Lake of the Woods Watershed Stressor Identification Report

A study of the stressors limiting the aquatic biological communities of watercourses in the Lake of the Woods Watershed.

East Branch Warroad River

Minnesota Pollution Control Agency

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Cover Photo

East Branch Warroad River at CSAH 12

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Acronyms

AUID – Assessment Unit Identification

BMP – Best Management Practice

CADDIS – Causal Analysis/Diagnosis Decision Information System

CR – County Road

CSAH – County State Aid Highway

DO – Dissolved Oxygen

DNR – Minnesota Department of Natural Resources

EPA – United States Environmental Protection Agency

HSPF – Hydrological Simulation Program - FORTRAN

HUC – Hydrologic Unit Code

IBI – Index of Biological Integrity

IWM – Intensive Watershed Monitoring

LOWW – Lake of the Woods Watershed

MPCA – Minnesota Pollution Control Agency

MSHA – MPCA Stream Habitat Assessment

NAIP – National Agriculture Imagery Program

NLCD – National Land Cover Database

SID – Stressor Identification

SOE – Strength-of-Evidence

TALU – Tiered Aquatic Life Use

TIV – Tolerance Indicator Value

TMDL – Total Maximum Daily Load

TSS – Total Suspended Solids

USGS – United States Geological Survey

WHAF – Watershed Health Assessment Framework

Executive summary

The Minnesota Pollution Control Agency (MPCA) follows a watershed approach to systematically monitor and assess surface water quality in each of the state's 80 major watersheds. A key component of this approach is Intensive Watershed Monitoring (IWM), which includes biological (i.e., fish and macroinvertebrate) monitoring to evaluate overall stream health. Between 2012 and 2014, the MPCA conducted biological monitoring at several stations throughout the Lake of the Woods Watershed (LOWW). An Index of Biological Integrity (IBI) score was then calculated for the fish (F-IBI) and macroinvertebrate (M-IBI) communities of each station using the IWM and previously collected data. The biological monitoring results for the watershed were assessed to identify individual stream reaches that were not supporting a healthy fish and/or macroinvertebrate assemblage. A stream segment with a low IBI score(s) (i.e., below an established threshold) is considered "impaired" (i.e., unable to support its designated beneficial use) for aquatic life. Six reaches were determined to have an F-IBI and/or M-IBI impairment in the LOWW: Williams Creek, East Branch Warroad River, Willow Creek, West Branch Zippel Creek, Unnamed Ditch, and County Ditch 20.

This report identifies the main causes, or "stressors", that are likely contributing to the biological impairments in the watershed. Five candidate causes were examined as potential stressors in the report: loss of longitudinal connectivity, insufficient base flow, insufficient physical habitat, high suspended sediment, and low dissolved oxygen. Causal analysis was performed to determine and evaluate connections between each candidate cause and the biological impairments. Table 1 lists the stressors identified for each of the biologically impaired reaches in the LOWW.

Table 1. Summary of the stressor associated with the biologically impaired reaches in the LOWW.

AUID Suffix	Reach Name	Biological Impairment(s)	Stressors				
			Loss of Longitudinal Connectivity	Insufficient Base Flow	Insufficient Physical Habitat	High Suspended Sediment	Low Dissolved Oxygen
501	Williams Creek	F-IBI/M-IBI		●	●	●	●
504	East Branch Warroad River	M-IBI		●	●	●	●
505	Willow Creek	F-IBI		●	●	●	●
515	West Branch Zippel Creek	F-IBI/M-IBI		●	●	●	●
523	Unnamed Ditch	F-IBI/M-IBI		●	●	●	●
560	County Ditch 20	M-IBI		●	●	●	●

Each of the reaches is adversely affected by the following stressors: insufficient base flow, insufficient physical habitat, high suspended sediment, and low dissolved oxygen. Many of the reaches are prone to extended periods of intermittency, particularly in late summer. All of the reaches have physical habitat-related issues (e.g., embeddedness of coarse substrate). The reaches are also prone to periods of high suspended sediment. Lastly, each of the reaches is subject to periods of low dissolved oxygen, particularly during low flow conditions.

