Nemadji River Watershed Stressor Identification Report

A study of local stressors limiting the biotic communities in the Nemadji River Watershed.

Minnesota Pollution Control Agency

August 2014

Legislative Charge

Minn. Statutes § 116.011 Annual Pollution Report
A goal of the Pollution Control Agency is to reduce the amount of pollution that is emitted in the state. By April 1 of each year, the MPCA shall report the best estimate of the agency of the total volume of water and air pollution that was emitted in the state the previous calendar year for which data are available. The agency shall report its findings for both water and air pollution, etc.
HIST: 1995 c 247 art 1 s 36; 2001 c 187 s 3

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Key Terms & Definitions

303(d) list – state list of impaired waters submitted to Environmental Protection Agency
ATV – all terrain vehicles
AUID – assessment unit identification
BEHI – bank erosion hazard index
CAD – computer aided drawing
CADDIS - Causal Analysis/Diagnosis Decision Information System (CADDIS).
DELT – deformities, lesions, tumors
DO – dissolved oxygen
EOR – Emmons & Olivier Resources, Inc.
EPA – Environmental Protection Agency
EPT – Ephemeroptera, Plecoptera, Trichoptera
F-IBI – fish index of biologic integrity
GIS – geographic information system
HBI – Hilsenhoff Biologic Index
HSPF – Hydrologic Simulation Program FORTRAN
HUC – hydrologic unit code
IBI – index of biologic integrity
IWM – intensive watershed monitoring
LI-DAR – light imaging detection and radar
M&A Rpt – monitoring and assessment report
MDNR – Minnesota Department of Natural Resources
mg/l – milligram per liter
MN – Minnesota
MN DNR - Minnesota Department of Natural Resources
MPCA – Minnesota Pollution Control Agency
MS4 –Municipal Stormwater Plan, level 4
MSHA – Minnesota Stream Habitat Assessment
MSUM – Minnesota State University Mankato
Natural Background – amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors
NPDES – National Pollutant Discharge Elimination System
NTU – nephelometric turbidity unit
pH – a measure of the acidity or basicity of an aqueous solution
SABS – suspended and bedded sediments
SID – stressor identification
SOE – strength of evidence
SOO Line – paved trail for recreational uses following old railroad bed
SWCD – soil and water conservation district
TMDL – total maximum daily load
Tolerance indicator value – a measure of the relative tolerance of common fish species to a physicochemical parameter
TP – total phosphorus
TSS – total suspended sediment
ug/l – microgram per liter
USGS – United States Geological Survey

VSS – volatile suspended solids
WHAF – watershed health assessment framework
WI – Wisconsin
WMA – wildlife management area
WRAPS – watershed restoration and protection strategies

Executive Summary

Over the past few years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of the state's rivers and streams. This basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat conditions at multiple sites throughout a major watershed. From these data, an Index of Biological Integrity (IBI) score can be developed, which provides a measure of overall community health. If biological impairments are found, stressors to the aquatic community must be identified.

Stressor identification is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems and provides a structure for organizing the scientific evidence supporting the conclusions (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to aquatic life. Stressor identification (SID) is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act. This report summarizes stressor identification work in the Nemadji River Watershed.

The Nemadji River Watershed spans the Minnesota and Wisconsin border, with its headwaters to the south and east of Duluth, Minnesota and discharging to Lake Superior near Superior, Wisconsin (Figure 3). The Minnesota portion of the watershed includes approximately 178,000 acres (64%) of the 277,400 total acres. The watershed includes numerous streams, which are tributaries to the mainstem of the Nemadji River. Relatively few lakes occur within the watershed, and are primarily located in the headwaters areas. Land use in the Minnesota portion of the watershed is mostly related to rural forestry, pasture production for hay cutting, and some beef cattle. Lakeshores are developed, although not as intensively as is typical in northern Minnesota counties.

Water quality and biological monitoring in the Nemadji River Watershed have been ongoing since 2001, with less frequent water quality monitoring dating back to 1967. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2011-2012, and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2001, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages. In the Nemadji River Watershed, six Assessment Unit Identifications (AUIDs) are currently impaired for a lack of biological assemblage. All impaired reaches are Minnesota Department of Natural Resources (MN DNR) designated trout streams.

General candidate causes of stress to the biological communities are summarized for the entire Nemadji River Watershed. Specific candidate causes of stress to the biological communities of individual impaired AUIDs are also described. Relevant reports, water quality analyses, and documentation for the SID process are included in several appendices as a separate electronic document.

After examining many candidate causes for the biological impairments, the following stressors were identified as probable causes of stress to aquatic life:

1. **Historic flow alteration:** Historic flow alteration was included as an underlying cause of several other candidate causes, including physical habitat quality, bedded sediment, habitat fragmentation, and suspended sediment/turbidity. Historical logging led to increased runoff which destabilized streams and initiated a channel evolution process.
2. **Recent flow alteration:** Recent flow alteration refers to climate changes, impoundments, and land use changes over the past several decades that are impacting stream flow, natural stream processes, and the availability of aquatic life habitat.
3. **Physical habitat quality:** Habitat is a broad term encompassing all aspects of the physical, chemical and biological conditions needed to support a biological community. Degraded physical habitat quality can impact the ability of fish and macroinvertebrates to spawn, forage, or find refuge.
4. **Habitat fragmentation:** Habitat fragmentation refers to the lack of connectivity in a stream that prevents fish passage, and is caused by dams, incorrectly sized or perched culverts, or flow barriers.
5. **Dissolved oxygen:** Dissolved oxygen refers to the concentration of oxygen gas within the water column. Low concentrations or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species.
6. **Water temperature:** Optimal growth of many fish species occurs in specific range of water temperature. Many of the impaired streams in the Nemadji River Watershed support coldwater fish species (namely trout) whose optimal growth occurs at lower temperatures than other fish species, with high water temperatures resulting in stressful or even lethal conditions.
7. **Suspended solids/ turbidity:** Excess suspended solids (turbidity) can harm aquatic life through direct, physical effects on biota such as abrasion of gills, suppression of photosynthesis, and avoidance behaviors, or through indirect effects such as loss of visibility.

Table 1 identifies probable stressors for the six impairments. Common probable stressors for streams located inside the red clay zone (Rock Creek, Clear Creek, Deer Creek, and Mud Creek) were suspended solids/ turbidity and physical habitat quality, driven by historic flow alterations in the watershed. In contrast, the common probable stressor for impaired stream reaches located outside the red clay zone (Elim Creek and Blackhoof River) was habitat fragmentation.

One objective of this Stressor Identification study was to inform the Total Maximum Daily Load (TMDL) process by identifying the parameters that will require a load or wasteload allocation. Based on the evidence presented in this report, it is recommended that TMDL efforts focus on developing target sediment loads for the Nemadji River watershed that will reduce turbidity and improve habitat. In addition, several future study recommendations arose during the SID investigation that are needed to improve the health of the biological communities in the Nemadji River Watershed: longitudinal stream surveys, environmental flows, aluminum toxicity, red clay stability, cold water biota movement in the watershed, and groundwater contributions to cold water resources.

Table 1. Summary of probable stressors in the Nemadji River watershed

Candidate Stressor	Elim (-501)	Rock (-508)	Blackhoof (-519)	Clear (-527)	Deer (-531)	Mud (-537)
Historic Flow Alteration	-	ü ü	x	ü ü	ü ü	ü ü
Recent Flow Alteration	-	ü ü	-	-	ü	?
Physical Habitat	-	ü	xx	ü	ü ü	-
Habitat Fragmentation	ü ü	-	ü ü	?	-	-
Dissolved Oxygen	xx	x	x	xx	xx	xx
Water Temperature	xx	ü ü	xx	xx	-	-
Turbidity (TSS)	x	ü ü	xx	ü ü	ü ü	ü ü

ü ü = Primary stressor with strong supporting evidence
ü = Likely stressor with some supporting evidence
- = Potentially a stressor with little supporting evidence
x = Not likely a stressor with little supporting evidence
xx = Supporting evidence indicates that it is not a stressor
? = Insufficient evidence to assess

Table 2. Recommended prioritization of TMDLs relative to the stressors contributing to the biological impairment in the Nemadji River Watershed.

Stressor	Priority	Comment
Historic Flow Alteration	Low	A thorough understanding of how restoration and protection efforts in the watershed will be impacted and driven by channel instability and evolution resulting from historic flow alteration is imperative for success.
Recent Flow Alteration	Unknown	The impact of impoundments on the flow regime is difficult to determine given the lack of flow data before the impoundments were installed.
Physical Habitat Quality	Unknown	Physical habitat quality is expected to improve from efforts to increase stream connectivity (Habitat Fragmentation stressor) and decrease turbidity.
Habitat Fragmentation	High	Restoration efforts should focus on prioritizing the removal of fish barriers that will reconnect downstream portions of impaired reaches with high quality coldwater fish refuges in headwater tributaries.
Water Temperature	Low	Water temperature is expected to decrease from efforts to increase stream connectivity and decrease turbidity.
Suspended solids/ turbidity	High	Sediment imbalance results in loss of habitat and direct physical and indirect behavioral harm to aquatic organisms. Figure 32 provides further details on pathways and expressions of sediment imbalances. TSS water chemistry violations in the impaired streams require completion of a TMDL.

The following figures summarize pertinent information provided in the stressor report for each biota impaired stream.

Elim Creek (04010301-501): Fish Impairment

Cold water stream

Dam & reservoir:
- Upstream, channel incising
- Downstream, channel stable

Stream temperatures supportive of brook trout

Downstream barrier in Skunk Creek. Log jam barrier in Elim Creek.

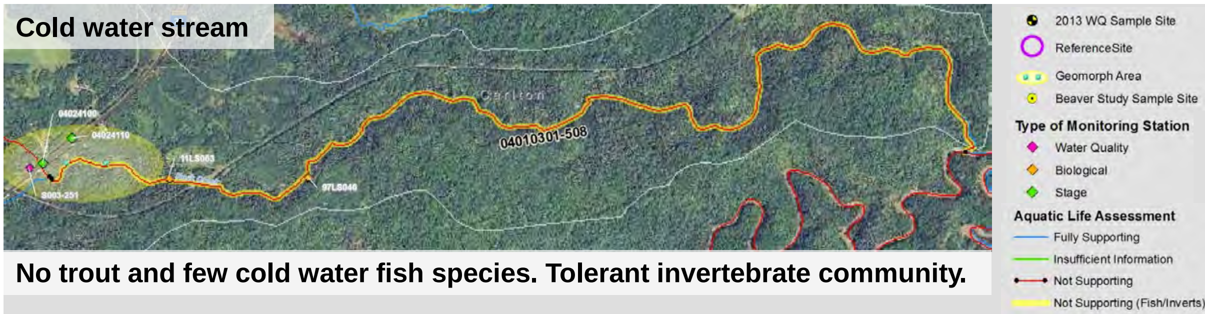
No trout observed above barriers.

Stressor Summary

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	Past land use changes caused channel instability & evolution	Potentially a stressor	
Recent Flow Alteration	Dam and reservoir constructed to manage channel incision	Potentially a stressor	
Physical Habitat	Stable channel at bio site; incising channel upstream of dam	Potentially a stressor	
Habitat Fragmentation	**Large dam and pipe barrier near confluence with Skunk Ck**	**Primary stressor**	« «
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Supportive to aquatic life	Not a stressor	
TSS/ Turbidity	Partly in clay zone but TSS levels not as high as other turbid creeks	Not likely a stressor	

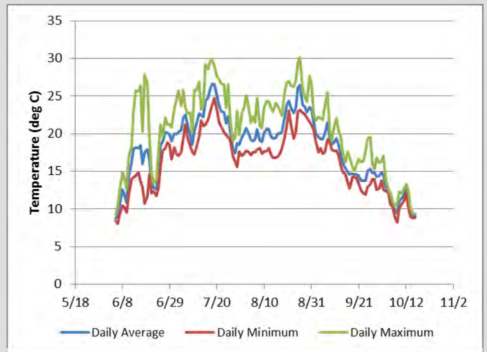
Rock Creek (04010301-508): Fish and Macroinvertebrate Impairment

Cold water stream



No trout and few cold water fish species. Tolerant invertebrate community.

Bank slump below MN 23, incised channel, and eroding banks

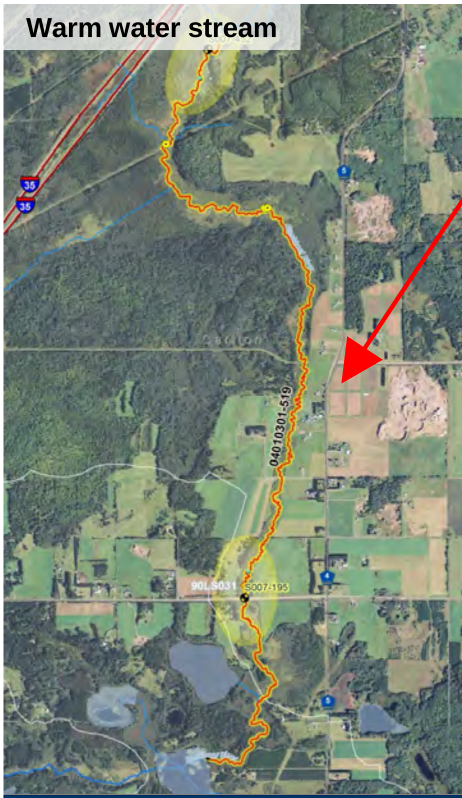


Stream temperatures sometimes in lethal range for trout

Stressor Summary

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	**Lack of headwater storage & recent climate change contribute to extremely low baseflow**	**Primary stressor**	« «
Physical Habitat	Bank slump below MN 23, lack of woody material, channel incision	Likely a stressor	«
Habitat Fragmentation	Current and historic beaver dams and log jams present	Potentially a stressor	
Dissolved Oxygen	Low near a perched culvert, but overall supportive to aquatic life	Not likely a stressor	
Water Temperature	**Frequent stressful temps, lethal temps on occasion**	**Primary stressor**	« «
TSS/ Turbidity	**TSS levels very high (up to 1200 mg/L); stream in clay zone**	**Primary stressor**	« «

Blackhoof Creek (04010301-519): Fish and Macroinvertebrate Impairment



Few fish and invert species with no sensitive species observed.

Agricultural, pasture, and mining land uses mid-watershed

Significant beaver activity with numerous dams and impoundments and limited woody debris in stream

Stressor Summary

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	Past land use changes caused channel instability & evolution	Not likely a stressor	
Recent Flow Alteration	Beaver dams and ditched wetlands	Potentially a stressor	
Physical Habitat	Stable banks with dense vegetation, sandy substrate	Not a stressor	
Habitat Fragmentation	**Numerous beaver dams and impoundments**	**Primary stressor**	« «
Dissolved Oxygen	Low DO wetland headwaters, overall DO supporting	Not likely a stressor	
Water Temperature	Supportive of a warm water fishery	Not a stressor	
TSS/ Turbidity	TSS levels low	Not a stressor	

Clear Creek (04010301-527): Fish and Macroinvertebrate Impairment

Exposed soil and eroding banks

Very few sensitive fish species and a single trout observed. Lack of stoneflies and dragonflies and few overall number of macroinvertebrate species observed.

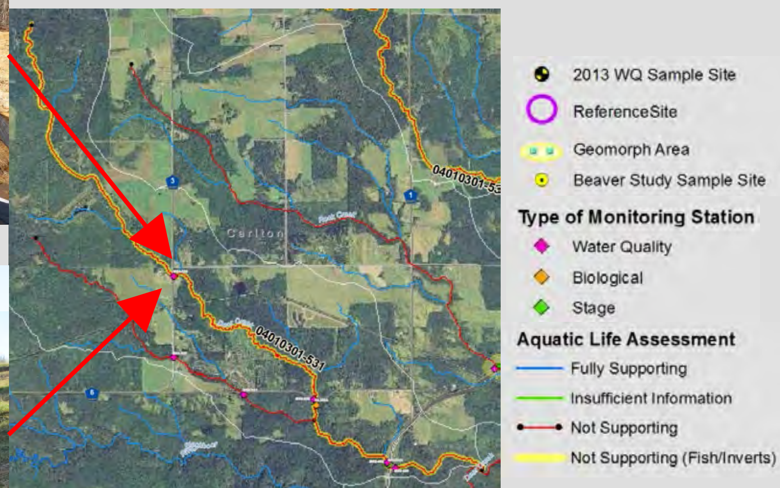
Stressor Summary

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Low flows in late August, biota tolerant of altered flows	Potentially a stressor	
Physical Habitat	Exposed soil and eroding stream banks	Likely a stressor	«
Habitat Fragmentation	No obvious barriers. SOO line crossing in WI a potential barrier.	Insufficient evidence	
Dissolved Oxygen	Supporting to aquatic life	Not a stressor	
Water Temperature	Supporting to aquatic life	Not a stressor	
TSS/ Turbidity	**Very high TSS levels**	**Primary stressor**	« «

Deer Creek (04010301-531): Fish Impairment

Sediment volcanos in stream

Fish community dominated by Creek Chubs and other non-sensitive species. No trout.



Extremely high TSS levels

TMDL completed for TSS/ turbidity

Stressor Summary

Stressors	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Flashy hydrology. More frequent, higher flow events in spring.	Likely a stressor	«
Physical Habitat	**Mud volcanos, high TSS, sedimentation in Cty 6 culvert**	**Primary stressor**	« «
Habitat Fragmentation	Beaver activity upstream of MN 23 and several perched culverts	Potentially a stressor	
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Water temperatures occasionally stressful to trout, denuded banks	Potentially a stressor	
TSS/ Turbidity	**Mud volcanos discharge sediment, extremely high TSS**	**Primary stressor**	« «

Mud Creek (04010301-537): Fish Impairment

Fish community dominated by Creek Chubs and Fathead Minnows. No trout.

High TSS levels and mud volcanos

Fair habitat with low fish cover score and little woody material.

Stressor Summary

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Low flows from July through October in 2013	Insufficient evidence	
Physical Habitat	Low fish cover, small riffles/ pools and little woody material	Potentially a stressor	
Habitat Fragmentation	Beaver activity with dams on tribs. Culvert at SOO line trail.	Potentially a stressor	
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Lethal temperatures on occasion	Potentially a stressor	
TSS/ Turbidity	**TSS levels high and mud volcanos present in stream**	**Primary stressor**	« «

1. Introduction

1.1. Monitoring and Assessment

Water quality and biological monitoring in the Nemadji River Watershed have been ongoing since 2001, with less frequent water quality monitoring dating back to 1967. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2011-2012, and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2001, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1).

Once a biological impairment is discovered, the next step is to identify the source(s) of stress on the biological community. A Stressor Identification (SID) analysis is a step-by-step approach for identifying probable causes of impairment in a particular system. Completion of the SID process does not result in a finished Total Maximum Daily Load (TMDL) study. The product of the SID process is the identification of the stressor(s) for which the TMDL may be developed. In other words, the SID process may help investigators nail down excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to restore the impaired condition.

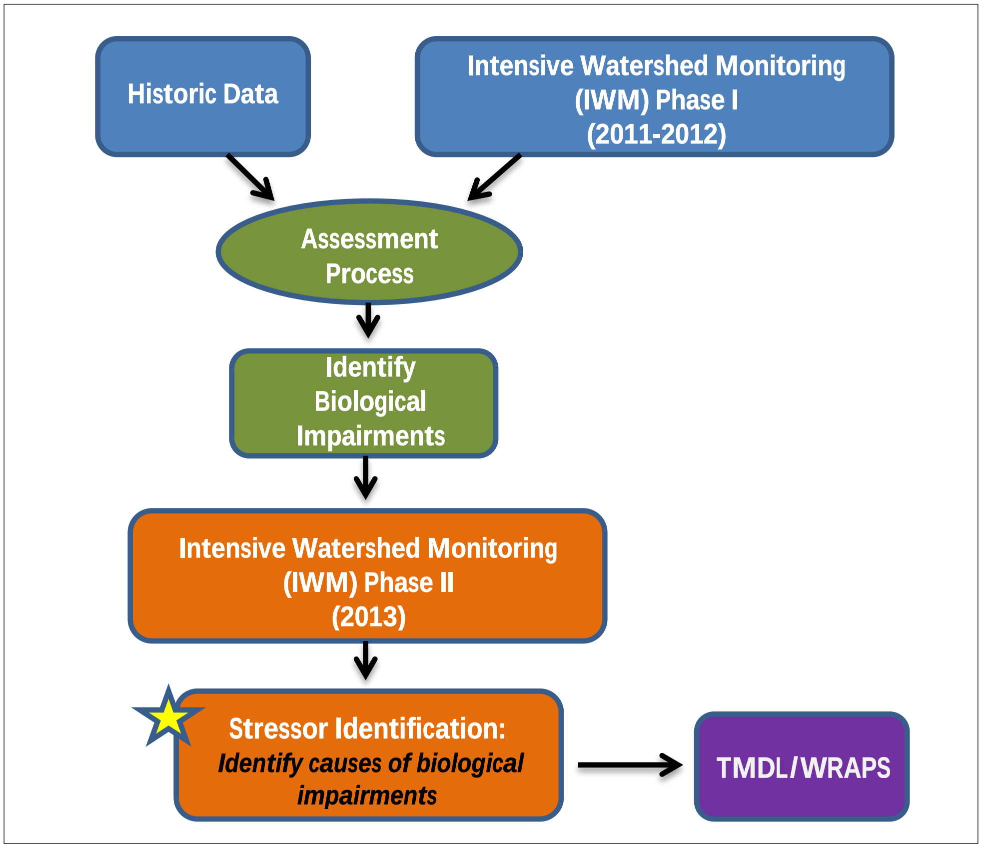


Figure 1. Process map of Intensive Watershed Monitoring, Assessment, Stressor Identification and TMDL processes.

1.2. Stressor Identification Process

The MPCA follows the EPA's process of identifying stressors that cause biological impairment, which has been used to develop the MPCA's guidance to stressor identification (Cormier et al. 2000; MPCA 2008). The EPA has also developed an updated, interactive web-based tool, the Causal Analysis/Diagnosis Decision Information System (CADDIS; EPA 2010). This system provides an enormous amount of information designed to guide and assist investigators through the process of Stressor Identification. Additional information on the Stressor Identification process using CADDIS can be found here: http://www.epa.gov/caddis/

Stressor Identification is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act. SID draws upon a broad variety of disciplines and applications, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. A conceptual model showing the steps in the SID process is shown in Figure 2. Through a review of available data, stressor scenarios are developed that aim to characterize the biological impairment, the cause, and the sources/pathways of the various stressors.

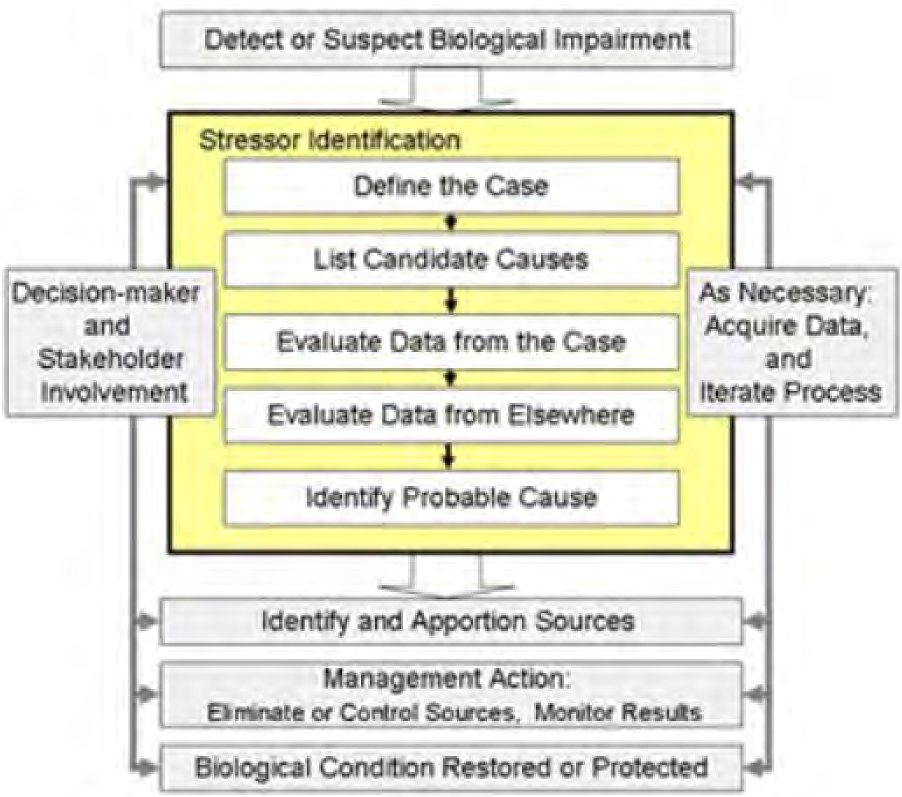


Figure 2. Conceptual model of Stressor Identification process (Cormier et al. 2000).

Strength of evidence (SOE) analysis is used to evaluate the data for candidate causes of stress to biological communities. The relationship between stressor and biological response are evaluated by considering the degree to which the available evidence supports or weakens the case for a candidate cause. Typically, much of the information used in the SOE analysis is from the study watershed (i.e., data from the case). However, evidence from other case studies and the scientific literature is also used in the SID process (i.e., data from elsewhere).

Developed by the EPA, a standard scoring system is used to tabulate the results of the SOE analysis for the available evidence (Table 65). A narrative description of how the scores were obtained from the evidence should be discussed as well. The SOE table allows for organization of all of the evidence, provides a checklist to ensure each type has been carefully evaluated and offers transparency to the determination process.

The existence of multiple lines of evidence that support or weaken the case for a candidate cause generally increases confidence in the decision for a candidate cause. The scoring scale for evaluating each type of evidence in support of or against a stressor is shown in Table 66. Additionally, confidence in the results depends on the quantity and quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s) causing impairment. Additional detail on the various types of evidence and interpretation of findings can be found here: http://www.epa.gov/caddis/si_step_scores.html

1.3. Common Stream Stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired water body. Table 3 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 3. Common streams stressors to biology (i.e., fish and macroinvertebrates).

Stream Health	Stressor(s)	Link to Biology
Stream Connections	**Loss of Connectivity** · Dams and culverts · Lack of Wooded riparian cover · Lack of naturally connected habitats/ causing fragmented habitats	Fish and macroinvertebrates cannot freely move throughout system. Stream temperatures also become elevated due to lack of shade.
Hydrology	**Altered Hydrology** **Loss of habitat due to channelization** **Elevated Levels of TSS** · Channelization · Peak discharge (flashy) · Transport of chemicals	Unstable flow regime within the stream can cause a lack of habitat, unstable stream banks, filling of pools and riffle habitat, and affect the fate and transport of chemicals.
Stream Channel Assessment	**Loss of Habitat due to excess sediment** **Elevated levels of TSS** · Loss of dimension/pattern/profile · Bank erosion from instability · Loss of riffles due to accumulation of fine sediment · Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.
Water Chemistry	**Low Dissolved Oxygen Concentrations** **Elevated levels of Nutrients** · Increased nutrients from human influence · Widely variable DO levels during the daily cycle · Increased algal and or periphyton growth in stream · Increased nonpoint pollution from urban and agricultural practices · Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream Biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

1.4. Report Format

This SID report follows a format to first summarize general candidate causes of stress to the biological communities for the entire Nemadji River Watershed, and then summarize specific candidate causes of stress to the biological communities of individual impaired AUIDs. Section 2 briefly describes the water quality, geology, history, land use and biology of the Nemadji River Watershed. Section 3 describes general information about how each stressor relates broadly to the Nemadji River Watershed, water quality standards, and general effects of biology. Section 4 is organized by impaired stream reach (AUID) and discusses available data and support for identification of primary and secondary stressors to the biological community of that stream. Section 5 summarizes the final candidate causes and provides recommendations for future work to improve the health of the biological communities in the impaired stream reaches (AUIDs). Relevant reports, water quality analyses, and documentation for the SID process are included in several appendices.

2. Overview of the Nemadji River Watershed

2.1. Background

The Nemadji River Watershed spans the Minnesota and Wisconsin border, with its headwaters to the south and east of Duluth, Minnesota and discharging to Lake Superior near Superior, Wisconsin (Figure 3). The Minnesota portion of the watershed includes approximately 178,000 acres (64%) of the 277,400 total acres.

The Nemadji River Watershed includes numerous streams, which are tributaries to the mainstem of the Nemadji River. Relatively few lakes occur within the watershed, and are primarily located in the headwaters. Land use in the Minnesota portion of the watershed is mostly related to rural forestry, pasture production for hay cutting, and some beef cattle. Lakeshores are developed, although not as intensively as is typical in northern Minnesota counties.

Land cover changes from 1990 to 2000 for the Minnesota portion of the Nemadji River were analyzed using land cover data from the University of Minnesota Remote Sensing and Geospatial Analysis Laboratory (land.umn.edu). Agricultural land cover decreased in area from 12% in 1990 to 7.9% in 2000. Conversely, forest land cover increased in area from 65% in 1990 to 75% in 2000, and impervious land cover increased in area from 510 acres in 1990 to 830 acres in 2000. More recent land cover changes (2001 to 2010) were analyzed using land cover data from the National Oceanic and Atmospheric Administration’s (NOAA) Coastal Change Analysis Program (C-CAP). The largest shift in land cover was in forested land, with a combined loss of 2,228 acres. Grasslands increased by 1,798 acres, and minor increases occurred for pastures (250 acres) and cultivated crops (46 acres). Developed land uses were not noted to change between 2001 and 2010.

2.1.1. Red clay zone versus headwater streams

Approximately 33% of the Nemadji River Watershed occurs in a geologic clay zone (Figure 4). Red clay was deposited when glacial lakes covered the region about 10,000 years ago. Red clay is a natural source of turbidity in the system and land uses (past and present) accelerated the rates of erosion. Specifically, historic logging in the late 1800s has had lasting impacts to the hydrology of many streams across the watershed. See Section 3.3.1 for more detailed information.

Sediment volcanoes are known features in the Nemadji River Watershed, especially in Deer Creek, one of the most turbid streams in the Watershed. Sediment laden groundwater flowing into the Nemadji River and streams from these geologic features are known to exacerbate turbidity impairments in the Watershed (Figure 5).

Streams outside of the red clay zone have significantly lower turbidity levels, and are characterized by slow moving streams, wetlands, and beaver dams (Figure 6). All or part of five of the six biologically impaired stream reaches addressed by this SID report is located in the red clay zone. Although there may be some consistent chemical and physical stressors found throughout the Nemadji River Watershed, most stressors are distinctly different in headwater versus red clay zone streams.

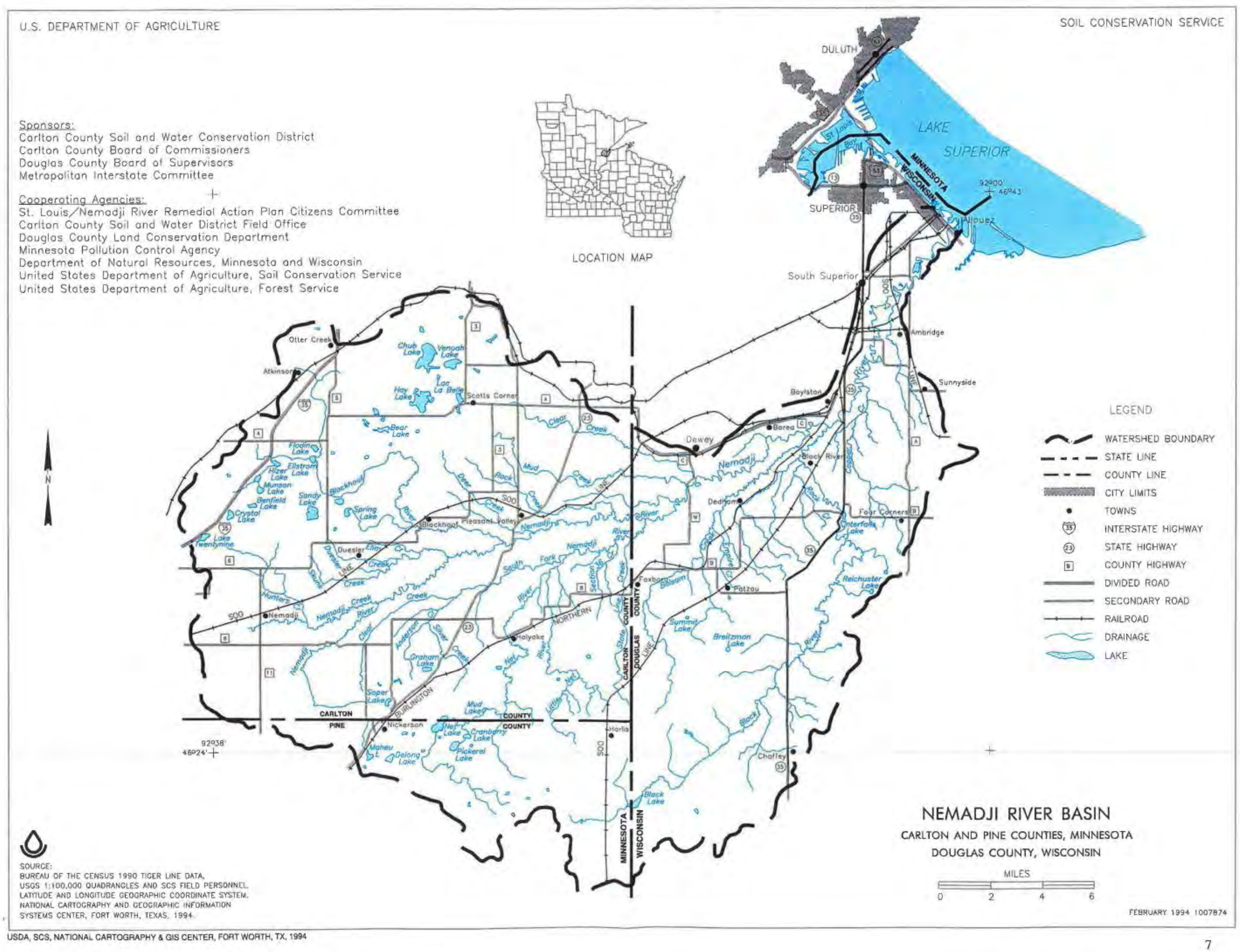


Figure 3. Map of the Nemadji River Watershed (Nemadji River Basin Project Executive Summary).

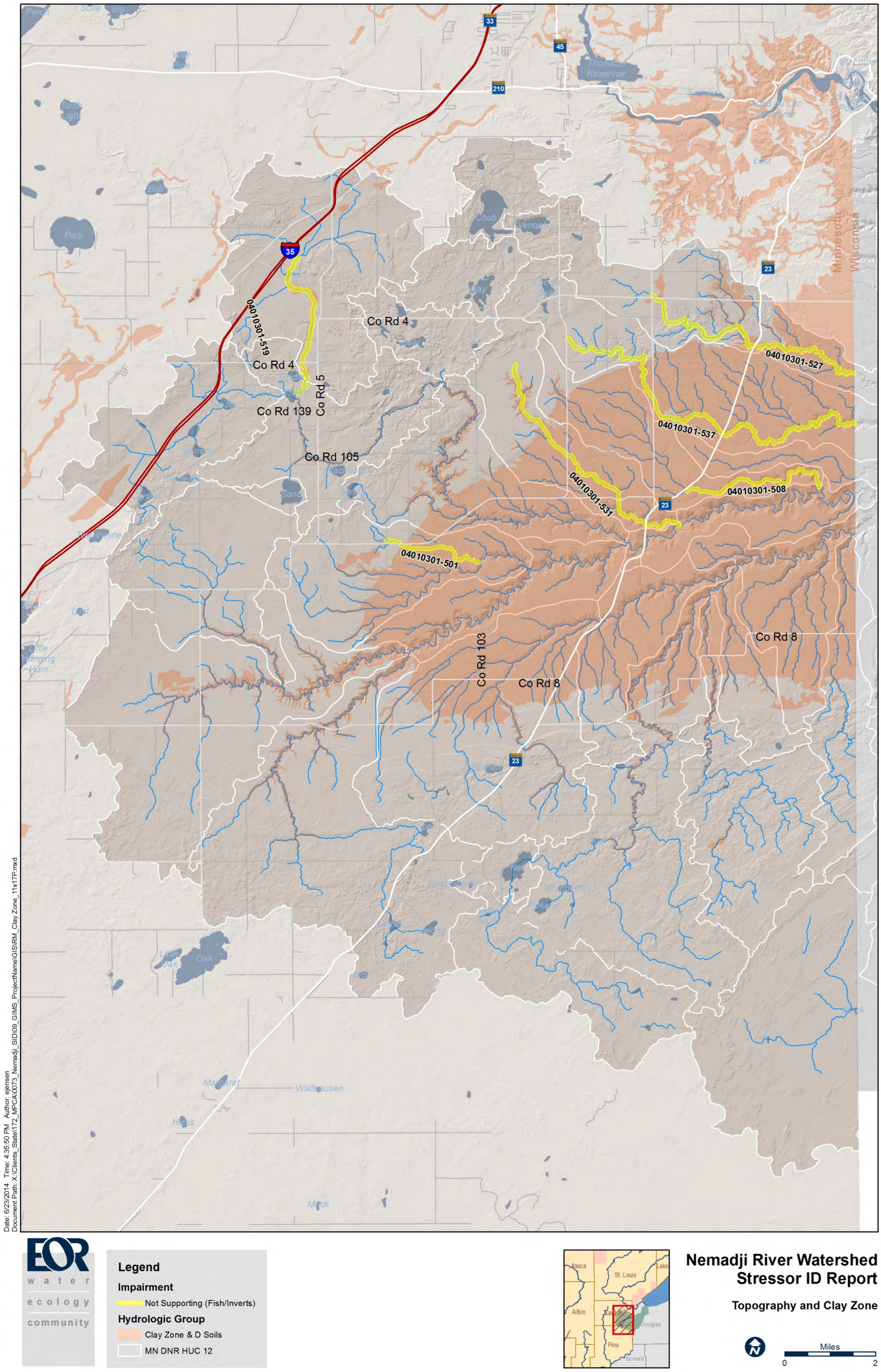


Figure 4. Nemadji River Watershed topographic map and red clay zone extent

Figure 5. High turbidity in a clay soil stream in the Nemadji River Watershed

Figure 6. Upper watershed areas contain slow flowing streams, wetlands, and beaver dams

2.2. Monitoring Overview

Biological monitoring and assessment conducted in 2011 for the Nemadji River Watershed (Figure 7) was used to identify and characterize the biological impairments addressed in this SID report. For detailed information regarding monitoring in the Nemadji River Watershed, please reference the *Nemadji River Watershed Monitoring and Assessment Report* available online at the Nemadji River Watershed webpage:

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/nemadji-river.html

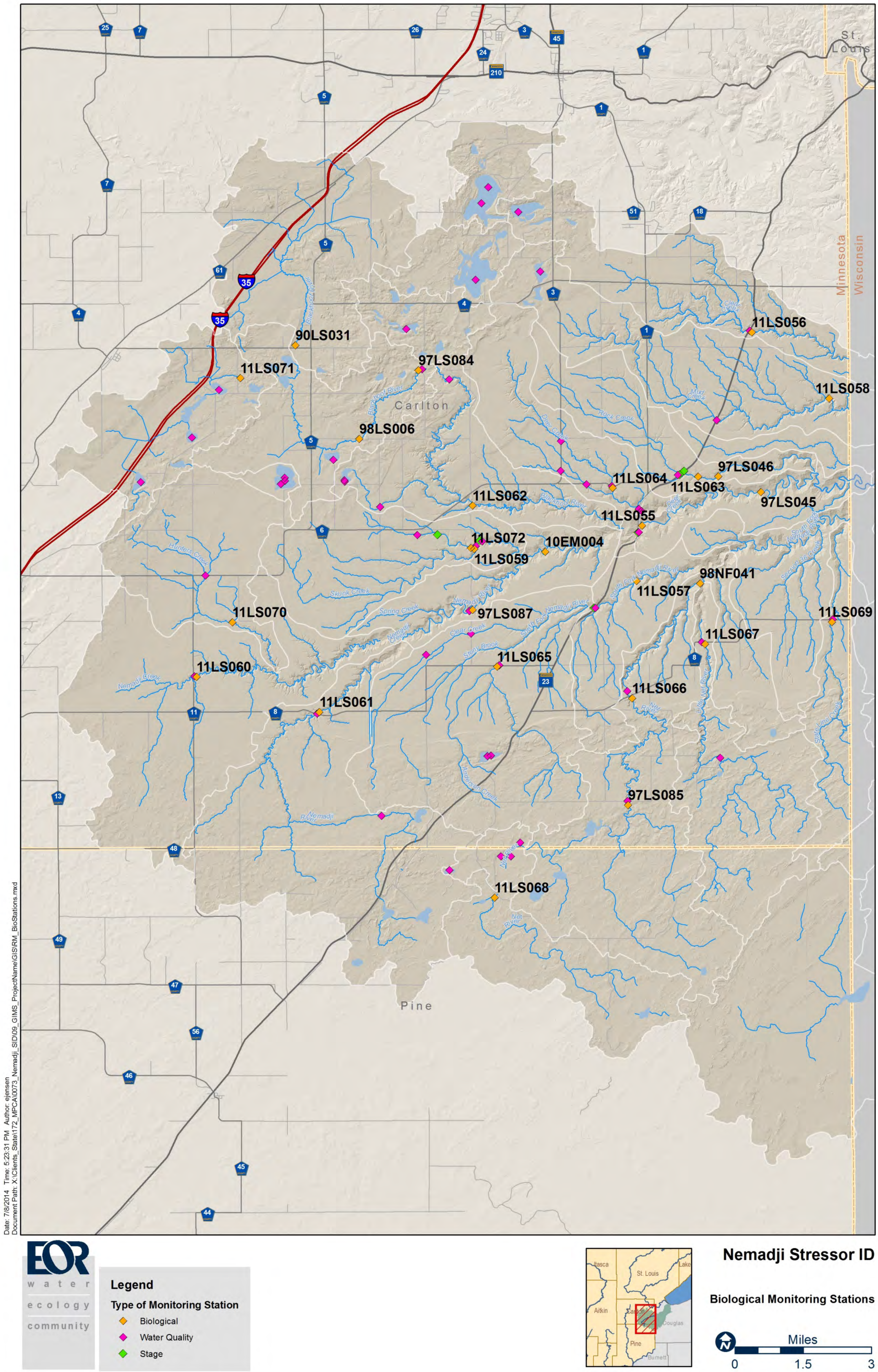


Figure 7. Biological monitoring stations in the Nemadji River Watershed

2.3. Summary of Biological Impairments and Data

In the Nemadji River Watershed, six AUIDs are currently impaired for a lack of biological assemblage (Table 4). All impaired reaches are DNR designated trout streams. The biological community of the Blackhoof River (04010301-519) was assessed against biological integrity thresholds for the aquatic life beneficial use class 2B/2C (warmwater and coolwater), and all other impaired stream reaches were assessed against biological integrity thresholds for the aquatic life beneficial use class 2A (coldwater). Individual fish and macroinvertebrate IBI scores of impaired reaches in the Nemadji River Watershed, and the corresponding aquatic life beneficial use class IBI thresholds and confidence limits are summarized in Table 5. Additional information on the biological impairments for each individual reach can be found in Section 4.

