH W Station 163048

	Lab parameters						Field parameters					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(C)	(mg/l)	(%)	(SU)	(umhos/cm)	(cm)
06/23/2009	ND	0.02	0.73	25	7	11.2	23.4	9.8	114.7	8.4	231	60.5
07/29/2009					11	26.8	20.3	10.8	119.4	8.3	223	40
08/20/2009					454	505	14.6	9.1	90.2	7.7	165	3
09/14/2009					5	11.5	20.8	9.3	104	8	255	78
09/29/2009					3	8.8	11.4	11	101.7	7.9	292	95
10/07/2009					28	46.2	8.3	12.9	110	7.5	210	22
10/30/2009							6.5	12.5	101.3	7.5	142	8
Range =					3-454	8.8-505		9.1-12.9		7.5-8.4	142-292	3-95
Median =					9	19.2		10.8		7.9	223	40

Crawford Ck. @ Hammond Ave Station 10015466

	Lab						Field					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(C)	(mg/l)	(%)	(SU)	(umhos/cm)	(cm)
06/23/2009	ND	ND	1.25	106	23	35.6	14.7	6.9	68.6	7.3	337	21
07/29/2009					7	12	16.1	8.4	86	7.7	367	76
08/20/2009					81	152	15	8.4	84.3	7.7	170	7
09/14/2009					14	12.5	17.6	6.1	64.1	7.7	296	40
10/07/2009					5	8.6	8.6	2.4	20.7		392	83
10/30/2009					37	155	7.1	11.2	92.7	7.1	164	8.5
08/09/2010					39	100	20.2	7.8	85.5	7.1		13
Range =					5-81	8.6-155		2.4-11.2		7.1-7.7	164-392	7-83
Median =					23	35.6		7.8		7.5	316.5	21

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Balsam Ck. @ Deadham Rd. Station 10007599

	Lab parameters						Field parameters					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(C)	(mg/l)	(%)	(SU)	(umhos/cm)	(cm)
06/23/2009	ND	ND	0.57	42	21	46	22.4	8.9	102.8	8.3	206	17
07/29/2009					22	53.4	19.5	10.2	111.3	8.3	195	19.5
08/20/2009					222	228	14.6	9.7	95.6	7.7	97	5
09/14/2009					14	39.7	19.6	8.9	97.6	7.9	253	30
10/30/2009					65	138	7.1	12.2	100.4	7.4	123	9.5
08/09/2010					16	38.8	23.2	8.1	91.5	8		24
10/23/2010					10	35.3	9.3	7.8	68.3	7.7		25
Range =					10-222	35.3-228		7.8-12.2		7.4-8.3	97-253	5-30
Median =					21	46		8.9		7.9	195	19.5

Clear Ck. @ CTH W Station 10030272

	Lab parameters						Field parameters					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(C)	(mg/l)	(%)	(SU)	(umhos/cm)	(cm)
06/23/2009	ND	ND	0.45	35	20	21.6	21	9.4	106	8.3	523	38
07/29/2009					23	30.7	18.1	11.3	119.7	8.2	517	35
08/20/2009					364	303	14.4	9.7	95	7.6	250	4
09/14/2009					9	16.2	18.2	10.2	107.1	7.7	566	55
09/29/2009					6	14.3	10.8	10.2	100.9	7.6	614	65
10/07/2009					30	41.4	8.3	13.4	114.4	7.8	530	25
10/30/2009					145	193	6.8	12.2	100.6	7.7	305	7
08/09/2010					10	21.5	22	9.1	104.3	8.4		34.5
08/16/2010					22	49.4	17.6	9.5	99.9	8.1	438	22
08/18/2010					1120	933	17.2	9.1	94.7	7.8	781	4.5
10/06/2010							9.3	7.9	68.5	8		55
10/25/2010					22	31.5	8.1	11.8	100.2	8.2	426	28

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Clear Ck. @ CTH W (cont.) Station 10030272

	Lab parameters						Field parameters					
	NH3 (mg/l)	NO3+2 (mg/l)	TKN (mg/l)	TP (ug/l)	TSS (mg/l)	Turbidity (NTU)	Temp (C)	D.O. (mg/l)	D.O.sat. (%)	pH (SU)	Cond. (umhos/cm)	Transp. (cm)
Range =					6-1120	14.3-933		7.9-13.4		7.6-8.4	250-781	4-65
Median =					22	31.5		10.0		7.9	520	31.3

Clear Ck. US Ski Trail Station 10031940

	Lab parameters						Field parameters					
Date	NH3 (mg/l)	NO3+2 (mg/l)	TKN (mg/l)	TP (ug/l)	TSS (mg/l)	Turbidity (NTU)	Temp (C)	D.O. (mg/l)	D.O.sat. (%)	pH (SU)	Cond. (umhos/cm)	Transp. (cm)
10/25/2010					29	32.4	8.2	8.1	96.5		402	35

TABLE 4. NEMADJI RIVER AND TRIBUTARY STREAMS WATER QUALITY MONITORING DATA (CONT.)

Mud Ck. @ CTH W Station 10030271

	Lab						Field					
	NH3	NO3+2	TKN	TP	TSS	Turbidity	Temp	D.O.	D.O.sat.	pH	Cond.	Transp.
Date	(mg/l)	(mg/l)	(mg/l)	(ug/l)	(mg/l)	(NTU)	(C)	(mg/l)	(%)	(SU)	(umhos/cm)	(cm)
06/23/2009	ND	ND	0.85	41	24	38.3	22.1	9.1	104.1	8.2	455	26
07/29/2009					29	91.6	19.1	10.1	109.3	8.1	355	15
08/20/2009					396	409	14.5	9.8	95.5	7.5	178	1.5
09/14/2009					19	27.4	18.9	7.9	84.2	7.8	466	46
09/29/2009					7	14.8	10.9	9	89.4	7.7	553	69
10/07/2009					24	54.5	8.7	12.6	108	7.8	420	18
10/30/2009					203	250	6.6	12.4	101.6	7.5	207	6
08/09/2010					5	12.6	23.6	8.6	101.6	8.3		61
08/16/2010					20	59.6	18.7	7.9	84.7	8	364	16
08/18/2010					140	191	18.4	8.7	91.7	7	310	5
10/06/2010					11	36.3	9.7	7.5	65.8	7.7		45
10/25/2010					46	60.9	7.8	10.6	97.9	8.1	353	15
Range =					7-396	12.6-409		7.5-12.6		7-8.3	178-466	1.5-69
Median =					24	57		9		8	360	17

TABLE 4-2. MEDIAN WATER CHEMISTRY VALUES FOR NEMADJI RIVER AND TRIBUTARY SITES

	NH3 (mg/l)	NO3+2 (mg/l)	TKN (mg/l)	TP (ug/l)	TSS (mg/l)	Turbidity (NTU)	Chl. A (ug/l)	DP (ug/l)	Transp. (cm)	pH (SU)	Cond. (umhos/cm)
Nemadji R @ CTH C	<0.015	0.029	0.62	46	16	27.5	1.5	3	25	7.8	227
Nemadji R @ Finn Rd	<0.015	0.038	0.55	30	12	34.6			42	7.8	232
Nemadji R @ CTH W					9	19.2			40	7.9	223
Crawford Ck @ Hammond Ave					23	35.6			21	7.5	316
Balsam Ck @ Deadham Rd					21	46			19.5	7.9	195
Clear Ck @ CTH W					22	31.5			31.3	7.9	520
Mud Ck near CTH W					24	57			17	8.0	360

Conclusions

The sites monitored in Wisconsin's portion of the Nemadji River watershed are diverse, with natural stream communities ranging from Cool-Cold headwaters to Warm mainstems. Erodible clay soils interspersed with sands and silts dominate the drainage areas for most sites. Erosion of stream banks and drainageways are the dominant source of sediment loads. Common stream concerns in this area include:

- High peak flows resulting from rapid runoff from clay soils.
- Low base flows resulting from limited groundwater discharge.
- Scouring of stream bed, and bank erosion resulting from high peak flows.
- High bed loads of sand and silt, reducing the substrate quality for fish and macroinvertebrates. .
- High TSS and turbidity, and low transparency resulting from erosion of clay soils.

Most of the Black River watershed extends south of the red clay plain area and has soils dominated by stony and sandy loams, and organic wetland soils. Water quality is likely to be better in that stream, but water sampling was not done at the Black River monitoring site. Both the fish IBI and the macroinvertebrate IBI for this site were excellent.

The Nemadji River and Crawford Creek have already been placed on Wisconsin's 303d list of impaired waters, as discussed in the introduction section. The data collected during this project does not provide any further supporting information for having these streams on the list.

WISCALM guidance (2014) indicates at least two samples of one biological assemblage (fish or macroinvertebrates) collected in different calendar years and having "poor" ratings are required to list a stream as impaired. Neither the Nemadji River nor Crawford Creek had any poor ratings for fish IBI's or macroinvertebrate IBI's (table 5).

Total phosphorus (TP) concentrations can also be used toward listing a stream as impaired. Six monthly samples collected from May to October are needed for this assessment. The lower bound of the 90% confidence interval of the mean must exceed 75 ug/l to list a stream as impaired. Only two sites on the Nemadji River (CTH C and Finn Road) had the needed samples collected (table 5). At both sites the 75 ug/l TP threshold is not exceeded.

The data collected during this project for the other streams does not support 303d listing. No poor ratings for fish IBI's or macroinvertebrate IBI's were found. Sampling for TP concentrations was inadequate to determine if the 75 ug/l threshold is exceeded (table 5).