Introduction

Stressor identification (SID) is a formal and rigorous methodology for determining the causes, or "stressors", that are likely contributing to the biological impairment of aquatic ecosystems (EPA, 2000). The initial step in the SID process (Figure 1) is to define the subject of the analysis (i.e., the case) by determining the geographic scope of the investigation and the effects that will be analyzed. Thereafter, a list of candidate causes (i.e., potential stressors) that may be responsible for the observed biological effects is developed. The candidate causes then undergo causal analysis, which involves the evaluation of available data. Typically, the majority of the data used in the analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon. Analyses conducted during this step combine measures of the biological response, with direct measures of proximate stressors. Upon completion of causal analysis, strength-of-evidence (SOE) analysis is used to determine the probable stressors for the biological impairment. Confidence in the final SID results often depends on the quality of data available to the process. In some cases, additional data collection may be necessary to accurately identify the stressors.

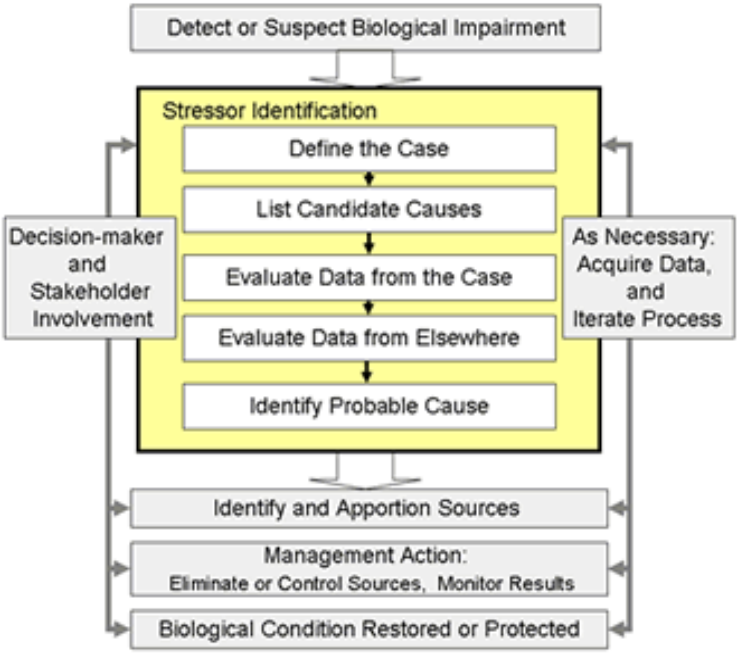


Figure 1. Conceptual model of the SID process (EPA, 2012).

Section 1: Watershed overview

1.1 Physical setting

The LOWW, United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 09030009, is part of the larger Rainy River Basin. The LOWW has a drainage area of 1,151 square miles and encompasses portions of the following counties, listed in order of the percentage of watershed area: Lake of the Woods (80%) and Roseau (20%). Cities in the watershed include Roosevelt, Warroad, and Williams.

1.2 Surface water resources

Lake of the Woods is the prominent surface water feature in the LOWW, encompassing 41% of the total area. The LOWW also contains 172 miles of intermittent stream, 166 miles of intermittent drainage ditch, 157 miles of perennial drainage ditch, 95 miles of perennial stream, and 64 miles of river (DNR, 2015). According to the MPCA (2013), 60% of the watercourses in the LOWW have been hydrologically altered (i.e., channelized, ditched, or impounded).

1.3 Surficial geology and soils

The surficial geology of the LOWW is dominated by sediments that were deposited during the last glaciation and later modified and reworked by glacial Lake Agassiz. Two distinct physiographic regions are represented in the watershed. The drift plain/beach ridges region, which includes glacial drift deposits and the ancient shorelines of Lake Agassiz, follows an approximately 10 mile wide corridor along the southern edge of Lake of the Woods. This region is characterized by an undulating topography (0-8% slope) and soils of varying textures. The peatlands region is located south of the drift plain/beach ridges region. The region is characterized by a flat topography (0-2% slope) and poorly drained, organic soils that formed over a mantle of lacustrine sediments.

1.4 Land use and ecoregions

According to the National Land Cover Database (NLCD) 2011 (USGS, 2011), wetlands (42%) and open water (41%) were the predominant land cover groups in the LOWW. Other notable land cover groups in the watershed included cultivated crops (7%), hay/pasture (4%), developed (2%), forest (2%), and herbaceous (1%).