Currently the mainstem of the Nemadji River, from its headwaters to the Wisconsin border, and two of its tributaries (Deer Creek and do not meet water quality standards for aquatic life beneficial uses due to turbidity impairment. Additional monitoring conducted since the start of this SID project indicates that other tributaries are also impaired for turbidity.

Table 4. Aquatic life beneficial use impairments in the Nemadji River Watershed

Reach AUID	Reach Name	Impairment Type
04010301-501	Elim Creek	Fish Bioassessments
04010301-508	Rock Creek	Fish & Macroinvertebrate Bioassessments
04010301-519	Blackhoof River	Fish & Macroinvertebrate Bioassessments
04010301-527	Clear Creek	Fish & Macroinvertebrate Bioassessments
04010301-531	Deer Creek	Fish Bioassessments
04010301-537	Mud Creek	Fish Bioassessments

2.3.1. Index of Biological Integrity

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrates communities and related habitat conditions at sites throughout a watershed. The resulting information is used to develop an index of biological integrity (IBI). For the purposes of IBI development, Minnesota's streams and rivers were partitioned into **nine fish and nine macroinvertebrate "classes"**, differentiated by region, drainage area, gradient, and thermal regime. The classification framework partitions natural variability in fish and macroinvertebrate community structure, based largely on patterns observed among least-impacted sites. Fish and macroinvertebrate communities occurring at sites within each class are more similar to each other than to those in other classes. The classification factors are unaffected by human disturbance to ensure that the framework reflects natural variability and that the resulting IBI reflects impacts.

The fish and macroinvertebrates within each Assessment Unit Identification (AUID) were compared to the **IBI threshold and confidence interval** for their respective fish or macroinvertebrate classes. The water quality standards call for the maintenance of a healthy community of aquatic life. IBI scores provide a measurement tool to assess the health of the aquatic communities. IBI scores higher than the impairment threshold indicate that the stream reach supports aquatic life. Conversely, scores below the impairment threshold indicate that the stream reach does not support aquatic life. Confidence limits around the impairment threshold help to ascertain where additional information may be considered to help inform the impairment decision. When IBI scores fall within the confidence interval, interpretation and assessment of the waterbody condition involves consideration of potential stressors, and draws upon additional information regarding water chemistry, physical habitat, and land use, etc.

Table 5. Fish and invertebrate IBI scores for the Nemadji River Watershed and corresponding class thresholds and confidence limits

Class Name	Use Class	IBI Threshold	Lower Confidence Interval	Upper Confidence Interval
Fish IBI Scores				
Low Gradient	**2B, 2C**	**40**	**30**	**50**
Blackhoof River (04010301-519)		29		
Northern Coldwater	**2A**	**37**	**27**	**47**
Elim Creek (04010301-501)		20		
Rock Creek (04010301-508)		37		
Clear Creek (04010301-527)		26		
Deer Creek (04010301-531)		19		
Mud Creek (04010301-537)		29		
Invertebrate IBI Scores				
Northern Forest Streams (Glide/ Pool Habitats)	**2B, 2C**	**52.4**	**38.8**	**66**
Blackhoof River (04010301-519)		36		
Northern Coldwater	**2A**	**26**	**13.6**	**38.4**
Elim Creek (04010301-501)		33		
Rock Creek (04010301-508)		16		
Clear Creek (04010301-527)		16		
Deer Creek (04010301-531)		44		
Mud Creek (04010301-537)		25		

2.3.2. Individual IBI Metric Scores

Each fish and macroinvertebrate class has a unique suite of **IBI metrics**, scoring functions, impairment thresholds, and confidence intervals (see Table 5). Individual metric scores used in the calculation of the fish or macroinvertebrate IBI score for each impaired stream reach are illustrated below in Figure 8 through Figure 11. Descriptions of the individual metrics used to score the impaired streams are summarized in Table 67 through Table 70 in the Appendix. Additional metrics were quantified from the full suite of biological data for each impaired stream reach that are not summarized in this report but available from MPCA. It is important to note that only one IBI score was collected at one location for each impaired stream reach, limiting the strength of biological response evidence in this Stressor ID report.

Many individual fish and macroinvertebrate IBI metrics are known to respond in predictable ways to biological stressors. **Individual metrics and their biological response to several candidate causes of stress** that were used as evidence in this SID report are summarized in Table 6.

Table 6. Relationships between fish and macroinvertebrate IBI metrics and biological stressors

Biological Stressor	IBI metric	Biological response
Low Dissolved Oxygen	Invert % EPT	Decrease
Flow Alteration	Invert % EPT	Decrease
	Invert % Long-Lived	Decrease
	Invert % Swimmer	Increase (at low flow)
	Fish % Generalist	Increase
	Fish % Non-Lithophilic Spawners	Increase
	Fish % Tolerant	Increase
Degraded Physical Habitat Quality	Invert % Clinger	Decrease
	Fish % Benthic Insectivores	Decrease
	Fish % Simple Lithophilic Spawners	Decrease
	Fish % Tolerant	Increase
Increased Temperature	Fish % Coldwater species	Decrease
Turbidity	Invert % Collector-filterer	Decrease
	Invert % EPT	Decrease
	Fish % Tolerant	Increase

Figure 8. Individual fish IBI metric scores for Low Gradient streams

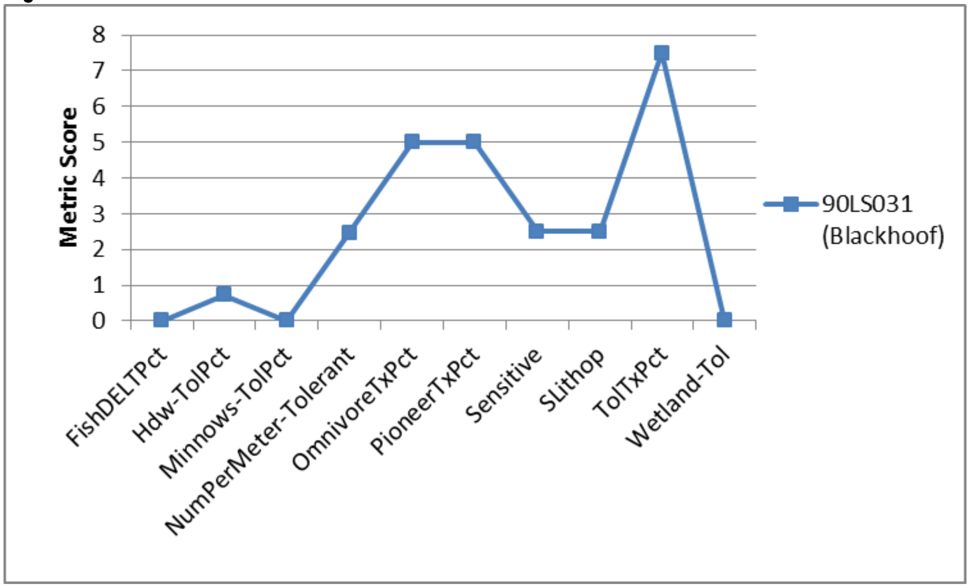


Figure 9. Individual fish IBI metric scores for Northern Coldwater streams

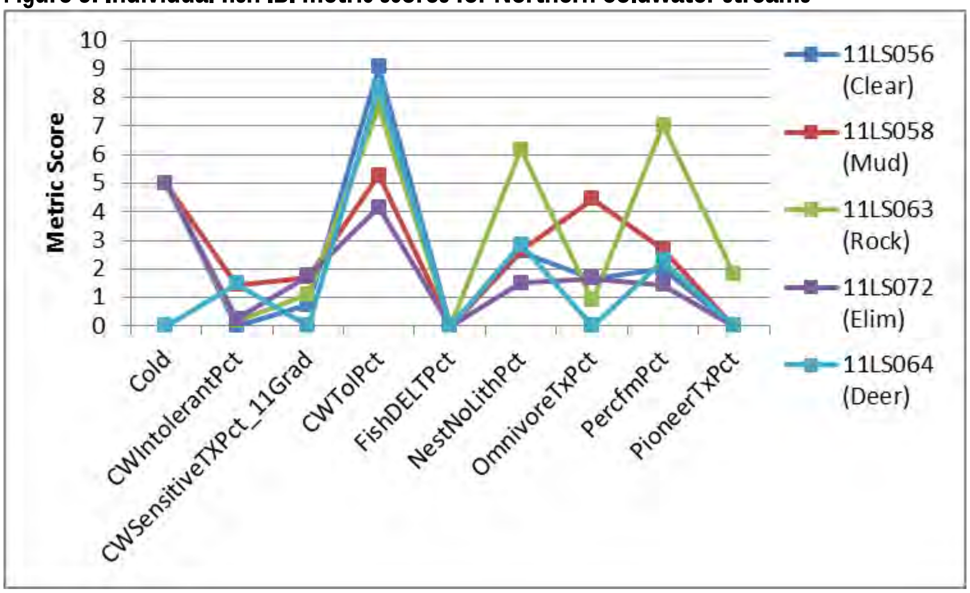


Figure 10. Individual macroinvertebrate IBI metric scores for Northern Forest Streams (Glide/Pool habitats)

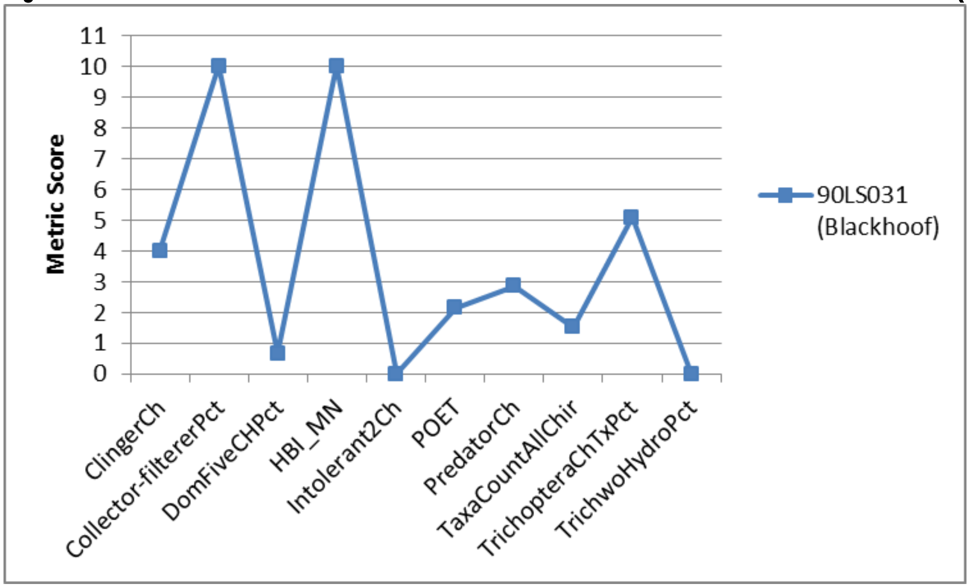
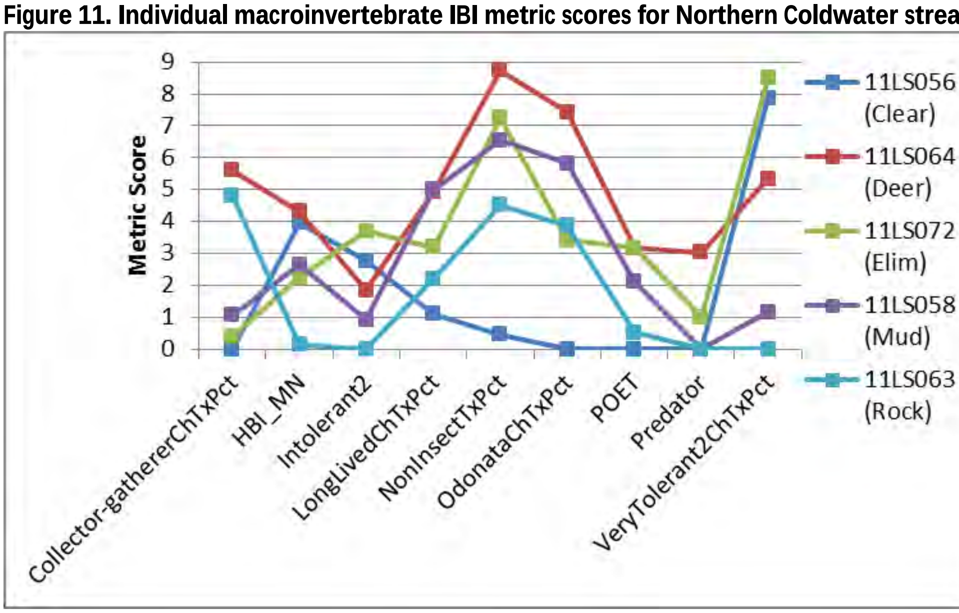


Figure 11. Individual macroinvertebrate IBI metric scores for Northern Coldwater streams



2.3.3. Tolerance Indicator Values

The fish and macroinvertebrate species and community data collected for the IBI metrics can also be used to quantify the relative pollutant tolerance of a fish or macroinvertebrate community, called **tolerance indicator values (TIVs)**. Fish and physicochemical data from 773 stream sites collected as part of the U.S. Geological Survey's National Water Quality Assessment Program was used to calculate tolerance indicator values for 10 physicochemical variables using weighted averaging for 105 common fish species of the United States. TIVs for dissolved oxygen and suspended sediment were calculated by MPCA staff and used as biological evidence for this report. An example of fish weighted average TIVs for suspended sediment, grouped by TIV quartile, is provided in Table 7 below.

Table 7. Example fish weighted average TIVs for suspended sediment grouped by quartile (Meador and Carlisle 2007)

1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
CommonName	*WA*	*CommonName*	*WA*	*CommonName*	*WA*	*CommonName*	*WA*
largescale stoneroller	11	golden shiner	30	black crappie	56	spottail shiner	74
silver redhorse	20	pumpkinseed	30	johnny darter	56	black bullhead	76
yellow perch	21	largemouth bass	31	shorthead redhorse	61	channel catfish	81
banded darter	24	tadpole madtom	34	green sunfish	62	emerald shiner	84
bowfin	24	bluegill	36	white sucker	62	common carp	93
mimic shiner	24	golden redhorse	37	stonecat	63	fathead minnow	106
logperch	25	common shiner	38	hornyhead chub	64	sand shiner	111
brown bullhead	26	walleye	45	spotfin shiner	65	freshwater drum	127
rock bass	28	creek chub	46	blackside darter	67	white bass	137
central stoneroller	29	bluntnose minnow	48	yellow bullhead	73	orangespotted sunfish	174
		northern pike	48				

Sensitive to High Suspended Sediment → Less Sensitive to High Suspended Sediment

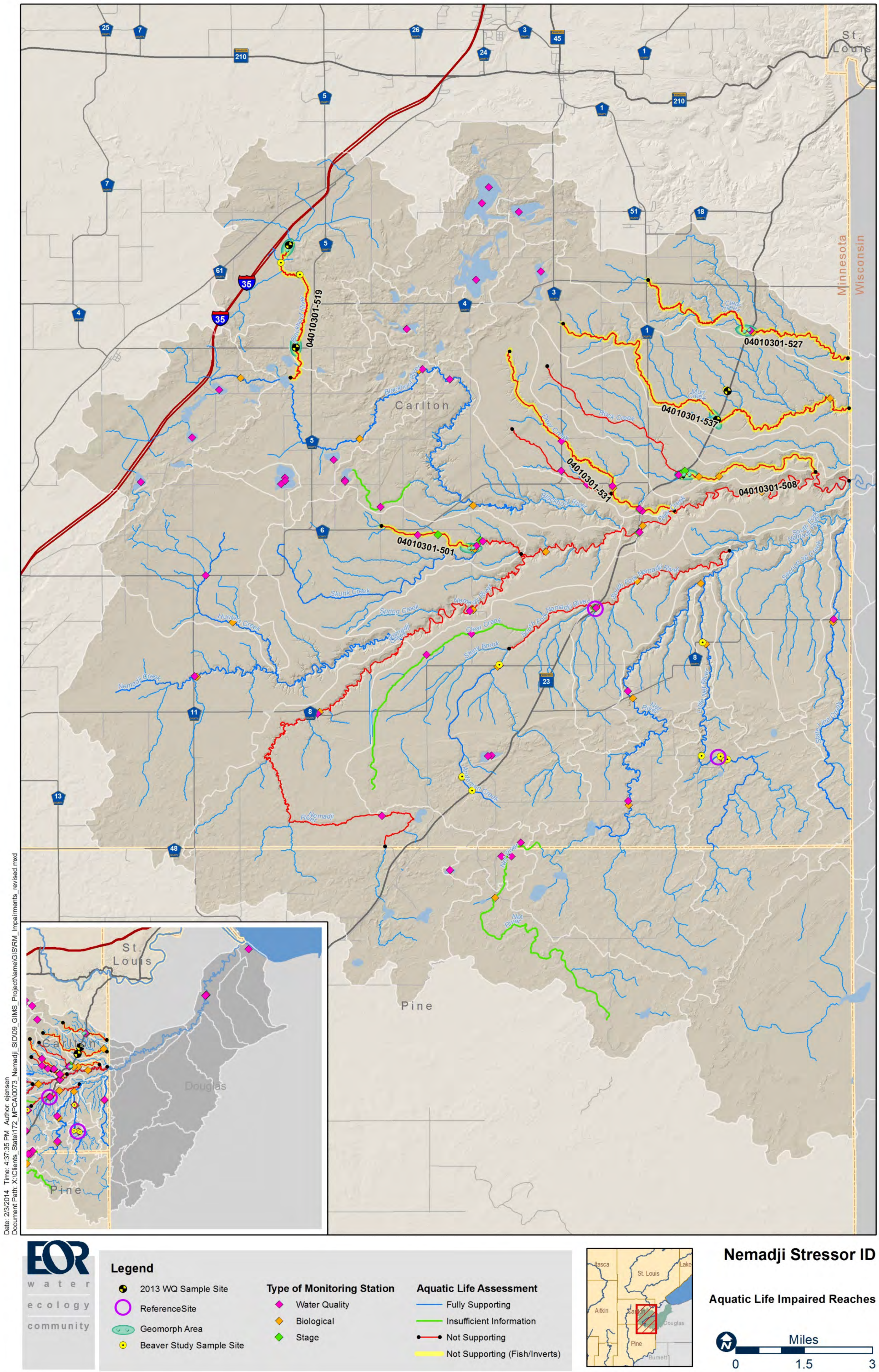


Figure 12. Nemadji River Watershed Impaired reaches and data collection points

2.4. Watershed Health Assessment Framework

The Minnesota Department of Natural Resources (MDNR) has a web-based tool called the Watershed Health Assessment Framework (WHAF). This tool can be used to determine the overall ecological health of a watershed based on the five components of a healthy stream: hydrology, geomorphology, biology, connectivity and water quality. The assessment is based on a multi-metric index, and compiles a total score based on metric values. The assessment tool can be accessed online at:

http://www.dnr.state.mn.us/whaf/index.html.

This tool compares conditions from today against conditions dating back to around 1890. Scores are ranked on a scale from 0 (extremely poor) to 100 (extremely good).

The overall score for the Nemadji River Watershed is 64, compared to a low and high for the state of 45 and 84 (Figure 13). Watersheds around the Nemadji River Watershed also have scores in the 60's. Much of the score is driven by relatively intact hydrology with a score of 91. From the five components evaluated by the WHAF, the biology and geomorphology scores were average or below average.

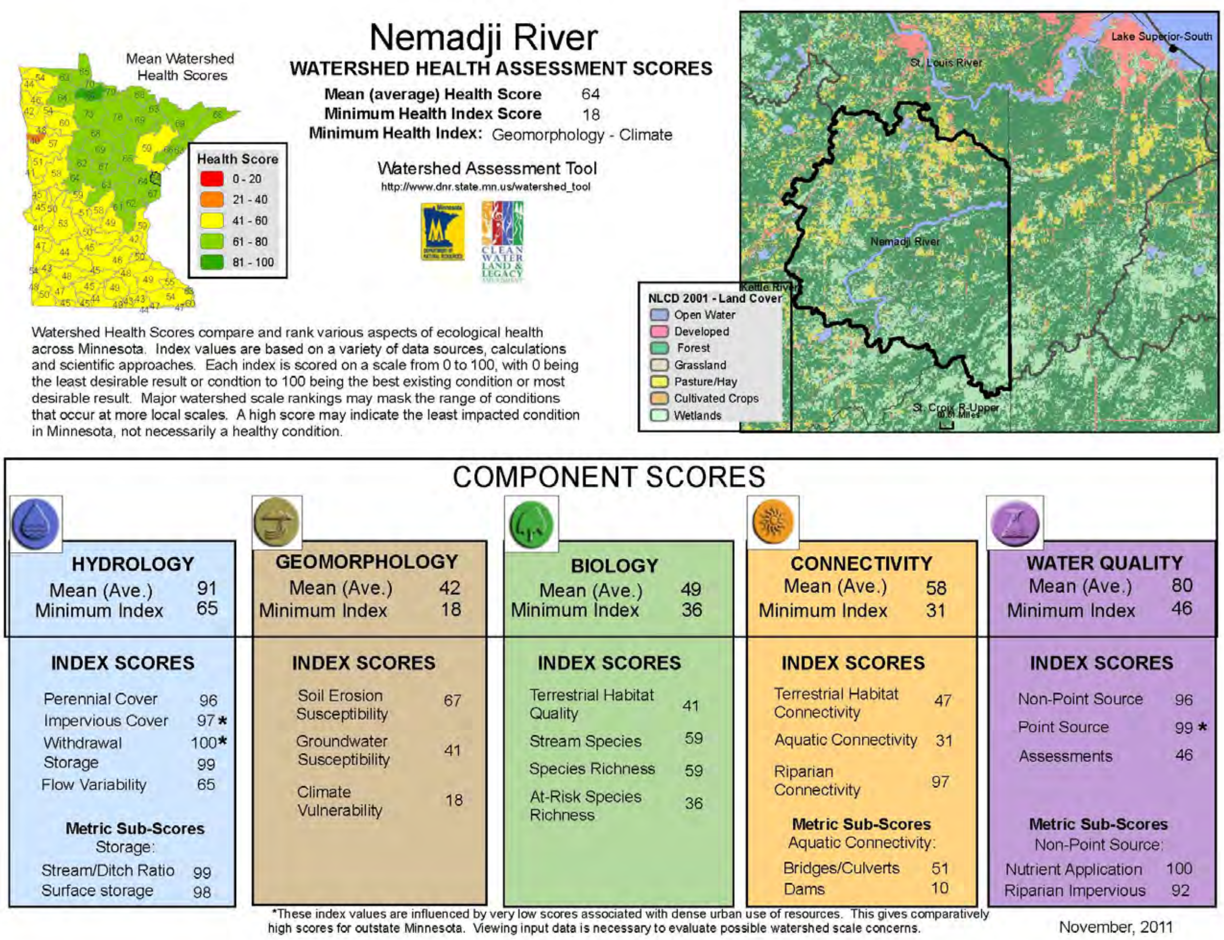


Figure 13. MDNR Watershed Health Assessment Framework for Nemadji River Watershed

3. Possible Stressors to Biological Communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found here (http://www.epa.gov/caddis/si_step2_stressorlist_popup.html). This comprehensive list serves two purposes. First, it can serve as a checklist for investigators to consider all possible options for impairment in the watershed of interest. Second, it can be used to identify potential stressors that can be eliminated from further evaluation. In some cases, the data may be inconclusive and limit the ability to confidently determine if a stressor is causing impairment to aquatic life. It is imperative to document if a candidate cause was suspected, but there was not enough information to make a scientific determination of whether or not it is causing harm to aquatic life. In this case, management decisions can include modification of sampling plans and future evaluation of the inconclusive case. Alternatively, there may be enough information to conclude that a candidate cause is not causing biological impairment and therefore can be eliminated. The inconclusive or eliminated causes will be discussed in more detail in the following section.

Eighteen possible causes of stress were initially identified to represent the broadest range of possible stressors to the biological community in the Nemadji River Watershed. Supporting data was developed for each possible cause to evaluate its potential impact on the biological community. In addition, data gaps were identified and a monitoring plan was developed to collect missing data during the summer of 2013. The initial list of possible causes, supporting data, and monitoring plan were reviewed and approved by the technical advisory group during a meeting on April 10, 2013 (see Section 8, **Supporting Document 8.1, 8.2, and 8.3**).

1. Low dissolved oxygen
2. Hydrologic regime alteration
3. Nutrient regime alteration
4. pH regime alteration
5. Salinity regime alteration
6. Bed sediment load changes including siltation
7. Suspended solids and/or turbidity
8. Water temperature regime alteration
9. Habitat destruction
10. Habitat fragmentation
11. Physical crushing and trampling
12. Toxic substances
13. Heavy metals
14. Herbicides
15. Halogens and halides (e.g., chloride, trihalomethanes)
16. Fish-killing agents (e.g., rotenone)
17. Insecticides
18. Hydrocarbons and endocrine disruptors

To assess the eighteen possible causes, a wide range of desktop data was collected and analyzed, including climate, land cover, hydrology, groundwater, historical photography, and sediment load data. A paired watershed approach was used to compare stream conditions of impaired and reference (background condition) sites. Two sites from streams fully supporting of aquatic life within the Nemadji River Watershed were selected as reference reaches to help isolate stressors in the biologically impaired reaches: Little Net at Bley Road to represent headwater stream reaches, and the South Fork Nemadji

River at MN 23 to represent red clay zone stream reaches. Additional targeted data was collected during the summer of 2013, including stream surveys identifying channel sediment contributions, geomorphology, and groundwater and stream flow inputs. The stream survey protocol was developed with input from the technical staff from MPCA, DNR, and Carlton SWCD, and built on the results from previous stream geomorphology studies conducted in the watershed (see reference list included in Section 8: Related Reports). In addition, synoptic water quality surveys were conducted on May 7, June 5, June 26, August 20, September 10, and October 16 in 2013 to collect dissolved oxygen (DO), temperature, flow, pH, and other water quality parameters in-situ during diverse flow levels for the purpose of representing a range of stream conditions and to fill monitoring data gaps. Continuous temperature and stage measurements were collected from two sites on the upper Blackhoof River and from one site on Clear Creek, Deer Creek, Elim Creek, Mud Creek, Little Net River, and South Fork Nemadji River. Flow measurements were also collected during the synoptic survey sampling dates to develop stage-discharge curves for these sites. These data are provided in the Section 7, **Supporting Document 8.6**. A beaver study was conducted on the Blackhoof River, Little Net River, Anderson Creek and tributary to Mud Creek to investigate the impacts of beaver activity and impoundments in the Nemadji River Watershed on stressors to the biological community (see Section 7, **Supporting Document 8.5**). Lastly, a geomorphic stream survey of the impaired and reference reaches was conducted in October 2013 (see Section 7, **Supporting Document 8.4**).

During the technical review meeting on February 17, 2014, all supporting desktop and targeted investigation data were reviewed and used to determine whether or not there was sufficient supporting evidence for each candidate cause in the six biologically impaired stream reaches (see Section 7, **Supporting Document 8.7 and 8.8**). This led to the following eliminated, inconclusive, and candidate causes described in the following sections.

3.1. Eliminated Causes

Nutrient regime alteration, pH regime alteration, salinity regime alteration, and physical crushing and trampling were eliminated as possible causes of stress to the biological community due to acceptable levels of nutrients, pH, and salinity in the impaired stream reaches based on desktop and targeted data analysis, and the lack of the evidence of physical crushing and trampling observed in the impaired stream reaches.

3.1.1. Total Phosphorus

While not identified as a candidate cause of aquatic life use impairments in the Nemadji River Watershed, total phosphorus levels are higher in the Nemadji River Watershed compared to other Northern Nutrient Region streams in Minnesota. High total phosphorus levels have been observed to be positively correlated with high turbidity levels in the Nemadji River and other Lake Superior Basin watersheds.

During the period of monitoring and assessment (2011-2013), Minnesota had no stream eutrophication standards, only ecoregion data summaries and guidance. In mid-2014, stream eutrophication standards were approved by administrative law judge review and the MPCA Board. Under those standards, a stream will be listed as impaired for eutrophication if the causal variable (total phosphorus) and at least one of three response variables (sestonic chlorophyll-a, daily DO flux or BOD) exceeds the standards.

Total phosphorus data has been collected for streams in the Nemadji watershed. While most total phosphorus concentrations in the Nemadji River watershed are high, very little or no response variable data has been collected for these same streams. Of the streams with recent DO flux evaluations, either no violations were observed or there was insufficient data to indicate violations. Stream benthic and sestonic algal growth has not been evaluated; however, observations made in the course of stressor-response work on these streams did not indicate elevated levels of algae.

For these reasons, total phosphorus was not addressed as a likely stressor. The streams of the Nemadji watershed are scheduled for another monitoring and assessment review in 2021, at which time a larger data set of total phosphorus and response variables will be compiled and assessed.

3.2. Inconclusive Causes

There was insufficient data to assess the potential that toxic substances, herbicides, halogens/halides, fish-killing agents, insecticides, and hydrocarbons/endocrine disruptors are causing stress to the biological communities in the Nemadji River Watershed. Targeted data was collected for dissolved aluminum in the Nemadji River Watershed, but there was inconclusive evidence to support that the concentrations measured in 2013 are toxic to fish and macroinvertebrates. See Section 3.2.1 for more detailed information.

3.2.1. Heavy metals (aluminum toxicity)

Metals and metalloids are electropositive elements that occur in all ecosystems, although natural concentrations vary according to local geology. Land disturbance in metals-enriched areas can increase erosion and mobilize metals into streams. Human activities redistribute and concentrate metals in areas that are not naturally metals-enriched. These metals can reach water bodies when they are released into the air, water, and soil. Unlike sediment and nutrient impairments, there is often no visible evidence of metals contamination. While some metals are essential as nutrients, all metals can be toxic at some level and some metals are toxic in minute amounts. Impairments result when metals are biologically available at toxic concentrations affecting the survival, reproduction, and behavior of aquatic organisms.

Aluminum (Al), for example, can be acutely toxic to fish in acidic waters. There are different soluble forms of aluminum that are toxic to aquatic biota and may enter the wider food web, becoming potentially toxic to all living organisms including humans through bioaccumulation and biomagnifications processes. Gills, skeleton, kidney, liver and muscles are the main target organs for Al toxicity; former three being more susceptible. The effects of pH and Al on fish vary not only from species to species but also among different life stages.

Aluminum toxicity can be greatly altered by organism microenvironments. For example, the chemical condition of fish gill surfaces can modify aluminum speciation, sorption and precipitation resulting in chemical or physical toxicity. There is evidence that calcium (i.e. hardness) can compete with monomeric aluminum (and other soluble hydroxide forms) and prevent its binding to fish gills and impacts on ionic regulation but this is just one of the proposed toxicity mechanisms of action for aluminum (Gunderson et al., 1994). For example, particulate aluminum can cause physical suffocation and/or irritation especially if it precipitates out in the fish gill microenvironment and polymeric and colloidal forms may be important in fish growth inhibition (Gunderson et al., 1994).

3.2.1.1. *Water Quality Standards*

There is no water quality standard that addresses aluminum in Minnesota.

The EPA criteria for aluminum published in August 1988 (EPA 440/5-86-008) states on page 10 that "freshwater aquatic organisms and their uses should not be affected unacceptably, when the pH is between 6.5 and 9.0, if the four-day average concentration of aluminum does not exceed 87 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 750 ug/L more than once every three years on the average." Comparatively, British Columbia standards are 100 ug/L for dissolved aluminum.

3.2.1.2. *Sources and Causal Pathways Model for Metals*

Heavy metals, such as aluminum, are naturally occurring. Aluminum is more readily mobilized from soils and leached into surface waters under low pH conditions. The causes and potential sources for heavy metals in the Nemadji River watershed can be found at EPA's CADDIS Heavy Metals webpage: http://www.epa.gov/caddis/ssr_met4s.html.

3.2.1.3. *Overview of Heavy Metals (aluminum toxicity) in the Nemadji River Watershed*

Historically, sulfite paper mills were noted to have occurred in the Cloquet/Duluth area. On the theory that elevated sulfate emissions and deposition in the Nemadji River Watershed may have occurred, present day aluminum concentrations in runoff from clay zones were briefly examined through limited sampling. Correlations between turbidity and high aluminum levels were investigated in the impaired streams located within the clay layer to determine whether toxic levels of aluminum are contributing to low fish and macroinvertebrate IBI scores in the impaired reaches. Total aluminum was initially analyzed from water samples and after review, total dissolved aluminum was also analyzed.

The acid-soluble aluminum values noted for the October 6, 2013 Nemadji sampling ranged from 58 to 1060 ug/L. These grab sample values suggest periodic exceedance of EPA criteria published in 1988 as described above. Rock Creek had highest dissolved aluminum concentration of all sites in October 2013 (1,060 µg/L) (Figure 14). However, the protocol for measuring the toxic dissolved form of aluminum is currently being updated. It is not known what fraction of the dissolved aluminum measured during this targeted investigation is toxic to biological life.

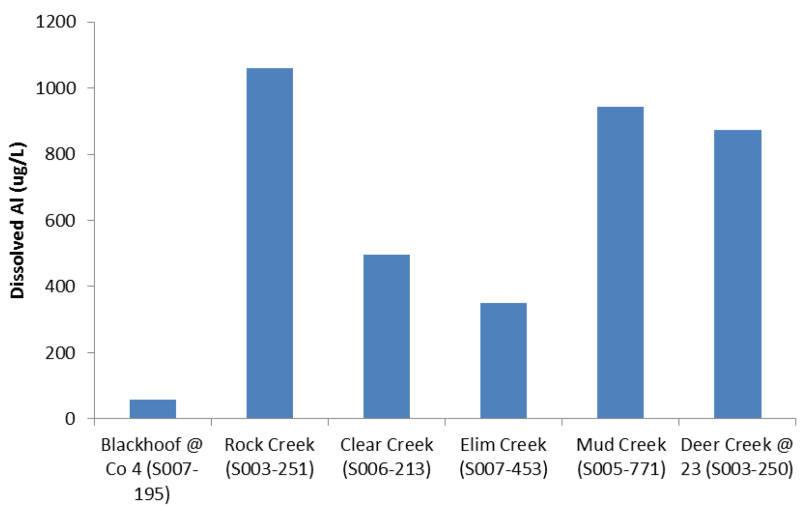


Figure 14. Dissolved aluminum concentrations in the impaired reaches (October 2013)

3.3. Summary of Candidate Causes

Seven candidate causes were selected as possible drivers of biological impairments in the Nemadji River Watershed based on the consensus from the February 17, 2014 technical review meeting and subsequent reviews of the report draft (Table 8). Several of these causes were modified from the initial list to better represent conditions in and characteristics of the Nemadji River Watershed. First, hydrologic regime alteration was split into **historic flow alteration** and **recent flow alteration** candidate causes to more explicitly separate the effects of channel instability and evolution on the biological community that resulted from widespread logging in the 1800s, from the effects of recent flow alterations due to impoundments, road crossings, climate, and beaver activity. Second, bed sediment load changes and habitat destruction were combined into one **physical habitat quality** candidate cause to better represent the combined effects of turbidity, channel instability, beaver activity, and impoundments on the loss of physical habitat in the impaired stream reaches.

Table 8. Candidate causes in the Nemadji River Watershed

Initial cause	Modified cause
Hydrologic regime alteration	**Historic flow alteration**
	Recent flow alteration
Bed sediment load changes	**Physical habitat quality**
Habitat destruction	
Habitat fragmentation	**Habitat fragmentation**
Dissolved oxygen	**Dissolved oxygen**
Temperature regime alteration	**Water temperature**
Suspended solids and/or turbidity	**Suspended solids/turbidity**

In this section, the seven candidate causes are discussed generally for the entire Nemadji River Watershed, even though several of them are likely to be operative within specific streams. Each stream has its own unique subset of candidate causes that are driving the individual stream biological impairments, described in more detail in Section 4 below.

3.3.1. Historic Flow Alteration

Hydrologic change is a major driver of stream erosion and subsequent channel evolution. Channel evolution begins when a stream is destabilized (hydraulic energy becomes out of balance with the volume of sediment transport) and results in rapid erosion for the stream channel to change shape and reach a stable form. A common evolution sequence is for a stream with increased runoff to incise and cut into its bed. In the process, the stream often becomes straighter due to channel avulsions, and therefore becomes steeper, further increasing sheer stress on the bed. The deeper the channel incises, the greater the flood that is need for the stream to reach its floodplain, meaning greater and greater sheer stress with large events. As the stream channel gets deeper, blank slopes become steeper until they are too steep and they begin to collapse. The stream channel gets wider and wider through bank erosion. The channel becomes further entrenched and unable to reach its old floodplain. Eventually the channel downcuts again, creating a smaller channel within what was the old over-wide channel, which becomes the new floodplain of the stream at a lower elevation. This process requires the moving of massive amounts of sediment and results in high stream turbidity and sediment loads, which cause stress to biological communities.

3.3.1.1. *Overview of Historic Flow Alteration in the Nemadji River Watershed.*

The Nemadji River is unique in the northern forested region of Minnesota and Wisconsin in that it carries the highest sediment load of any river in the region. Its location in a former glacial lake bed within northeastern Minnesota, its land-use history, and groundwater seepage dynamics have all contributed to the high sediment load.

There have been several periods of land-cover change in the Nemadji River Watershed from forestry and agricultural activities over the past 150 years that have led to periods of increased streamflow and resultant channel evolution (Reidel et al. 2002). Forestry in the mid-1800s cleared most of the coniferous trees which were replaced by smaller aspen trees. This tree species shift caused reduced interception and transpiration of water, leading to greater stream flow. Following the early logging activity, the remnant forest slash and drought led to large fires in the 1890s that denuded the landscape, burning thousands of acres. The barren landscape promoted large runoff events. A period of vegetation recovery followed in the early 1900s. Then in the 1920s through the 1950s agricultural expansion occurred, again increasing runoff. While row crop farming declined there was a still a fair amount of grazing taking place in the stream valleys. Many pasture lands have been abandoned in the past twenty years and are now reverting to shrub, prairie or forest cover. These past land-use and hydrologic changes led to channel incision events in the main Nemadji River and the lower reaches of many of the tributaries. Channel incision has had lasting consequences on sediment supply and in-stream dynamics. Incision has contributed to greater mass-wasting of high stream banks and bluffs (Magner and Brooks 2008) which in turn has negative impacts on stream biota by introducing more sediment to the stream. Recent large floods in the summer of 2011 and 2012 added a new dynamic to hydrologic change in the Nemadji.

Historic flow alteration is an underlying cause of many other candidate causes, including physical habitat quality, bedded sediment, habitat fragmentation, and suspended sediment/turbidity. Historical logging led to increased runoff which destabilized streams and initiated a channel evolution process. High turbidity and suspended sediment and bed load are typically an indication of channel instability. While clay soils probably slow channel evolution because clay is very cohesive, clay particles also dramatically increase turbidity. In addition, the dams that were built along Nemadji streams in the past that are now causing stress to the biological community by preventing fish passage and altering hydrology, were originally constructed as a means to address turbidity and flow issues associated with channel instability. In this way, high sediment loads, high turbidity, poor habitat quality, embedded gravel, and sometimes even loss of suitable cool water temperature and connectivity, are really symptoms of channel instability from historic flow alteration in the watershed.

See Section 8, Supporting Document 8.4 and a list of other related reports in Section 9 for more detailed information on the causes and lingering effects of historic flow alteration in the Nemadji River Watershed.

3.3.2. Recent Flow Alteration

Movement of water through stream and river channels influences all processes and biota within. Flow characteristics vary throughout a watershed, longitudinally along a stream channel, laterally from channel to floodplain, and longitudinally within groundwater as a function of landscape features. The variability of flow, both regionally and temporally, results from variance in rainfall patterns, vegetation, development, geology, and other watershed characteristics. Biological characteristics at a given site relate to volume, velocity, and variance of flow (EPA CADDIS).

Flow alteration refers to modification of flow characteristics, relative to reference or natural conditions. Across the conterminous U.S., Carlisle et al. (2010) found that there is a strong correlation between diminished streamflow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to a decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space and when flows are reduced beyond normal baseflow, competition for resources increases. Pollutant concentrations often increase when flows are lower than normal, making it more difficult for populations to maintain a healthy diversity. Often tolerant individuals that can outcompete in limiting situations will thrive. Low flows of prolonged duration tend to lead to invertebrate and fish communities that have preference for standing water or are comprised of generalist species (CADDIS, 2011). Biological responses to low flow alteration include: reduced total stream productivity, elimination of large fish, changes in taxonomic composition of fish communities, fewer species of migratory fish, fewer fish per unit area, and a greater concentration of some aquatic organisms (potentially benefiting predators).

High flows can also cause the displacement of fish and invertebrates downstream if they cannot move into tributaries or refuges along the margins of the river or if refuges are not available. High stream velocities and the mobilization of sediment, woody debris and plant material can also be detrimental especially to the fish and invertebrates because they cause significant dislodgement. When high flows become more frequent, species that do not manage well under those conditions will be reduced, leading to altered community composition. Invertebrates may shift from those of long life cycles to short life cycles due to a need to complete their life history within the bounds of the recurrence interval of flow conditions (CADDIS, 2011).

Trout habitat has a strong relationship with the annual flow regime and is highly dependent on the baseflow period (Raleigh, 1982). Binns and Eiserman (1979) identified late summer stream flow, annual stream flow variation, and maximum summer stream temperatures as primary limiting factors to trout density. Brook trout spawning occurs in areas of groundwater upwelling (Curry and Noakes, 1995). Brook trout may also be affected by decreased water velocity, as juvenile and adult salmonids require certain velocities for optimal foraging and growth (Baker and Coon, 1997). Additionally, lack of flow and increased sediment aggradation also add to the impairment. Stream discharge also has a significant influence on peak water temperatures during low flow periods in the summer months; high water temperatures may be reduced with an increased in-stream flow (Sinokrot and Gulliver, 2000).

