Erosion and Sedimentation in the Nemadji River Basin

Nemadji River Basin Project Final Report

Natural Resources Conservation Service

U.S. Forest Service

January, 1998
2nd printing, July, 1998
3rd printing, June, 1999

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Acknowledgments

The Nemadji River Basin Project and this document are the result of the commitment and work of many organizations and people who received no compensation except for the knowledge that they contributed to a very worthwhile project. The project coordinators would like to express their thanks to all of them for the many hours of work devoted to this project.

Nemadji River Basin Project Steering Committee:

Brad Borgelt - Chairman
Gordon Aanerud - Carlton County, Minnesota County Commissioner
Paul Brown - Douglas County, Wisconsin County Commissioner
Michael Denton - Metropolitan Interstate Committee
J. Howard McCormick - Formerly of the Environmental Protection Agency, Duluth, MN

Citizens Planning Committee:

Don Busch - Co-chairman, Duluth, MN
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Kent Jacobson - Potlatch Corporation, Cloquet, MN
J. Howard McCormick - Formerly of the Environmental Protection Agency, Duluth, MN
Katherine McKenzie - Douglas County, Wisconsin County Supervisor
Mary Munn - Holyoke, MN
Tatiana Nawrocki - Natural Resources Research Institute, Duluth, MN
Milo Rasmussen - Carlton County, Minnesota Carlton County Land Committee
Eric Rehorst - Carlton County, MN
Herb Udeen - Douglas County Fish & Game League, South Range, WI

Advisors:

Tom Cogger - Natural Resources Conservation Service, Ashland, WI
Tim Koehler - Natural Resources Conservation Service, St. Paul, MN
Sheryl Paczwa - Natural Resources Conservation Service, Madison, WI
Karen Plass - Wisconsin Department of Natural Resources, Superior, WI
Jeff Stewart - Natural Resources Conservation Service, Duluth, MN

Units of Government:

Carlton County Board
Carlton County Soil and Water Conservation District
Douglas County Board
Douglas County Land Conservation Committee
Metropolitan Interstate Committee

Americorps:

Anthony Krozka
Tim Reese
R. C. Boheim

Funding Sources Subcommittee:

Larry Nelson - Chair, Natural Resources Conservation Service, Mora, MN
Mark Nelson - Board of Water and Soil Resources, Duluth, MN
Mike Peloquin - Minnesota Department of Natural Resources, Duluth, MN
JoAnn Nelson - Natural Resources Conservation Service, Mora, MN
Jeff Stewart - Natural Resources Conservation Service, Duluth, MN
Dave Vold - Natural Resources Conservation Service, Spooner, WI

Study Coordinators and Report Editors:

Pete Cooper - Natural Resources Conservation Service, St. Paul, MN
Barbara Lensch - Natural Resources Conservation Service, Madison, WI

Technical Subcommittees:

Agriculture
Dennis Tressel - Natural Resources Conservation Service, Duluth, MN
Randy Gilbertson - Natural Resources Conservation Service, Spooner, WI

Economics
Jan Whitcomb - Chair, Natural Resources Conservation Service, Madison, WI
Bill Stokes - Natural Resources Conservation Service, St. Paul, MN
Lee Raeth - Carlton County Extension, Carlton, MN

Fish, Wetland & Wildlife
Tom Cogger - Chair, Natural Resources Conservation Service, Ashland, WI
Jack Arthur - Environmental Protection Agency, Duluth, MN
Pat Collins - Minnesota Department of Natural Resources, Two Harbors, MN
J. Howard McCormick - formerly of the Environmental Protection Agency, Duluth, MN
Mark Nelson - Minnesota Board of Soil and Water Resources, Duluth, MN

Karen Plass - Wisconsin Department of Natural Resources, Superior, WI
John Spurrier - Minnesota Department of Natural Resources, Duluth, MN
Rich Staffon - Minnesota Department of Natural Resources, Cloquet, MN
Fred Strand - Wisconsin Department of Natural Resources, Brule, WI

Advisors:
Larry Brooke - University of Wisconsin-Superior, Superior, WI
Jay Gallagher - Wisconsin Department of Natural Resources, Brule, WI
Frank Koshere - Wisconsin Department of Natural Resources, Spooner, WI
Tim Quincer - Minnesota Department of Natural Resources, Cloquet, MN
Dennis Pratt - Wisconsin Department of Natural Resources, Superior, WI
Ted R. Smith - Wisconsin Department of Natural Resources, Superior, WI

Forestry
Mike Majeski - Chair, U.S. Forest Service, St. Paul, MN
Lew Castle - Potlatch Corporation, Cloquet, MN
Paul Flynn - Natural Resources Conservation Service, St. Paul, MN
Jay Gallagher - Wisconsin Department of Natural Resources, Brule, WI
Kent Jacobson - Potlatch Corporation, Cloquet, MN
Tim Quincer - Minnesota Department of Natural Resources, Cloquet, MN
Milo Rasmussen - Carlton County, Carlton, MN
Rich Wiest - U.S. Forest Service, St. Paul, MN
Dick Rollefson - Carlton County, Carlton, MN
Marty Wiley - Minnesota Department of Natural Resources, Moose Lake, MN

GIS/Aerial Photography
Adrian Smith - Chair, Natural Resources Conservation Service, Lincoln, NE
Cindy Brooks - formerly Natural Resources Conservation Service, St. Paul, MN
Carol Johnston - Natural Resources Research Institute, Duluth, MN
Dr. Lloyd Queen - formerly of University of Minnesota, St. Paul, MN
Tatiana Nawrocki - Natural Resources Research Institute, Duluth, MN
Don Fruehling - Duluth, MN
Tony Kroska - Americorps, Cloquet, MN
Maryam Mashayeskhi - South Florida Water Management District, West Palm Beach, FL

Hydrology
Pete Cooper - Chair, Natural Resources Conservation Service, St. Paul, MN
Bob Leibfried - Minnesota Department of Natural Resources, Grand Rapids, MN
Dr. Ken Brooks, Ph.D. - University of Minnesota, St. Paul, MN
Elon S. Verry - U. S. Forest Service, Grand Rapids, MN

Sediment and Erosion

Barb Lensch - Chair, Natural Resources Conservation Service, Madison, WI
Ed Bacig - Bay West Inc., St. Paul, MN
Al Klein - U. S. Army Corps of Engineers, Duluth, MN
Steve Lacy - Natural Resources Conservation Service, Albuquerque, NM
Wayne Wold - formerly of University of Minnesota, St. Paul, MN
Faith Fitzpatrick - U.S. Geological Survey, Madison, WI
Tom Alvarez - Natural Resources Conservation Service, Nashville, TN

Transportation

Jeff Stewart - Chair, Natural Resources Conservation Service, Duluth, MN
Robert Ege - Minnesota Department of Transportation, Duluth, MN
Paul Jones - Superior, WI
Dave Ostrowski - Wisconsin Department of Transportation, Superior, WI
Wayne Olson - Carlton County Highway Department, Carlton, MN
Herb James - Burlington Northern Railroad, Superior, WI
George Palo - Douglas County Highway Commission, Superior, WI

Water Quality

Jim Kaap - Chair, Natural Resources Conservation Service, Madison, WI
Marna Butler-Fasteland - formerly Carlton County Soil & Water Conservation Department, Cloquet, MN
Brian Fredrickson - Minnesota Pollution Control Agency, Duluth MN
Karen Plass - Wisconsin Department of Natural Resources, Superior, WI
Greg Johnson - Minnesota Pollution Control Agency, St. Paul, MN
Tim Koehler - Natural Resources Conservation Service, St. Paul, MN

A flowchart showing the interrelationships between the above committees can be found in the Appendix A. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Introduction

The environmental damages caused by sediment laden flows from the Nemadji River Basin have been a concern for decades. It is estimated that the Nemadji River discharges over 130,000 tons of sediment per year into Superior Bay at the entrance to Lake Superior. The Nemadji River has the highest average annual suspended sediment load per square mile drainage area among all U.S. Geological Survey monitored rivers in Minnesota and Wisconsin (personal communication: Tornes, 1987 and Bill Rose, USGS).

Events from the recent geologic past set the stage for the highly erosive state of the Nemadji River Basin today. Ten-thousand years ago, glacial Lake Duluth, which was formed by glacier meltwater blocked by the glacier to the northeast, backed meltwater over a large area including approximately one-half of what is today the Nemadji River Basin. About one-third of the Nemadji River Basin was covered by a thick layer of clay left by previous advances of the glacier and from clay settling offshore in the deep portion of glacial Lake Duluth. Further retreat of the glacier eventually allowed the level of glacial Lake Duluth to drop, exposing the highly erosive clay.

Although much of the basin landscape has a naturally high potential for erosion due to soil type and the difference in elevation between uplands and present day Lake Superior, human activities since European settlement have accelerated the process many fold. Turn of the century logging techniques, clearing of land for agriculture, drainage, over-grazing, and road building have altered the hydrology of the basin. These hydrologic changes have resulted in increased runoff volumes and peak flows which in turn have increased streambank erosion and high bluff slumping.

Due to concern over accelerated pollution of the Great Lakes, the U.S. and Canada entered into the Great Lakes Water Quality Agreement (WQA) in 1972. Subsequent amendments to the Agreement resulted in the designation of 43 "Areas of Concern" of which the St. Louis River System was identified. The Nemadji River Basin is considered a part of the St. Louis River System designation.

Remedial Action Plans (RAPs) for these "Areas of Concern" were formulated to implement provisions of the WQA and restore beneficial uses to those areas. To help coordinate a solution, the RAP committee enlisted the assistance of the Carlton County Soil and Water Conservation District, the Douglas County Land Conservation Committee and the Onanegozie Resource Conservation and Development Council. The result was a project called the **Nemadji River Basin Project**. Participating sponsors include the Carlton County Board of Commissioners, the Douglas County Supervisors and Land Conservation Committee, the Carlton County Soil and Water Conservation District and the Metropolitan Interstate Committee. Coordination of the technical investigations, committee activities, and development of this report were the responsibility of the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA).

The mission of the Nemadji River Basin Project is to recommend remedial actions and treatments that, when implemented, restore beneficial uses to the Nemadji River Basin.

Past Studies

A number of past studies and reports by groups and agencies have contributed greatly to this report. These documents and their findings were brought together and utilized by the Nemadji River Basin Project to avoid duplication of effort. Three main documents and their authors and sponsors deserve mention at this time.

Red Clay Project (Andrews, et al., 1982) - This effort was sponsored jointly by the Environmental Protection Agency (EPA) and the Carlton County (Minnesota) Soil and Water Conservation District (SWCD) and Douglas County (Wisconsin) Land Conservation Department (LCD). This project was a multi-year research and demonstration project carried out in the 1970's. It concentrated mainly on structural measures to stabilize streambanks and steep slopes.

Erosion-Sedimentation and Nonpoint Source Pollution in the Nemadji River Watershed: Status of our Knowledge (Banks and Brooks, 1992) - This is a research document that summarizes the massive amount of research information available on the Nemadji River Basin. This document became Appendix L of the stage one RAP report. Funding for this study was provided by the Carlton County SWCD and the EPA through the Water Quality Division of the Minnesota Pollution Control Agency. The document was completed by Dr. Kenneth Brooks and graduate student Gregory Banks from the University of Minnesota Department of Forest Resources. The Minnesota Department of Natural Resources (DNR) Waters Division was also instrumental in completion of this document.

Analysis of Soil Mass Wasting in the Nemadji River Watershed (Wold, et al., 1994) -This report was co-sponsored by the Carlton County SWCD, the Minnesota Board of Water and Soil Resources, and the University of Minnesota Department of Forest Resources. This effort had two primary goals: 1) to examine cause and effect relationships between slumping and watershed characteristics and 2) develop a prototype Geographic Information System (GIS) for use by the Carlton County SWCD. The report was compiled by Dr. Kenneth Brooks, Dr. Lloyd Queen and graduate student Wayne Wold.

Scoping of Concerns

Scoping of concerns involves soliciting input from local land users and other interested parties. This process provides those working on the project with a local perspective on basin problems and concerns. As part of this process a project "kickoff meeting" was held on January 14, 1994, in Superior, Wisconsin. The purpose of this meeting was to provide information to the watershed community and to solicit input on the project. Two public meetings were subsequently held to obtain input from other parts of the watershed. Numerous resource concerns, issues, questions, and proposed solutions were recorded during these three meetings.

This information was provided to the technical committees to guide them in addressing the resource concerns that were consistent with achieving the mission of the project. Appendix B is a compendium of all the statements made at the three public meetings, as well as opinions solicited from previous Red Clay Project personnel. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

The following table lists resource issues that emerged consistently through the public participation process.

Table 1: Major Resource Issues Raised in the Nemadji River Basin

RESOURCE ISSUE	ISSUES RAISED
Agriculture	What is the impact of livestock grazing on sedimentation in the watershed?
Forestry	How do forest age and species composition affect peak flows?
Economics	To what extent does excessive sedimentation increase dredging costs in the harbor?
Transportation	How much do roads contribute to the sedimentation problem?
Sedimentation and Streambank Erosion	What are the sources of sediment; which subwatersheds contribute the most sediment?
Hydrology	How are volume and peak flow affected by land cover; what is the relationship between hydrology and sedimentation?
Fisheries	What are the impacts of sedimentation and turbidity on the composition and population of fish and fish habitat?
Wildlife	Are beaver dams detrimental or beneficial?
Water Quality	Is sediment impacting water quality in the Nemadji River?

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Project Setting

Location

The Nemadji River Basin has approximately 433 square miles (277,400 acres) of drainage area and is located just south of Duluth straddling the Minnesota-Wisconsin border (Figure 1). Approximately 60 percent of the watershed lies in Minnesota and 40 percent lies in Wisconsin. The Nemadji River Basin is within United States Geological Survey Hydrologic Unit 04010301. The watershed includes southeastern Carlton County and northeastern Pine County in Minnesota, and northwestern Douglas County in Wisconsin. Flows from the Nemadji River enter Superior Bay at Superior, Wisconsin then enter Lake Superior through the Superior Entry navigation channel.

Geology and Soils

The area underlying the Nemadji River Basin consists of primarily igneous and sedimentary rocks which were formed during the Precambrian Era. About 1,100 million years ago, in the area now known as the Lake Superior Basin, the continent began to split apart and a rift zone was formed. Over a period of 25 million years lava flowed out of the rift zone covering hundreds of miles and creating an immense pile of volcanic rocks perhaps two to three miles thick (LaBerge, 1994). As volcanic activity ceased the area began to subside, becoming a basin. Rivers flowed into the low lying area depositing thick layers of sediment which gradually became rock. As a result of this geologic history the predominant rock types in the Nemadji River Basin are extremely thick basalt and other volcanic rocks, thick conglomerate and some sandstone and shale.

Although the Lake Superior Region has a long geologic history, the relatively recent glacial and post-glacial events of the region have contributed greatly to the unstable, erodible soils in the Nemadji River Basin. Approximately two million years ago the Laurentide Ice Sheet covered much of Canada and parts of the United States, including the Nemadji River Basin. Multiple advances and retreats of glacial ice continued until the end of the Pleistocene Epoch, around 10,000 years ago. The glacier scoured out the Lake Superior Basin and deposited the debris as poorly sorted, poorly layered material (till) and the meltwater from the glacier left behind moderately to well sorted, stratified deposits (outwash).

Near the end of the ice age, the Superior Lobe of the Laurentide Ice Sheet began to retreat northeastward. Meltwater was trapped within the basin by the ice mass that lay to the northeast. The water level rose to 1,100 feet above sea level to form glacial Lake Duluth, 500 feet above present day Lake Superior. Roughly half of the what is now the Nemadji River Basin was covered by the lake. The water level in Lake Duluth dropped as the glacier retreated, exposing the red-clay. Wave action on the lake, lake currents, meltwater rivers, and the dense flow of sediment mixed with water beneath the surface of the lake are all ways in which water sorted glacial debris into complex local patterns and landforms. These geologic events produced the following four geomorphic regions:

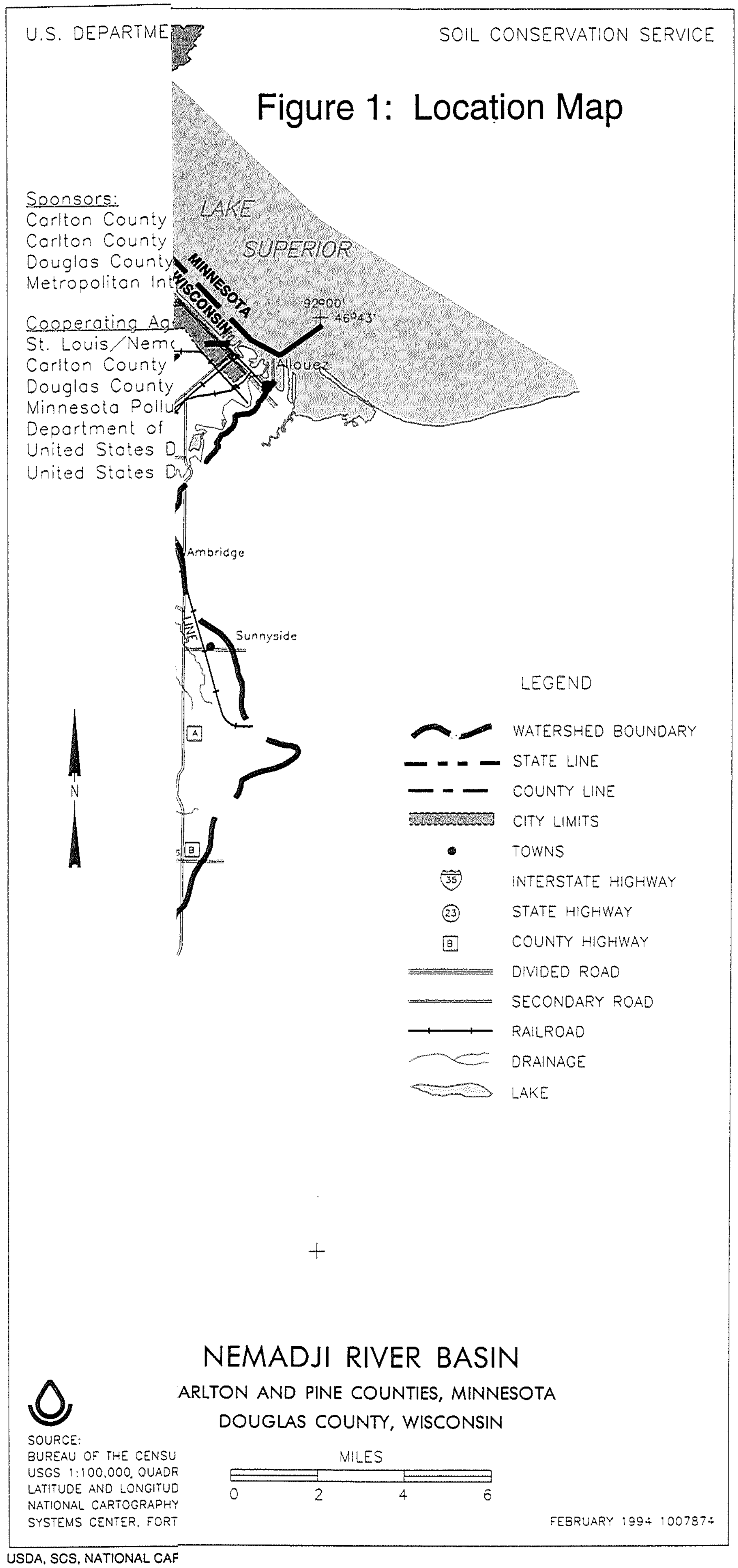
1. red-clay region
2. transition-zone
3. shallow-water and beach deposits
4. upland-till and outwash region

The red-clay geomorphic region consists of clayey deposits ranging from 50 to 200 feet thick. In some areas thin layers of lake-laid clay was deposited over thick clayey glacial till. The lake-laid clay and clayey glacial till are commonly referred to as "red-clay" and are found below 1,100 feet mean sea level (MSL). Red-clay soils cover 33 percent of the Nemadji River Basin and correspond to the offshore-clay geologic unit in Figure 2. Post-glacial erosional processes have produced narrow, steep-sided valleys in the red-clay. The red-clay is highly erodible and subject to extensive mass wasting (slumping, sliding, etc.) particularly where silt or sand is present in discrete layers within the clay. Such layers underlie substantial parts of the clayey deposits within the Nemadji River Basin. The red-clay has low permeability and does not yield much flow to streams. Surface runoff is the major source of streamflow from the red-clay soils.

Bordering the red-clay region is the transition zone, so named since it marks the gradual shift from the deep-water offshore clay to the shallow water beach deposits of Lake Duluth. The transition zone is important to the hydrologic character of the watershed. The zone commonly contains varying thicknesses of sandy or loamy (i.e. containing roughly equal amounts of sand, silt and clay) deposits over heavier clayey or dense loamy till. Water flows laterally through the sand and over the less permeable, dense layers. The upland till and outwash region upslope provides large volumes of runoff to the transition zone soils, especially where slopes meet. Seeps (areas where groundwater discharges at the side of a hill) are present along the base of slopes and along steep banks where coarse and fine-grained materials are interlayered. These seep areas, although of minor extent, are critical to soil stability and streamflow. Seeps on steep slopes are prime areas for slope failure. The slow release of water into stream channels from ground-water makes a significant contribution to the source of base flow (sustained or fair-weather flow) for streams in the Nemadji River Basin.

At the margin of the transition zone are the shallow water and beach deposits (units **Sln** and **Slb** on Figure 2). Laminated (very thin layers) sand and silt were laid down near the shore of glacial Lake Duluth. The very sandy areas were formerly beaches.

Surrounding the shallow water and beach deposits are sandy and loamy upland tills and outwash which make up a distinctly different landscape. The soils derived from this till and outwash are not lake-laid and are generally sandier and less erodible than those derived from the red-clay. The base flow of streams in the Nemadji River Basin is largely derived from infiltration into the sandy till and outwash in the upland area of the watershed.


U.S. DEPARTME
SOIL CONSERVATION SERVICE
Figure 1: Location Map
Sponsors:
Carlton County
Carlton County
Douglas County
Metropolitan Int
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St. Louis/Nem
Carlton County
Douglas County
Minnesota Pollu
Department of
United States D
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LAKE
SUPERIOR
MINNESOTA
WISCONSIN
92°00'
46°43'
Allouez
Ambridge
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WATERSHED BOUNDARY
STATE LINE
COUNTY LINE
CITY LIMITS
TOWNS
INTERSTATE HIGHWAY
STATE HIGHWAY
COUNTY HIGHWAY
DIVIDED ROAD
SECONDARY ROAD
RAILROAD
DRAINAGE
LAKE
NEMADJI RIVER BASIN
ARLTON AND PINE COUNTIES, MINNESOTA
DOUGLAS COUNTY, WISCONSIN
SOURCE:
BUREAU OF THE CENSU
USGS 1:100,000, QUADR
LATITUDE AND LONGITUD
NATIONAL CARTOGRAPHY
SYSTEMS CENTER, FORT
MILES
0 2 4 6
FEBRUARY 1994 1007874
USDA, SCS, NATIONAL CAF

In addition to leaving behind a clay plain and mounds of sand and gravel there is another, lesser known, effect of the recent presence of the glacier. There is a phenomenon in which the crust of the earth is depressed by the weight of the glacier and slowly rebounds once the ice is gone. Although the glacier has been gone for nearly 10,000 years the land has not reached equilibrium and is still rising. The Lake Superior Basin has been rebounding unevenly. The mouths of the Nemadji and St. Louis Rivers are being drowned very slowly (15 cm depth per century) while the north shore of the lake is slowly rising.

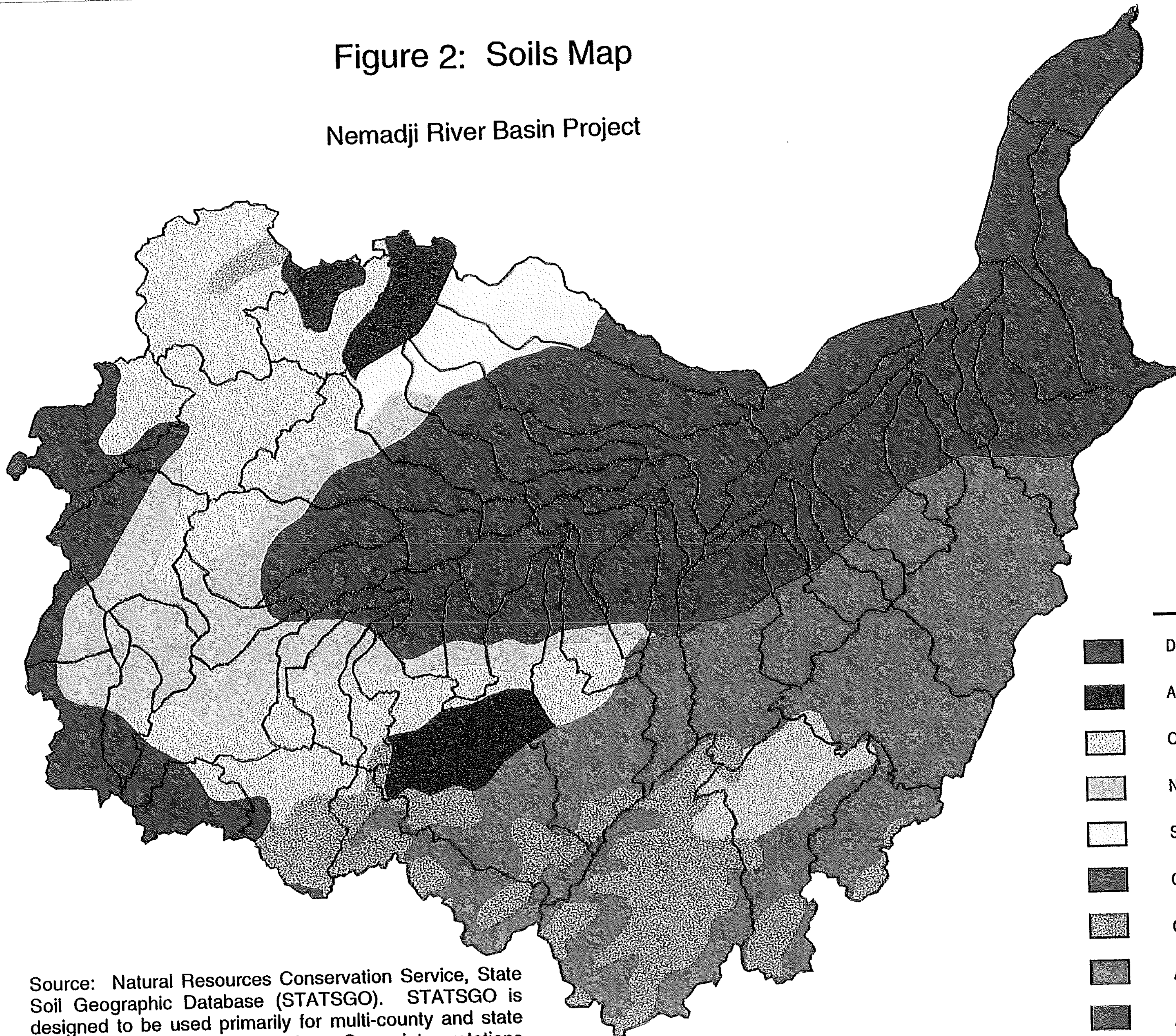
A soils map of the watershed is shown in Figure 2. Comparison of Figures 2 and 3 show the close link between the soils and geology of the basin. The Miskoaki-Amnicon-Cuttre-Bergland (formerly Ontonagon-Bergland-Rudyard) soils coincide with the glacial lake bottom (offshore-clay geologic unit). Abbreviated soils descriptions are found later in this section and more comprehensive descriptions are found in the Soil Survey of Carlton County, Minnesota. For information and a map of the glacial geology of northern Wisconsin, reference the publication Pleistocene Geology of the Lake Superior Region, Wisconsin (Clayton, 1984).

Because bluffs along streams are the principal source of transported sediment in the Nemadji River Basin, the soils lining stream valleys are very important. Dominant soils in stream valleys are Ontonagon silty clay, Bergland clay, and Udorthents (thin soils formed on steep slopes along deeply entrenched streams cut into glacial till and glacial lake clay) the three of which make up 90 percent of the red-clay soils. The remainder of the soils in the red-clay region are organic soils developed in lowlands and wetlands.

There is much interest in the source of sand in the Nemadji River Basin because sand makes up approximately 50 percent (see Figures 18 and 19 on pages 78 and 79) of the dredged material in the harbor. Sand represents 11 percent of the entire sediment load from the mouth of the Nemadji River. Most of the soil in the Nemadji watershed contains sand. Appendix C contains a map showing the percentages of sand occurring in soil at the surface. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover. The sand percentages in the soil vary greatly throughout the watershed and averages roughly 35 or 40 percent.

Figure 2: Soils Map

Nemadji River Basin Project



	SOIL ASSOCIATION	PERCENT OF BASIN
	DUSLER-DULUTH-BLACKHOOF	5%
	AHMEEK-OMEGA-GREENWOOD	4%
	OMEGA-CROMWELL-CLOQUET	14%
	NEMADJI-NEWSON-OMEGA	9%
	SPOONER-BAUDETTE-BEARVILLE	3%
	OMEGA-NEMADJI-MAHTOMEDI	<0.5%
	GREENWOOD-RIFLE-CATHRO	8%
	AHMEEK-RONNEBY-PREBISH	22%
	AMNICON-RUDYARD-BERGLAND	33%
	SAYNER-RUBICON-OMEGA	2%

Source: Natural Resources Conservation Service, State Soil Geographic Database (STATSGO). STATSGO is designed to be used primarily for multi-county and state resource evaluation and planning. Some interpretations may not be suitable for use with watershed projects.

0 4 8 MILES

One Inch Equals Four Miles

Soils Descriptions

The soils map describes general soil associations, named for the dominant soil series in each map unit. The dominant soil types comprise roughly 60 to 90 percent of each unit. There are small percentages of many other soil types present such as wetland soils, alluvial (floodplain) soils, steep ravine areas, and soils strongly contrasting to the dominant soils in the unit. Consult a soil survey of the area (Carlton County, MN) or NRCS office for more specific information.

Duluth-Dusler-Blackhoof These soils are formed in glacial moraines (a landform of assorted, unconsolidated rock material deposited by a glacier; generally an irregular band of hills that has the outline of the margin of the glacier) in loamy glacial till (unsorted, unlayered glacial material). They are found on level to steep slopes. Duluth soils are well and moderately well drained soils on upland slopes, and Dusler and Blackhoof are somewhat poorly to poorly drained soils on flats and in depressions. There are seven drainage classes which refer to the frequency and duration of periods of saturation or partial saturation during soil formation. They range from very poorly drained (water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season) to excessively drained (water is removed from the soil rapidly and soils are commonly very coarse textured, rocky or shallow). Permeability is slow and available water capacity (the capacity of soils to hold water available for use by most plants) is high. Most of the soils are cleared and in hay and pasture, with the rest primarily in woodland. Common tree species are red pine, northern red oak, aspen, eastern white pine and white spruce.

Ahmeek-Omega-Greenwood These soils are formed in glacial moraines and drumlins (an oval or elongated, streamlined hill of glacial till, formed at the base of an ice sheet on a till plain, oriented in the direction the glacier moved, typically with steeper end facing the direction from which the ice came) and associated sandy outwash plains (a broad expanse of sorted, stratified material deposited by meltwater streams). They are found on nearly level to rolling landscapes, with organic soils in depressions. Ahmeek soils are well and moderately well drained sandy loam till soils, with moderately rapid permeability in the upper part and slow in the underlying dense till. They have moderate available water capacity. Omega soils are somewhat excessively drained sandy soils, with rapid permeability and low available water capacity. Greenwood soils are poorly and very poorly drained deep organic soils. Some areas are in hay and pasture, with the dominant cover in woodland. Common tree species are red pine, northern red oak, aspen, eastern white pine and white spruce, with pine species dominating on excessively drained areas.

Omega-Cromwell-Cloquet These soils are formed in sandy outwash plains, eskers (a low, narrow ridge, often sinuous, composed of crudely stratified sand and gravel deposited by meltwater in a tunnel within or at the base of a stagnant glacier, and retaining its form after the ice has melted), kames (steep sided conical hill of water-sorted sands and gravels) and kettles (a depression typically caused by the melting of a block of ice which was buried in glacial deposits). They are found primarily on nearly level landscapes, with steep slopes in eskers, kames and kettles. These soils are somewhat excessively drained with rapid permeability and low available water capacity. Most of the soils in this area are in woodland, with a few areas in hay and pasture. These soils tend to be droughty (dry out easily). Common tree species include red pine, eastern white pine and jack pine.

Nemadji-Newson-Omega These soils are formed in sandy glacial outwash, deltaic (formed in delta) and old beach deposits along the margin of the clay plain. They are found primarily on level glacial lake plains, with some areas of rolling landscapes and steep slopes along drainage ravines. Nemadji and Newson soils are somewhat poorly and poorly drained soils with a high water table, rapid permeability and low available water capacity. Omega soils are somewhat excessively drained sandy soils on higher landscape positions, with rapid permeability and low available water capacity. These soils are primarily in woodland, with a few areas cleared for pasture. Common tree species include red pine, eastern white pine and jack pine. Black spruce and tamarack are common on the poorly drained Newson soils.

Spooner-Baudette-Bearville These soils formed in silty lake-laid material on glacial lake plains and in thin sandy deposits overlying clayey till. The poorly and somewhat poorly drained Spooner and moderately well drained Baudette soils are silt loam to silty clay loam soils with moderate permeability and high available water capacity. The poorly drained Bearville soils have 20 to 40 inches of sandy material overlying clay. They have rapid permeability in the upper material and very slow permeability in the underlying clay, and available water capacity is moderate. The better drained areas are typically cleared for hay, pasture or cropped, having fairly high fertility. Favored tree species for existing woodland stands are red pine, northern red oak, aspen, eastern white pine and white spruce. Black ash, speckled alder, cedar and black spruce are common in poorly drained areas.

Omega-Nemadji-Mahtomedi These soils formed in sandy deposits in glacial outwash and lake plains. Omega and Nemadji soils have loamy sand to fine sand in the upper 20 inches, with sand below, and Mahtomedi soils are medium and coarse sand throughout. They all have rapid permeability and low available water capacity. The somewhat excessively drained Omega and excessively drained Mahtomedi soils occur on upland slopes and the somewhat poorly drained Nemadji soils occur on level landscape positions and have a high water table. These soils are primarily in woodland, with the predominant species being red pine, eastern white pine and jack pine.