TABLE 5. NEMADJI RIVER AND TRIBUTARIES TOTAL PHOSPHORUS AND IBI SUMMARY*							
STREAM /SITE	SWIMS ID NO.	Year	May-Oct TP	MIBI	Small Stream IBI	Cool warm Transitional IBI	Warmwater L. Superior IBI
Nemadji R @ CTH C	163003	2006-12	lower 90% C.I.< 75ug/l	no sample			no survey
Nemadji R @ Finn Road	163233	2007-9	lower 90% C.I.< 75ug/l	no sample			excellent
Nemadji R @ CTH W	163047	2009	insufficient samples	excellent	good	excellent	
Crawford Ck @ Hammond Ave	10015464	2006-10	insufficient samples	no sample	fair		
Crawford Ck @ CTH C	10031796	2010	no samples	fair	no survey		
Crawford Ck @ Vally Brook Rd	10032010	2010	no samples	good	no survey		
Crawford Ck @ Eskelson Rd	10031826	2010	no samples	excellent	fair		
Black R @ Finn Road	10030272	2009	no samples	excellent		excellent	
Balsam Ck @ Dedham Road	10007599	2009	insufficient samples	excellent		excellent	
		2010					
Clear Ck @ CTH W	10030271	2009	insufficient samples	good	fair	good	
Clear Ck @ Hillpiper Rd	10031879	2010	no samples	excellent	no survey	no survey	
Clear Ck US Ski Trail	10031940	2010	insufficient samples	excellent	good		
Mud Ck near CTH W	10030270	2009	insufficient samples	good	good	excellent	
		2010		good			
Mud Ck South of Hillpiper Road	10031880	2010	no samples	good	no survey	no survey	

*May-October total phosphorus sample sufficiency considers all samples collected since 2006.
MIBI = macroinvertebrate index of biotic integrity
IBI = index of biotic integrity

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Nemadji R @ Finn Rd 06/31/2008

SWIMS sta. no. 163233 Station length 425m

Fish Species	Number	Thermal	Size	Tolerance	
common shiner	29	warmwater	medium	tolerant	
creek chub	4	transient	small	tolerant	
hornyhead chub	22	warmwater	medium	intermediate	
johnny darter	1	transient	medium	intermediate	
lamprey	1				
logperch	1	warmwater	large	intermediate	
rock bass	29	warmwater	large	intolerant	
sand shiner	11	warmwater	large	intermediate	
shorthead redhorse	7	warmwater	large	intermediate	
silver redhorse	6	warmwater	large	intermediate	
smallmouth bass	2	warmwater	large	intolerant	
stonecat	2	warmwater	medium	intermediate	
troutperch	7	transient	large	intermediate	
walleye	1	transient	large	intermediate	
white sucker	2	transient	medium	tolerant	
Total number	124				
% Coldwater	0	% small	3	% intolerant	26
% Transitional	13	% medium	48	% intermediate	44
% Warmwater	87	% large	49	% tolerant	30

Model-predicted natural community - Warm mainstem

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - yes, but

% medium slightly less than 50-100%

Warmwater Lake Superior basin IBI: 80 = excellent

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Nemadji R @ CTH W 09/11/2009

SWIMS sta. no. 163048 Station length 440m

Fish Species	Number	Thermal	Size	Tolerance
common shiner	54	warmwater	medium	intermediate
creek chub	3	transient	small	tolerant
hornyhead chub	78	warmwater	medium	intermediate
johnny darter	11	transient	medium	intermediate
logperch	70	warmwater	large	intermediate
longnose dace	38	transient	medium	intermediate
muskellunge	1	transient	large	intolerant
rock bass	25	warmwater	large	intolerant
sand shiner	1	warmwater	large	intermediate
silver redhorse	38	warmwater	large	intermediate
smallmouth bass	3	warmwater	large	intolerant
stonecat	7	warmwater	medium	intermediate
troutperch	4	transient	large	intermediate
walleye	3	transient	large	intermediate
white sucker	18	transient	medium	tolerant
Total number	354			

% Coldwater	0	% small	1	% intolerant	8
% Transitional	22	% medium	58	% intermediate	71
% Warmwater	78	% large	41	% tolerant	21

Model-predicted natural community - Cool-Warm HW

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - no

Sampled population indicates a Warm mainstem community

Small stream (intermittent) IBI: 80 = good

Warmwater Lake Superior basin IBI: 90 = excellent

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Crawford Ck @ Hammond Ave 07/07/2006

SWIMS sta. no. 10015464 Station length 210m

Fish Species	Number	Thermal	Size	Tolerance	
central mudminnow	2	transient	small	tolerant	
creek chub	10	transient	small	tolerant	
golden shiner	1	warmwater	medium	tolerant	
muskellunge	1	transient	large	intolerant	
troutperch	1	transient	large	intermediate	
white sucker	8	transient	medium	tolerant	
Total number	23				
% Coldwater	0	% small	52	% intolerant	4
% Transitional	96	% medium	39	% intermediate	4
% Warmwater	4	% large	9	% tolerant	92

Model-predicted natural community - Cool-Cold HW

Does sampled population include > 25 fish? - no

Does sampled population support predicted community? - yes, but < 25 fish and % tolerant > 75

Small stream (intermittent) IBI: 40 = fair

Cool-Cold IBI: 20 = poor

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Crawford Ck @ Eskelson Rd 08/23/2010

SWIMS sta. no. 10031826 Station length 107m

Fish Species	Number	Thermal	Size	Tolerance	
brook stickleback	11	transient	small	tolerant	
central mudminnow	12	transient	small	tolerant	
creek chub	24	transient	small	tolerant	
western blacknose dace	2	transient	small	tolerant	
white sucker	23	transient	medium	tolerant	
Total number	72				
% Coldwater	0	% small	68	% intolerant	0
% Transitional	100	% medium	32	% intermediate	0
% Warmwater	0	% large	0	% tolerant	100

Model-predicted natural community - Cool-Cold HW

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - yes but % tolerant > 75

Small stream (intermittent) IBI: 40 = fair

Cool-Cold IBI: 30 = fair

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Black R @ Finn Rd 09/11/2009

SWIMS sta. no. 10030272 Station length 470m

Fish Species	Number	Thermal	Size	Tolerance
common shiner	258	warmwater	medium	intermediate
creek chub	76	transient	small	tolerant
hornyhead chub	41	warmwater	medium	intermediate
johnny darter	11	transient	medium	intermediate
logperch	6	warmwater	large	intermediate
northern pike	1	transient	small	intermediate
rock bass	2	warmwater	large	intolerant
sand shiner	43	warmwater	large	intermediate
shorthead redhorse	7	warmwater	large	intermediate
smallmouth bass	6	warmwater	large	intolerant
troutperch	3	transient	large	intermediate
walleye	3	transient	large	intermediate
western blacknose dace	1	transient	small	tolerant
white sucker	90	transient	medium	tolerant

Total number 548

% Coldwater	0	% small	14	% intolerant	2
% Transitional	34	% medium	73	% intermediate	68
% Warmwater	66	% large	13	% tolerant	30

Model-predicted natural community - Cool-Warm mainstem

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - yes

Cool-Warm IBI: 80 = excellent

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Balsam Ck @ Dedham Rd 09/21/2010

SWIMS sta. no. 10007599 Station length 370m

Fish Species	Number	Thermal	Size	Tolerance	
brassy minnow	6	transient	small	intermediate	
common shiner	207	warmwater	medium	intermediate	
creek chub	155	transient	small	tolerant	
hornyhead chub	46	warmwater	medium	intermediate	
johnny darter	6	transient	medium	intermediate	
logperch	4	warmwater	large	intermediate	
longnose dace	18	transient	medium	intermediate	
northern redbelly dace	1	transient	small	intermediate	
rock bass	6	warmwater	large	intolerant	
shorthead redhorse	6	warmwater	large	intermediate	
stonecat	2	warmwater	medium	intermediate	
troutperch	38	transient	large	intermediate	
western blacknose dace	19	transient	small	tolerant	
white sucker	30	transient	medium	tolerant	
Total number	544				
% Coldwater	0	% small	33	% intolerant	1
% Transitional	50	% medium	57	% intermediate	61
% Warmwater	50	% large	10	% tolerant	38

Model-predicted natural community - Cool-Warm mainstem

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - yes

Cool-Warm IBI: 90 = excellent

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Clear Ck @ CTH W 08/05/2009
SWIMS sta. no. 10030271 Station length 255m

Fish Species	Number	Thermal	Size	Tolerance	
bluntnose minnow	1	warmwater	medium	tolerant	
common shiner	102	warmwater	medium	intermediate	
creek chub	115	transient	small	tolerant	
hornyhead chub	10	warmwater	medium	intermediate	
johnny darter	6	transient	medium	intermediate	
logperch	1	warmwater	large	intermediate	
longnose dace	17	transient	medium	intermediate	
sand shiner	2	warmwater	large	intermediate	
shorthead redhorse	1	warmwater	large	intermediate	
troutperch	28	transient	large	intermediate	
western blacknose dace	40	transient	small	tolerant	
white sucker	87	transient	medium	tolerant	
Total number	410				
% Coldwater	0	% small	38	% intolerant	0
% Transitional	72	% medium	54	% intermediate	41
% Warmwater	28	% large	8	% tolerant	59

Model-predicted natural community - None
Does sampled population include > 25 fish? - yes
Does sampled population support predicted community? - none predicted
Sampled population indicates a Cool-Warm mainstem, but also close to Cool-Warm HW
Cool-Warm IBI: 60 = good
Small stream (intermittent) IBI: 60 = fair

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Clear Ck US Ski Trail 08/24/2010

SWIMS sta. no. 10031940 Station length 153m

Fish Species	Number	Thermal	Size	Tolerance	
brook stickleback	6	transient	small	tolerant	
common shiner	9	warmwater	medium	intermediate	
creek chub	134	transient	small	tolerant	
hornyhead chub	1	warmwater	medium	intermediate	
johnny darter	21	transient	medium	intermediate	
longnose dace	2	transient	medium	intermediate	
mottled sculpin	27	coldwater	small	intolerant	
western blacknose dace	57	transient	small	tolerant	
white sucker	1	transient	medium	tolerant	
Total number	258				
% Coldwater	10	% small	87	% intolerant	10
% Transitional	86	% medium	13	% intermediate	13
% Warmwater	4	% large	0	% tolerant	77

Model-predicted natural community - None

Does sampled population include > 25 fish? - yes

Does sampled population support predicted community? - none predicted

Sampled population indicates Cool-Warm HW or Cool-Cold HW

Small stream (intermittent) IBI: 90 = good

Cool-Warm IBI: 80 = excellent

Cool-Cold IBI: 50 = good

APPENDIX A. FISH SURVEY DATA FOR NEMADJI RIVER AND TRIBUTARIES (CONT.)