Increased flows may directly impair the biological community or may indirectly contribute to other stressors that impair the biological community. Increased channel shear stresses, associated with increased flows, often causes increased scouring and bank destabilization which negatively affect fish and invertebrate habitat by increasing sediment in the water column. Incision has contributed to greater mass-wasting of high stream banks and bluffs (Magner and Brooks 2008) which in turn has negative impacts on stream biota by introducing more sediment to the stream. Channel incision is known to have numerous negative impacts by increasing in-stream shear forces on stream banks that are already high from the down-cutting of the stream bed (Rosgen 1996; Magner and Brooks 2008). Excessive in-stream shear forces can virtually eliminate in-stream vegetation (floating, submerged or emergent life forms). In turn, plants help to reduce velocity and induce deposition on point bars. Recent extreme flow events may uproot much existing vegetation and add to prolonged high turbidity which can inhibit aquatic plant growth. The greater in-stream erosive forces mobilize more sediment leading to reduction of in-stream habitat and less area of active floodplain. The development of point bars may be greatly reduced due to the presence of fine soils that don't deposit readily and high in-stream shear forces. The resultant greater width-depth ratio without any active floodplain leads to higher stream temperatures and potentially other adverse impacts on aquatic life at low flow.

Changes to the timing and duration of high and low flows can adversely impact aquatic life by altering their ability to carry out different life cycle needs such as feeding and reproduction. Extreme low flow or zero flow can also be very detrimental to aquatic biota. Many aquatic and riparian species are adapted to high spring flows. In contrast, high summer flows could potentially impact fish, riparian vegetation and temporary riparian residents such as turtles by impacting their normal reproductive cycles. Low flow or zero flow in the winter can lead to the stream bed freezing solid which makes it impossible for fish to survive in that reach. Stream beds without substantial baseflow can freeze the stream substratum down to a depth of feet, impacting the invertebrate population as well. If there are not refugia for the fish and invertebrates to migrate to in the winter this could lead to lower IBI in these reaches.

3.3.2.1. *Water Quality Standards*

There is no water quality standard that addresses stream flow.

3.3.2.2. *Types of Flow Alteration Data*

Long-term, continuous stream stage and or flow measurements are typically collected to identify stream flow alterations (Figure 15). In addition, the location of impoundments, beaver dams, and undersized culverts can be identified from stream surveys or stream cross section profiles developed with Li-DAR (Figure 16).

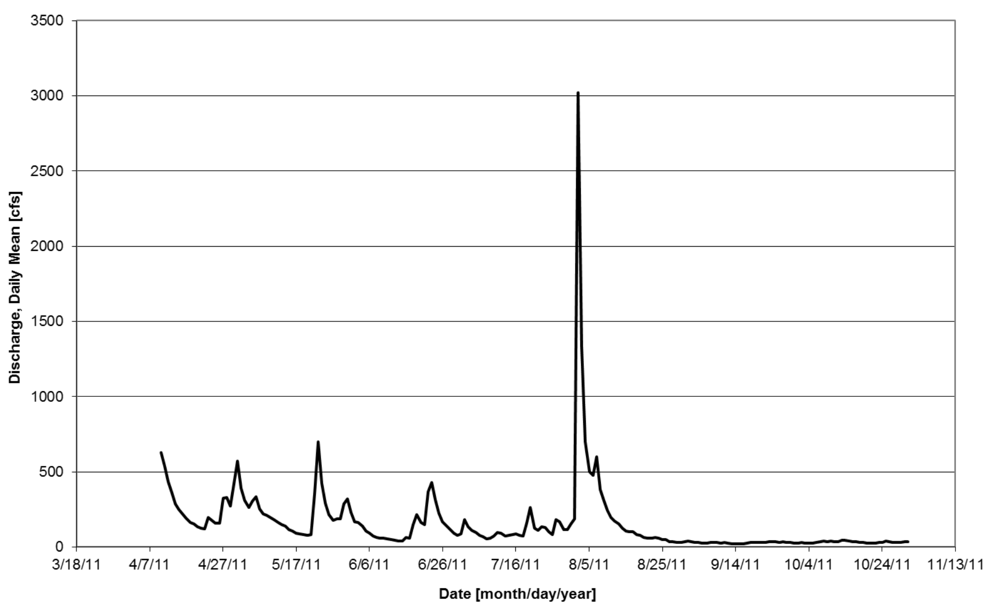


Figure 15. Continuous stream flow, North Fork Nemadji River at MN23 (2011)

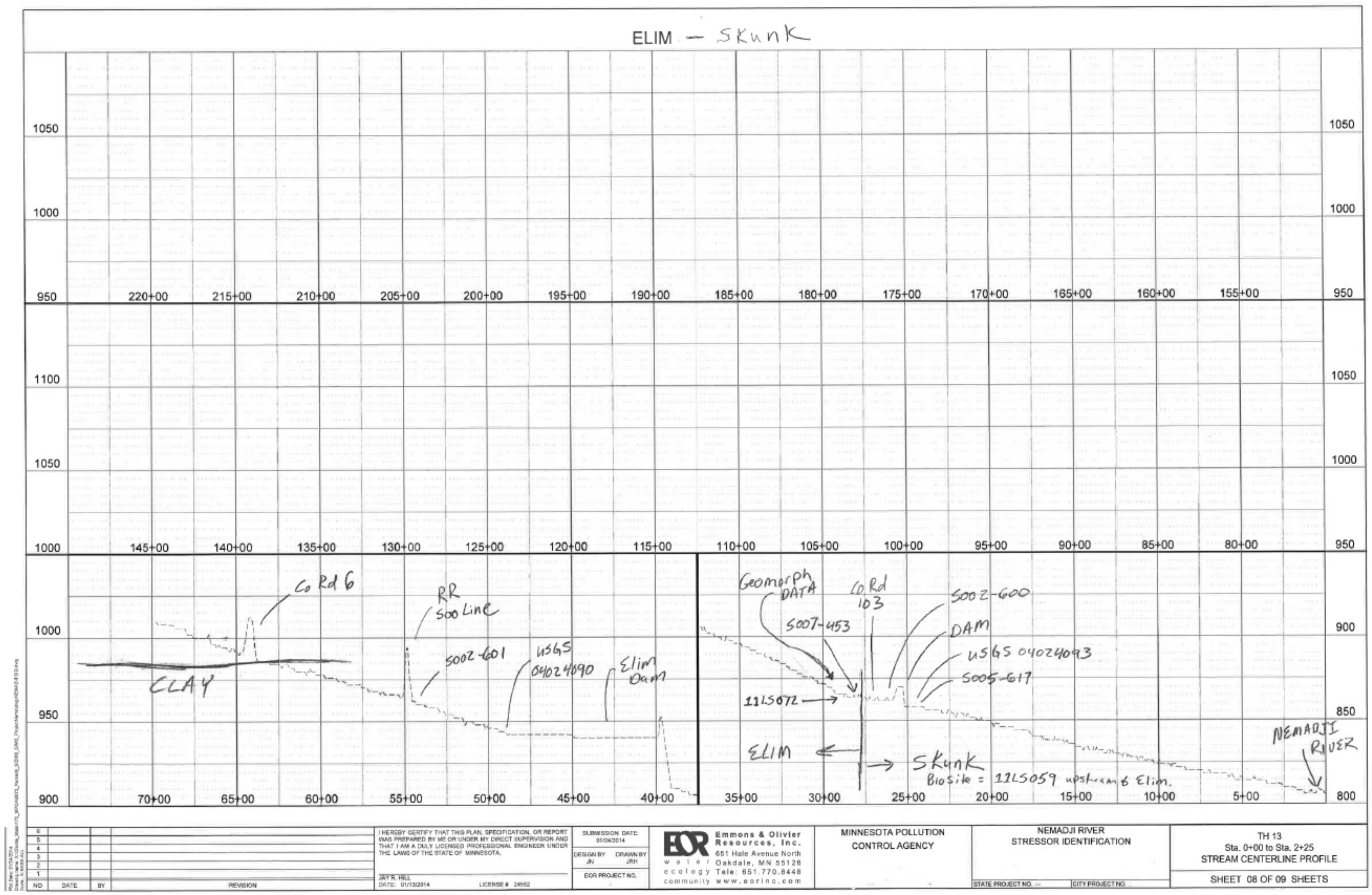


Figure 16. Elim Creek cross section profile

3.3.2.3. *Sources and Causal Pathways Model for Altered Hydrology*

Impoundment structures (dams), including man-made and beaver dams, on river systems alter stream flow, water temperature regime, and sediment transport processes – each of which can cause changes in fish and macroinvertebrate assemblages (Waters, 1995). Additionally, channelization and ditching of streams will affect the hydrology and flow. Changes in precipitation patterns can also lead to alterations in flow patterns. For example, heavy rain events cause increased flashy flow while extended dry periods cause decreased flow. The causes and potential sources for altered flow in the Nemadji River Watershed are modeled in Figure 17.

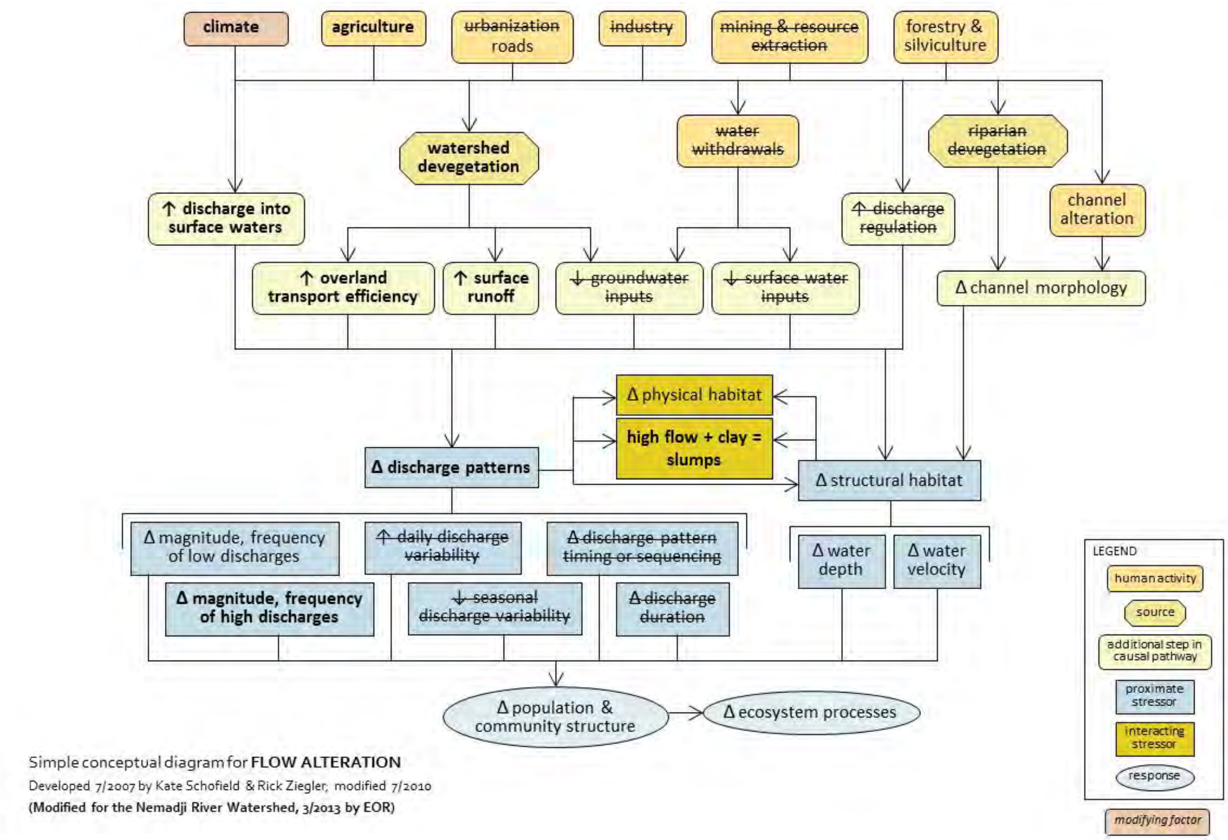


Figure 17. Conceptual causal pathway of flow alteration, modified for the Nemadji River Watershed

3.3.2.4. *Overview of Recent Flow Alteration in the Nemadji River Watershed*

Climate Variability

Increasingly variable climate has become apparent in the greater northeast part of Minnesota as witnessed by severe floods shifting to drought in a 6-8 month time period in 2012. Clay groups with a high shrink-swell capacity may damage vegetation (particularly shallow rooted crops) during dry spells, as the soil contracts, pulling roots apart. The most striking hydrologic events in the past decade were the occurrence of extremely high summer floods in 2011and 2012. The Nemadji River recorded large stream flows of 33,000 and 32,600 cfs that occurred in 2011 and 2012, respectively, both of which were more than twice the previously largest flow recorded in April 2001 since monitoring began in 1974 (Figure 18). Altered timing of high flows could have detrimental effects on the life cycle activities of stream life, particularly if it were to become a regular occurrence (Poff et al. 2007). Many aquatic and riparian species are adapted to high spring flows. In contrast, high summer flows could potentially impact fish, riparian vegetation and temporary riparian residents such as turtles by impacting their normal reproductive cycles.

Wet and dry periods per year were tabulated for Foxboro, WI from 1970-2013. A wet period was tabulated if there was rainfall in the preceding 1, 2, 3, 5 or 10 day period with the converse for dry period tabulations. The number of wet periods per year in the Nemadji River Watershed appears to be declining (Figure 19) for all precipitation classes while the number of dry periods shows an increasing pattern (Figure 20). The floods of August 3, 2011 and June 21, 2012 were the two highest events recorded over the 39 year record.

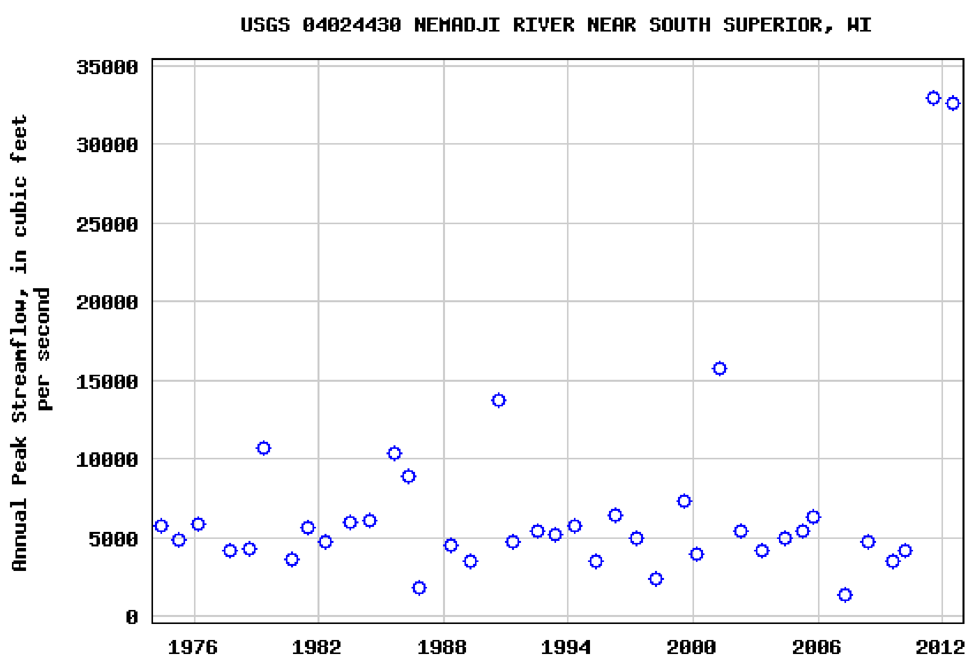


Figure 18. Peak flows in the Nemadji River at the Superior, Wisconsin USGS gauge

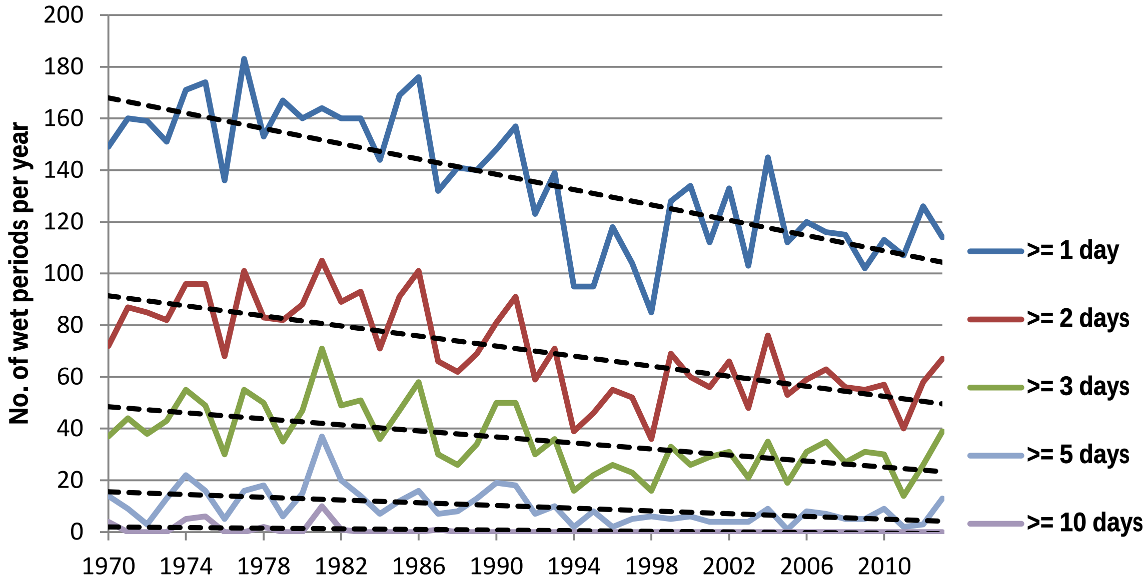


Figure 19. Number of wet periods per year by length, all months, 1970-2013

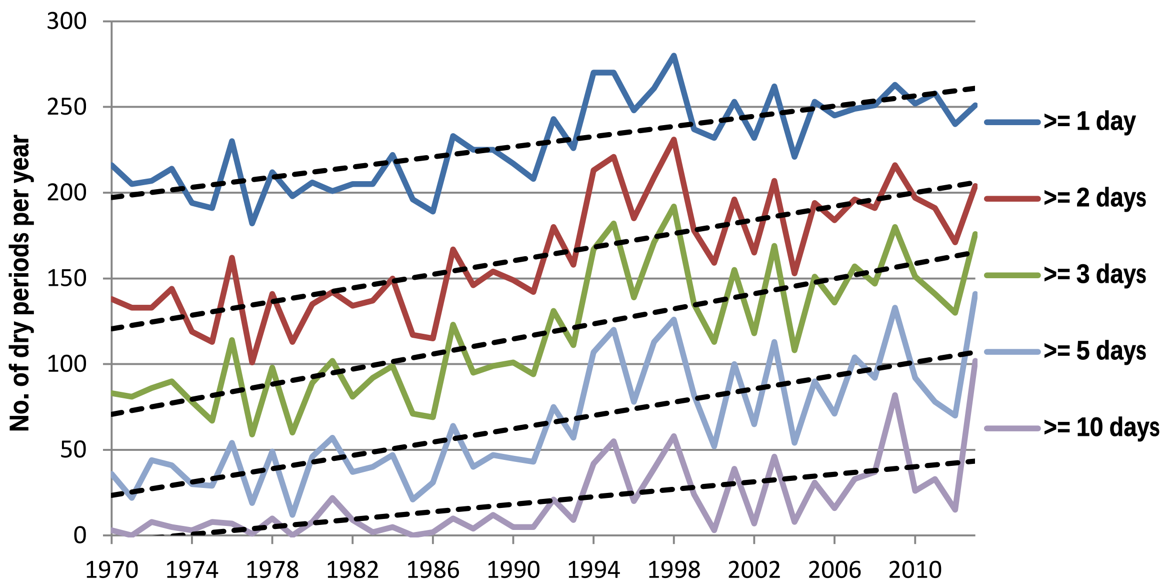


Figure 20. Number of dry periods per year by length, all months, 1970-2013

Impoundments

Undersized culverts and impoundments, initially constructed to reduce stream flow and increase sedimentation of suspended solids to improve water clarity, can affect stream hydrology. There are many constructed dams in the Deer Creek and Skunk/Elim Creek systems that vary in their state of condition and current function. These dams were part of a BMP impoundment program to manage erosion and sediment in the Nemadji River. However, there was no plan put in place for their long-term management or routine maintenance. Consequently, the Carlton SWCD and local landowners are working together to evaluate the current condition of these structures and create a management plan.

The Carlton SWCD recently conducted a road culvert inventory of the entire Nemadji River Watershed (Figure 22), and several culvert barriers have been replaced in the past decade. Carlton SWCD recently secured funding to survey ATV trail culverts and prioritize culverts for replacement. In addition, the Carlton SWCD is supporting projects to remove historic red clay dams throughout the watershed, beginning with the Hammitt Dam on Elim Creek. Beaver activity is also common along many of the stream reaches within the watershed. Impoundments created by beaver dams have affected the hydrology of many streams by reducing flow velocities above the dam and decreasing flow below the dams. This is especially evident on Anderson Creek where the dam had been in place so long that water no longer was observed flowing immediately downstream of the beaver dam in the fall of 2013 (Figure 21).

Figure 21. No discernible channel immediate downstream of beaver dam on Anderson Creek.

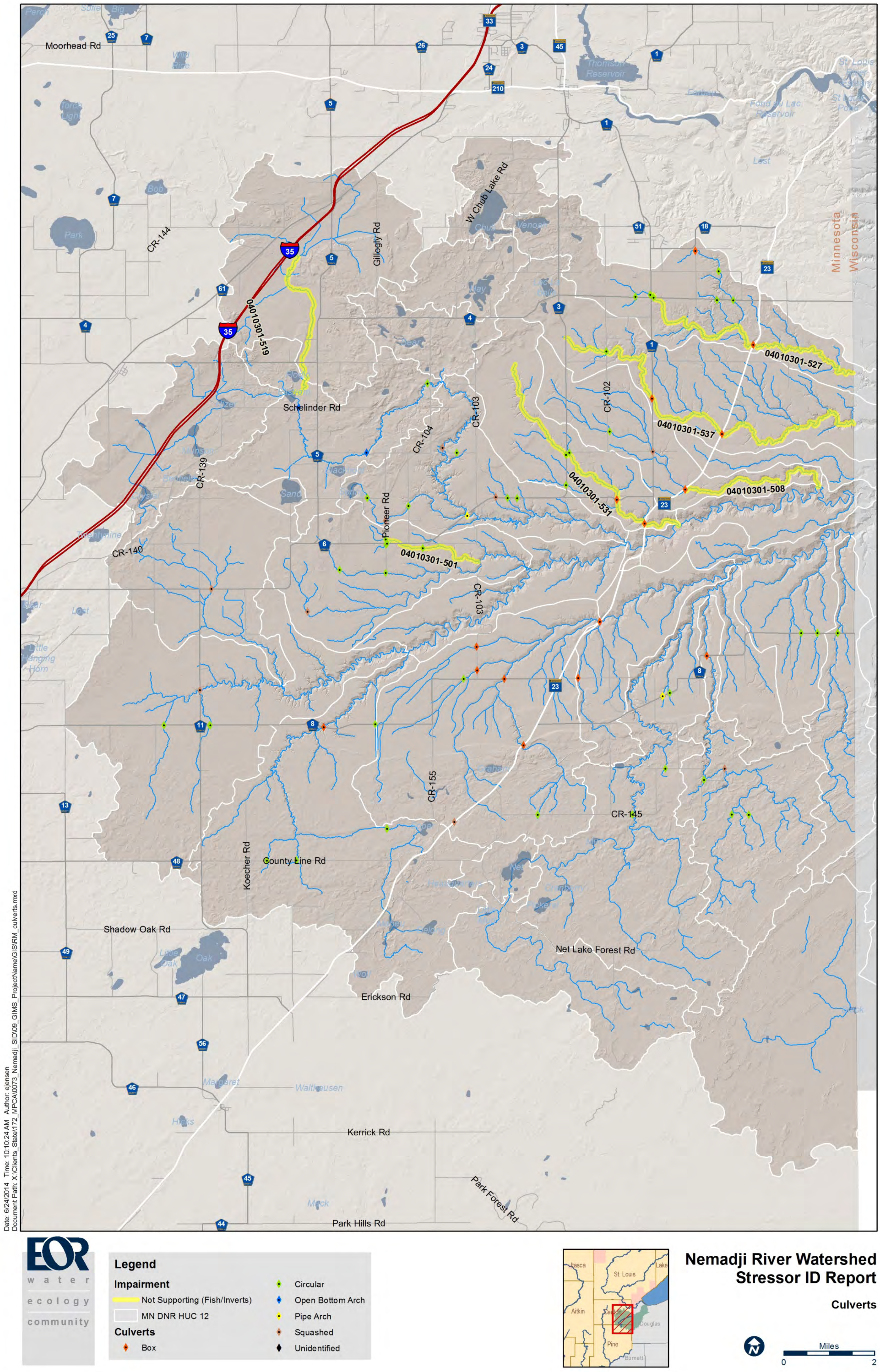


Figure 22. Carlton SWCD 2013 road culvert inventory of the Nemadji River Watershed

3.3.3. Physical Habitat Quality

Habitat is a broad term encompassing all aspects of the physical, chemical and biological conditions needed to support a biological community. This report will focus on the physical habitat structure of streams, including geomorphic characteristics and vegetative features (Griffith et al., 2010). Habitat features in streams range from deep pools to gravel riffles, along with areas of woody habitat both in the forms of trees shading the riparian corridor and branches and leaves falling into the stream channel.

Physical habitat diversity enables fish and invertebrate habitat specialists to prosper, allowing them to complete their life cycles. Some examples of the requirements needed by habitat specialists are: sufficient pool depth, cover or refuge from predators, and riffles that have clean gravel or cobble which are unimpeded by fine sediment (Griffith et al., 2010).

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on our landscape by way of resource extraction, agriculture, forestry, silviculture, urbanization, and industry. These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat; or reduced habitat quality, such as embedded gravel substrates. Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (Griffith et al. 2010). A lack of woody vegetation along the stream corridor causes increased stream temperatures, lack of suitable habitat for invertebrates that feed on leaf material (shredders), and general bank instability from missing root structure to armor the banks.

3.3.3.1. *Water quality standard*

There is no state or federal water quality standard for physical habitat.

3.3.3.2. *Types of Physical Habitat Data*

MPCA Stream Habitat Assessment (MSHA) is conducted on streams and rivers to assess qualitative physical habitat conditions at stream monitoring sites. MSHA provides a score for various in-stream and riparian characteristics within the sampling reach (Table 9) following the MPCA Protocol for Stream Monitoring sites. The scores from each characteristic are then summed to determine the total MSHA score for the site. Total scores range from 100 (highest quality) to 0 (lowest quality). MSHA scores were collected by MPCA during the 2011 biological monitoring and by EOR during the 2013 stream survey.

Table 9. MSHA habitat characteristics and highest potential scores

Habitat Characteristic	Highest Potential Score
Surrounding Land Use	5
Riparian Zone	15
Instream Zone	
Substrate	27
Cover	17
Channel Morphology	36
Total	**100**

Field measurement of bedded sediment (bedload) is very difficult when using traditional bedload samplers. Bedded sediment can also be assessed using a visual observation of the amount of fine sediment surrounding the coarse substrate on the stream bottom. This measurement was part of the qualitative habitat assessment conducted during stream geomorphic surveys in 2013 by EOR (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information). Assessment of particle size was also conducted at select biological monitoring sites in 2013 to assess the D50 or the mean particle size of the stream bottom.

Topographic relief and clay soil maps were also developed for the Nemadji River Watershed with LiDAR imagery, and are provided for each impaired stream in Section 4 of this report.

3.3.3.3. *Sources and Causal Pathways Model for Physical Habitat Quality*

The causes and potential sources for lack of habitat in the Nemadji River Watershed are modeled in Figure 23. Many riparian areas along the impaired creeks in the Nemadji River Watershed are influenced by beaver activity and culverts. Along with altered hydrology, the alteration of habitat caused by impoundments, has numerous pathways of influence affecting the biological community. There have been several periods of land-cover change from forestry and agricultural activities over the past 150 years that have led to periods of increased streamflow and resultant channel evolution (Reidel et al. 2002). Incision has contributed to greater mass-wasting of high stream banks and bluffs (Magner and Brooks 2008) which in turn has negative impacts on stream biota by introducing more sediment to the stream.

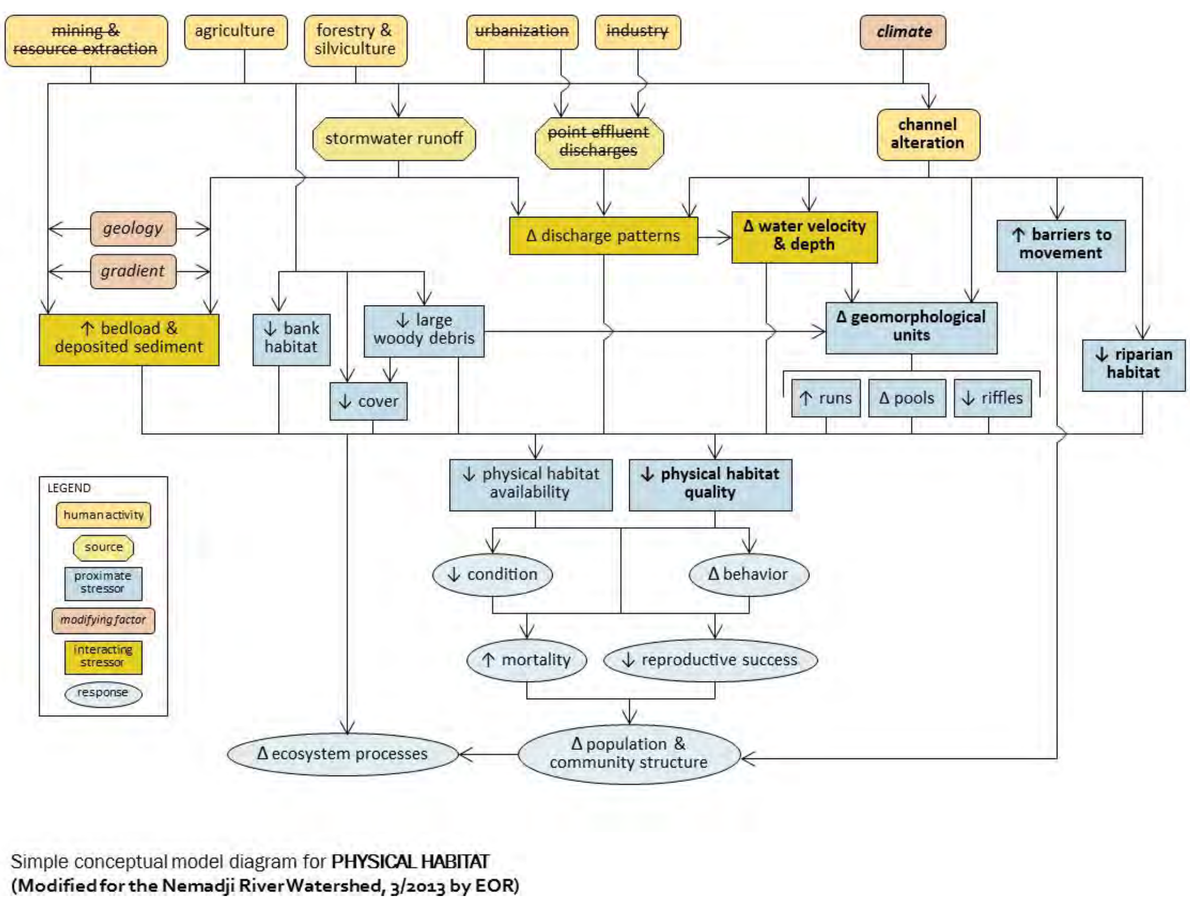


Figure 23. Conceptual model for habitat modified for the Nemadji River Watershed

3.3.3.4. *Overview of Physical Habitat in the Nemadji River Watershed*

The MSHA scores for all assessed streams ranged from poor to good. In general, the habitat characteristics that have the largest effect on aquatic life (cover and substrate) had the lowest scores across the watershed, indicating the stream habitats do not provide optimal conditions for fish (Table 10).

Of the 2013 geomorphic survey sites, there were some areas of fine sediment deposition but not widespread throughout a stream (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information); fine sediment deposition was confined to lower velocity areas. Magner's 2001 data showed higher D_{50} than the sites EOR surveyed in 2013 (Magner and Brooks 2008). The 2001 survey data had mostly gravel or cobble bed streams while 5 of 6 streams were sand bed (Rosgen Types E5 or C5) in our 2013 survey. It is possible that sediment from channel erosion led to filling of the channel bed. The two large flood events in 2011 and 2012 may have mobilized a lot of sediment that has not been flushed from the system yet. Fine sediment accumulation would be particularly noticeable during low flow samples such as during October 2013. However the difference between the 2001 and 2013 data could be from natural variability; a much larger data set is needed to determine whether there is a statistically significant difference between the two years.

Field observations indicated that some in-stream habitat features have been destroyed in the Nemadji River Watershed, including log jams and riparian vegetation that provided in-stream structure and depth variety. Loss of riparian vegetation may have resulted from streamside grazing or clearing to the streamside near trail crossings and other human activities in the watershed. In addition, there is less input of very large wood pieces to the streams as a result of past land cover conversion from coniferous forest to shrub forests. Lack of large woody debris limits the diversity of stream habitat for fish and macroinvertebrates. The presence of beaver dams can improve habitat by creating deep-water refuges for some fish species, and also destroy habitat by reducing flows and increasing water temperatures.

Table 10. Minnesota Stream Health Assessment (MSHA) Scores (Emmons & Olivier Resources Inc., 2013)

Stream name	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
Blackhoof Creek at CR104	5	14	21	9	33	82	Good
Blackhoof Creek at CR4	5	9	18	4	24	60	Fair
Elim Creek	5	15	19	4	18	61	Fair
Mud Creek	5	10	15	7	19	56	Fair
Rock Creek	5	11	12	9	16	53	Fair
Clear Creek	5	9	15	10	19	58	Fair

3.3.4. Habitat Fragmentation

Connectivity in river ecosystems refers to how waterbodies and waterways are linked to each other on the landscape and how matter, energy, and organisms move throughout the system (Pringle, 2003). There are many components of connectivity, but this section will only address physical barriers in streams. Dams, both human made and natural, can cause changes in stream flow, sediment transport processes, water temperature regime, and habitat and chemical characteristics of a waterbody. Dams can block fish migrations and can greatly reduce or even extirpate local populations (Tiemann, Gillette, Wildhaber, & Edds, 2004; Brooker, 1981). Additionally, they can alter the hydrologic connectivity, which may obstruct the movement of migratory fish causing a change in the population and community structure. The stream environment is also altered by a dam to a predominately lentic surrounding (Mitchell and Cunjak, 2007). Humans have placed dams on the landscape for many reasons including flood control, livestock watering, and irrigation. Beavers build dams to create impoundments with adequate water depth for a winter food cache (Collen and Gibson, 2001), which also can be barriers to fish migration. In Minnesota, there are over 800 dams on streams and rivers for a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

3.3.4.1. *Water Quality Standards*

There is no applicable water quality standard for stream connectivity.

3.3.4.2. *Types of Habitat Fragmentation Data*

LiDAR imagery was also used to develop stream cross section profiles for each impaired and reference stream reach (Figure 16, see Section 3.3.2.3). An accurate stream alignment was hand digitized following the low point of each stream valley. This profile was then converted to CAD and plotted. These plots were used to identify barriers, beaver dams and stream slope. Some locations of beaver dams were identified during stream surveys. And the Carlton SWCD recently conducted a limited public road culvert inventory of the entire Nemadji River Watershed (Figure 22, see Section 3.3.2.4) and will be conducting a survey of ATV trail culverts in 2014.

3.3.4.3. *Sources and Causal Pathways Model for Habitat Fragmentation*

The causes and potential sources for habitat fragmentation include impoundments placed on rivers and streams which can create barriers to fish passage and can alter the aquatic community. The causes and potential sources for habitat, including barriers to migration, in the Nemadji River Watershed are modeled in Figure 23 (see *Section 3.3.3.3*).

3.3.4.4. *Overview of Habitat Fragmentation in the Nemadji River Watershed*

Several barriers to fish movement occur across the Nemadji River Watershed, including perched culverts, dams, lack of water depth in culverts, or high velocity flows in culverts. Due to the steep topography of the Nemadji River Watershed there are several large bridges and box culverts in the watershed, and the potential for perched culverts or large drops in water surface elevation are greater in these steeper streams. Low flow blockages may occur at road crossings during low flows, and high velocity barriers may develop for fish that have less ability to jump or swim through high-velocity water during high flows (including some of the small resident stream fishes and bottom-dwelling fishes). Trout and some other game fish species such as walleye and bass species have the ability to traverse minor water surface drops and would be less impeded by blockages. Additionally, beaver dams are numerous on many of the stream reaches. The Carlton SWCD recently conducted a road culvert inventory of the entire Nemadji River Watershed (Figure 22), and several culvert barriers have been replaced in the past decade. Carlton SWCD recently secured funding to survey ATV trail culverts and prioritize culverts for replacement. In addition, the Carlton SWCD is supporting projects to remove historic red clay dams throughout the watershed, beginning with the Hammitt Dam on Elim Creek.

3.3.5. Dissolved Oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low concentrations or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker, 1991). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If dissolved oxygen concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or even fatality (Allan, 1995). Many species of fish avoid areas where DO concentrations are below 5 mg/L (Raleigh, 1986).

In most streams and rivers, the critical conditions for stream DO usually occur during the late summer season when water temperatures are high and stream flows are near base flow. As water temperature increases, the saturation level of DO decreases but the DO needs for many species of fish increases (Raleigh, 1986). Low DO can be an issue in streams with slow currents, excessive temperatures, high biological oxygen demand, and/or high groundwater seepage (Hansen, 1975).

3.3.5.1. *Water Quality Standards*

According to Minnesota Rule 7050.0220, the daily minimum DO standard is 5 mg/L for class 2A (coldwater fisheries) waters, and 7 mg/L for class 2B (cool and warmwater fisheries) waters. The DO standard must be met at least 90 percent of the time during both the 5-month period of May through September and the 7-month period of October through April. Accordingly, no more than 10 percent of DO measurements can violate the standard in either of the two periods. Further, measurements taken after 9:00 in the morning during the 5-month period of May through September are no longer considered to represent daily minimums, and thus measurements of >5 DO later in the day are no longer considered to be indications that a stream is meeting the standard. A stream is considered impaired if 1) more than 10 percent of the "suitable" (taken before 9:00) May through September measurements, or more than 10 percent of the total May through September measurements, or more than 10 percent of the October through April measurements violate the standard, and 2) there are at least three total violations.

3.3.5.2. *Types of Dissolved Oxygen Data*

Instantaneous DO data is available throughout the watershed and can be used as an initial screening for low DO (Figure 24). These measurements represent discrete point samples. Because DO concentrations can vary significantly with changes in flow conditions and time of day, instantaneous measurements need to be used with caution and are not completely representative of the DO regime at a given site.

A synoptic monitoring approach gathers data across a large spatial scale with minimal temporal scale (as close to simultaneously as possible). In terms of DO, the objective is to sample a large number of sites from upstream to downstream under comparable ambient conditions. For the most part, the surveys take place in mid to late summer when low DO is most commonly observed. Dissolved oxygen readings are typically taken at pre-determined sites in the early morning in an attempt to capture the daily minimum DO reading.

YSI sondes are deployed to capture diurnal fluctuations over the course of a number of diurnal patterns. This information is then used to look at the diurnal flux of DO along with the patterns of DO fluctuation (Figure 25).

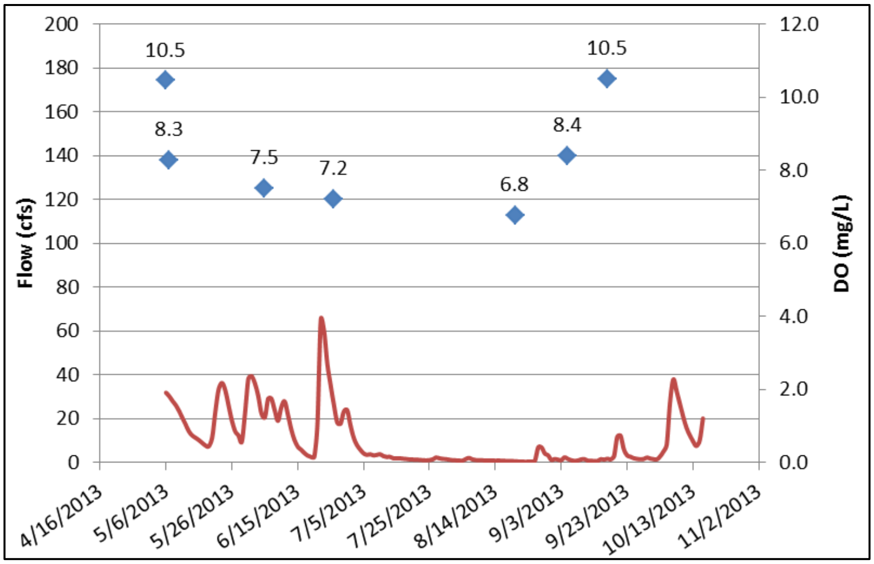


Figure 24. Instantaneous DO measurements, Blackhoof River at CR4 (2013)

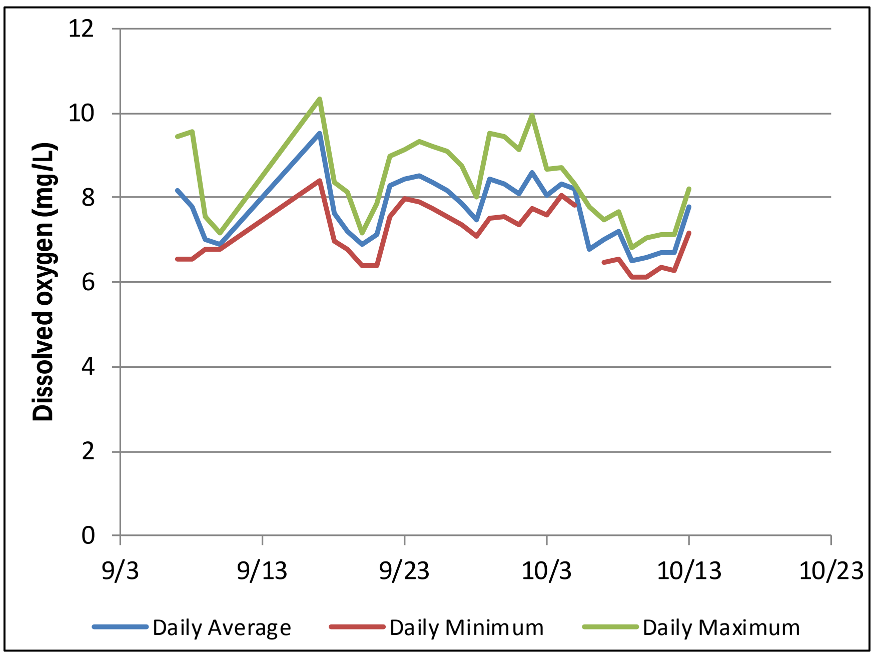


Figure 25. Continuous DO measurements, Blackhoof River at CR4 (2013)

3.3.5.3. *Sources and Casual Pathways Model for Dissolved Oxygen*

Dissolved oxygen concentrations in streams are driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the DO regime of a waterbody. Agricultural and urban land uses, impoundments (dams), and point-source discharges are just some of the anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. The causes and potential sources for low dissolved oxygen in the Nemadji River Watershed are modeled in Figure 26.