1.5 Ecological health

The Minnesota Department of Natural Resources (DNR) developed the Watershed Health Assessment Framework (WHAF) to assess the overall ecological health of a watershed. The WHAF evaluates and provides a score to each of the five core components of watershed health: hydrology, geomorphology, biology, connectivity, and water quality. Scores are ranked on a scale from 0 (“extremely poor”) to 100 (“extremely good”). Statewide mean health scores ranged from 40 (Marsh River Watershed) to 84 (Rapid River Watershed).

Figure 2 presents the watershed health scorecard for the LOWW. The mean health score for the watershed was 65. The overall score was limited by the following component indices: altered streams (0), water quality assessments (10), at-risk species (40), stream species quality (47), hydrologic storage (48), flow variability (57), species richness (59), terrestrial habitat quality (61), and groundwater susceptibility (62).

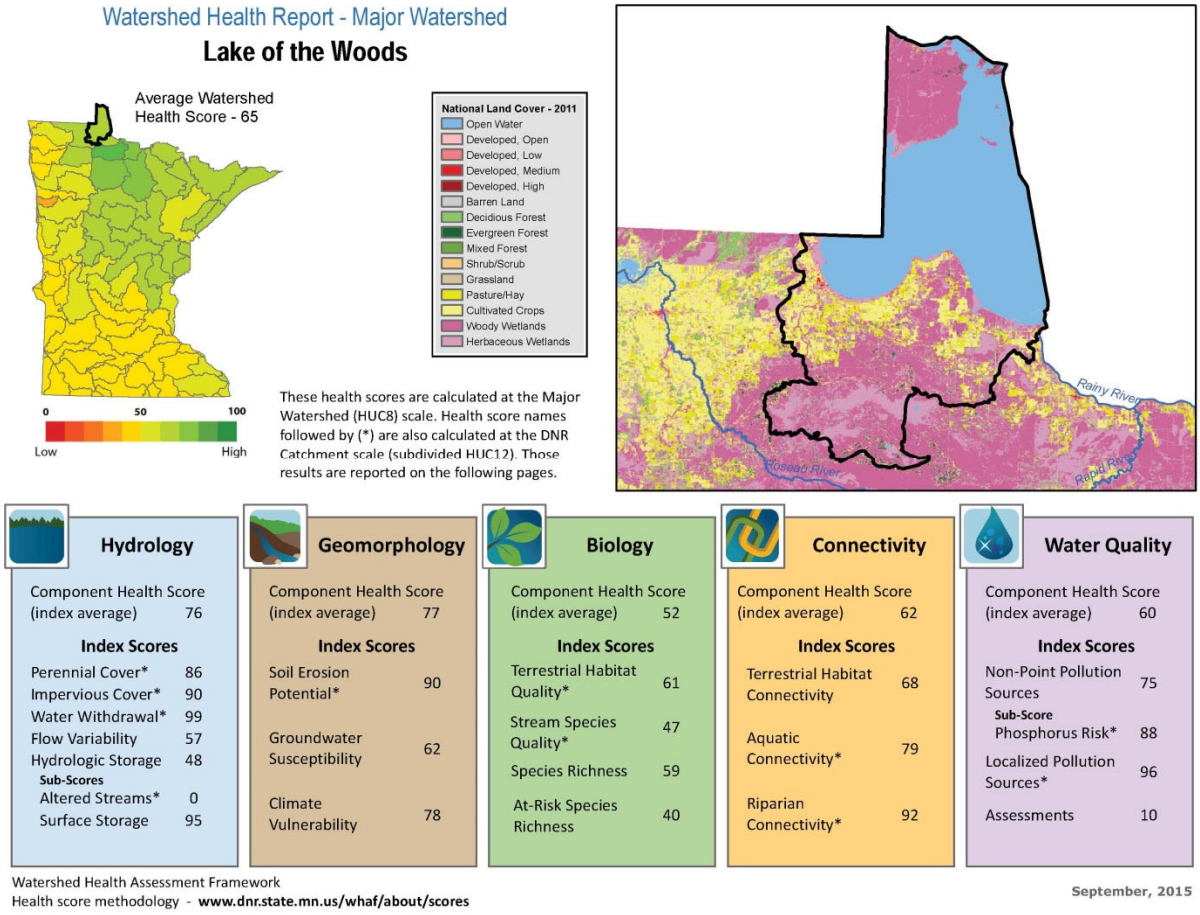


Figure 2. Watershed health assessment scores for the LOWW.