(HW = headwater, IBI = index of biotic integrity, DS = downstream, US = upstream)

Mud Ck near CTH W 09/01/2009

SWIMS sta. no. 10030270 Station length 152m

Fish Species	Number	Thermal	Size	Tolerance
common shiner	108	warmwater	medium	intermediate
creek chub	102	transient	small	tolerant
hornyhead chub	55	warmwater	medium	intermediate
johnny darter	3	transient	medium	intermediate
logperch	3	warmwater	large	intermediate
longnose dace	1	transient	medium	intermediate
muskellunge	1	transient	large	intolerant
pearl dace	1	transient	small	intermediate
rock bass	1	warmwater	large	intolerant
sand shiner	23	warmwater	large	intermediate
smallmouth bass	4	warmwater	large	intolerant
troutperch	22	transient	medium	tolerant
walleye	1	transient	large	intermediate
western blacknose dace	4	transient	small	tolerant
white sucker	12	transient	medium	tolerant

Total number 341

% Coldwater	0	% small	31	% intolerant	2
% Transitional	43	% medium	53	% intermediate	63
% Warmwater	57	% large	16	% tolerant	35

Model-predicted natural community - Cool-Warm HW
Does sampled population include > 25 fish? - yes
Does sampled population support predicted community? - no
Sampled population indicates Cool-Warm mainstem
Station sampled is very close to confluence with Nemadji R
Cool-Warm IBI: 100 = excellent
Small stream (intermittent) IBI: 90 = good

Appendix 9

Lower Nemadji River Water Quality and Macroinvertebrate Community Assessment (Pertains to management action 6.05)

LOWER NEMADJI RIVER WATER QUALITY AND MACROINVERTEBRATE COMMUNITY ASSESSMENT, 2015

Craig Roesler – WI Dept. of Natural Resources, Spooner

Introduction

The Nemadji River watershed is located in northwest Wisconsin and northeast Minnesota (figure 1). The watershed is included in the St. Louis River Area of Concern (AOC). Both Wisconsin and Minnesota have listed the Nemadji River as an impaired water. Wisconsin added the Nemadji River to the 303d list of impaired waters in 2010. The high sediment load was judged to exceed the narrative water quality standard found in NR 102.4 (a) of the Wisconsin Administrative Code, that states, "Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state." Other considerations that contributed to the listing decision were:

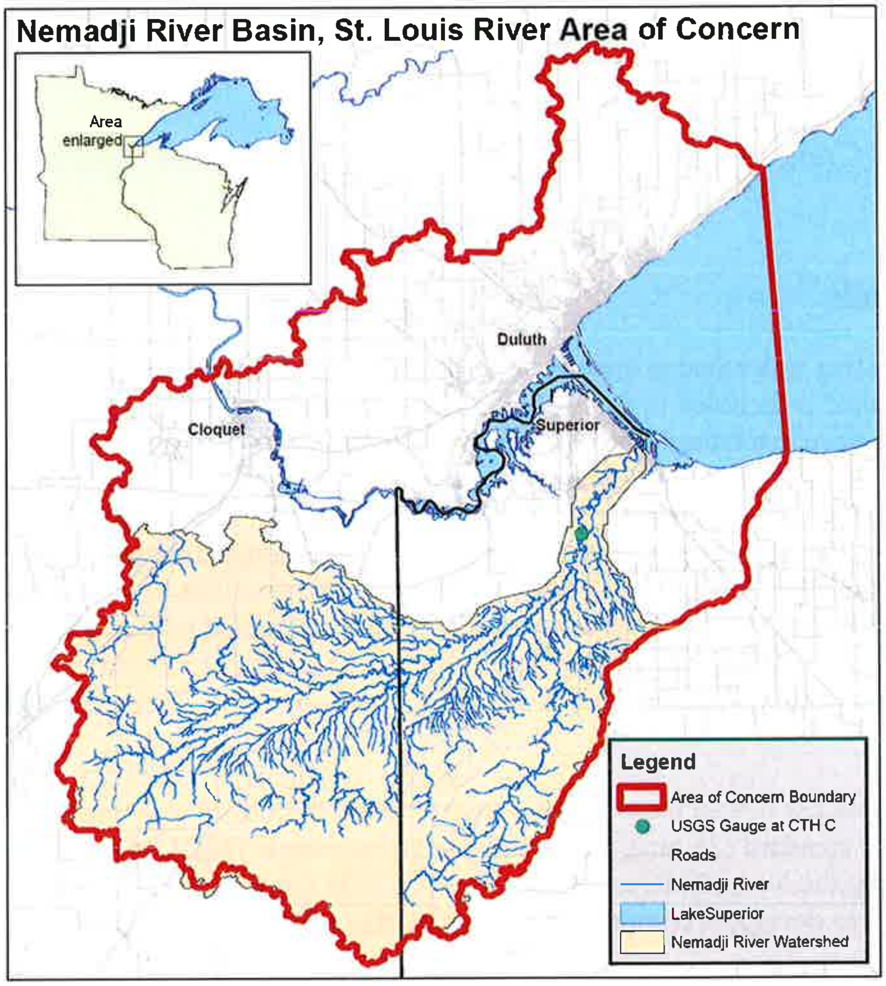
- Creosote and PAH's from Crawford Creek are a continuing source of pollutants to the Nemadji River.

- Minnesota has placed the Nemadji River on their 303d list due to exceedences of their turbidity standard (25 ntu), and has begun developing a TMDL to address turbidity. Including the Nemadji River on Wisconsin's 303d list will allow the two states to work together to develop a comprehensive TMDL that will benefit the entire watershed.

- The median turbidity measured in the Nemadji River at CTH C during 2006-2012 was 27.5 ntu, which exceeds Minnesota's turbidity standard.

Nemadji River turbidity results from the erosion of clay rich soils in the lower portion of the watershed. The majority of the suspended clay in the river is derived from channel and bank erosion in the river, tributaries, and drainageways. Despite the high turbidity, biological assessments have shown good quality fish and macroinvertebrate communities are present at previous locations monitored (Roesler 2014).

Figure 1.



However, there has been a lack of monitoring in the lower reach of the river in the past. Lake Superior seiche influence, which causes partial backflow in the lower 8.8 miles of the river, has discouraged water quality monitoring. The most downstream water quality data was collected at CTH C, 11.9 miles above the river mouth.

Deep water and lack of coarse substrate has discouraged macroinvertebrate sampling. The most downstream macroinvertebrate sample previously collected was at CTH W, 31.2 miles above the river mouth.

Higher percentages of urban and agricultural land use are present in the lower portion of the watershed. Three intermittent point source outfalls are also present. This suggests poorer water quality and macroinvertebrate communities may be present in the lower river. Monitoring of water quality, and macroinvertebrate sampling were done in 2015 to allow an initial evaluation of conditions in the lower river. Fish community monitoring in 2015 was also done in a separate project (Nelson 2016).

Methods

Water Quality

Water quality monitoring was conducted at three sites (fig. 2 and below), monthly from May to October. Monitoring was scheduled for the second Wednesday of each month to provide a systematic random distribution of samples.

Site Description	SWIMS Station No.	Coordinates
Nemadji R. @ CTH C	163003	46.6333, -92.0942
Nemadji R. @ Woodlawn Rd.	10037076	46.6662, -92.0642
Nemadji R. @ USH 2/53	163049	46.6966, -92.0346

Water samples were collected and field parameters were measured following standard DNR protocols. Samples at the two downstream sites were collected with a Kemerrer sampler which was lowered from the bridge near the river center. This was done to avoid any direct influence from backflows caused by Lake Superior seiches. During the periodic backflows, water was observed moving upstream near the stream banks, but continued to move downstream near the stream center.

Water samples were preserved, as needed, and most were shipped on ice to the Wisconsin State Lab of Hygiene for analysis. E. coli samples were delivered on ice to the Lake Superior Research Institute at UW-Superior for analysis so that holding time requirements could be met.

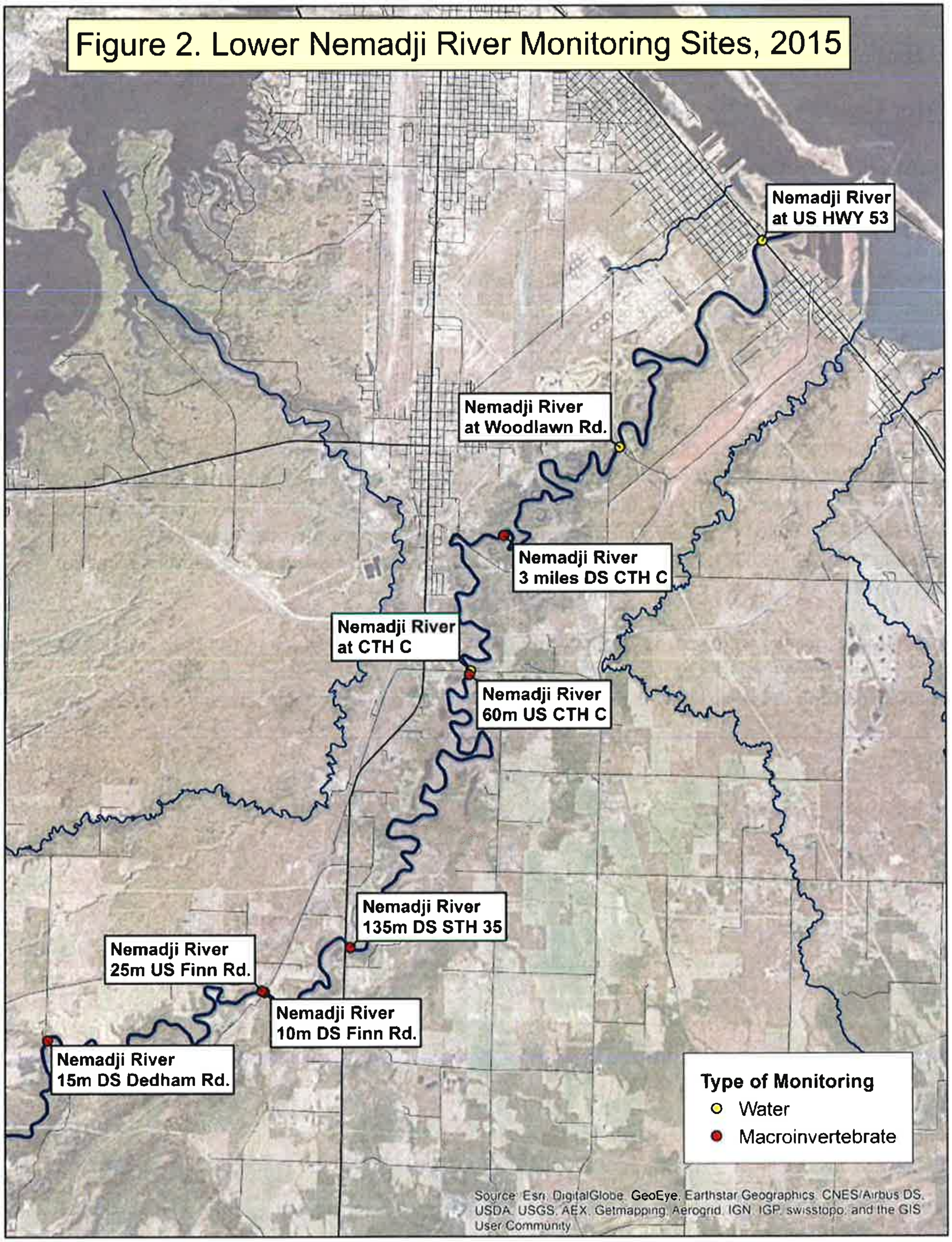


Figure 2. Lower Nemadji River Monitoring Sites, 2015
Nemadji River at US HWY 53
Nemadji River at Woodlawn Rd.
Nemadji River 3 miles DS CTH C
Nemadji River at CTH C
Nemadji River 60m US CTH C
Nemadji River 135m DS STH 35
Nemadji River 25m US Finn Rd.
Nemadji River 10m DS Finn Rd.
Nemadji River 15m DS Dedham Rd.
Type of Monitoring
Water
Macroinvertebrate
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Field parameters measured were:

- Temperature
- pH
- Dissolved Oxygen
- Conductivity
- Transparency (using a transparency tube)

Lab parameters were:

- Total Phosphorus
- Dissolved Ortho Phosphorus
- Ammonia – N
- Total Kjeldahl N
- Ammonia-N
- Nitrate plus Nitrite – N
- Total Suspended Solids
- Turbidity
- E. coli

Macroinvertebrate Sampling

The six macroinvertebrate sampling sites are shown in figure 2.
Macroinvertebrate communities were assessed by collecting kick samples using a 500 um mesh D-frame net. Due to the lack of riffles and scarcity of coarse substrate (gravel/cobble), all but one sample were collected from woody debris draped with leaf packs and other vegetative debris. One sample, just upstream of Finn Road was collected from cobble substrate to allow a comparison to a sample just downstream of Finn Road collected from woody debris/leaf snags.