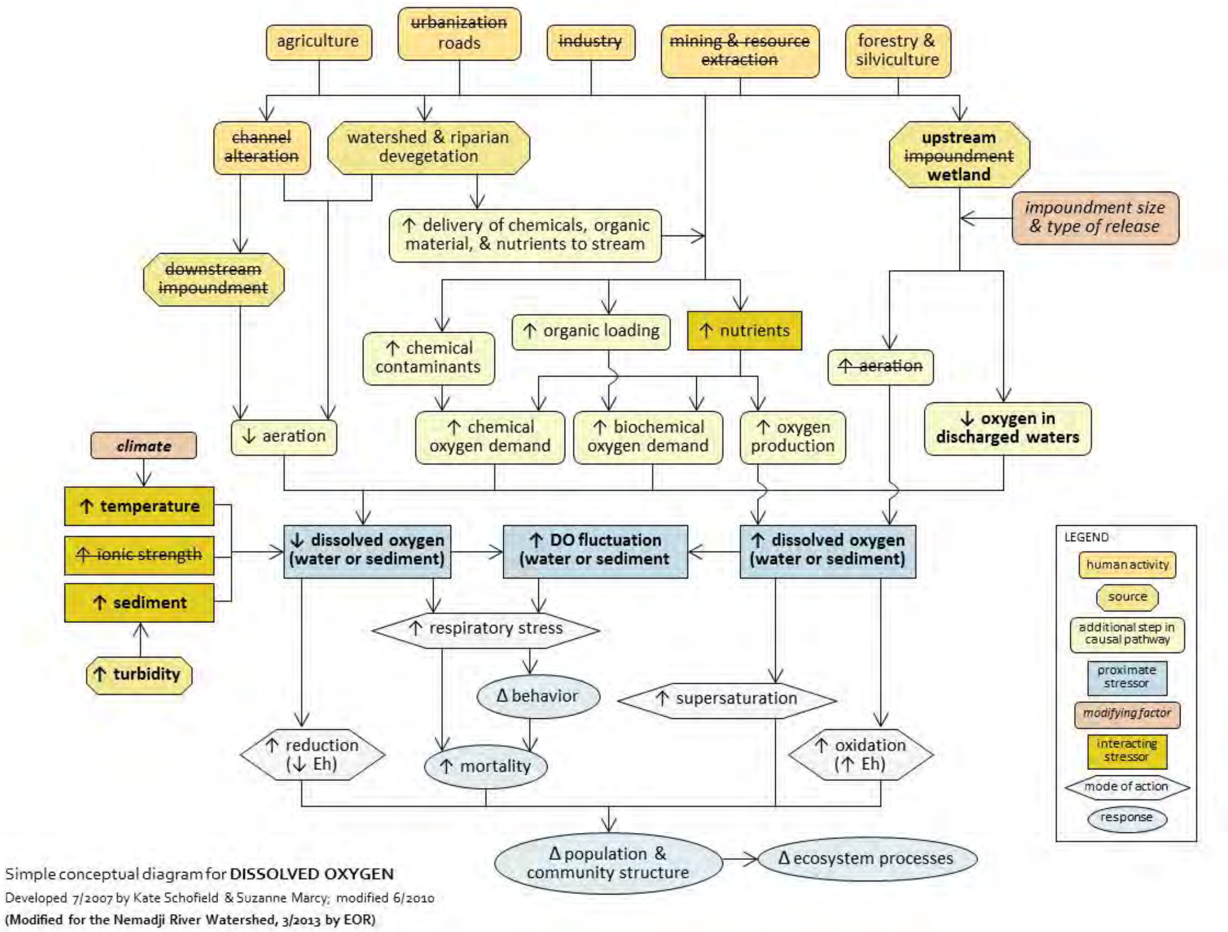


Figure 26. Conceptual diagram for dissolved oxygen modified for the Nemadji River Watershed

3.3.5.4. *Overview of Dissolved Oxygen in the Nemadji River Watershed*

Continuous DO measurements were collected for one to two week time periods at two sites on the upper Blackhoof River, and one site on Clear Creek and Little Net River (a reference stream) to measure daily DO fluxes. Instantaneous DO measurements were collected on May 7, June 5, June 26, August 20, September 10, and October 16 during a range of stream flows. Lastly, MPCA data collected from the past 10 years was also summarized for each stream.

In general, DO concentrations on all streams that were sampled remained above water quality standards. For several days in the end of September of 2013, DO decreased below water quality standards on the Blackhoof River at the Wait site, but eventually recovered. It is likely that DO concentrations near the Wait site are lower due to the presence of wetlands in the headwaters of the river. DO concentrations improve and are supporting further downstream on the Blackhoof River. Additionally, DO on Rock Creek falls below water quality standards, but input from the technical advisory group indicated that this was likely related to a culvert issue causing low flows.

3.3.6. Water Temperature

When temperatures rise close to 21°C, other fish have been shown to have a competitive advantage over trout for the food supply (Behnke, 1992). Fish continue to feed and gain weight at what is considered their functional feeding temperatures. Brown trout growth is maximized between 4 – 19.5 degrees Celsius (Elliot and Elliot, 1995); however for brown trout egg development temperatures between 0 and 15°C are required (Elliot, 1981). Functional feeding temperatures for brook trout are between 12.7°C and 18.3° (Raleigh, 1982). Temperatures near 22.2°C can be briefly tolerated, but temperatures of 23.8°C for a few hours are typically lethal (Flick, 1991). Density of juvenile brook trout has been shown to be negatively correlated with July mean water temperatures (Hinz and Wiley, 1997). Juvenile brook trout are highly dependent, for growth and distribution, on temperature (McCormick et al. 1972).

Optimal growth, stress, and lethal threshold temperature ranges for cold water fish species, such as trout, have been developed by the MN DNR, and vary slightly from temperatures reported in the literature. The temperatures in Table 11 were used to evaluate temperature as a stressor in the Nemadji River Watershed.

Table 11. Temperature ranges for trout species (MN DNR)

Temperature range	Brook Trout	Rainbow Trout	Brown Trout
Range below which growth occurs	<45.9° F or 7.9° C	<49.9° F or 9.9° C	<40.9° F or 4.9° C
Range of growth	46-67.9° F or 8-20° C	50-67.9° F or 10-20° C	41-73.4° F or 5-23° C
Range of thermal stress	68-76.9° F or 20-24.9° C	68-77.9° F or 20-25.5° C	73.5-79.4° F or 23.1-26.3° C
Lethal threshold	>77° F or 25° C	>78° F or 25.6° C	>79.5° F or 26.4° C

3.3.6.1. *Water Quality Standard*

Fish can be negatively impacted due to increases in temperature (Raleigh et al., 1986). The state standard for temperature in Class 2A streams is “no material increase” (7050.0222 Specific Water Quality Standards for Class 2 Waters of the State; Aquatic Life and Recreation). The temperature at which physiological stress, reduced growth and egg mortality occur for brown trout is called threat temperature at 18.3°C and critical temperature for life occurs at 23.9°C (Wherly et al., 2007).

3.3.6.2. *Types of Temperature Data*

Continuous water temperature data was collected at the biological monitoring sites by the MPCA in 2011, by MDNR at many sites along the impaired stream reaches within the past 5 years (Figure 27), and during the 2013 summer season by EOR (Figure 28). These data are used to assess the length of time stream water temperatures reach stressful or lethal temperatures for trout species, as listed in Table 11.

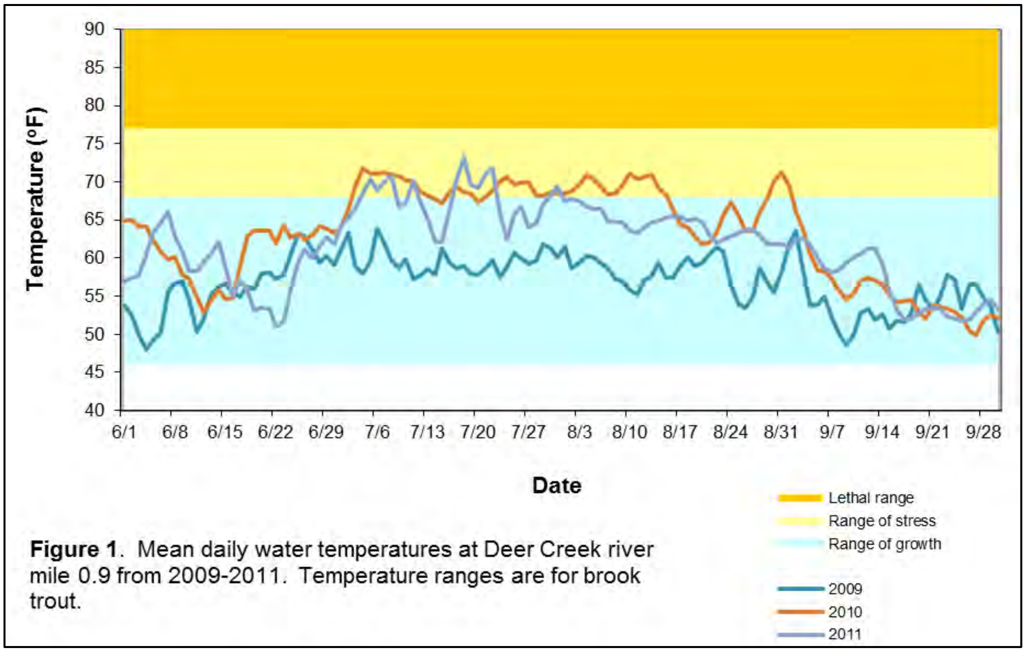


Figure 27. Mean daily water temperatures at Deer Creek at MN23 (MDNR 2009-2011)

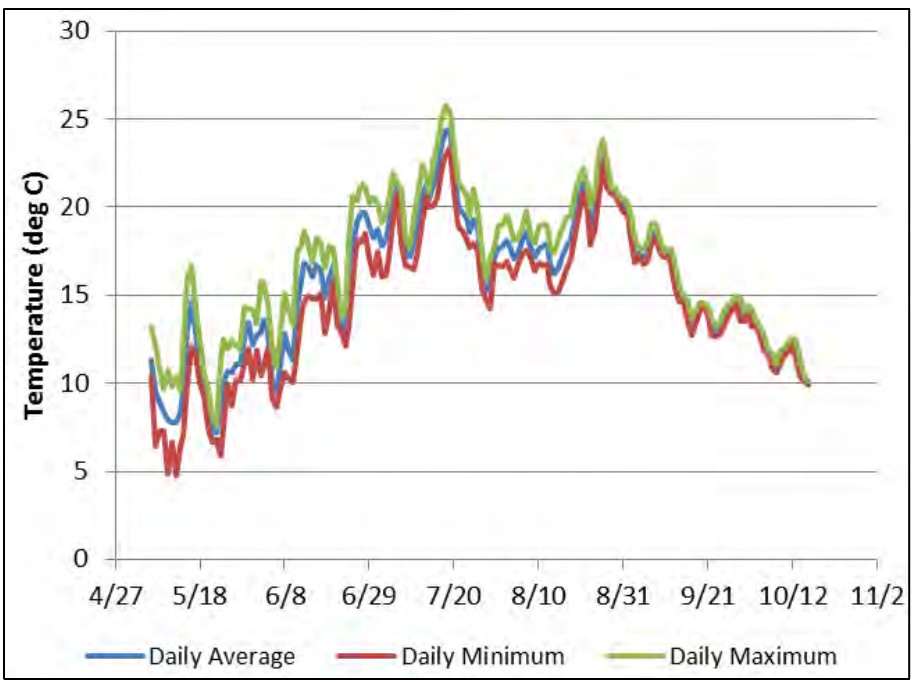


Figure 28. Daily average, minimum and maximum water temperatures in Deer Creek at CSAH6 (EOR 2013)

3.3.6.3. *Sources and Causal Pathways Model for Temperature Alteration*

Land cover alteration in the watershed and in the riparian corridor may be connected to changes in stream temperature. Decreased canopy cover due to changes in land use, such as clearing of forested land and conversion to row crop agricultural land may lead to increases in solar heating and warm surface runoff. The causes and potential sources for increases in temperature in the Nemadji River Watershed are modeled in Figure 29.

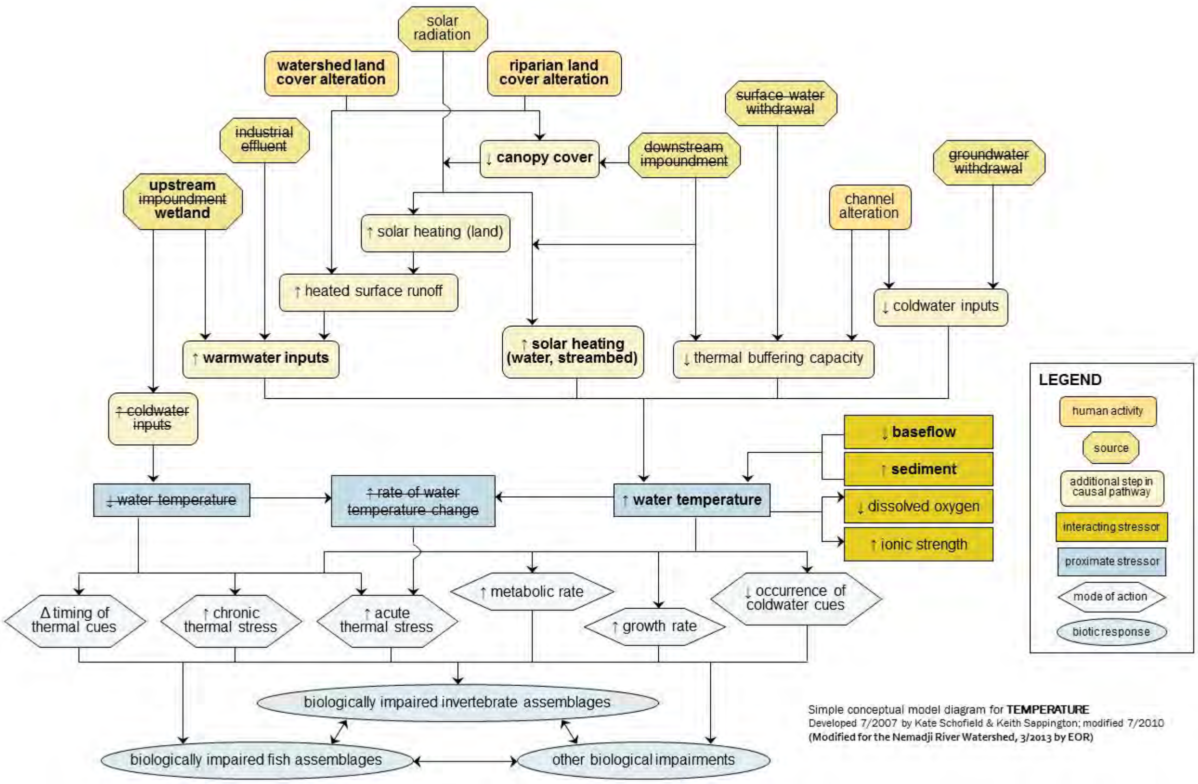


Figure 29. Conceptual model for water temperature modified for the Nemadji River Watershed.

3.3.6.4. *Overview of Temperature in the Nemadji River Watershed*

Maximum daily stream temperatures reaching into the lethal range for trout (above 25 degrees C) were observed on occasion for several days in Mud and Clear Creeks, and for several week long periods in Rock Creek in 2013.

Water temperatures also vary longitudinally in the impaired streams, with the water temperatures within the red clay zone rising into the stressful or lethal range for trout at certain times of the year, while the upper reaches located outside of the clay zone remain cooler and provide coldwater refuges for trout. Therefore, an underlying cause to water temperature as a stress to the biological community is habitat fragmentation, whereby trout passage to the coolwater refuges of the upper portion of impaired streams is blocked by any of the fish barriers described in Section 3.3.4: Habitat Fragmentation.

3.3.7. Suspended Solids/ Turbidity

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairment in the United States (U.S. EPA, 2003). Although sediment delivery and transport are important natural processes for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat in addition to the direct harm to aquatic organisms. As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (i.e. abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (i.e. loss of visibility, increase in sediment oxygen demand). Elevated turbidity levels and total suspended solids (TSS) concentrations can reduce the penetration of sunlight and thus impede photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

3.3.7.1. *Water Quality Standards*

Turbidity is a measure of reduced transparency that can increase due to suspended particles such as sediment, algae, and organic matter. The Minnesota turbidity standard is 10 Nephelometric Turbidity Units (NTU) for class 2A waters and 25 NTU for class 2B waters. The State of Minnesota has amended state water quality standards and replaced stream water quality standards for turbidity with standards for TSS. One component of the rationale for this change is that that turbidity unit (NTUs) is not concentration-based and therefore not well-suited to load-based studies (Markus, 2011; http://www.pca.state.mn.us/index.php/view-document.html?gid=14922)

The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The assessment window for these samples is April-September, so any TSS data collected outside of this period will not be considered for assessment purposes. The TSS standard for the Nemadji River and trout streams has been set at 10 mg/L. For assessment, this concentration is not to be exceeded in more than 10 percent of samples within a 10-year data window. TSS results are available for the watershed from state-certified laboratories, and the existing data covers a much larger spatial and temporal scale in the watershed.

3.3.7.2. *Types of Suspended Solids/ Turbidity Data*

Total suspended solid concentrations, turbidity optical readings, and transparency tube readings have been collected by the MPCA at monitoring stations throughout the Nemadji River Watershed. Monthly average TSS concentrations can be compared across stream reaches to determine the variability of suspended solids spatially and seasonally (Figure 30). TSS concentrations tend to be higher during spring snowmelt and following rainfall events.

The size of suspended particles affects the rate at which suspended solids naturally settle out of the water column. Clay particles tend to be very fine and remain suspended for a long period of time, while sands settle out very quickly from the water column. Particle size was of particular interest in the Nemadji River Watershed where there is a clearly defined clay zone with well-documented clay erosion linked to high stream turbidity. Whole water samples were collected from the impaired and reference stream reaches on August 27, 2013 to visually observe the settling rates of suspended sediment out of the water column. Samples taken from the clay zone streams were turbid at the time of collection. Stained water was noted in the wetland influenced sites, such as Blackhoof at Wait, Blackhoof at CR4, and Little Net at Bley Road. The sites were ranked relative to each other based on how quickly the water cleared over a period of one week following disturbance of the water sample. Settling rates were slowest (i.e., suspended particle size were the smallest) in Clear and Deer with approximately 6 days for full settling of sediments (Table 12, Figure 31).

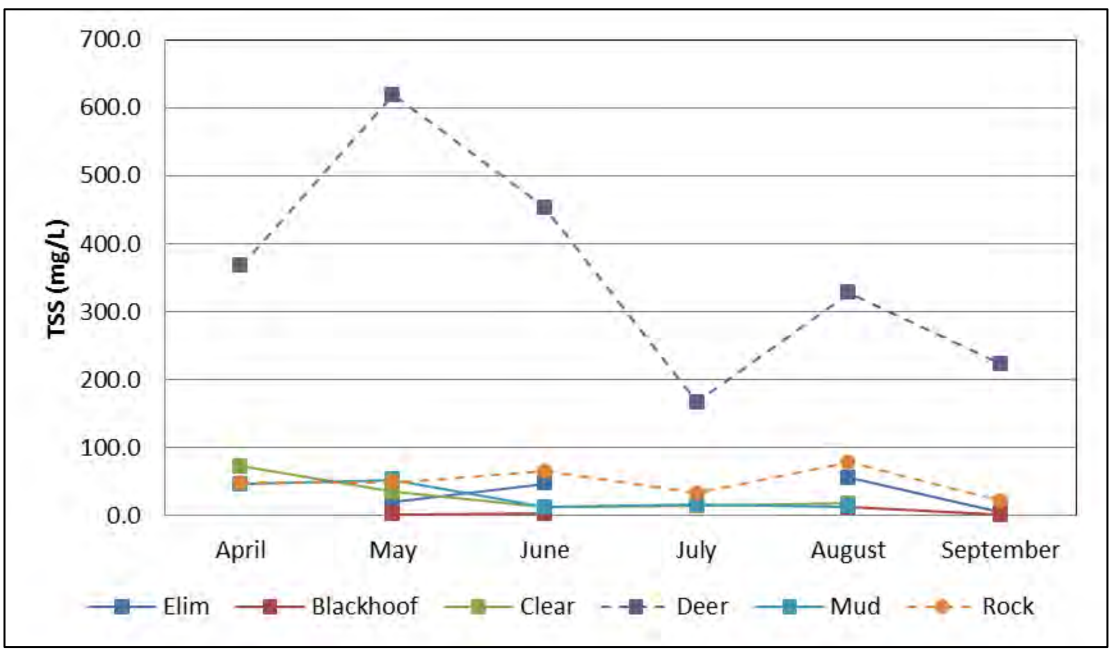


Figure 30. Mean TSS concentrations on impaired stream reaches between 2002 and 2013.

Table 12. Suspended sediment settling rates.

Time	Elim	Blackhoof @ CR4	Blackhoof @ Wait	Little Net	South Fork	Rock	Clear	Deer	Mud
Within 2 hours			X	X					X
Within 1 day		X							
Within 2 days						X			
> 5 days	X				X		X	X	

Figure 31. Photo showing sediment settling collected from streams. Refer to Table 12 for order of bottles.

3.3.7.3. *Sources and Causal Pathways Model for TSS/ Turbidity*

The causes and potential sources for increases in TSS and turbidity in the Nemadji River Watershed are modeled in Figure 32. As described in Section 3.3.1, historic land use changes that resulted in major flow alterations and subsequent channel instability and evolution are the major source of suspended solids/ turbidity in the Nemadji River Watershed today. Channel instability and evolution in the Nemadji River Watershed results in increased sediment delivery to the stream, increased mobilization of bank and channel sediment, and increased steambank erosion. Other causes and potential sources of increased TSS/turbidity include erosion of unprotected soils and dirt roads during heavy rainfall events (MPCA and MSUM 2009). Soils in the Nemadji River watershed are unprotected for a variety of reasons, including poor forestry practices, inadequate recovery of harvested forests, construction, mining, agriculture, insufficiently vegetated pastures, and establishment of secondary dirt road networks.

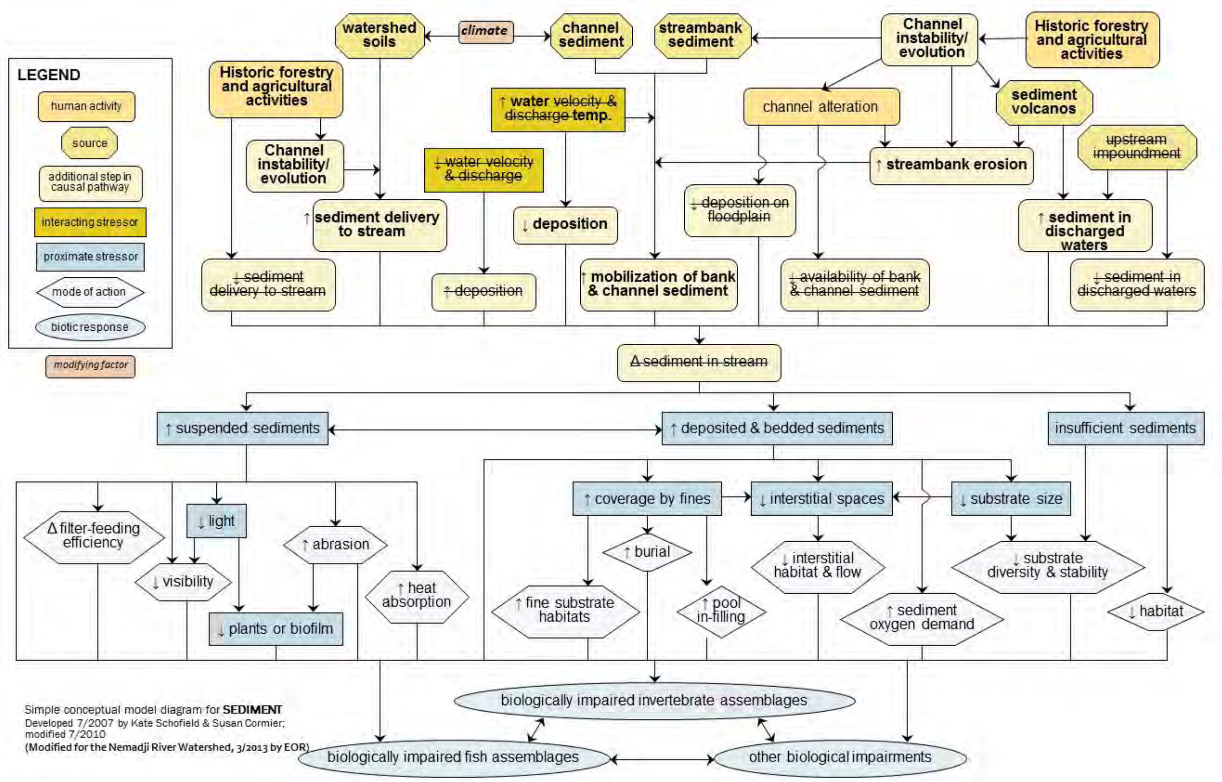


Figure 32. Conceptual model for sediment modified for the Nemadji River Watershed.

3.3.7.4. *Overview of Suspended Solids/ Turbidity in the Nemadji River Watershed*

A central portion of the watershed (adjacent to the mainstem of the Nemadji) is comprised of red clay. These fine lacustrine deposits accumulated 10,000 to 20,000 years ago when glacial Lake Duluth covered the Nemadji basin. The fine red sediment particles are picked up by flowing waters and then stay in suspension for a very long time causing turbidity issues for streams that flow through these red clay soils. For at least two of the impaired streams (Mud and Deer) sediment volcanoes are known to exist. These features are caused by a groundwater upwelling from springs that pick up clay as water moves through the subsurface layer, and then expressed at the surface by turbid water and sediment deposition that resembles volcanoes. The Deer Creek Turbidity TMDL provides significant documentation of the sediment volcanoes on Deer Creek.

The high sediment yield of the Nemadji River Basin is largely a result of historic land use changes that resulted in major flow alterations and subsequent channel instability and evolution (See Section 3.3.1). Channel instability and evolution increase streambank and bluff erosion and slumping. Prolonged turbidity in the Nemadji tributaries results from a residual supply of fine sediment in or near the channel, such as slumped bank material at the toe of the slopes, and the low settling velocities of the red clay soils.

TSS data was available for all streams and, in some cases, collected over many years. In general, TSS concentrations varied across the Nemadji River Watershed. In many of the streams, TSS/ turbidity was high for most of the monitoring season. Deer Creek had extremely high TSS concentrations every month over the period of record (Figure 30). On the Blackhoof River, however, TSS was below water quality standards.

4. Evaluation of Candidate Causes by AUID

4.1. Elim Creek (04010301-501)

Elim Creek is a small, 2.5-mile long tributary of the Nemadji River that is located upstream of the confluence with Skunk Creek. It has a small watershed with a drainage area of 1.94 mi^2 (1,241 acres). Land use within the watershed is approximately 55% forest and wetland with 45% disturbed (38% agriculture/rangeland and 7% developed) (Figure 33).

For the SID process, data was collected at one MPCA station (S007-453) and one biological station (11LS072) (Figure 34). Additionally, continuous stage and temperature measurements were collected in 2013. The majority of Elim Creek (except the headwaters) occurs in the clay zone of the Nemadji River Watershed (Figure 35). Several barriers occur along the reach, including a significant log jam observed upstream of station S007-453.

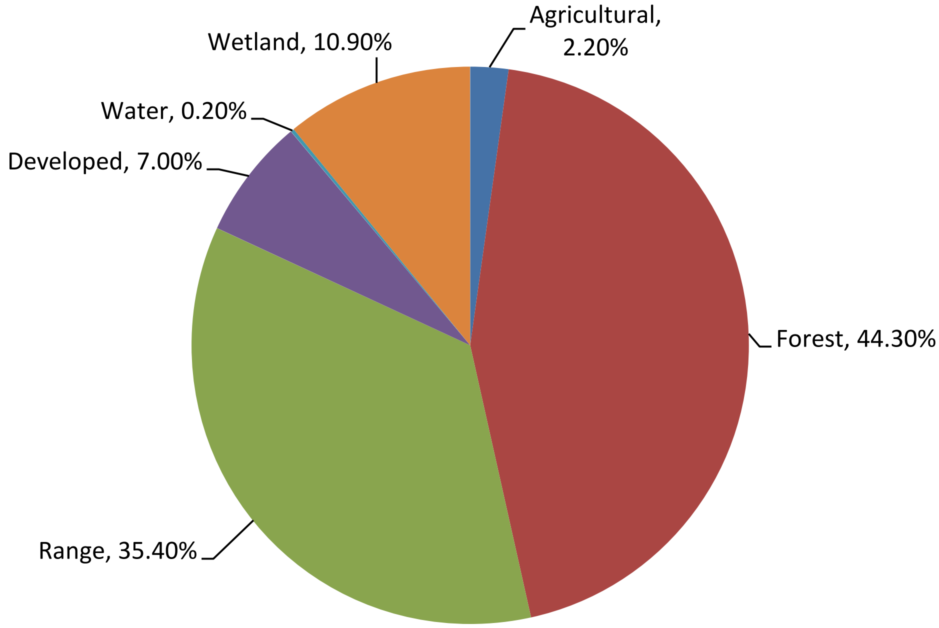


Figure 33. Land cover distribution in the Elim Creek subwatershed

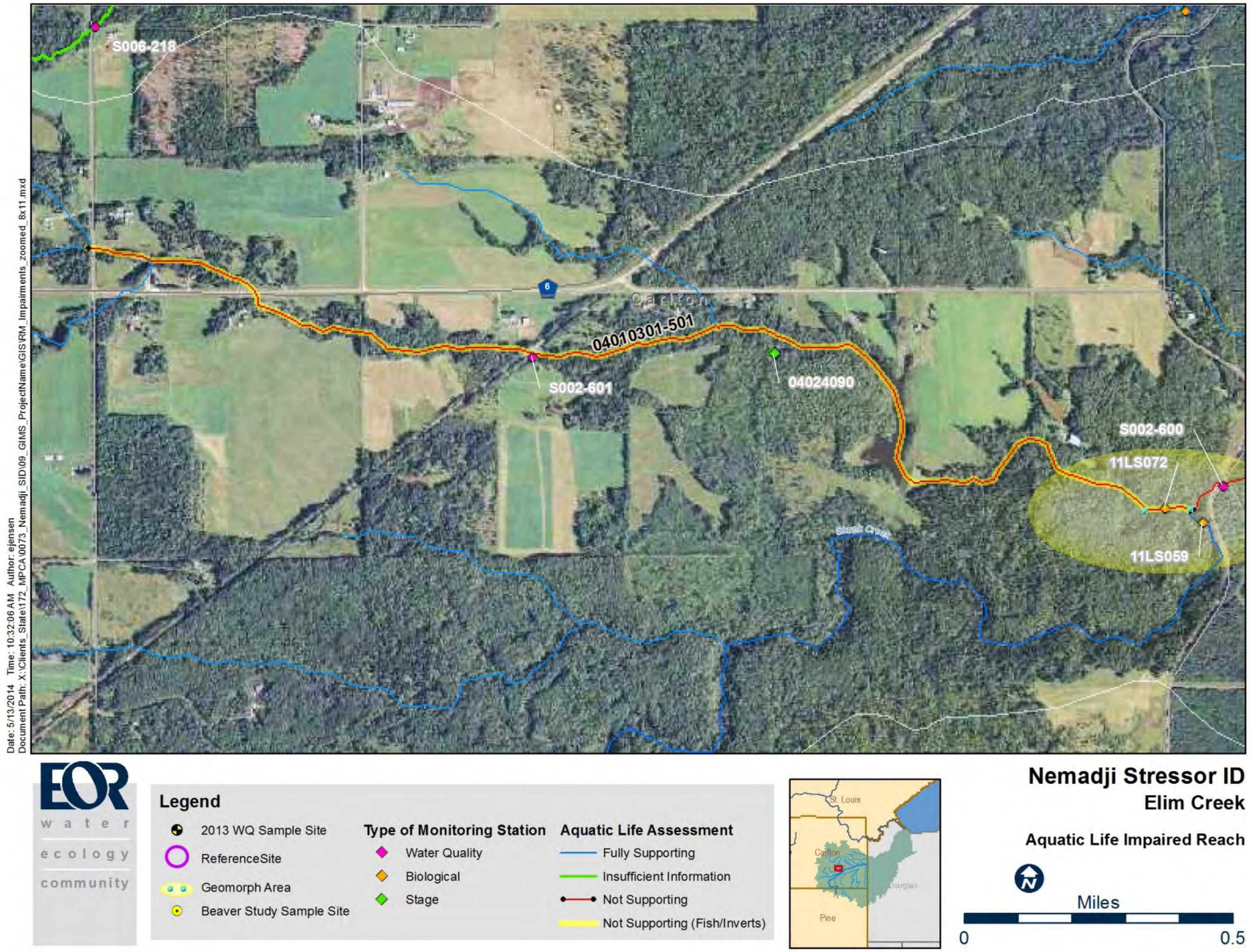


Figure 34. Elim Creek aerial photograph and monitoring station locations

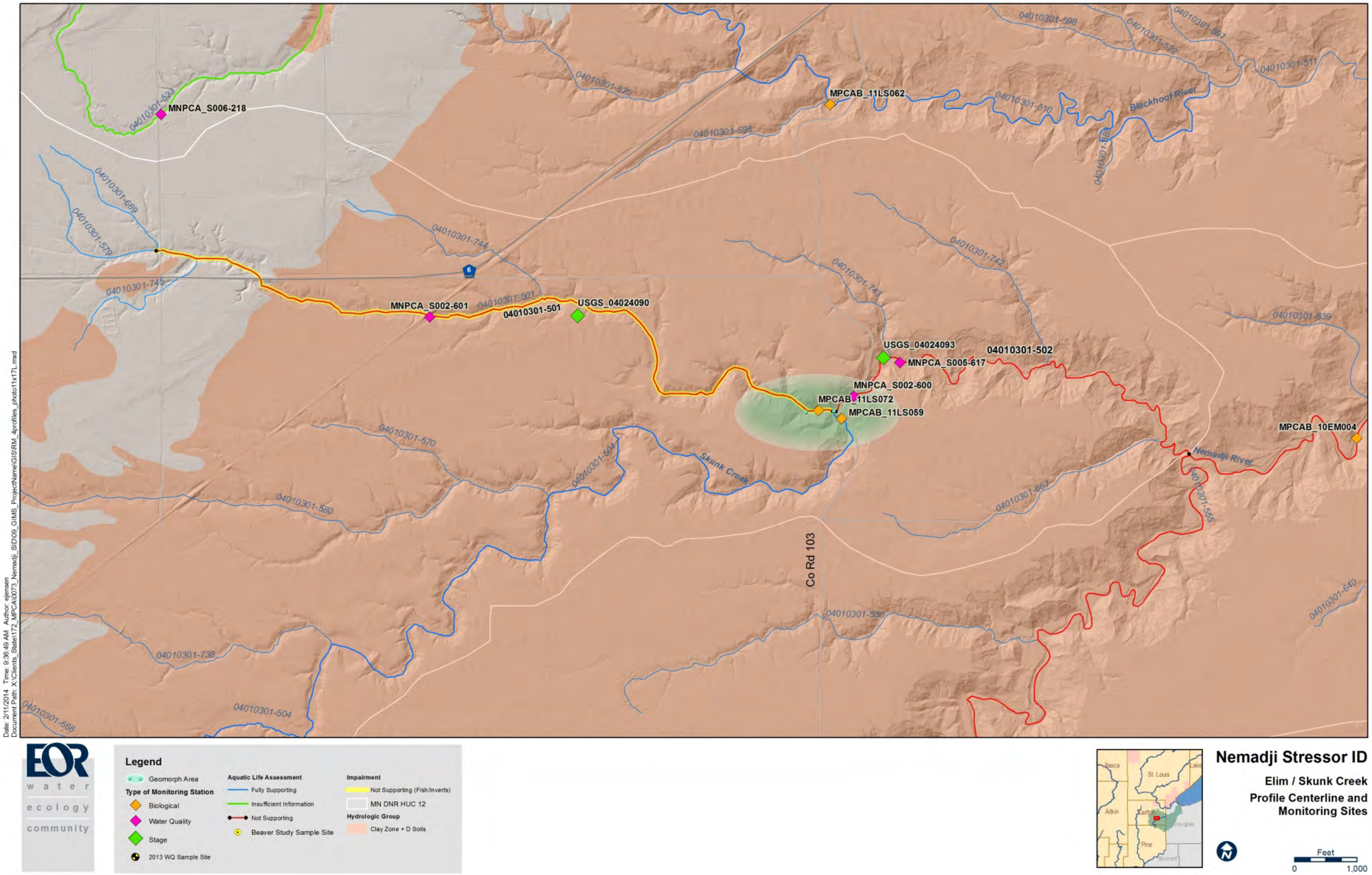


Figure 35. Elim Creek topographic map showing clay zone.

4.1.1. Biological Communities

The fish community was assessed at one site (11LS072) in 2011 during a single visit. The fish IBI score was 20, which is below the threshold and lower confidence interval for Northern Coldwater Streams (Table 5). Six species were sampled during the site visit (Table 13), and the attributes of species observed is in Table 14. The thermal regime is supportive of a brook trout fishery, but none were sampled during the site visit. Physical barriers, including a pipe, perched culverts, log jams, and beaver dams, are also known along the stream and likely limit fish passage. Additionally, in the late summer and fall of 2013 there was lack of sufficient flow and depth to support fish. Elim Creek is non-supporting of a healthy coldwater fish community.

The macroinvertebrate community was assessed at one site (11LS072) during a single visit in 2011. The invertebrate IBI score was 33, which is above the threshold and within the upper confidence interval for Northern Coldwater Streams (Table 69). Several sensitive and intolerant taxa were present (Table 15 and Table 16). Elim Creek is supporting of a healthy coldwater macroinvertebrate community.

Table 13. Fish species sampled in 2011, Elim Creek (11LS072)

Species	Count	Min Length (mm)	Max Length (mm)
bluegill	3	32	36
creek chub	11	38	185
fathead minnow	3	41	47
johnny darter	6	57	67
longnose dace	1	55	55
mottled sculpin	23	29	107

Table 14. Attributes of fish species sampled in 2011, Elim Creek (11LS072)

Attribute	Count
DELT (abnormalities)	0
Darter species	1
Exotic species	0
Fish per 100 m	31.3
Game fish species	1
Gravel spawning species	1
Piscivore species	0
Pollution intolerant species	1
Special concern species	0
Total species	**6**

Table 15. Invertebrate species sampled in 2011, Elim Creek (11LS072)

Invertebrates
black flies
broad-winged damselflies
caddisflies
circular-seamed flies
common stoneflies
crane flies
fingernail clam
long-horn caddisflies
Maccaffertium
mayflies
midges
Nemata
net-spinning daddisflies
Oligochaeta
Orconectes
primitive daddisflies
riffle beetles
trumpet-net caddisflies

Table 16. Attributes of invertebrate species sampled in 2011, Elim Creek (11LS072)

Attributes	Count
EPT Taxa	10
Ephemeroptera Taxa	3
Hilsenhoffs Biotic Index (HBI)	4.9
Intolerant Families	5
Percent Pollution Tolerant	0.3
Percent Chironomidae	22.4
Percent Diptera	46.1
Percent Dominant Taxa	22.4
Percent Dominant Two Taxa	44.8
Percent Filterers	45.1
Percent Gatherer	45.8
Percent Hydropsychidae	22.4
Percent Scraper	4.9
Plecoptera Families	1
Total Families	17
Trichoptera Families	6

4.1.2. Evaluation of Candidate Causes

4.1.2.1. *Historic Flow Alteration*

Most of Elim Creek (04010301-501) passes through the red clay zone (Figure 35) where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). The effects of channel erosion and stream turbidity on aquatic life is confounded by the presence of a large dam and reservoir located upstream of the biological monitoring station. Therefore, historic flow alteration is potentially a stressor to aquatic life in Elim Creek.

4.1.2.2. *Recent Flow Alteration*

Alterations to the hydrologic regime, specifically flow, are likely due to changes in precipitation patterns. As discussed in Section 3.3.2, wet and dry periods have changed with an increase in dry periods and a decrease in wet periods. Flow data collected on Elim Creek indicate that during dry periods in late summer, flows are reduced to almost 0 cfs (Figure 36).

Additionally, fragmentation of habitat caused by dams, culverts, log jams, and beaver activity are affecting flow upstream and downstream of the biological monitoring site. The profile of Skunk Creek and Elim Creek illustrates the location of the Elim Dam and a dam constructed on Skunk Creek, downstream of Elim Creek (Figure 37). The Elim Dam, initially constructed to manage channel incision in the clay zone, is likely leading to flow alterations in Elim Creek.

In addition, there were no invertebrate swimmers sampled in 2011. Swimmers would not be expected in stream reaches that do not maintain pools or flowing water. Elim Creek also had a greater percent of non-lithophilic spawners and one of the lowest percent of lithophilic spawners compared to other unimpaired stream reaches in the Nemadji Watershed in 2011. Few lithophilic spawners indicate a lack of clean gravel or cobble in a stream that are kept clean by flowing water. Other fish and invertebrate metrics that are sensitive to flow alterations, such as % EPT and % long-lived invertebrates, or very tolerant of flow alterations, such as % generalist fish, were comparable to other unimpaired stream reaches in the Nemadji River Watershed in 2011.

Therefore, recent flow alterations are potentially a stressor to aquatic life in Elim Creek.