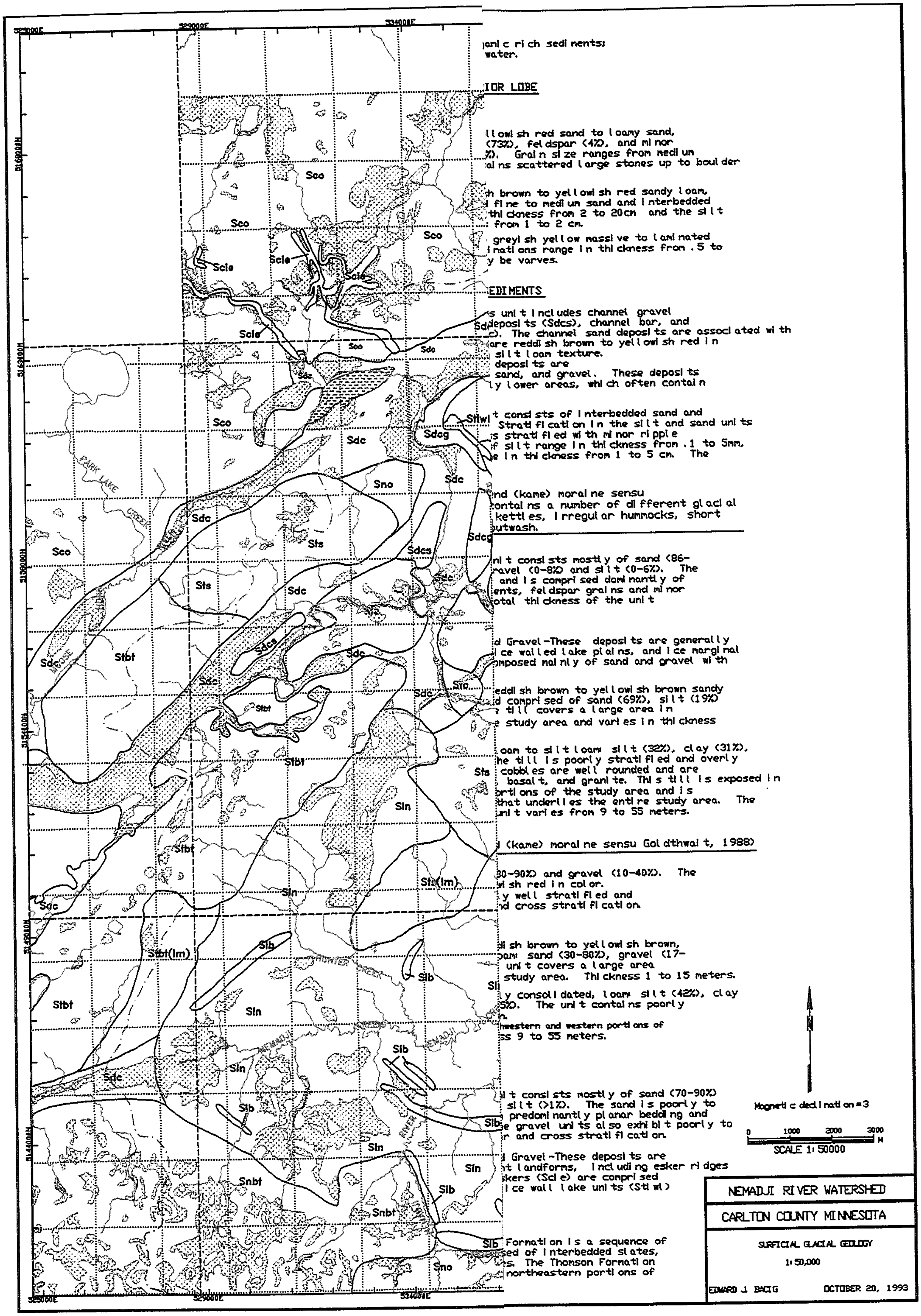
Greenwood-Rifle-Cathro These soils are bogs and swamps which occur in depressions and drainageways. They are organic soils, with 16" or more of accumulated muck, peat or woody debris over mineral soil. These are very poorly drained, having a high water table from one foot above to one foot below the surface for some time in most years. Permeability is moderately rapid to moderately slow. Small mineral soil (non-organic) "islands" and ridges occur in these areas, with well drained to somewhat poorly drained conditions. These swamps are generally in native vegetation, either sedge meadow, alder, or black ash in non-acid swamps, and black spruce, tamarack, or northern white cedar with sphagnum moss in more acid bogs.

Ahmeek-Ronneby-Prebish These soils formed in silty and loamy glacial till, on drumlins, ground moraine (rock debris carried by a glacier and deposited under the ice as it moved or melted) and end moraines (a moraine deposited at the end of a glacier). Slopes range from level to moderately steep. Ahmeek soils are well and moderately well drained, Ronneby soils are somewhat poorly drained and Prebish are poorly and very poorly drained. They have moderately rapid permeability in the upper part, commonly with dense, slowly permeable sandy loam to loam till at 40 to 60 inches depth. Stones and cobbles are commonly abundant. These soils have perched water tables above the contact with dense materials. They have moderate available water capacity. These soils are primarily in woodland, of mixed deciduous-conifer forest. Major species of trees include aspen, northern red oak, balsam fir, eastern white pine and paper birch. Some areas are used for hay and pasture.

Amnicon-Rudyard-Bergland These soils formed in clayey glacial till and lake plains. They are the predominant soils in the lower part of the Nemadji Basin, and occur on level to gently rolling landscapes with steep ravines in drainageways. Amnicon soils are moderately well drained, Rudyard soils are somewhat poorly drained and Bergland are poorly drained. They have very slow to extremely slow permeability, moderate available water capacity, and high shrink-swell capacity due to the high clay content. These soils have perched water tables at or near the surface with duration of saturation dependent on landscape position. These soils are in mixed woodland and cleared for hay and pasture. Some areas are in small grain crops, but adaptability for cropping is limited by the low permeability and limited rooting zone. Common tree species include aspen, red maple, balsam fir, white spruce, red pine, eastern white pine, and paper birch.

Sayner-Rubicon-Omega These soils formed in sandy deposits in glacial outwash and lake plains. Sayner and Omega soils have loamy sand to fine sand in the upper 20 inches, with sand below, and Rubicon soils are medium and coarse sand throughout. Sayner soils also are very gravelly below 20 inches. They are excessively drained, have rapid permeability and low available water capacity. These soils are primarily in woodland, with the predominant species being red pine, eastern white pine and jack pine.

ıgic Map (Minnesota only)



Hydrologic Setting

Rivers and Tributaries

The Nemadji River is comprised of three main tributaries: the main stem Nemadji River, the South Fork Nemadji River, and the Black River. For study purposes, the entire watershed was divided into 67 subwatersheds for hydrologic, sedimentation, and land use evaluations. These subwatersheds range from 140 to 16,100 acres in size. Figure 4 on page 25 shows these divisions. Table 6 on page 38 within the land use section of this report gives the subwatershed names and associated drainage areas.

There is a difference in elevation of approximately 720 feet from the source of the Nemadji River in Pine County to the outlet in Superior Bay. In its lower reaches the main stem of the Nemadji River is highly sinuous with many meanders and abandoned meanders, termed oxbow lakes, in its floodplain. This reach has an average gradient of two feet per mile and extends up to approximately the confluence with the Black River. From this confluence upstream to approximately the 1,100 foot MSL (mean sea level) elevation the Nemadji River becomes markedly entrenched and its channel is from 100 to 200 feet below the surrounding nearly level former lake plain. The 1,100 foot elevation is significant in that it represents the abandoned shoreline of glacial Lake Duluth. Below the 1,100 foot elevation, most of the channels are incised into glacial clay and drainage patterns are well developed. Typical channel slopes of the Nemadji River from this 1,100 foot elevation down to the confluence with the Black River are approximately 30 feet per mile. Typical channel slopes of the tributaries flowing down from this elevation to the main rivers average 45 to 55 feet per mile. Above the 1,100 foot elevation the terrain is relatively flat with several lakes and large wetlands. Slopes of tributaries in this upland region are in the range of 15 to 25 feet per mile. See Figure 5 on page 28 for a depiction of the gradients of the tributaries with respect to the main and south stems of the Nemadji River.

Wetlands

An analysis of the soils data indicates that approximately 24 percent of the soils within the Nemadji River Basin are classified as wetland type soils (hydric). This percentage includes both current wetland soils and drained wetland soils. The acreage of each separately is difficult to determine. The largest amount of wetland loss has been predominantly in agricultural areas. Approximately 10 percent (5,000 acres) of cropland/hayland acreage contain hydric soils that have been drained or filled for agricultural purposes. Urban development and road building have also contributed to loss of wetland.

Climate and Climatic Trends

The average temperature throughout the year in the watershed is about 40 degrees Fahrenheit (F). The monthly average temperatures range from a low of 8 degrees F in January to a high of 68 degrees F in July. The average last spring date having a low minimum daily temperature of 32 degrees F or colder is June 1. The average first fall date having a low minimum daily temperature of 32 degrees F or colder is September 14. Using 32 degrees F as a base, there are approximately 105 days in the growing season.

Data from a climate station located at Cloquet, Minnesota, shows that average annual rainfall is 30.6 inches. Of this precipitation, 62 percent occurs during May through September. There is an average of 57 days per year with precipitation greater than 0.1 inches. Average snowfall is 67 inches with an average of 140 days with at least 1 inch of snow on the ground.

Variations in precipitation patterns over time can have a significant impact on the runoff volume of a region. Records from the Cloquet, Minnesota climate station suggest that annual rainfall totals have increased about 20 percent since 1912. An analysis of variance (ANOVA) statistical test shows that this upward trend was highly significant at the one percent level. Also, the annual mean precipitation from 1953 through 1994 is 2.7 inches higher than the 1911-1952 mean. A Student's T-test comparing these different means show the difference to be statistically significant at the one percent level.

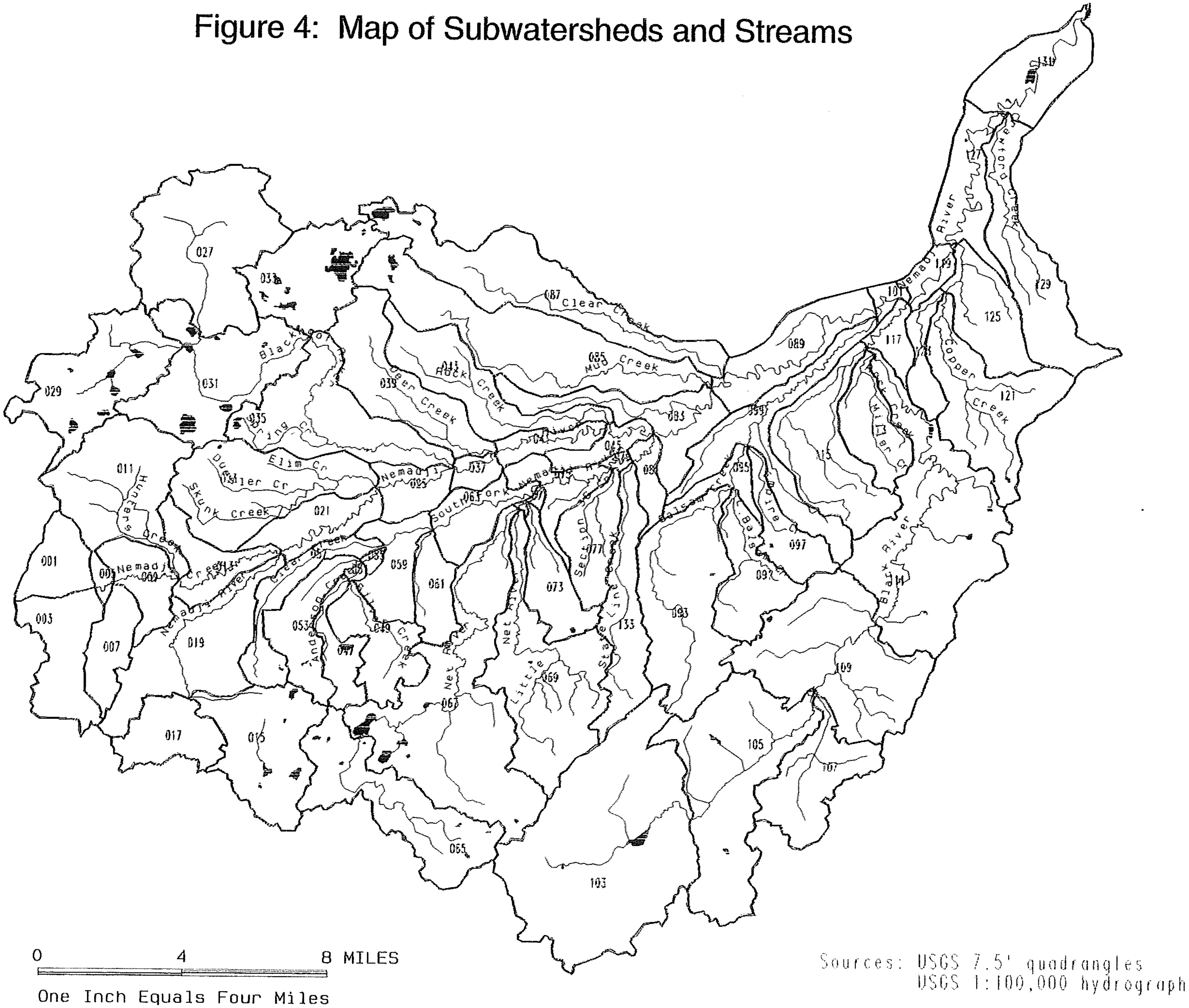
Another way to express long term climatic trends is the Palmer Drought Severity Index (PDSI). The PDSI is an indicator of prolonged and abnormal moisture deficiency or excess. Data used for the PDSI include weekly precipitation, average temperature and indices from previous periods. PDSI values are available for the East Central Minnesota Climate Region for the period 1895-1995 (NOAA Climate Analysis Center and State of Minnesota Climatology Office). Two patterns are apparent in the data:

1. Six distinct periods of extreme drought: 1910-1911; 1920-1924; 1932-1934; 1936-1937; 1976-1977; 1987-1988

2. The three wettest periods are: 1902-1908; 1981-1986; 1990- present

The PDSI is useful when interpreting results from other studies. For example, several data sets for the Red Clay Project were gathered during 1976-1977. Conclusions from these studies should be interpreted by recognizing 1976 into the fall of 1977 as one of the three biggest droughts in the past century. These cycles also may play a role in explaining differing sedimentation rates found in Superior Bay. Wetter years will obviously increase sediment loading.

Figure 4: Map of Subwatersheds and Streams



Runoff Characteristics

Much of following runoff information comes from streamflow records maintained by the U.S. Geological Survey. Table 2 summarizes U.S. Geological Survey streamflow records available within the Nemadji River Basin.

Table 2: USGS Streamflow Stations

Station Name	Station Number	Drainage) Area (mi.^{2})	Period of Record	Statiion Type
Elim Creek near Holyoke	04024090	1.06	1976 - 1978	C
Skunk Creek below Elim Creek	04024093	8.83	1976 - 1978	C
Nemadji River near Holyoke	04024095	118	1972 - present	P
Deer Creek near Holyoke	04024098	7.77	1976 - present	C
Rock Creek near Blackhoof	04024100	4.94	1961 - 1987	P
Rock Creek Trib. near Blackhoof	04024110	0.20	1961 - 1986	P
South Fork Nemadji near Holyoke	04024200	19.4	1961 - 1985	P
Little Balsam Creek at Patzau	04024314	5.00	1976 - 1978	C
Little Balsam Creek near Patzau	04024315	4.57	1976 - 1978	C
Little Balsam Trib. near Patzau	04024318	0.64	1976 - 1978	C
Little Balsam Creek near Foxboro	04024320	6.27	1977 - 1978	C
Nemadji River near South Superior	04024430	420	1974 - present	C

C - Continuous
P - Partial Record (annual peak only)

A water budget was developed utilizing U.S. Geological Survey stream gage and local climate records from 1974 through 1996. The water budget, which is an accounting of all forms of moisture in a hydrologic system, is as follows:

Precipitation	=	Runoff	+	Evapotranspiration
30.8"	=	13.1"	+	17.7"

The average annual runoff of 13.1 inches (43 percent of rainfall) is among the highest in both Minnesota and Wisconsin. The high runoff rate of the Nemadji River is likely a function of its: 1) cooler temperatures during the summer resulting in less evapotranspiration, and 2) heavy, poorly drained clay soils in the interior third of the watershed (see Figure 3 on page 21 for a map).

Figure 6 on page 29 shows annual runoff amounts by water year (October through September) for the Nemadji River near South Superior. Runoff ranges from a low of about six inches

(1980) to a high of 25 inches (1986). Precipitation during water year 1986 was extreme with about 44 inches. The ratio of runoff to precipitation for the Nemadji River Basin is about 45 percent and is fairly consistent year to year.

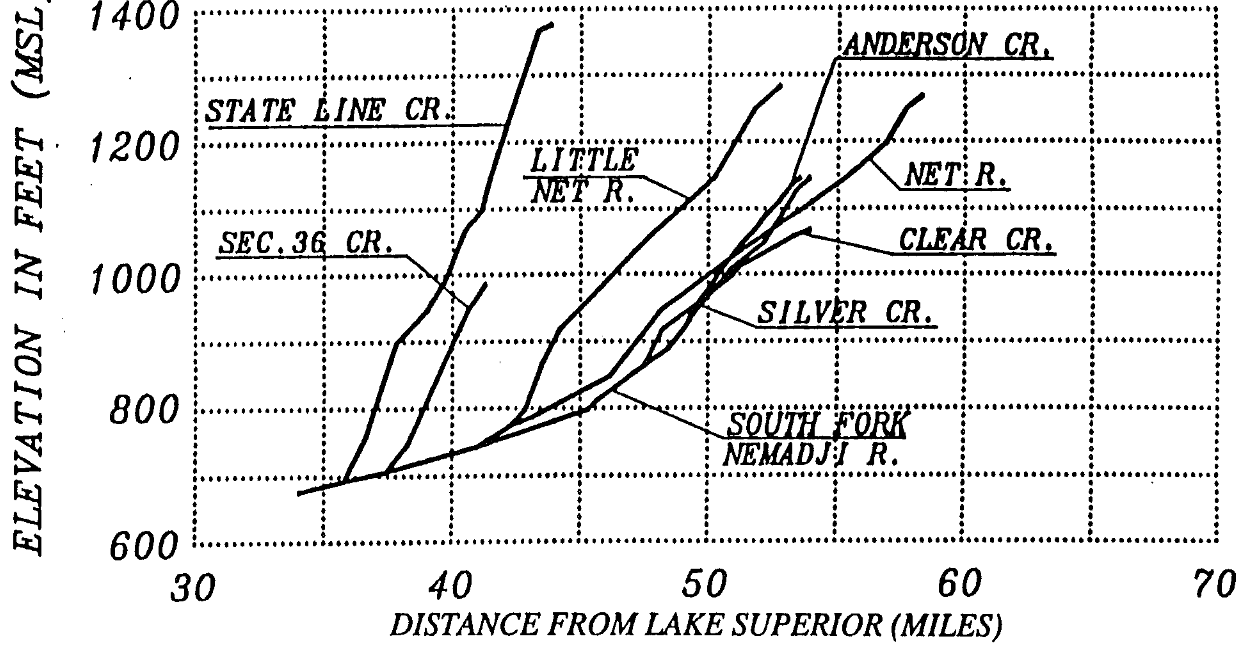
Figure 7 on page 29 shows the average distribution of runoff throughout the year. This bar chart also shows relative amounts of base flows and surface runoff with respect to total runoff. This separation of flows was determined using a U.S. Geological Survey method that separates streamflows into rapid runoff (surface) and longer duration (base flow) discharges. The figure shows that approximately 50 percent of all runoff occurs during the snowmelt period of March through May. Runoff amounts decrease from June through August then increase again in September. This pattern demonstrates the impact that vegetation can have on streamflow. The runoff decrease from June through August reflects the increased use of water by transpiring plants which lowers soil moisture levels in turn decreasing runoff potential. The increase in runoff in September reflects a lessening of consumptive water use by vegetation which increases runoff potential.

Peak Flows

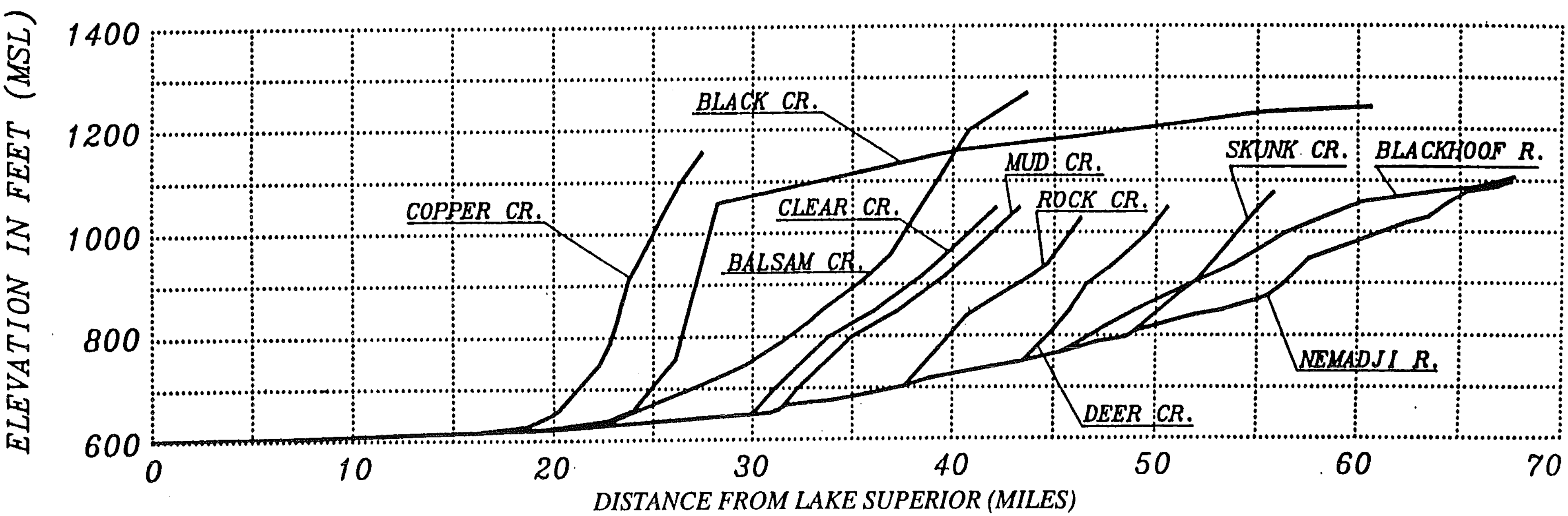
According to flow records on the Nemadji River near South Superior (433 square miles drainage area) from 1974 through present, for any given year, there is a 50 percent chance that the highest peak for that year will occur during snowmelt. Streamflow records on Deer Creek (7.8 square mile drainage area) reveal a somewhat different situation. For the period of record 1977-1994, snowmelt produced the highest yearly peak discharge only 28 percent of the time. This difference between the main stem Nemadji River and the Deer Creek tributary is a typical scale type response of watersheds in northern climates. Peak flows on smaller watersheds are usually the result of thunderstorm type events while larger watersheds tend to have peak flows that are the result of snowmelt.

The peak flows on the Nemadji River main stem were compared to similar-sized watersheds within Minnesota and Wisconsin. Only six gaged watersheds were found to exceed the Nemadji River in terms of flow/frequency. The Nemadji River has the highest peak flows for watersheds with similar percent forested area. The peak flow from Deer Creek was compared to all Minnesota gaged streams of similar size. Deer Creek was found to have the highest flow/frequency value of all Minnesota gaged streams in the 5 to 10 square mile drainage area range. Only one gaged watershed within Wisconsin (Spillerberg Creek near Cayuga) having similar physical characteristics as Deer Creek had higher discharges.

Figure 5: River Gradient Profile



SOUTH FORK NEMADJI RIVER



NEMADJI RIVER

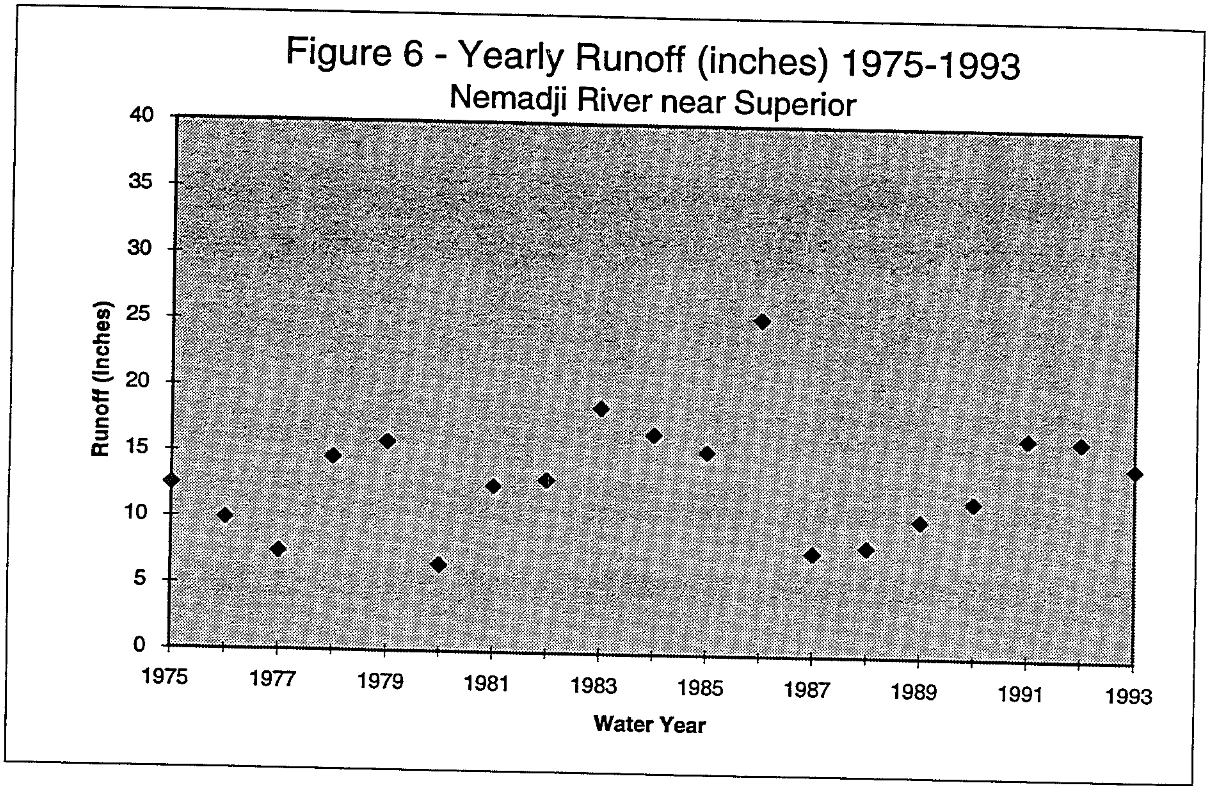


Figure 6 - Yearly Runoff (inches) 1975-1993
Nemadji River near Superior
Runoff (inches)
40
35
30
25
20
15
10
5
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
Water Year

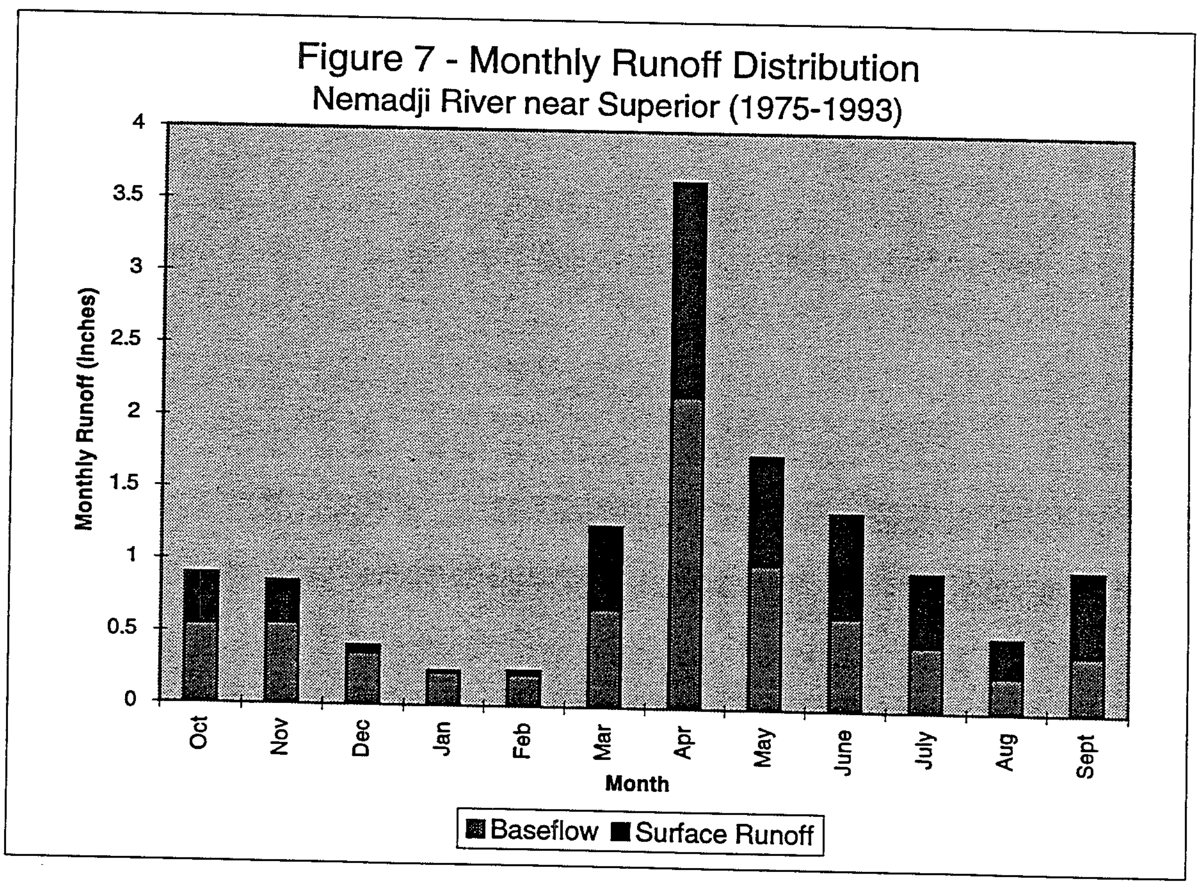


Figure 7 - Monthly Runoff Distribution
Nemadji River near Superior (1975-1993)
Monthly Runoff (inches)
4
3.5
3
2.5
2
1.5
1
0.5
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Month
Baseflow
Surface Runoff

Forest Resource

Pre-European Forest Resource

The Nemadji River Basin was forested before European settlement. The forest was most likely a mosaic of young, old, and recently burned blocks in a complicated, interlocking pattern. Blowdowns, insects and disease, fires, and different soils caused the diversity in age and species.

Fire is the force that caused most of the diversity in the pre-settlement forests. Fire in the forest is expected and normal. Fires burned with various intensities, missing some areas entirely, creating a patchwork of ages and types of stands in the forest. "Forests born and raised by fires are diverse - but not in their number of species. Rather, they are an incredible mosaic of varying ages and combinations of species" (Addison, 1994).
Three prominent forest types existed in the watershed at the time of the original land surveys. The original land survey occurred just before or just at the beginning of the white pine harvest in the 1850s.

1. The red-clay portion of the watershed had what Marschner (Heinselman, 1974) called the Pine Flats type and Hole (1994) called the Boreal Forest type. White pine was the dominant overstory tree. Stands which had not been recently burned contained understories of balsam fir, spruce, and northern white cedar. Most of the white pine in the watershed was found in this type.

2. On the non-red-clay soils, the sugar maple-tamarack-yellow birch-white pine complex was the most dominant type. White pine was the prominent conifer in this type, but not the most prominent species in the stand (Heinselman, 1974).

3. The aspen-birch (conifer) was the third prominent forest type. It was found on all soil types after a disturbance. These were young stands dominated by quaking aspen, bigtooth aspen, and paper birch. They also had significant conifer elements either as co-dominant (pines and white spruce) or as understories (balsam fir, white and black spruce, or northern white cedar) (Heinselman, 1974).

Forest Resource During European Settlement

Much of the following description of the forest resource during European settlement in the Nemadji River Basin is from Carroll (1987). White pine lumber from the Nemadji River Basin helped build towns and cities of the upper Midwest and the eastern states. For over 40 years, this area was a major supplier of building materials for the nation. The harvesting of white pine in the Nemadji River Basin began in about 1856. There is some information that indicates that logging and "cleaning" of the lower Nemadji River could have begun in the 1840's (personal communication: Elon S. Verry, USFS, 1996). By the early 1880's, 11 sawmills existed on St. Louis Bay, and two sawmills in Superior, Wisconsin. The Nemadji River Basin was a prime source of timber for these sawmills.

To reach sawmills, logs were driven down the river or loaded onto railroad cars traveling across the northern part of the watershed. The amount of logs coming down the Nemadji River, harvested by different sawmills, increased to such a point in the 1880's and 1890's that the Nemadji Boom Company was established to sort the logs. The last log drive on the Nemadji River took place in 1904.

The Mitchell and McClure Company built the largest sawmill in the world in 1890 on Rice's Point in Duluth. To supply the mill, they bought large holdings on the north shore of Lake Superior and in the Nemadji River Basin. As the timber along the banks of the Nemadji River was cut, a logging railroad was constructed across the northern tributaries of the Nemadji River Basin as far west as the Blackhoof River. It was estimated that as much as 500 million board feet of white pine were taken out of the Nemadji River Basin by Mitchell and McClure between 1881 and 1890.