Samples were preserved in 85% ethanol and were processed by UW – Superior's Aquatic Biomonitoring Lab. Macroinvertebrates were counted and identified to the lowest possible taxa. Biotic indices and other statistics were generated.

Results and Discussion

Sub-watershed characteristics

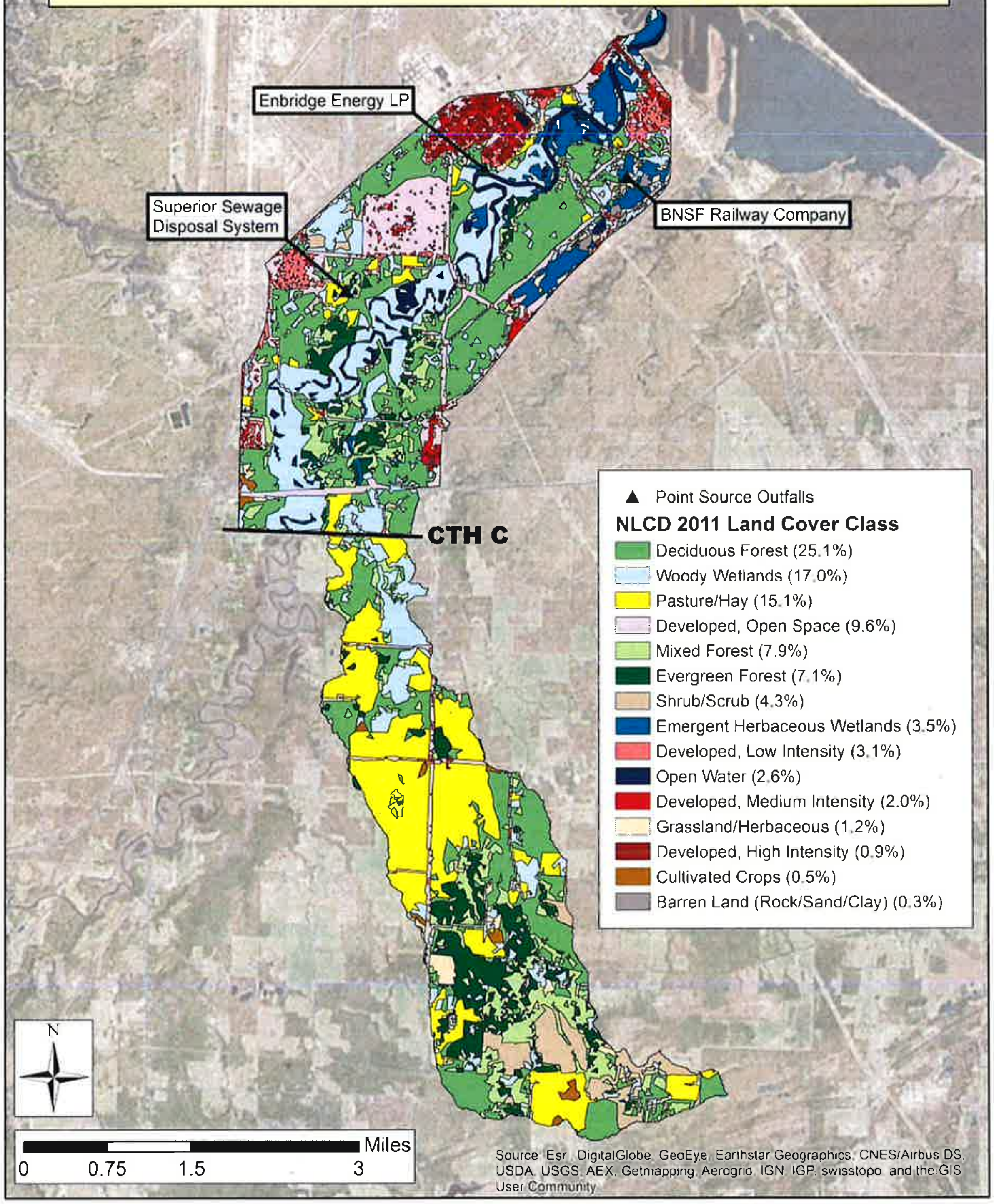
Land Cover

The sub-watershed and land cover for the lower Nemadji River is shown in figure 3. This is the drainage area that contributes water to the river downstream of CTH C. The three point source outfalls in the sub-watershed are also shown. The sub-watershed has an area of 16.2 mi^2, which is only 3.7% of the total Nemadji River watershed.

Undeveloped land covers occupy 69% of the sub-watershed. Developed agricultural land covers occupy 15.6%, with 15.1% being pasture or hay, and only 0.5% being cultivated crops. Developed urban land covers also occupy 15.6%, with most (12.7%) being developed open space, and low intensity development.

The remainder of the watershed for the Nemadji River, upstream of CTH C, has 87.3% undeveloped land covers. Developed agricultural land covers occupy 9.6%, and developed urban land covers occupy 3%.

Figure 3. Lower Nemadji River Sub-Watershed Land Cover and Point Source Outfalls (Downstream of CTH C)



Point Sources

There are three point source outfalls in the sub-watershed (figure 3):

- Superior Sewage Disposal System; combined sewer treatment plant (CSTP5)
- Enbridge Energy LP
- BNSF Railway Company

The characteristics of the three point sources and their potential influence on the Lower Nemadji River are discussed in the Water Quality section below.

Water Quality

Water Quality Monitoring Results for 2015

Results of water quality monitoring are shown in table 1.
Dissolved oxygen (D.O.) concentrations range from 6.3 to 11.5 mg/l. All values exceed the 5 mg/l water quality standard for fish and aquatic life.

Conductivity ranges from 93 to 275 umhos/cm. Conductivity tends to be lower when flows are higher since the surface runoff contributing to the high flows tends to have lower conductivity. Transparency (measured with a transparency tube) ranges from 3 to 65 cm. Lowest transparencies occur during highest flows. Erosion of clay from stream and drainageway channels is greatest during high flows. A transparency of 104 cm was measured at the CTH C site during macroinvertebrate sampling on October 22nd, following an extended period of dry weather.

Total phosphorus (TP) concentrations are low to high, ranging from 33 to 501 ug/l. TP concentrations are highest when flows are highest due to watershed runoff and channel scouring. Median TP concentrations at the three sites (49 – 56.3 ug/l) were below Wisconsin's stream water quality standard of 75 ug/l. The upper 90% confidence limit of the median ranged from 133.5 – 159 ug/l. Wisconsin DNR 2016 WisCALM guidance indicates these sites "may meet" the 75 ug/l standard since the median is below, but the 90% upper confidence limit is above the standard.

Dissolved ortho phosphorus (DOP) concentrations are low, ranging from <1.7 – 13 ug/l. The percent of TP as DOP ranges from 2.2 – 25%. There is a tendency for DOP to comprise a smaller percentage of TP when flows are higher, and more particulate bound TP is present.

Total Kjeldahl nitrogen (TKN) concentrations are moderate, ranging from 0.56 to 1.62 mg/l. TKN concentrations are higher when flows are higher due to watershed runoff. Ammonium-nitrogen (NH_4-N) and Nitrate plus nitrite-nitrogen (NO_{3+2}-N) concentrations are very low. NH_4-N concentrations range from <0.0150 – 0.0303 mg/l. NO_{3+2}-N concentrations range from <0.0190 – 0.0868 mg/l.

Table 1.

LOWER NEMADJI RIVER WATER QUALITY DATA, 2015 (Sites listed from upstream to downstream)

Nemadji River at CTH C (163003)

Date	Temp. (°C)	D.O. (mg/l)	pH (s.u.)	Conductivity (umhos/cm)	Transp. (cm)	Total P (ug/l)	Diss. ortho P (ug/l)	TKN (mg/l)	NH_4-N (mg/l)	NO_{3+2}-N (mg/l)	TSS (mg/l)	Turbidity (n.t.u.)	E. coli (cfu/100ml)	Mean daily flow (cfs)
05/12/2015	6.5	11.3	6.9	147	5	350	8	1.42	0.03	0.0868	344	374	980	1,490
06/10/2015	19.9	8.6	6.9	149	29	53	4	0.751	0.0154	0.037	30.7	26.3	35.9	265
07/08/2015	18.2	8.1	7	93	10	161	10	1.37	0.0243	<0.0190	130	121	648.8	1,580
08/06/2015	19.5	8.2	6.8	275	54	33	2	0.584	<0.0150	<0.0190	6.2	6.98	57.6	50
09/09/2015	19.1	8.4	7.8	194	32	54	7	0.72	0.0193	0.0411	24.8	23.5	81.6	140
10/14/2015	9.1	10.6	7.7	182	65	36/35	8/7	0.638/0.653	<.0150/<.0150	<.0190/<.0190	6.0/6.2	9.73/10.7	22.8/37.3	132
median	18.7	8.5	7.0	165.5	30.5	53.5	7.3	0.736	0.0174	0.0233	27.8	24.9	69.6	202.5

Nemadji River at Woodlawn Rd. (10037076)

Date	Temp. (°C)	D.O. (mg/l)	pH (s.u.)	Conductivity (umhos/cm)	Transp. (cm)	Total P (ug/l)	Diss. ortho P (ug/l)	TKN (mg/l)	NH_4-N (mg/l)	NO_{3+2}-N (mg/l)	TSS (mg/l)	Turbidity (n.t.u.)	E. coli (cfu/100ml)
05/12/2015	6.7	11.5	6.8	162	4	436	11	1.62	0.0272	0.0823	346	520	980
06/10/2015	19.9	8.4	6.7	153	31	49	5	0.753	0.0189	0.0368	17.4	28.3	20
07/08/2015	18.6	8	6.8	97	8	186	12	1.41	0.0236	<0.0190	161	142	980.4
08/06/2015	21	7.6	6.7	267	60	33	<1.7	0.698	<0.0150	<0.0190	7	6.47	24.6
09/09/2015	20.7	7.4	7.7	209	30	49	7	0.738	0.0161	0.047	11.8	22.2	83.6
10/14/2015	10.5	9.5	7.6	202	52	34/33	6/6	0.557/0.557	<.0150/<.0150	<.0190/<.0190	5.8/6.2	11.6/12.2	24.3/27.5
median	19.3	8.2	6.8	182.0	30.5	49	6.5	0.746	0.0175	0.0232	14.6	25.3	54.8

Nemadji River at USH 2/53 (163049)

Date	Temp. (°C)	D.O. (mg/l)	pH (s.u.)	Conductivity (umhos/cm)	Transp. (cm)	Total P (ug/l)	Diss. ortho P (ug/l)	TKN (mg/l)	NH_4-N (mg/l)	NO_{3+2}-N (mg/l)	TSS (mg/l)	Turbidity (n.t.u.)	E. coli (cfu/100ml)
05/12/2015	6.7	11.5	6.6	186	3	501	11	1.51	0.0296	0.0866	392	729	1120
06/10/2015	19.8	8.2	6.9	173	30	46	4	0.732	0.021	0.0337	15.2	26.6	37.3
07/08/2015	18.4	7.5	6.8	101	9	164	13	1.3	0.029	0.022	106	138	866.4
08/06/2015	21.5	7.1	6.9	240	47	43	2	0.736	0.0191	0.0407	10.4	7.1	9.7
09/09/2015	21.4	6.3	7.5	229	29	69	10	0.85	0.0303	0.0461	10.2	27.2	98.7
10/14/2015	11.6	8.5	7.6	225	62	35/37	9/9	0.532/0.571	<.0150/<.0150	<.0190/.0200	5.8/5.8	10.9/10.9	15.6/8.6
median	19.1	7.9	6.9	206	30	57.5	9.5	0.793	0.0293	0.0372	12.8	26.9	68.0

Total suspended solids (TSS) concentrations and turbidity are moderate to high. TSS concentrations range from 5.8 – 393 mg/l. Turbidities range from 7.1 – 729 ntu. Both parameters are much higher during high flows due to watershed runoff and channel erosion of clay.