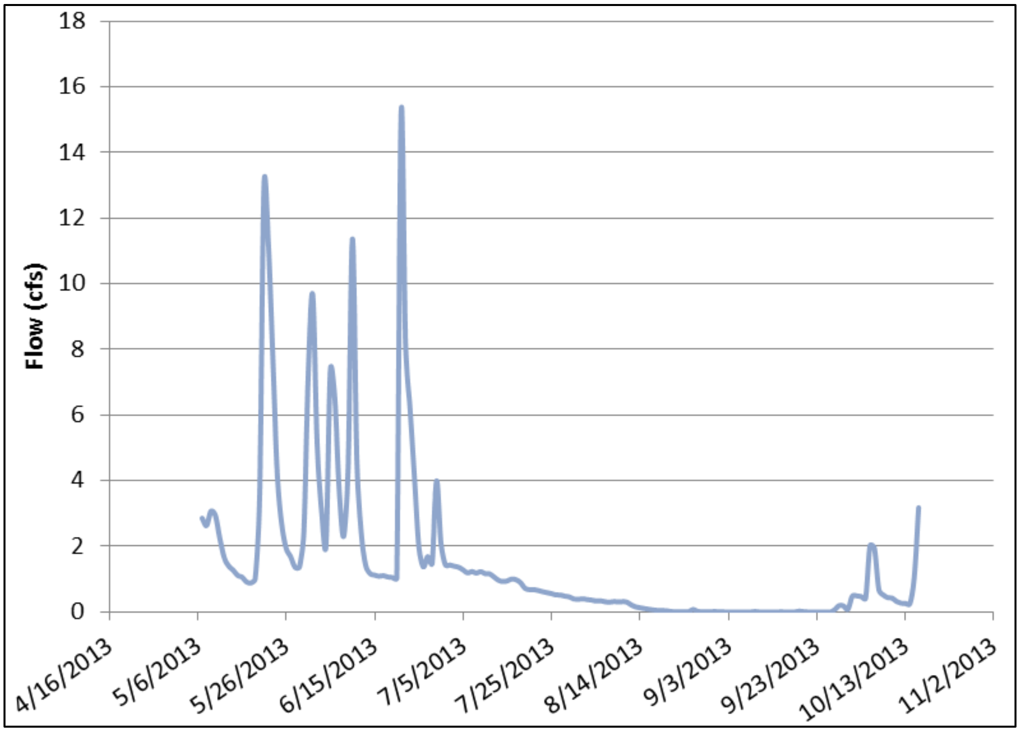


Figure 36. Continuous flow data collected on Elim Creek in 2013

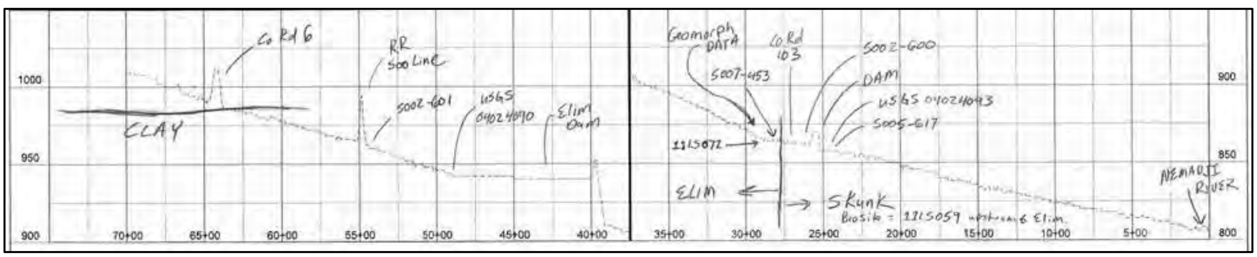


Figure 37. Elim and Skunk Creek stream cross section profile based on LiDAR data

Figure 38. Elim Creek, August 2013

4.1.2.3. *Physical Habitat Quality*

Physical habitat quality in Elim Creek was rated fair during the MSHA conducted by EOR in September 2013 and by MPCA in 2011 (Table 17). Fish cover had the lowest relative score, followed by channel morphology, and substrate. Fish cover could be improved in this reach, but the stream bed appears to have sufficient habitat diversity to support a healthy macroinvertebrate assemblage.

Elim Creek is located upstream of the confluence with Skunk Creek. Channel incision occurred below a large log jam located approximately 200 feet upstream of the confluence. The BEHI rating completed for the site below the log jam scored very low (Table 18). Just upstream of the log jam, the stream channel was not rapidly eroding and contained well vegetated, shallow-sloped banks. Large woody debris occurred within the pools with ample source material within the floodplain. Bed materials consisted primarily of large gravels and small cobbles, and instream habitat consisted of fairly long riffles and small pools. However, the stream is incised and eroding upstream of the Elim Dam and physical habitat is likely poorer upstream of the Elim Dam than near the biological monitoring site.

In addition, Elim Creek had one of the lowest percent of lithophilic spawners compared to other unimpaired stream reaches in the Nemadji Watershed in 2011. Few lithophilic spawners indicate a lack of clean gravel or cobble kept clean of sediment. In the case of Elim, low flow limits the available extent of washed gravel and cobble.

Therefore, physical habitat quality is potentially a stressor to aquatic life throughout Elim Creek.

Table 17. Elim Creek MSHA ratings

MSHA Survey	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
EOR 2013	5	15	19	4	18	61	Fair
MPCA 2011	5	13	19.7	5	20	62.7	Fair

Table 18. Elim Creek Bank Erosion Hazard Index (BEHI) score (EOR 2013)

Stream name	Bank height/ Bankfull height	Root depth/ Study bank height	Weighted root density	Bank angle	Surface protection	Total BEHI Score	BEHI Descriptor
Elim Creek above log jam	1	1.9	3.5	2	1	9.4	Very low

4.1.2.4. *Habitat Fragmentation*

Significant barriers (numerous dams, perched culverts and log jams) along Elim Creek likely inhibit fish passage, especially during low flows (Figure 39). A pipe barrier located below the biological monitoring site on Skunk Creek, may also be limiting fish passage. Trout have been observed just below the barrier, but not above, a major factor driving down the F-IBI score. Skunk Creek above the barrier is dominated by mottled sculpin and other sensitive species (longnose dace and pearl dace). Due to the isolation of fish species above the pipe barrier, habitat fragmentation was identified as the primary stressor to aquatic life in Elim Creek.

Figure 39. Log jam acting as a fish barrier on Elim Creek; facing downstream (above) and upstream (below)

4.1.2.5. *Suspended Solids/ Turbidity*

Mean total suspended solids concentrations on Elim Creek over the 10 year period (2003-2012) exceeded the TSS coldwater standard of 10 mg/L for every month during the growing season except September (Table 19). Overall, August had the highest TSS concentrations with up to 100 mg/L of TSS. TSS data collected on Elim Creek in 2013 followed a similar seasonal trend in TSS concentrations compared to long-term records. TSS concentrations were highest in late August, but lowest in September (Figure 40). A portion of Elim Creek passes through the clay zone which is likely contributing TSS. However, TSS concentrations are not as high as compared to other impaired reaches in the Nemadji River Watershed. BEHI scores indicate that bank erosion is low at the site of the geomorphic survey (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information).

In addition, the fish community TSS tolerance index score (11.65; Table 74) was slightly greater than the median score (11.44; Table 73) for all fish class 11 streams in the state, suggesting that the fish community has mid-level tolerance for TSS. Other fish and invertebrate metrics that are sensitive to high turbidity, such as % EPT, % collector-filterer invertebrates, and % tolerant fish were comparable to other unimpaired stream reaches in the Nemadji River Watershed in 2011.

While TSS concentrations exceed the TSS coldwater standard of 10 mg/L, TSS is not likely driving the low invertebrate and fish IBI scores in Elim Creek relative to the more pronounced impacts that flow alteration, physical habitat quality, and habitat fragmentation are having on the health of the biological community. It is also important to note that water quality standards are based on a range of acceptable conditions that support a beneficial use (such as aquatic life), with the standard chosen to be conservatively protective. As a result, suspended solids/ turbidity is not likely a stressor to aquatic life in Elim Creek.

Table 19. TSS concentration summary for Elim Creek (2003-2012)

Station	Month	Mean	#	Min	Max
S007-453	May	21	1	21	21
	June	47	2	18	76
	August	56	2	12	100
	September	5.2	2	4	6.4
	October	16	1	16	16

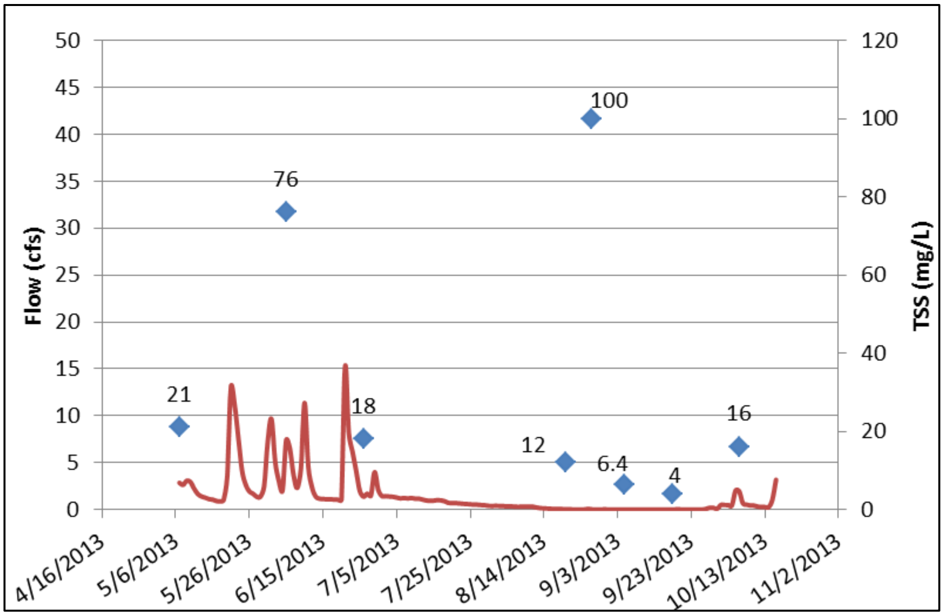


Figure 40. TSS concentrations in Elim Creek, 2013

4.1.3. Summary

Table 20. Summary of candidate causes of stress to the biological community of Elim Creek

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	Past land use changes caused channel instability & evolution	Potentially a stressor	
Recent Flow Alteration	Dam and reservoir constructed to manage channel incision	Potentially a stressor	
Physical Habitat	Stable channel at bio site; incising channel upstream of dam	Potentially a stressor	
Habitat Fragmentation	**Large dam upstream and pipe barrier near confluence with Skunk Ck**	**Primary stressor**	« «
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Supportive to aquatic life	Not a stressor	
TSS/ Turbidity	Partly in clay zone but TSS levels not as high as other turbid creeks	Not likely a stressor	

4.2. Rock Creek (04010301-508)

Rock Creek is a 3.9-mile long tributary to the Nemadji River. Over half of the land use within the subwatershed is undeveloped forest and wetlands, and the remaining 45% is primarily agricultural, including row-crops and pasture (Figure 41). The drainage area is 4.8 square miles (3,086 acres). For the SID process, data was collected from one MPCA water quality monitoring station (S003-251) and one biological monitoring station (11LS063) (Figure 42). This reach was located downstream of MN 23 and occurs within the clay region of the watershed (Figure 43).

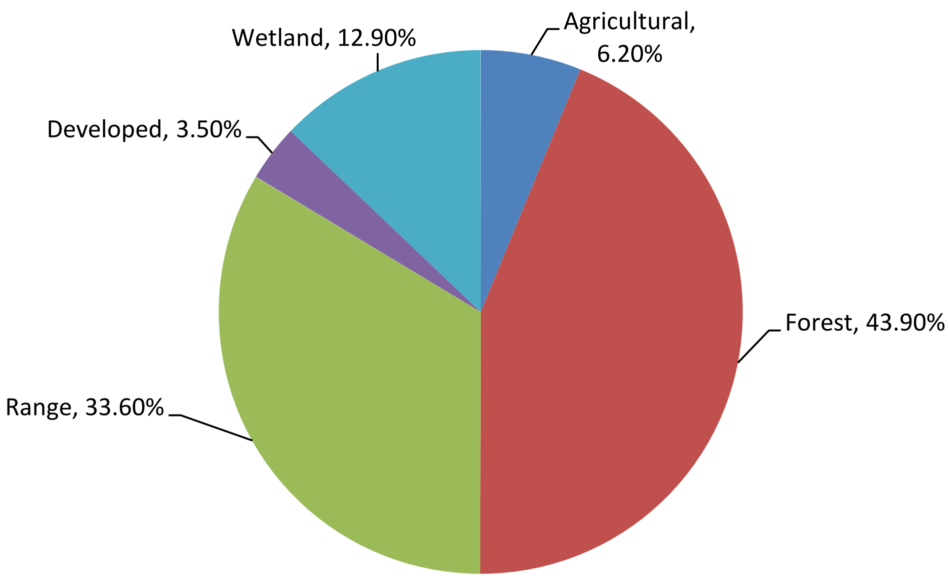


Figure 41. Land cover distribution in the Rock Creek subwatershed

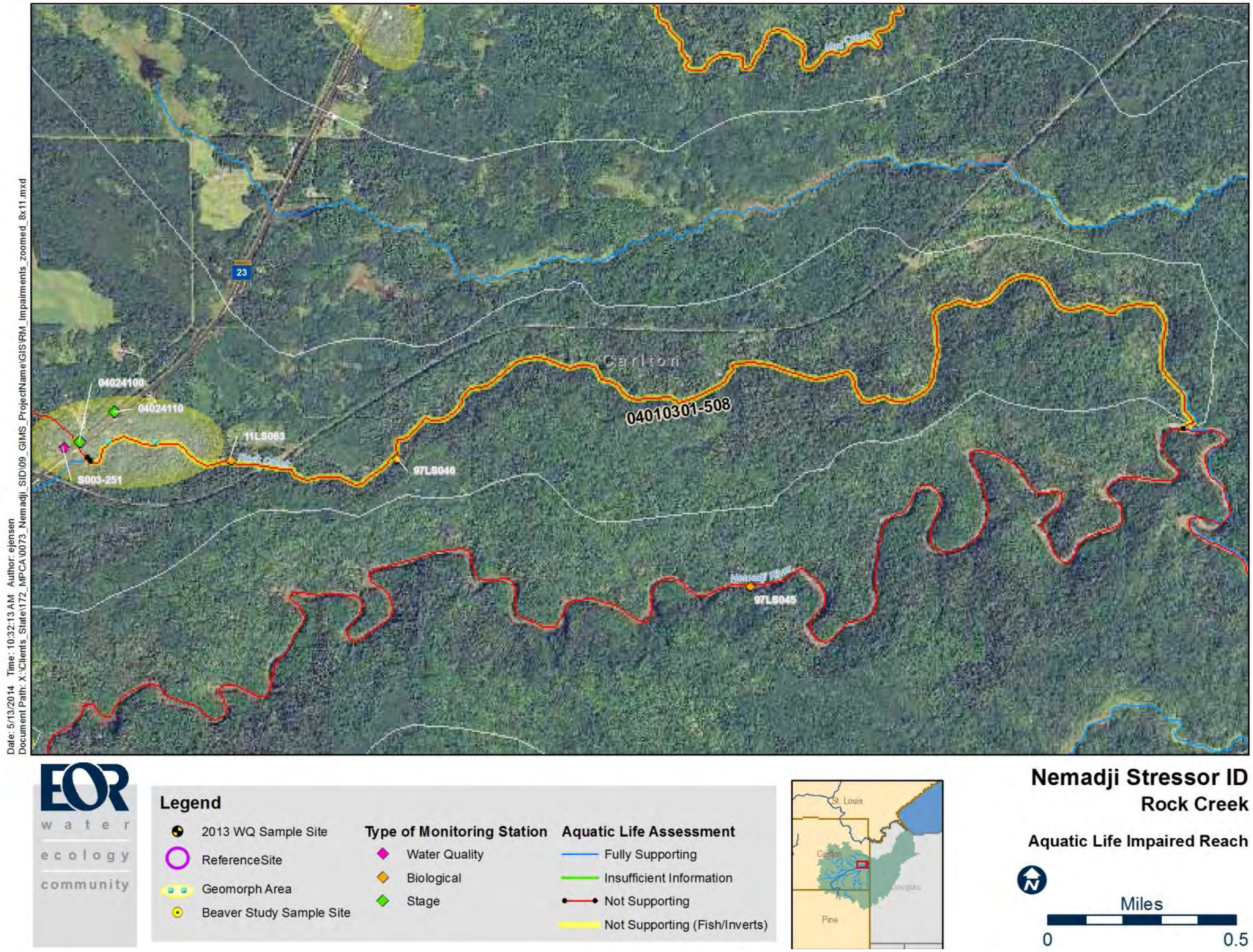


Figure 42. Rock Creek aerial photograph and monitoring station locations

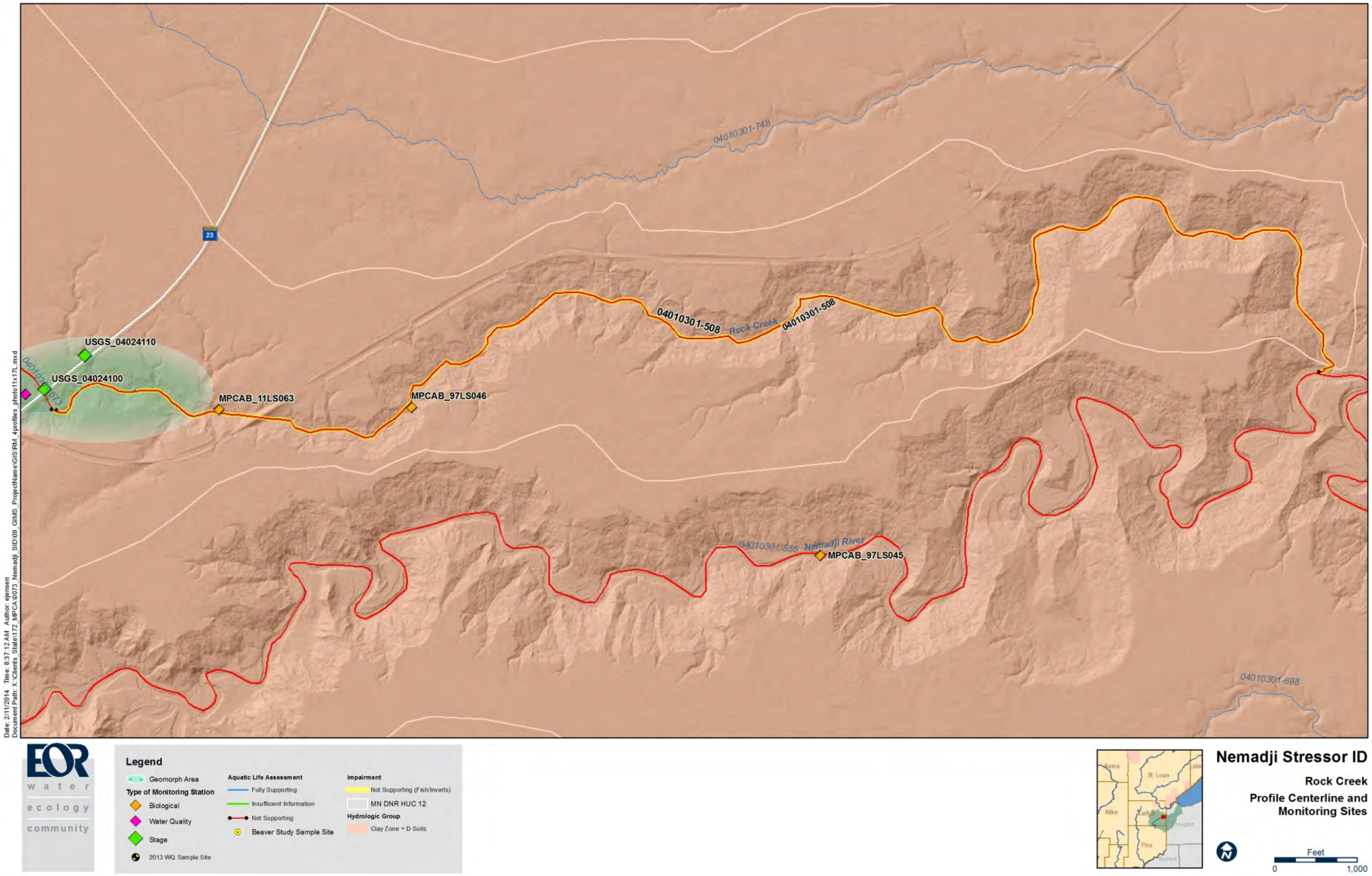


Figure 43. Rock Creek topographic map showing clay zone

4.2.1. Biological Communities

The fish community was assessed at one site (11LS063) during a single visit in 2011. The fish IBI score was 37, which is at the threshold for Northern Coldwater Streams (Table 5). The fish community was dominated by creek chubs and common shiners (70%) (Table 21 and Table 22). Minnesota Department of Natural Resources staff suggested that the thermal regime is supportive of a brook trout fishery, but no trout were observed with very few cold/coolwater obligate species captured. Minnesota Pollution Control Agency Stream Habitat Assessment (MSHA) showed that the habitat within this reach was in good condition (68 out of 100). During fish sampling water seemed to be very turbid (turbidity tube reading of 44.5), and bank erosion was noted throughout reach. Rock Creek is non-supporting of a healthy coldwater fish community.

The macroinvertebrate community was assessed at one site (11LS063) during a single visit in 2011. The macroinvertebrate IBI score was 16, which is below the impairment threshold and within the lower confidence interval for Northern Coldwater Streams (Table 69). The aquatic macroinvertebrate community contains several tolerant/very tolerant taxa (Table 23, Table 24). At the time of sampling, bank erosion and woody debris dams were observed, which likely reflects the flashiness of this stream. Rock Creek is non-supporting of a healthy coldwater macroinvertebrate community.

Table 21. Fish species sampled in 2011, Rock Creek (11LS063)

Species	Count	Min Length (mm)	Max Length (mm)
blacknose dace	36	30	82
brook stickleback	1	45	45
common shiner	78	26	121
creek chub	159	28	223
fathead minnow	4	58	63
hornyhead chub	2	77	104
johnny darter	6	35	57
longnose dace	5	75	89
mottled sculpin	7	53	97
trout-perch	14	77	95
white sucker	14	86	154

Table 22. Attributes of fish species sampled in 2011, Rock Creek (11LS063)

Attribute	Count
DELT (abnormalities)	0
Darter species	1
Exotic species	0
Fish per 100 m	206.3
Game fish species	0
Gravel spawning species	4
Piscivore species	0
Pollution intolerant species	1
Special concern species	0
Total species	11

Table 23. Invertebrate species sampled in 2011, Rock Creek (11LS063)

Invertebrate Species
black flies
broad-winged damselflies
chiggers
crane flies
gastropods
Maccaffertium
mayflies
midges
net-spinning caddisflies
Oligochaeta
Orconectes
riffle beetles
snail-case caddisflies
Thienemannimyia Gr.

Table 24. Attributes of invertebrate species sampled in 2011, Rock Creek (11LS063)

Attributes	Count
EPT Taxa	5
Ephemeroptera Taxa	3
Hilsenhoffs Biotic Index (HBI)	4.9
Intolerant Families	1
Percent Pollution Tolerant	0
Percent Chironomidae	24.9
Percent Diptera	39.6
Percent Dominant Taxa	35.5
Percent Dominant Two Taxa	60.4
Percent Filterers	48.9
Percent Gatherer	42.5
Percent Hydropsychidae	35.5
Percent Scraper	5.8
Plecoptera Families	0
Total Families	11
Trichoptera Families	2

4.2.2. Evaluation of Candidate Causes

4.2.2.1. *Historic Flow Alteration*

All of Rock Creek (04010301-508) passes through the red clay zone (Figure 43) where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). Channel instability from historic flow alteration in the watershed has resulted in high sediment loads, high turbidity, poor habitat quality, embedded gravel, and sometimes even loss of temperature and connectivity. Therefore, historic flow alteration is a primary stressor to aquatic life in Rock Creek.

4.2.2.2. *Recent Flow Alteration*

During summer months (July through August), flow in Rock Creek is reduced to nearly 0 cfs (Figure 44). Compared to other impaired streams, the Rock Creek watershed is smaller and lacks significant water storage in the form of lakes and wetlands in the headwaters. The lack of storage and high precipitation runoff rates for non-forested clay soil in this watershed has resulted in extremely low summer baseflows.

In addition, there was a low percent of invertebrate swimmers and a high percent of generalist fish and percent non-lithophilic spawners sampled in 2011. Swimmers would not be expected in stream reaches that do not maintain pools or flowing water, non-lithophilic spawners do not require clean gravel or cobble in a stream that are kept clean by flowing water, and generalist fish species are tolerant to flow alterations.

As a result, the altered flow regime for Rock Creek is a primary stressor to aquatic life in Rock Creek.

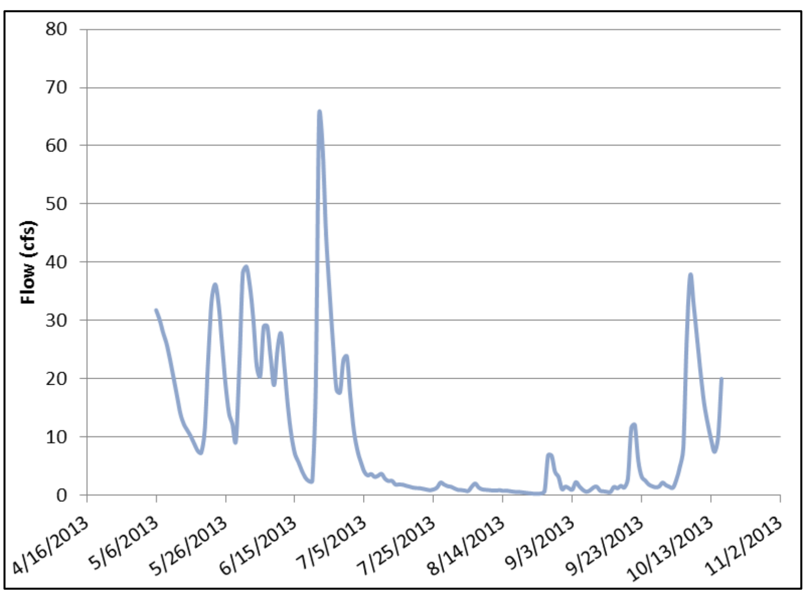


Figure 44. Continuous flow monitoring, Rock Creek (2013)

4.2.2.3. *Physical Habitat Quality*

In-stream habitat was assessed in September 2013 near the MN 23 crossing. Cobble and gravel dominated riffles and several deep pools were noted. Large woody material was mostly absent within the stream channel but smaller branches and logs were observed in the pools. At the time of the habitat assessment, a MSHA was also conducted and the overall rating was fair (Table 25). Substrate, fish cover, and channel morphology were all rated fairly low. Rock Creek occurs within the clay region of the watershed. A significant bank slump is present below MN 23 at the upstream end of the reach, and the degree of channel incision and sedimentation increases downstream of the geomorphic survey site (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information). Few trees exist on the slump and significant erosion is occurring near the toe of the slope. The BEHI ranged from high to moderate at two sites on Rock Creek (Table 26). The stream channel is beginning to incise at MN 23 and becomes entrenched further downstream, with bed material composition transitioning to sand and silt.

In addition, the fish community was dominated by the pioneer species creek chubs and the macroinvertebrate community was comprised of tolerant species that can survive in disturbed or degraded habitats. Other fish and invertebrate metrics that are sensitive to physical habitat quality, such as % clinger invertebrates and % benthic insectivore fish were comparable to other unimpaired stream reaches in the Nemadji River Watershed in 2011. Therefore, poor physical habitat quality is likely a stressor to aquatic life in Rock Creek.

Table 25. Rock Creek MHSA ratings

MSHA Survey	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
EOR 2013	5	11	12	9	16	53	Fair
MPCA 2011	4.5	11	16.3	13	23	67.8	Good

Table 26. Rock Creek Bank Erosion Hazard Index (BEHI) score (EOR 2013)

Stream name	Bank height/ Bankfull height	Root depth/ Study bank height	Weighted root density	Bank angle	Surface protection	Total BEHI Score	BEHI Descriptor
Rock Creek in slump bluff area	7.8	7	8.8	5	6	34.6	High
Rock Creek beyond slumps	7	4.5	6.5	3	2	23	Mod

4.2.2.4. *Habitat Fragmentation*

A review of aerial photographs shows that several barriers, including current and historic beaver dams or log jams, occur on Rock Creek and likely impede fish movement. In addition, a SOO line culvert may also impede fish movement (Figure 45), and the DNR is repairing an improperly sized box culvert downstream of MN 23. Consequently, there is some evidence to suggest that habitat fragmentation is potentially a stressor to aquatic life in Rock Creek. However, further study is needed to determine fish barriers and confirm locations of coldwater fish refuges in the headwater tributaries of Rock Creek.

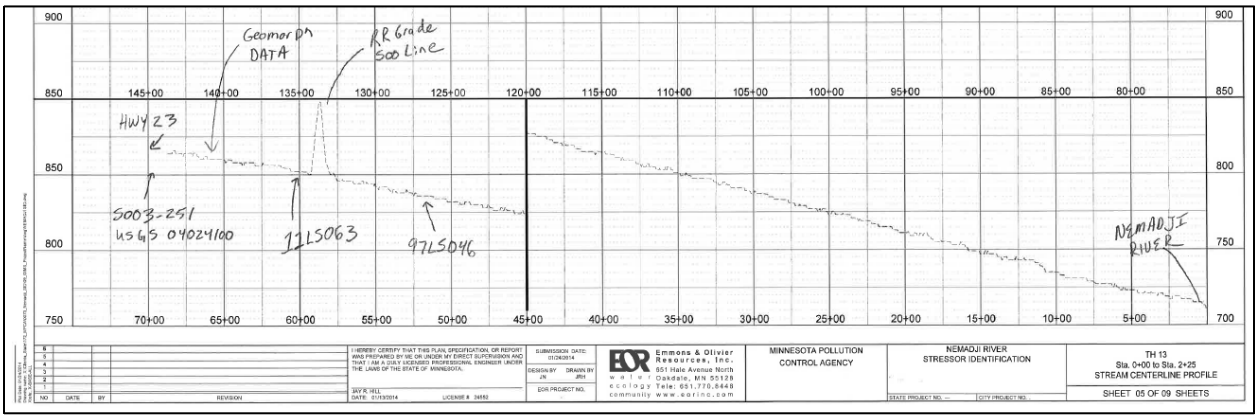


Figure 45. Rock Creek cross section profile based on LiDAR data

4.2.2.5. *Dissolved Oxygen*

Minimum DO concentrations monitored between 2003 and 2012 in Rock Creek are below 7 mg/L during the growing season (June – September, Table 27). In 2013, all DO samples were greater than 7 mg/L, even during low flows (Figure 46). According to the MDNR, DO is low near a perched culvert in Rock Creek, but there is not enough evidence to suggest that dissolved oxygen concentrations are low along the entire impaired reach.

The fish community DO tolerance index score (7.24; Table 74) is near the median score for all streams of that class (7.35; Table 72) in the state suggesting that the fish community has mid-level DO tolerance, and the invertebrate community DO tolerance index score (7.57; Table 74) is near the 75th percentile score for all streams of that class in the state (7.61; Table 72) suggesting that the invertebrate community is not DO tolerant. Therefore, dissolved oxygen is not likely a stressor to aquatic life in Rock Creek.

Table 27. DO concentration summary for Rock Creek at station S003-251 (2003-2012)

	Dissolved Oxygen (mg/L)		
Month	#	Min	Max
February	1	12.5	12.5
March	3	15.8	17.0
April	6	9.8	18.0
May	9	8.7	12.7

Month	Dissolved Oxygen (mg/L)		
	#	Min	Max
June	14	5.3	11.4
July	6	6.1	9.2
August	14	5.2	10.9
September	9	6.7	10.4
October	2	10.4	11.6
November	2	12.5	13.4

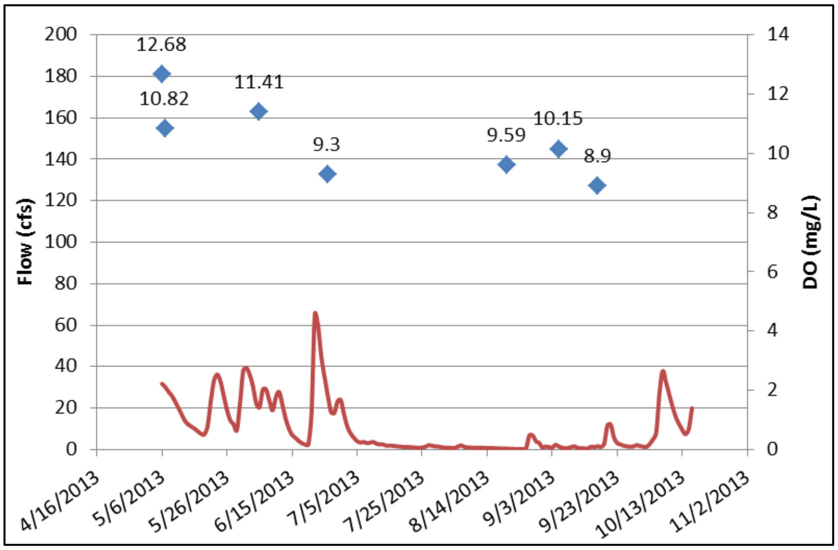


Figure 46. 2013 DO data compared to flow on Rock Creek

4.2.2.6. *Water Temperature*

Monthly temperature data was collected at one station on Rock Creek between 2003 and 2012. Average monthly temperatures did not exceed the stressful range for trout (Table 28). Stressful temperatures occurred 15% of time during summer months in 2009-2011 according to monitoring data collected by the MDNR. Average daily temperatures measured in 2013 exceeded the stressful range for long periods of time between late June and late August in the headwaters, but not further downstream, and daily maximum temperatures reached the lethal range on several occasions during the growing season of 2013 (Figure 48). Water temperatures on Rock Creek were compared to water temperatures on the South Fork Nemadji in the late summer of 2013. Temperatures on the South Fork Nemadji did reach into the stressful range in late August, but did not reach the lethal range as on Rock Creek (Figure 48). MDNR staff indicated that the thermal regime is supportive of a Brook Trout fishery, but no trout were observed with very few cold/coolwater obligate species captured during the 2011 biological assessment. High water temperature is a primary stressor to aquatic life in Rock Creek. Further study is needed to confirm locations of coldwater fish refuges in the headwater tributaries of Rock Creek that require protection.

Table 28. Water temperature data summary in Rock Creek at station S003-251 (2003-2012)

Month	Water Temperature (°C)			
	Mean	#	Min	Max
February	0.2	1	0.2	0.2
March	0.0	5	0.0	0.2
April	3.9	9	-0.1	9.1
May	10.3	11	4.8	20.4
June	14.2	19	9.0	19.0
July	17.3	7	15.8	19.4
August	18.3	16	14.4	23.2
September	14.6	13	11.2	19.3
October	8.2	2	7.9	8.5
November	2.3	2	1.5	3.1

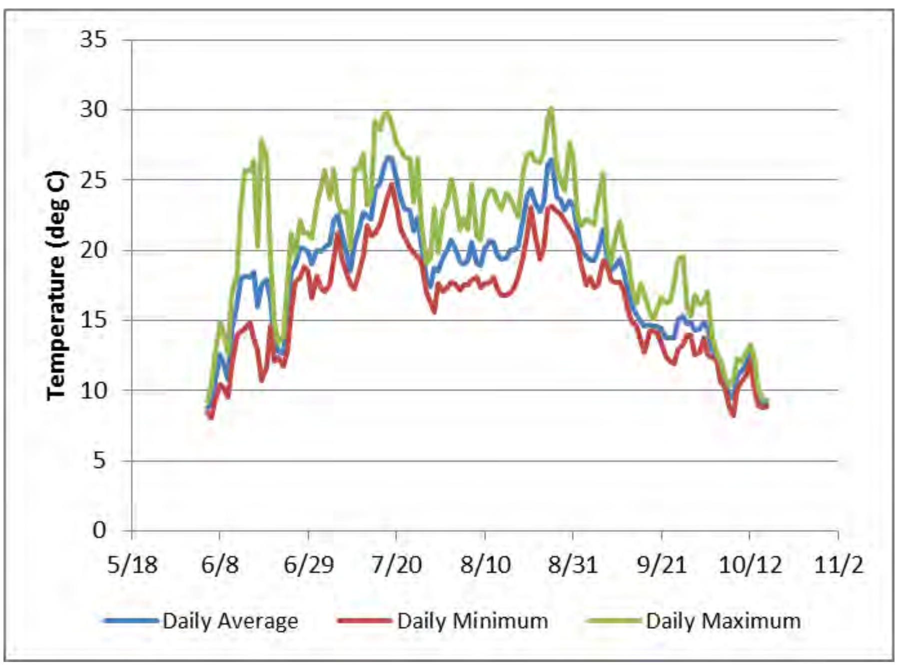


Figure 47. 2013 continuous water temperature in Rock Creek

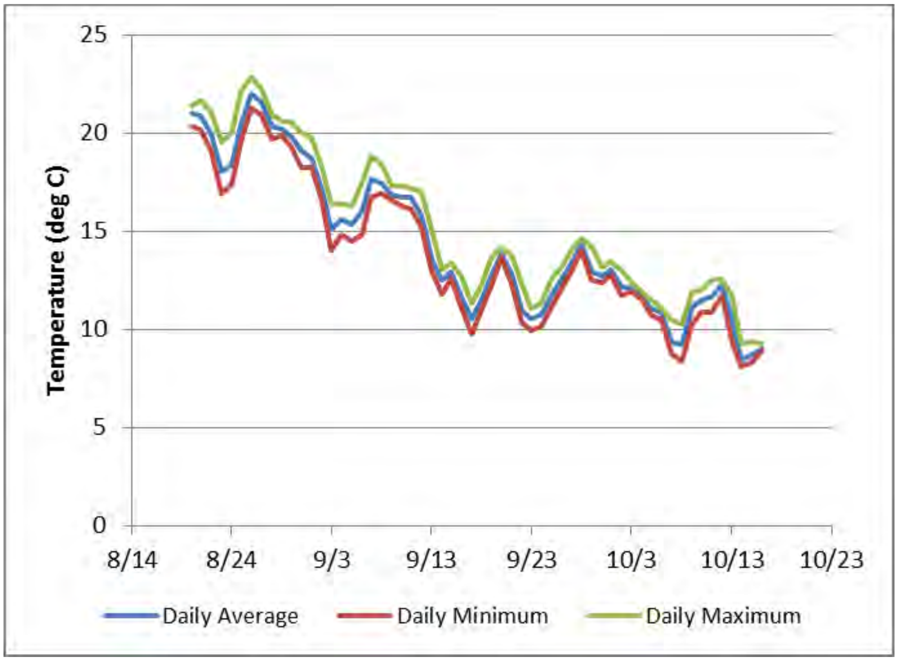


Figure 48. 2013 continuous water temperature in South Fork Nemadji River

4.2.2.7. *Suspended Solids/ Turbidity*

Total suspended solids data was collected at one station by MPCA between 2003 and 2012. Mean TSS concentrations exceeded the standard of 10mg/L in all months that data was collected (Table 29). Rock Creek was compared to the unimpaired reference reach, South Fork Nemadji River. The ten year monthly data indicate that TSS concentrations were significantly higher on the South Fork Nemadji River for April through June than on Rock Creek, with concentrations > 1200 mg/L. However, TSS was higher on Rock Creek later in the growing season.

Rock Creek is a visibly turbid stream (Figure 49). Rock Creek passes through the clay zone of the Nemadji River Watershed, which likely contributes to increased levels of TSS. Bank erosion BEHI scores were moderate to high at two sites on Rock Creek (Table 26). The fish and invertebrate community TSS tolerance index scores (Table 74) are both greater than the 75th percentile of all streams with the same class in the state (Table 73) suggesting that the fish and invertebrate community have high TSS tolerance. Therefore, suspended sediments and turbidity are a primary stressor to aquatic life in Rock Creek.

Table 29. TSS concentration summary for Rock Creek and South Fork Nemadji (2003-2012)

		Total Suspended Solids (TSS, mg/L)			
Stream	Month	Mean	#	Min	Max
Rock Creek	March	25.4	5	20.0	37.0
	April	48.3	16	6.0	360.0
	May	49.1	14	5.0	225.0

Stream	Month	Total Suspended Solids (TSS, mg/L)			
		Mean	#	Min	Max
Rock Creek	June	65.2	18	6.0	320.0
	July	33.2	6	14.0	105.0
	August	77.9	15	8.0	470.0
	September	21.6	14	6.0	110.0
	October	108.0	7	9.0	254.0
	November	17.5	2	12.0	23.0
South Fork Nemadji	March	24.0	1	24.0	24.0
	April	104.3	3	15.0	282.0
	May	253.9	11	11.0	1240.0
	June	210.4	9	6.0	1130.0
	July	20.8	4	13.0	28.0
	August	51.2	9	5.2	166.0
	September	14.7	7	8.0	30.0
	October	24.9	7	5.0	73.0

Figure 49. Rock Creek (2013)

4.2.3. Summary

Table 30. Summary of candidate causes of stress to the biological community of Rock Creek

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	**Lack of headwater storage & recent climate change contribute to extremely low baseflows**	**Primary stressor**	« «
Physical Habitat	Bank slump below MN 23, lack of woody material, channel incision	Likely a stressor	«
Habitat Fragmentation	Current and historic beaver dams and log jams present	Potentially a stressor	
Dissolved Oxygen	Low near a perched culvert, but overall supportive to aquatic life	Not likely a stressor	
Water Temperature	**Frequent stressful temps, lethal temps on occasion**	**Primary stressor**	« «
TSS/ Turbidity	**TSS levels very high (up to 1200 mg/L); stream in clay zone**	**Primary stressor**	« «

4.3. Blackhoof River (04010301-519)

The Blackhoof River begins in a wetland complex at the northern edge of the Nemadji River Watershed. Five miles of the Blackhoof River is impaired between the headwaters and Ellstrom Lake. The subwatershed has a drainage area of 13.34 square miles with many wetlands. Several impoundments and barriers occur along the reach due to beaver activity. Approximately 30% of the watershed is agricultural or developed, and the remaining 70% is forested or wetlands (Figure 50).

Two MPCA monitoring stations (S007-452 and S007-195) and 1 biological monitoring station (90LS031) were visited in 2011 for the SID process (Figure 51). Station S007-452 is located upstream on the Wait property and S007-195 is downstream near CR4. The impaired portion of the Blackhoof River does not pass through the red clay zone. (Figure 52).