1.6 Hydrological Simulation Program – FORTRAN (HSPF) Model

A Hydrological Simulation Program – FORTRAN (HSPF) model was developed for the LOWW to simulate the hydrology and water quality conditions throughout the watershed on an hourly basis from 1996 to 2009. The HSPF model incorporates watershed-scale Agricultural Runoff Model and Non-Point Source models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. The model allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient concentrations, along with a time history of water quantity and quality at the outlet of each subwatershed. The HSPF model outputs were used in the evaluation of several of the candidate causes outlined in this report.

Section 2: Biological monitoring and impairments

2.1 Watershed approach

The Minnesota Pollution Control Agency (MPCA) utilizes a watershed approach (Figure 3) to systematically monitor and assess surface water quality in each of the state's 80 major watersheds. A key component of this approach is Intensive Watershed Monitoring (IWM), which includes biological (i.e., fish and macroinvertebrate) monitoring to evaluate overall stream health. Between 2012 and 2014, the MPCA conducted biological monitoring at several stations throughout the LOWW. An Index of Biological Integrity (IBI) score was then calculated for the fish (F-IBI) and macroinvertebrate (M-IBI) communities of each station using the IWM and previously collected data. The biological monitoring results for the watershed were assessed to identify individual stream reaches that were not supporting a healthy fish and/or macroinvertebrate assemblage. A stream segment with a low IBI score(s) (i.e., below an established threshold) is considered "impaired" (i.e., unable to support its designated beneficial use) for aquatic life. The biological impairments of the LOWW are the focus of this SID report. The results of the SID process will guide the development of implementation strategies to correct the impaired conditions, which may include the preparation of a Total Maximum Daily Load (TMDL) study.

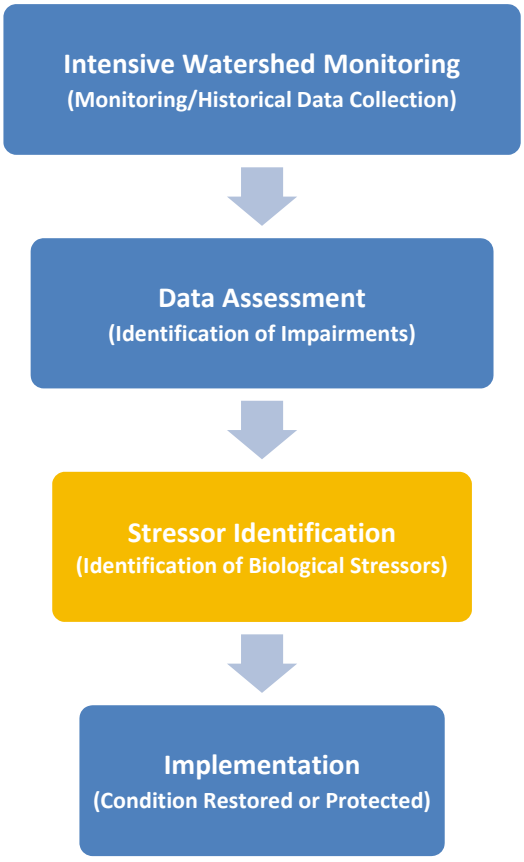


Figure 3. Conceptual model of the watershed approach processes.

2.2 Monitoring stations

Table 2 lists the 26 biological monitoring stations that were sampled for fish and/or macroinvertebrates in the LOWW. The stations are situated along 18 separate reaches. For the purpose of this report, individual reaches will be referred to by their respective three-digit Assessment Unit Identification (AUID) number suffix.

Table 2. List of biological monitoring stations in the LOWW.