Minnesota has a stream turbidity standard of 25 ntu's, which Wisconsin is using as one reason for designating the Nemadji River as an impaired stream. Median turbidities at the three sites are very close to the 25 ntu standard, ranging from 24.9 to 26.9 ntu's (table 1).

E. coli concentrations are low to high, ranging from 9.7 to 1,120 cfu/100ml. Concentrations are much higher during high flows due mostly to watershed runoff. Wisconsin does not currently have an E. coli standard from streams, but it does apply EPA E. coli standards to swimming beaches. An "advisory" standard of 235 cfu/100ml results in a caution sign being placed at a beach to warn of an increased risk of exposure to fecal bacteria and viruses. A "closure" standard of 1,000 cfu/100ml results in beach closure. Only the two dates with flows >1,000 cfs (May 12th and July 8th) have E. coli concentrations > 235 cfu/100ml. The samples collected on May 12th had concentrations very close to the "closure" standard (980,980, 1,120 cfu/100ml).

Potential Influences on Water Quality Differences at the Three Monitoring Sites

A substantial amount of water quality data from other sources is available for the Nemadji River at CTH C. A USGS gaging station is also operated at that location. No previous water quality data was available for the two downstream sites, Woodlawn Road and USH 2/53. Monitoring the two downstream sites simultaneously with the CTH C site was intended to allow an initial comparison between the sites, and provide some sense of additional inputs to the Nemadji River not being measured at the CTH C site.

There are multiple potential sources of influence on water quality in the Lower Nemadji River that need to be considered. These include the Lake Superior seiche effect, runoff from the Lower Nemadji River sub-watershed, Crawford Creek inflow, and point source discharges.

Lake Superior Seiche Effect

Lake Superior seiches cause backflows up the Nemadji River for about 8.8 miles upstream. The distance the backflows move upstream was determined by observing the lack of, or presence of, vegetative debris snagged on submerged wood during the Fall. Where backflow pulses occured regularly, wood was free of vegetative debris. Beyond the extent of backflows, flow is unidirectional (downstream) and vegetative debris was retained on wood.

During the periodic backflows, water is observed moving upstream near the stream banks, but continues to move downstream near the stream center. The backflows have the effect of providing another water source to the lower Nemadji River. The water backflowing up the river is derived mostly from the St. Louis River Estuary (SLRE), with additional contributions from Lake Superior.

St. Louis River estuary water quality is compared to Lower Nemadji River water quality below:

Parameter	St. Louis River Estuary (median)*	Lower Nemadji River (median)**
Total phosphorus (ug/l)	27.2	53.3
Total nitrogen (ug/l)	912	786
NO_x-N (ug/l)	182	27.9
NH_4-N (ug/l)	35.2	21.4
Total suspended solids (mg/l)	9.9	18.4

*average of May-October 2012 and 2013 medians for St. Louis River estuary harbor zone (downstream of USH 2), in Bellinger 2015

**average of May-October 2015 medians from the three sites on the Lower Nemadji River

The Superior entrance to Superior Bay is in close proximity to the mouth of the Nemadji River (0.6 miles). This makes it uncertain how adequately SLRE water quality represents backflow water, since Lake Superior water may be a larger component of SLRE water in that area.

The SLRE has lower TP and TSS concentrations, roughly similar TN and NH_4-N concentrations, and higher NO_{3+2}-N concentrations. Backflow of SLRE water into the lower Nemadji River would be expected to contribute to lower TP and TSS concentrations, and higher NO_{3+2}-N concentrations.

Conductivity, temperature and dissolved oxygen (D.O.) data for the SLRE is available from the Barker's Island continuous monitoring station operated by the Lake Superior National Estuarine Research Reserve System (NERR). If this data is representative of backflow water, it indicates backflows are contributing to Nemadji River water quality for all of these three parameters:

- Conductivity was higher in the SLRE than in the Nemadji River on five of six dates and so may have contributed to conductivity increases between CTH C and USH 2/53 on those five dates. On the sixth date (August 6th), SLRE water was lower in conductivity and so may have contributed to the decline in the Nemadji River.

- Temperature was higher in the SLRE than in the Nemadji River on five of six dates and so may have contributed to temperature increases between CTH C and USH 2/53 on those five dates. On the sixth date (June 10th), SLRE water was lower in temperature and so may have contributed to the slight temperature drop in the Nemadji River.

- On four of five dates when Nemadji River D.O. declined between CTH C and USH 2/53, D.O. was lower in the SLRE than in the Nemadji River and so may have contributed to the declines.

<u>Lower Nemadji River Sub-watershed runoff</u>

Some sense of possible total phosphorus contributions from the lower Nemadji River sub-watershed runoff can be obtained as follows:

- The sub-watershed is 3.7% of the total watershed.
- Developed land covers are 18.6% higher in the sub-watershed than in the remaining watershed upstream of CTH C.
- Developed land covers can be roughly assumed to export 0.7 kg/ha/yr of TP and undeveloped land covers can be assumed to export 0.1 kg/ha/yr of TP. The weighted average TP export rate for the upper watershed would then be 0.18 kg/ha/yr. Developed land cover TP export in the lower sub-watershed (0.7 kg/ha/yr) is 3.9 times higher than the weighted average for the upper watershed.
- The increase in TP loading to the Nemadji River from the lower sub-watershed would then be - 3.7% x 18.6% x 3.9 = 2.7% increase.

This suggests that increased concentrations or loads of total phosphorus from sub-watershed runoff would be less than 3%.

Increased concentrations or loads of nitrogen and TSS due to runoff from the lower Nemadji River sub-watershed are also likely to be small. However, nitrogen concentrations or loads are typically poorly correlated with land cover. TSS concentrations or loads in the Nemadji River have been shown to be mostly derived from channel and drainageway erosion and so are unlikely to be predictable from land cover.

Crawford Creek

Crawford Creek flows into the Nemadji River between CTH C and Woodlawn Road. Its watershed is about half the area of the Lower Nemadji River sub-watershed, and about 1.8% of the total Nemadji River watershed. Crawford Creek is contaminated with creosote and PAH's from a former wood preserving facility. Crawford Creek conductivities at Hammond Road during 2009-10 had a median of 316.5 umhos/cm. This is higher than the Nemadji River (166 umhos/cm at CTH C) and so would be expected to cause a slight increase in downstream Nemadji River conductivities.

Point Sources

Superior Sewage Disposal System

The Superior combined sewer treatment plant discharges to the Nemadji River between CTH C and Woodlawn Road (figure 3). The plant only discharges intermittently following heavy rainfalls, when Nemadji River flows are usually high, and so considerable dilution capacity is usually available. During 2015 discharges occurred on 5 days during the May to October Nemadji River monitoring period (July 6,7,8th and September 24,25th).

Discharges can at times have high concentrations of BOD_5 (2-60 mg/l), E. coli (100-250,000cfu/100ml), ammonia (0.2-5.36 mg/l), total phosphorus (40-793 ug/l), and total suspended solids (9-189 mg/l). Maximum reported discharge rate in July was 4.6 cfs. Nemadji River flow on July 8th was 1,580 cfs (table 1).

E. coli increases in the Nemadji River from this point source may be one of the more distinguishable impacts. E. coli concentrations were higher at the two sampling sites downstream of this source than at the upstream sampling site on July 8th (table 1).

BOD_5 concentrations from this point source may contribute to reduced dissolved oxygen concentrations downstream, as was observed on July 8th (table 1). Deposition of oxygen-demanding solids on the stream bottom might contribute to delayed, chronic, oxygen demand.

Enbridge Energy

Enbridge Energy discharges to the Nemadji River between Woodlawn Road and USH 2/53 (figure 3). Enbridge Energy typically has occasional discharges of water used to pressure test tanks and pipelines. Pressure test water is tested for a range of petroleum related compounds to assure permit limits are met. Pressure test water is treated with carbon filtration prior to release, when necessary.

During 2015 a much larger than usual pipeline pressure test occurred that resulted in discharge of water during most of October. Discharge averaged about 4.6 cfs, with a mean TP concentration of 238 ug/l. The Nemadji sampling site downstream of the discharge point had a 1.5 ug/l higher TP concentration than the upstream sampling site on October 14th (table 1).

Average concentrations of other parameters from the three outfall sites in October were:

- BOD_5, 3 – 8.7 mg/l.
- Ammonia, 0.54 – 1.3 mg/l
- TSS, 5.3 – 16.9 mg/l

These concentrations are unlikely to produce measureable impacts in the Nemadji River. Conductivity of the discharges is not reported, so they are a possible contributor to higher conductivities in the Nemadji River.

BNSF Railway Company

BNSF Railway Company discharges to the Nemadji River between Woodlawn Road and USH 2/53 (figure 3). BNSF Railway Company discharge is mostly taconite storage pile runoff that is treated in a retention/settling pond. Small amounts of maintenance washwater pass through a grit chamber, an oil/water separator, and a concrete lagoon, before also entering the retention/settling pond. Pond discharge was generally continuous during April through October of 2015 and averaged 1.5 cfs. Average concentrations of water quality parameters in past years were:

- TP, 120 ug/l (one sample)
- TSS, 8.9 mg/l
- BOD5, 2 mg/l
- Chloride, 104 mg/l
- Iron, 0.5 mg/l

With the exception of chloride, this point source appears unlikely to produce measureable impacts to the Nemadji River. Nemadji River samples were not tested for chloride in 2015. Chloride does contribute strongly to conductivity, which was tested. Conductivity was higher at the downstream monitoring site (USH 2/53) than the upstream monitoring site (Woodlawn Rd.) on 5 of the 6 sampling dates.