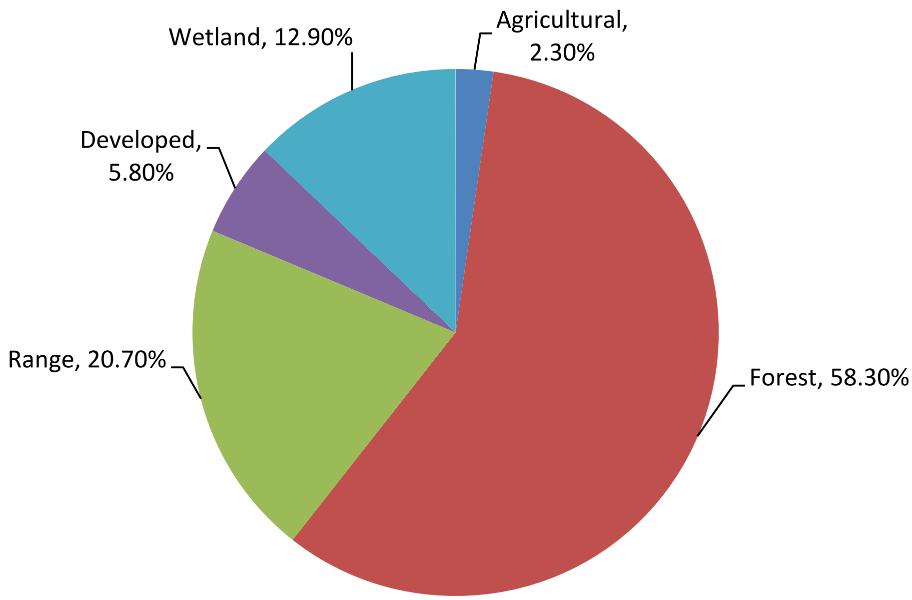


Figure 50. Land cover distribution the upper Blackhoof River subwatershed

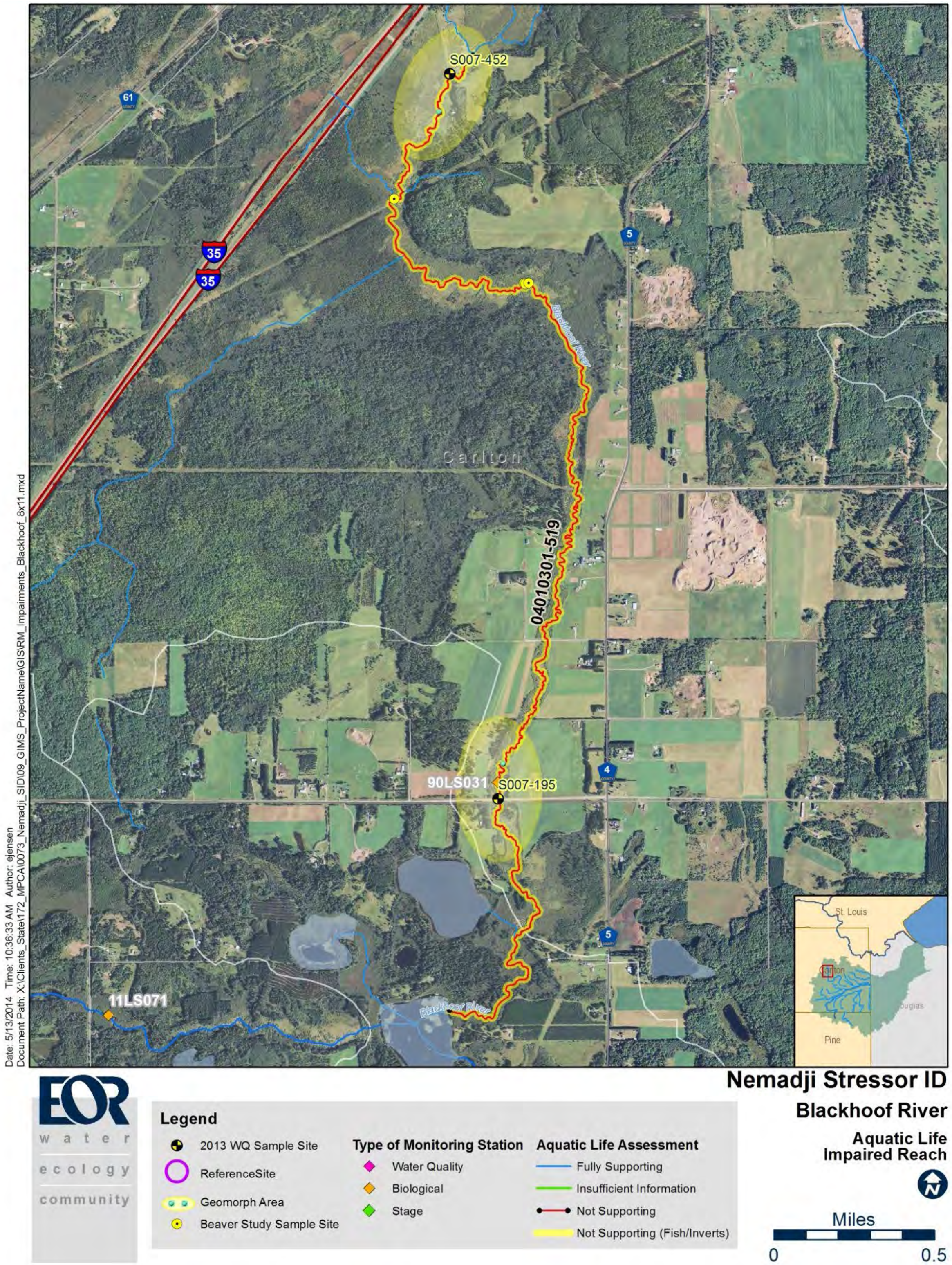


Figure 51. Upper Blackhoof River aerial photograph and monitoring station locations

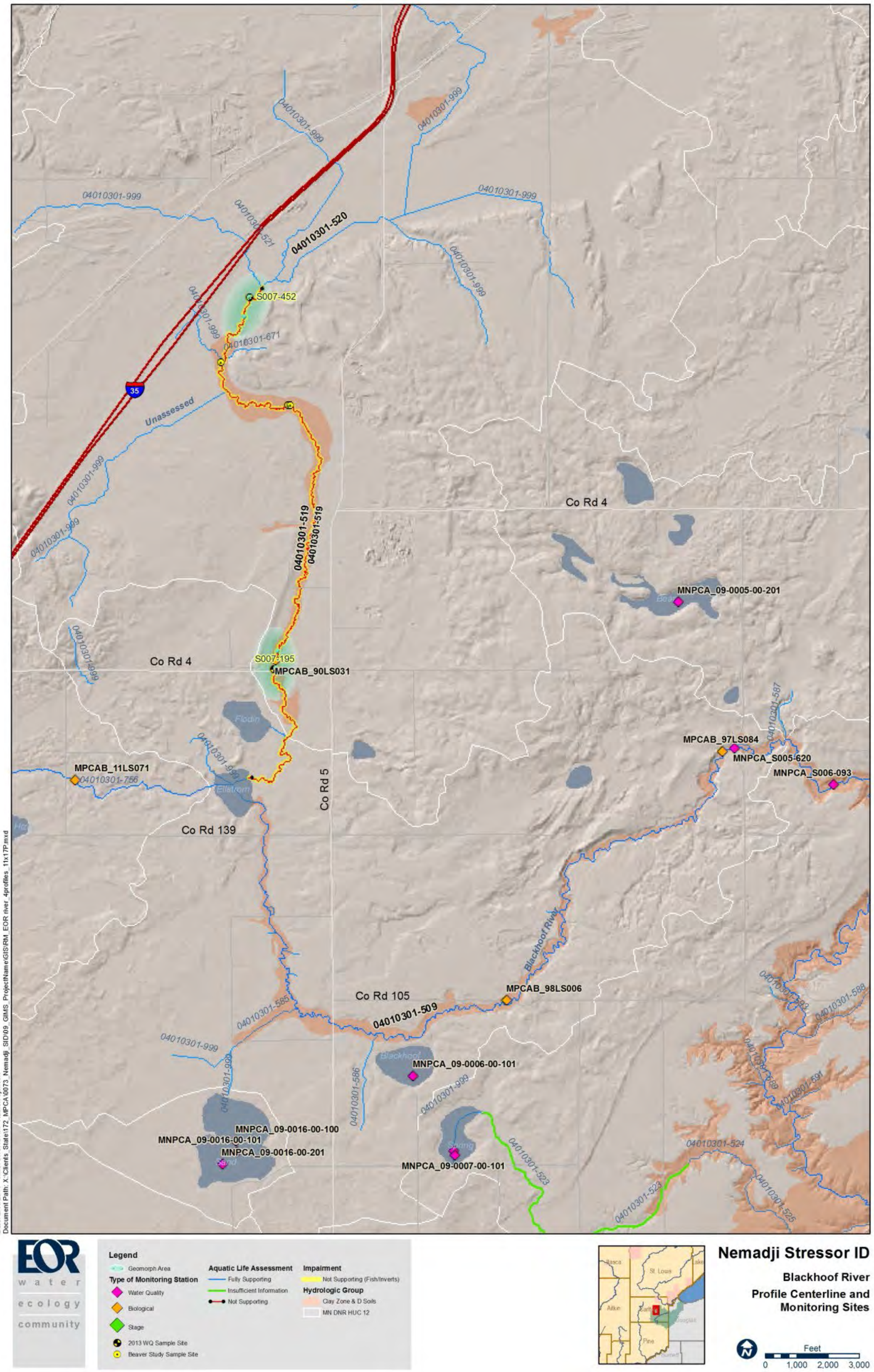


Figure 52. Blackhoof River topographic map showing the wetland soils and red clay zone

4.3.1. Biological Communities

The Blackhoof River (04010301-519) is a designated DNR trout stream. However, MPCA is in the process of changing the aquatic life beneficial use class for protection of water quality from coldwater (2A) to coolwater/warmwater (2B). During initial investigations by MPCA staff, the field review of the stream and biological results were such that MPCA staff determined the reach would be more appropriately classed as a 2B stream.

The fish community was assessed at one site (90LS031) during a single visit in 2011. The fish IBI score was 29, which is below the threshold and the lower confidence interval (29) for Low Gradient Streams (Table 68). The fish community was dominated by johnny darters and central mudminnows (91%) (Table 31). No sensitive species were captured during sampling in 1990 and 2011 (Table 32). Seven fewer fish species were sampled at the CR4 site compared to the fully supporting site 11LS071 on a tributary to Blackhoof River. Game fish present at 11LS071 that are missing at CR4 include northern pike, black crappie, yellow perch, pumpkinseed, and green sunfish. Personal communication with Mr. Wait confirmed this upper reach of the Blackhoof River and the small lake (Wait Lake) on the north side of the I-35 supported a healthy population of brown trout circa 1965. The upper Blackhoof River is non-supporting of a healthy fish community.

The macroinvertebrate community was assessed at one site (90LS031) during a single visit in 2011. The macroinvertebrate IBI score was 36, which is below the threshold and lower confidence interval for Northern Forest Streams: Glide/Pool Habitats (Table 70). Aquatic macroinvertebrate taxa richness is low (24) with two taxa (*Simulium* and *Leptophelibiidae*) dominating the sample. The upper Blackhoof River is non-supporting of a healthy macroinvertebrate community.

Table 31. Fish species sampled in 2011, Blackhoof River (90LS031)

Species	Count	Min Length (mm)	Max Length (mm)
central mudminnow	41	42	100
johnny darter	67	38	71
mottled sculpin	3	96	107
white sucker	8	59	194

Table 32. Attributes of fish species sampled in 2011, Blackhoof River (90LS031)

Attribute	Count
DELT (abnormalities)	0
Darter species	1
Exotic species	0
Fish per 100 m	79.3
Game fish species	0
Gravel spawning species	1
Piscivore species	0
Pollution intolerant species	0
Special concern species	0
Total species	4

Invertebrate species sampled in 2011, Blackhoof River (90LS031)

Invertebrate species
amphipods
biting midges
black flies
chiggers
electric light bugs
gastropods
mayflies
midges
net-spinning caddisflies
Orconectes
predaceous diving beetles
riffle beetles
Thienemannimyia Gr.
water scavenger beetles

Table 33. Attributes of invertebrate species sampled in 2011, Blackhoof River (90LS031)

Attributes	Count
EPT Taxa	4
Ephemeroptera Taxa	3
Hilsenhoffs Biotic Index (HBI)	4.1
Intolerant Families	1
Percent Pollution Tolerant	.9
Percent Chironomidae	4.7
Percent Diptera	47
Percent Dominant Taxa	41.1
Percent Dominant Two Taxa	78.2
Percent Filterers	45.2
Percent Gatherer	51.1
Percent Hydropsychidae	4
Percent Scraper	.9
Plecoptera Families	0
Total Families	14
Trichoptera Families	1

4.3.2. Evaluation of Candidate Causes

4.3.2.1. *Historic Flow Alteration*

None of the upper Blackhoof River (04010301-519) passes through areas (Figure 52) where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). Therefore, historic flow alteration is not likely a stressor to aquatic life in the upper Blackhoof River.

4.3.2.2. *Recent Flow Alteration*

The upper Blackhoof River contains wetlands in the headwaters, which moderate flow by reducing flashiness. However, there is heavy beaver activity along this reach, with many impoundments that alter stream flows. In addition, several of the tributaries are ditched and excavated through large wetlands which likely alter flows. Macroinvertebrate biological indicators of flow alteration were mixed, with low % long-lived invertebrates, but low % swimmer invertebrates and % EPT comparable to other unimpaired stream reaches in the Nemadji River Watershed. Therefore, recent flow alteration is potentially a stressor to aquatic life in the upper Blackhoof River.

4.3.2.3. *Physical Habitat Quality*

At both 2013 targeted monitoring sites on the Blackhoof (Wait and CR4), in-stream habitat consisted of undercut banks, short riffles, and small pools with limited large woody debris present. In-stream wood was comprised of willow and alder branches most prevalent near old beaver dam locations, and the bed materials were dominated by sandy substrates. The Minnesota Pollution Control Agency Stream Habitat Assessment (MSHA) rating for this reach was fair to good in 2013 (Table 34), with the lowest score for cover. The MSHA rating for the unimpaired reference reach, Little Net River, was lower than any of the assessed sites on the upper Blackhoof River.

During the geomorphic assessment conducted in October 2013, minimal in-stream erosion was observed (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information). Dense riparian vegetation occurred along the reach, and the substrate was dominated by sand. However, streamside grazing has been observed and may result in the loss of riparian vegetation. The BEHI scores for the upper Blackhoof River at both the Wait site and CR4 were low (Table 35).

In addition, the relative percentage of pioneer and tolerant fish species was comparable to unimpaired low gradient streams (Table 68). Therefore, physical habitat quality is not a stressor to aquatic life in the upper Blackhoof River. However, recent mining operations along Highway 4 may result in future increased sediment load to and loss of habitat in the upper Blackhoof River. Physical habitat quality should be reassessed in several years to determine if the new mining operations are negatively impacting the stream.

Table 34. Blackhoof and Little Net River MSHA ratings (except otherwise noted, all surveys EOR 2013)

Stream location (Blackhoof stations are listed upstream to downstream)	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
Blackhoof at Wait	5	12	18	8	23	66	Good
Blackhoof, mid reach	5	12	15	11	33	76	Good
Blackhoof at CR4	5	9	18	4	24	60	Fair
Blackhoof at CR4 (MPCA 2011)	2.5	14	9	15	20	60.5	Fair
Blackhoof at 104	5	14	21	9	33	82	Good
Little Net (reference site)	5	14	9	7	24	59	Fair

Table 35. Blackhoof River Bank Erosion Hazard Index (BEHI) score (EOR 2013)

Stream location	Bank height/ Bankfull height	Root depth/ Study bank height	Weighted root density	Bank angle	Surface protection	Total BEHI Score	BEHI Descriptor
Blackhoof at Wait	1	2.2	3	8.8	0	15	Low
Blackhoof at CR4	1	2	3	8.3	0	14.3	Low

4.3.2.4. *Habitat Fragmentation*

According to Mr. Wait, beavers are very active along the upper Blackhoof River and he removes dams on his property several times per year. The surrounding area was historically used for hay production, at which time beavers were not present in the upper Blackhoof River likely due to lack of woody species for a food source, and brown trout were abundant in the upper Blackhoof River. Since hay production ceased and woody species have regenerated, beaver activity has increased and the trout population is no longer present. Therefore, habitat fragmentation caused by beaver dams and impoundments is the primary stressor to aquatic life in the upper Blackhoof River.

4.3.2.5. *Dissolved Oxygen*

Minimum dissolved oxygen concentrations in the Blackhoof River have been greater than the water quality standard of 5mg/L every month over the past 10 years (Table 36). However, in 2013 DO levels remained low over several days in mid-September at the Wait site with small daily DO fluxes (Figure 53). Dissolved oxygen levels were observed to decrease near beaver dams but recover to at least upstream dam levels in the downstream stream reaches as part of the beaver study (see Section 8, Supporting Document 8.5). DO concentrations at CR4 (downstream of the Wait site) remained above water quality standards (Figure 54) suggesting that low DO concentrations on the upper Blackhoof River are likely caused by wetlands in the headwater. In addition, both the fish and macroinvertebrate DO tolerance index scores (Table 74) were both greater than the 75^{th} percentile for their respective classes in the state (Table 72), suggesting that the fish and macroinvertebrate communities are not DO tolerant. Therefore, DO is not likely a stressor to aquatic life in the upper Blackhoof River.

Table 36. Dissolved oxygen summary in the upper Blackhoof River (2003-2012)

Station	Month	#	Min	Max
S007-195	May	2	8.3	10.5
	June	2	7.2	7.5
	August	1	6.8	6.8
	September	2	8.4	10.5
S007-452	May	1	7.7	7.7
	June	2	6.4	6.7
	August	1	7.1	7.1
	September	2	7.6	8.7

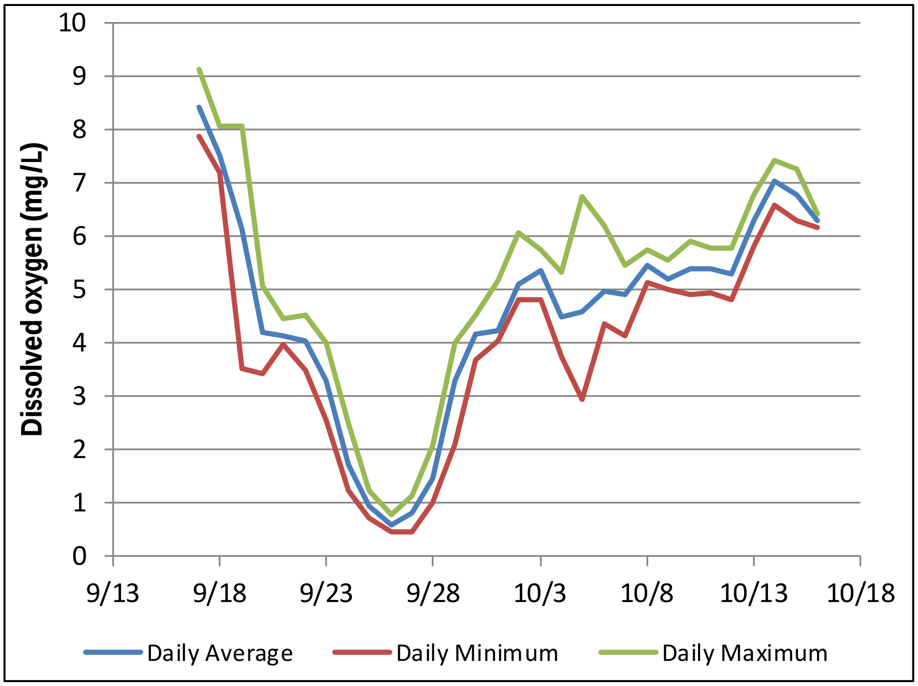


Figure 53. Continuous dissolved oxygen concentration in the Blackhoof River at the Wait property (2013)

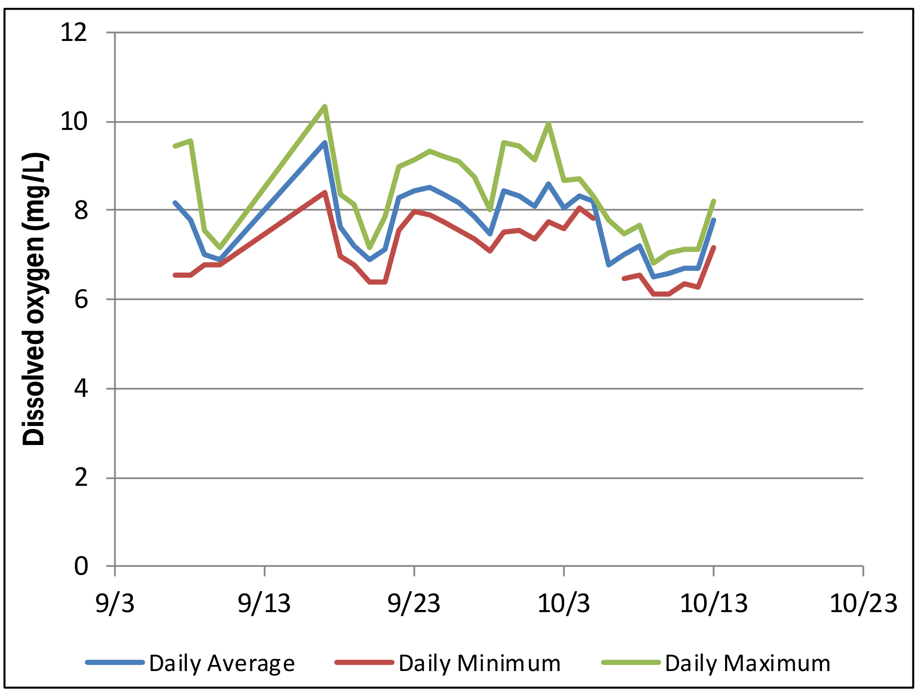


Figure 54. Continuous dissolved oxygen concentration in the Blackhoof River at CR4 (2013)

4.3.3. Summary

Table 37. Summary of candidate causes of stress to the biological community of upper Blackhoof River

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	Past land use changes caused channel instability & evolution	Not likely a stressor	
Recent Flow Alteration	Beaver dams and ditched wetlands	Potentially a stressor	
Physical Habitat	Stable banks with dense vegetation, sandy substrate	Not a stressor	
Habitat Fragmentation	**Numerous beaver dams and impoundments**	**Primary stressor**	« «
Dissolved Oxygen	Low DO wetland headwaters, overall DO supporting	Not likely a stressor	
Water Temperature	Supportive of a warm water fishery	Not a stressor	
TSS/ Turbidity	TSS levels low	Not a stressor	

4.4. Clear Creek (04010301-527)

Clear Creek is 7.9-mile long with a drainage area of 12.2 square miles. Approximately 41% of the land use is agricultural or developed, and the remainder of the watershed is forests, wetlands, and rangeland (Figure 55). For the SID process, water quality data was collected at one MPCA sampling station (S006-213) and one biological monitoring station (11LS056) (Figure 57). Approximately half of Clear Creek, including the locations of the monitoring stations occurs in the red clay zone of the Nemadji River Watershed (Figure 57).

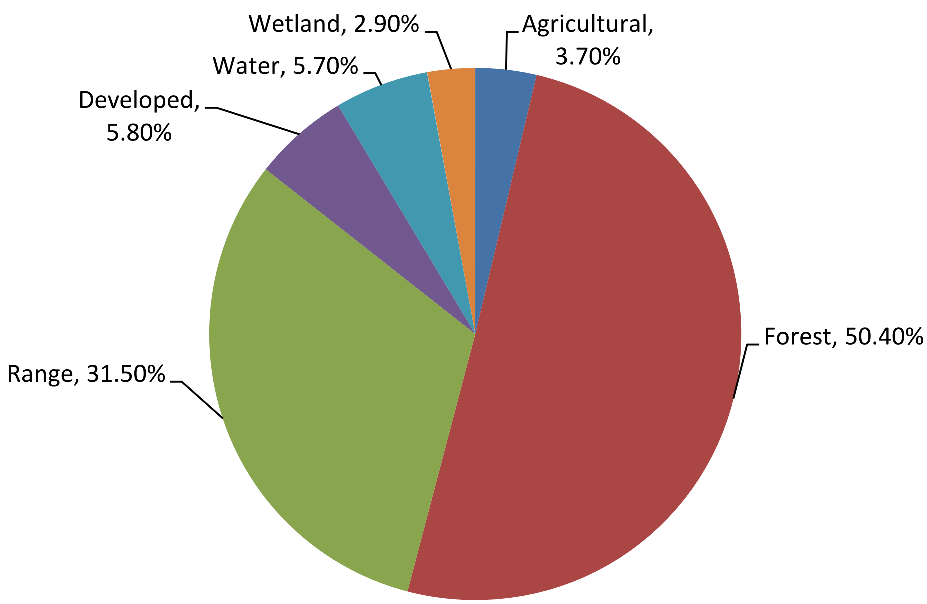


Figure 55. Land cover distribution in the Clear Creek subwatershed

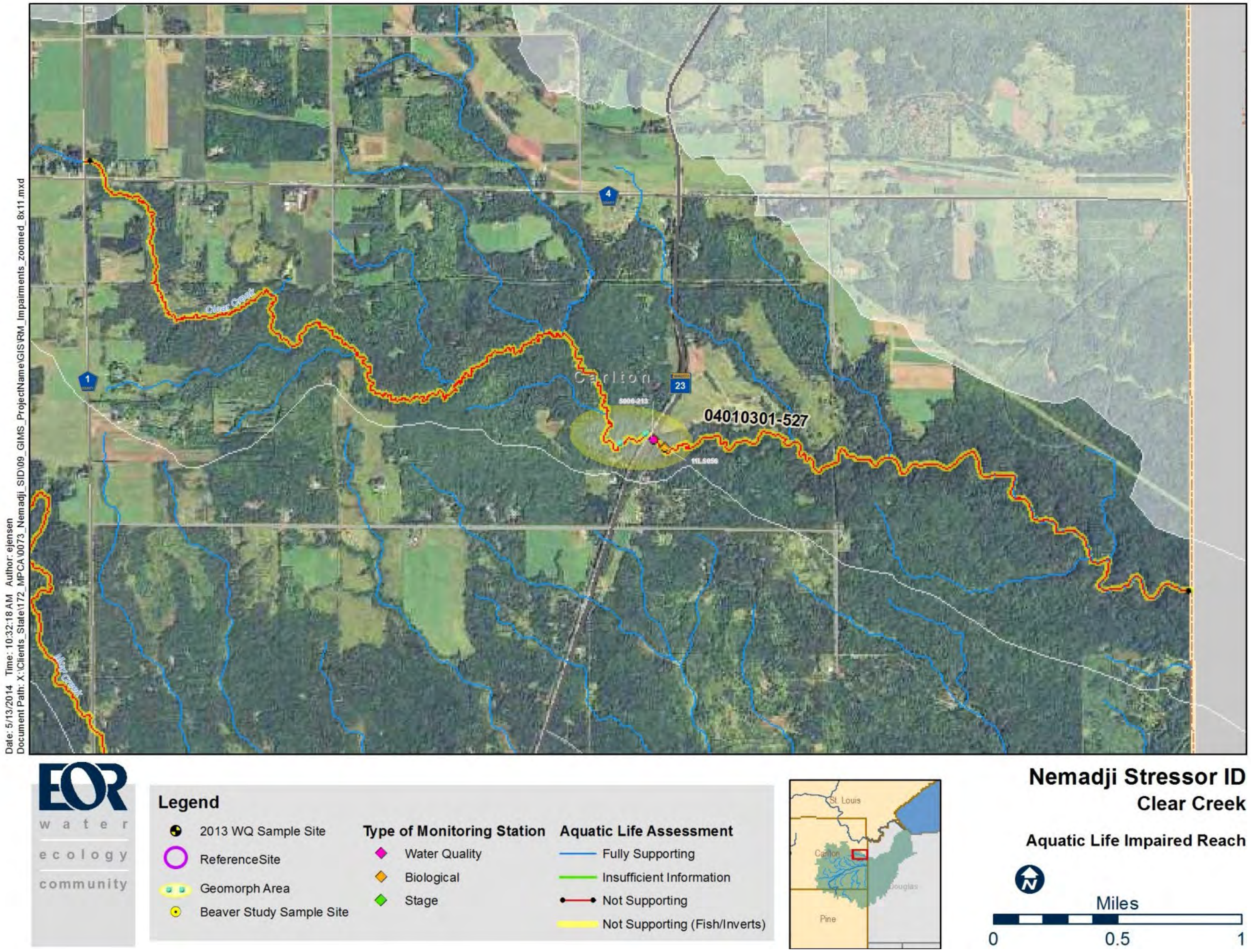


Figure 56. Clear Creek aerial photograph and monitoring station locations

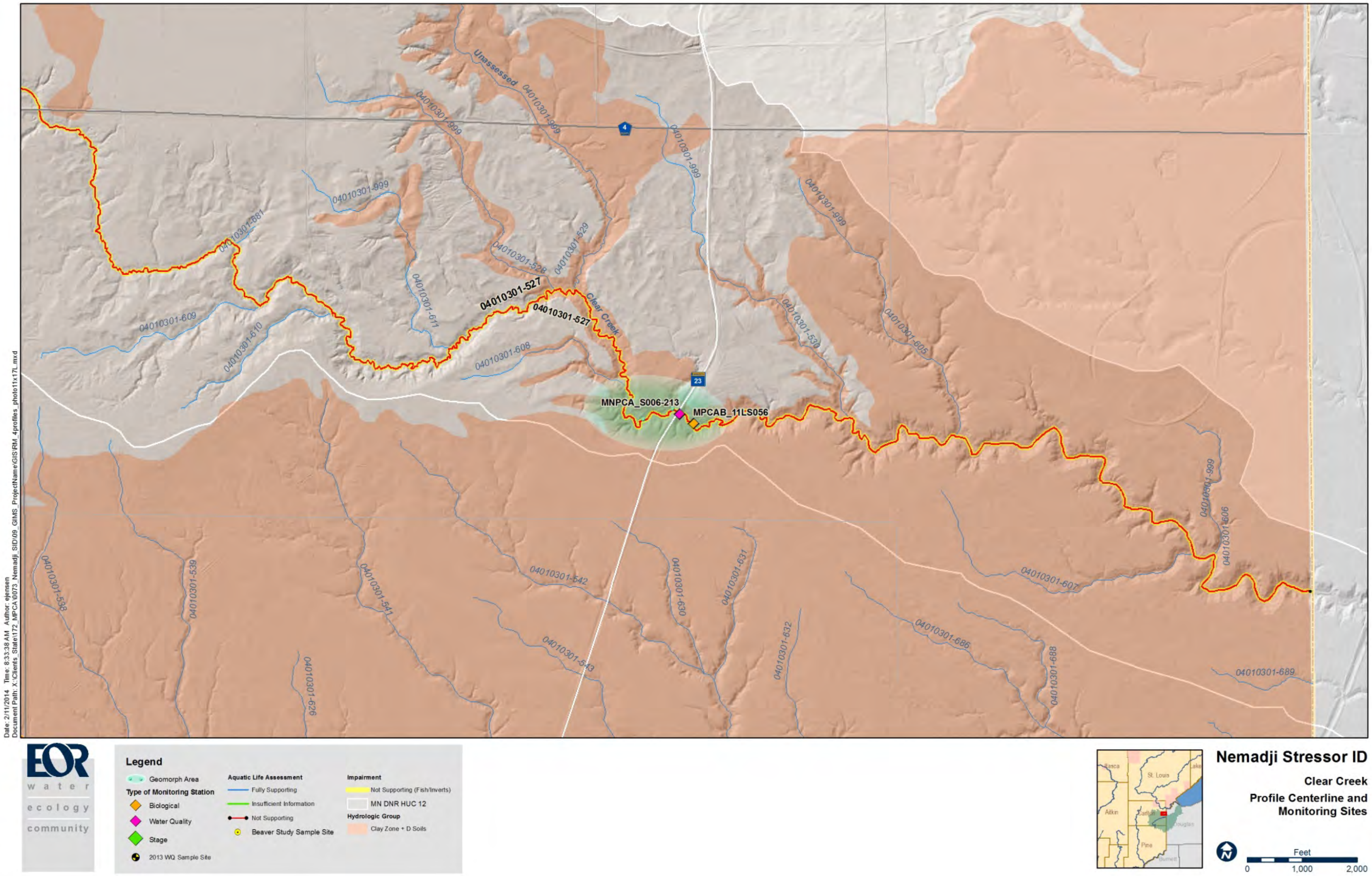


Figure 57. Clear Creek topographic map showing clay zone

4.4.1. Biological Communities

The biological community of Clear Creek was assessed at one site (11LS056) during a single visit in 2011. The fish IBI score was below the threshold and the lower confidence interval (26) for Northern Coldwater Streams (Table 5). The fish community was dominated by creek chubs and johnny darters (76%) (Table 38), and very few sensitive species were captured (e.g., mottled sculpin) (Table 39). A single brook trout was sampled at this location by the MDNR on 7/14/2008. Clear Creek is non-supporting of a healthy coldwater fish community.

The macroinvertebrate community was assessed at one site (11LS056) during a single visit in 2011. The macroinvertebrate IBI score was 16, which is below the impairment threshold and within the lower confidence interval for Northern Coldwater Streams (Table 69). Several sensitive mayfly (*Ephemeroptera*) and caddisfly (*Trichoptera*) taxa were captured (Table 40, Table 41). However, an overall lack of stoneflies (*Plecoptera*) and dragonflies (*Odonata*) and overall low taxa richness (25) is likely resulting in the poor macroinvertebrate IBI score for this site. Clear Creek is non-supporting of a healthy coldwater macroinvertebrate community.

Table 38. Fish species sampled in 2011, Clear Creek (11LS056)

Species	Count	Min Length (mm)	Max Length (mm)
blacknose dace	29	26	96
brook stickleback	1	62	62
creek chub	163	25	162
fathead minnow	1	49	49
johnny darter	42	27	66
mottled sculpin	34	30	118

Table 39. Attributes of fish species sampled in 2011, Clear Creek (11LS056)

Attribute	Count
DELT (abnormalities)	0
Darter species	1
Exotic species	0
Fish per 100 m	170.9
Game fish species	0
Gravel spawning species	1
Piscivore species	0
Pollution intolerant species	0
Special concern species	0
Total species	6

Table 40. Invertebrate species sampled in 2011, Clear Creek (11LS056)

Invertebrate species
amphipods
black flies
caddisflies
chiggers
circular-seamed flies
fingernail clam
gastropods
long-horn caddisflies
Maccaffertium
mayflies
midges
net-spinning caddisflies
Oligochaeta
riffle beetles

Table 41. Attributes of invertebrate species sampled in 2011, Clear Creek (11LS056)

Attributes	Count
EPT Taxa	7
Ephemeroptera Taxa	2
Hilsenhoffs Biotic Index (HBI)	4.8
Intolerant Families	3
Percent Pollution Tolerant	1.6
Percent Chironomidae	14.9
Percent Diptera	39.6
Percent Dominant Taxa	23.7
Percent Dominant Two Taxa	47.1
Percent Filterers	48.1
Percent Gatherer	48.7
Percent Hydropsychidae	23.4
Percent Scraper	1.9
Plecoptera Families	0
Total Families	14
Trichoptera Families	5

4.4.2. Evaluation of Candidate Causes

4.4.2.1. *Historic Flow Alteration*

The lower half of Clear Creek (04010301-527) passes through the red clay zone, including the biological monitoring site (Figure 43), where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). Channel instability from historic flow alteration in the watershed has resulted in high sediment loads, high turbidity, poor habitat quality, embedded gravel, and loss of connectivity. Therefore, historic flow alteration is a primary stressor to aquatic life in Clear Creek.

4.4.2.2. *Recent Flow Alteration*

Instantaneous flow data was collected in 2013 during the synoptic surveys (Figure 58). Flow was reduced in late August, but there is no continuous flow data available for Clear Creek. However, several biological metrics that respond to flow alteration indicated that Clear Creek stream flows are altered, with low % EPT, high % generalist fish, high % non-lithophilic spawner fish, and high % tolerant fish. Therefore, recent flow alteration is potentially a stressor to aquatic life in Clear Creek.

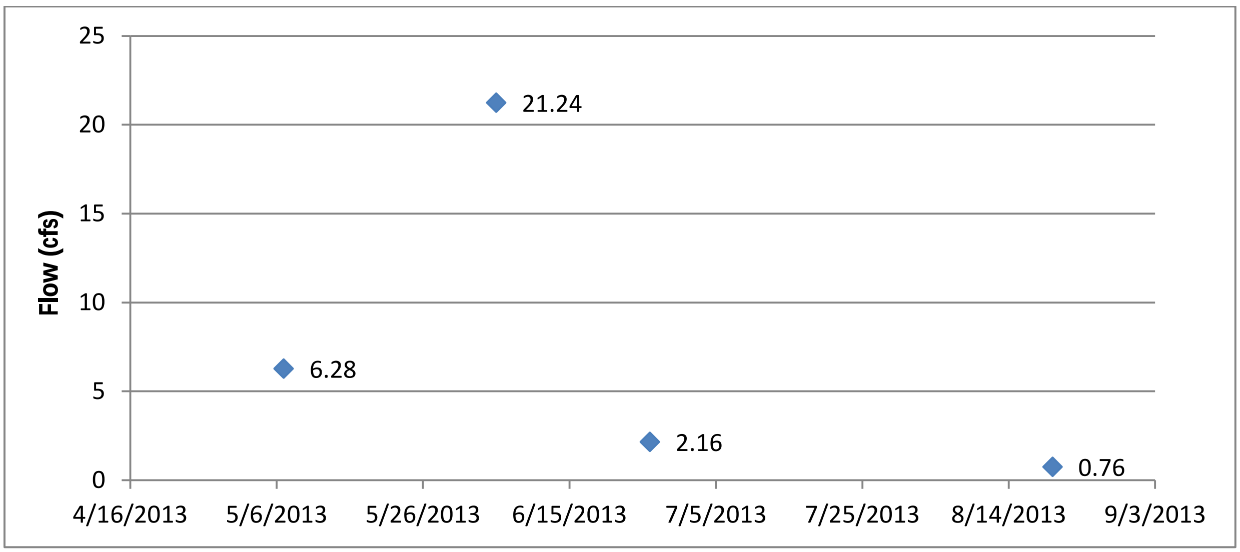


Figure 58. Instantaneous flow collected in Clear Creek in 2013

4.4.2.3. *Physical Habitat Quality*

The Minnesota Pollution Control Agency Stream Habitat Assessment (MSHA) rating for this reach in 2013 was good (58 out of 100), but a full geomorphic assessment including descriptions of substrate, pools and riffles, and cover was not conducted.

The BEHI for this location on Clear Creek scored moderate at the geomorphic survey site (Table 43; see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information). The abundance of large roots (1 mm < x < 60mm) was much greater for trees than grasses at depths greater than one foot on Clear Creek. Grasses provided dense root cover in the top 1 foot but almost all roots were all <1mm diameter. Large tree roots are important to bank stability because they increase the soil shear strength therefore reducing bank erosion rates in the long-term. In contrast, grasses provide more surface protection but the roots are smaller and concentrated in a shallower depth. It is likely that the removal of large old deep-rooted trees from past logging, road construction and power-line corridors may have worsened past and current bluff and stream bank slumping. While the relationship is complex between bank stability and vegetation type, it is clear that trees reduce erosion in the long-term, although they can expedite bank collapse when the bank angle gets to the point of failure. Figure 59 shows exposed soil and eroding stream banks on Clear Creek.

The fish community was dominated by creek chub and johnny darters which are pioneer species and don't require clean gravel for nesting. This may be an indication that substrate conditions are poor in Clear Creek. In addition, the biological community had high % generalist fish and high % tolerant fish which would be expected in a disturbed or degraded habitat. Therefore, physical habitat quality is likely a stressor to aquatic life in Clear Creek.

Table 42. Clear Creek MSHA ratings

MSHA Survey	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
EOR 2013	5	9	15	10	19	58	Fair
MPCA 2011	4.5	12	19	8	29	72.5	Good

Table 43. Clear Creek Bank Erosion Hazard Index (BEHI) score (EOR 2013)

Stream name	Bank height/ Bankfull height	Root depth/ Study bank height	Weighted root density	Bank angle	Surface protection	Total BEHI Score	BEHI Descriptor
Clear Creek at 23 below slumps	7.9	3.1	4.5	8	1.5	25	Mod
Clear Creek at 23 near slumps	8.4	3.8	5.2	8.2	1.8	27.4	Mod

Figure 59. Eroding streambanks on Clear Creek

4.4.2.4. *Habitat Fragmentation*

There are no obvious barriers to fish movement based on the LiDAR stream cross section profile. There is a potential barrier at the SOO Line Crossing in Wisconsin and beaver activity is evident upstream of Hwy 23. However, there is insufficient evidence to determine whether habitat fragmentation is a stressor to aquatic life in Clear Creek. Further study is needed to confirm the SOO Line Crossing barrier in Wisconsin and whether this is affecting fish migration in Clear Creek.

4.4.2.5. *Suspended Solids/ Turbidity*

TSS concentrations in Clear Creek were highest in April (up to 256 mg/L) and May over the 10 year period during spring high flows (Table 44). In June through August, average monthly TSS concentrations were lower, but still exceeded the standard of 10 mg/L. Suspended settling rates in Clear Creek are likely very slow (> 2 days) (See Table 12 and Figure 31 in Section 3.3.7). The fish community TSS tolerance index score (13.7; Table 74) was greater than the 75th percentile for all fish class 11 streams in the state (12.82; Table 73) suggesting that the fish community has high TSS tolerance. In addition, the invertebrate community TSS tolerance index score (14.2; Table 74) was greater than the median score for all invertebrate class 8 streams in the state (13.39; Table 73) suggesting that the invertebrate community has mid-level TSS tolerance. Therefore, suspended solids/turbidity is a primary stressor to aquatic life in Clear Creek.