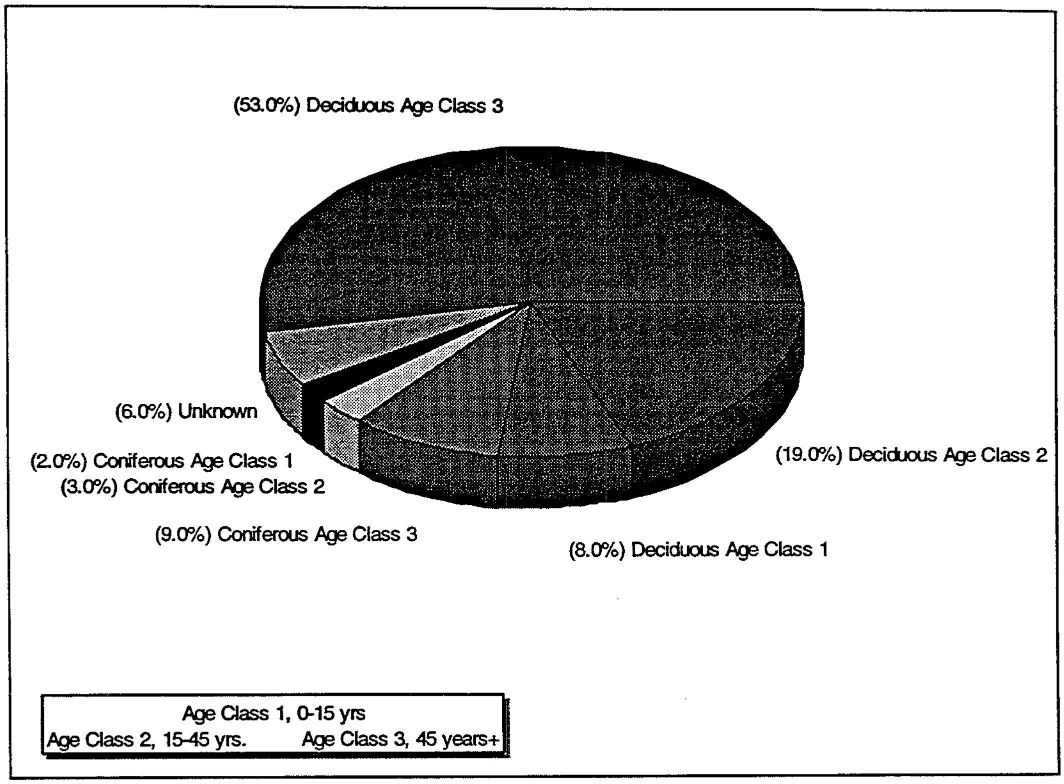
The lumber market was geared toward white pine. No market existed for the other trees. The Northwest Paper Company partially filled this void when they established a paper mill on the St. Louis River in 1899. A second paper mill using ground spruce pulp was built in Cloquet, Minnesota in 1900. An auxiliary mill was built a half mile upriver in 1901. When it appeared that there was a growing shortage of spruce for mechanically ground pulp, they built a sulfite plant in 1915 to manufacture higher grade papers. The Cloquet Tie and Post Company was opened in 1900 to cut cedar and tamarack on lumber company property.

The white pine harvest was followed by the farmer. "The basic philosophy of the lumberman towards the forest contrasted sharply with the attitude of the pioneer farmer. The lumberman looked upon the forests as an articles of wealth and commerce; the farmer regarded them as a hindrance to plow and hoe" (Rector, 1951). "The work done by early settlers finished the job started by logging of the big pine. Fields were cut and cleared, and it was considered progress to burn trees, brush, and land. Much other land was managed as pasture. Wildfires were common" (Angell, 1972). The 1920s to 1930s was the peak of farming. About 50 percent of the basin was in this land use. It wasn't until the 1940s and 1950s that agricultural land was abandoned and trees began to regenerate.

Forest Resource Today

Today, forest land is the major land cover in the Nemadji River Basin. There are 192,520 acres of forest land comprising 69 percent of the watershed. The majority, 53 percent, of the forest land is deciduous forest greater than 45 years old. Figure 8 displays the entire forest land breakdown by age class and deciduous and coniferous forest types. The unknown forest land category represents sections where there was no forest inventory information or not enough forest inventory information to determine type or age class. The unknown forest land type is all in Wisconsin.

Figure 8: Forest Land Type and Age Class



The Nemadji River Basin Project Forestry Technical Committee estimates that between one and two percent of all industrial, county, and state forest lands are harvested each year. The amount of private forest being harvested each year is unknown.

About 49 percent of the basin is deciduous forest, primarily aspen trees greater than 45 years old. Nemadji River Basin Project inventory data shows that about 25 percent of the Nemadji River Basin is in open and young forest. Open is defined as land that is used for agricultural purposes (row crops, hayland, pasture, etc.), grasslands, urban or built-up land, and other non-forest uses. Young forest is the area of trees less than 15 years old. Hydrologic impacts are often related to the percentage of open/young forest.

Aspen is a small- to medium-sized, fast growing and short-lived tree. In northern Minnesota, aspen has a life span of about 55 to 60 years. It grows on a variety of soils ranging from shallow and rocky to deep loamy sand and heavy clay. "Good aspen soils are usually well drained, loamy, and high in organic matter, calcium, magnesium, potassium, and nitrogen. Heavy clay soils do not promote the best growth because of limited available water and poor aeration" (Burns and Honkala, 1990).

Species breakdown is approximately 70 percent deciduous and 30 percent coniferous, based on the number of trees in the watershed. Table 3 displays the percentage of sawtimber, pole timber, and seedlings and saplings by major species.

Table 3: Major Tree Species by Age Class

Deciduous (percent)			
Species	Saw[1]	Pole[2]	S&S[3]
Aspen/Birch	70	51	45
Maples	13	22	30
Black Ash		11	12
Other Hardwoods	17	16	13
TOTAL	100	100	100

Coniferous (percent)			
Species	Saw[1]	Pole[2]	S&S[3]
Balsam Fir	50	57	60
Black Spruce		25	31
Red Pine	19		
White Pine	7		
Other Softwoods	24	18	9
TOTAL	100	100	100

Footnotes:

1) Sawtimber is defined in this survey as hardwoods > 11" diameter, breast height (DBH). and softwoods > 9" DBH. DBH is the diameter measured at 4.5 feet above the ground.

2) Pole timber is > 5" DBH to 11" DBH for hardwoods, 5" DBH to 9" DBH for softwoods.

3) Seedlings and saplings are > 1" to 5"DBH. Anything < 1" was not considered in this analysis.

Although conifers make up approximately 30 percent of the total number of trees, it is important to note that most of them are found under the aspen overstory. If no disturbance occurs, the conifers occupying the understory will eventually grow and replace the aspen as the overstory species. This process of change over time is called succession.

Succession has progressed to a point in the watershed that some mid- to full-shade tolerant species are present in the understory and some are in the overstory. As Table 3 shows, balsam fir, maples, black ash, and black spruce are becoming the most prevalent understory tree species as shown by their increasing percentages in the pole and seedling/sapling categories.

Succession proceeds until plants and their environment are essentially in equilibrium. Thereafter, further change is very slow. This relatively stable situation is sometimes called the successional climax. A major disturbance such as a fire, insect infestation, disease, or land use change can return the successional process to the beginning.

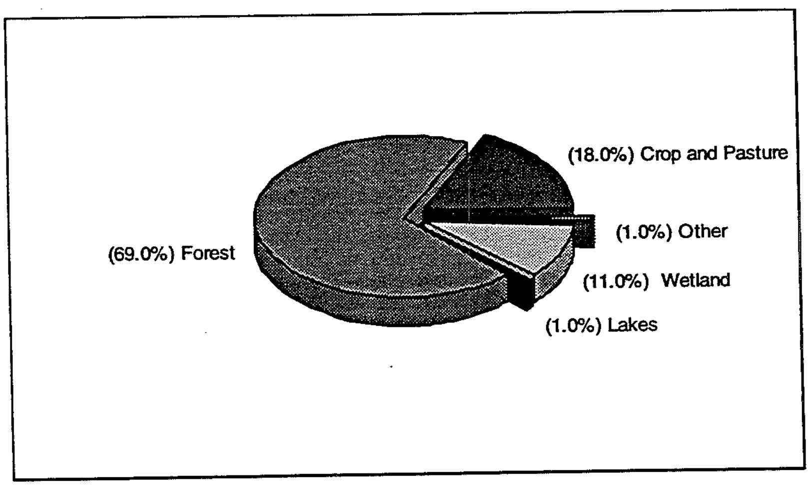
Land Use

General

Present day land use in the Nemadji River Basin was determined from U. S. Geological Survey land use and land cover data. This data set was derived using interpretations of high altitude 1:250,000 scale aerial photographs with source years ranging from 1971 to 1982. The table below lists the land uses along with the number of acres associated with each land use. Figure 9 displays percentages of each land use category within the Nemadji River Basin in a pie chart format. Figure 10 on page 37 displays locations of land use types superimposed on a project area map.

Land Use	Area	Percent
Forest	192,520 Acres	69.4%
Cropland/Pasture	51,040 Acres	18.4%
Wetlands	29,680 Acres	10.7%
Lakes	1,660 Acres	0.6%
Other	2,500 Acres	0.9%
TOTAL	**277,400 Acres**	**100 %**

Figure 9: Land Use Pie Chart



For detailed information on the forested portion of land use within the Nemadji River Basin, see the Project Setting - Forest Resource section of this report.

Methods

Land use by subwatershed was determined with GIS techniques employing three data layers: 1) U. S. Geological Survey land use and land cover data, 2) detailed state, county, industrial, and private forest inventory data, and 3) subwatershed boundary information. The results are summarized in Table 6 on page 38. In Table 6 "Agriculture" includes row crops, meadow, and pasture. "Wetland" includes both forested and unforested wetlands. "Unknown Forest" includes areas that appeared as forests in aerial photos but detailed stand information was not available. "Other" includes urban, transportation, and areas of transition land uses. The column marked "Upstream Drainage Area" is the cumulative drainage area flowing through that subwatershed. This includes all upstream subwatersheds in addition to the area of the subwatershed itself.

It should be noted that forest age class percentages are very approximate. Actual forest inventory data were collected during different years and attempts were made to present the percentages relative to the same baseline year.

Agriculture

Of the 18.4 percent of land use devoted to crop and pasture, most farm types are still livestock oriented with dairy, beef, and associated forage production. Cropping systems consist of grass-legume hay rotated with small grain or corn silage. The number of farmland acres that have continuous or long term annual cropping systems is very small. Livestock operations consist primarily of dairy (33%) and beef cattle (53%) and other, generally horses, sheep, and poultry (14%). A survey of feedlot sites or locations with concentrations of livestock identified 127 sites. Over 50 percent of these had more than 20 animals. Dairy operations are generally 20 to 100 animal units in size, beef is split between < 20 and 20 to 100 animals, horses are < 20 and poultry, sheep, and swine are <20 animal units in size.

Roads

There are approximately 670 miles of roads in the Nemadji River Basin. Table 4 gives a general breakdown of the road system type.

Table 4: Roads within the Nemadji River Basin

Interstate Highway (I-35)	11 miles
U.S. Highways (US-23, US-35)	34 miles
County Roads	296 miles
City/Neighborhood Roads	171 miles
Railroads	100 miles
Other	58 miles
Total	670 miles

Percent Open Area

The phrase "Percent Open" in two of the column titles on page 38 in Table 6 refers to the total of the percentage agricultural land use plus roads and forest in the 0-15 year age class. This figure can be related to the current hydrologic condition of a watershed. In general, open areas tend to generate more runoff during rainstorms and melt faster during spring snowmelt. See the Hydrologic System Changes section of this report for discussion on the relationships between percent open area and runoff. Open area is expressed for each subwatershed in two ways:

1. Percent Open in Subwatershed - This is the percent open area within the subwatershed itself.

2. Percent Open Upstream - This is the percent open area of the entire watershed upstream of and including the subwatershed.

Land Ownership

Plat books were used to determine the breakdown of private versus public lands within the basin. This analysis is summarized in Table 5 below. There are approximately 3,900 landowners within the basin. Land owned by timber companies is included in the railroad and industrial land category.

Table 5: Nemadji River Basin Land Ownership

Land Ownership	Minnesota	Wisconsin	Total
Non-Industrial Private	33%	22%	**55%**
Railroad and Industrial Land	3%	3%	**6%**
County Land	8%	14%	**22%**
State Land	16%	1%	**17%**
Other	<1%	<1%	**<1%**
Total	**60%**	**40%**	**100%**

Figure 10: Map of Land Use/Land Cover

Nemadji River Basin and Subwatersheds

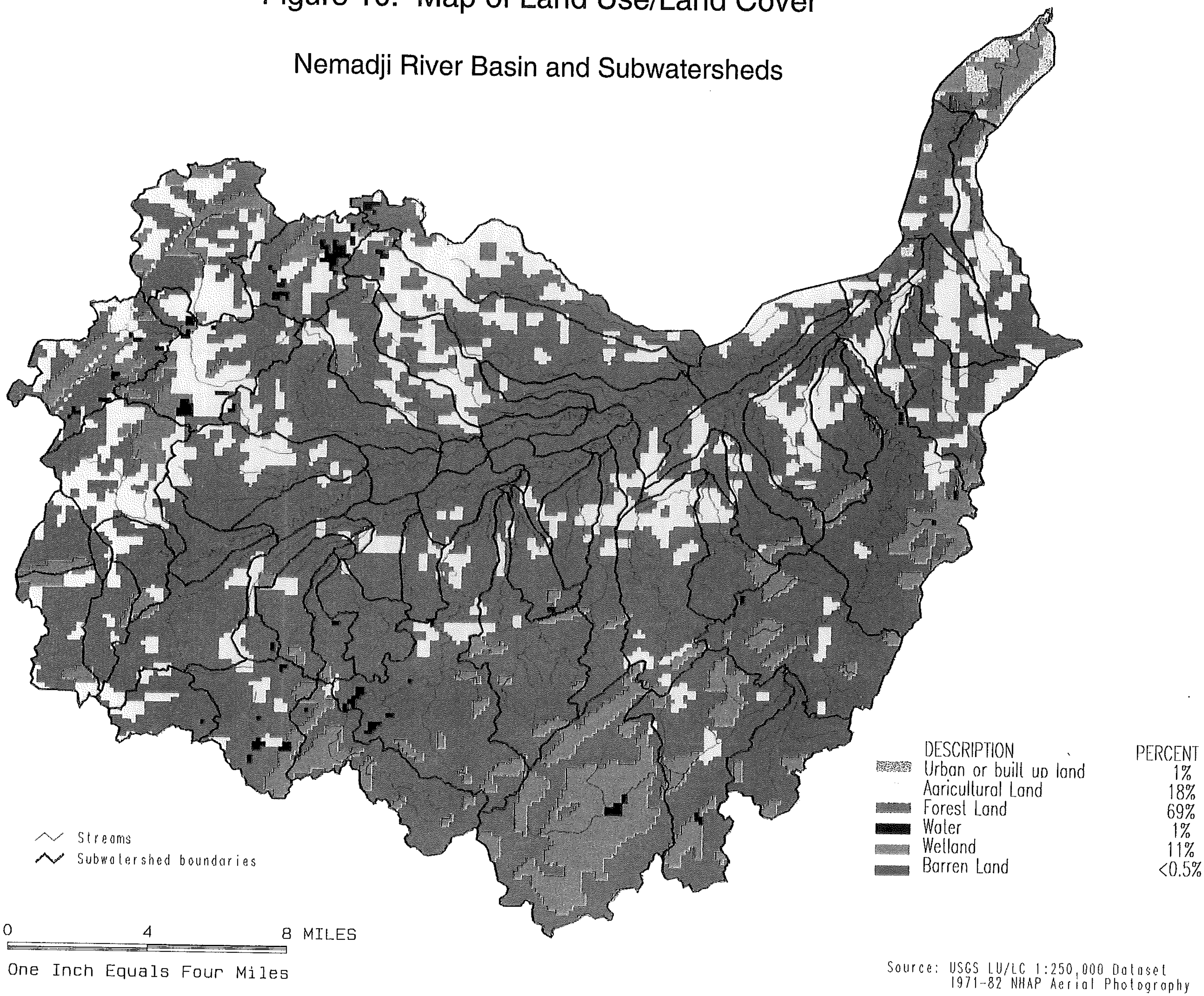


Table 6: Land Use by Subwatershed

Number	Subwatershed Name	Drainage Area (acres)	Agriculture	Wetland	Water	Forest 0-15 Year	Forest 15-45 Year	Forest > 45 Year	Unknown Forest	Other	Percent Open In Subwatershed	Upstream Drainage Area (acres)	Percent Open Upstream
1	Upper Nemadji Creek	2,160	21%	18%			3%	57%			21%	2,160	21%
3	Hill Top Road Tributary	3,770	14%	11%		3%	4%	66%	1%		18%	3,770	18%
5	Upper Nemadji Ck/Hilltop Rd Trib Conf	370	31%	9%			0.1%	60%			31%	5,930	19%
7	Unnamed Upper Nemadji Creek Tributary	2,130	12%	13%		6%	7%	63%			18%	2,130	18%
9	Nemadji Creek	2,220	23%	5%		1%	17%	54%			24%	10,650	20%
11	Hunters Creek	6,480	44%	14%	0.3%	0.4%	2%	39%	0.2%	0.04%	45%	6,480	45%
13	Nemadji Creek/Hunters Creek Confluence	2,330	11%	0.3%		6%	19%	64%			17%	19,460	28%
15	Upper Nemadji River/ Soper Lake	5,660	10%	13%	3%	8%	6%	17%	43%		18%	5,660	18%
17	Unnamed Upper Nemadji River Tributary	2,800	21%		0.3%	5%	4%	9%	60%		27%	2,800	27%
19	Nemadji River	6,190	17%	2%		16%	29%	35%	1%		33%	14,650	26%
21	Nemadji River/Nemadji Creek Confluence	2,430	3%			2%	20%	74%			6%	36,540	26%
23	Skunk Creek	6,620	25%	2%	0.1%	1%	9%	63%			26%	6,620	26%
25	Nemadji River/Skunk Creek Confluence	1,750	0.3%			2%	38%	59%			3%	44,910	25%
27	Upper Blackhoof River	8,900	35%	17%	0.3%	4%	7%	35%		2%	39%	8,900	39%
29	Upper Blackhoof River/Hizer Lake	6,030	23%	25%	2%	1%	4%	42%	0.2%	3%	25%	6,030	25%
31	Blackhoof River/Sandy Lake	6,910	41%	11%	3%	2%	2%	42%		0.03%	42%	21,840	36%
33	Hay Lake	4,870	25%	11%	7%	2%	2%	45%	8%	0.2%	27%	4,870	27%
35	Blackhoof River	6,580	18%	1%	0.4%	3%	15%	63%			21%	33,290	32%
37	Nemadji Riv/Blackhoof Riv Conf	740	7%			1%	50%	42%			8%	78,940	28%
39	Deer Creek	5,160	30%	6%		2%	14%	48%			32%	5,160	32%
41	Nemadji River/Deer Creek Confluence	1,280	4%			1%	21%	74%			5%	85,380	27%
43	Rock Creek (Minnesota)	4,560	39%	0.4%		4%	9%	47%			43%	4,560	43%
45	Nemadji River/Rock Creek Confluence	1,160	0.4%			0.04%	49%	51%			0%	91,100	28%
47	Anderson Creek	1,660	5%	4%	1%	27%	15%	49%			32%	1,660	32%
49	Silver Creek	3,050	3%	0.1%	1%	13%	24%	60%			16%	3,050	16%
51	Anderson Ck/Silver Ck Conf	140	9%			3%	53%	36%			12%	4,850	21%
53	Stony Creek	2,900	6%	6%	0.3%	27%	26%	35%			33%	2,900	33%
55	Anderson Ck/Stony Ck Conf	180	43%			0.2%	36%	21%			43%	7,930	26%
57	Clear Creek	2,450	22%	4%	1%	13%	25%	35%			36%	2,450	36%
59	Upper South Fork Nemadji River	2,440	14%			4%	39%	43%			18%	12,820	26%
61	No Name Creek	1,880	14%		0.5%	5%	22%	59%		0.4%	19%	1,880	19%
63	S. Fork Nemadji Riv/No Name Ck Conf	2,290	9%			15%	33%	43%			24%	16,990	25%
65	Upper Net River/Headquarters Lake	6,450	0.2%	26%	1%	10%	34%	24%	4%		10%	6,450	10%
67	Net River/Net Lake	13,010	6%	8%	1%	9%	23%	53%		0.1%	15%	19,460	13%
69	Little Net River	8,070	5%	9%	0.1%	11%	22%	52%			17%	8,070	17%
71	Net River/Little Net River Confluence	180	8%			2%	29%	62%			9%	30,130	15%
73	Unnamed Net River Tributary	2,420	12%	7%	1%	8%	31%	42%			20%	2,420	20%
75	S.Fork Nemadji Riv/Net Riv Conf	1,960	6%			2%	30%	61%			8%	49,080	18%
77	Section 36 Creek	2,690	20%	0.0%		5%	30%	45%			24%	2,690	24%

[1] "Percent Open" is the sum of agricultural land uses plus forest in the 0-15 year age class

Table 6: Land Use by Subwatershed

Number	Subwatershed Name	Drainage Area (acres)	Agriculture	Wetland	Water	Forest 0-15 Year	Forest 15-45 Year	Forest > 45 Year	Unknown Forest	Other	Percent Open in Subwatershed	Upstream Drainage Area (acres)	Percent Open Upstream
79	S. Fork Nemadji Riv/Sec 36 Ck Conf	190	0.4%			0.1%	58%	41%			0%	51,960	18%
81	S.Fork Nemadji Riv/State Line Ck Conf	1,020	40%			2%	21%	28%	9%		42%	57,850	20%
83	Nemadji Riv/S. Fork Nemadji Riv Conf	3,790	11%			5%	42%	40%	2%		16%	152,740	24%
85	Mud Creek	9,670	30%	1%	1%	2%	18%	47%	1%	0.0%	32%	9,670	32%
87	Clear Creek	7,700	45%	1%	1%	0.3%	11%	38%	4%	0.2%	45%	7,700	45%
89	Nemadji Riv/Mud Ck/Clear Ck Conf	3,890	34%	0.1%		5%	18%	21%	22%		39%	174,000	26%
91	Little Balsam Creek	3,450	15%	10%	0.01%	7%	22%	45%	1%		22%	3,450	22%
93	Balsam Creek	7,860	24%	4%		17%	19%	29%	7%		41%	7,860	41%
95	Balsam Crk/Little Balsam Ck Conf	1,110	40%			2%	35%	10%	13%		41%	12,420	36%
97	Empire Creek	2,220	11%	9%		9%	4%	67%			20%	2,220	20%
99	Balsam Ck/Empire Ck Conf	4,720	19%	2%		15%	12%	33%	18%		34%	19,360	33%
101	Nemadji River/Balsam Ck Conf	440	51%	1%		0.2%	26%	2%	19%		52%	192,990	27%
103	Black River/Black Lake	16,260	0.5%	49%	1%	2%	15%	32%	1%		2%	16,260	2%
105	Black River	9,680	6%	24%	0.4%	8%	14%	49%			14%	25,940	7%
107	Summit Trail Tributary	4,100	1%	10%		5%	21%	64%			6%	4,100	6%
109	Black Riv/Summit Trail Trib Conf	9,460	4%	13%	0.2%	12%	18%	53%			16%	39,500	9%
111	Black River/Reichuster Lake	11,640	6%	21%	0.3%	15%	15%	41%	1%	1%	21%	51,140	12%
113	Rock Creek (Wisconsin)	2,750	29%	1%	0.1%	11%	2%	41%	14%	2%	40%	2,750	40%
115	Miller Creek	5,410	30%	6%		12%	12%	35%	5%		43%	5,410	43%
117	Black River/Miller Creek Confluence	1,060	42%	0.1%		9%	15%	21%	13%	0.1%	50%	60,360	16%
119	Nemadji River/Black River Confluence	990	22%			5%	10%	48%	12%	4%	27%	254,340	24%
121	Copper Creek	6,110	31%	3%	0.2%	11%	10%	39%	4%	1%	43%	6,110	43%
123	Stony Brook	1,370	44%		0.2%	10%	4%	21%	18%	2%	54%	1,370	54%
125	Rocky Run	3,410	46%			11%	3%	32%	7%	1%	57%	10,890	49%
127	Nemadji River/Rocky Run Confluence	3,230	19%	0.3%		3%	2%	60%	10%	5%	22%	268,460	25%
129	Crawford Creek	5,170	38%	2%		2%	1%	27%	28%	2%	40%	5,170	40%
131	Nemadji River/Superior Harbor Basin	3,770	1%	50%		1%		4%	10%	35%	1%	277,400	25%
133	State Line Creek	4,060	15%	6%		13%	15%	51%			28%	4,060	28%
	Nemadji River Basin Total:	277,400	18%	11%	1%	7%	15%	43%	4%	1%	25%	277,400	25%

[1] "Percent Open" is the sum of agricultural land uses plus forest in the 0-15 year age class

Surface Water Quality

Statewide water quality standards define water quality goals for a water body. The Minnesota Pollution Control Agency (MPCA) and Wisconsin Department of Natural Resources (WDNR) are the two regulatory water quality agencies for the Nemadji River Basin system, Superior Bay and Lake Superior. Each state has different classification systems for their waters thus each will be addressed separately below.

Minnesota Stream Classification

There are three components of a state water quality standard: 1) designated uses; 2) water quality criteria; and 3) a non-degradation policy designed to maintain existing uses and the level of water quality needed to protect those uses. All rivers are classified for agricultural, navigational, and industrial use. If monitoring determines that standards are being met, then that water body is described as supporting its designated use. If not, it is described as either partially supporting or not supporting its designated use, depending on the frequency with which its standards are being violated (MPCA Background Paper, 1995). In addition, waters are classified based on their designation as trout waters.

The MPCA has classified the Minnesota portion of the Nemadji River system. The notations (i.e. 1B, 2A, etc.) are part of an MPCA coding system that signifies designated uses. From the confluence of the main stem and south fork of the Nemadji River near the Minnesota and Wisconsin border *up*stream, waters have been classified as having three designated uses: 1B) With proper disinfecting, such as simple chlorination, the treated water will meet all requirements for drinking water standards; 2A) It will permit the propagation and maintenance of warm or cold water sport or commercial fishes and their habitats and be suitable for aquatic recreation of all kinds, and is protected as a source for drinking water; and 3B) General industrial uses with moderate degree of treatment.

Many tributaries of the Nemadji River in Minnesota have been designated 2A trout streams. This classification is supported by the state designation of these reaches as a trout stream. These reaches are classified to support cold temperature fisheries, like trout.

Lake Superior has been classified and is rated: 1B) and 2A) see explanation above, as well as 3A) Industrial use without chemical treatment.

Wisconsin Stream Classification

The classification system or water quality standard designation used in Wisconsin defines four formal categories:

1. Fish and other aquatic life use waters - There are five subcategories to this classification. The COLD, WWSF, and WWFF classifications are suitable for protection and propagation of a balanced fish and other aquatic life community.

Streams having LFF and LAL classifications are considered to have naturally limited habitat or water quality and therefore are not capable of supporting a balanced community.

a) Cold Water Communities (COLD) - capable of supporting a community of cold water fish and other aquatic life

- COLD I - high quality streams where populations are sustained by natural reproduction
- COLD II - streams have some natural reproduction but need stocking to maintain a desirable fishery
- COLD III - streams sustain no natural reproduction and require annual stocking of legal size fish for sport fishing

b) Warm Water Sport Fish Communities (WWSF) - capable of supporting a community of warm water sport fish or of serving as a spawning area for warm water sport fish

c) Warm Water Forage Fish Communities (WWFF) - capable of supporting an abundant diverse community of forage fish and other aquatic life

d) Limited Forage Fishery (LFF) - communities capable of supporting only a limited community of forage fish and aquatic life

e) Limited Aquatic Life (LAL) - communities are capable of supporting only a limited community of aquatic life

2. Great Lakes Communities - Waters of Lakes Michigan and Superior including Green Bay and all arms and inlets

3. Outstanding Resource Waters (ORW) - Streams and lakes with this designation are considered to have very high quality water and fisheries. Discharges are not allowed to these waters unless the quality of the discharge is equal to or better than that of the receiving water.

4. Exceptional Resource Waters (ERW) - This category is the same as the ORW except that the water already receives some sort of discharge

The Federal Clean Water Act assumes that any water that is not formally classified meets the goals of supporting a balanced warm-water fish and other aquatic life community. These streams are classified as "default" or DEF.

Table 7 shows the classifications given to the waters of the Nemadji River within Wisconsin. These classifications are taken from the April, 1996 draft Lake Superior Water Quality Management Plan.

Table 7: Stream Classification for Waters Within Wisconsin

Stream Name	Length (miles)	Classification
Copper Creek	0-10	DEF
	10-12	COLD II
Unnamed Trib. to Copper Creek (T47N R14W S22)	1	ERW
Crawford Creek	8	DEF
Lower Nemadji River	20	DEF
Balsam Creek (Big Balsam)	0-2.5	COLD III
	2.5-15	COLD II
	15-17.5	COLD I
Unnamed Trib. to Balsam Creek	1	ERW
(T46N R15W S7)		
Unnamed Trib. to Balsam Creek	4	ERW
(T47N R15W S23)		
Black River	0-8	DEF
	18-38	COLD III
Clear Creek	4	DEF
Empire Creek	4	ERW
Little Balsam Creek	5	ERW
Little Black River	5	DEF
Miller Creek	0-3	DEF
	3-6	COLD II
Mud Creek	4	DEF
South Fork Nemadji River	2	DEF
Upper Nemadji River	17	DEF
Rock Creek	0-3.5	COLD III
	3.5-5	ERW

The St. Louis River has been designated an Area of Concern for the development of a Remedial Action Plan (RAP) through the Great Lakes Water Quality Agreement. The MPCA, WDNR, numerous federal, state and local agencies and groups and local citizens are developing the St. Louis River System RAP for the cleanup of contaminated sediment and restoration of beneficial uses (MPCA and WDNR, 1992). Superior Bay and the lower reaches of the Nemadji River are included in the St. Louis River RAP.

Water quality data have been collected over the past thirty years in the Nemadji River Basin. This data set is quite small and provides a snapshot in time of water quality conditions and is not a long-term statistically significant data set. During 1994-95, MPCA and WDNR completed a review of STORET water quality data. STORET, short for STOrage and RETrieval of U.S. Waterways Parametric Data, is a data base of water quality information for waters within the U.S. and is maintained by U.S. Environmental Protection Agency. The detailed analyses compiled by the MPCA and WDNR are found in appendix D and are summarized below. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover. Additional water quality data were also analyzed as a part of this project and are detailed below.

Water quality followed seasonal trends and varied with flow; the worst water quality problems generally occurred during spring thaw and during storm events. At low flows dissolved solids were very high. The high concentrations fell off with increased flows. In contrast, chemical parameters that are suspended rather than dissolved (suspended solids, total nitrogen, total phosphorus and bacteria) increased with higher flows (Banks and Brooks, 1991).

Very high total suspended solids concentrations were observed during spring thaw and storm events. A strong correlation exists between total suspended solids and total phosphorus (P) concentrations. Much of the suspended sediment in the water is associated with fine clay soils typical of the watershed.

Most phosphorus in the river is in particulate form. Dissolved orthophosphate (soluble P) concentrations are usually low. Suspended clay particles tend to remove dissolved orthophosphate (Bahnick, 1977). These clay particles are unusual since they absorb P even when they are washed into the water. Most soils release P in this situation. Turbid streams in the red-clay area had lower orthophosphate (dissolved) levels than clear streams except when the water was affected by barnyard runoff (Devore, et al., 1980). Although the high total P levels from sediment (which absorbs dissolved P) results in excessive P loadings to Lake Superior and the bay, few algae blooms occur due to low dissolved P levels in the lake and cold water temperatures.

Although the Nemadji River contributes high levels of suspended clay particles and total P to the bay, concentrations of total phosphorus, ammonia and organic nitrogen have decreased since the 1970's (MPCA and WDNR, 1992). Improved wastewater treatment facilities at Duluth/Superior in the late 1970's have greatly reduced P and have led to improved water quality and biological conditions in Superior Bay (Turville-Heitz, 1994). Total phosphorus concentrations in the bay remain at high levels--approximately 0.07 milligrams of phosphate per liter (mg PO_4/L)--which is considered eutrophic or nutrient rich. However, algae levels for the bay are very low, which is typical of a clean, cold and oligotrophic (nutrient poor) lake having less than 0.01 mg PO_4/L. The low algae levels may be partially explained by limited light penetration due to turbidity and tanin stained water.

Dissolved oxygen (DO) levels in the Nemadji River and its tributaries are considered good throughout the year. Average DO values were 10.3 milligrams per liter (mg/L) with a high value of 13.28 mg/L. Summer DO levels are slightly lower than other times of the year. Turbid conditions do not seem to significantly reduce the DO levels.

According to STORET data retrieved for the Nemadji River in Douglas County, Wisconsin at County Road C, the Wisconsin State fecal coliform standards were violated 18 percent of the time during the period 1978 through 1991. Very high levels were observed during storm events, suggesting a problem with animal waste runoff. In the upstream parts of the watershed, no pesticide or organic concentrations were detected in the STORET data.

Fish and Wildlife

The Nemadji River Basin contains a wide array of fish and wildlife species. The remoteness of much of the basin provides habitat for a number of endangered and threatened wildlife species. Although little detailed data for threatened and endangered plants and animals exist, some of these species are represented in the watershed. For example, bald eagles (Haliaeetus leucocepahlus) utilize the area during fall and spring. A pack of timber or gray wolves (Canis lupis) is reported to frequent the watershed. LeConte's sparrow (Ammoramus leconteii), and the wood turtle (Clemmys insculpta), in addition to other species, are represented in the watershed.

Threatened plants are also present in the watershed. The floating marsh marigold (Caltha natans), a plant listed on the threatened and endangered plant list for Wisconsin, is reported to be present in the basin. Minnesota lists several plant and animal species in the "special concern" category that are believed to occur in the watershed. Although these species are not considered threatened or endangered, they are considered extremely uncommon in Minnesota. Examples of flora and fauna of special concern include: Wild Chives (Allium schoenoprasm), Dragon's Mouth Orchid (Arethusa bulbosa), Lake Sturgeon (Acipenser fulvescens), and Snapping Turtle (Chelydra serpentina). See Appendix E for more complete listings of Minnesota and Wisconsin endangered, threatened, and special concern species. See Appendix H for interviews with fish and wildlife managers regarding the current and future condition of fish and wildlife in the watershed. Appendix I contains the thoughts of one fish biologist on the effects of erosion on fish in the Nemadji River basin. All appendices are in a separate document located at

NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Wisconsin's Bureau of Endangered Resources is in the process of completing a biotic inventory of the Wisconsin portion of the Lake Superior Watershed. During the course of this inventory, several stands of forested and open wetlands within the Nemadji River Basin were surveyed. While far from pristine, some of these sites have either retained or recovered many of their natural attributes, and support uncommon animals and very unusual plant species assemblages. These flora and fauna are worthy of recognition, protection, and special management, as they may be regionally important.