Water Quality Differences at the Three Monitoring Sites

Water quality parameter differences between the upstream site (CTH C) and the downstream site (USH 2/53) are shown in table 2, below. Some parameters show changes that appear to be significant. The previous discussion on potential influences on water quality identifies some possible explanations for occasional differences. Due to the limited data collected and the complexity of the inputs that occur, further interpretations are difficult or speculative.

Potential influence of backflows on conductivity, temperature, and dissolved oxygen (D.O.) are discussed above (Lake Superior Seiche Effect). Other potential influences on temperature and D.O. include:

- The Nemadji River widens, deepens, and slows between CTH C and USH 2/53. Solar radiation inputs may also be a contributor to the increases.

- Reduced oxygen solubility due to temperature increases may also contribute to the decreases (up to 1 mg/l). Sediment oxygen demand might be higher in the lower river if temporary deposition of organic solids is occurring due to reduced stream velocities. This could also contribute to D.O. decreases.

Total phosphorus increases on five of six dates, but two of the five increases are ≤ 3 ug/l and not significant. Turbidity increases on all six dates, but half of the increases are less than 1 n.t.u. and probably not significant. Transparency decreases on five of six dates, although most decreases are 3 cm. or less and may not be significant.

Table 2.

Unit change and % Change from CTH C to USH 2/53

Date	Temp. (oC) unit ch.	Temp. (oC) % ch.	D.O. (mg/l) unit ch.	D.O. (mg/l) % ch.	pH (s.u.) unit ch.	pH (s.u.) % ch.	Conductivity (umhos/cm) unit ch.	Conductivity (umhos/cm) % ch.	Transp. (cm) unit ch.	Transp. (cm) % ch.	Total P (ug/l) unit ch.	Total P (ug/l) % ch.	Mean daily flow (cfs)
05/12/2015	0.2	3.1	0.2	1.8	-0.3	-4.3	39	26.5	-2	-40.0	151	43.1	1,490
06/10/2015	-0.1	-0.5	-0.4	-4.7	0	0.0	24	16.1	1	3.4	-7	-13.2	265
07/08/2015	0.2	1.1	-0.6	-7.4	-0.2	-2.9	8	8.6	-1	-10.0	3	1.9	1,580
08/06/2015	2	10.3	-1.1	-13.4	0.1	1.5	-35	-12.7	-7	-13.0	10	30.3	50
09/09/2015	2.3	12.0	-2.1	-25.0	-0.3	-3.8	35	18.0	-3	-9.4	15	27.8	140
10/14/2015	2.5	27.5	-2.1	-19.8	-0.1	-1.3	43	23.6	-3	-4.6	0.5	1.4	132
mean =	1.2	8.9	-1.0	-11.4	-0.1	-1.8	19	13.4	-2.5	-12.3	28.8	15.2	

Table 2 (cont.)

Date	Dissolved ortho P (ug/l) unit ch.	Dissolved ortho P (ug/l) % ch.	TKN (mg/l) unit ch.	TKN (mg/l) % ch.	NH4-N (mg/l) unit ch.	NH4-N (mg/l) % ch.	NO3+2-N (mg/l) unit ch.	NO3+2-N (mg/l) % ch.	TSS (mg/l) unit ch.	TSS (mg/l) % ch.	Turbidity (n.t.u.) unit ch.	Turbidity (n.t.u.) % ch.	E. coli (cfu/100ml) unit ch.	E. coli (cfu/100ml) % ch.
05/12/2015	3.00	37.5	0.090	6.3	-0.0004	-1.3	-0.0002	-0.2	48	14.0	355	94.9	140	14.3
06/10/2015	0	0	-0.019	-2.5	0.0056	36.4	-0.0033	-8.9	-15.5	-50.5	0.3	1.1	1.4	3.9
07/08/2015	3	30	-0.070	-5.1	0.0047	19.3	ND	ND	-24	-18.5	17	14.0	217.6	33.5
08/06/2015	0	0	0.152	26.0	ND	ND	ND	ND	4.2	67.7	0.12	1.7	-47.9	-83.2
09/09/2015	3	42.9	0.130	18.1	0.011	57.0	0.005	12.2	-14.6	-58.9	3.7	15.7	17.1	21.0
10/14/2015	1.5	20	-0.093	-17.2	ND	ND	ND	ND	-0.3	-4.9	0.7	6.7	-17.9	-59.7
mean =	1.8	21.7	0.032	4.3	not calc.	not calc.	not calc.	not calc.	-0.4	-8.5	62.8	22.4	51.7	-11.7

Macroinvertebrate Samples

Initial plans to collect samples at multiple sites downstream of CTH C had to be altered due to flow conditions in that section of the river. A relatively wide and deep channel, and low discharge rates in late summer and early fall resulted in inadequate current velocities (< 0.3 ft/sec) to meet sampling protocols for applying Wisconsin DNR macroinvertebrate biotic indices for streams (>0.5 ft/sec) or rivers (>0.3 ft/sec). Furthermore, the periodic backflows prevented any accumulation of leaf packs or other vegetative debris on the woody debris present that would have provided a suitable sampling substrate.

The most downstream site with suitable flow conditions was 3 miles downstream of CTH C. This site was just upstream of the extent of seiche influence and had leaf packs on woody debris.

Summarized macroinvertebrate sample results are shown in table 2. Very healthy macroinvertebrate communities were found at all six sites. All samples had high macroinvertebrate index of biotic integrity (MIBI) values that are rated as excellent. Hilsenhoff biotic index (HBI) values ranged from good to excellent, indicating oxygen availability is consistently good and little organic pollution is present.

Species richness is fairly high ranging from 19 to 41. Percent EPT individuals is high (40-75%), and percent Chironomidae individuals is low (2-21%), which both also suggest good water quality.

The two Finn Road samples were collected from different substrates for comparison. The downstream sample was collected from leaf packs snagged on woody debris, while the upstream sample was collected from cobble. The cobble had fairly heavy coatings of periphyton and silt. The sample from cobble had a similar MIBI, a poorer HBI, higher species richness, a lower percent EPT, and a higher percent Chironomids. The coatings of periphyton and entrapped silt on the cobble substrate were probably a major reason for these differences.

The high quality of the macroinvertebrate community found is consistent with past findings for the Nemadji River. One of the conclusions of "The Red Clay Project Final Report Summary" (Andrews et al. 1979) was that "number of macroinvertebrates per unit area, total number of taxa, diversity, and biomass are not significantly affected by clay turbidity and siltation within the Nemadji River system".

Table 3. Lower Nemadji River Macroinvertebrate Sample Results

Site	SWIMS station #	Date	Macroinvertebrate Index of Biotic Integrity (MIBI)	MIBI Condition Category	Hilsenhoff Biotic Index (HBI)	HBI Condition Category
Nemadji R. 15 m DS Dedham Rd.	10044435	11/02/2015	8.75	excellent	3.99	Very good
Nemadji R. 25 m US Finn Rd.	163233	10/22/2015	9.04	excellent	4.96	Good
Nemadji R. 10 m DS Finn Rd.	163233	10/22/2015	9.32	excellent	2.78	Excellent
Nemadji R. 135 m DS STH 35	163048	11/02/2015	8.69	excellent	3.85	Very good
Nemadji R. 60 m US CTH C	163003	10/22/2015	11.62	excellent	3.73	Very good
Nemadji R. 3 mi. DS CTH C	10044397	10/22/2015	11.34	excellent	3.61	Very good

Table 3.(cont.) Lower Nemadji River Macroinvertebrate Sample Results				
Site	Species Richness	% EPT* Individuals	% EPT* Genera	% Chironimidae Individuals
Nemadji R. 15 m DS Dedham Rd.	39	60	46	13
Nemadji R. 25 m US Finn Rd.	36	40	41	21
Nemadji R. 10 m DS Finn Rd.	19	75	78	2
Nemadji R. 135 m DS STH 35	41	52	38	15
Nemadji R. 60 m US CTH C	33	69	61	13
Nemadji R. 3 mi. DS CTH C	35	72	58	9
*EPT = ephemeroptera (mayflies), plecoptera (stoneflies), trichoptera (caddisflies) Complete sample result information is available on WI DNR's SWIMS data base.				

REFERENCES

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Roesler, C.R. 2014. Nemadji River and trbutaries water quality assessment. Wisconsin Dept. of Natural Resources.

Appendix 10

Nemadji River Watershed Implementation Planning Report
(Pertains to management action 6.05)

January 15th, 2017

Final Project Report

Project Name: Nemadji Watershed Implementation Planning

Name and Contact Information: Christine Ostern, Douglas County Land Conservation Department

Project Deliverables Summary

The following activities have been completed.

Phase 1 Activities: December 2015 – June 2016

- Develop a Nemadji Watershed Implementation Strategy
- Compile landowner database
- Compile natural resource information for the watershed
- Compile watershed maps
- Develop a newsletter and mail to resident landowners (approximately 1600 residents)
- Conduct a Watershed Informational Workshop
- Coordinate with Carlton County Soil and Water Conservation District

Phase 2 Activities: July 2016 – December 31st, 2017

Implement the Nemadji Implementation Plan developed during Phase 1.

Convene and coordinate a Wisconsin stakeholder group

- Convene a minimum of 4 meetings of this group

A watershed stakeholder group was formed that included 10 watershed residents. This group included three county board members and one town elected official. Other participants included staff from City of Superior Environmental Services, Douglas County Ag/Horticulture Extension and Carlton County Soil and Water Conservation District. This group met four times at the Superior Town Hall from 6-8pm.

Develop informational workshops to provide information on water quality issues.

- Target audience of at least 30 watershed residents

Topics of informational workshops that were developed included stormwater management, public and private landowner forest management strategies, land stewardship, watershed management and erosion control.

Identify a minimum of 3-5 landowners who agree to explore cost-share opportunities to implement best management practices on their property.

- Schedule site visits and provide technical assistance to landowners to apply for relevant cost-share opportunities.
- Schedule follow-up site visits for landowners with other natural resource professionals.

Site visits were conducted on 5 properties (see attached map). Referrals were made to NRCS for 3 of the sites which have been followed up with site visits by NRCS staff.

Maintain communication with Carlton County SWCD to identify ways to continue to collaborate on outreach activities.

Carlton County staff attended several of our staff planning meetings, participated in the watershed tours, provided resources/handouts to workshop participants and invited staff to attend several of the CC SWCD meetings.