Table 44. TSS concentration summary for Clear Creek (2003-2012)

Station	Month	Mean (mg/L)	#	Min	Max
Clear Creek S006-213	April	72.5	4	7.0	256.0
	May	35.3	4	7.0	71.0
	June	12.5	4	8.0	19.0
	July	14.7	6	6.0	23.0
	August	18.0	4	15.0	26.0

4.4.3. Summary

Table 45. Summary of candidate causes of stress to the biological community of Clear Creek

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Low flows in late August, biota tolerant of altered flows	Potentially a stressor	
Physical Habitat	Exposed soil and eroding stream banks	Likely a stressor	«
Habitat Fragmentation	No obvious barriers. SOO line crossing in WI a potential barrier.	Insufficient evidence	
Dissolved Oxygen	Supporting to aquatic life	Not a stressor	
Water Temperature	Supporting to aquatic life	Not a stressor	
TSS/ Turbidity	**Very high TSS levels**	**Primary stressor**	« «

4.5. Deer Creek (04010301-531)

Deer Creek is a small, perennial tributary to the Nemadji River with a drainage area of 5.22 square miles. The majority of the land (> 90%) is privately owned land with the remainder in a state owned wildlife management area. More than 75% of the land in the Deer Creek subwatershed is undeveloped (Figure 60). Data was collected at two MPCA monitoring stations (S003-250 and S004-932) from 2003 to 2012 and at one biological monitoring station in 2011 (11LS064) (Figure 61). Deer Creek has been identified as a significant sediment loading tributary within the Nemadji River basin and ultimately to Lake Superior, as a majority of the creek occurs within the clay zone of the Nemadji River Watershed (Figure 62). Additionally, confined aquifer discharge through the lacustrine sediments along the streams adds suspended sediment to the system.

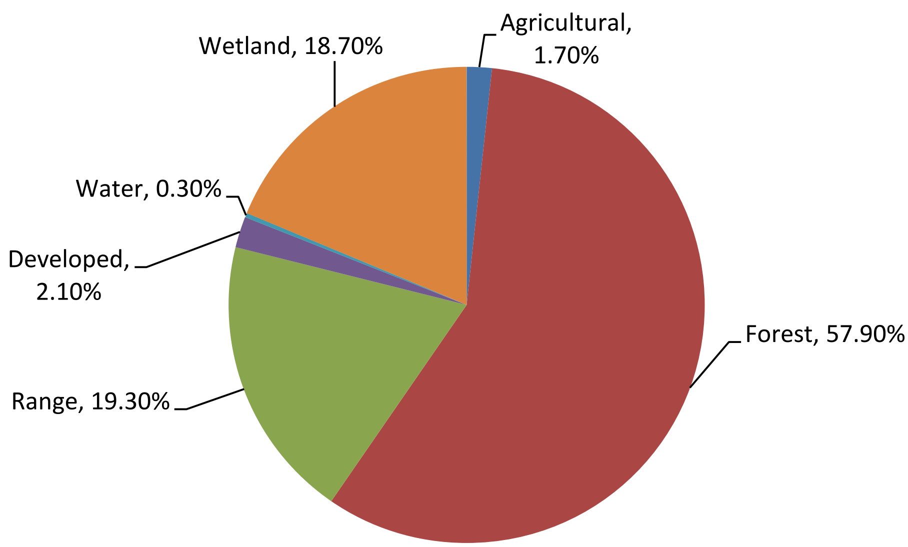


Figure 60. Land cover distribution in the Deer Creek subwatershed

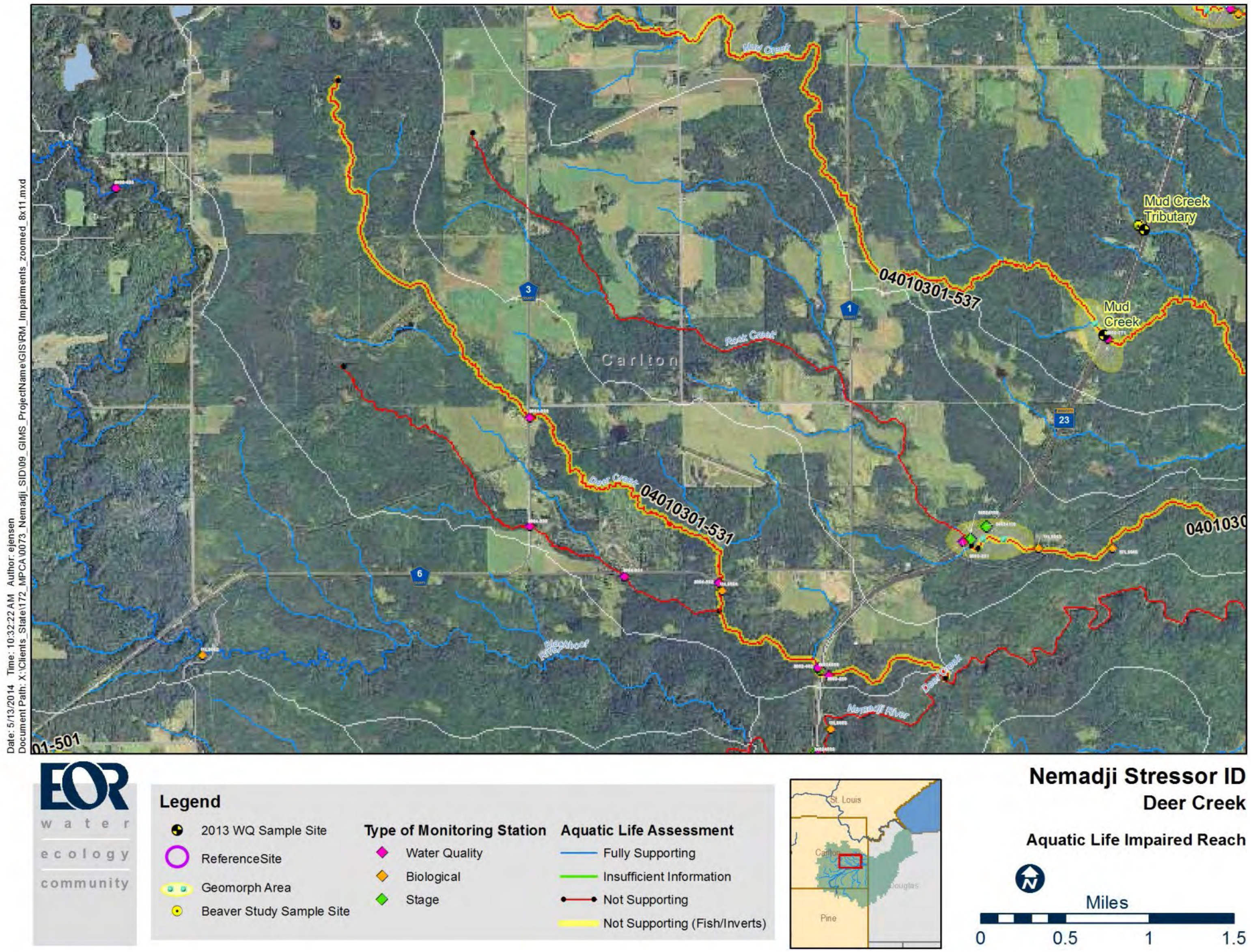


Figure 61. Deer Creek aerial photograph and monitoring station locations

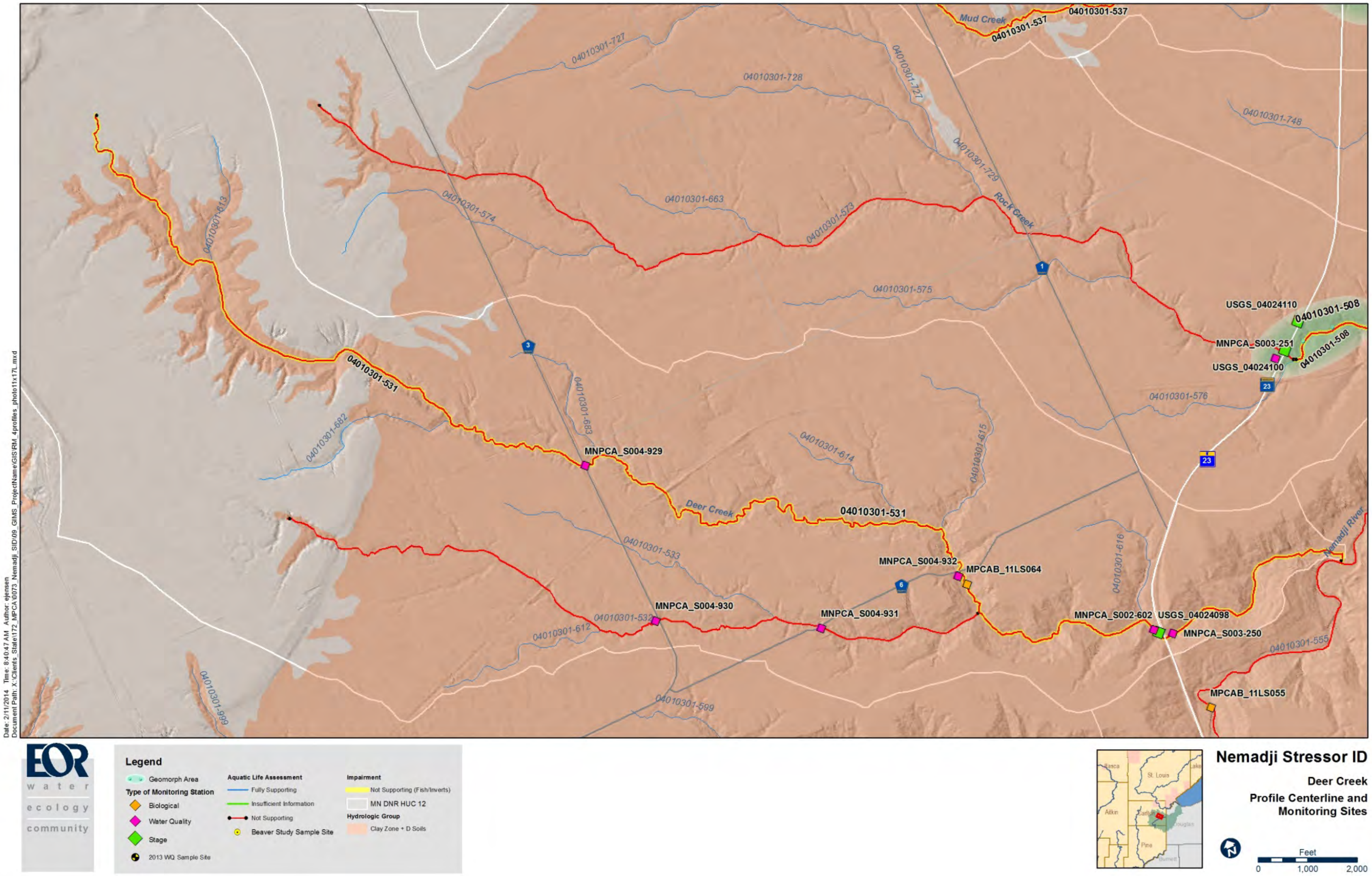


Figure 62. Deer Creek topographic map showing clay zone

4.5.1. Biological Communities

The fish community was assessed at one site (11LS064) during a single visit in 2011. The fish IBI score was 19, which is below the threshold and the lower confidence interval for Northern Coldwater Streams (Table 5). No brook trout or mottled sculpin were sampled, which would be expected in a coldwater stream. The fish community was dominated by creek chubs and other non-sensitive species (Table 46). Attributes of fish species are listed in Table 48. Deer Creek is non-supporting of a healthy coldwater fish community.

The macroinvertebrate community was assessed at one site (11LS064) during a single visit in 2011. The macroinvertebrate IBI score was 44, which is above the upper confidence interval for Northern Coldwater Streams (Table 69). Invertebrate species sampled and their attributes are listed in Table 47 and Table 49, respectively. Deer Creek is supporting of a healthy coldwater macroinvertebrate community.

Table 46. Fish species sampled in 2011, Deer Creek (11LS064)

Species	Count	Min Length (mm)	Max Length (mm)
blacknose dace	3	41	86
common shiner	8	80	118
creek chub	59	52	216
fathead minnow	1	67	67
johnny darter	18	26	53
longnose dace	16	49	105
northern redbelly dace	3	52	63
trout-perch	8	67	94
white sucker	13	73	157

Table 47. Invertebrate species sampled in 2011, Deer Creek (11LS064)

Invertebrate Species
amphipods
balloon flies
Bezzia/Palpomyia
biting midges
black flies
broad-winged damselflies
caddisflies
chiggers
circular-seamed flies
crane flies
darners
dixid midges
green-eyed skimmers
long-toe water beetles
mayflies
micro-caddisflies
midges
moth flies
net-spinning caddisflies
northern caddisflies
Orconectes
riffle beetles
Thienemannimyia Gr.

Table 48. Attributes of fish species sampled in 2011, Deer Creek (11LS064)

Attribute	Count
DELT (abnormalities)	1
Darter species	1
Exotic species	0
Fish per 100 m	86
Game fish species	0
Gravel spawning species	4
Piscivore species	0
Pollution intolerant species	1
Special concern species	0
Total species	9

Table 49. Attributes of invertebrate species sampled in 2011, Deer Creek (11LS064)

Attributes	Count
EPT Taxa	10
Ephemeroptera Taxa	4
Hilsenhoffs Biotic Index (HBI)	4.6
Intolerant Families	6
Percent Pollution Tolerant	0.7
Percent Chironomidae	26.7
Percent Diptera	49.7
Percent Dominant Taxa	26.7
Percent Dominant Two Taxa	38.7
Percent Filterers	22.7
Percent Gatherer	50.3
Percent Hydropsychidae	12
Percent Scraper	2.3
Plecoptera Families	0
Total Families	24
Trichoptera Families	6

4.5.2. Evaluation of Candidate Causes

4.5.2.1. *Historic Flow Alteration*

Nearly all of Deer Creek (04010301-531) passes through the red clay zone (Figure 62), where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). Channel instability from historic flow alteration in the watershed has resulted in high sediment loads, high turbidity, poor habitat quality, embedded gravel, and loss of connectivity. Therefore, historic flow alteration is a primary stressor to aquatic life in Deer Creek.

4.5.2.2. *Recent Flow Alteration*

Stream flow in Deer Creek appears to be very flashy with several high flow events that occur throughout the season. Over the past 6 years, this flashiness appears to be increasing with more frequent and higher flow events (Figure 63). In 2013, most of the high flow events occurred earlier in the season, and are likely caused by increased precipitation and snowmelt due to climate change (Figure 64). In addition, several biological metrics that respond to flow alteration indicated that Deer Creek stream flows are altered, with low % EPT, very high % generalist fish, and high % tolerant fish. Based on this evidence, recent flow alteration is likely a stressor to aquatic life in Deer Creek.

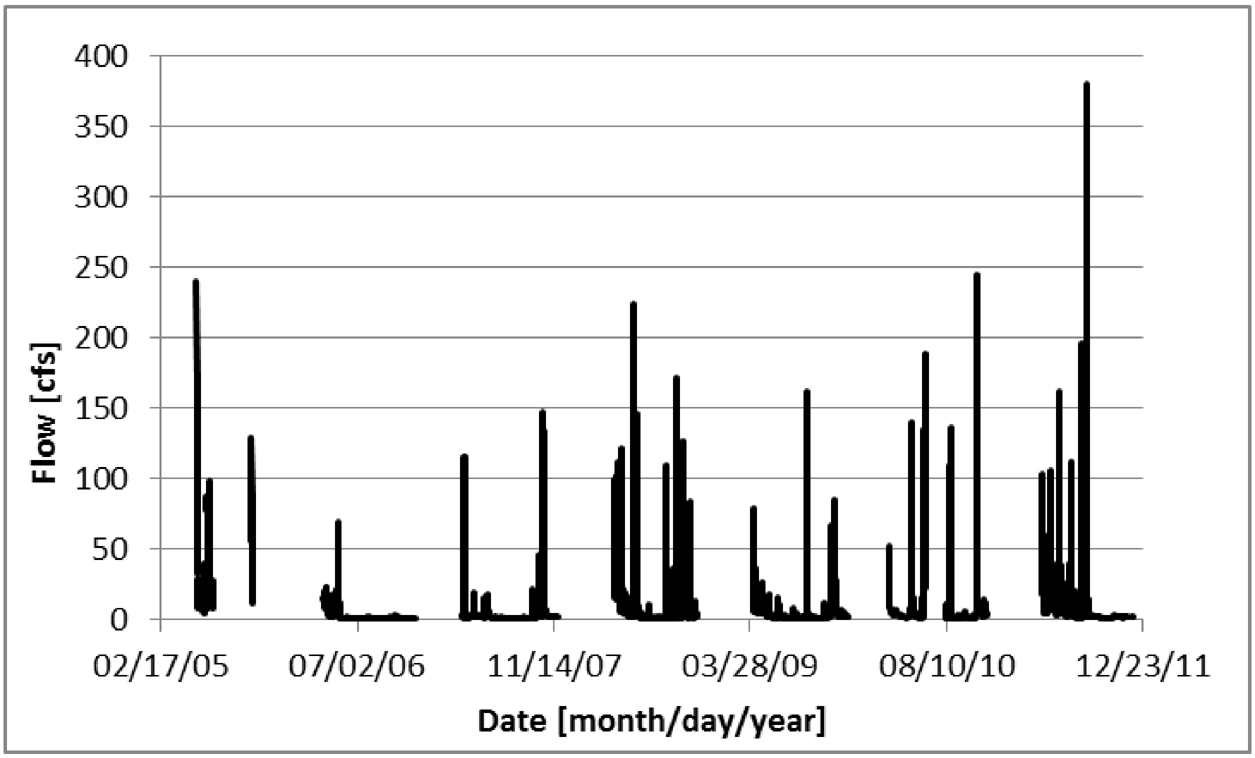


Figure 63. Continuous flow monitored in Deer Creek (2005-2011)

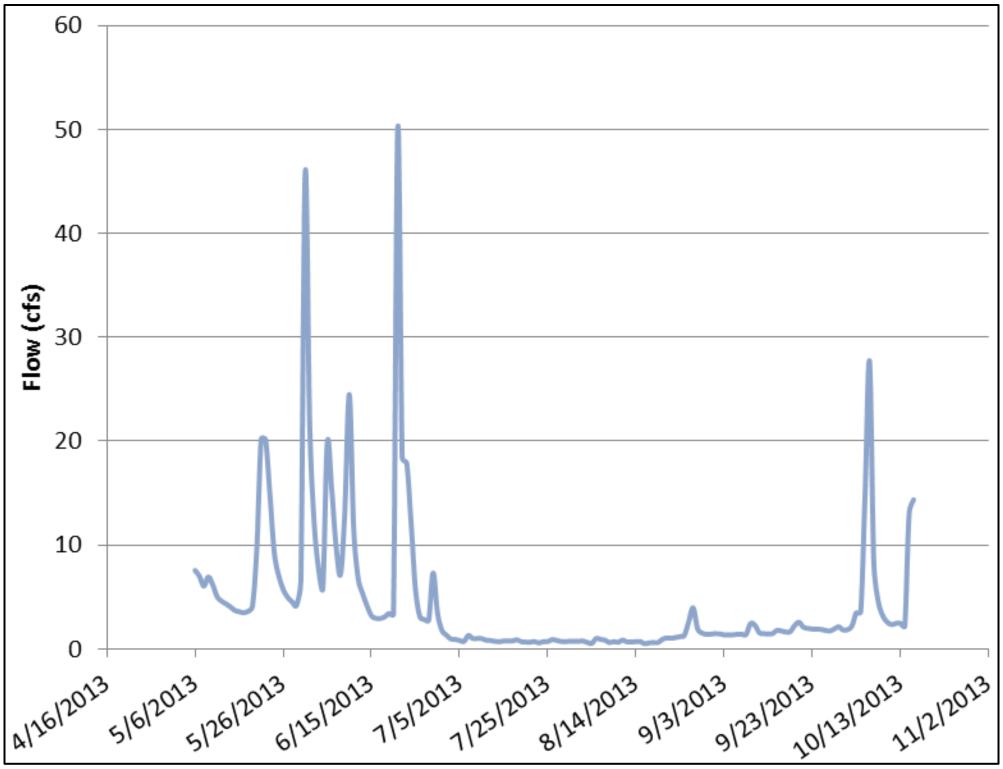


Figure 64. Continuous flow monitored in Deer Creek in 2013

4.5.2.3. *Physical Habitat Quality*

A MSHA was not conducted for Deer Creek in 2013, but the MPCA conducted a MSHA in 2011 and rated Deer Creek as good (66.1 out of 100). In-stream habitat is dominated by pools with the main substrate type being clay. Channel incision was observed up to County Road 3. Changes in substrate due to sediment volcanoes and high concentrations of TSS could potentially affect fish and macroinvertebrate habitat. Mud volcanoes occur on Deer Creek, which increase clay and fine particle sediments in the stream. Additionally, it was observed that significant sedimentation within the boxed culvert at CSAH6 has occurred, but it is not known if similar sedimentation is occurring further downstream.

The fish community was dominated by creek chubs and johnny darters which are pioneer species and don't require clean gravel for their nests, and low % simple lithophilic spawners compared to other unimpaired stream reaches in the Nemadji River Watershed. This may be an indication that substrate conditions are poor in Deer Creek. In addition, there was low % EPT which require high quality habitat, and high % tolerant fish which are tolerant to degraded habitat. Therefore, physical habitat quality is a primary stressor for Deer Creek. More detailed information regarding mud volcanoes in Deer Creek can be found in related reports listed in Section 9.

Table 50. Deer Creek MSHA Ratings

MSHA Survey	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
MPCA 2011	4.5	12	15.6	13	21	66.1	Good

4.5.2.4. *Habitat Fragmentation*

Beaver activity is evident upstream of Highway 23, which could impede fish passage. Additionally several perched culverts and constructed dams occur along the reach. Therefore, habitat fragmentation is potentially a stressor to aquatic life in Deer Creek.

4.5.2.5. *Water Temperature*

At two long-term monitoring stations on Deer Creek, average temperatures did not exceed the normal range for trout; however, maximum daily temperatures were within the stressful range for trout (20-25 degrees C) in June through September (Table 51). Temperature monitoring conducted by MDNR indicated that Deer Creek sustained temperatures greater than 20 degrees C (trout thermal stress range) in July and August of 2010 but not 2009 or 2011 (Figure 65). Temperatures in 2010 and 2011 were also, on average, higher than in 2009. In 2013, water temperatures exceeded the stressful range several times from June through August (Figure 66). In mid-July and again in late August 2013, the minimum daily temperatures rose above 20 degrees C, but did not reach the lethal range. High water temperatures in Deer Creek could result from high turbidity and the lack of stream cover.

Moreover, no brook trout or mottled sculpin, which would be expected in a coldwater stream, were sampled during the biological assessment in 2011. Therefore, high water temperature is potentially a stressor to aquatic life in Deer Creek, at least for some period of the year. Further study is needed to confirm locations of coldwater fish refuges in the headwater tributaries of Deer Creek.

Table 51. Water temperature data summary for Deer Creek (2003-2012)

Station	Month	Mean	#	Min	Max
S003-250	March	0.3	7	0.0	1.3
	April	4.5	17	0.0	12.1
	May	10.2	17	2.8	19.2
	June	13.7	26	9.1	22.7
	July	19.4	13	15.9	23.3
	August	18.5	20	14.9	22.4
	September	15.5	16	11.1	20.4
	October	7.9	7	4.7	9.3
S004-932	March	0.7	2	0.5	0.9
	April	6.7	7	3.1	9.3
	May	11.3	8	7.3	19.9
	June	13.8	14	9.3	19.6
	July	18.9	9	15.7	22.9
	August	18.5	9	15.2	23.8
	September	15.6	10	11.3	21.0
	October	9.2	1	9.2	9.2

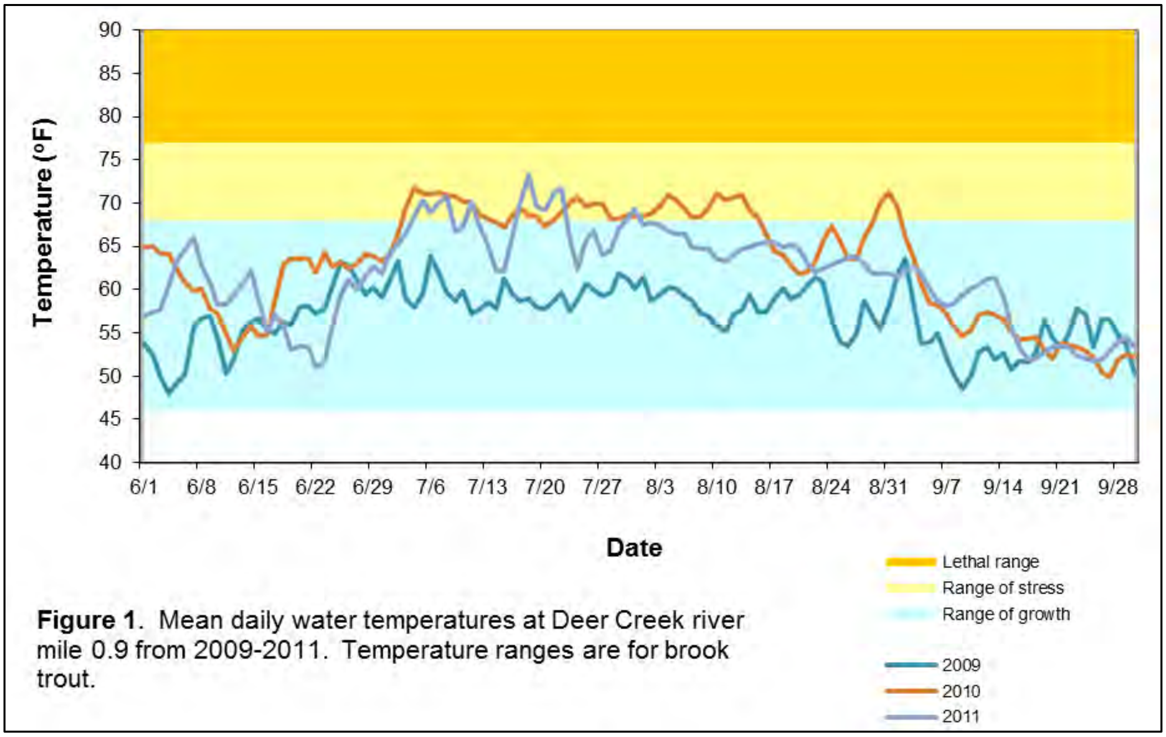


Figure 65. Mean daily water temperatures in Deer Creek at Highway 23 (mile 0.9), 2009-2011

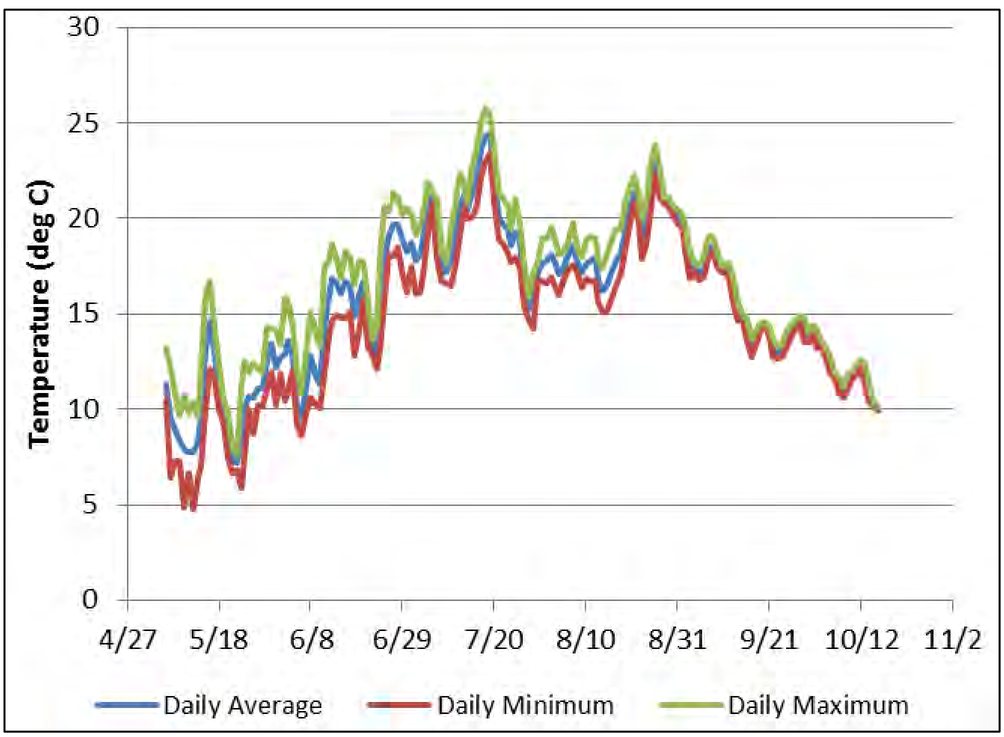


Figure 66. Continuous water temperature monitoring in Deer Creek at CR6 (2013)

4.5.2.6. *Suspended Solids/ Turbidity*

Sediment volcanoes formed in the Deer Creek watershed in the early 1990s. The formation of the sediment volcanoes are likely linked to the use of dynamite used to destroy a beaver dam causing rapid pond drainage and/or fracturing of the glacio-lacustrine clay confining layer over a local aquifer (Mossberger, 2010). The sediment volcanoes occur at the toe of 10 meter high slumps. Groundwater flow discharged at the surface expression of the slump faults transport coarse sediments which are deposited near the discharge point, forming a volcano-shape structures, and finer sediment into suspension causing excess turbidity in the creek (Mooers and Wattrus, 2005). In a positive feedback process, the dewatering of the aquifer caused subsidence which leads to more slumping and more sediment being transported through the volcano. Approximately 10 volcanoes have been observed between 2006 and 2008 discharging approximately 100 gallons per minute of groundwater to the creek (Mooers and Wattrus, 2005).

Deer Creek is an extremely turbid stream (Figure 67). Mean TSS concentrations during 2003 and 2012 were extremely high, with maximum concentrations > 3700mg/L (Table 52). TSS concentrations in 2013 ranged from 151 to 1,200 mg/L in April and May, with concentrations between ~50-100 mg/L in June-October (Figure 64). Suspended settling rates very slow (> 2 days) (See Table 12 and Figure 31 in Section 3.3.7). The fish community TSS tolerance index score (14.17; Table 74) was greater than the 75th percentile for all fish class 11 streams in the state (12.82; Table 73) suggesting that the fish community has high TSS tolerance. In addition, the invertebrate community TSS tolerance index score (14.03; Table 74) was greater than the median score for all invertebrate class 8 streams in the state (13.39; Table 73) suggesting that the invertebrate community has mid-level TSS tolerance. Deer Creek is currently impaired for turbidity and a TSS TMDL has recently been completed. Therefore, suspended solids/ turbidity is a primary stressor to aquatic life in Deer Creek.

Table 52. TSS concentration summary for Deer Creek (2003-2012)

Station	Month	Total Suspended Solids (mg/L)			
		Mean	#	Min	Max
S003-250	March	293.7	7	56.0	650.0
	April	367.1	21	20.0	2,410.0
	May	619.0	23	16.0	3,740.0
	June	453.4	25	17.0	2,300.0
	July	166.5	14	11.0	1,770.0
	August	328.0	21	17.0	1,970.0
	September	223.4	16	9.0	1,180.0
	October	559.1	14	30.0	2,720.0
	November	123.5	2	110.0	137.0

Figure 67. Turbid water in Deer Creek (2013)

4.5.3. Summary

Table 53. Summary of candidate causes of stress to the biological community of Deer Creek

Stressors	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Flashy hydrology. More frequent, higher flow events in spring.	Likely a stressor	«
Physical Habitat	**Mud volcanos, high TSS, sedimentation in County Road 6 culvert**	**Primary stressor**	« «
Habitat Fragmentation	Beaver activity upstream of MN 23 and several perched culverts	Potentially a stressor	
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Water temperatures occasionally stressful to trout, denuded banks	Potentially a stressor	
TSS/ Turbidity	**Mud volcanos discharge sediment, extremely high TSS**	**Primary stressor**	« «

4.6. Mud Creek (04010301-537)

Mud Creek has a drainage area of 12.40 square miles. The majority of the land in the subwatershed is undeveloped, with some agricultural, rangeland and residential development (Figure 68). Data for the SID process was collected at one MPCA water quality monitoring station (S005-771) and one biological monitoring station (11LS058) (Figure 69). Mud Creek is located upstream of MN 23 and occurs within the clay region of the watershed (Figure 70).

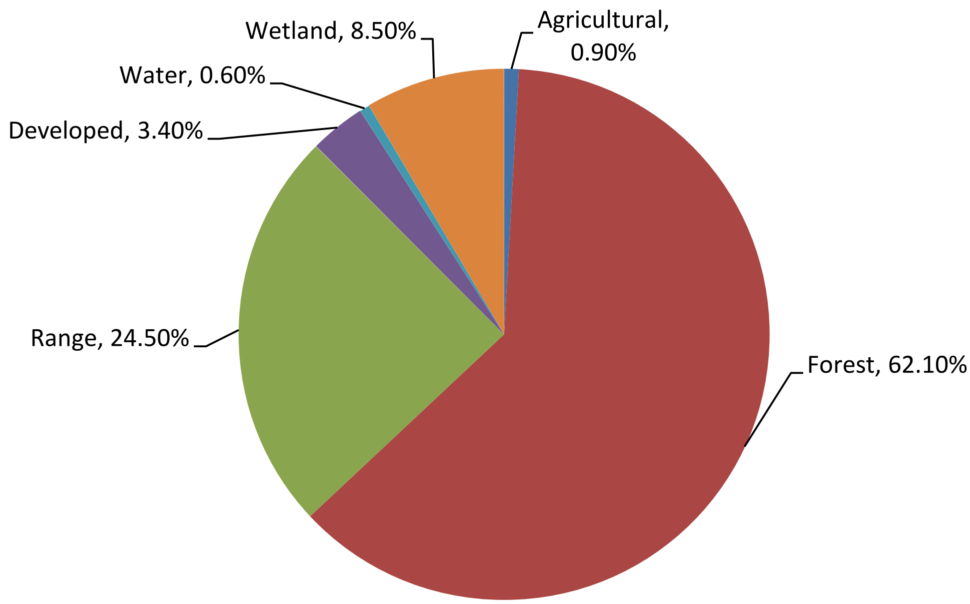


Figure 68. Land cover distribution in the Mud Creek subwatershed

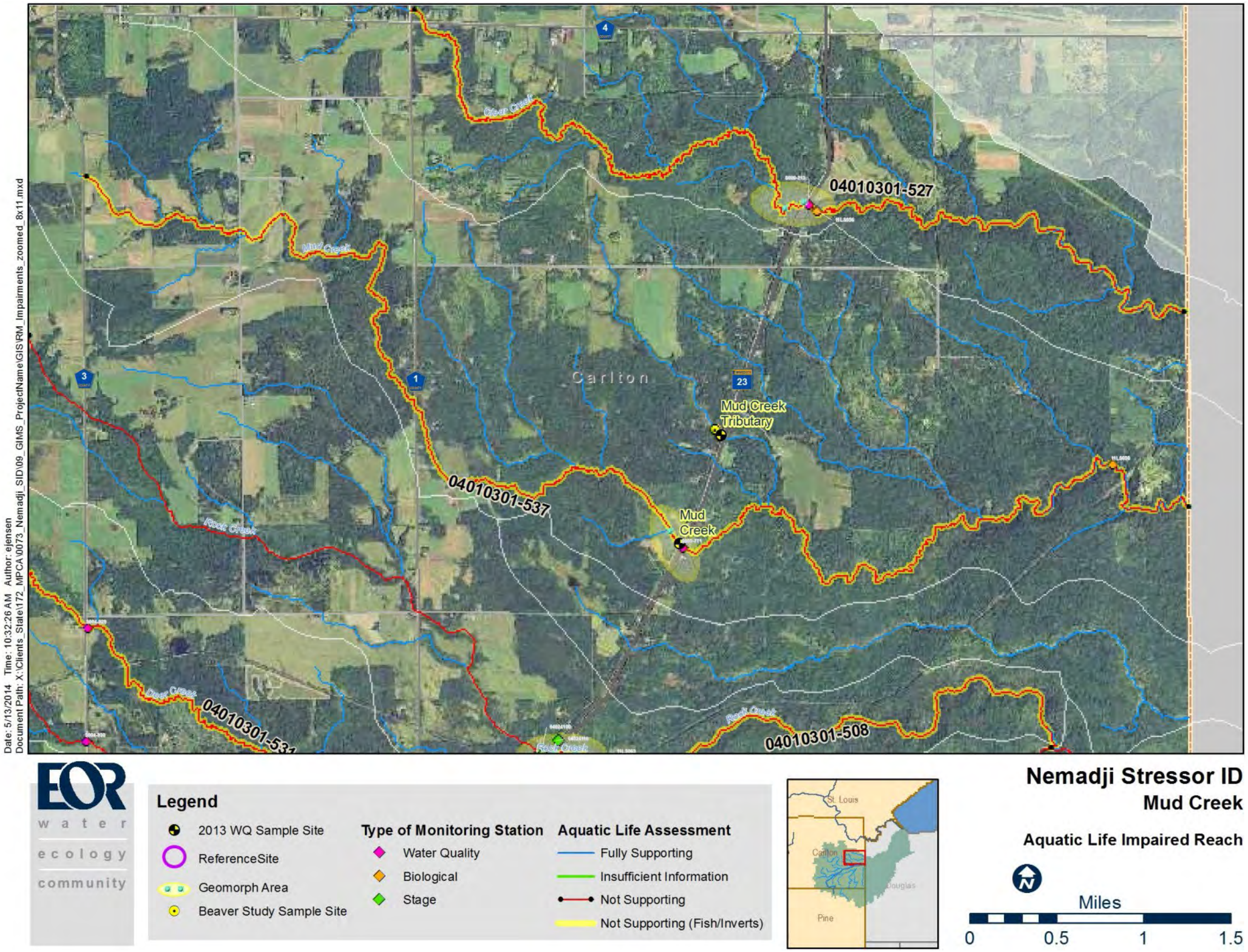


Figure 69. Mud Creek aerial photograph and monitoring station locations

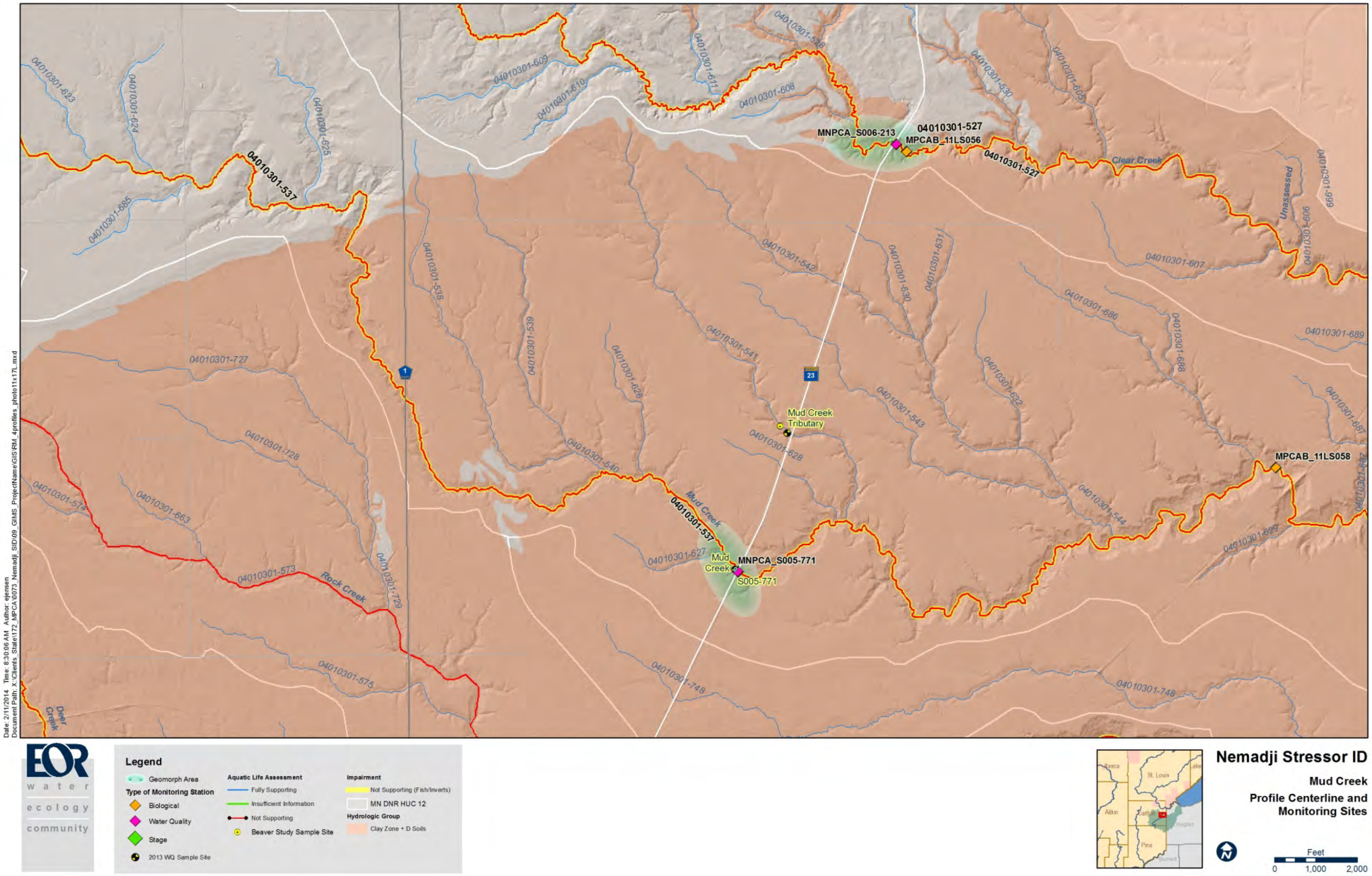


Figure 70. Mud Creek topographic map showing the clay zone

4.6.1. Biological Communities

The fish community was assessed at one site (11LS058) during a single visit in 2011. The fish IBI score was 29, which is below the threshold but within the lower confidence interval for Northern Coldwater Streams (Table 5). The fish community was dominated by creek chubs and tolerant fathead minnows, and no trout species were sampled (Table 54). Fish species attributes are listed in Table 56. Mud Creek is non-supporting of a healthy coldwater fish community.

The macroinvertebrate community was assessed at one site (11LS058) during a single visit in 2011. The macroinvertebrate IBI score was 25, which is just below the impairment threshold and within the lower confidence interval for Northern Coldwater Streams (Table 69). Several sensitive taxa were sampled, but the absence of dragonfly and other predacious taxa and the presence of very tolerant taxa contributed to an IBI score near the impairment threshold (Table 55 and Table 57). Overall, Mud Creek is supporting of a healthy coldwater macroinvertebrate community.