Fish species valued by anglers in both Minnesota and Wisconsin include the anadromous (migratory) rainbow and brown trout. The Wisconsin portion of the watershed includes a warm-water fishery in the extreme lower four to five miles of the Nemadji River. Walleye is a highly sought fish species with northern pike, bullhead, yellow perch, and rock bass being caught incidentally. Some burbot and suckers are caught during their spawning runs in winter and spring, respectively. The upper tributaries of the Nemadji River system are dominated by Class I, II, and III trout streams. Physical barriers such as waterfalls and beaver dams in streams in the lower (Wisconsin) part of the basin restrict access of Lake Superior trout and salmon to the upper reaches of these tributaries. Forty seven species of fish occur in the Wisconsin portion of the Nemadji River Basin. Two species of redhorse followed by minnows and shiners are the dominant species of fish numerically. The Minnesota portion of the watershed contains approximately 400 miles of trout stream (see Figure 11 on page 47). Nearly all the tributaries, including the main stem of the Nemadji River, are classified as IA, IB, IC, or ID trout streams in Minnesota. It should be noted that Minnesota and Wisconsin have slightly different systems of defining trout waters (Table 8).

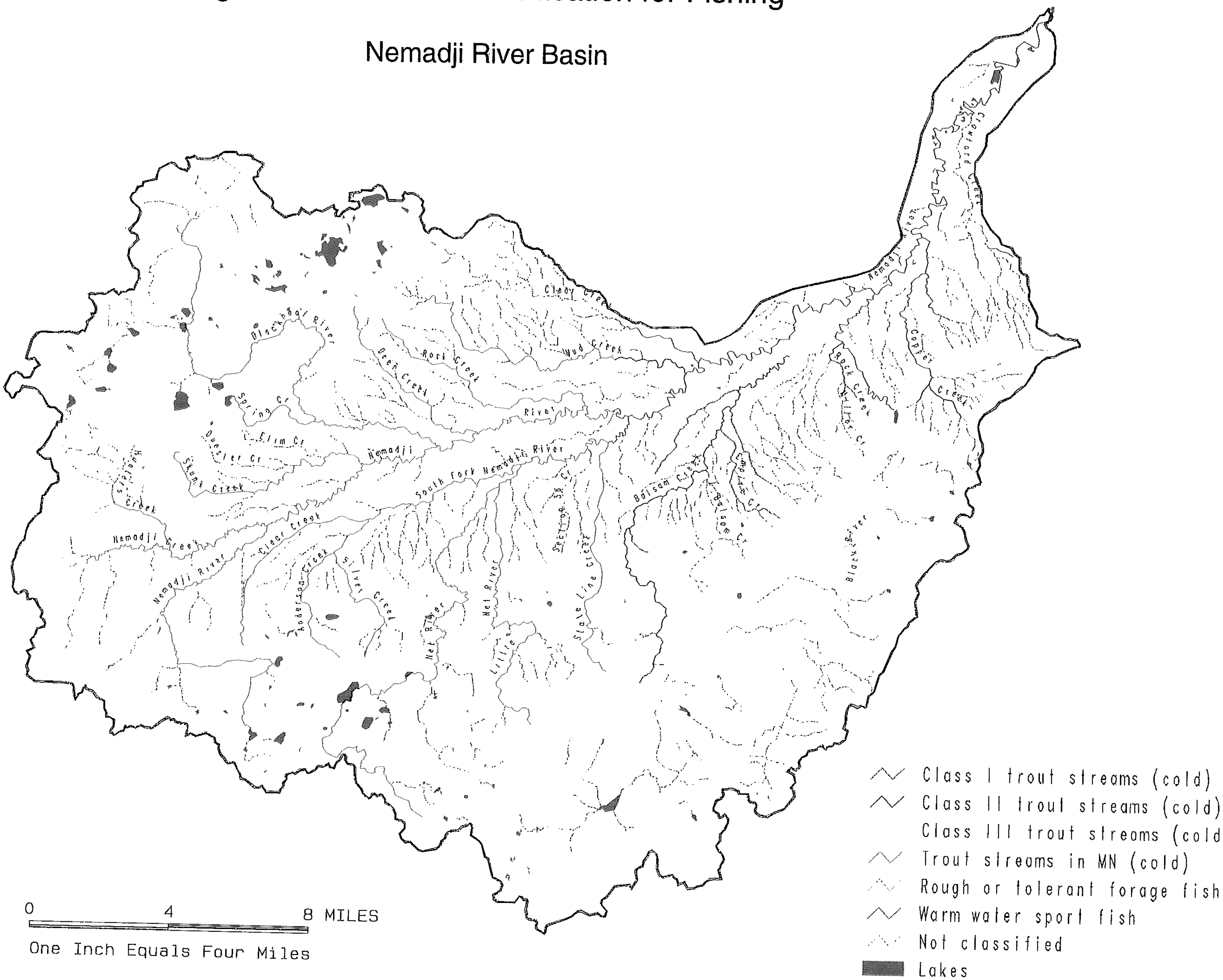
Table 8: Trout Water Classification Systems for Minnesota and Wisconsin

Minnesota
Class IA (wild trout)
Reproduction is adequate and these streams generally do not need stocking. Reintroductions are sometimes necessary where populations have been extirpated.
Class IB (cold water tributary)
Tributary streams often provide nursery habitat and can be stocked with fry or fingerlings if not being utilized by wild fish.
Class IC (semi-wild trout)
Generally these waters have inconsistent reproduction and can be stocked with any size-class.
Class ID (marginal trout)
Marginal trout streams lack suitable habitat and water quality for reproduction and year round survival. Stocking rates and sizes will vary within the state depending on local management priorities.

Wisconsin
Class I
These are high quality trout waters, having sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity. Consequently, streams in this category require no stocking of hatchery trout. These streams or stream sections are often small and may contain small or slow-growing trout, especially in the headwaters.
Class II
Streams in this classification may have some natural reproduction but not enough to utilize available food and space. Therefore, stocking sometimes is required to maintain a desirable sport fishery. These streams show good survival and carryover of adult trout often producing some fish of better than average size.
Class III
These waters are marginal trout habitat with no natural reproduction occurring. They require annual stocking of legal size fish to provide trout fishing. Generally, there is no carryover of trout from one year to the next.

Figure 11: Stream Classification for Fishing

Nemadji River Basin



Socioeconomic Conditions

The watershed is experiencing uneven patterns of growth. The estimated population of the basin was 9,100 in 1970, 9,600 in 1980, and 9,000 in 1990. Most of the population decline from 1980 to 1990 occurred in the City of Superior, although rural Wisconsin portions of the watershed also lost some people during this period. The rural population in the Minnesota portion of the Nemadji River Basin grew from 1970 to 1980, and then decreased slightly from 1980 to 1990.

Stronger growth in the Minnesota portion of the basin is evidenced by the number of residential building permits issued. The number of building permits issued per year averaged 37 in Wisconsin and 83 in Minnesota.

The population of the basin in 1990 is estimated to be 50 percent female and three percent minority, with Native Americans representing two percent of the basin total. Figures for 1980 show that the population was 50 percent female and one-half of one percent minority. The 1970 census shows the population to be 50 percent female and less than one-half of one percent from various minority groups.

Hydrologic, Forestry and Geologic Considerations

Hydrologic System Changes

Introduction

The widespread streambank erosion and slumping seen in the Nemadji River Basin today is due largely to past alterations to the hydrologic system. These hydrologic system changes include alterations to the rainfall/runoff response and to the actual runoff delivery system (water courses, tributaries, streams, etc.) of the basin. Evidence from a detailed study on a nearby watershed indicates that major sedimentation changes coincide with European settlement of the area (Fitzpatrick, 1996). Some specific hydrologic changes which have probably occurred since the middle 19th and early 20th centuries and their potential impacts on erosion include the following:

1. Increased seasonal runoff volumes- Higher amounts of runoff throughout the year translates into more aggressive channel downcutting. Channel downcutting accelerates the rate of mass wasting (slumping).

2. Increased peak discharges from individual storm and snowmelt events- Increases in peak flows from individual runoff events yield higher sediment volumes due to increased transport capacity of the streamflows and higher rates of streambank erosion.

3. Increased soil moisture levels- In some areas of the red-clay region, higher soil moisture levels in steep areas adjacent to streams may aggravate slumping through increased soil matrix weight and lubrication of slippage planes. This also impacts 1) and 2) above in that the higher the soil moisture levels, the larger the runoff volume expected.

Significant events and activities that played a part in increasing the rates and volume of runoff in the basin include: the conversion of forest land to permanent agriculture, surface drainage systems for agriculture and roads, channel modifications for log transport, and climatic changes.

Conversion of Forest to Agricultural Production

Conversion of lands to permanent agriculture played a significant role in altering the hydrology of the basin. Establishment of permanent agriculture reduced infiltration in the watershed by 1) the destruction of the extensive macro-pore system found in forest soils, 2) the creation of a soil surface that is easily "sealed" by sediment laden runoff, and 3) reduction of organic matter content that maintains soil texture conducive to infiltration.

Today, approximately 18 percent of the Nemadji River Basin is in permanent agriculture. It is thought that this percentage of agriculture may have been as high as 50 percent in the 1920's through the 1930's.

NRCS Runoff Curve Numbers (RCN) can be used to estimate the relative impacts of forest conversion to permanent agriculture. Using the RCN procedure, Figure 12 on page 59, was developed to show runoff amounts from a three inch, 24-hour rainfall for forest, pasture, and row crops for three different soil types found in the Nemadji River Basin. For a sandy loam soil, runoff from a forested condition is approximately 50 percent less than that from a pasture condition and 68 percent less than that of a row crop condition. As the texture of the soil becomes finer, runoff differences decrease. For a clay soil, runoff from a forested condition is about 14 and 33 percent less than that from pasture and row crop conditions, respectively.

Detailed infiltration studies performed in southeastern Minnesota in 1940 provide a good example of varying infiltration capacities by land use (USDA-1940). These studies were run on fourteen variations of land use and cover on three soil types as part of a flood control survey done by NRCS, Bureau of Agricultural Economics, and the U.S. Forest Service. Although this data is over fifty years old, it still provides an excellent comparison between land use/cover and infiltration rates. Table 9 summarizes the results from this study for a silt loam soil. The final infiltration values given in the table represent a rate that could be expected after the soil has been sufficiently wetted. From these values it is apparent that conversion of forest to other land uses can drastically alter runoff amounts from a watershed.

Table 9: Infiltration by Land Use/Cover from 1940 Flood Control Survey

Land Use/Cover	Infiltration Rate (in/hr)
Clean Tilled	0.26
Fair Open Pasture	1.06
Hay	1.64
Moderately Grazed Woods	2.10
Ungrazed Grass	3.75
Ungrazed Woods	9.77

Surface Drainage for Agricultural Lands and Roads

When forest land was originally converted to agriculture, surface drainage was required to move water off the fields in some locations. With this drainage, land that once had a high proportion of small, land-locked depressions would now contribute more surface runoff to the tributaries of the Nemadji River. Even though as much as 50 percent of agricultural lands present in 1940 have reverted back to a forest cover, surface ditches still convey surface runoff directly to tributaries of the Nemadji River (personal communication: Tom Cogger, NRCS, 1995).

The construction of roads in the watershed has contributed to increased rates of runoff. Prior to road building, runoff used to flow in a non-concentrated, less direct route to the main channels, allowing more opportunity for infiltration to occur. The nature of laying out a system of roads in most types of terrain requires intercepting surface water runoff from the upslope side of the road and directing it to an outlet channel by means of a ditch. The Nemadji River Basin has a relatively high concentration of roads. It averages over one and one-half miles of road for every square mile of drainage area (970 miles of road total excluding unimproved roads, logging trails, field lanes, abandoned roads, etc.). The highest concentration of roads is on the north side of the main Nemadji River in Minnesota and the downstream lower 10 percent of the watershed in Wisconsin where red-clay is predominant.

Precipitation Cycles

Significant long-term precipitation trends can add to the problem. From the Hydrologic Setting section it was pointed out that data from the Cloquet climate station showed an increase in average annual precipitation of about 20 percent over the period 1912-1994. Unfortunately, there is not sufficient streamflow monitoring to evaluate the impact of increased precipitation over this period (continuous streamflow monitoring within the Nemadji River Basin did not begin until 1974). Verry (1986) notes, however: "Climate and climate change are the long-term controls on streamflow, springs, floods, and droughts. Land use is secondary in importance to climate." Knox (1988) studied the climatic influences on flows in the upper Mississippi River valley and found that individual monthly frequencies of floods are very sensitive to seasonal climatic shifts. Ohmann et al (1979) note that streamflows in large areas are mainly influenced by groundwater inflows which are a function of climate over several years.

Alteration of Channels for Log Transport

Another major impact on the hydrology of the Nemadji River Basin was the practice of "driving" logs (floating logs to the sawmills). This practice was used primarily in the late 1800's to move logs down to Lake Superior. Rivers and tributaries were altered to facilitate this. Changes to channels included removing fallen trees, and snags; clearing brush and trees from the streambanks; and construction of cut-offs across channel meanders (Rector, 1951). Also, "splash" dams were often used to help float logs downstream. These temporary dams were constructed to pond water. After sufficient water levels were built up, these dams were breached to create large flood waves to float the stored logs downstream (personal communication: Elon S. Verry, USFS, 1995). All of these practices have the effect of increasing the velocity of flows throughout the system, increasing stream downcutting and streambank erosion. Recent evidence from tree dating in the first terrace above the current floodplain on the main stem Nemadji River indicate that downcutting may have become accelerated as early as the late 1840's. This would correspond to initial river cleaning efforts aimed at improving log river transport in the region (personal communication: Elon S. Verry, USFS, 1996).

Evidence of Hydrologic Impacts and Sedimentation Changes

The specific hydrologic impacts and changes in sedimentation rates since European settlement have not been thoroughly investigated in the Nemadji River Basin. Ideally, one would use long term stream monitoring records accompanied by historic land use information to correlate streamflows and sediment rates with changes in land use. Rarely is so much data available. Significant streamflow records for the Nemadji River Basin have only been available since 1974. Suspended sediment is available only for 1974 through 1978. Such information alone provides only a "snapshot in time" look at the flows and sedimentation characteristics of the Nemadji River Basin.

When detailed monitoring information is not available, a hydraulic analysis of abandoned river meanders along with examination of floodplain sediments can be used to determine historic hydrologic and sedimentation changes. These investigations would involve gathering information from historic photos, survey notes, tree corings, etc. Although this type of information is currently not available for the Nemadji River Basin, a study that was performed on a nearby watershed can be used. Historic erosion rates have been estimated as part of a U.S. Geological Survey study in North Fish Creek, a tributary to Lake Superior about 50 miles east of the Nemadji River having similar geologic, climatic, and land cover conditions.

Preliminary findings for North Fish Creek (Fitzpatrick, 1996) suggest that historical sedimentation rates in the lower nine mile reach of the stream are almost ten times greater than pre-European settlement (natural) rates. However, changes in sedimentation rates are not limited only to the past century. Several catastrophic events prior to European settlement are recorded in the layers of sediment within the floodplain. In addition, historical erosion rates have not been constant, and appear to be decreasing since approximately 1950. The decrease in erosion may be the result of reduction in agricultural land since the 1940's and subsequent reforestation. Sediment movement within the modern channel continues to be a problem because large amounts of sediment are stored on the floodplain from historical floods. A comparison of channel width with historical information indicates that the sand load carried by the stream has increased since European settlement.

In a study of the adjacent St. Louis River watershed (Kingston et al, 1987), sediment cores reveal that lake water has changed from high transparency and low nutrients to low transparency and high nutrients. The largest change occurs in the mid-19th century, coincident with deforestation.

Timber Harvesting Impacts on Hydrology

Since the Nemadji River Basin is over 69 percent forested, management of timber harvesting has the potential for impacting short and long term hydrologic changes. As stated in the Forestry Management section of this report, 62 percent of the forest in the Nemadji River Basin is greater than 45 years old thus creating a high potential for timber harvesting.

Literature (Verry, et. al., 1983; Lu, 1994; Hibbert, 1966) on the subject of timber harvesting impacts on streamflows show differing opinions. Forest type, soils, and climate differences may explain some of the variation between watersheds. Lull and Reinhart (1972), upon reviewing data from clearcuts in North Carolina, West Virginia, and Japan conclude that "... heavy cutting is possible without serious watershed deterioration as long as the mineral soil is not greatly exposed or compacted." Regional studies in the lake states suggest that timber harvesting can significantly increase streamflows due to higher soil water levels for harvested areas versus unharvested areas. This impact, however, is usually minimal when one considers the percent of a watershed that is typically harvested at any one time (Corbett and Spencer, 1975; Lull and Reinhart, 1972; Verry, 1972).

In Minnesota, when harvesting is performed in the winter and when frost is deep, infiltration properties of a site are altered very little. In this situation, the main hydrologic differences that occur due to the harvesting activities include the following:

- reduction in the amount of precipitation that is intercepted by the trees
- reduction of evapotranspiration (consumptive use of soil water by trees)
- acceleration of snowmelt rates

Timber harvesting increases the total effective precipitation reaching the ground by removing the trees which intercept a portion of the precipitation. Using a procedure outlined by Verry (1976) and annual precipitation figures from the Cloquet, Minnesota climate station, this loss of interception can translate into an increase of precipitation reaching the ground of 19 percent and 28 percent for aspen and pine clearcuts, respectively. Also, harvesting usually increases soil moisture content by decreasing evapotranspiration which in turn reduces storage within the soil profile. Both of these effects, however, usually diminish quickly as vegetation returns to the site (Corbett and Spencer, 1975; Ahlgreen, 1981; personal communication: Mark Diers, NRCS, 1995).

A faster snowmelt rate in recently harvested areas is largely due to an increase in energy levels responsible for melting snow. The dense coverage of aspen suckers (41,000 stems/acre) established during the first summer following harvest of aspen stands can generate far more longwave (reflective) radiation on snowpacks than the amount one would expect from mature stands. This effect diminishes as trees mature and stem per acre densities decrease (Verry, et al., 1983).

The time required for the hydrologic system of a clearcut area to recover to pre-harvest conditions is highly variable and will be a function of climate, soils, species, topography, and harvesting methods. Table 10 summarizes Lu's (1994) literature search on recovery times.

Table 10: Studies on Harvesting Impacts and Recovery Times

Location	Impact	Time of Recovery	Investigator
Oregon	Increased Water Yield	27 years	Harr
Colorado Rockies	Increased Water Yield	60-80 years	Troendle
Southwest U.S.	Increased Water Yield	3-7 years	Baker
North Carolina	Increased Water Yield	15 years	Swank
Northern Minnesota	Increased Snowmelt Q_{peak}	15 years	Verry
Northern Minnesota	Increased Growing Season Q_{peak}	3-5 years	Verry

As can be seen from the table, the effects of timber harvesting on hydrology are transient in nature when regrowth is permitted. Clearcutting followed by either natural regeneration or by tree planting is far less detrimental to the hydrology of a watershed than full conversion to agriculture or urbanization. Rienhart (1964) notes this with the following: "There is little doubt that complete forest destruction ... does great harm ... But a distinction should be made between clearcutting steep lands, followed by conversion to pasture or hillside crops, and clearing without serious soil compaction followed by regrowth ... As long as the forest floor remains intact, most of the beneficial hydrologic effects of the forest may still be present."

When harvesting takes place in the summer or during poor frost conditions in the winter, compaction of soils can reduce the infiltration properties of forest soils. Research from the U.S. Forest Service North Central Forest Experiment Station shows that harvesting under these conditions can cause compaction in the upper 20-30 cm of the soil profile. It is estimated that aspen regeneration is 20 to 30 percent less in terms of biomass between compacted and uncompacted sites. Infiltration characteristics of the soil have not fully recovered on the research sites since the compaction tests were run six years ago (personal communication, Elon S. Verry, USFS, 1997).

As the size of a precipitation event increases, effects of harvesting usually decrease. Harr, et al. (1975) note this in their study of storm hydrographs after clearcutting and road building in Oregon: "For larger storms, differences between cut and uncut areas become smaller, so that increases in storm runoff after clearcutting would be smaller . . . . These large events are wet mantle floods caused by such great amounts of precipitation that differences in soil moisture content and interception between cut and uncut areas becomes insignificant." Douglass and Swank (1975) note the same phenomenon in their studies in the Coweeta Experimental Forest in North Carolina. Lu (1994) performed a modeling analysis of the Marcell Experimental Forest runoff plots and noted that effects were greatest on events with smaller recurrence intervals. Frequency curves that were developed showed that differences in discharges between pre- and post-harvest become insignificant at approximately the ten-year recurrence interval.

Harvesting Impacts on Streamflow - Marcell Experimental Forest Data

Much of the data on increases in streamflow due to timber harvesting in Minnesota comes from research done at the Marcell Experimental Forest located in north-central Minnesota. Most of the following information comes from two papers (Verry, et al., 1983 and Verry, 1987) and from personal communication from Elon S. Verry (USFS) and Dr. Ken Brooks (University of Minnesota). The paired watershed study at Marcell included two regenerative aspen-birch sites 130 and 84 acres (control and clearcut, respectively) in size each having sandy loam upland soils with black spruce bogs located in the center. Nine years of discharge data was gathered to calibrate discharges on both watersheds prior to the actual clearcutting. Discharge measurements continued following the clearcut. One-half of the clearcut was made prior to spring snowmelt in 1971 providing insights to the impacts of partial clearcuts on streamflow. Key results are summarized below:

1. For runoff resulting from rainfall, peak discharges approximately doubled the first year following clearcutting. This effect lasted three to five years after which it returned to pre-harvest levels. Runoff volumes doubled, however, the effect lasted only two years.

2. For runoff resulting from snowmelt, peak discharges approximately doubled. This effect persisted for up to 15 years following harvest. Runoff volumes essentially remained the same. Timing of peak flow from snowmelt occurred an average of five days sooner on the clearcut area versus the control area.

3. When considered on an annual basis, most streamflow changes between a harvested and unharvested condition took place during the growing season. Soil moisture differences between open and forested areas are expected to be greatest during the growing season.

4. Partial clearcuts reduced peak discharges on snowmelt events by "desynchronizing" or separating runoff hydrographs from open and unharvested areas. This relationship holds for cleared areas up to about 50 percent, beyond which peak discharges from snowmelt can substantially increase.

Using concepts from 2) and 4) above, one arrives at the conclusion that to minimize hydrologic impacts, timber harvesting should be managed so that no more than 50 percent of the total watershed area should be in trees in the 0-15 year age (young forest) class. In dealing with watersheds with other land uses, the open area is defined as the percent of young forest *plus* agriculture and other non-forest uses. With this percentage of open area and trees in this age class, peaks from both snowmelt and growing season runoff events should not be significantly higher than those from the original mature forest. Above the

50 percent level, hydrologic impacts become significant. This guideline is used extensively throughout Wisconsin and Minnesota.

Applicability of Marcell Experimental Forest Data to the Nemadji River Basin

As with any information from a specific location, caution must be used when considering its use at other locations having different physical characteristics. Some important differences between the Nemadji and Marcell settings are as follows:

1. The Marcell plots are approximately 20 percent bog or peatland. Verry notes that the bog or peatland alone probably decreases peak flows. For watersheds without the natural "flow buffering" effects of landscape storage (bogs, ponds, wetland, etc.), hydrologic impacts of timber harvesting will likely be more pronounced. The 50 percent open/young forest guideline may be too high to use on a watershed without natural storage features.

2. The desynchronization effect (timing effect of melting snow on open versus forested areas) on the size of management unit recommended for the Nemadji River Basin (about 10 square miles - see Watershed Management Recommendation) is unlikely to be as pronounced as what was seen on the Marcell sites (84 and 130 acres). This is due to the varied topography and aspects found in the Nemadji River Basin (personal communication: Dr. Ken Brooks, Univ. of Minn., 1996). Federer, et al. (1972) also noted this lack of desynchronization effect in the hilly terrain of New England. Variable melting rates between open and forested areas are likely to be occurring in the Nemadji River Basin. Review of snowmelt hydrographs from U.S. Geological Survey monitoring data in Deer Creek from 1977 through 1988, however, reveal no discernible desynchronization effect. The decynchronization effects in this watershed need to be evaluated at a later date.

3. The conclusions from the Marcell Experimental Forest data are often interpreted to include agricultural land uses within the same hydrologic category as young forest when determining "open area" percentage. This is due to the assumption that during snowmelt, soils are frozen and therefore the hydrologic differences between young forest and agricultural settings would be minimal. However, as the density of agricultural land use increases, other landscape changes that accompany agriculture (roads, drainage, soil structure alteration, etc.) become significant. These other landscape changes begin to significantly affect the hydrology of a watershed beyond that shown by the Marcell data. Because of the relatively high percentages of permanent agricultural lands within many of the smaller watersheds of the Nemadji River Basin, the "percent open" level at which significant hydrologic change takes place is likely to be lower than the 50 percent level identified from the Marcell Experimental Forest data.

Preliminary work by Verry indicates that peak flows in the clay belt of South Superior double at a lower percentage of open area than would be expected using Marcell Experimental Station data. Verry attributes this to the mixture of road density, abandoned drainage ditches in reforested areas, and compacted soils on pastures, all features found within the Nemadji River Basin (personal communication: Elon Verry, USFS, 1996).

A similar effort to Verry's was done as part of the Nemadji River Basin Project. In an attempt to look at the relationship between forest area and peak discharge within the region, data from eight U.S. Geological Survey gaged watersheds located near the southern shore of Lake Superior were analyzed. The watersheds selected for this analysis are within the red-clay region and have less than 20 square miles drainage area. The discharge or streamflow having a 50 percent chance of occurring within any given year (Q_2 or sometimes called the 2-year event since the probability of it occurring is once every two years) was used for this analysis. Q_2 is relatively close to the channel forming discharge ($Q_{1.5}$ or one and a half year discharge) defined by geomorphic principles and is thus important to streambank stability (Rosgen, 1994).

Table 11 lists the stream gages used. A procedure was used to "normalize" (eliminate) the drainage area and watershed slope differences between the watersheds. Figure 13 on page 59 displays the percent forest versus the normalized Q_2 peak discharge. Results from a statistical test (Student's T-Test using a 5 percent level of significance) comparing the averages of two independent sets of data show that watersheds with more than 40 percent unforested area have Q_2 discharges that are at least 25 percent higher than those from watersheds with less than 40 percent unforested area.

Table 11: USGS Stream Gages on South Shore Lake Superior - Red-Clay Region

USGS Gage No.	Description	Drainage Area (mi^2)	% Forest	Slope (ft/mile)	Q_2 (ft^3/sec)	Q_2 Normalized for Area and Slope
4026200	Sand River Trib. near Red Cliff	1.09	98	204	116	26.7
4024200	South Fork Nemadji near Holyoke	19.40	73	37	770	23.6
4024098	Deer Creek near Holyoke	7.77	68	41	376	24.6
4024110	Rock Creek Trib. near Blackhoof	0.20	65	91	17	20.7
4024100	Rock Creek near Blackhoof	4.94	57	42	431	41.3
4024400	Stoney Brook near Superior	1.86	52	56	205	41.9
4025200	Pearson Creek near Maple	4.07	40	75	356	34.5
4026700	Trout Brook Trib. near Marengo	0.66	24	178	124	45.5

<u>Forest Stand Type Considerations</u>

A diverse forest cover type of latter successional species, especially coniferous species, will improve hydrologic condition. Diverse cover conditions tend to have a greater buffering effect on the hydrology of a watershed since the varying cover types convert precipitation to runoff and infiltration differently. The result is usually a more balanced state of surface runoff, infiltration, and snowmelt rates which in turn produces less runoff and lower peak discharges. Timber harvesting can be done in such a manner to encourage establishment of the later successional conifer types. This will result in a more diverse land cover along with an improved hydrologic condition.

Conifers tend to have a longer transpiration period during the year and intercept and evaporate more annual precipitation than deciduous trees. For northern Minnesota climates, it is estimated that conifer stands use approximately 2.5 inches more water than deciduous stands (Verry, 1986). The result is drier soils which reduce surface runoff by: 1) improving infiltration at the soil surface and 2) providing more storage of infiltrated water within the soil profile. Much of the improved infiltration from conifer stands can be attributed to better macropore connections between the soil surface and the root zones below (personal communication, Dr. Ken Brooks, 1996).

Three major considerations/implications of stand conversion on a large scale are: 1) establishment time scales, 2) soils, and 3) economics. Development of thicker humus layers through stand conversion and thus improvements in hydrologic condition would be measured in terms of decades. The heavier red clay soils should be managed for the coniferous understory present in many of the aspen stands. In the non-red clay soils area of the basin, red pine is a tree that could be planted. Economics will play a significant role in the decision of when and what a landowner decides to harvest. It may appear that a clearcut of the aspen would be the most profitable. However, harvesting aspen and saving the understory may be more profitable in the long run (balsam fir boughs for holiday wreaths may be a better economic option). The feasibility of managing for later successional species would obviously have to be conducted using long range planning principles that consider both the economics of future land management options, costs of management options, and environmental impacts.

<u>Summary</u>

Changes in the hydrology of the Nemadji River Basin are largely responsible for the accelerated streambank erosion and slumping that is occurring today. Significant events and activities that have altered the hydrology of the basin include: conversion of forest land to permanent agriculture, surface drainage systems for agriculture and roads, channel modifications for log transport, and climatic changes. These activities have increased total runoff volumes and the rates (i.e. peak flows) at which runoff leaves the watershed. Preliminary results from a detailed study on nearby North Fish Creek (Fitzpatrick, 1996) suggest that sedimentation rates in the lower reaches of the watershed are almost ten times greater than pre-European settlement rates. Due to the similar land use, soils, and climatic conditions in the Nemadji River Basin, it is assumed that North Fish Creek estimates of historical sedimentation rates apply in the Nemadji River Basin Project area also.

Figure 12 - Runoff Amounts by Land Use and Soil From 3 Inch, 24-Hour Rainfall

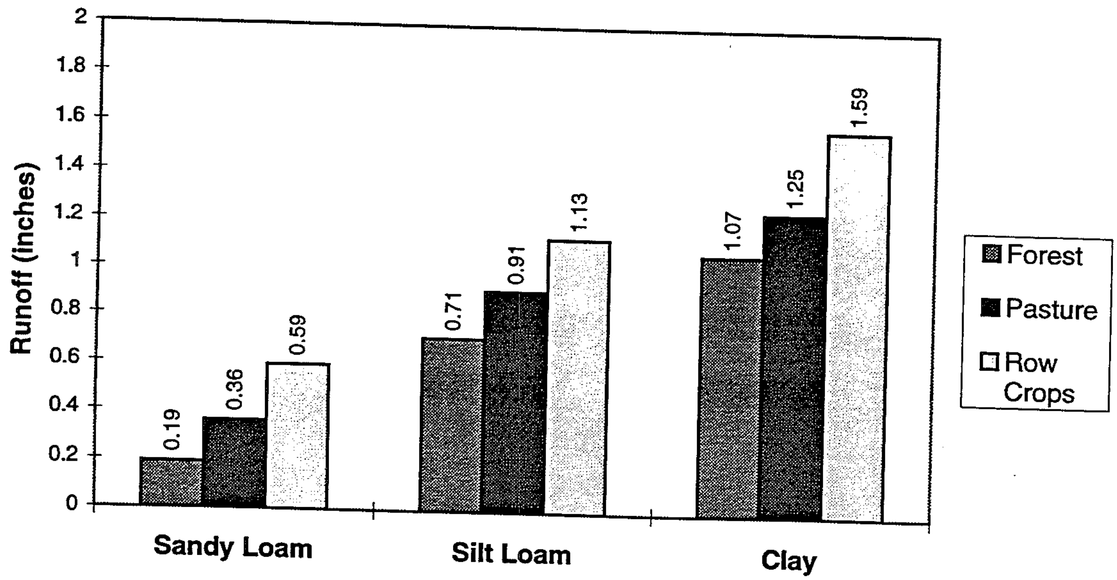
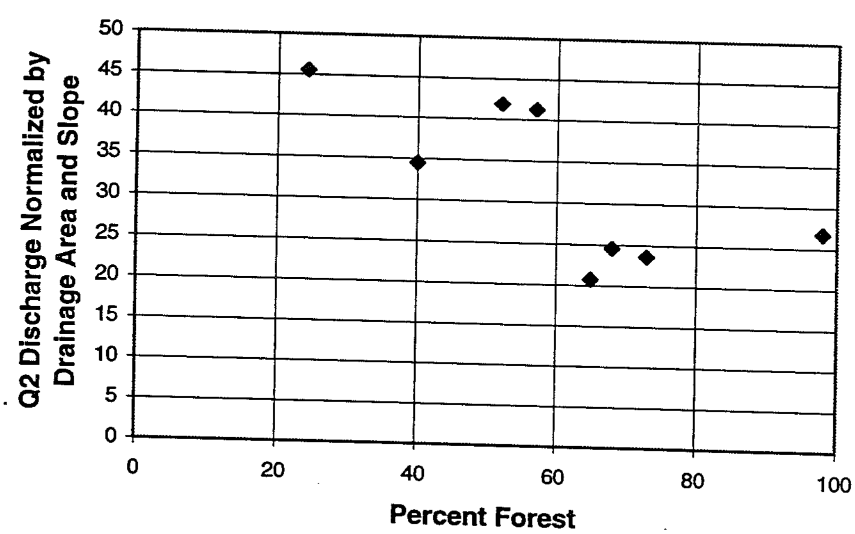


Figure 13 - Discharge vs. Percent Forest South Shore Lake Superior - Red Clay Region (Gages < 20 Square Miles Drainage Area)



Since 62 percent of all forest land within the Nemadji River Basin is over 45 years old, there is a high potential that timber harvesting may become accelerated in the near future. Management is important in making sure that the hydrologic condition of the basin is not degraded further. In the northern Lake States region, it is generally agreed that timber harvesting affects water yield and peak discharges on the harvest site itself through: 1) reduction of interception, 2) reduction of soil moisture storage, and 3) acceleration of snowmelt rates. However, due to natural re-establishment or tree planting efforts, the majority of clearcuts recover hydrologically to pre-harvest conditions relatively quickly. Based on research in the Marcell Experimental Forest in Minnesota, this recovery period is estimated to be about 3-5 years for growing season runoff events and 15 years for snowmelt events.

Another important consideration is the percentage of a watershed that is actually harvested. Watersheds have the ability to "buffer" the effects of upstream activities with landscape storage (bogs, ponds, channel and floodplain storage, etc.). Beyond a certain threshold, however, the buffering effect cannot compensate and hydrologic impacts become apparent. Research from the Marcell Experimental Forest suggest that impacts become significant when the percent of open area (young forest 0-15 years old and agricultural land) in a watershed exceeds 50 percent. Because of landscape and soil differences between the Marcell sites and the Nemadji River Basin, it is recommended that harvesting activities be managed for a lower threshold. Utilizing data from stream gages along the south Superior shore as a guide, an upper limit of 40 percent open area is recommended for the Nemadji River Basin. This recommendation should be carried out on the subwatershed level (watershed based units about 10 square miles in size) in order to prevent adverse hydrologic impacts at the local level.