Summary of Activities Completed

Activity	Target #	Actual #	# Contacts	Comments
Implementation plan	Completed	Completed		
Compilation of landowner database	Completed	Completed		
Compilation of natural resource information and maps	Completed	Completed		
Stakeholder committee members	10	10		
Stakeholder committee meetings	3	4		
Workshops/Informational Sessions	4	5	119	
Landowner site visits	3-5	5		3 have submitted NRCS applications
Coordination with Carlton County SWCD	-	On-going		
Newsletter	-	1	1600	
Mailings	1	2	1640	

<u>Supporting documents</u>

- Implementation Plan
- Map of landowner parcels who scheduled site visits
- Stakeholder committee contacts
- Stakeholder committee meeting agenda
- Open House Flyer
- Workshop Invitation
- Landowner site visit form
- Newsletter
- Photos

Nemadji Watershed Implementation Strategy

Douglas County has increased the local capacity for addressing watershed issues in the Nemadji River through the engagement of landowners, community leaders and local decision-makers. Educational workshops have increased stakeholder knowledge of water resource problems and provided information on best management practices to reduce runoff and facilitate the implementation of projects that will improve watershed health.

Year One Activities

Information on the Nemadji River Watershed organized

Landowner database compiled

- A Wisconsin landowner database was compiled and organized into categories for mailings and other contacts. These categories included full-time residents, part-time residents, in-state or out-of-state landowners and non-resident landowners.

Natural resource information for watershed compiled

- Information on the Nemadji River watershed (WI and MN) was compiled into a database including planning, research and management documents that are relevant to watershed issues, research, modeling and best management practices.

Watershed maps compiled

- The open lands update for the watershed (2014) was incorporated into Douglas County Lake Superior basin information. The current information on wetland functions and potentially restorable wetlands were identified in the Nemadji watershed and updated. The high priority subwatersheds in the Nemadji watershed were identified from the watershed-based plan for the County.

Outreach Programming Developed

Outreach programs were developed and implemented for several target audiences: Wisconsin (and Minnesota) landowners, local government officials and a focused watershed group of Wisconsin stakeholders. Information and outreach materials were developed for each audience targeted and included:

- A newsletter was developed and mailed to Wisconsin landowners. It was developed in coordination with Carlton County Soil and Water Conservation District (SWCD) staff. The content was watershed-wide and had information on both the Carlton County SWCD and the Douglas County Land Conservation Department management efforts in the Nemadji River watershed. In addition to several short articles it also included map(s), contact information a short survey to identify landowners who are interested in receiving additional information and attending an informational workshop.

- Watershed informational workshop
  Landowners responding to the survey (sent in the newsletter) were invited to attend an informational workshop in April. This workshop provided information on watershed health, wetland functions in watersheds and current management activities to reduce erosion. Information and recommendations about the watershed-based plan developed for Douglas County were presented with specific information related to the Nemadji River watershed. Contact lists were developed from the list of attendees at this workshop in order to identify stakeholders who have an interest in receiving additional information.

- Wisconsin stakeholder meeting (#1)
  Recruitment for the stakeholder watershed planning committee commenced with this workshop. The goal was to recruit 15 stakeholders to participate in the next phase of planning. City and County local government officials and other community leaders whose jurisdictions include areas within the watershed were contacted and invited to participate. This planning committee participated in several meetings and workshops and stakeholders who committed to participating in the Nemadji watershed planning committee were eligible for the stipend available through this project and expectations for participation were discussed (minimum number of meetings, workshops). The focus of this stakeholder group was to learn about watershed issues, best management practices for reducing runoff and erosion and initiated the development of a 'slow the flow' outreach strategy for the watershed. They learned more about opportunities for funding and cost-share for individual implementation projects. The first workshop was scheduled summer 2016.

- Presentations and outreach materials were developed for Wisconsin landowners and focused on watershed health issues. They included the work recently completed by the Douglas County Lake Superior Basin watershed-based plan that includes identification of wetland restoration and preservation priorities, riparian restoration and forest management best management practices to slow stormwater runoff. Watershed (HUC 12) and subwatershed (HUC 14) maps depicting high priority areas for implementation of these practices in the Nemadji River watershed were discussed. Additional land use/land cover information available for the watershed was also included in these presentations.

- Watershed-wide outreach
  A watershed-wide (Wisconsin and Minnesota) watershed tour was coordinated in the spring with the Carlton County Soil and Water Conservation District (SWCD). This tour included site visits to areas where current management practices are being implemented. Information on best management practices to reduce erosion were discussed and outreach materials containing information to assist landowners in implementation of BMPs on their land were distributed.

Coordination with other Nemadji Watershed projects

Staff coordinated outreach efforts with groups involved with Nemadji Watershed research and outreach that included in-person meetings, phone conversations and/or other means of communication on the progress of the project. These contacts included the following: Andy Robertson (SMUMN), Carlton County Soil and Water Conservation District, modeling scenarios (TetraTech), TMDL modeling (MPCA), Army Corps of Engineers (sediment modeling) and Lake Superior Basin Restoration Partnership (WDNR).

Year Two Activities

Outreach Programming

Workshops were scheduled for the WI Nemadji Watershed committee in order to assist participants in the identification of best management practices that could be implemented at a variety of scales in the watershed to reduce runoff and minimize erosion. This included on-site water retention and infiltration practices, riparian restoration, streambank stabilization techniques and landowner forest management programs. Participants learned about cost-share opportunities for implementation of these projects. Local and regional experts were available to present and discuss the types of practices currently being utilized.

The goals of these workshops were to 1) develop an increased understanding of how watershed issues impact individual landowners and the cumulative impacts of land use practices on aquatic resources and 2) increase local capacity for implementing projects through engagement of local government, community leaders and stakeholders.

Workshops for the WI. Nemadji Watershed committee were scheduled as follows:
- Workshop #3: October 2016
- Workshop #4: April 2017

Meetings were coordinated to assist participants in the development of an outreach and implementation strategy for other landowners and community leaders in the watershed. These stakeholders were encouraged to disseminate their experiences of implementing BMPs to neighbors and community members. Topics were determined by the watershed planning committee and included discussions of the goals, development of successful outreach strategies and long-term strategies for stakeholder engagement.

WI Nemadji Watershed committee meetings were scheduled as follows:
- Meeting #1 : September 2016
- Meeting #2: January 2017
- Meeting #3: March 2017

Watershed-wide outreach

A second watershed tour was coordinated with the SWCD in May/June 2017. Additional events were developed through discussions with SWCD staff.

Next Steps

Primary considerations for next steps beyond this grant effort will include:

- Identifying needs for project design assistance, cost share and other support for implementing best management practices for reducing runoff and erosion
- Strategies for continuing funding and outreach efforts in the watershed
- Expanding watershed partnerships to include groups such as (for example) Northern Institute of Applied Climate Science, West Wisconsin Land Trust, Wisconsin Towns Association, Wisconsin Farmers Union, Ruffed Grouse and American Woodcock Society. This will form the foundation for a coalition with the capacity to further develop and implement watershed protection, restoration and participation into the future and beyond any one grant-funded project.

Timeline

Activities	Q1 12/2015 – 3/2016	Q2 4/2016 – 6/2016	Q3 7/2016 – 9/2016	Q4 10/2016 – 12/2016	Q5 1/2017 – 3/2017	Q6 4/2017 – 6/2017	Q7 7/2017 – 9/2017	Q8 10/2017 – 12/2017
Develop and finalize Implementation Plan								
Organize information on the Nemadji River Watershed								
Compile landowner database								
Compile watershed maps								
Develop Outreach Programming								
Design and send newsletter *(2nd newsletter sent through other funding)*								
Landowner informational workshop								
Stakeholder Meetings								
Stakeholder workshops								
Watershed tours and outreach coordination with MN partners								

Stakeholder committee contact information

Nemadji Watershed Planning Committee

Planning committee members	Affiliation	email
Doug and Donna Hank	Watershed resident	joshua4340@yahoo.com
Susi Pakes	Watershed resident	badger5757@gmail.com
Mary McConnell	Watershed resident	aandeg1952@gmail.com
Janet Dalbec	Town of Superior	jan4joy@centurytel.net
Pat Ryan	Douglas County Board	pat.ryan@douglascountywi.org
Dan Corbin	Douglas County Board	dandcorbin@gmail.com
Jeff O'Flanagan	Watershed resident	jeffrey.oflanagan@wisconsin.gov
Kay McKenzie	Watershed resident	kamck@chartermi.net
Terry White	Douglas County Board	twmillwhite@yahoo.com
Jane Anklam	Douglas County Extension	jane.anklam@ces.uwex.edu
Andrea Crouse	City of Superior	crousea@ci.superior.wi.us
Melanie Bormier	Carlton County SWCD	melanie.bomier@carltonswcd.org
Nicky Martin	WDNR	nichol.martin@wisconsin.gov

Example meeting agenda

Nemadji Watershed Planning Committee Meeting Superior Town Hall
February 2, 2017

Attendees:

Mary McConnell	Kay McKenzie
Mark McConnell	Jeff O'Flanagan
Doug Hank	Donna Hank
Andrea Crouse	Jane Anklam
Christine Ostern	Mike Gardner
Sue O'Halloran	

Agenda Items

- Restate purpose of planning group
- Site visits, reviewed form for participation
- Stipends
  - Discussed stipends available to committee; described process for sign-up
- Proposed outreach activities: workshop or open house in spring 2017
  - Venue, date, potential topics, etc. for workshop/open house

Committee members expressed interest in an open house
General theme: stewardship planning, watershed practices to protect/improve water quality, wildlife habitat
Types of presentations and displays:
Venue

- Superior Town Hall, Saturday afternoon in April

Audience

- Postcard/invitations sent to landowners; City of Superior; local elected officials
- PR for event; Andrea will provide her contact list

Speakers

- 2-3 presentations, each ~ 15 mins. plus Q&A
- Scheduled through the afternoon

Displays

- Stewardship planning
- Managing land/forests for wildlife and water quality
- Native plants, pollinators and gardens
- Forest management on public/private land
- Erosion control
- Groundwater

Provide refreshments, native plants for sale, tree seedling give-away?
Survey for attendees: interest in receiving information, site visit, etc.

Additional discussion items: Mary Mc. discussed her project with UWS: native plant guide, handed out plant guide

Landowner Site Visit Form

Nemadji Watershed Implementation Planning Project

Landowner Application for Implementation Information

Landowner and Property Information:

Name____

Address____

Phone____________________ **Email**________________________

Property location if different from address:

Size of property (acres):

Landowner interests (circle all that apply):

agriculture practices
erosion control
forest planning & management
pollinator habitat
preservation/conservation easements
shoreland management
water quality in watershed
wetland planning & management
wildlife habitat
others (please list):

Interested in cost-sharing? yes no

Landowner Request

I wish to implement conservation practices on my property that will address my interests. I also wish to meet with a conservation specialist at my property to evaluate how my interests can be met implementing various practices utilizing programs that are available through multiple agencies. I understand that this determination does not obligate me to participate in a program nor does it obligate the Douglas County Land Conservation Department to provide cost share assistance to me.