Table 54. Fish species sampled in 2011, Mud Creek (11LS058)

Species	Count	Min Length (mm)	Max Length (mm)
blacknose dace	7	34	72
common shiner	12	31	128
creek chub	54	29	159
fathead minnow	5	30	60
hornyhead chub	6	28	120
johnny darter	15	42	53
longnose dace	15	36	85
mottled sculpin	7	33	88
trout-perch	3	47	91

Table 55. Invertebrate species sampled in 2011, Mud Creek (11LS058)

Invertebrate Species
black flies
chiggers
circular-seamed flies
common stoneflies
darners
fingernail clam
long-horn caddisflies
Maccaffertium
mayflies
micro-caddisflies
midges
narrow-winged damselflies
net-spinning caddisflies
Oligochaeta
Orconectes
riffle beetles
small winter stoneflies
Thienemannimyia Gr.

Table 56. Attributes of fish species sampled in 2011, Mud Creek (11LS058)

Attribute	Count
DELT (abnormalities)	0
Darter species	1
Exotic species	0
Fish per 100 m	78.5
Game fish species	0
Gravel spawning species	3
Piscivore species	0
Pollution intolerant species	1
Special concern species	0
Total species	9

Table 57. Attributes of invertebrate species sampled in 2011, Mud Creek (11LS058)

Attributes	Count
EPT Taxa	8
Ephemeroptera Taxa	3
Hilsenhoffs Biotic Index (HBI)	4.4
Intolerant Families	3
Percent Pollution Tolerant	1
Percent Chironomidae	19.5
Percent Diptera	30.7
Percent Dominant Taxa	26.2
Percent Dominant Two Taxa	45.7
Percent Filterers	35.5
Percent Gatherer	53.4
Percent Hydropsychidae	26.2
Percent Scraper	4.2
Plecoptera Families	2
Total Families	14
Trichoptera Families	3

4.6.2. Evaluation of Candidate Causes

4.6.2.1. *Historic Flow Alteration*

The lower half of Mud Creek (04010301-537) passes through the red clay zone, including the biological monitoring site (Figure 70), where past land use changes resulted in present day channel instability and evolution (See Section 3.3.1 for more information). Channel instability from historic flow alteration in the watershed has resulted in high sediment loads, high turbidity, poor habitat quality, embedded gravel, and sometimes even loss of temperature and connectivity. Therefore, historic flow alteration is a primary stressor to aquatic life in Mud Creek.

4.6.2.2. *Recent Flow Alteration*

Continuous flow measurements collected from Mud Creek in 2013 were significantly reduced during early July through mid-October, which would likely impede fish passage and reduce available habitat for aquatic life (Figure 71). However, there is insufficient data to determine if this is an annual trend. Additional continuous flow measurements should be conducted in Mud Creek. In addition, macroinvertebrate metrics that are sensitive to altered flows were comparable to other unimpaired streams in the Nemadji River Watershed, including % EPT, % long-lived, and % swimmers. Therefore, there is insufficient evidence at this time to determine whether recent flow alteration is a stressor to aquatic life in Mud Creek.

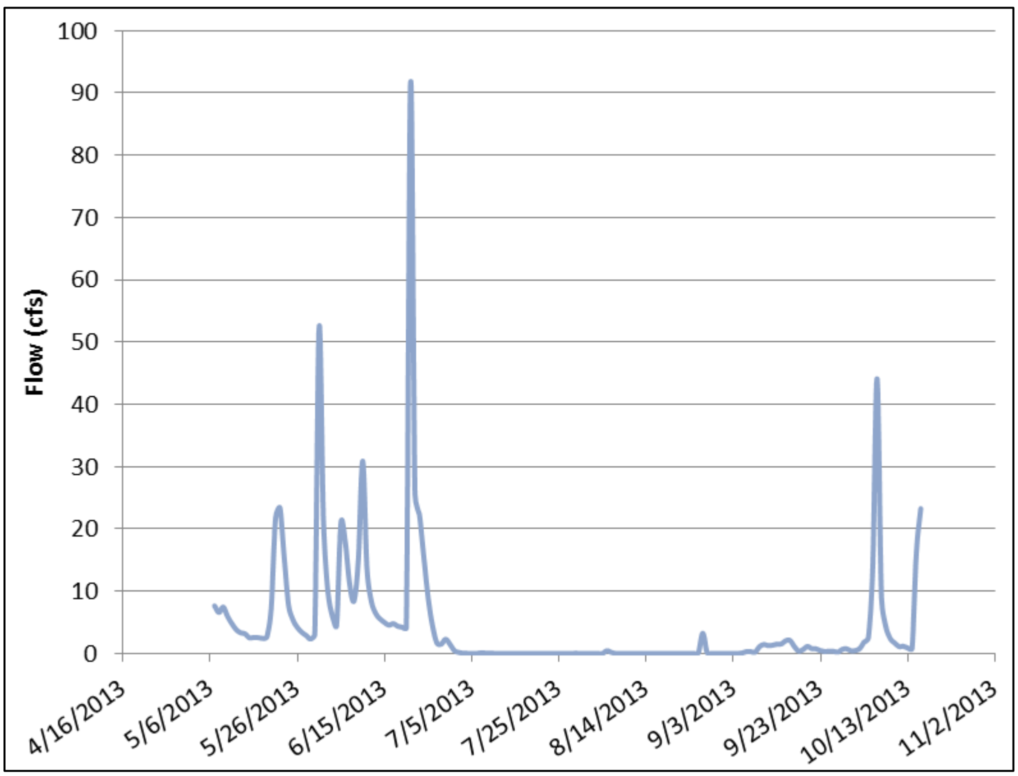


Figure 71. Continuous flow measurements for Mud Creek (2013)

4.6.2.3. *Physical Habitat Quality*

The MSHA assessment conducted for Mud Creek was rated fair in 2013 by EOR, and good by MPCA during the biological survey in 2011. In 2013, fish cover scored the lowest of all the MSHA variables (Table 58). This stream reach is located upstream of MN 23 and occurs within the clay region of the watershed. The upper third of the steep, cohesive clay banks were well vegetated and the lower banks were relatively raw with scattered vegetative cover at the time of the geomorphic assessment in September 2013 (see Supporting Document 8.4: *Hydrologic Change in Relation to IBI Impairment* for more information).

The BEHI score was moderate at the geomorphic survey site (Table 59). The in-stream habitat was comprised of small riffles and pools with limited woody material present within the stream channel. The stream channel was beginning to incise at this reach and became more entrenched downstream of MN 23. A scour pool occurs below a large beaver dam located at the upstream end of the reach. Bed material composition was sand and silt, with gravels occurring within the riffles. Sediment volcanoes have also been observed on Mud Creek.

In addition, the fish community was dominated by creek chubs and johnny darters which are pioneer species and don't require clean gravel for their nests. This may be an indication that substrate conditions are poor in Mud Creek. However, the % simple lithophilic spawners are comparable to and the % clinger invertebrates and % benthic insectivore fish higher than other unimpaired stream reaches in the Nemadji River Watershed. Therefore, physical habitat quality is potentially a stressor to aquatic life in Mud Creek.

Table 58. Mud Creek Minnesota Stream Health Assessment MSHA Ratings

MSHA survey	Land use (5)	Riparian (15)	Substrate (27)	Fish cover (17)	Channel morphology (36)	MSHA score (100)	MSHA rating
EOR 2013	5	10	15	7	19	56	Fair
MPCA 2011	4.5	10	17.3	12	28	71.8	Good

Table 59. Bank Erosion Hazard Index (BEHI) scores, September and October 2013 on Mud Creek.

Stream name	Bank height/ Bankfull height	Root depth/ Study bank height	Weighted root density	Bank angle	Surface protection	Total BEHI Score	BEHI Descriptor
Mud Creek	7.4	6	7	5	3	28.4	Mod

4.6.2.4. *Habitat Fragmentation*

Beaver activity is evident upstream and downstream of Highway 23 which could potentially impede fish passage. Additionally, two large beaver dams have been observed on a tributary to Mud Creek. During MPCA biological monitoring it was observed that the culvert at SOO Line Trail may be preventing natural migration of fish upstream during normal flows. Therefore, habitat fragmentation is potentially a stressor to aquatic life in Mud Creek.

4.6.2.5. *Water Temperature*

Maximum instantaneous measurements of water temperature did not reach the stressful range for coldwater fish in Mud Creek during 2003-2012 monitoring period (Table 60). However, continuous water temperature data collected in 2013 did exceed the stressful range several times between late June and late August, and maximum daily temperatures exceeded the lethal range in mid-July (Figure 72). Moreover, no coldwater trout species were sampled during the 2011 biological assessment. Therefore, high water temperature is potentially a stressor to aquatic life in Mud Creek. Further study is needed to confirm locations of coldwater fish refuges in the headwater tributaries of Mud Creek that require protection.

Table 60. Water temperature data summary for Mud Creek (2003-2012)

Station	Month	#	Mean	Min	Max
S005-771	February	1	0.1	0.1	0.1
	March	1	0.0	0.0	0.0
	May	3	6.3	4.8	7.2
	June	4	15.9	9.2	19.5
	July	1	17.7	17.7	17.7
	August	2	17.6	14.8	20.5
	September	3	14.7	12.3	16.4
	November	2	3.1	2.7	3.4

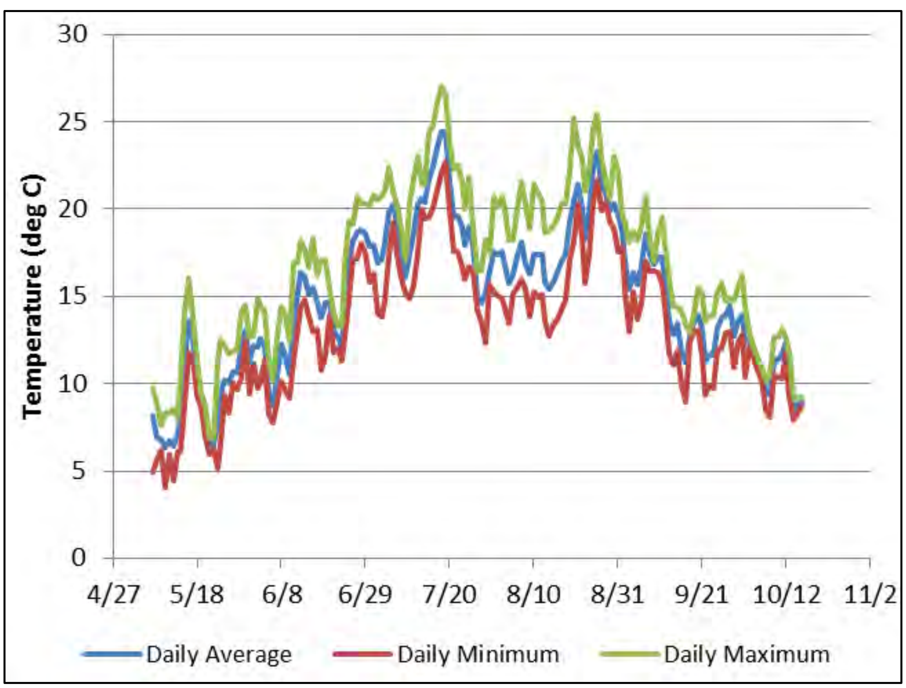


Figure 72. Continuous water temperature measurements in Mud Creek (2013)

4.6.2.6. *Suspended Solids/ Turbidity*

Mud Creek is visually a turbid stream (Figure 73). TSS concentrations on Mud Creek exceeded 100 mg/L in April and May and ranged from 25-30 mg/L in June through August between 2003 and 2012 (Table 61), which exceeds the water quality standard. Sediment volcanoes have also been observed on Mud Creek which would contribute TSS to the stream. The fish and invertebrate community TSS tolerance index scores (Table 74) are both greater than the 75th percentile of all streams with the same class in the state (Table 73) suggesting that the fish and invertebrate community have high TSS tolerance. Therefore, suspended solids/ turbidity is a primary stressor to aquatic life in Mud Creek.

Table 61. TSS concentration summary for Mud Creek (2003-2012)

Station	Month	Total Suspended Solids (TSS, mg/L)			
		Mean	#	Min	Max
Mud Creek S005-771	April	46.5	4	3.0	148.0
	May	52.5	4	12.0	170.0
	June	12.8	4	2.0	27.0
	July	15.8	4	9.0	30.0
	August	13.4	5	5.0	25.0

Figure 73. Mud Creek (2013)

4.6.3. Summary

Table 62. Summary of candidate causes of stress to the biological community of Mud Creek

Stressor	Description	Conclusion	Rank
Historic Flow Alteration	**Past land use changes caused channel instability & evolution**	**Primary stressor**	« «
Recent Flow Alteration	Low flows from July through October in 2013	Insufficient evidence	
Physical Habitat	Low fish cover, small riffles/ pools and little woody material	Potentially a stressor	
Habitat Fragmentation	Beaver activity with dams on tribs. Culvert at SOO line trail.	Potentially a stressor	
Dissolved Oxygen	Supportive to aquatic life	Not a stressor	
Water Temperature	Lethal temperatures on occasion	Potentially a stressor	
TSS/ Turbidity	**TSS levels high and mud volcanos present in stream**	**Primary stressor**	« «

5. Conclusions and Recommendations

5.1. Summary of Probable Stressors

Common probable stressors impacting the stream biology for streams located inside the red clay zone (Rock Creek, Clear Creek, Deer Creek, and Mud Creek) were suspended solids/ turbidity and physical habitat quality, driven by historic flow alterations in the watershed. In contrast, the common probable stressor for biologically impaired stream reaches located outside the red clay zone (Elim Creek and Blackhoof River) was habitat fragmentation.

Table 63. Summary of probable stressors in the Nemadji River watershed

Candidate Stressor	Elim (-501)	Rock (-508)	Blackhoof (-519)	Clear (-527)	Deer (-531)	Mud (-537)
Historic Flow Alteration	-	ü ü	x	ü ü	ü ü	ü ü
Recent Flow Alteration	-	ü ü	-	-	ü	?
Physical Habitat	-	ü	xx	ü	ü ü	-
Habitat Fragmentation	ü ü	-	ü ü	?	-	-
Dissolved Oxygen	xx	x	x	xx	xx	Xx
Water Temperature	xx	ü ü	xx	xx	-	-
Turbidity (TSS)	x	ü ü	xx	ü ü	ü ü	ü ü

ü ü = Primary stressor with strong supporting evidence
ü = Likely stressor with some supporting evidence
- = Potentially a stressor with little supporting evidence
x = Not likely a stressor with little supporting evidence
xx = Supporting evidence indicates that it is not a stressor
? = Insufficient evidence to assess

5.1.2 Conclusions relevant to TMDL completion

One objective of this Stressor Identification study was to inform the Total Maximum Daily Load (TMDL) process by identifying the parameters that will require a load or wasteload allocation. Based on the evidence presented in this report, it is recommended that TMDL efforts focus on developing target sediment loads for the Nemadji River watershed that will reduce turbidity and improve habitat. A second objective of the report is to provide the technical information necessary to complete a larger watershed protection and restoration strategies (WRAPS) report. All watershed TMDLS are integrated into WRAPS reports and provide further information on implementation practices to improve and protect water resources.

In the streams located inside the red clay zone (Rock Creek, Clear Creek, Deer Creek, and Mud Creek), the major stressors to the fish and macroinvertebrate communities were suspended solids/ turbidity and physical habitat quality, driven by historic flow alterations from major land cover changes in the watershed. Because the high turbidity levels are ultimately driven by the evolution of the stream channel to reconnect to a new floodplain, the goal of restoration would be managing high flows and preventing further landscape disturbances that may speed up the rate and severity of channel evolution. This can be accomplished through management of culverts and impoundments, and ordinances to appropriately guide and manage the amount of land cover change in the watershed.

Another major stressor for all streams was habitat fragmentation from culverts, impoundments and beaver dams that restrict trout passage to coldwater refugia in the headwater reaches and tributaries. Due to the large number of physical barriers in the impaired reaches and the benefits of some of these structures to reduce turbidity, stream connectivity would be restored at targeted locations in the watershed. These locations would be identified through a future recommended longitudinal survey of the impaired streams that would identify coldwater refugia and actively eroding portions of the stream. The results from this survey would guide the targeting and prioritization of culvert replacements and dam removals to balance both restoration of trout access to headwater coldwater refuges and sediment reduction benefits from strategic impoundment locations.

Recent mining operations along Highway 4 may result in future increased sediment load to and loss of habitat in the upper Blackhoof River. Physical habitat quality should be reassessed in several years to determine if the new mining operations are negatively impacting the stream.

Table 64. Recommended prioritization of TMDLs relative to the stressors contributing to the biological impairment in the Nemadji River Watershed.

Stressor	Priority	Comment
Historic Flow Alteration	Low	A thorough understanding of how restoration and protection efforts in the watershed will be impacted and driven by channel instability and evolution resulting from historic flow alteration is imperative for success.
Recent Flow Alteration	Unknown	The impact of impoundments on the flow regime is difficult to determine given the lack of flow data before the impoundments were installed.
Physical Habitat Quality	Unknown	Physical habitat quality is expected to improve from efforts to increase stream connectivity (Habitat Fragmentation stressor) and decrease turbidity.
Habitat Fragmentation	High	Restoration efforts should focus on prioritizing the removal of fish barriers that will reconnect downstream portions of impaired reaches with high quality coldwater fish refuges in headwater tributaries.
Water Temperature	Low	Water temperature is expected to decrease from efforts to increase stream connectivity and decrease turbidity.
Suspended solids/ turbidity	High	Sediment imbalance results in loss of habitat and direct physical and indirect behavioral harm to aquatic organisms. Figure 32 provides further details on pathways and expressions of sediment imbalances. TSS water chemistry violations require completion of TMDLs.

5.2 Recommended for discussion in WRAPS Implementation development

The following recommendations were provided by Emmons and Olivier staff, Nemadji watershed stakeholders and technical reviewers during meetings and document reviews of SID technical material. They are captured here to provide for further discussion as implementation strategies during that phase of the WRAPS process. Several Carlton County offices have initiated ongoing BMPs to reduce or minimize stream health impacts. These practices should continue and also be captured in the final WRAPS implementation table. These practices include improved culvert and road management, strategic county forestry management, continued education and outreach via the county water management plan program, stream restorations, clay dam removals, livestock exclusions, and reforestation.

5.2.1 Longitudinal Stream Surveys

The condition of streams in the Nemadji River Watershed varies greatly from headwaters to the confluence with the Nemadji River. Many of these trout streams have cold water refuges located in headwater tributaries that are important for sustaining trout populations. These refuges need to be surveyed and documented with respect to known barriers and areas of channel incision to guide targeting of restoration and protection activities throughout the watershed. In addition, there are few road crossings in the watershed, and stream conditions for entire stream reaches are generalized based on point surveys. A better understanding of the critical protection or restoration areas will be gained through a comprehensive field survey of the length of each stream.

5.2.2 Environmental Flows

Environmental flows describe the hydrologic characteristics of a stream or river that are critical to the health of these lotic ecosystems. The Nemadji River Watershed contains high quality cold water fisheries as well as rare riparian fauna dependent upon specific flow regimes to support their lifecycle needs. The timing, duration and frequency of high, mid and low flows should be studied within the context of specific lifecycle needs for the high priority species in the Watershed.

5.2.3 Aluminum Toxicity

Little is known about the levels of aluminum in the waters of the Nemadji River Watershed, the source of the aluminum, and its potential effects on the riverine biota.

5.2.4 Red Clay Stability

The stability of red clay soils in portions of the Nemadji River Watershed has long been a topic of research. The causes of mass wasting as well as predictive tools to determine slumping susceptibility have been investigated. LiDAR imagery and GIS modeling were used for slope evaluation and BMP prioritization in the Deer Creek TMDL. For streams with slope instability issues, utilizing these tools for prioritization of slump and slope stabilization is recommended. Further modeling efforts and data input (eg. longitudinal stream surveys) may be required to develop field or parcel scale targeting of BMP projects. Emerging issues like climate change may also impact slope stability. Understanding the role of climate change scenarios that include longer dry cycles and larger precipitation events on the shrink-swell and stability characteristics of red clay is a topic in need of further research. Ongoing work to stabilize erosional "hot spots" like impoundment/dam failures and cattle crossings should continue.

5.2.5 Cold Water Biota Movement in the Watershed

Many of the streams in the Nemadji River Watershed are classified as a cold water stream but do not support a healthy cold water assemblage of species. It is important to know how cold water species move throughout this Watershed, or if they indeed do move from stream to stream. In cases where brook trout, for example, are not found (or no longer found) in a cold water stream, is it feasible for them to recolonize from an adjacent stream with an extant population. Continued work in culvert evaluation and the influence of culverts on fish movements is also recommended. The SWCD, county Highway Department and DNR have begun preliminary work on a culvert inventory with prioritization of critical culverts.

5.2.6 Groundwater Contributions to Cold Water Resources

Cold water streams are undoubtedly supported by groundwater in the Nemadji River Watershed. Understanding the ground water recharge areas, subsurface flow patterns and discharge locations is important to protecting the cold water resources in the Watershed. Consideration factors in this research should include the role of lakes, wetlands, beaver impoundments, soil and landuse/landcover.

5.2.7 Mass Wasting and Log Jam Assessment

Valley wall and stream bank instability within the Nemadji River Watershed has been exacerbated by large flooding events in 2011 and 2012. The entire region sustained extensive infrastructure damage with restoration activities continuing through 2014. Recent surveys of remote portions of the Nemadji River Watershed have identified significant destruction of in-stream habitat caused by mass wasting and log jams. In many cases these sites have created impoundments that are causing the channel to aggrade and are acting as fish passage barriers. Many of these sites were found to be actively slumping in 2014. A complete survey of the watershed is needed to identify logjams caused by massive valley wall and stream bank failures. Each site should be assessed for the most practicable means to remove the obstruction while giving consideration to minimizing slumping soil from clogging the stream channel in the future. A similar project is currently being led by Minnesota Trout Unlimited on the Blackhoof River.

5.2.8 Deer Creek Turbidity Impairment Implementation Projects

The Deer Creek Turbidity TMDL and Implementation Plan identify BMPs and implementation projects to reduce the sources of turbidity to Deer Creek. Similar turbidity impairments are found throughout the Nemadji River Watershed, and therefore the Deer Creek BMPs and implementation projects can be applied throughout the watershed. Specific activities include: sediment volcano monitoring and feasibility study, assessment of Red Clay Dam failures, culvert inventory, sediment volcano impoundment, streambank slump stabilization, updated feedlot inventory, and implement livestock exclusions and continued improvements to forestry management.

5.2.9 Sand & Gravel Mining Assessment

Portions of the Nemadji River Watershed contain valuable sand and gravel resources. Many of these resources are in close proximity to high priority coldwater fisheries. Surface and subsurface hydrology within a trout stream watershed are critical components to the health of aquatic organisms in the stream. Cumulative effects of watershed and groundwater flow alteration can be detrimental to these streams that are particularly sensitive to changes in flow regime and temperature. An assessment should be conducted to evaluate current effects of mining activities on the hydrology of coldwater streams in the Nemadji River Watershed, and projections made of these effects if mining operations are expanded.

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7 Appendix

Table 65. Values used to score evidence in the Stressor Identification Process

Value	Meaning	Caveat
Strength of evidence values used to score all possible stressors		
+	evidence supports as a candidate cause	but strength of cause unknown
0	some evidence supports as a candidate cause	but not all evidence supports as a candidate cause
-	evidence does not support as a candidate cause	
NE	no evidence or data available to support or not support as a candidate cause	ambiguous evidence
Strength of evidence values used to score the candidate causes		
ü ü	Primary stressor with strong supporting evidence	
ü	Likely stressor with some supporting evidence	
-	Potentially a stressor with little supporting evidence	
x	Not likely a stressor with little supporting evidence	
x x	Supporting evidence indicates that it is not a stressor	
?	Insufficient evidence to assess	

Table 66. Types of evidence used to assess possible stressors

Possible Stressor	Desktop data evaluation	Targeted data collection
Low DO	% wetland watershed cover	Continuous DO/Temp monitoring
	Known impoundments or beaver dams	Beaver study
		Paired watershed study
Hydrologic regime alteration	Artificial drainage & impoundments	Continuous stage & flow monitoring
	L-THIA historic flow trends & land use	Beaver study
	IHA analysis	
Nutrient regime alteration	L-THIA/HSPF loading rates	WQ synoptic monitoring
	WQ monitoring data	
~~Organic matter regime alteration~~	No evidence available, eliminated as a possible stressor	
pH regime alteration	WQ monitoring data	pH/alkalinity monitoring
	Sulfate deposition rates	Beaver study
		Paired watershed study
Salinity regime alteration	WQ monitoring data	Specific conductivity/ chloride monitoring
		Paired watershed study
Bed sediment load changes	Corps sediment modeling and reports	Geomorph survey (Mecklenburg)
	Superior Harbor dredging volumes	Beaver study
	Deer Creek modeling	
Suspended solids/ turbidity	Slope stability (past reports)	TSS/ turbidity/ transparency monitoring
	Channel downcutting	Sediment settling experiment
	Clay soils	Beaver study
	Known sediment volcanoes	Paired watershed study
	Flow and TSS relationships	BEHI
Water temperature regime alteration	DNR monitoring data	Continuous temperature monitoring
	% wetland watershed cover	Beaver study

Possible Stressor	Desktop data evaluation	Targeted data collection
	Deer Creek MODFLOW/ GW analyses	Paired watershed study
	GW discharge points	
	Turbidity/ temperature relationships	
Habitat destruction	Sedimentation	Geomorph survey
	Siltation (past reports)	Road, trails, bridges, and culverts
	Bank instability and % tree cover	Beaver study
	Deer Creek slump predictive analysis	Pebble Counts
Habitat fragmentation	Known knick points	Geomorph survey
	Known impoundments/ beaver dams	Beaver study
	Known barriers	Stream profiles
	USFS-Verry MESBOAC	Knickpoint Identification
		Clear and Mud WI barrier evaluation
Physical crushing and trampling	% pasture land cover	Field reconnaissance
Toxic substances	Known railroad tracks/trestles	Field reconnaissance
	Pesticide applications	
	WLSSD waste application	
Metals	Historical industrial emissions	Total & dissolved aluminum monitoring
	Dominant wind direction	Paired watershed study

Table 67. Fish Metrics for Northern Coldwater Streams

Metric Name	Category	Response	Metric Description	Clear	Deer	Elim	Mud	Rock
CWSensitiveTX Pct_11Grad	tolerance	positive	Relative abundance (%) of taxa that are sensitive in coldwater streams (scoring adjusted for gradient)	0%	0%	0%	0%	0%
CWIntolerantPct	tolerance	positive	Relative abundance (%) of individuals that are intolerant in coldwater streams	0%	12%	2%	12%	1.5%
PioneerTXPct	life history	negative	Relative abundance (%) of taxa that are pioneer species	50%	33%	50%	33%	27%
Cold	habitat	positive	Taxa richness of coldwater species	1	0	1	1	1
CWTolPct	tolerance	negative	Relative abundance (%) of individuals that are tolerant in coldwater streams	<1%	<1%	6%	4%	1%
PercfmPct	composition	negative	Relative abundance (%) of individuals that are members of the order Perciformes	16%	14%	19%	12%	2%
OmnivoreTXPct	trophic	negative	Relative abundance (%) of taxa that are omnivorous	17%	22%	17%	11%	18%
NestNoLithPct	reproductive	negative	Relative abundance (%) of individuals that are non-lithophilic nest-guarders	16%	15%	26%	16%	3%
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with Deformities, Eroded fins, Lesions, or Tumors	0%	<1%	0%	0%	0%

Table 68. Fish Metrics for Low Gradient Streams

Metric Name	Category	Response	Metric Description	Blackhoof
Hdw-TolPct	habitat	positive	Relative abundance (%) of individuals that are headwater species (excludes tolerant species)	2.5%
Minnows-TolPct	composition	positive	Relative abundance (%) of individuals that are Cyprinids (excludes tolerant species)	0%
NumPerMeter-Tolerant	composition	positive	Number of individuals per meter of stream sampled (excludes tolerant species)	
OmnivoreTXPct	trophic	negative	Relative abundance (%) of taxa that are omnivorous	25%
PioneerTXPct	life history	negative	Relative abundance (%) of taxa that are pioneers	25%
Sensitive	tolerance	positive	Taxa richness of sensitive species	1
SLithop	reproductive	positive	Taxa richness of simple lithophilic spawning species	1
TolTXPct	tolerance	negative	Relative abundance (%) of taxa that are tolerant	50%
Wetland-Tol	habitat	positive	Taxa richness of wetland species (excludes tolerant species)	0
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with Deformities, Eroded fins, Lesions, or Tumors	0%

Table 69. Invertebrate Metrics for Northern Coldwater Streams

Metric Name	Category	Response	Metric Description	Clear	Deer	Elim	Mud	Rock
Collector-gathererChTxPct	Trophic	Increase	Relative percentage of collector-gatherer taxa	44%	32%	41%	40%	33%
HBI_MN	Tolerance	Increase	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	6.03	5.93	6.46	6.36	6.99
Intolerant2Ch	Tolerance	Decrease	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, Using MN TVs	3	2	4	1	0
LongLivedChTxPct	Life History	Decrease	Relative percentage of long-lived taxa	8%	15%	12%	15%	10%
NonInsectTxPct	Composition	Increase	Relative percentage of non-insect taxa	20%	6%	9%	10%	13%
OdonataChTxPct	Composition	Decrease	Relative percentage of taxa belonging to Odonata	0%	6%	3%	5%	3%
POET	Richness	Decrease	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)	8	14	14	12	9
Predator	Trophic	Decrease	Taxa richness of predators (excluding Chironomidae predator taxa)	3	8	6	5	2
VeryTolerant2ChTxPct	Tolerance	Increase	Relative percentage of taxa with tolerance values equal to or greater than 8, using MN TVs.	16%	21%	15%	30%	33%

Table 70. Invertebrate Metrics for Northern Forest Streams (Glide/Pool Habitats)

Metric Name	Category	Response	Metric Description	Blackhoof
ClimberCh	Habitat	Decrease	Taxa richness of climber	4
Collector-filtererPct	Trophic	Decrease	Relative abundance (%) of collector-filterer individuals in a subsample	46%
DomFiveChPct	Composition	Increase	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)	88%
HBI_MN	Tolerance	Increase	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	5.45
Intolerant2Ch	Tolerance	Decrease	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs	0
POET	Richness	Decrease	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon	5
PredatorCh	Richness	Decrease	Taxa richness of predators	8
TaxaCountAllChir	Richness	Decrease	Total taxa richness of macroinvertebrates	24
TrichopteraChTxPct	Composition	Decrease	Relative percentage of taxa belonging to Trichoptera	8%
TrichwoHydroPct	Composition	Decrease	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	0%

Table 71. 2011 MPCA Biological Assessment Summary

Name	Elim	Rock	Blackhoof	Clear	Deer	Mud
AUID	04010301-501	04010301-508	04010301-519	04010301-527	04010301-531	04010301-537
Station	11LS072	11LS063	90LS031	11LS056	11LS064	11LS058
Sample Date	9/15/2011	9/15/2011	6/14/2011	9/15/2011	6/16/2011	9/15/2011
Water Temp (deg C)	9.6	7.9	19.3	9.8	11.8	9
Cond (umhos/cm)	229	415	196.5	586	293	434
DO (mg/L)	11.01	9.61	7.7	11.25	10.12	10.39
pH	8.11	8.14	7.23	8.32	8.21	8.25
Nitrogen (mg/L)	0.432	< 0.05	0.128	0.396	0.076	0.116
TP (mg/L)	0.12	0.037	0.057	0.039	0.124	0.071
TSS (mg/L)	9.6	8	12	4.8	130	< 4
Ammonia (mg/L)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Fish Community Metrics						
DELT (abnormalities)	0	0	0	0	1	0
Darter species	1	1	1	1	1	1
Exotic species	0	0	0	0	0	0
Fish per 100 m	31.3	206.3	79.3	170.9	86	78.5
Game fish species	1	0	0	0	0	0
Gravel spawning species	1	4	1	1	4	3
Piscivore species	0	0	0	0	0	0
Pollution intolerant species	1	1	0	0	1	1

Name	Elim	Rock	Blackhoof	Clear	Deer	Mud
Special concern species	0	0	0	0	0	0
Total species	6	11	4	6	9	9
Fish IBI	**20**	**37**	**29**	**26**	**19**	**29**
Invertebrate Community Metrics						
EPT Taxa	10	5	4	7	10	8
Ephemeroptera Taxa	3	3	3	2	4	3
Hilsenhoffs Biotic Index (HBI)	4.9	4.9	4.1	4.8	4.6	4.4
Intolerant Families	5	1	1	3	6	3
Percent Pollution Tolerant	0.3	0	0.9	1.6	0.7	1
Percent Chironomidae	22.4	24.9	4.7	14.9	26.7	19.5
Percent Diptera	46.1	39.6	47	39.6	49.7	30.7
Percent Dominant Taxa	22.4	35.5	41.1	23.7	26.7	26.2
Percent Dominant Two Taxa	44.8	60.4	78.2	47.1	38.7	45.7
Percent Filterers	45.1	48.9	45.2	48.1	22.7	35.5
Percent Gatherer	45.8	42.5	51.1	48.7	50.3	53.4
Percent Hydropsychidae	22.4	35.5	4	23.4	12	26.2
Percent Scraper	4.9	5.8	0.9	1.9	2.3	4.2
Plecoptera Families	1	0	0	0	0	2
Total Families	17	11	14	14	24	14
Trichoptera Families	6	2	1	5	6	3
Invert IBI Score	**33**	**16**	**36**	**16**	**44**	**25**

Table 72. Fish and Invertebrate Community Index Scores of DO Tolerance (lower scores = more tolerant)

HUC8	N	Mean	Min	Q25	Median	Q75	Max
Fish Class 11 (Includes: Elim, Rock, Clear, Deer, and Mud)							
Cloquet River	3	7.26	6.59	6.59	7.27	7.91	7.91
Lake Superior - North	42	7.76	5.93	7.37	7.66	8.42	9.52
Lake Superior - South	74	7.80	6.59	7.37	7.75	8.18	9.38
Nemadji River	20	7.49	7.03	7.25	7.41	7.61	8.56
St. Louis River	36	7.27	5.67	6.99	7.34	7.51	8.04
Statewide	273	7.38	5.51	6.96	7.35	7.78	9.52
Fish Class 7 (Includes: Blackhoof)							
Cloquet River	1	6.48	6.48	6.48	6.48	6.48	6.48
Lake Superior - South	1	6.35	6.35	6.35	6.35	6.35	6.35
Nemadji River	2	6.08	5.56	5.56	6.08	6.59	6.59
St. Louis River	24	6.29	5.46	5.72	6.43	6.68	7.21
Statewide	384	6.15	5.25	5.73	6.11	6.54	7.32
Invert Class 8 (Includes: Elim, Rock, Clear, Deer, and Mud)							
Cloquet River	3	7.04	6.65	6.65	7.08	7.40	7.40
Lake Superior – North	31	7.18	6.37	6.79	7.27	7.45	7.87
Lake Superior – South	62	7.39	5.56	7.16	7.56	7.73	8.02
Nemadji River	14	7.56	6.58	7.43	7.60	7.71	8.20
St. Louis River	28	7.04	5.87	6.71	7.13	7.34	7.90
Statewide	199	7.19	5.56	6.78	7.31	7.61	8.20
Invert Class 4 (Includes: Blackhoof)							
Lake Superior - South	1	6.16	6.16	6.16	6.16	6.16	6.16
Nemadji River	5	5.25	3.96	4.15	4.49	6.64	7.03
St. Louis River	81	6.35	3.51	6.09	6.50	6.72	7.62
Statewide	439	6.40	3.51	6.11	6.48	6.78	7.92

Table 73. Fish and Invertebrate Community Index Scores of TSS Tolerance (higher scores = more tolerant)

HUC8	N	Mean	Min	Q25	Median	Q75	Max
Fish Class 11 (Includes: Elim, Rock, Clear, Deer, and Mud)							
Cloquet River	3	11.31	8.02	8.02	12.46	13.46	13.46
Lake Superior - North	42	9.59	4.69	7.16	9.16	11.99	15.18
Lake Superior - South	74	9.95	4.05	8.46	10.15	11.43	16.97
Nemadji River	20	12.52	9.12	10.85	12.97	13.93	16.02
St. Louis River	36	11.96	8.28	10.36	11.79	13.00	17.61
Statewide	273	11.15	4.05	9.54	11.44	12.82	18.59
Fish Class 7 (Includes: Blackhoof)							
Cloquet River	1	11.71	11.71	11.71	11.71	11.71	11.71
Lake Superior - South	1	13.09	13.09	13.09	13.09	13.09	13.09
Nemadji River	2	11.31	11.15	11.15	11.31	11.46	11.46
St. Louis River	24	12.29	10.03	11.06	12.06	13.05	16.22
Statewide	384	15.11	8.87	11.73	13.38	16.59	37.66
Invert Class 8 (Includes: Elim, Rock, Clear, Deer, and Mud)							
Cloquet River	3	12.29	11.73	11.73	12.28	12.86	12.86
Lake Superior - North	33	12.16	10.12	11.20	12.21	12.77	15.49
Lake Superior - South	81	13.24	9.94	12.26	13.39	14.12	16.15
Nemadji River	18	14.99	12.07	14.03	14.89	15.88	18.21
St. Louis River	32	13.67	10.92	13.02	13.56	14.28	17.06
Statewide	231	13.45	9.69	12.33	13.39	14.45	18.21
Invert Class 4 (Includes: Blackhoof)							
Lake Superior - South	1	13.12	13.12	13.12	13.12	13.12	13.12
Nemadji River	5	12.79	11.52	12.10	12.70	12.74	14.89
St. Louis River	76	14.48	11.05	13.11	14.37	15.21	26.81
Statewide	433	14.40	8.62	13.40	14.39	15.33	26.81

Table 74. Fish and Invertebrate Community Index Scores of TSS and DO Tolerance for the Impaired Streams

Visit Date	Site	Stream Name	Fish Class	Fish DO Index	Fish TSS Index	Invert Class	Invert DO Index	Invert TSS Index
14-Jun-11	90LS031	Blackhoof River	7	6.59	11.46	4	7.03	12.74
15-Sep-11	11LS056	Clear Creek	11	7.33	13.70	8		14.20
16-Jun-11	11LS064	Deer Creek	11	7.29	14.17	8	7.57	14.03
15-Sep-11	11LS072	Elim Creek	11	7.70	11.65	8		15.39
15-Sep-11	11LS058	Mud Creek	11	7.32	13.61	8	7.68	16.19
15-Sep-11	11LS063	Rock Creek	11	7.24	14.39	8	7.57	16.71

Table 75. Strength of evidence table for candidate causes

Candidate Stressor	Elim (-501)	Rock (-508)	Blackhoof (-519)	Clear (-527)	Deer (-531)	Mud (-537)
Historic Flow Alteration	x	ü ü	x	ü ü	ü ü	ü ü
Recent Flow Alteration	ü	ü	-	x	ü	?
Physical Habitat	xx	ü	xx	ü	ü ü	-
Habitat Fragmentation	ü ü	-	ü ü	?	-	-
Dissolved Oxygen	xx	x	x	xx	xx	xx
Water Temperature	xx	ü ü	xx	xx	-	-
Turbidity (TSS)	x	ü ü	xx	ü ü	ü ü	ü ü

8 SID Supporting Documents

The following supporting documents are available by request from MPCA staff. Contact the watershed project manager listed on the Nemadji River Watershed webpage. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/ watersheds/nemadji-river.html

8.2 Technical Memo: Available Data (February 28, 2013)

8.3 Technical Memo: April 10 Technical Review Meeting (March 29, 2013)

8.4 Technical Memo: Spring 2013 Monitoring Plan (May 1, 2013)

8.5 Report: Hydrologic Change in Relation to IBI Impairment (February 6, 2014)

8.6 Report: Nemadji River Watershed Beaver Study (February 7, 2014)

8.7 Technical Memo: Additional Data Collection Summary (February 10, 2014)

8.7.7 Nemadji River Watershed Data Packet

8.7.7.1 Aerial Photo Map Packet

8.7.7.2 Topographic Map Packet

8.7.7.3 Stream Profile Map Packet

8.8 Technical Memo: Biologically Impaired Stream Summaries (February 11, 2014)

8.9 Technical Memo: Preliminary Strength of Evidence (April 3, 2014)

9 Related Reports

The following list of reports pertain to Nemadji Watershed stream investigations of channel instability and evolution, clay erosion, sediment transport to Lake Superior and mud volcanoes. Most are available online at several locations, or contact MPCA watershed staff or Carlton County SWCD staff for copies.

Andrews, S. C., Christensen, R.G., Wilson, C.D. 1980. Impact of nonpoint pollution control on western Lake Superior. Red clay project final report part III. USEPA report 905/9-76-002, Washington, D.C.

Banks, G., Brooks, K. 1996. Erosion–sedimentation and nonpoint pollution in the Nemadji Watershed: status of our knowledge. University of Minnesota, Department of Forest Resources, St Paul.

Kemp, A.L.W., Dell, C.I., Harper, N.S., 1978. Sedimentation rates and a sediment budget for Lake Superior. J. Great Lakes Res. 4 (3–4), 276–287.

Koch, R.G., Kapustka, L.A., Koch, L.M., 1977. Presettlement vegetation of the Nemadji River Basin. J. Minn. Academy Sci. 43, 19–23.

Magner, J. 2004. Channel Stability Monitoring in the Nemadji River Basin.

Mooers, H.D., and Wattrus, N.L., 2005. Results of Deer Creek Groundwater Seepage Investigation Report to Carlton County Planning and Zoning Department, 29p.

Mossberger, I.G. 2010. Potential for Slumps, Sediment Volcanoes, and Excess Turbidity in the Nemadji River Basin. M.S. Thesis. University of Minnesota.

MPCA, 2013. Deer Creek Watershed Total Maximum Daily Load Implementation Plan: Turbidity Impairment.

NRCS, 1998a. Nemadji River Basin Project Report. USDA Natural Resources Conservation Service, St Paul, MN.

NRCS, 1998b. Appendix F—Sediment Budget Process. In: Nemadji River Basin Project Report. USDA Natural Resources Conservation Service, St Paul, MN.

Riedel, M. S., Brooks, K. N., Verry, E. S. 2006. Stream Bank Stability Assessment in Grazed Riparian Areas. Proceedings of the Eight Federal Interagency Sedimentation Conference (8th FISC), April 2-6, 2006 Reno, NV.

Riedel, M. S., Verry, E. S., Brooks, K. N. 2005. Impacts of lake use conversion on bankfull discharge and mass wasting. Journal of Environmental Management. 76 326-337.