AUID Suffix	AUID	Name	Monitoring Station(s)
501	09030009-501	Williams Creek	10EM161, 12RN020
502	09030009-502	Warroad River	05RN116
503	09030009-503	West Branch Warroad River	05RN118, 12RN004, 12RN006, 13RN001
504	09030009-504	East Branch Warroad River	05RN115, 10EM017, 12RN010
505	09030009-505	Willow Creek	05RN188, 12RN015
515	09030009-515	West Branch Zippel Creek	12RN018
516	09030009-516	Tomato Creek	05RN117
518	09030009-518	Tomato Creek	12RN017
523	09030009-523	Unnamed Ditch	12RN016
526	09030009-526	Unnamed Ditch	05RN017
528	09030009-528	Unnamed Creek	05RN173
531	09030009-531	County Ditch 6	05RN127
533	09030009-533	Clausner Creek	12RN005
537	09030009-537	Bostic Creek	12RN021
557	09030009-557	Unnamed Creek	12RN007
558	09030009-558	Judicial Ditch 62	12RN008, 14RN153
560	09030009-560	County Ditch 20	12RN012
561	09030009-561	Unnamed Ditch	12RN014

2.3 Monitoring results

Table 3 provides the F-IBI and M-IBI scores for each of the biological monitoring stations in the LOWW. A total of seven stations (29%) scored below their F-IBI impairment threshold, while 13 stations (59%) scored below their M-IBI impairment threshold; these stations are highlighted red.

Table 3. Summary of F-IBI and M-IBI scores for biological monitoring stations in the LOWW.

Fish					Macroinvertebrate				
AUID Suffix	Station	F-IBI Class[1] (Use[3])	F-IBI Impairment Threshold	F-IBI Score (Mean)	AUID Suffix	Station	M-IBI Class[2] (Use[3])	M-IBI Impairment Threshold	M-IBI Score (Mean)
501	10EM161	NH(G)	42	38	501	10EM161	NGP(G)	51	67
501	12RN020	NH(G)	42	30	501	12RN020	NRR(G)	53	43
502	05RN116	NS(G)	47	59	502	05RN116	Non-Reportable		
503	05RN118	NS(G)	47	68	503	05RN118	NRR(G)	53	62
503	12RN004	NS(G)	47	66	503	12RN004	NGP(G)	51	58
503	12RN006	NS(G)	47	59	503	12RN006	NGP(G)	51	65
503	13RN001	NS(G)	47	53	503	13RN001	NRR(G)	53	55
504	05RN115	LGS(G)	42	86	504	05RN115	NRR(G)	53	51
504	10EM017	NH(G)	42	67	504	10EM017	NGP(G)	51	43
504	12RN010	NH(G)	42	54	504	12RN010	NRR(G)	53	55
505	05RN188	LGS(G)	42	26	505	05RN188	NGP(G)	51	31
505	12RN015	NH(G)	42	0	505	12RN015	NGP(G)	51	13
515	12RN018	LGS(G)	42	45	515	12RN018	NGP(G)	51	36
516	05RN117	NC(G)	35	42	516	05RN117	NC(G)	32	28
518	12RN017	NH(G)	42	57	518	12RN017	NGP(G)	51	37
523	12RN016	NH(G)	42	34	523	12RN016	NRR(G)	53	41
526	05RN017	NH(G)	42	47	526	05RN017	NRR(G)	53	60
528	05RN173	NH(M)	23	22	528	05RN173	Not Sampled		
531	05RN127	Not Sampled			531	05RN127	NGP(G)	51	41
533	12RN005	NH(G)	42	54	533	12RN005	Not Sampled		
537	12RN021	LGS(G)	42	53	537	12RN021	NGP(G)	51	30
557	12RN007	NH(G)	42	65	557	12RN007	NRR(G)	53	59
558	12RN008	NH(G)	42	48	558	12RN008	NGP(G)	51	39
558	14RN153	Not Sampled			558	14RN153	NGP(G)	51	63
560	12RN012	LGS(M)	15	38	560	12RN012	NGP(M)	37	31
561	12RN014	NH(G)	42	7	561	12RN014	Not Sampled		

[1] F-IBI Classes: Low Gradient Streams (LGS), Northern Coldwater (NC), Northern Headwaters (NH), Northern Streams (NS)
[2] M-IBI Class: Northern Coldwater (NC), Northern Forest Streams-Glide/Pool Habitats (NGP), Northern Forest Streams-Riffle/Run Habitats (NRR)
[3] Tiered Aquatic Life Use (TALU) Framework Designation: General Use (G), Modified Use (M)

2.4 Assessments and impairments

The biological monitoring results for the LOWW were formally assessed as part of the development of the *Lake of the Woods Watershed Monitoring and Assessment Report* (MPCA, 2016) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 4, six reaches were determined to be biologically impaired; these reaches are highlighted red. The relative location of these reaches is displayed in Figure 4.