Landowner signature:

____ **date**__________________

County Conservationist signature:

____ **date**__________________

- for internal use only –

Site visit notes:

Recommended programs/agency contacts (check all that apply):

__ County wetland program
__ County cost-share program
__ NRCS (standard programs and LSHRP)
__ WDNR Wildlife Prog.
__ WDNR MFL
__ WDNR WFLGP
__ USFWS Private Landowner Prog.
__ Other(s):

Follow-up correspondence to landowner done and filed:

Date and initials ______________________________

Appendix 11

Total Phosphorus Data for Western Lake Superior Site Su19

Total Phosphorus Data for Western Lake Superior Site Su19
USEPA Biology Monitoring Program (1996-2015)

Data Source: https://cdx.epa.gov/

Season	Year	Type (1)	Station Depth (m)	TP (ug/L)
Spring	1996	INT	183.02	3.9
Summer	1996	INT	185.00	4.5
Spring	1997	INT	192.94	2.1
Summer	1997	INT	191.41	3.0
Spring	1998	INT	192.02	8.0
Summer	1998	INT	188.37	4.2
Summer	1999	DCL	191.40	2.4
Spring	1999	INT	193.00	2.8
Summer	1999	INT	191.40	2.8
Spring	2000	INT	188.70	1.5
Summer	2000	INT	186.00	1.3
Spring	2001	INT	192.30	1.0
Summer	2001	INT	192.30	3.8
Spring	2002	INT	194.00	3.1
Summer	2002	INT	186.30	2.3
Summer	2003	DCL	187.70	1.1
Spring	2003	INT	184.60	2.5
Summer	2003	INT	187.70	1.2
Summer	2004	DCL	185.80	1.9
Spring	2004	INT	187.80	1.5
Summer	2004	INT	185.80	2.5
Summer	2005	DCL	186.80	2.3
Spring	2005	INT	187.70	1.9
Summer	2005	INT	186.80	2.5
Summer	2006	DCL	185.80	2.9
Spring	2006	INT	187.70	2.4
Summer	2006	INT	185.80	2.5

Season	Year	Type (1)	Station Depth (m)	TP (ug/L)
Summer	2007	DCL	191.10	2.9
Spring	2007	INT	187.70	1.6
Summer	2007	INT	191.10	2.9
Summer	2008	DCL	185.80	1.8
Spring	2008	INT		2.0
Summer	2008	INT		2.4
Summer	2009	DCL	185.80	1.4
Spring	2009	INT		1.6
Summer	2009	INT		2.0
Summer	2010	DCL	185.80	3.2
Spring	2010	INT	187.70	3.0
Summer	2010	INT	185.80	3.0
Summer	2011	DCL	185.80	2.2
Spring	2011	INT	187.80	1.9
Summer	2011	INT	185.80	2.7
Summer	2012	DCL	185.80	3.5
Spring	2012	INT	186.80	3.3
Summer	2012	INT	185.80	1.9
Summer	2013	DCL	181.20	2.2
Spring	2013	INT	183.00	2.1
Summer	2013	INT	181.20	3.9
Summer	2014	DCL	186.00	3.0
Spring	2014	INT	183.20	2.2
Summer	2014	INT	186.00	2.8
Summer	2015	DCL	179.00	1.7
Spring	2015	INT	183.00	2.4
Summer	2015	INT	179.00	3.3
			Mean from 1996 to 2015	**2.6**
			Range from 1996 to 2015	**1.0 - 8.0**

(1)

INT = integrated sample collected from the whole water column (spring) or the epilimnion (summer)

DCL = Deep Chlorophyll Layer, a discrete sample from the summer deep chlorophyll maximum

Appendix 12

Public Involvement Process and Letters of Support

BUI 6 Technical Team Members (2016-2019)

Jane Anklam	Wisconsin Landmark Conservancy
Richard Axler	UMN Natural Resource Research Institute
Donalea Dinsmore	Wisconsin Department of Natural Resources
Kari Hedin	Fond du Lac Band
Joel Hoffman	US Environmental Protection Agency
Richard Kiesling	US Geological Survey
Tonia Kittelson	City of Superior
Diane Nelson	City of Superior
Christine Ostern	Douglas County
Hannah Ramage	Lake Superior Reserve
Euan Reavie	UMN Natural Resource Research Institute
Craig Roesler	Wisconsin Department of Natural Resources
Shon Schooler	Lake Superior Reserve
Michele Wheeler	Wisconsin Department of Natural Resources
Ashley VandeVoort	Douglas County

Huberty, Barbara (MPCA)

From:	ntf5418@lakeconnections.net
Sent:	Friday, March 20, 2020 5:46 PM
To:	Huberty, Barbara (MPCA)
Cc:	Matthew.Steiger@wisconsin.gov; Kris Eilers
Subject:	Comments of Proposal to Remove SLRAOC the Excessive Sediment and Nutrient Loading Beneficial Use Impairment
Attachments:	20200318 NTF SED-NUT BUI REMOVAL COMMENTS.pdf

Barb,

I am pleased to provide you with my thoughts regarding the proposal to remove the SLRAOC Sediment and Nutrient Impairment.

I fully concur with the fact that identified "Legacy" issues have been addressed and the acknowledgment that full implementation of existing and any future regulatory programs must be conducted to ensure long term protection of the St. Louis River Estuary and Lake Superior. 3 of 9 impairments removed! Congratulations on a job well done! Looking forward to the removal of 6 more impairments and full SLRAOC delisting by 2025!

My 10 cents worth for what it is worth.

Congrats on the continued forward progress.

Regards,

Nelson T. French
The Boulders
5418 Rocky Wall Road
Silver Bay, MN 55614-4245

Mobile: 612.237.5171
Email: ntf5418@lakeconnections.net

"In the shadow of a nation
That once had its head so high
Hope for generations
Where white doves did fly

Now fear and dread are upon us
The soul of the land on a thread
Freedom's disappearing
Lady Liberty hangs her head

The halls of justice are bleeding
Illusion and lies swirl around

Right and wrong a talk show game
Truth cannot be found

A deceiver is among us
Spinning nightmares in our head
Fear and division his trademark
Fanning the flames to spread"

Scarlet Rivera
Lady Liberty

COMMENT FORM

for

St. Louis River Area of Concern

Removing the Excessive Sediment and Nutrient Loading Beneficial Use Impairment

Your feedback is very important to the four agencies implementing the St. Louis River Area of Concern Program: the Fond du Lac Bank of Lake Superior Chippewa, the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, and the Wisconsin Department of Natural Resources. In the space below, please provide your comments regarding the proposal to remove the Excessive Sediment and Nutrient Loading Beneficial Use Impairment (BUI).

Please complete this form and return it by email to: barbara.huberty@state.mn.us or mail it to: Barb Huberty (MPCA) at the mailing address on the back of the form. ***All comments must be submitted before 5:00 pm on Tuesday, March 24, 2020.*** You may attach additional pages if needed.

To submit comments or petitions to the AOC agencies through the mail or email, you must state:

1) Name and address
2) The action you wish the AOC agencies to take, including specific references to the section of the draft BUI removal you believe should be changed.
3) The reasons supporting your position, stated with sufficient specificity as to allow the AOC agencies to investigate the merits of the position.

Please print clearly:

Name: Nelson T. French

Mailing address: 5418 Rocky Wall Rd., Silver Bay, MN 55614

Email address: ntf5418@lakeconnections.net

Actions desired (please reference pages of the BUI removal document that pertain) & supporting reasons:

I have reviewed the proposed Removal Recommendation for Excessive Loading of Sediment and Nutrients Beneficial Use Impairment in the St. Louis River Area of Concern and am pleased to inform you that I fully concur with said proposal as the SLRAOC Team has fully documented that the conditions for removal have been met.

Specifically I concur with the articulation in the Executive Summary on pages ii-v that the team has documented that the following conditions have been met:

1. All federal, state, and local point source and nonpoint source discharge permits in the AOC are in compliance with regard to controlling sources of nutrients (particularly nitrogen and phosphorous), organic matter, and sediment.
2. Total phosphorus concentrations in the Lake Superior portion of the AOC do not exceed 0.010 mg/L (upper limit of oligotrophic range)
3. There are no exceedances of the most protective water quality standard for either state in the western basin of Lake Superior due to excessive inputs of organic matter or algal growth attributed to loadings from wastewater overflows into the St. Louis River
4. Total phosphorus concentrations within the St. Louis River portion of AOC do not exceed an interim guide of 0.030 mg/L (upper limit of esotrophic range) or the most restrictive water quality standards. This ensures that anthropogenic sources and activities in the St. Louis River AOC do not result in excessive productivity and nuisance conditions within the St. Louis River Estuary.

Additional Comments:

I found the use of paleolimnological data documenting historic trends from "presettlement" through present a particularly useful analysis. Not only did this study document the success of environmental regulations implemented in the 1970's, but also provideded a better understanding about the pre-industial conditions present in the natural system. I fully concur with the fact that identified "Legacy" issues have been addressed and the acknowledgment that full implementation of existing and any future regulatory programs must be conducted to ensure long term protection of the St. Louis River Estuary and Lake Superior. 3 of 9 impairments removed! Congratulations on a job well done! Looking forward to the removal of 6 more impairments and full SLRAOC delisting by 2025!

Thank you for your feedback!

ST. LOUIS RIVER ALLIANCE
Working together to protect, restore, and enhance the St. Louis River

St. Louis River Alliance
394 Lake Avenue S, Suite 208
Duluth, Minnesota 55802-2338
Phone: 218-733-9520

April 3, 2020

Barb Huberty
St Louis River Area of Concern Coordinator
Minnesota Pollution Control Agency
Remediation Division
525 Lake Avenue South Suite 400
Duluth, MN 55802

Re: Support for Proposal to remove the St Louis River Area of Concern Excessive Loading of Sediments and Nutrients BUI

Dear Ms. Huberty,

On behalf of Board of Directors of the St. Louis River Alliance I am pleased to inform you that our board has reviewed the information provided by your agency and we are in agreement with the recommendation put forward by the Wisconsin Department of Natural Resources (WDNR), Minnesota Department of Natural Resources (MNDNR), Minnesota Pollution Control Agency (MPCA) and the Fond du Lac Band of Lake Superior Chippewa to request to the United States Environmental Protection Agency (USEPA) Great Lakes National Program Office's (GLNPO) to approve removal of the St. Louis River Area of Concern Excessive Loading of Sediments and Nutrients BUI.

As you know, the St. Louis River Alliance was actively involved in the development of the St. Louis River Remedial Action Plan and has been participating in the discussions of the specific actions that have been fully completed by the Area of Concern Coordinators. Completion of this work and documentation that all actions have been taken is a tangible milestone for the delisting of the St. Louis River Area of Concern. This is a major accomplishment and we thank you for your work and commitment to this process.

We look forward to our continuing work together to remove the remaining 6 beneficial use impairments and to the eventual delisting of the St. Louis River Area of Concern.

Sincerely,

Kristi S Eilers
Executive Director
St. Louis River Alliance