Economic considerations may be taken into account to accommodate exceptional circumstances such as: 1) salvage of diseased or blow down areas and 2) allowing higher harvesting rates for areas with high percentages of trees past an economically optimal harvesting age. For details, see the Upland Forestry Management recommendation.

An example of applying this recommendation follows:

> Assume a subwatershed has 22 percent agriculture, 75 percent forest, and the remaining three percent is wetlands and open water. Using the 40 percent open guideline, this leaves (40 - 22) or 18 percent of the total subwatershed area that could be managed for trees in the 0 to 15 year age class without experiencing significant hydrologic impacts.
>
> Since the percent forest is 75 percent of the total subwatershed area, the percentage of the *total forest area* that could be managed for trees in the 0 to 15 year age class would be $0.18 \div 0.75 = 0.24$ or 24 percent. The constant rate of harvesting that would result in 24 percent of the total forested area in trees that are 0 to 15 years old is $0.24 \div 15 = 0.016$ or about

1.6 percent[1]. In other words, if 1.6 percent of the trees are harvested each year, 24 percent of the forested area or 18 percent of the total subwatershed area will be in trees 0 to 15 years old. Combined with 22 percent agriculture, this would keep the percent open area below the 40 percent level.

Based on current harvesting trends, managing timber harvests to keep the percent open/percent forest below the 40 percent for the whole Nemadji River Basin through management of its subwatersheds should not be difficult. According to the land use inventory conducted as part of this study, approximately 10 percent of all forested land in the Nemadji River Basin is dominated by trees less than 15 years old. This translates into, on the average, a current harvesting rate of less than 0.7 percent per year on all forest land. Harvest rate estimates on state, county, and industrial lands developed by the Nemadji River Basin Project Forestry Committee put harvest rates at somewhere between one and two percent per year. Assuming agriculture remains steady at 18 percent and an aggressive constant harvesting rate of 1.5 percent per year (about double the current estimate) on all the forest land within the Nemadji River Basin, the total percent open land would be about 33 percent, well below the recommended 40 percent.

It should be acknowledged here that such "percentage type" recommendations for upland forest management are not site specific and have no correction for other factors that make some subwatersheds react differently to harvesting than others (i.e. presence of wetlands, soil type, channel morphology, slope, tree species, etc.). Grant (1986) suggests that watershed hydrologic response to timber harvesting does not occur with large shifts beyond some threshold value of cutting but is actually a curvilinear response. He goes on to suggest more of a geomorphic approach: How much change can the current hydrologic system tolerate before channel instability becomes a problem? Unfortunately, this approach requires extensive data and analysis. The work currently being performed in the watershed by Mark Reidel, University of Minnesota, is a step in this direction. It is hoped that the proposed recommendation based on percentages of open area within a subwatershed is flexible and practical enough to be used until better, subwatershed specific recommendations can be developed.

Forest Management

Introduction

The present watershed forest is dominated by early successional species, and much of it is close to the same age class. These two attributes create challenges and opportunities. The challenges focus on what will happen to the forest in the next 20 years. Opportunities arise in the process of applying what we understand about the impact of forestry on the

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[1] To determine the rate of constant harvest that would result in a given percent of trees in the 0-15 year age class, take the percent of trees in the 0-15 year age class and divide it by 15.

condition of a watershed. We must apply our knowledge on a voluntary basis, allowing landowners to attain objectives they have for their land.

Forest landowners make decisions on how the forest resource will be managed. These decisions will impact the forest community and watershed for years to come. Some landowners will make decisions based on sound scientific and economic information, while some will make uninformed decisions. Some will make decisions based on a long range plan for the future, and some will make decisions based on immediate needs.

The following guidelines contain some broad silvicultural ideas that landowners may want to consider as they plan how to use their land:

- Understand the site and its capabilities when conducting harvests and regenerating a forest. Be sensitive to natural successional changes that are becoming evident in forest understories and the silvicultural options these future cover types may offer.

- Consider developing age class distribution to obtain multiple benefits, and lessen the impact of any one silvicultural activity in the future.

- "Do nothing" is a valid conscious management decision, particularly in sensitive areas and areas in which the result of other management decisions may be in doubt.

These considerations intensify management efforts resulting in more planning time, an increase in plan complexity, more involved prescriptions and timber sale specifications, and potentially increased logging costs. As resource management becomes more sophisticated, harvesting decisions will likely become more complex and involve compromises.

In the Nemadji River Basin, about 48 percent of forest land is owned by the states, counties, and private industries. Government agencies and private industries follow the above guidelines in long range plans. Non-industrial private forest landowners can access this knowledge through the development of a forest stewardship plan. Non-industrial private landowners may need the advice of a professional forester to make informed decisions about managing their land and harvesting timber. However, there is presently not enough forestry technical assistance available to meet the demand. Before an effort is undertaken to increase non-industrial private forest management planning and implementation, consideration should be given to increasing the number of foresters available to help the landowner develop the plan.

<u>Tree Species and Diversity</u>

The species composition of the future Nemadji River Basin forest will be more diverse than the current forest. Balsam fir and black spruce are understory trees in many of the aspen stands. Some of the aspen stands are on sites where they do not grow well and will never be harvested because they do not have sufficient volume for a commercial harvest. Over 50 percent of the watershed is in private ownership, and some of these landowners will choose not to harvest. Non-industrial private forest landowners should be encouraged to adopt some of the practices of the private forest industry. The private forest industry manages its land for multiple uses, and regenerates its land to the species best suited for the site. For example, it regenerates spruce and fir on red-clay soils, and red and white pine on other soils.

Management of the current forest will affect the rate at which this diversity develops. Timber harvests can leave more understory species and accelerate the successional process. Timber harvests that clearcut aspen with the goal of regenerating aspen slow the successional process. It is predicted by foresters working in the basin, however, that even without a conscious decision on the part of the landowner the forest type in the watershed will be primarily spruce-fir or maple-basswood within two or three rotations. These species are in the understory currently and will compete very well with aspen on many of the sites in the basin.

The cumulative effect of all these actions will be a forest with more species diversity. The diversity will eventually improve the watershed condition by increasing the depth of duff layers, the rate of water infiltration, and the amount of water held on the land after a rainstorm or during snowmelt.

Trees in the Riparian Zone

A strong relationship exists between life in the stream and the life and death of trees bordering the stream. This relationship occurs in an area called the riparian zone. The riparian zone is the band of land of varying width that significantly influences the stream ecosystem, or conversely is significantly influenced by the stream. The riparian zone can partially override climatic and geologic effects, especially in small streams found in the Nemadji River Basin. Undisturbed, forested headwater streams have similar characteristics worldwide, because trees provide shade, organic matter, energy, and large woody debris (Verry, 1992).

Every ecosystem has structure and function.

Structure of an ecosystem is the arrangement of three components:

1. Biologic community
2. Energy and material resources - sun, decaying organic matter, and minerals
3. Physical habitat

Function of an ecosystem is the collection of biological, chemical, and physical processes which govern the flow of energy and materials through the ecosystem (Verry, 1992).

Trees in the riparian zone significantly affect the structure and function of stream ecosystems. "In small streams, up to 99 percent of the organic matter entering the food web is derived from trees. Commonly, leaves, twigs, and groundwater entering the stream provide about two thirds of the energy sources (carbon and other nutrients) in first to fourth order forested streams" (Verry, 1992). Tree root systems reduce streambank erosion rates, and more stable streambanks affect the shape of the stream channel. "Logs falling into streams become food for decomposers, and a source of invertebrate and fish habitat diversity. By acting as dams, logs can divide what might otherwise be a uniformly flowing stream into one marked by alternating pools and riffles. Hydraulically, woody debris dams can reduce the effective slope of a stream by 6 to 90 percent. The pools formed are important, for it is here that organic matter collects and stays long enough for decomposers to work on it, and fish to eat the decomposers" (Verry, 1992).

In the Nemadji River Basin, a mixture of deciduous and coniferous trees in the riparian zone is most beneficial to the stream ecosystem. Deciduous trees provide a large amount of leaf litter and shade to forest streams. They also allow early spring warming. Because of their shorter life spans, they provide more frequent canopy openings along the channel. However, aspen and birch do not provide stable large woody debris in stream channels. Large conifers are the best source of large woody debris since their size creates deep pools for habitat and stream structure and they are resistant to decay. Therefore, a mixture of deciduous and coniferous species provides food, stream structure, and sunlight openings to maximize stream biological production (Verry, 1992).

The following information on streambank erosion in the basin comes from some recent evaluations by Elon S. Verry, Research Hydrologist, U.S. Forest Service, Grand Rapids, Minnesota, and Mark Riedel, Research Assistant, Forest Resources, University of Minnesota, St. Paul, Minnesota. The research is not complete. These studies should be followed to keep appraised of new developments. New information will help forest managers make decisions on forest practices that will meet landowner needs and improve the health of the watershed.

In the clay portions of the basin, two types of streambank erosion are occurring. Bluff erosion occurs where the outside bends of streams are against a valley wall. The stream has meandered to the edge of its floodplain, and is eroding a terrace (previous floodplain), often to a great height above the normal water elevation. The outside bend of a meander is a typical location for streams to cause erosion. The rate of erosion is accelerated by high peak flows. Additional erosion at much lower bank heights is occurring in straight sections of streams. This is again accelerated by high peak flows, and by vegetation along streambanks with very low root strength. Loss of deep, dense rooting along stream channels has allowed straight channel erosion to become extensive. Large trees have deep and large root systems, small trees shallower and less extensive root systems, shrubs even less, and sedges and grasses the least. Due to undercutting of the banks during high flows, slumping often occurs along streambanks vegetated with only grasses.

The forested riparian zones contain widely spaced ash, balsam poplar (balm-of-gilead), and balsam fir. Because they are so widely spaced they are not very effective at slowing the rate of bank slumping in the straight sections. Large trees about 30 feet apart right on the bank are needed to reduce bank slumping. The riparian zones in the Nemadji River Basin are 40 years into a 300-year cycle. It will take a long time for the mixture of late successional hardwoods and softwoods to become large trees that reduce streambank erosion rates, and eventually fall into the stream and add structure to the channel.

River Morphology

Stream channels are formed through erosion and deposition. Stream discharge and frequency of discharge determines the effectiveness of the erosion and deposition process. High discharges are very effective in erosion and deposition, but they don't occur very often. For example, during a four year period on Deer Creek, 74 percent of the total suspended sediment yield over the 1,440 days of record came during only 18 days of high flows. Research and field observations have determined that, over time, bankfull discharges do the work to form and maintain the channel. The bankfull discharge corresponds to an event having a 67 percent chance of occurring in any given year or occurring, on the average, once every one and a half years (Leopold, 1994).

The relationship of the floodplain of a stream to its channel is significant. Stable streams are connected to their floodplains and during large runoff events, the force of the water is dissipated by being spread out over the floodplain. In unstable systems, the higher discharges are confined to the channel resulting in the full force of the water being exerted upon the streambanks and streambeds. Such instability is found in stream channels in the red-clay soils of the Nemadji River Basin.

Cumulative effects of early logging practices, construction of roads, and conversion of forest to agriculture have increased discharges in the Nemadji River Basin (see Hydrologic System Changes section of this report). These increased discharges have accelerated downcutting of the Nemadji River and its tributaries. It is possible that this downcutting is still working its way up the tributary streams. For a visual display of this concept, consider Figure 5 on page 28 which shows the channel slopes for the Nemadji River and its tributaries. From these figures one can see the main stem Nemadji River has already undergone a "flattening" while the tributaries have yet to catch up.

A method for classification of rivers was recently developed by hydrologist David Rosgen. This classification system categorizes streams based on gradient, entrenchment, width/depth ratio, sinuosity, and streambed material. Stream classification is a tool for: 1) determining the relative stability or instability of a stream reach and 2) designing in-stream rehabilitation measures. A field classification of Skunk Creek was made in the fall of 1994 and both "B" and "E" type channels were noted. "B" channels are moderately entrenched, have moderate sized floodplains and moderate sinuosity (length of valley divided by the length of the river). "E" channels are relatively stable. They are not entrenched, have wide floodplains and tend to have a high sinuosity. However, in the agricultural areas of the Nemadji River Basin "E" channels have roughly half the sinuosity expected. This implies the streamflow has more erosive energy due to increased discharge from increased runoff from agricultural lands.

Slumping Mechanism

In the sediment budget developed for this report it is estimated that 98 percent of the sediment yielded from the Nemadji River into Superior Bay comes from the valley slopes and streambanks (see Table 12 and pie chart on page 73). Therefore, understanding the dynamics of streambank and bluff stability is very important to any type of remediation activities. Streambank and bluff stability factors include the following:

- water (soil moisture, groundwater, surface water)
- soil stratification
- roots (density and depth)
- bank height
- bank angle
- soil chemistry
- particle size

<u>Surface Water, Soil Moisture and Groundwater</u>

Unstable bluffs along much of the Nemadji River and many of its tributaries result in mass wasting (slumping, sliding, etc.) of large volumes of soil. Bloom (1978) provides an explanation of mass wasting and the role of water. "The collective term for all gravitational or downslope movements of weathered rock debris, including soil, is mass wasting. The term implies that gravity is the sole important force and that no transporting medium such as wind, flowing water or ice is involved. Although flowing water is excluded from the process by definition, water nevertheless plays an important role in mass wasting by oversteepening slopes through surface erosion at their bases and by generating seepage forces through groundwater flow."

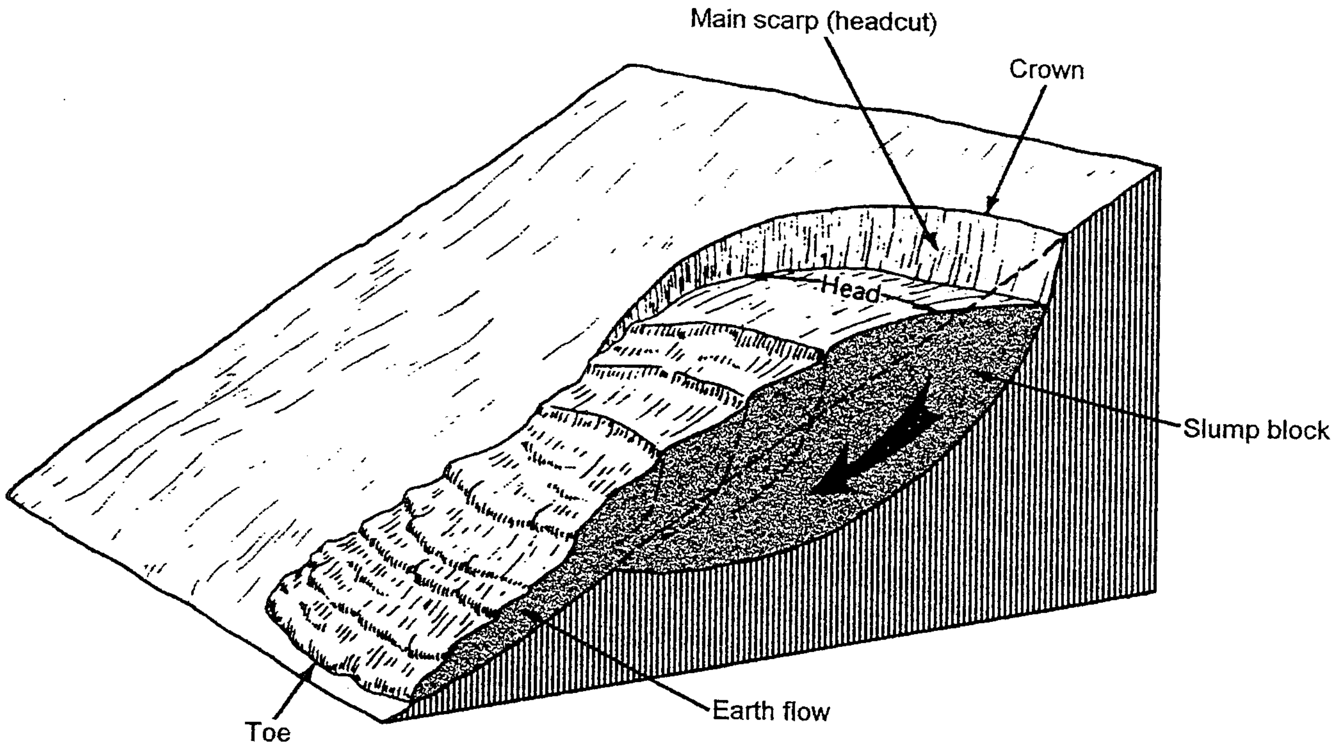
Slumping is the most prominent type of mass wasting occurring in the Nemadji River Basin. Bloom (1978) provides an excellent diagram and description of this type of mass wasting. Figure 14 shows a slump (rotational slip along a concave up surface of rupture) passing downhill into an earthflow. This is an extremely common form of mass wasting although some of the named components might be absent in any single example.

Moisture adds weight to the soil and acts as a lubricant. Moisture is particularly critical to the stability of red-clay soils since the soil is stable in a rather narrow range of moisture content. Soil shear strength (resistance to sliding along a plane) increases with moisture to a maximum and then decreases to a very low shear strength as moisture is further increased. Dry conditions encourage soil fractures and crumbling, while wet conditions create liquid-like conditions and soil slippages.

The Red Clay Project report states that "slope instability results when decreased moisture causes fissure development in the brittle surface zone, which slides over plastic clay below if moisture accumulates in the fissures. . . ." Although this process does occur, it should be noted that these observations were made during the fall of 1976 through the summer of

1977, which was a very dry period. Records indicate this period to be the worst drought since 1910. Some of the conclusions of the Red Clay Project may have been influenced by making observations during this dry period. It should be noted that the Red Clay Project found that maximum rates of slumping occurred during the spring snowmelt when soil moisture levels are high.

Figure 14: Types of Mass Wasting Occurring in the Nemadji River Basin



source: Bloom, 1978

Groundwater has a great effect on the stability of soils. Giacomini (1980) discusses groundwater flow in the clay having two distinct modes: flow through connected pore space in the soil, and flow through fissures, joints and slippage planes. The low hydraulic conductivity, or rate at which water moves through a permeable medium, of the clay allows only slow groundwater movement. Water moves more rapidly through secondary openings such as desiccation fissures at the land surface, joint sets (parallel fracture surfaces) in clay, root pores, and slippage planes in slump areas. Giacomini's study of groundwater flow in Skunk and Deer Creeks using piezometers[2] indicated that both modes of flow conditions exist.

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[2] Piezometers are non-pumping wells used to measure the elevation of the water table or potentiometric surface. The potentiometric surface is the surface that represents the level to which water will rise in tightly cased wells. Water in a piezometer will rise to the same level of elevation as the water in the ground, above or below that level depending upon: 1) whether or not there is an overlying confining layer and 2) the direction of groundwater flow in the area.

The piezometers showed that flow "generally moves downward or laterally in the upland areas. Near the valley bottom, groundwater flow is mainly upward to the creeks" (Giacomini, 1980). Groundwater originating in the uplands may flow into the clay, contribute to slumping and discharge through seeps. Any groundwater influence on slumping may be the result of long-term precipitation trends since groundwater recharge within the red-clay area tends to occur slowly. A sustained period of wet years may create increased pore pressure within the clay through an elevated water table. A continuous series of dry years may result in more surface cracking of clay soils which increases macropore flow of any rainfall deeper into a clay mass. The extent to which the precipitation trends actually influence slumping is still very much unknown.

An elevated water table is evidenced by more seeps and an increase in pore pressure resulting in greater flow through existing seeps. Vegetation removes water from the soil and contributes to physical alteration of soil structure and soil drying. When trees are harvested the amount of water yielded from the area generally increases (Douglass and Swank, 1975). After harvest, water must still move through the soil to reach the stream although there are no longer trees to take up water. This usually results in greater streamflow and wetter soils (personal communication: Ulf Gafvert, NRCS).

Stratigraphy

The stratigraphy, or variation in geologic or soil strata, also plays a part in mass wasting. Variation in layers can cause zones of weakness. In addition, these layers may provide a pathway for excess soil moisture from upland areas. Layers of gray silt and very fine sand are often found in the wet slip planes of slumps (personal communication: Ed Bacig, graduate student, University of Minnesota, Duluth). Water collects in stringers or layers which are coarser than the surrounding material since such material has the greatest volume of interconnected pore space.

Vegetation

The Red Clay Project of the 1970's conducted research on the relationship between erosion and vegetation. One study found that grasses and herbaceous plants yield beneficial anti-erosion effects. Another study done during the Red Clay Project measured the root tensile strength (resistance to a force tending to tear the roots apart) of various woody species. The study found aspen, white spruce, and white pine to have similar root tensile strengths. Balsam fir has somewhat stronger tensile strength than the above species. Red maple and hazel have the strongest root tensile strengths. In addition, the root distribution under various cover types was reviewed during the Red Clay Project. It was found that on similar clay soils tree cover has roughly twice the root mass as herbaceous cover. Therefore, tree roots may have greater holding power to counteract soil movement.

Although most vegetation reduces sheet and rill erosion, the effectiveness of using vegetation to prevent slumping in the Nemadji River Basin is in question. For example, field investigations made during 1995 revealed several trees greater than six inch diameter that were split through the center of the trunk. This action was caused by the trees having half their root systems within the upslope stationary material and the other half within the downslope slumping soil mass. Field observations during the Red Clay Project found that essentially all roots in clay soils were found above 20 inches depth and, therefore, have little anchoring capability. On the other hand, vegetation *can* be beneficial when used to reduce some of the erosive force of the streamflow on the toe of a slope. Mengel and Brown (1979) recognized the value of vegetation in stabilizing the base of slopes thus reducing the likelihood of initiating slumping.

Wold et al. (1994, page 102) found a correlation between the number of slumps and the percent unforested land in a watershed. He states that the reason for the relationship is the increased water yield from unforested land causing undercutting of streambanks and acceleration of slumping.

Bank Height and Angle

Steep, high bluffs along the streams are often unstable. While the cause of instability is uncertain, it is possible to note which slope angles are stable. Mengel and Brown (1979) state "Slopes up to 14 percent are stable when covered by permanent vegetation. Slopes of 14 to 27 percent appear stable but have soil creep. Slopes of 27 percent and greater experience translational slides. There may not be any movement for years while materials are loosened and prepared for transport by the erosion agents and then the net erosion of decades may take place in a short time." Soil creep is imperceptible and non-accelerating downslope movement. It is too slow to be observed although the results of creep can be observed over a period of years (Bloom, 1978). The downslope displacement of material on a surface roughly parallel to the general ground surface is termed a translational slide.

Size and Chemistry of Particles

The particle size and chemistry of soils in the Nemadji River Basin are also factors contributing to mass wasting. Sand-sized particles tend to be quartz and there is little chemical interaction between grains. Clay sized particles are the product of weathering and breakdown of rock-forming minerals such as feldspars which are often chemically charged. Most clay is cohesive but some clay contains particles which repel one another and are termed dispersive. The Badlands of South Dakota have an excellent example of dispersive soils, which erode readily. Some soils in the Nemadji River Basin were sampled and found to be dispersive. This usually indicates the presence of salts in the soil.

In addition, some clay in the Nemadji River Basin contains smectites, a group of minerals which expand greatly when in contact with water. Due to their great shrink/swell capacity smectites contribute to slumping by creating cracks in the soil surface. Water enters these cracks promoting slippage.

Even though the conditions in the watershed have improved (see hydrologic system changes section of this report), a great deal of mass wasting still occurs in the red-clay portion of the Nemadji River Basin, and some of the tributaries carry tremendous amounts of suspended sediment. **The causes of mass wasting in the Nemadji River Basin are not completely understood, but surface water, groundwater, soil moisture, soil stratification, density and depth of roots, bluff height and angle, soil chemistry, and particle size are factors.**

Sediment Budget

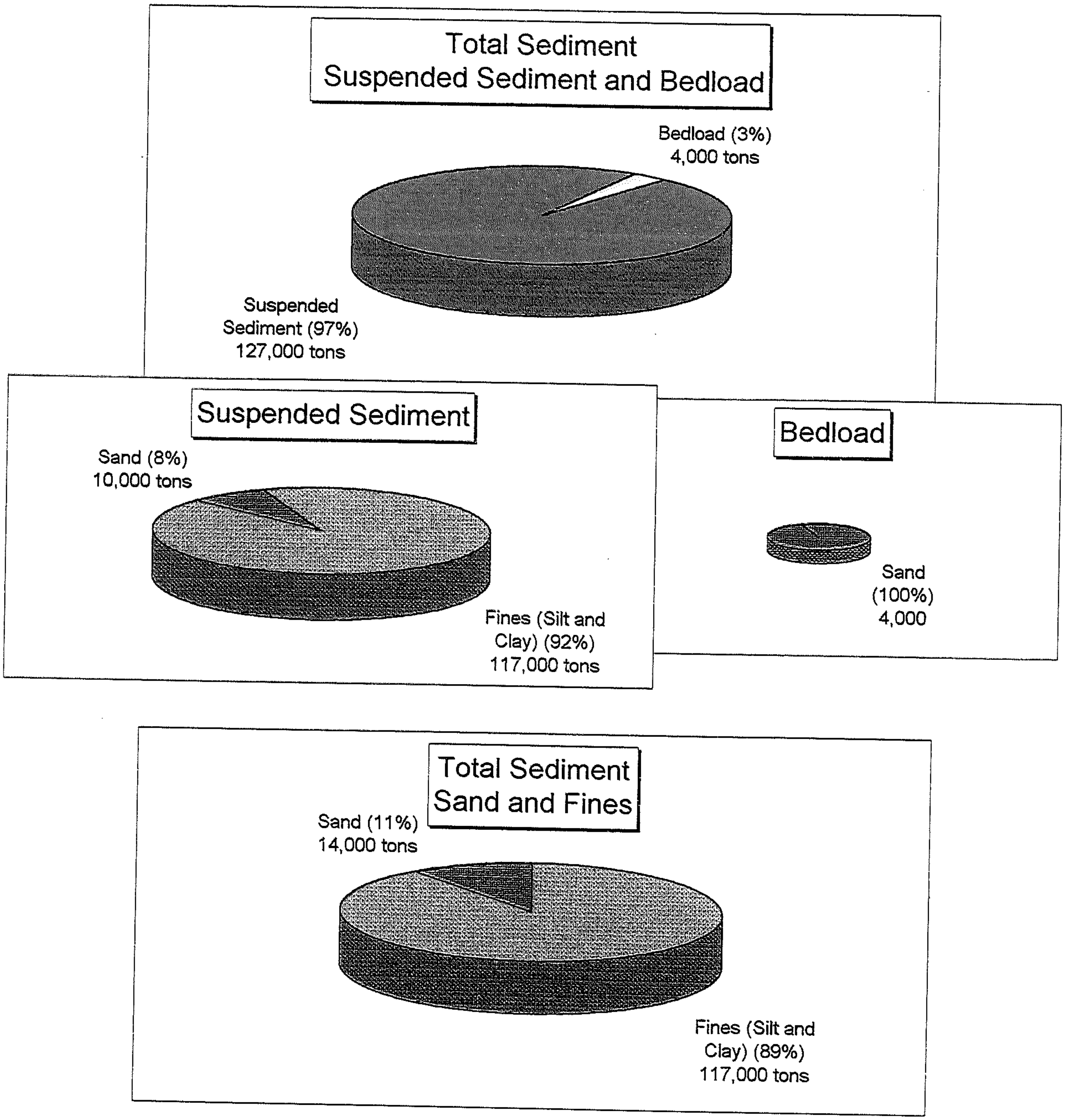
A sediment budget is an accounting of where and how much erosion occurs and also the movement and settlement of that eroded material through the watershed. The objective of the sediment budget for the Nemadji River Basin was to determine sources of eroded material and the contribution of each source to sediment deposited in Superior Bay. There are three major categories of sediment considered in this sediment budget. They are sheet and rill erosion, roadside erosion, and bluff erosion along streams. Appendix F contains the procedures and data used to develop the sediment budget. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

The following description from Water in Environmental Planning (Dunne and Leopold, 1978) defines sheet and rill erosion. Sheet erosion occurs when soil is removed by water which accumulates on the land surface and runs downslope as a sheet. This sheet contains tiny streams and threads of water that are slightly deeper and faster than the average of the sheet. These tiny streams of water move back and forth across the hillslope during a rainstorm. If the minute streams of water cut separate channels, the process is called rill erosion. Roadside erosion is mass wasting, sheet and rill erosion occurring adjacent to roads. Roadside erosion commonly occurs on the upslope side of a hill from which earth was removed to make the road. Erosion also takes place in road ditches, on road surfaces and embankments (downslope side of a hill where earth was placed to construct the road). In this budget, the phrase, "bluff erosion along streams," refers to streambank erosion and mass wasting (slumping) occurring anywhere in the valleys of the watershed. The sediment budget in this report includes only those particles of silt and clay size. These particles represent 89 percent of the total sediment load from the Nemadji River (see Figure 15 on next page).

Many interrelated and complex factors determine the quantity of erosion and sediment yield (the amount of sediment which reaches the outlet of a watershed). Erosion and sediment yield are determined by the following factors:

- land use
- geology/soils (texture, chemical composition)
- kind and condition of vegetation

Figure 15 - Average Annual Sediment Discharged from Nemadji River

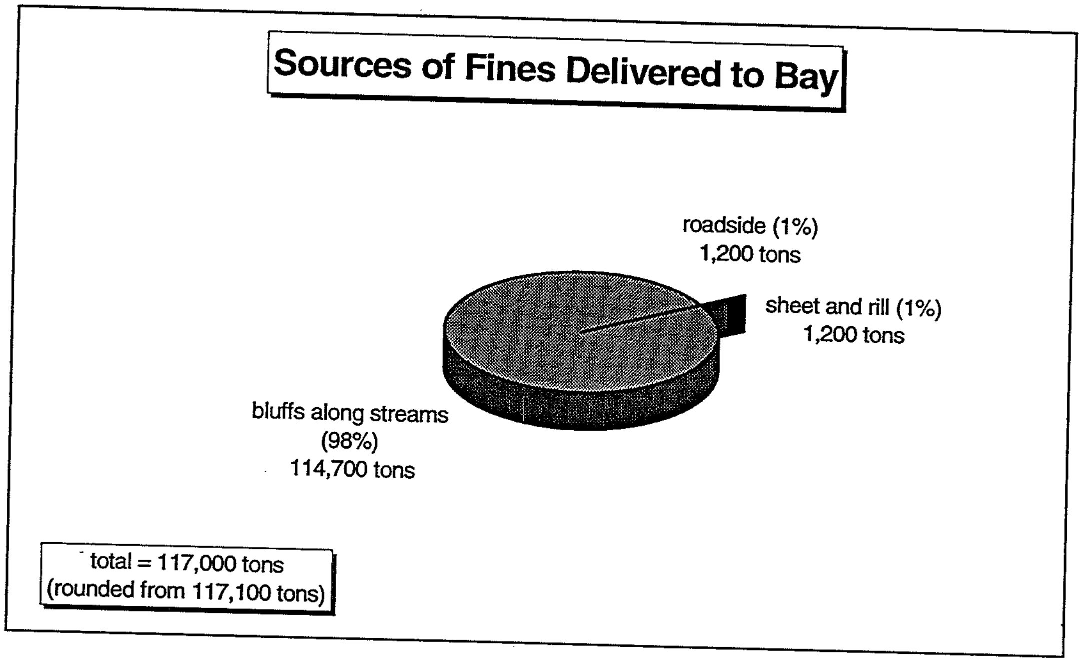


- climate
- topography
- drainage density (stream length per area)
- channel shape
- watershed shape and size
- sediment source
- proximity of sediment sources to the stream
- depositional areas (wetlands, lakes, floodplains)
- stream gradient (slope)

We estimate the average annual sediment load at the mouth of the Nemadji River at 131,000 tons per year. This can be broken down into roughly 117,000 tons of silt and clay and 14,000 tons of sand (see Figure 15). The suspended sediment load is estimated at 127,000 tons per year (97% of total load). Suspended sediment includes all 117,000 tons of silt and clay plus 10,000 tons of fine sand. The bedload, which includes particles which travel along the streambed or which move by a process called saltation (bouncing along the streambed), accounts for the remaining 4,000 tons (3% of total load). The percentages of suspended sediment and bedload come from sampling work done during the Red Clay Project (Rose, 1980) while the total sediment loading comes from U.S. Geological Survey suspended sediment monitoring (see Appendix F). All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Our estimate of 127,000 tons of suspended sediment loading is far less than that reported by the EPA (Bahnick, 1979) which was 562,000 tons per year. The reason for the vast difference is that several more years of streamflow and suspended sediment monitoring were available for the current estimate than were available in 1979.

Of the silt and clay reaching the mouth of the Nemadji River, 98 percent is estimated to have originated as bluff erosion. Sheet and rill erosion together contribute only about one percent of the total silt and clay load, as does roadside erosion. The pie chart on the next page illustrates the sources of fines delivered to Superior Bay. The sediment delivery ratios shown in the last column of Table 12 on the next page represent the percentages which reach the mouth of the Nemadji River and are not deposited along the way.