Table 4. Assessment results for stream reaches with biological monitoring data in the LOWW.

AUID Suffix	Name	Description	Length (mi)	Biological Impairment(s)
501	**Williams Creek**	**Headwaters to Zippel Creek**	**13**	**F-IBI, M-IBI**
502	Warroad River	W&E Branch Warroad River to Lake of the Woods	5	None
503	West Branch Warroad River	Headwaters to Warroad River	29	None
504	**East Branch Warroad River**	**Headwaters to Warroad River**	**34**	**M-IBI**
505	**Willow Creek**	**Headwaters to Lake of the Woods**	**15**	**F-IBI**
515	**West Branch Zippel Creek**	**Headwaters to Zippel Bay (Lake of the Woods)**	**6**	**F-IBI, M-IBI**
516	Tomato Creek	Headwaters to T161, R34W, S3, North Line	3	None
518	Tomato Creek	T162, R34W, S34, South Line to Unnamed Creek	1	None
523	**Unnamed Ditch**	**Unnamed Ditch to Unnamed Ditch**	**1**	**F-IBI, M-IBI**
526	Unnamed Ditch	Unnamed Ditch to East Branch Warroad River	3	None
528	Unnamed Creek	Headwaters to Unnamed Creek	2	Not Assessed
531	County Ditch 6	Unnamed Ditch to Warroad River	5	Not Assessed
533	Clausner Creek	Unnamed Creek to Unnamed Creek	2	None
537	Bostic Creek	Headwaters to Lake of the Woods	4	None
557	Unnamed Creek	Headwaters to West Branch Warroad River	3	None
558	Judicial Ditch 62	Headwaters to Unnamed Ditch	2	None
560	**County Ditch 20**	**Headwaters to Lake of the Woods**	**3**	**M-IBI**
561	Unnamed Ditch	Headwaters to Lake of the Woods	5	Not Assessed

In addition, three of the abovementioned biologically impaired reaches in the LOWW have an existing or proposed water quality impairment that affects aquatic life (Table 5). Each of these reaches is listed for low dissolved oxygen (DO), while two reaches (i.e., AUIDs 501 and 515) are also listed for high total suspended solids (TSS).

Table 5. Water quality impairments associated with reaches in the LOWW.

AUID Suffix	Name	Description	Water Quality Impairment(s)
501	Williams Creek	Headwaters to Zippel Creek	DO[2], TSS[2]
505	Willow Creek	Headwaters to Lake of the Woods	DO[1]
515	West Branch Zippel Creek	Headwaters to Zippel Bay (Lake of the Woods)	DO[2], TSS[2]

[1] Existing impairment included on the 2012 Impaired Waters List
[2] New impairment to be included on the proposed 2016 Impaired Waters List

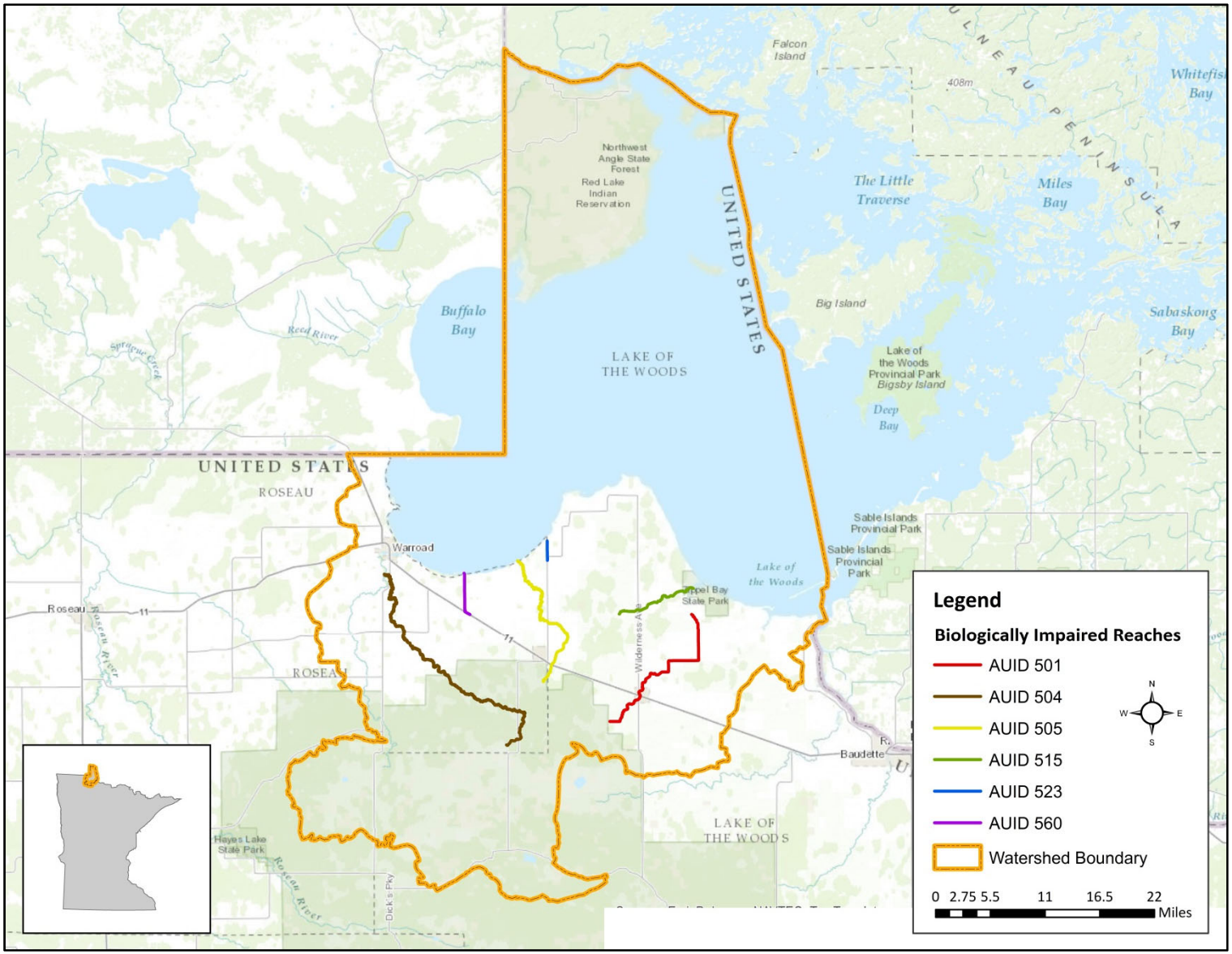


Figure 4. Map of the LOWW and associated biologically impaired reaches.

Section 3: Stressor identification

3.1 Identification of candidate causes

A candidate cause is defined as a "hypothesized cause of an environmental impairment that is sufficiently credible to be analyzed" (EPA, 2012). Identification of a set of candidate causes is an important early step in the SID process and provides the framework for gathering key data for causal analysis. Table 6 lists the 10 common biotic stressors that were considered as potential candidate causes in the LOWW. The list was developed based upon the results of other completed SID reports in the state. The credibility of each potential candidate cause as a stressor was then evaluated through a comprehensive review of available information for the watershed, including water quality and quantity data, as well as existing plans and reports, including the *Lake of the Woods Watershed Monitoring and Assessment Report* (MPCA, 2016), the *Lake of the Woods Major Watershed Restoration and Protection Plan Watershed Conditions Report* (HEI, 2012), the *Overall Plan of the Warroad River Watershed District* (Money, 2007), the *Lake of the Woods County Local Water Management Plan* (LOWCSWCD, 2010), and the *Roseau County Local Water Management Plan* (RCSWCD, 2010). Based upon the results of this evaluation, five candidate causes were identified to undergo causal analysis (Section 3.3).

Table 6. Summary of common biotic stressors evaluated as potential candidate causes for the biologically impaired reaches of the LOWW.