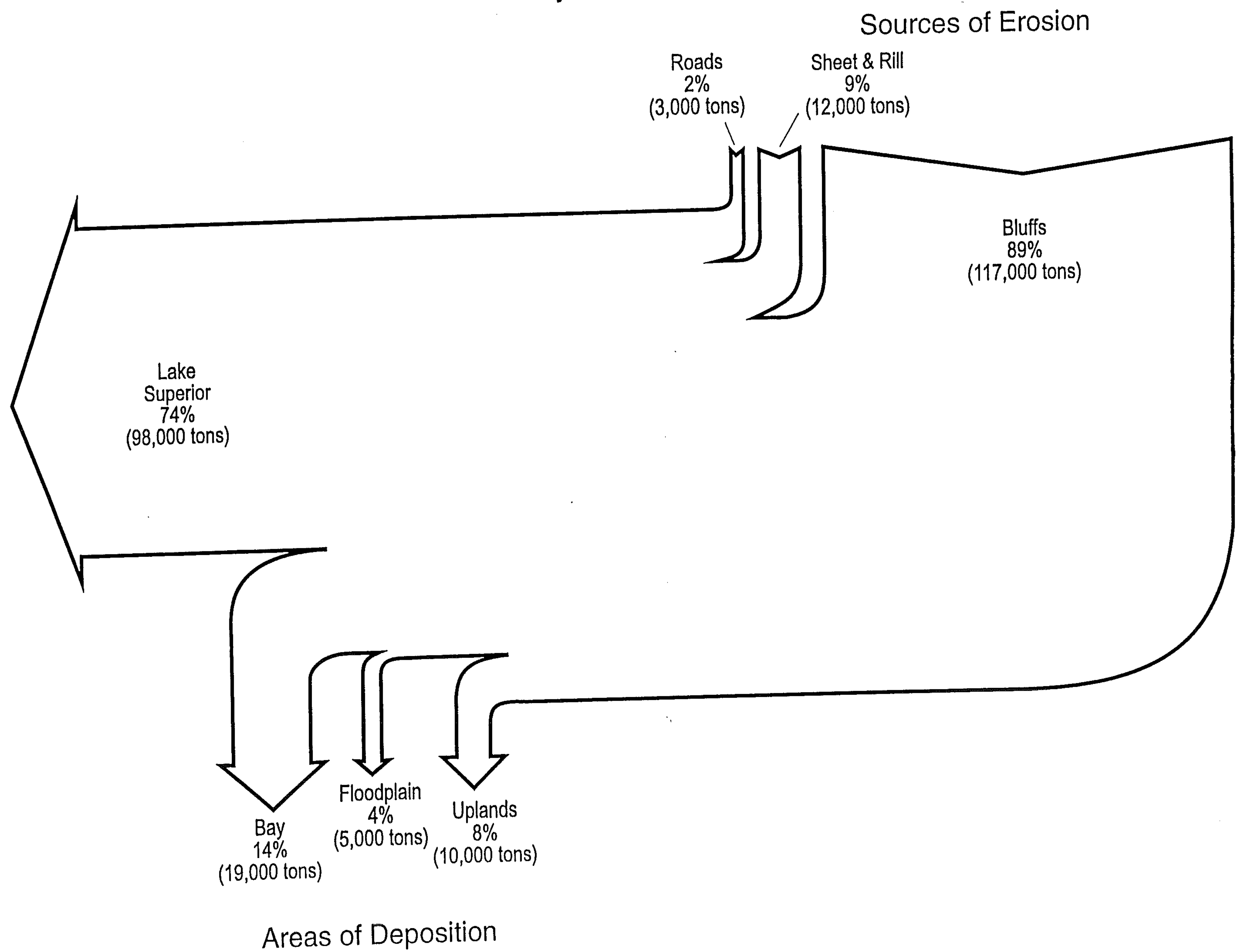
It is important to make a distinction between the amount of erosion and the amount of sediment yielded. Sources of great erosion may not yield the most sediment. The sediment budget on the next page illustrates the sources of erosion and areas of deposition for silt- and clay-sized particles all the way from the uplands of the watershed on out to Lake Superior. Roughly 132,000 tons of silt and clay are eroded in the Nemadji River Basin annually. Sources of erosion include roads (3,000 tons), sheet and rill erosion (12,000 tons) and bluffs (117,000 tons). There are numerous places the sediment can be deposited en route to the bay. Areas of deposition include the uplands, floodplain and Superior Bay.

Table 12: Erosion and Sediment Yield for *Silt and Clay*

Type of Erosion	Average Annual Erosion (tons)	Sediment Yield at Superior Bay (tons)	Sediment Delivery Ratio (tons)
Sheet and Rill	12,000	1,200	10%
Roadside	3,000	1,200	40%
Bluff Along Streams	117,000	114,700	98%
Total	**132,000**	**117,100**	**89%**

Note: Sediment Delivery Ratio = $\frac{\text{Sediment Yield}}{\text{Erosion}} \times 100\%$

Figure 16: Sediment Budget for Fines (Silt and Clay)
Nemadji River Basin



Upland Deposition

Upland deposition is eroded material from sheet, rill and roadside erosion which does not reach a channel where it can be transported to the Nemadji River floodplain or Superior Bay. Although some roadside erosion does reach ditches, these ditches are not necessarily connected to a channel which reaches a stream. Upland deposition material includes deposits on hillslopes, at the bottom of hillslopes, or in road ditches unconnected to the river system. Eight percent (10,000/132,000) of the eroded material in the Nemadji River Basin is deposited in the uplands.

Floodplain Deposition

The slope of the Nemadji River changes from steep (.0015 ft./ft.) to fairly flat (.0008 ft./ft.) at the confluence of Mud Creek and the main stem of the Nemadji River. Due to flattening of the river's slope, the water loses velocity and drops much of its sediment load. As a result, a wedge of sediment is expected to be found in the floodplain of the Nemadji River. Such a wedge would follow the length of the river with the thick end where the slope flattens, and thinning towards the mouth of the Nemadji River. The amount of fine sediment deposited in the floodplain is difficult to estimate without a detailed geologic investigation. Four percent (5,000/132,000) of the eroded silt and clay in the Nemadji River Basin is deposited in the floodplain.

Some sand is found in the floodplain of the lower reaches of the Nemadji River. This sand may have entered the stream system at the time of European settlement and may still be in the process of moving through the system. Refer to Appendix C for further discussion of sand sources. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Superior Bay Deposition

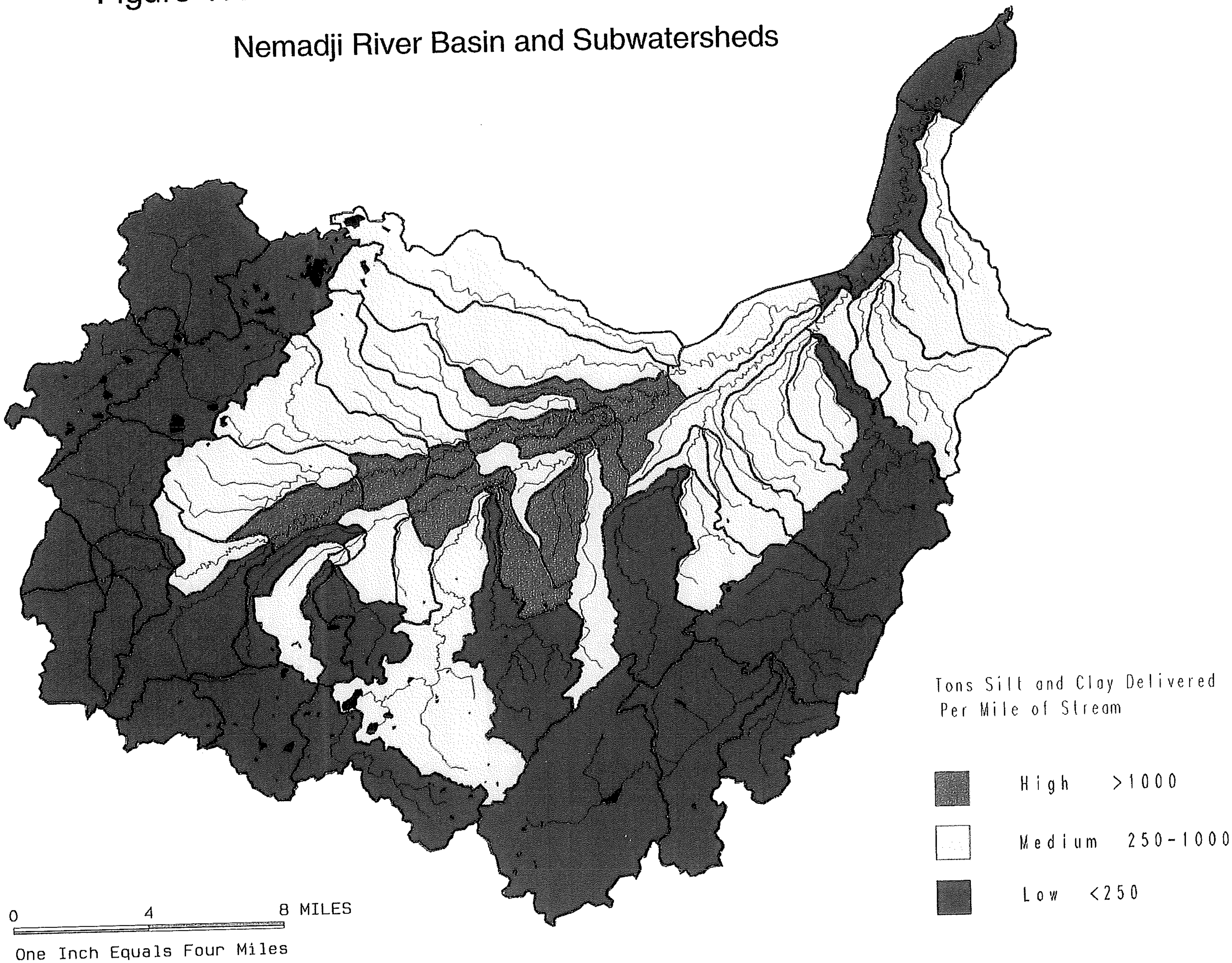
In addition to a general sediment budget for the Nemadji River Basin, sediment contribution was also estimated for each hydrologic unit (subwatershed). Each unit was placed in the high, medium, or low category based upon its sediment contribution to Superior Bay (see Figure 17 on page 76). The categories are expressed in tons of silt and clay delivered per mile of stream within each subwatershed.

Roughly 14 percent (19,000/132,000) of the eroded silt and clay in the Nemadji River Basin is deposited in Superior Bay. To determine the amount of sediment from the Nemadji River deposited in the bay, dredging records were reviewed and changes in bathymetry (topography of the bay floor) in non-dredged areas were investigated.

The U. S. Army Corps of Engineers (COE) has maintained a dredging program in Duluth-Superior Harbor for a number of years. Dredging is necessary in order to keep channels open for ship traffic. The COE has maintained excellent records regarding the amount, type, and location of dredged materials. The data used to determine the amount of

Figure 17: Relative Sediment Delivery to Superior Bay

Nemadji River Basin and Subwatersheds



dredging attributable to the Nemadji River was obtained from the COE office in Duluth. The data spans the years 1975-1994. For each area dredged, the year in which dredging took place and the amount dredged are listed in the following table. Figure 19 on page 79 shows the locations of these dredged areas.

Table 13: Dredged Quantities (cubic yards) by Year for Superior Bay Near Nemadji River

Year	Superior Front Channel	Superior Harbor Basin	Superior Entry
1975		25,300	
1976			
1977	36,700		
1978		97,200	
1979			
1980		170,000	
1981	108,900		
1982			
1983		44,000	
1984			
1985		147,461	
1986			
1987			
1988	10,494	86,696	
1989	74,757	100,650	
1990			45,724
1991	76,842		
1992	53,686		
1993			
1994			
Total:	361,379	671,307	45,724

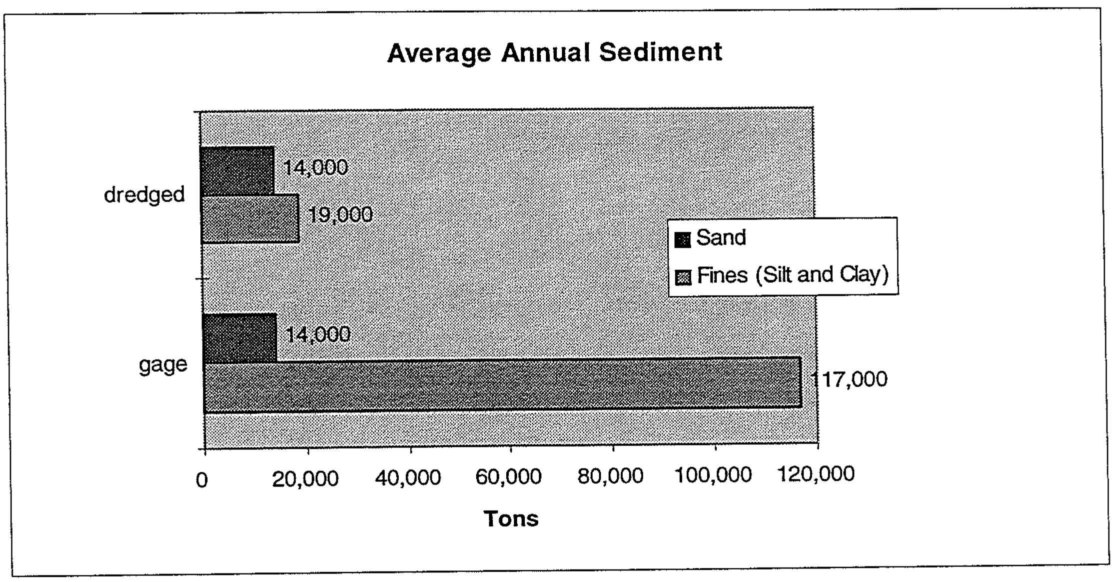
Source: U. S. Army Corps of Engineers

It is important to note the area of influence of the Nemadji River in the bay. The heavier sand particles are deposited near the mouth of the river. The lighter silt and clay particles remain suspended for longer periods of time and can be transported farther. This is supported by the grain size analysis of sediment samples from the bay shown in Figure 19 on page 79.

In our sediment budget we assume that sand is deposited over half the area called "Superior Harbor Basin" and all "Superior Entry". The area of silt and clay deposition from the Nemadji River is assumed to be half of "Superior Front Channel" and all of "Superior Harbor Basin" and "Superior Entry". These assumptions are supported by the grain size analysis, COE dredging records and USGS gage data.

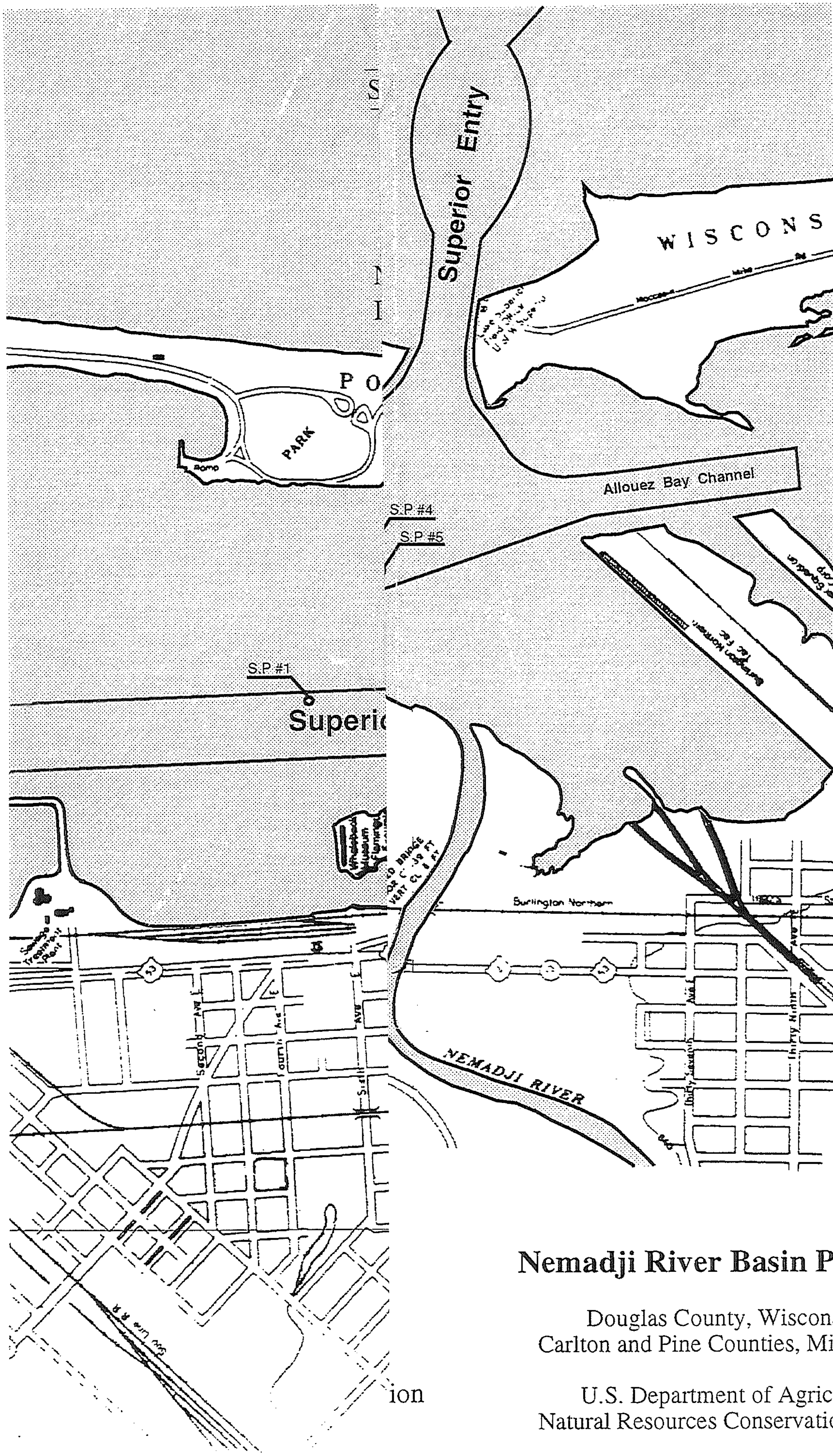
Using these assumptions an estimated 33,000 tons (roughly 33,000 cubic yards) of sediment dredged per year originates from the Nemadji River Basin. This breaks down into approximately 19,000 tons of fines (silt and clay) and 14,000 tons of sand. The amount of sand dredged is roughly equal to the amount of sand discharged from the Nemadji River. Only 16 percent (19,000/117,000 tons) of the fines that are present in the flows of the Nemadji River are deposited in the bay. The remaining 84 percent (98,000/117, 000 tons) continues out into Lake Superior beyond the Superior Entry. See Figure 18 (below) for a graphical representation comparing the amount of sediment gaged and dredged.

Figure 18: Comparison of Sediment Measured at Gage and Sediment Dredged



The numbers used in this chart are based upon 20 years of data. The chart shows that all 14,000 tons of the average annual sand load carried by the Nemadji River are dredged. Sixteen percent (19,000 tons/117,000 tons) of the average annual load of fines measured at the mouth of the Nemadji River are dredged. Adding the sand and fines together the average annual amount of sediment dredged from the Nemadji River is 33,000 tons per year.

Detailed calculations for the sediment budget can be found in Appendix F. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover. Information on a sediment survey of the Hanson Dam Reservoir on Skunk Creek, which was important to sediment budget calculations, can be found in appendix G.



Nemadji River Basin Project

Douglas County, Wisconsin
Carlton and Pine Counties, Minnesota

U.S. Department of Agriculture
Natural Resources Conservation Service

July 1996

Any decrease in the volume of Superior Bay at the mouth of the Nemadji River over time can be attributed to sediment brought from the Nemadji River. Using this assumption, changes in the volume of the bay over time were investigated. This involved looking at the very oldest maps of the bay and comparing them to more recent maps. A Duluth-Superior Harbor map from 1893 was found but could not be used for comparative purposes due to significant human alteration of the shoreline features (see Appendix F). All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Data was obtained from navigational charts of Duluth-Superior Harbor. A comparison was made between the water depth contours in 1964 and 1991. The analysis, which focused on the non-dredged portion of the harbor, showed that although some areas gained sediment and some areas lost sediment, the net change for the total area was zero for the period 1964 through 1991. See Appendix F for details of this analysis. **This suggests that for silt and clay particles entering the bay from the Nemadji River 19,000 tons (16%) drops into the dredged channels of Superior Bay and the balance of 98,000 tons (84%) remains suspended and is carried out into Lake Superior.**

Sand is being dredged from other areas of the bay although its source is not the Nemadji River. Much sand dredged elsewhere was originally brought to the bay long ago and may now come from the sides of the dredged channels, artificial islands or be stirred up by storms or ship traffic. A sample taken in the channel near Barker's Island shows 42 percent sand (Figure 19 on page 79). Barker's Island is an artificial island constructed of sandy dredged material, which may be the source of sand for this sample. Another source of sand in the bay is the bay mouth bars, Minnesota Point and Wisconsin Point. These bars formed some time during the past 10,000 years as a result of wind and wave action. The soil survey for Douglas County (Douglas County Soil Survey, Field Sheet No. 27, unpublished) shows the soils on Wisconsin Point to be beaches and sandy soils. The sediment which becomes suspended due to storm waves or ship traffic settles in the topographic lows of the dredged channels. The suspended sediment creates a layer of fluid with a greater density than clear water. With the help of gravity this dense fluid moves downward into the topographic lows of the dredged channels.

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Erosion and Sedimentation Concerns

Problems within the watershed, Superior Bay and in Lake Superior include erosion and sedimentation. During runoff events water flows across very erodible soils, along roadsides and into streams of the watershed carrying eroded particles of soil with it. The streams, bay and Lake Superior often become turbid causing concerns related to aquatic plants, fish, recreation and dredging. The attachment of pollutants to sediment and its effect on fish, plants and wildlife is also a concern.

Concerns in the watershed can be divided into those on-site and those off-site. Off-site damages occur in locations other than the source of erosion. Off-site damages include deposition of sediment in ponds, wetlands, Superior Bay, and Lake Superior. Clogging of fish gills, covering of fish nesting beds, increased water temperature, decreased competition for undesirable exotic plants and fish, dredging, and decrease in recreation are other off-site concerns. On-site damages are those which are caused by erosion. Land voiding is an on-site concern because it causes damage to roads and property.

On-site damages

Roadside Erosion

Roadside erosion contributes to total erosion and sedimentation in the Nemadji River Basin. The properties of red-clay soils cause many problems for maintenance of roads, railroads and structures.

A roadside erosion survey was completed in November 1994. The survey estimated that 2,500 tons per year erode from ditches and slopes that are part of public roads located in the Nemadji River Basin. Most low or minimum maintenance township roads were not inventoried.

Although much of the erosion in the watershed comes from bluffs along streams, many of these areas are inaccessible and therefore could not be treated. In contrast, all of the roadside erosion sites in the watershed are accessible.

Three problems inherent to all roads and trails but magnified in the Nemadji River Basin are the following:

1. *Faster Runoff*: Because of surface drainage associated with roads and trails, runoff moves quickly by direct routes to the streams causing higher peak flows and a greater potential for downcutting and bank undercutting.

2. *Concentrated Flow Energy*: Stream and tributary crossings are typically designed to pass a certain flow through one opening or culvert. This creates a highly erosive concentrated flow directly downstream of the crossing. For some distance downstream, the important soil stabilizing riparian/floodplain zones become nonfunctional.

3. *Recreational Vehicles*: Recreational vehicle users are attracted to the area due to: 1) the proximity to Duluth/Superior and Minneapolis/St. Paul, 2) the need of landowners to reach their otherwise inaccessible land; and 3) the enjoyment of driving through the slick, red-clay. There is deep concern about the careless operation of these vehicles which may cause rutting, channelization, and compaction problems.

Factors contributing to the high cost and difficulty of road- and trail-building and maintenance in the red-clay include the following:

- right-of-ways are too narrow to build stable slopes and the cost of acquiring right-of-ways is high
- need for ditch blocks, road cut/fill drainage, and energy dissipators
- short construction season and soil limitations

Property Damage From Slumping and Cracking

Since the watershed is sparsely populated, personal property damage has been relatively low. Over the years, however, slumping along roads, railroads, streams, and rivers has caused an inordinately high amount of property damage. Slumping has also damaged fences, numerous constructed dams, and many trees. A few houses that were built too close to a river or a steep hillside are also currently in danger of being destroyed due to slumping. Other houses in the red-clay portion of the watershed have cracked foundations and driveways that are a rutted mess much of the year.

Soil Productivity

The upper Nemadji River Basin is composed primarily of sandy or fine sandy loam soils. These soils are fairly easy to crop (prepare a seedbed, plant and harvest). Most farming currently takes place in the upper watershed. The red-clay soils of the watershed are very difficult to farm. They have a very high shrink-swell capacity, low strength for road and construction material, very slow permeability, low available phosphorus, and a low organic matter content.

Many people have tried to farm this soil in the northern Minnesota/Wisconsin climate without success. Small intensive operations that concentrate on maintaining soil tilth seem to do best. When the soil is dry enough to work with farm implements it becomes extremely hard. Very large tractors and equipment are needed to break up the soil, making it very expensive to work into a proper seedbed. Even when the soil is near the correct moisture for tilling, large equipment is still needed. Large clods of soil are turned up and become almost impossible to break apart into a good seedbed. The clay soil is also slow to warm in the spring, tends to be wet, and very sticky.

Off-site damages

Major off-site damages relating to erosion include the following:

- in-stream ecosystem damages
- increased populations of undesirable exotic species
- filling in of navigation channels in Superior Bay
- loss of watershed recreation values
- transport of pollutants attached to sediment

Details of each of these damages are outlined in the following sections.

In-Stream Ecosystem Damages

Sediment deposited in water course bottoms interferes with the feeding and reproduction of fish and aquatic insects. Sedimentation damages to the in-stream ecosystem include reduced density and biomass of macroinvertebrates (a primary food source for fish), as well as destruction of aquatic plant diversity and populations. In addition to this intricate food chain disruption, sediment can have a direct effect on fish populations from the standpoint of physical damages (i.e. gill abrasion).

Studies in other watersheds have shown that levels of sediment constitute the strongest statistical correlation to reduced density and biomass of macroinvertebrates (Wagener and LaPerriere, 1985 and Cummins, 1974). As sediments and their associated nutrient levels increase, populations of pollutant sensitive macroinvertebrates (mayflies, stoneflies, caddisflies, water-penny, and riffle beetles) decrease. This in turn leads to a reduced diversity of species while the population growth of a few tolerant species increases (Soil Conservation Service, 1994). Higher populations of pollution tolerant macroinvertebrate organisms (aquatic worms, midge fly larva, and snails) usually result in smaller populations of desirable fish species such as trout and walleye.

Another impact of sediment is that natural reproduction of fish species is reduced. As sediments accumulate on the streambed (substrate), much of the pore space required for optimal spawning conditions becomes clogged or "embedded". Embedded substrates reduce the flow of water which limits oxygen availability to incubating eggs and reduces removal of metabolic wastes (U.S. Forest Service, 1991). Research shows that there is a significant loss of trout spawning habitat when the substrate becomes more than 30 to 40 percent embedded (Hunter, 1991).

Turbidity and sedimentation also affect the growth of aquatic plants. Although the specifics of native aquatic plant populations are unknown, it is likely that some species have been suppressed or stressed out of the system and the location, density, and size of vegetation beds have been altered (personal communication: F. Koshere, WDNR, 1995). Sedimentation negatively affects the rooting substrate, decreases the available nutrient supply, and decreases the amount of light available for photosynthesis. Since many wildlife species feed on healthy aquatic vegetation, they are negatively affected when it declines.

No specific inventories relating to macroinvertebrates, substrate embeddedness, or aquatic plant populations were made as part of the Nemadji River Basin Project. However, the Fish and Wildlife Technical Committee has stated that if in-stream sediment is not reduced, trout populations are expected to remain the same or decline. This is especially true on the lower Nemadji River where the gradient lessens and a higher percentage of sediments settle out due to lower flow velocities.

Physical damages to fish in the form of gill abrasion can occur at sediment concentrations as low as 200 PPM (U.S. Forest Service, 1991). U.S. Geological Survey suspended sediment records at the Nemadji River near South Superior show daily average suspended sediment concentrations exceed 200 PPM about 10 percent of the time. Similar records at Deer Creek show this 200 PPM limit is exceeded about five percent of the time. Sediment concentration exceeding 20,000 PPM can cause mortality in adult fish by clogging gill filaments (U.S. Forest Service, 1991). These high levels can be tolerated for short periods of time (personal communication: Elon S. Verry, USFS and Dr. Ken Brooks, University of Minnesota, 1995). Daily average suspended sediment concentrations in Deer Creek and the main stem Nemadji River rarely exceed 1,500 PPM. The U.S. Geological Survey suspended sediment numbers stated above must be viewed in light of the fact that they represent an average over an entire day. Values for shorter time intervals can be much higher.

A significant study which examined the effects of turbidity and sedimentation on aquatic life was conducted as part of the Red Clay Project in the late 1970's (DeVore, et al., 1980). Water quality monitoring, aquatic organisms population sampling, and aquatic environment assessment were used to determine the effects of sedimentation and turbidity on aquatic life in red-clay area streams. The period of study included 1975-1978 and examined eight sites. Two of the sites were on the main stem Nemadji River with the remaining six on smaller tributaries within the red-clay area. The Summary Report of the Final Report on the Red Clay Project (Andrews, et al., p. 15-16, 1980b) summarizes the results of this particular study:

> "Aquatic problems attributed in the past to red-clay turbidity have included the substitution of undesirable fish species for more desirable ones, negative effects on spawning runs, decreased oxygen levels and increased nutrients as well as general observations on 'adverse effects on biological

life processes.' None of these statements can be supported by the findings from this research in the Nemadji River Basin."

Primary findings from the Red Clay Project as they relate to impacts on aquatic life include the following:

1. Primary production does not appear to be significantly affected by existing turbidities within the range of depths at which most production occurs in these relatively shallow streams.

2. 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.

3. Substrate size had much greater effects on macroinvertebrates than turbidity and sedimentation.

4. Fish populations were not demonstrated to change as a result of turbid conditions. Water temperature and discharge differences between turbid and clear water sites accounted for species changes.

5. Channel form and available cover are the primary factors affecting fish population size for all species complexes in the Nemadji River system.

The authors tempered their "limited impact" conclusions, however, by stating that even though a positive balance seems to have occurred between turbidity/sedimentation and existing aquatic life, the potentially severe effects should not be underestimated. It was felt that poor soil management had the potential to upset the natural balance enough to incur severe short-term and long-term consequences for aquatic flora and fauna. The conclusions of the report also relate to the Nemadji River as a single unit. However, from the data, it appears that the lower reaches of the Nemadji River are in a more advanced state of degradation than other parts of the watershed. It appears that the lower Nemadji River would be the most sensitive to sedimentation damages to aquatic life since it is here that sand movement and accumulations and the likelihood of fine sediment deposition are highest.

Exotic Species

Proliferation of undesirable exotic species can occur as a result of excessive suspended sediment. Increased turbidity and sedimentation tend to favor certain exotic fish and plant species. Most of these impacts are currently an issue only in the lower reaches of the Nemadji River, Superior Bay and Lake Superior.

With aquatic plants, disturbances, including increased turbidity and sedimentation, tend to favor pioneer species including new exotics. Exotics such as Eurasian water milfoil or curly leaf pondweed may have better admittance to the Nemadji River. They are nuisance species that would be detrimental to human uses such as boating or swimming. On the other hand these "nuisance species" may provide some benefit in terms of fish or wildlife habitat, since turbidity and sedimentation in the river probably limit the abundance and diversity of native aquatic plants.

High levels of suspended sediments can also favor certain species of fish. Since some exotic species can live in highly turbid, low light conditions they may be able to out-compete native species. One of these exotic species of concern is the ruffe. Diurnal behavior and an unusually well developed lateral-line system enables the ruffe to be active at night and under low light conditions associated with turbid water. These adaptations have allowed the ruffe to compete quite favorably against native fish species. Populations of this exotic fish have dramatically risen since its first appearance in Superior Bay ten years ago. In 1995 it was the most frequently trawl-caught fish in the estuary. The ruffe has also been found in the lower reaches of the Nemadji River. Unfortunately the ruffe does not attain a size useful for commercial or sport fishing. In addition, a new exotic species, the round goby, has recently been discovered in Superior Bay. At present, the goby has been found in the St. Louis River system but has yet to be found in the Nemadji River. Where found in the Great Lakes, the round goby is displacing the sculpin, a traditional trout food. See Appendices H and I for further discussion regarding sediment and aquatic life.

Sediment Impacts on Navigation

The U.S. Army Corps of Engineers (COE) has maintained a dredging program in Superior Bay for over a century. The COE first became involved in 1867 when congress approved appropriations for improvements to the Superior Entry. Today, Duluth-Superior is the largest port, in terms of tonnage, on the Great Lakes. This dredging program is required to ensure passage of deep draft ships into and out of Superior Bay. Dredging of the harbor is a concern of the St. Louis RAP and a major reason for initiation of the Nemadji River Basin Project.

Bay areas impacted by Nemadji River sediments are Superior Harbor Basin, Superior Front Channel, and Superior Entry (see Figure 19 on page 79). The amount of material dredged by location and year is shown on Table 13 on page 77. An approximate average annual amount of 33,000 tons (converts to 33,000 cubic yards) of sediment dredged can be attributed to the Nemadji River.

An average annual estimate of the cost of dredging due to the Nemadji River is $200,000. Dredged material from areas impacted by the Nemadji River costs approximately $8.00 per cubic yard to dredge and transport to the disposal site located at Erie Pier. This 82-acre disposal site, located on the Minnesota side of the St. Louis River, was developed by the COE in 1978. Because the Erie Pier dredge spoil disposal site has limited storage capacity, there has been concern about the cost of developing a new confined disposal facility in the harbor. This concern has resulted in broad support for efforts to operate Erie

Pier as a dredged material processing facility and for recycling of the dredged material for fill. Recycling efforts allow for perpetual use of this site. Dredged material from this site has been recycled and used as fill for construction projects in the region.

Using U.S. Geological Survey monitored suspended sediment data and bedload estimates from Rose (1980) the average annual sediment load for the basin is estimated at 117,000 tons of fines (silt and clay) and 14,000 tons of sand. Sand dredged is roughly equal to the sand coming from the Nemadji River in the area near the river. Dredging in areas away from the mouth of the Nemadji may be removing sand which comes from the sides of the navigation channels during storms or due to ship traffic. Of the fines, only 16 percent (19,000/117,000 tons) settle out in the navigation channels. Eighty-four percent of fines (approximately 94,000 tons annually) remain in suspension far out into Lake Superior. For perspective, this is equivalent to 23 dump trucks[3] of sediment per day discharging out into Lake Superior.

Loss of Watershed Recreation Values

Loss of recreation value relates to the undesirable appearance of Lake Superior and the river and tributaries themselves. Potential canoeists, hunters, and anglers that drive through the red-clay area of the watershed are most likely to form negative opinions of the region based on the non-aesthetic qualities of the waters. As pointed out by Lloyd, et al. (1987) several studies have been conducted that conclude the obvious: anglers tend to avoid turbid waters. Unfortunately for the Nemadji River Basin, the small particle size of the clay combined with its extractable iron oxide content causes the water to appear "very turbid" when in fact the actual sedimentation level may be low and fish abundant (Andrews, et al., 1979).

Sediment plumes have long been seen extending from the mouth of the Nemadji River through the bay and out into Lake Superior. This plume is not only unsightly but also has a negative effect on people seeking recreational outings near the mouth of the Nemadji River.

Transport of Pollutants Attached to Sediment

Pollutants that bind to sediments are impacting the uses of the Nemadji River, Superior Bay and Lake Superior. Once sediments reach the lower river and bay they are often considered to be contaminated due to high levels of metals and other chemical pollutants that are present nearby. Once contaminated, the cost of disposal increases many fold.

Although toxic pollutants are continually being introduced into the system, the contribution of in-place sources is generally believed to be significant. Ship traffic, dredging, and waves re-suspend pollutants that have been sequestered in the sediments. These re-suspended substances contribute to increased concentrations of toxins in the

[3] Assumes a 12 cubic yard dump truck and a soil weight of 70 pounds per cubic foot.

water column, and subsequently in elevated toxin levels in tissues in the biota of the area. Some of these organisms are the food of the fishes sought by anglers. The consequences of these events lead to a biomagnification effect in the food chain which results in fish consumption advisories and potential effects on humans (McCormick, 1995). Currently each state issues advisories which often recommend no more than one meal per month be eaten consisting of fish from this area.

Mercury enters waters mainly by way of air pollution from sources such as coal-burning power plants and garbage incinerators. Mercury can damage an adult's nervous system but its most severe effects are on developing fetuses in pregnant women. In areas with high concentrations of mercury the larger predator fish (walleye, northern pike, and lake trout) contain the highest levels (Minnesota DNR, 1995). At this time Lake Superior is the least contaminated of the Great Lakes in relation to mercury (Minnesota Department of Health, 1992). Even though this is true, mercury contamination severely impacts the amount of fish that can be safely eaten from this lake.

Health guidance on the consumption of walleye caught downstream of the Fond du Lac Dam on the St. Louis River, which includes Superior Bay, is given for mercury contamination. It is as follows:

1. For fish under 18 inches in length, pregnant women are advised to eat no more than one meal a month. Everyone else may eat unlimited amounts. Skin on fillet samples average 0.5 PPM (parts per million) mercury or less.

2. For fish 18 to 22 inches in length, pregnant or breastfeeding women, women who plan to have children, and children under 15 are advised to avoid consumption. Everyone else should eat no more than 26 meals within one year. Of these 26 meals, no more than 13 meals in any one month should be consumed. Space the remaining 13 meals over the rest of the year at a rate of one or two meals a month. Fillet samples average 0.5 to 0.75 PPM of mercury.

3. For fish 22 to 26 inches in length, pregnant or breastfeeding women, women who plan to have children, and children under 15 are advised to avoid consumption. Everyone else should eat no more than 13 meals of this size fish per year. Eat no more than 7 of these 13 meals in any one month, and space the remaining 6 meals over the rest of the year at a rate of no more than one meal a month. Fillets average 0.75 to 1.0 PPM mercury.

4. No one should eat walleye over 26 inches from Superior Bay. Samples contain 1.0 PPM mercury.

A considerable portion of the sediment delivered to the Nemadji River system disperses into the water as fine particles (less than 2 microns) which remain suspended for lengthy periods of time. Some dissolved pollutants have the capacity to attach themselves to these finer suspended particles. The suspended material can be carried for long distances into Lake Superior before deposition on the bottom of the lake occurs. The clay material which is deposited out to 70 feet in depth is susceptible to re-suspension during certain wind events (Bahnick et al., p. 1, 1979). This normally occurs in late spring and fall when the southwestern part of the lake is turning over as the cold water sinks and then moves to the surface and is frozen. This re-suspension adversely impacts the waters of the area.

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Other Natural Resource Concerns

Beaver

There are both positives and negatives to beaver dams within the Nemadji River Basin. Beaver dams can be a significant source of high quality type 3 or 4 wetlands in the upland where streams flow through extensive flat terrain. Here, peak flows are low and streambanks are less likely to be subject to streambank erosion. However, in the rolling and steep terrain where streams are flashier, beaver dams frequently are destroyed by natural events, resulting in extremely high flows, which in turn can cause extensive streambank erosion downstream. Also, beaver dams can block fish movement within the streams and increase water temperatures. This is especially important in designated trout habitat stream reaches.

Sharptail Grouse Habitat

In Minnesota, the sharptail grouse management areas are in the upper reaches of the watershed. The area tends to be very flat and poorly drained, with little runoff. The area typically has few trees, and they are predominantly deciduous. To provide sharptail grouse habitat, more open land is desirable. The sharptail management program benefits a variety of plant and animal life; a number of which are on Minnesota's endangered-threatened-special concern list. The portion of the watershed in an early successional stage is important for grouse habitat.

Lack of Fish Habitat

There is concern that large woody debris is not available for fish habitat since aspen, which are small when harvested, are favored by forest managers. However, topography generally prevents tree harvest in close proximity to streams. Buffers near water are recommended. Long-lived conifers are especially favored in these areas. Most of the large conifers were removed from the stream corridor in the past. Deer browsing and bank slumping have hindered regeneration of conifers. Current setbacks (restrictions in logging close to the stream) along streams will eventually allow natural succession to re-establish large long-lived trees adjacent to streams. Large woody debris is important to the stabilization of streams and riparian forest communities.

Removal of debris in streams has greatly altered brown and brook trout habitat. Recent studies in Alaska showed declines in salmonid species subsequent to the removal of only small or unstable pieces of debris. Large woody debris was added to a stream in Oregon with the effect of providing cover and protection for brown and brook trout during high flow periods (Meehan, 1991).

Livestock

Livestock and the concentration of livestock have an effect on the basin in a number of ways. Feedlot runoff into watercourses, overgrazing of pastures and uncontrolled access to sensitive riparian areas are the primary areas of concern. All these conditions were noted through visual observation and feedlots surveys.

During a 1995 feedlot survey, 127 feedlot sites with concentrations of livestock were identified in the Nemadji River Basin. Minnesota Pollution Control Agency criteria was used (10 or more large livestock minimum in an area devoid of vegetation). These sites were rated with a water quality hazard rating of high, medium, or low based on proximity to lakes, streams, and population centers, soil type, depth to water table and number of animal units. Ninety sites were determined to have a high or medium hazard rating. Seventy three sites had more than 20 animals. Thirteen sites had direct impact on adjacent streams and riparian areas.

Overgrazing can have an adverse impact on vegetation and soils, especially during the spring, fall and rainy periods. Compaction from large animals can drive the air space out of an already impermeable soil, decreasing the water holding capacity and increasing runoff.

Uncontrolled grazing has a major impact on stream morphology. In comparing two basins in red-clay, each with approximately a 3.5 square mile area, the forested basin had a stream with a bankfull width of 4.5 feet and maximum depth of 2.5 feet. The grazed basin had a maximum depth of 2.5 feet, but a bankfull width of 25 feet (personal communication: Elon S. Verry, USFS). The change in width of the channel may lead to an unstable stream.

Groundwater

Groundwater is very important as a source of drinking water. Groundwater makes up 95 percent of the rural water supply in the Nemadji River Basin. It also provides base flow to surface streams. Chemical spills, hazardous waste sites, industrial contamination, leaking underground petroleum storage tanks, and inadequately operating sewage treatment systems are potential threats to groundwater, especially when near a well. The Wisconsin Department of Natural Resources has identified numerous groundwater contamination sites in and around the City of Superior.

Little information is available on groundwater quality in the Nemadji River Basin. The Carlton County Soil and Water Conservation District (SWCD) conducted a voluntary county wide private well testing program in 1992. Private wells were tested for the presence of coliform bacteria and the amount of nitrate/nitrogen present. The testing resulted in 162 wells being tested in the Nemadji River Basin. Eighty-two percent were considered safe and drinkable due to the absence of coliform bacteria and nitrate levels less than 1 parts per million (PPM). Ten percent were considered unsafe for drinking, and the remaining eight percent were considered drinkable but had levels of nitrates ranging between 1.0 PPM and 10 PPM even though no coliform bacteria were detected.

The U.S. Geological Survey Water Resources Investigations Report (85-4334) completed in 1986 looked at the hydrogeology of the sand plain aquifers in Carlton County along with two other counties. The U.S. Geological Survey characterized the aquifers in several ways including water table elevations, transmissivity, saturated thickness, etc. This report shows sand plain aquifers in the western portions of the Nemadji River Basin. A major portion of these aquifers are overlain by sandy soils, which are considered aquifer recharge areas. The general direction of movement of the groundwater in these aquifers is towards the Nemadji River. This fact could possibly help explain the many flowing wells and seeps near the river and may even help explain what is causing some of the slumping. More study of the groundwater/slumping relationship needs to take place to determine the cause and effect of this relationship.

From the groundwater information collected it can generally be assumed that few groundwater quality problems exist in the watershed. The lack of problems is probably due to the low level of agriculture in the watershed, its undeveloped nature, its relatively low human population, and its predominantly deep, fine textured soils. There are areas in the western sandy portions of the watershed, however, that are highly sensitive to local contamination. In these sandy areas there have been cases of wells contaminated by nearby feedlots. If portions of the sand plain aquifers in the Nemadji River Basin receive significant contamination, it could lead to contaminated water entering the Nemadji River.

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Conclusions

Problem Identification

Major resource concerns within the Nemadji River Basin that were identified by the Nemadji River Basin Project can be summarized as follows:

- In-stream sedimentation problems are generally limited to the lower reaches of the Nemadji River where sediments have higher potential for settling out due to reduced velocities. This may have implications for fish.

- Fish consumption advisories are limited to the lower reaches of the Nemadji River and Superior Bay due to migration of fish from other sections of the bay where contaminants are prevalent.

- Problems arising due to sediment from the Nemadji River entering Superior Bay are the associated dredging costs, and adsorption and subsequent transport of contaminants out into Lake Superior.

- Upstream on-site erosion damages include increased road maintenance and loss of property due to mass soil movements.

- Lack of natural in-stream structure of "large woody debris" has resulted in lower quality fish and wildlife habitat.

Dynamics of the Erosion Process

The sediment yield at the mouth of the Nemadji River is among the highest in both Minnesota and Wisconsin. The primary sediment source is streambank/bluff erosion. According to a detailed sediment budget completed as part of the Nemadji River Basin Project, 98 percent of all sediment yielded to Superior Bay is from mass wasting of the bluffs along the streams.

The high sediment yield from streambanks can be traced to natural factors. However, human activity has accelerated the natural erosion process. A simplified cause and effect relationship for sediment loading from the Nemadji River follows:

1. Approximately one-third of the watershed is composed of highly erosive glacial clay that is up to 200 feet thick. This clay originated as glacial till and thin lake bottom sediments from Glacial Lake Duluth. The clay makes up the lake plain landform.

2. About 10,000 years ago, gradual lowering of Glacial Lake Duluth exposed the glacially derived clay to erosion. The difference in elevation between the abandoned lake plain and Lake Superior today is about 500 feet. Downcutting of stream channels to reach the new lake level steepens valley slopes which perpetuates the slumping process.

3. The cool climate of this area combined with low infiltration properties of red-clay create a scenario of naturally high runoff rates. The high runoff rates provide the excessive energy for channel downcutting.

Management Impacts on Sediment Loading

An important aspect of the erosion processes of the Nemadji River system is that, although the sediment yield is naturally high, human activity can accelerate erosion. Increased erosion rates from "natural" conditions cannot be accounted for by a single activity. Higher erosion rates since European settlement are the result of several factors primarily: 1) permanent conversion of forested areas to agricultural land uses, 2) the alteration of surface drainage patterns that usually accompanies road construction, 3) lack of in-stream large woody debris, and 4) reducing diversity of cover. Agricultural areas usually generate higher surface runoff volumes compared to forested areas while increased road density increases peak discharges by reducing runoff travel times. These higher runoff volumes and rates, in turn, result in more transport of sediment from slumping hillslopes along the channels. Lack of large woody debris within a channel destabilizes channel slopes thus increasing downcutting. Although 69 percent of the watershed is forested, much of it has been artificially reduced to very early successional stages. This results in a lack of cover diversity and humus development which leads to poor hydrologic conditions.

Goals

The mission of the Nemadji River Basin Project is to "... recommend remedial actions and best management practices that can be implemented to restore beneficial uses to the Nemadji River System." Most recommendations developed are general in nature and should be applicable to resource settings with similar soils. Some recommendations, however, are specific to the Nemadji River Basin.

When following these recommendations both short- and long-term goals must be kept in mind. Categorizing goals in this manner acknowledges that basin-wide hydrologic changes utilizing land management techniques often require long periods of time before significant benefits are realized. At the same time, short-term goals are needed to establish a commitment to prevention of further degradation.

Specific short-term goals include the following:

- preventing any further degradation of current hydrologic condition through coordination of timber harvesting on the subwatershed level so that open plus young forest area does not exceed 40 percent of a subwatershed (see Forest Management Recommendations)
- ensuring that forest and land resource uses maintain economic viability for the land user
- continuing to expand partnerships and coordination to address watershed problems

Specific long-term goals include the following:

- keep recommendations flexible so that Nemadji River Basin Committees may make changes based on results from research
- reducing channel downcutting by maintaining or re-establishing a healthy riparian zone
- ensuring that all land users coordinate major land management decisions to minimize adverse basin-wide impacts (see Coordinated Forestry Management on page 104)
- improving soil infiltration characteristics within the red-clay area through long-term application of timber harvesting best management practices (BMPs) which affect the forest floor
- using education as a key tool in all implementation activities
- inventory abandoned field ditches and block off to disrupt drainage

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Recommendations

General Recommendations

The ultimate long-term goal of the recommendations outlined in this section is to restore beneficial uses to the Nemadji River system. The interaction of past human and natural alterations of the watershed have accelerated erosion to the point where negative impacts have become a concern to local landowners and resource managers. It was recognized that the accelerated erosion is due mainly to an alteration in the hydrologic processes of the watershed. Specific hydrologic processes requiring restoration include decreased runoff volumes and peak discharges through increased infiltration, "de-channelizing" runoff paths from uplands to main channels, re-establishing healthy riparian corridors, and maintaining diverse land cover conditions.

Although structural practices such as rip-rap, streambank protection, and reservoirs can certainly help reduce sediment yield from the Nemadji River they are not emphasized in this report due to their high costs. These applications should only be considered in situations where high loss potential exists, such as threats to highways or railroad embankments, homes, or buildings. Recommendations emphasized in this report deal mainly with land treatment practices and land use coordination among land users.

Recommendations that modify hydrologic conditions are long-term. Improvements may take decades to be realized. To have a successful implementation plan, land managers should employ short-term goals in addition to the long-term goal of hydrologic modification. Short-term goals provide early focus for any implementation project and prevent the project from "losing momentum" when positive changes are not immediately achieved. Some useful short-term goals include: 1) prevent further degradation of hydrologic condition, 2) maintain economic viability for the current land users, and 3) formulate partnerships that can coordinate land use decisions.

These recommendations are based on reviewing previous research done in the Nemadji River Basin, looking at conditions in nearby watersheds, and consulting with resource managers within the region. This study identified mass wasting or "slumping" as the major source of sediment. Many of the recommendations relate to "slumping" in some manner. Several recommendations came from existing documents such as the St. Louis River Remedial Action Plan and the Minnesota and Wisconsin Forestry Best Management Practices guides (Minnesota Department of Natural Resources, 1995 and Wisconsin Department of Natural Resources, 1995). These recommendations are general in nature and may apply to most resource concern situations in the region. An example of a "generic" recommendation would be nutrient management on cropland. Other recommendations were developed for specific conditions within the Nemadji River Basin.

Many forestry recommendations are of this type. These recommendations specific to the Nemadji River Basin were formulated through a process that involved both the technical and planning committee members. Many of the latter are residents and/or resource managers in the watershed. The idea was to insure local viewpoints as to what was and what wasn't practical and effective.

Organization of Recommendations

Recommendations in this report are organized into five categories. The categories, along with a description, are given below:

1. Watershed Management Recommendations - These recommendations should be implemented on a hydrologic unit basis. Reduction of specific off-site problems depends on the cumulative impact of upstream management.

2. Treatments - These are specific best management practices that can be implemented on an individual basis. They are organized by: 1) description of the treatment, 2) specific recommendation on where to use the treatment, 3) positives to the recommendation, and 4) negatives to the recommendation.

3. Inventory - These recommendations relate to data collection that would be useful for guiding implementation efforts, determining effectiveness of any implementation plans, or for use in essential research.

4. Research - Recommendations for research are based on unknowns that repeatedly surfaced while conducting this study. Such research would lead to more efficient implementation and use of resources.

5. Watershed Organization - This recommendation component deals with organizational activities critical to a successful implementation plan. These activities would include newsletters, annual forums, establishment of watershed committees such as cooperative forestry interests, GIS data share groups, etc.

Measure of Success

Effectiveness of various treatments can be measured directly or indirectly. An example of a direct measurement is a monitoring program which tracks sediment loading before and after installation of a treatment. An example of an indirect measurement is macroinvertebrate sampling in streams. If installation of a treatment caused an increase in biodiversity, the results imply that the habitat was improved through sediment reduction.

The biggest challenge when dealing with natural resource problems of the Nemadji River Basin is that decades may pass before any detected change occurs. It may be difficult to maintain local enthusiasm for long-term implementation measures. For example, reducing erosion in subwatersheds with high slumping potential may require re-establishing a healthy riparian zone and coordinating the percentage of open areas within that subwatershed. Changing the hydrology of a watershed through implementation of these recommendations can be very long-term.

Since short-term interpretation of any monitoring data for detecting improvement isn't practical, the best way to measure success is simply to document the application of treatments. Such documentation would include the number of units of a treatment applied, the location, and how the practice or treatment worked out for the landowner. GIS would be an excellent tool in this record keeping process.

Watershed Management Recommendations

General

Watershed management can be defined as managing the application of practices within a watershed to affect positive, cumulative, watershed-wide changes while recognizing inherent on-site benefits. Watershed management should be carried out with individual landowner's resource objectives in mind. A good example of this is controlled grazing. Controlled grazing is usually marketed on its economic and pasture management benefits to the landowner. Widespread, long-term adaptation of this practice benefits downstream water resource users through improved in-stream habitat, aesthetics, reduced treatment costs, etc.

Management by Hydrologic Units

It is recommended that the Nemadji River Basin be managed by small hydrologic units. A hydrologic unit is defined here as that area of land draining to a common outlet. It is usually determined using topographic divides as boundaries and is sometimes referred to as a subwatershed. Management of the entire Nemadji River Basin through management of its parts will prevent localized resource problems on the subwatershed level and at the same time provide for spatial balance of diversified land use throughout the whole watershed. A good example of this idea is the recommendation to have no more than 40 percent of a hydrologic unit in open and young forest.

The definition of these units will need to be determined through input from the Nemadji River Basin Project Steering and Planning Committees, local zoning boards, and land resource managers. It is recommended that these hydrologic units be an average of about 10 square miles in size. As a starting point for discussion, these units could be defined as the individual subwatersheds as shown in Figure 4 on page 25 (i.e. Mud Creek - 9,600 acres, Rock Creek - 4,520 acres, etc.). Managing on this smaller level also may make landowners feel more a part of any implementation effort. Landowners will likely identify more with the immediate area in which they live rather than the Nemadji River Basin as a whole. Organization of volunteers for stream sampling or educational activities would also be more successful at this level.

Coordinated Forestry Management

Forestry management is a critical element affecting the hydrologic system. This is due to the fact that 69 percent of the Nemadji River Basin is forested and 62 percent of those trees are greater than 45 years old and potentially ready for harvest. There are several groups owning forest land in the watershed (state, county, industrial, and private) thus harvesting and other logging activities are seldom coordinated. Without coordination, cumulative effects of separate logging activities of two or more groups within the same area could have negative hydrologic impacts. Coordinated logging activities that would benefit the hydrology of the watershed include the following:

- on a small hydrologic unit basis, ensuring that no more than 40 percent of the area is in open land and young forest
- developing a coordinated, watershed-wide logging transportation plan
- coordinating activities within the defined riparian zone to maintain physical continuity of that zone throughout a hydrologic unit
- developing forest harvesting research proposals and seeking funding for those proposals as a unified group

(See Riparian Zone Management on page 121 and Upland Forest Management on page 126.)

Treatments

Agricultural Waste Management Systems and Nutrient Management

Description:

A livestock concentration inventory was completed in early 1995 as part of the Nemadji River Basin Project. It showed 85 sites in Minnesota and 42 sites in Wisconsin. Of the 127 total sites, 51 were rated as high hazard for surface or groundwater pollution potential.

The recommendations below are aimed at managing waste, fertilizers, biosolids, legume crop and crop residues in rural areas in a manner that prevents or minimizes degradation of air, soil, and water resources and protects public health and safety. Systems are planned to preclude discharge of pollutants to surface or groundwater and to recycle waste through soil and plants to the fullest extent practicable.

Agricultural waste management and nutrient management are closely related and will be addressed in one set of recommendations. The main difference is that agricultural waste management usually involves on-site animal waste storage or filtering whereas nutrient management includes the proper management and planned application of one or both inorganic (commercial) and organic (usually animal waste) fertilizers and nutrients.

All practices below are further outlined in the standards described in the Natural Resources Conservation Service Field Office Technical Guide, Section 4. Numbers after practices are the practice standard number.

* WASTE MANAGEMENT SYSTEM (312)

The practice actually includes one or more of a series of related practices that can be used to improve the management (storage, handling and land application) of inorganic fertilizers and liquid or solid animal waste including runoff from concentrated waste areas. These other practices include the following:

- waste storage ponds (425)
- waste storage structures (313)
- diversions (362)
- dikes (356)
- fencing (382)
- waste utilization (633)
- subsurface drains (606)
- streambank and shoreline protection (580)
- roof runoff management (558)

* NUTRIENT MANAGEMENT(680)

This practice is aimed at reducing the potential for applied nutrients to pollute surface or groundwater by applying only the amount needed to produce a crop consistent with the land user's goals. It accomplishes this by managing the amount, form, placement and timing of plant nutrients. Planning is done to properly supply plant nutrients for optimum forage and crop yields, minimize entry of nutrients to surface and groundwater, and to maintain or improve the chemical and biological condition of the soil.

Minimum requirements for the practice include a nutrient management plan developed, with assistance, by the farmer. This nutrient management plan will include a nutrient budget accounting for the following:

- current nutrients in the soil for the intended crop
- realistic yield goals
- nutrient credits or carryover

A progressive planning philosophy consisting of two levels of planning can be carried out. The first level is **awareness** and includes testing of soils, manure analysis, equipment calibration, etc., which results in improved management. The second level is **advanced** nutrient planning which consists of awareness plus field specific fertilizer and manure applications.

Recommendations:

1. Accelerate planning and monetary assistance to implement the nutrient management and waste management system practices in the watershed.
2. Potentially high hazard livestock concentration areas should receive priority assistance for agriculture waste management systems.
3. At a minimum, a first level **awareness** nutrient management education effort should be implemented in the watershed.
4. An effort should be made to inform local agribusiness of the efforts of the Nemadji River Basin Project. Local area crop consultants and agricultural chemical consultants may be able to assist with development of future recommendations for the Nemadji River Basin.

Positives of Recommendations:

1. Nutrient and bacterial loading to surface waters and groundwater will be reduced.
2. The nutrient management practice has a low initial cost and, in almost all cases, improves profitability for the farmer.

3. The technology needed to implement these practices is available, well-understood, and well-documented; networks of farmers using these practices can be established to encourage their use.

Negatives of Recommendations:

1. Waste management systems can be costly depending on barn and feedlot locations, water table, soils, etc.

2. Staff power is limited, so an accelerated effort would require more resources than are currently available.

Beaver Dam Management

Description:

In steep terrain, streams move with high velocity and tend to be good trout habitat. Beaver dams in such terrain can be detrimental to the trout fishery due to restriction of fish movement up or downstream and from increased water temperature which can occur in the pooled area behind the dam. In flat terrain, beaver dams may be a significant source of high quality type 3 or 4 wetlands. Because each situation is unique, decisions on whether beaver dams should remain or be removed should be made jointly by a knowledgeable hydrologist, wildlife manager and fisheries biologist.

Recommendations:

1. If beaver dams are removed, the water should be released slowly.
2. Retain beaver dams on non-trout streams in very flat terrain.
3. In areas where beaver are to be discouraged, manage riparian zones for conifers and long-lived hardwoods. Beaver prefer aspen and tend to leave large conifers and hardwoods.
4. Encourage coordination between county highway maintenance and land managers on the issue of dam removal and removal techniques.

Positives of Recommendations:

1. Slow release of dam pond will minimize erosion caused by removal of a dam.
2. Maintains potential for high quality wetlands created by beaver.
3. Root systems of long-lived conifers and hardwoods will help stabilize streambanks. These trees will also become large woody debris which will provide structure necessary to the health of the stream.

Negatives of Recommendations:

1. Managing riparian zones for conifers and long-lived hardwoods is long-term.
2. If dams are removed, negative impacts on wildlife that benefited from the pond and associated habitat may occur.

Engineering Techniques

Description:

Conventional engineering techniques reduce erosion and prevent downstream transport of sediments. Potential techniques within the Nemadji River Basin could involve one or more of the following:

- grade control using drop structures to reduce downcutting
- streambank/stream toe protection (rip-rap, sheet piling, concrete, etc.)
- drainage of slopes which are unstable due to high soil water content

Recommendations:

1. Use on sites where there is potential loss of life, where major transportation delays may result, and where there are property, building, recreational, or other losses which can justify the cost of these practices.
2. Use information from Red Clay Project Report when planning and designing practices.
3. Consider use of soil bioengineering/geotechnical construction techniques where economics for engineering techniques are not favorable.

Positives of Recommendations:

1. Usually considered long-term.
2. Highly effective if designed properly.
3. Benefit is usually realized immediately.
4. A highly visual indication that something is being done.
5. Recreational side benefits for reservoirs.

Negatives of Recommendations:

1. High cost.
2. Possible impacts on soil and fisheries during installation.
3. Potential site access problems.
4. Finite life span of these practices.
5. Potential foundation problems

Wetland Enhancement and Creation

Description:

Wetland enhancement and creation can improve water quantity, water quality, and wildlife conditions within a watershed. Water quantity benefits include reduction of peak flows by virtue of the storage properties of the wetland and maintaining base flows by acting as groundwater recharge areas. Water quality benefits include sediment filtering and nutrient uptake by wetland plants. Wildlife benefits include providing habitat for diverse species and a food and water source for land animals.

Wetlands also can benefit urban or residential areas. Incorporating wetlands in roadway designs can offset increased peaks associated with surface ditching. They can maintain flows and sediment loadings at pre-development levels for residential or commercial areas.

It is difficult to determine how many of the original wetlands in the Nemadji River Basin still remain. The largest amount of wetland loss has been predominantly in agricultural areas. Approximately 10 percent (5,000 acres) of cropland/hayland acreage contain hydric soils that have been drained or filled for agricultural purposes. Although agriculture in the area is declining, much of the drainage remains today. Urban development and road building have also contributed to wetland loss to a lesser degree.

The restoration of altered wetlands is more effective than the creation of wetlands because the hydrology, soils, and seed bank are usually still present on the site. In addition, restored wetlands have a higher functional value than created wetlands. Created wetlands do not support the diversity of plant and wildlife species which are found in natural or restored wetlands.

Minnesota has a "no net loss" policy on all types of wetlands as stated in the Wetland Conservation Act. Certain exemptions apply. Notably, landowners can fill or drain up to 10,000 square feet of types 1, 2, and 7 wetlands away from shoreland areas. Draining and filling over a half acre or near trout waters is not allowed without mitigation in Minnesota. Carlton County, Minnesota has prioritized wetland areas in its Comprehensive County Local Water Plan. Certain categories of wetlands will be targeted for high protection levels possibly including financial assistance.

The Wisconsin Administrative Code has NR103 for wetland protection, and NR115 for shoreland zoning. NR103 is the Water Quality Standards for Wetlands and applies to activities where the state has some type of regulatory authority, including Federal 404 permit actions. NR115 is the shoreland management program and requires that counties regulate activities in shoreland areas. Part of this mandate includes regulation of wetlands in the shoreland-wetland district adjacent to waterways. Essentially, the code prohibits most draining and filling of shoreland wetlands unless for specific permitted uses. The U.S. Army Corps of Engineers also has authority through the Clean Water Act Section 404 permits.

County highway departments and many citizens need access to a wetland bank to mitigate wetland impacts. These banks can be developed by governments or by private citizens. Carlton County has an existing protocol to establish a wetland bank through the Minnesota Wetland Conservation Act. The current Wetland Conservation Act requires the state to subsidize mitigation, providing relief for the Carlton County Highway Department.

Recommendations:

1. The existing wetlands within the Nemadji River Basin should be maintained through current local, state, and federal laws. Although the current level of wetland area within the Nemadji River Basin is high, the distribution and function of wetlands could be improved. Thus, wetland restoration, enhancement, and creation in the Nemadji River Basin should be encouraged.

2. Priority should be given to those sites having one or more of the following characteristics:

   - within the red-clay region
   - within or near the riparian zone (see Riparian Zone Management for definition) except in cases where water from the wetland can exit at seeps in bluffs and having a direct connection to zones of bluff slumping
   - within an area having a high concentration of artificial surface drainage
   - the site has potential for being an open water wetland
   - the site is within an area having urban development pressures

3. Emphasis should be placed on restoring drained wetlands rather than creating wetlands. Some specific design considerations include the following:

   - Where a wetland is being created or restored for mitigation purposes, its location should be within the same hydrologic management unit as the wetland that is being altered.
   - For open water wetlands, the potential safety hazards should be considered.
   - Care should be taken to locate sites so that unique or valuable upland habitats are not destroyed in the process of creating or restoring a wetland.
   - Ensure that any wetland restoration or creation does not restrict the movements of migratory fish.
   - Design of a wetland should be such that water bird nest predation is minimized.

Positives of Recommendations:

1. Storage characteristics can reduce peak discharges downstream.
2. Sediment and nutrient storage improves downstream water quality.

3. Can be part of "greenspace belt" in developed areas.
4. Protects downstream fish spawning habitat from sediment.
5. May improve current fish spawning and rearing.
6. More habitat for water birds, mammals, amphibians, etc.
7. Water level manipulation may allow intensive habitat improvement.

Negatives of Recommendations:

1. Structure failure may destroy downstream habitats.
2. Increased water temperature.
3. Created wetland may need operation, management, and maintenance plans.
4. Structures create liabilities in the event of failure.
5. Cost of mitigation is high due to need to create wetlands.

Erosion Control with Soil Bioengineering/Geotechnical Construction Techniques

Description:

Soil bioengineering/geotechnical construction techniques combine mechanical, biological and ecological concepts and treatments to reduce slope failures and erosion (NRCS Engineering Field Handbook, Chapter 18). Two approaches to soil bioengineering are woody vegetative systems and woody vegetative systems combined with simple structures. Nonliving approaches use rigid constructions, such as surface armoring, gravity retaining walls and rock buttresses. The type of system used must fit the site. Treatment sites should be carefully selected. Woody vegetation may not solve a stability problem caused by geologic parameters.

Field studies have shown instances where combined slope protection systems have proven more cost effective than the use of either vegetative treatments or structural solutions alone. Where construction methods are labor intensive and labor costs are reasonable, combined systems may be especially cost effective. Where labor is either scarce or extremely expensive, however, soil bioengineering systems may be less practical than structural measures.

Soil bioengineering/geotechnical construction offers a promising alternative to traditional riparian engineering techniques for the Nemadji River Basin. Most traditional engineering practices used to control bluff erosion along streams require good access to the site, and a great deal of earth moving on site to install the practices. In contrast, soil bioengineering can often be done by hand, with minimal disturbance to the site. Some common soil bioengineering techniques are fascines (bundles of small diameter live brush tied together), brushmattresses (many long branches criss-crossed and fastened to the ground with dead stakes), live stakes (insertion of medium (1") diameter live vegetative cuttings into the ground) and root wads (part of the trunk and roots of dead, uprooted trees). The Nemadji River Basin has many remote areas with poor road access. These areas are valued by the public as high quality aesthetic resources. If we wish to reduce erosion damage in the riparian corridor and still maintain high aesthetic values, these labor intensive, but simple, bioengineering practices seem to offer the best solution.

Recommendations:

1. Where possible use soil bioengineering/geotechnical construction to incorporate large woody debris, such as root wads, into streams. **It is highly recommended that a person with considerable experience in soil bioengineering techniques be consulted prior to planning these systems.** Soil bioengineering/geotechnical construction is a developing science that requires a good interdisciplinary understanding of the problem. Each site should be custom designed with someone knowledgeable in soil bioengineering/geotechnical construction techniques and, for streambank sites, the evolution of stream systems. All practices done to improve stream channel condition should be done with an understanding of channel

morphology and classification. Rosgen's stream classification, or a similar system, should be used. Stream classification used in combination with knowledge of the evolution of stream systems will assure that the practice applied will have the best potential to succeed.

2. Research done for the Red Clay Project led to the following recommendations: (1) where possible, woody species should be phased into the herbaceous cover; (2) among woody species, more advanced successional species are preferred, largely due to their greater root strength; (3) along streambanks and the associated drainage area, soil stability equations should be employed to demarcate the "100 foot safe zone" (i.e. a 50 ft. wide strip adjacent to each streambank). Within this zone, all human activity that arrests or reverts the successional process should be discouraged. This includes logging and building construction unless these activities are consistent with forest management practices that promote advanced successional stands; (4) in critical erosion sites, the establishment of advanced successional woody vegetation should be actively promoted by acceptable methods of forest management including planting of seedlings, selective cutting, and fertilizer application; and (5) on construction sites, vegetation should be established at the earliest opportunity. Critical area planting could be used to stabilize some slopes and eroding areas. It is preferable to use native plant species since exotic species often compete with native species, leading to their decline.

Positives of Recommendations:

1. Otherwise inaccessible sites can be treated.
2. Root mass development and leaf litter can help hold soil.
3. Soil bioengineering/geotechnical construction can have minimal impact on soil and fisheries during installation.
4. Soil bioengineering/geotechnical construction can cost much less than traditional engineering structures.
5. The aesthetic value of the Nemadji River Basin is enhanced.
6. Riparian wildlife habitat is protected and enhanced.

Negatives of Recommendations:

1. Soil bioengineering/geotechnical construction techniques will not solve all of the erosion problems in the riparian zone. Often these techniques must be used in combination with structural treatments.
2. The use of vegetative methods, specifically for reducing soil moisture content in the surface zones of red-clay soils, are not beneficial for controlling massive slides.

In-Stream Fish Habitat Improvement

Description:

Trout eggs must have gravel bed streams to successfully incubate. The eggs are dependent upon adequate oxygen and low silt loads in the water to survive. They also must have water moving over them to remove waste products. If the gravel in which the eggs are laid is covered with sediment, the eggs are smothered and die. There is a need to determine the trout spawning locations within the watershed and prevent these areas from being covered by sediment. Spawning beds can be improved by creating areas of constricted flow where the sediment is removed from the gravel by increased water flow.

Recommendations:

1. Inventory and map any in-stream areas suitable for fish spawning and designate these areas for preservation and enhancement. This process would consider water temperature, substrate embeddedness, forage base, pollution sources, conditions of stream crossings and access points, etc.

2. For those areas where enhancement is recommended, consider restoration measures such as channel constrictors, double and single wing deflectors, low stage check dams, rock vortex weirs, gravel traps, etc., ensuring that measures are appropriate for the stream type.

3. For those areas without adequate substrate, consider introduction of artificial substrates and shaping of the channel to maintain this substrate. If the velocity of the water is insufficient, the artificial substrate will become covered with fine sediment.

4. Encourage introduction of suitable large woody debris into stream channels through appropriate silvicultural management of riparian areas. (See Riparian Zone Management.) This treatment also will help provide adequate water temperatures for trout production.

Positives of Recommendations:

1. Improved trout and salmon habitat.

2. Improved recreational opportunities for local landowners.

3. Potential outside income from increased tourism.

Negatives of Recommendations:

1. Spot constriction of flow may cause erosion of the streambank at that point. Spot constriction of flow also causes more deposition to occur in the pool area. Spot constriction does not consider the overall health of the system.

2. Construction costs may be prohibitive.

3. Remoteness of sites from road access for construction machinery may limit treatment of some sites.

Livestock Management

Description:

Livestock have two major impacts on watershed condition: 1) Pastures in clay soils are compacted by livestock. The compaction decreases infiltration rates and increases runoff. The impact of increased water yield from compaction is an increase in channel forming flows, which accelerates streambank erosion; 2) Unrestricted livestock access to streams removes vegetation and root systems from streambanks. This removal of vegetation reduces the resistance of the streambank to erosion. As a result of compaction and removal of vegetation by livestock, the stream channel becomes wider and shallower.

Recommendations:

1. Reduce impacts of livestock grazing by using rotational or controlled grazing and other pasture management techniques. This will reduce compaction and produce healthier vegetation to reduce water yield from pastures.
2. Eliminate or control livestock access to riparian zone and stream channels.
   - Fence livestock out of riparian zone.
   - Regenerate trees in riparian zone by planting, seeding, or natural regeneration.
   - If livestock need to access the stream to cross to another pasture, use a rock ford.
   - Use other watering techniques when livestock do not need access to stream.

Positives of Recommendations:

1. Most practices used to improve grazing management have low initial costs and in many cases improve profitability for the farmer.
2. Practice will improve hydrologic condition of the managed area.
3. The technology needed to implement these practices is available, well understood, and well documented; networks of farmers using these practices can be established to encourage their use.
4. Practice will result in improved water quality of runoff from the managed area.
5. Prevents erosion, overgrazing, pollution.
6. Allows vegetation to recuperate.
7. Benefits riparian zone fish, wildlife, and wetlands.
8. Helps prevent livestock and woodland predator encounters.

Negatives of Recommendations:

1. Intensive management is required for many low cost practices.
2. Some practice components, such as fencing, are costly and not always well accepted by farmers. Some type of incentive, such as cost-sharing, may be needed to increase acceptance.
3. Installed conservation practice components require increased maintenance by landowner.
4. Soils and fisheries may be impacted during in-stream structure construction. For example, during construction of a livestock crossing, sediment may be introduced into the stream.

Open Land Management

Description:

Open land management is maintaining a small percentage of the area of a subwatershed in a condition devoid of large overstory trees and usually vegetated by healthy growth of native grasses, forbs, and shrubs. These open land areas are not grazed by livestock but are managed primarily for wildlife. The existence of both large and small openings can improve wildlife habitat for some species and can reduce the impacts of pest infestation through the creation of a more diversified landscape. Within the Nemadji River Basin, large open areas are critical habitat for several species that are on state or federal threatened or special concern lists. Examples include sharp-tailed grouse, sandhill cranes, bluebirds, kestrels, red-tailed and rough-legged hawks, and upland plover. There are also many forest dwelling species that utilize all openings for some or all of their habitat needs. Deer, wolves, bears, woodcock, great-horned and great gray owls, are but a few.

Open areas within otherwise predominantly forested subwatersheds can have beneficial impacts on hydrology on the small watershed scale. In small watersheds they contribute to the "desynchronization" of snowmelt runoff. The open areas will melt before the forested areas, thus lowering peak discharges of streams. Open areas will not reduce the peak flow from large, flood producing snowmelt peak flows.

Wildlife managers within the Nemadji River Basin feel that the current base of open areas is appropriate. However, efforts are needed to educate landowners on the benefits of open land acreage in situations where conversion to trees is not practical or does not meet the landowner's objectives, or where significant negative effects on wildlife could occur.

Recommendations:

1. Work with state and local wildlife managers and conservationists to create an inventory of current/planned open areas within the Nemadji River Basin. Maintain this inventory on a GIS (Geographic Information System) which is an excellent management tool.
2. Encourage all resource managers to consider benefits of maintaining open areas.
3. Encourage landowners to include input from wildlife managers, foresters and conservationists when deciding on options for land use conversion.
4. Open and young forest areas should not exceed 40 percent of the area by subwatershed planning unit (see Upland Forest Management Recommendation on page 126). Discourage tree planting initiatives in subwatersheds where the percent open and young forest area is less than 20 percent.

Positives of Recommendations:

1. Increase in wildlife habitat/foraging areas for certain species.
2. Decrease in potential movement of pest infestations.
3. Acts as fire break.
4. Potential for increase in recreational uses.
5. Potential for reduction of peak discharges from snowmelt events on small watersheds.
6. Improves landscape diversity.

Negatives of Recommendations:

1. Potential increase in soil wetness and sloped soil instability during establishment period.
2. Potential loss of income to landowners.

Riparian Zone Management

Description:

The riparian zone is land and vegetation bordering lakes, streams, and wetlands. It is the transition zone between the terrestrial (land) ecosystem and the aquatic (water) ecosystem. The terrestrial and aquatic ecosystems are modified by each other in this zone of transition. Open water and groundwater near the surface cause the riparian zone to have a humid microclimate which changes the type of vegetation, increases its growth rate, and increases the diversity of wildlife habitat. Vegetation in the riparian zone is a source of energy to the aquatic ecosystem. Trees that fall into smaller streams and remain in place are often a major component of stream structure and fish habitat. The riparian zone is a band of land that has a significant influence on the streams and is significantly influenced by the streams.

Recommendations:

1. Continue forestry coordination in the watershed that was begun by the Nemadji River Basin Project.

   - The counties, states, forest industries, and private landowners should meet periodically to develop understanding and implementation of riparian zone management recommendations.

2. Provide financial incentives, educational opportunities, and technical assistance to landowners to enable them to manage their riparian zones for stream ecosystem improvement.

   - Landowner implementation of riparian zone recommendations is on a voluntary basis. Therefore, a coordinated effort to inform and assist them is needed to implement recommendations.

3. Create a riparian management zone for streams in the Nemadji River Basin.

   - The width of the riparian zone in the red-clay portion of the watershed includes the entire floodplain plus adjacent slopes 20 percent or greater. This is a departure from the recommendation in the forestry best management practices (BMP) handbooks for both Wisconsin and Minnesota. The forestry coordinating committee should work with the forestry BMP committee in each state to have this width included in their recommendations.
   - The width of the riparian zone in the non-red-clay portions of the watershed follows the recommendations in the forestry BMP handbook for each state. Following this recommendation will also assure compliance with the forestry practices for Carlton and Douglas County shoreland ordinances.
   - The length of the riparian zone extends upstream into intermittent channels, and ends at the point when a streambank can no longer be identified.

- The riparian zone management area applies to agricultural and urban areas as well as forest land.
- Establish or manage riparian zones in agricultural and urban areas to have a buffer between the cultivated field and street and lawn runoff.

4. Manage the riparian zone for large, woody debris.
   - Thin stands that are too dense to enable large crowns to develop. Trees with large crowns have large root systems.
   - Plant long-lived deciduous and coniferous trees in sparsely forested areas. Plant trees 20 to 30 feet apart. Begin at the top of the streambank and end 50 to 100 feet from the stream. Some of these trees will be lost because the streambanks will continue to erode at a rapid rate. The goal is to have large trees right on the bank at about 30 feet apart.
   - Retain coniferous and deciduous trees throughout the riparian zone area. Harvesting should favor growth of long-lived coniferous and deciduous trees. A selective harvest of aspen and birch favors later successional coniferous and deciduous trees in the understory and should accelerate the growth of these species.
5. Livestock use of the riparian zone should be managed to prevent the loss of benefits from other uses.
   - Manage livestock grazing by complete exclusion or controlled grazing systems.
   - Where needed, provide controlled access to the stream by rock fords, or install off-site watering devices.
6. Take precautions to avoid blocking floodplains when building a road across a stream. Where roadbeds cross floodplains, use long bridges, multiple elevation culverts, or rock fords rather than single culverts in the streambed.
   - When a culvert or bridge is used to cross a stream, do not straighten the stream above the crossing because it causes downcutting in the upper part of the straightened section.

<u>Positives of Recommendations:</u>

1. Improve the hydrologic condition of the streams.
   - By acting as dams, large, woody debris can change a uniformly flowing stream into a stream of alternating pools and riffles.
   - Woody debris dams can reduce the effective slope of a stream, reduce stream velocity and erosion potential.
2. Provide food and habitat for aquatic organisms.

- Fallen leaves and other organic debris from trees are the base of the food chain for aquatic organisms in forested watersheds.
- The pools formed by large, woody debris retain organic matter in the stream long enough for microorganisms to decompose them, and for fish to eat the microorganisms.

3. Filter sediment and nutrients from runoff.
    - Forested riparian zones are a buffer between logging roads, skid trails, and log landings and streams.
    - In agricultural and urban areas, vegetated riparian zones are buffers between cultivated fields and city streets and lawns.
4. Large trees help stabilize streambanks and reduce erosion rates.
5. A mixture of deciduous and coniferous trees allows the stream to warm in the spring and prevents excessively high temperatures in the summer.
6. The nutrient-rich environment of the riparian zone and the presence of water result in increased wildlife diversity and use.
7. Allows flows above the bankfull level to spread out on the floodplain rather than being forced through a single culvert.

<u>Negatives of Recommendations:</u>

1. It will take a very long time for large, woody debris to have an impact on stream structure.
2. In forested areas outside the red-clay area, leaving trees in a riparian zone will reduce landowners' income from timber sales.
3. Maintaining a forested riparian zone adjacent to cultivated fields will reduce income and could add to production cost.
4. Removing or controlling grazing of livestock in riparian areas will cost the landowner money to install fencing and watering devices, and will increase maintenance costs.
5. Landowners receive little direct economic benefits from managing riparian areas for watershed improvement. Therefore, implementation will require financial incentives, education, and technical assistance.

Roadside Erosion Management

Description:

Difficulties with red-clay soil, including steep terrain and occasional sudden heavy rains, have caused many problems for road and structure maintenance.

One percent of all watershed erosion in the Nemadji River Basin is estimated to be from roadside erosion. Although one percent is a small value, this still represents over 3,000 tons per year. In addition, roads and ditches are efficient at delivering water to streams, which increases peak flows and streambank erosion.

All agree that road construction and maintenance should be performed using a watershed friendly approach. It should be done in a way that ensures the impact from roads is at the lowest level that can be reasonably achieved. In the red-clay portion of the watershed, many of the common erosion control practices used throughout the two states are not adequate or will require extra measures for success.

Recommendations:

1. Continue the coordination of the transportation committee that was begun during the Nemadji River Basin Project. Meet annually to discuss progress on practices and recommendations.
2. Utilize statewide Best Management Practice Standards and Specifications listed in the Construction Site Erosion and Sediment Control Plan Handbook for the appropriate state. In the red-clay portion of the watershed, modify practices where needed, to address the unique soil, runoff, and vegetation establishment problems.
3. Research measures that have been used in other areas dealing with the same type of soil.
4. Make more frequent use of traverse drains, ditch blocks, tile, cutouts, etc., to reduce road-ditch flow.
5. Use the roadside erosion inventory that was performed as part of the Nemadji River Basin Project and develop a prioritization system.
6. Work with township road supervisors to inventory and prioritize existing erosion problems on minimum maintenance roads.
7. Complete work on two or more problem sites each summer in each county.
8. Try bioengineering in select locations for erosion control.
9. Minimize road building in the red-clay area of the watershed.
10. Conduct workshops for road construction contractors to discuss special problems of working with red-clay soil in the watershed.

11. Gate and close "problem" minimum maintenance roads and other travel ways during wet times of the year to prevent erosion.

12. Coordinate construction of logging roads among different logging companies to minimize total miles of roads.

13. Work with Department of Tourism to educate people on the hydrologic impacts from rutting and compaction of the soil due to careless operation of recreational vehicles.

Positives to Recommendations:

1. Networking and sharing of technical knowledge by meeting annually will save time and money.
2. Bioengineering, tried first in some situations, may save earth-moving costs.
3. A group working together usually has a better chance of securing erosion control dollars.
4. Prioritizing will help solve the worst problems first.
5. Workshops are a cost-effective way to disseminate knowledge of practices that work.
6. Limiting new roads in the red-clay portion of the watershed will result in lower future maintenance costs.
7. Documenting modified sediment control practices for the red-clay portion of the watershed will help future practices succeed and prove their value when personnel change.

Negatives of Recommendations:

1. Coordination takes time and leadership, especially across state lines.
2. Implementing extra measures to stabilize erodible soil and slopes takes extra dollars that will need to be found.
3. Workshops take time and money to conduct.

Upland Forest Management

Description:

The entire Nemadji River Basin forested by late successional coniferous and deciduous species, similar to pre-European settlement conditions, would provide the best hydrologic condition for the basin. It is neither possible nor practical to go back to that condition. There will always be some agricultural land use in the basin. Some open land is needed for wildlife habitat diversity. However, good forest management based on an understanding of hydrology can significantly improve the watershed's condition.

The present forest is dominated by trees nearly ready for harvesting. Harvesting and regenerating trees is a critical time in forest management. The next generation of forest should be managed for more species diversity than the present forest since doing so will improve the hydrologic condition of the basin.

Based on current understanding of regional forest hydrology, watersheds having more than 40 percent of their area in open (agriculture, grassland) and young aspen forests (0-15 years old) will have increased channel forming flows (the peak flow that occurs about every one and a half years). Reducing these high peak flows will reduce the rate of erosion occurring in the basin.

Landowners with agricultural and open land need to consider opportunities to plant trees and manage for wildlife opportunities. (See Open Land Management and Livestock Management Recommendations.)

Maintaining a diverse forest cover goes beyond individual landowner decisions. When management decisions are made on single parcels of land while ignoring the conditions of the surrounding land, negative downstream impacts can result. A healthy watershed can result only through the coordinated efforts of all landowners. When all landowners are committed to improving the hydrologic condition of the watershed, decisions can then be made looking at the cover characteristics of the watershed as a whole.

Using the whole basin as the scale for percent open and young forest could mask some serious erosion problems in subwatersheds. It is only when the cumulative effects of all the subwatersheds are combined that the entire basin will improve.

The process of removing forest products from a harvest area can accelerate erosion. Logging roads, skid trails, and log landings are sources of soil erosion from a timber harvest. Forestry best management practices (BMPs) for water quality are recommended to reduce soil erosion on timber harvests.

The following guidelines contain some broad silvicultural ideas that landowners should consider as they plan how to manage their land.

- Understand the site and its capabilities when conducting harvests and regenerating a forest. Be sensitive to natural successional changes that are becoming evident in forest understories,and the silvicultural options these future cover types may offer.

- Consider developing a broader age class distribution to obtain multiple benefits, and lessen the impact of any one silvicultural activity in the future.

- A conscious management decision to do nothing is a valid management decision, particularly in sensitive areas and areas where the result of the management activity may be in doubt.

Recommendations:

1. Continue forestry coordination in the watershed that began with the Nemadji River Basin Project by forming a Forestry Coordination Committee.

   - The committee should be comprised of representatives from counties, states, forest industries, and private landowners. It would meet once or twice a year to coordinate harvesting on a subwatershed basis, to share data for input in a watershed-wide GIS (Geographic Information System) database, and discuss opportunities for improving the forest resource base.

2. It is recommended that the percent of open area (young forest less than 15 years old, agriculture, and grassland) within a subwatershed management unit (subwatersheds about 10 square miles in size - see Watershed Management Recommendations for details) not exceed 40 percent. To ensure flexibility and recognition of economic factors, the following exceptions to this limitation would apply:

   - Where natural disaster (disease, blow-down, etc.) has occurred, plans for salvaging operations could be used that exceed the 40 percent recommendation.

   - In circumstances where over 50 percent of the forest within a subwatershed unit is past its economically optimal harvesting age, the percent open land limitation could be increased to 50 percent.

   - A subwatershed could have a greater than 40 percent open land limitation for circumstances as identified by a Forestry Coordination Committee with advisement from other land managers within the Nemadji River Basin. For example, assume there is subwatershed with several different landowners desiring timber harvests on their land, and if all this harvesting is done in one year, the percentage of open area would exceed 40 percent. Because of the proximity of these sites, however, it is possible to construct one logging road system to provide access to all of them. By constructing a single road system using BMPs, followed by closure and seeding down following the harvest, less hydrologic impacts would be incurred than having separate roads built and operated over a longer period of time. Although this increases the amount of open land above the recommended 40 percent level, doing this operation within one season would reduce erosion and runoff from the system in the long run and reduce each landowner's harvesting cost.

3. Manage forest land for species and land cover diversity.

   - Some diversity will occur through succession. Some will occur because there is a diverse ownership pattern in the watershed, and different landowners will manage their land with different objectives. Some will occur because landowners make a conscious decision to manage for a variety of species.

- Later successional species should be encouraged where practical to accelerate their growth in the basin.

- Although a forested condition produces less runoff than an agricultural land use, not all abandoned or poor agricultural land should be planted to trees. Some open land is needed for maintaining a diversified wildlife habitat. Any tree planting efforts should be focused in hydrologic units that have more than 20 percent agricultural land. Landowners should consult a wildlife biologist, forester or conservationist to evaluate wildlife habitat, forestry or other options for their land. Consult a forester to determine cash crop potential for forest products. (See Open Land Management recommendation.)

- Non-industrial private forest landowners need the assistance of professional foresters to understand their forest management options.

4. Encourage the Minnesota and Wisconsin BMP Committees to accelerate the BMP monitoring process on red-clay soils.

   - Increase in sampling would provide a better evaluation of the effectiveness of BMPs on red-clay soils.

   - Participation of loggers, land managers, landowners, and foresters in BMP monitoring is an excellent tool for training them on BMP use and effectiveness.

5. Increase the amount of forestry technical assistance available to non-industrial private forest landowners.

6. Encourage non-industrial private forest landowners to manage their forest land.

   - A forest stewardship plan detailing landowner decisions is an excellent tool for non-industrial private forest landowners to use to reach their objectives.

   - Technical assistance and incentives should be targeted to activities that enhance the forest quality.

7. Encourage the use of a logging contract on all timber sales. The contract should specify adherence to harvesting BMPs as a condition of allowing logging. It will assure landowners that the harvest will be conducted in a manner that will meet their objectives. See Appendix J for a sample timber contract. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

8. Ongoing research on forest hydrology, causes of slumping in clay soils, logging BMPs, and soil compaction caused by logging equipment should be monitored. New knowledge may modify current recommendations.

Positives of Recommendations:

1. Based on current knowledge, following these recommendations will begin to reduce channel forming peak flows in the short-term. In the long-term, these recommendations should improve hydrologic conditions and reduce erosion in the basin.
2. Forest landowner objectives for owning forest land will be maintained.
3. Watershed conditions will not deteriorate because of timber harvesting.
4. The health of the forest resource will improve, because various tree species will be grown on sites best suited for them.
5. The watershed forest resource will have a greater diversity of species and ages because many different landowners will manage their land for different objectives.

Negatives of Recommendations:

1. These recommendations will require agencies, industries, and individuals to work together. It will cost them time and money in the short term, but it should benefit them in the long term.
2. Forest landowners may have to forego some of their individual preferences for the benefit of other landowners and the long-term health of the watershed.
3. Landowners may have to delay harvests, which may cause some loss of income.

Inventory

Thorough inventory of resources within the Nemadji River Basin is essential to any implementation efforts. A comprehensive resource inventory can provide landowners, land users, and managers with an assessment of the current resource situation. A present condition inventory is a logical start in determining desirable future conditions. Long-term inventories provide the planner with trend indicators. What direction is a resource tending? Is it improving or declining? Carefully designed monitoring programs allow treatment assessments. Are treatments effective? Do they need modification or reconsideration? Inventory data can also provide a common data base for cooperative efforts between different groups. Resource managers often maintain records of their own activities and do not track activities of others. A combined inventory of all activities will help facilitate cooperative efforts among landowners striving to improve the watershed.

The following inventory activities were identified as important to implementation efforts within the Nemadji River Basin:

1. The stream system should be classified using a geomorphic approach as outlined by Rosgen (1994). Such classification can aid in providing valuable insight into sources of sediment and how the system may react to upland/on-site treatments.

   A study is currently underway by the University of Minnesota entitled "Hydrologic and Geomorphic Analysis of Streams in the Nemadji River Basin". The objectives outlined in the proposal provide a good summary of the utility of such a classification effort:

   - recognizing current status and trends in-stream channel morphology
   - improving our understanding of sediment generation and transport in the watershed
   - improving the understanding of relationships between suspended sediment loads and discharge for streams in the watershed

2. A watershed-wide Geographic Information System (GIS) database would be extremely useful in future implementation efforts. It would be especially useful when implementing any upland forest management treatments where percentage of open/young forest areas by subwatershed is needed. It could also be used for the following:
   - tracking progress of implementation activities
   - determination of potential resource problem areas
   - targeting problem areas
   - future modeling efforts
   - presentation/demonstration purposes
   - defining extent of riparian zones

As part of the Nemadji River Basin Project, some very basic data sets were created. This effort needs to continue to expand to fulfill the potential of GIS. The system needs to be maintained and data must continue to be updated for useful analyses to be performed and for GIS maps/products to be provided to planners.

3. Provide a follow-up sampling program to the Red Clay Project study performed by DeVore, et al. (1980). Detailed in-stream sampling was performed as part of that study in an attempt to correlate aquatic species with nutrients, turbidity, and sedimentation rates. Resampling the sites to determine the changes that have taken place since that time would be useful. The study could be expanded to include more tributaries and hopefully a watershed-wide assessment of current conditions.

4. The collecting of U.S. Geological Survey water quantity information should continue to be supported. Due to budget constraints on the U.S. Geological Survey Cooperative Stream Gaging Program, the possibility of gage discontinuations becomes a very real concern. The current stations within the Nemadji River Basin with reasonable periods of record are the Nemadji River near South Superior (04024080 1973-present) and Deer Creek near Holyoke (04024098 1976-present). Data from these will be invaluable for comparing long-term hydrologic changes. Efforts must be made by all interested resource managers/planners/project personnel to support the U.S. Geological Survey for continued monitoring at these stations.

5. A consistent water quality monitoring program must be established. Stations should be maintained for a long enough period to ensure reliable data interpretation. Both the MPCA and WDNR have suggested the following:

   - Monitoring of toxic and conventional pollutant loading to the bay and Lake Superior. This type of study is currently underway as an MPCA project in the St. Louis River supporting the St. Louis River Remedial Action Plan and the Lake Superior Binational Program.

   - Monitoring to develop longitudinal profiles of pollutants such as suspended sediment total and dissolved phosphorus, and nitrogen series. This will help to understand the change in concentrations of these pollutants from the headwaters of the Nemadji River to Lake Superior. Heavy metals should also be monitored but not at the same frequency and locations as the other pollutants listed above.

   - Monitoring is needed to track the impacts of treatments. One of the best ways of doing this would involve a paired-watershed monitoring design. This involves the selection of one watershed as a control and a second watershed as the primary implementation area. The second watershed should have a high potential for implementation. Monitoring would involve both water quality sampling and the recording (tracking) of practice applications in the watersheds.

- Monitoring in the Nemadji River Basin can be coordinated with other monitoring efforts in Minnesota and Wisconsin. One immediate avenue of coordination can occur through the development of a monitoring plan for St. Louis River RAP, on which MPCA and WDNR are currently working.

Research

Below are five research recommendations submitted by the Nemadji River Basin Project Technical Committees. These areas of research will provide vital information for any implementation efforts.

It is recommended that all research that is proposed in the Nemadji River Basin be evaluated on a cost/benefit basis by the local watershed-wide organization (see Watershed Organization for Implementation section of this report). Endorsement of any research would be made only if there was high potential that it would help attain the natural resource goals of the local watershed-wide organization.

1. Research into long-term erosion and sedimentation rates and runoff characteristics of the Nemadji River Basin is needed. Questions needing answers include: 1) "How have the hydrology and erosion rates of the watershed changed since pre-European settlement?" and 2) "What baseline conditions should be used when measuring the effectiveness of implementation efforts?" This type of study could include the following activities:

   - dating core samples of bay and floodplain sediments
   - coring of floodplain trees to estimate when downcutting occurred in order to establish their age and the most recent period of stream stability
   - stream classification (Rosgen, Montgomery and Buffington, etc.)
   - estimation of historic bankfull discharges using geometry of abandoned meanders (oxbow lakes)
   - research of historic documents (Marschner and Trygg vegetation maps, original land office records, etc.)

   An excellent example of this type of research effort is a recent U.S. Geological Survey study done on nearby North Fish Creek (Fitzpatrick, 1996). A fluvial geomorphic study of this watershed showed that sedimentation increased following European settlement and also that rates have been decreasing since approximately 1950.

   Geologic layers within the Nemadji River Basin need to be researched to determine the usefulness of construction setback recommendations provided by the Red Clay Project. Updated information on the stratigraphy (layers of glacial material) of the Nemadji

River Basin may result in revised setback recommendations. The watershed was divided into three regions, according to the geologic layers present in each. These regions were roughly delineated during the Red Clay Project by Mengel and Brown (1979).

A literature review of geologic investigations in the area since the Red Clay Project may provide sufficient information. The stratigraphy of the area in Lee Clayton's report Pleistocene Geology of the Lake Superior Region and Mark Johnson's thesis Origin of the Lake Superior Red Clay and Glacial History of Wisconsin's Lake Superior Shoreline West of the Bayfield Peninsula should be reviewed and compared to the information in the Red Clay Project Report. Ed Bacig's thesis (in progress, University of Minnesota-Duluth) should also be reviewed to verify the accuracy of the regions outlined in the Red Clay Project report.

An improved and complete picture of the stratigraphic relationships within the Nemadji River Basin would also prove to be an invaluable tool for understanding the slumping mechanism and regional groundwater conditions (see research items 3 and 6 below). This type of information will be useful to zoning departments in designing zoning ordinances.

3. Further research on hillslope processes needs to be done. Understanding these processes is critical since an estimated 98 percent of the sediment yield from the Nemadji River is attributed to streambank and bluff erosion. Theories abound yet there is little consensus as to what are the most important causal factors.

   This study would likely include a investigation of regional groundwater characteristics such as: the extent of the aquifer system, recharge areas, direction and rates of groundwater flow, etc. It has been postulated that groundwater flows outletting through the red-clay slopes (seeps) may have a significant impact on slumping. This information is critical for determining where to target implementation efforts and which types of treatments will be effective. Another activity to consider would be to survey cross sections of the channel in various locations. Areas of active slumping could be found and changes tracked over time.

4. The Nemadji River Basin should be included as part of the research initiative of the U.S. Forest Service to study riparian corridor management. The unusual erosion problems and land ownership patterns of the Nemadji River Basin would make it an excellent candidate for that program. A sign of strong, unified commitment to implementation from the Nemadji River Basin Project organizational groups (steering, planning and technical committees) would increase the probability of inclusion in such an initiative.

5. Research is needed to determine the hydrologic impacts of timber harvesting on red-clay soils. The current percent open and young forest recommendation is based on limited stream gaging data along the south shore of Lake Superior and from the

Marcell Forest Experiment Station where conditions are very different from the Nemadji River Basin. Impacts of timber harvesting are needed that are specific to the soils and topography of the Nemadji River Basin. Results from such a research effort would be invaluable, not only to the Nemadji River Basin, but to other watersheds where heavy soils are present.

Funding Sources

Many of the recommendations described will require funding from outside sources. Several Federal, State, and Local programs exist which can provide financial assistance to natural resource related projects. Appendix K provides a listing of several key funding sources along with administering agencies, contact names with phone numbers, funding history, and brief descriptions of the programs. All appendices are in a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover.

Because many agencies, programs, and funding sources are tied to state or federal legislation or legislative mandates, many of the programs or grants listed in Appendix K may change or be discontinued over time. The local conservation agencies in each county are always the best places to start when searching for up-to-date information on funding sources. They also participate in, or are aware of, all of the land and water based conservation related projects and programs in their respective counties. The local conservation entities within the Nemadji River Basin are the Carlton County Soil and Water Conservation District and the Douglas County Land Conservation Committee.

Along with the funding sources listed in Appendix K, there are many foundations that fund conservation related projects. Listing these foundations in the appendix is impractical due to their large number and widely varying activity levels. To find out about foundations it is recommended that the Foundation Center be utilized. The Foundation Center is an independent national service organization established by foundations to provide an authoritative source of information on private philanthropic giving. The Center disseminates information on private giving through public service programs, publications and through a national network of library reference collections for free public use. To check on new locations or current information, call toll-free 1-800-424-9836. The public library in Duluth or Superior can also be contacted for this information.

Watershed Organization for Implementation

The mission of the Nemadji River Basin Project is to recommend remedial actions and best management practices that can be implemented to restore beneficial uses to the Nemadji River Basin. Through analysis of past, current, and ongoing sources of information, the project has developed recommendations to accomplish this mission.

Successful implementation of the recommendations depends on the leadership of a local watershed-wide organization. The Carlton County Soil and Water Conservation District (SWCD) and the Land Conservation Committee (LCC) of the Douglas County Board are the local organizations best suited to take leadership in forming a local watershed-wide organization. The organization could be composed of local units of government (municipalities, town boards, county boards), local groups, landowners, interested individuals, and federal and state agencies. Agencies and local units of government could combine their ongoing programs to help implement the recommendations.

The local watershed-wide organization should have at least one staff person coordinate activities among its members, and help the organization to make efficient and effective progress on the recommendations. This position could be a two- to three-year appointment to help the organization get started. This person would be stationed locally and be responsible for coordinating activities related to the recommendations listed in this report, writing grant applications, and carrying out a public participation plan. Primary responsibilities would include organization of Forestry and Geographic Information System (GIS) Committees. Carrying out the public participation plan might include: 1) organization of annual forums for landowners to get project updates or outcomes of any ongoing research; 2) the publication of an annual newsletter; 3) organization of volunteers for monitoring and sampling; and 4) pursuit of television, newspaper, and radio opportunities. Effectiveness of the local watershed-wide organization might be increased by having subcommittees. The subcommittees could focus on topics such as forestry coordination, establishment and maintenance of GIS, land use and zoning, road maintenance, and information and education.

Accomplishment of recommendations depends on the participation and cooperation among state and local agencies and non-industrial private forest and farm landowners. The most direct method of implementation is regulation; however, this approach does little to improve landowner attitudes or to encourage cooperation. A basic strategy for effective long lasting and voluntary implementation of natural resource protection and management relies on education and incentives.

Education includes providing information, guidance, technical assistance, and support for natural resource program activities. Education should be the primary component of any program which attempts to change human activities. Only through education can landowner attitudes be changed and a stewardship ethic developed, lessening the need for any regulatory programs. Therefore, education should reach all individuals, and be tailored to meet the special demands of the audience.

Incentives can be used to increase implementation. They can help attain desired values and attitudes. They can be both a reward for doing a desired activity and an attempt to discourage undesirable activities. Incentives should be directed at the entire public as well as targeted at certain areas, groups, or individuals. The cost of incentives must be borne by the beneficiaries of the practices. If the public benefits from the implementation of programs, then they should pay a portion or all of the costs. In addition, landowners should practice stewardship and pay a portion of the costs. Generous cost-sharing rates may encourage cooperation and participation, but they do not necessarily improve landowner attitudes.

All watershed management recommendations should be evaluated as new information becomes available. The local watershed-wide organization could monitor and sponsor further research and studies which increase the understanding of soil mass wasting on red-clay soils. Recommendations could be changed or eliminated as new information becomes available.

Where to Go for Assistance

Wildlife and fisheries management, forest planning, regulation of activities associated with surface waters:

Department of Natural Resources
1705 Tower Ave.
Superior, WI 54880

Telephone: (715) 392-0803
Fax: (715) 392-7993

Conservation planning assistance, federal cost share conservation programs, technical and engineering assistance for conservation projects, technical and financial assistance for wetland restoration and wildlife habitat projects:

Natural Resources Conservation Service
P.O. Box 267
Ashland, WI 54806

Telephone: (715) 682-4161
Fax: (715) 682-0320

Natural Resources Conservation Service
4850 Miller Trunk Hwy, Suite 2B
Duluth, MN 55811

Telephone: (218) 720-5209

Conservation planning assistance, technical and engineering assistance for conservation projects:

Ashland, Bayfield, Douglas and Iron County Land Conservation Department
P.O. Box 267
Ashland, WI 54806

Telephone: (715) 682-7187
Fax: (715) 682-5707

Carlton Co. Soil and Water Conservation District
310 Chestnut Ave.
P.O. Box 29
Carlton, MN 55718-0029

Telephone: (218) 384-3903

Fisheries research, technical and financial assistance for wetland restoration projects:

U.S. Fish and Wildlife Service
2800 Lake Shore Drive
Ashland, WI 54806

Telephone: (715) 682-6185
Fax: (715) 682-8899

Wetland regulations, lake, stream and other water related issues:

U.S. Army Corps of Engineers
120 State Road, Room 107
Two Harbors, MN 55616

Telephone: (218) 834-6630

General information for natural resource related questions:

U.W. Extension Service
Courthouse
1313 Belknap Street
Superior, WI 54880

Telephone: (715) 395-1363

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Appendix Information

Note: All appendices are published as a separate document located at NRCS field offices in both Ashland and Duluth. Addresses for these offices are inside the front cover. The list of appendix topics is included here for your information.

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APPENDIX B - PUBLIC INPUT

APPENDIX C - SAND SOURCE

APPENDIX D - WATER QUALITY STORET DATA

APPENDIX E - THREATENED AND ENDANGERED SPECIES IN THE NEMADJI RIVER BASIN

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