Stressor	Candidate Cause Identification	
	Summary of Available Information	Candidate Cause (Yes/No)
Loss of Longitudinal Connectivity	Several of the reaches have connectivity barriers (e.g., dam and perched culverts) that could potentially obstruct fish passage.	Yes
Insufficient Base Flow	Many of the reaches are prone to extended periods of intermittency.	Yes
Insufficient Physical Habitat	Several of the reaches have insufficient instream habitat to support a healthy and diverse biotic community.	Yes
High Suspended Sediment	Several of the reaches have discrete total suspended solids values that exceed the state standard (>15 mg/L). Two of the reaches have a proposed total suspended solids impairment.	Yes
Low Dissolved Oxygen	Several of the reaches have discrete dissolved oxygen values that are below the state standard (<5.0 mg/L). Three of the reaches have an existing or proposed dissolved oxygen impairment.	Yes
High Nitrate-Nitrite	Collectively, the highest discrete nitrate-nitrite value for the reaches was 0.7 mg/L, which is not expected to cause stress to aquatic biota.	No
Temperature Regime Alteration	Collectively, the highest discrete temperature measurement for the reaches was 26°C, which is not expected to cause stress to aquatic biota.	No
pH	Nearly all of the pH values associated with the biologically impaired reaches were within the state standard range (6.5-9.0). None of the reaches are pH impaired.	No
Pesticide Toxicity	There is no pesticide data for the reaches. As a result, there is insufficient information to declare pesticide toxicity as a candidate cause at this time.	No

3.2 Overview of candidate causes

3.2.1 Loss of longitudinal connectivity

Background

Connectivity in aquatic 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). Dams and other water control structures on river systems alter hydrologic (longitudinal) connectivity, often obstructing the movement of migratory fish and causing a change in the population and community structure (Brooker, 1981; Tiemann et al., 2004). These structures also alter stream flow, water temperature regime, and sediment transport processes; each of which can cause changes in fish and macroinvertebrate assemblages (Cummins, 1979; Waters, 1995). According to the DNR (2014), there are more than 1,200 dams in the state that serve a variety of purposes, including flood control, lake level control, wildlife habitat, and hydroelectric power generation. In addition to dams, culverts and beaver dams can also interfere with connectivity. A culvert that is raised (perched) above the stream level or undersized can limit the ability of fish to migrate throughout the stream. Beaver dams can also obstruct fish migration.

Applicable standards

There are no applicable standards for connectivity. However, the DNR's Public Waters Work Permit requires that road crossing structures be designed and installed to allow for fish passage.

3.2.2 Insufficient base flow

Background

Flow is considered a "maestro" (Walker et al., 1995) or "master variable" (Power et al., 1995) that affects many fundamental ecological characteristics of stream ecosystems, including biodiversity (Poff et al., 1997; Hart and Finelli, 1999; Bunn and Arthington, 2002). According to Poff and Zimmerman (2010), the flow regime of a stream is largely a function of climate (i.e., precipitation and temperature) and runoff-related controls (e.g., land cover and topography).

The natural flow regime of many streams in the watershed has been anthropogenically altered, primarily to expedite drainage for agricultural purposes (e.g., ditching, channelization of natural streams, modification/cultivation of headwater streams, subsurface tiling, and wetland drainage). These practices are known to cause increased and quicker peak discharges following rain events and reduced base flows during dry periods (Franke and McClymonds, 1972; Mitsch and Gosselink, 2007)

The United States Environmental Protection Agency's (EPA) Causal Analysis/Diagnosis Decision Information System (CADDIS) webpage contains a conceptual diagram of the sources and pathways for flow-related issues as a candidate cause for impairment.

Applicable standards

There are limited standards for the protection of base flow. The DNR regulates the appropriation of water resources and may restrict the withdrawal of surface water when flows are below protected levels.

3.2.3 Insufficient physical habitat

Background

Physical habitat is primarily a function of channel geomorphology (Rosgen, 1996) and flow (Bovee, 1986). Geomorphology is determined naturally by geology and climate (Leopold et al., 1994), but may

be altered directly by channelization and indirectly by land use changes affecting runoff and the removal of riparian vegetation (Aadland et al., 2005). A high frequency of bank-full flows often results in a subsequent increase in channel cross-sectional area (Verry, 2000) and a decrease in sinuosity (Verry and Dolloff, 2000). These geomorphic changes can result in reduced habitat quality and diversity, loss of interstitial space due to embeddedness, loss of pool depth due to sedimentation, and loss of cover (Aadland et al., 2005). Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (EPA, 2012).

The MPCA's Stream Habitat Assessment (MSHA) was used to evaluate the quality of habitat present at each of the biological monitoring stations in the LOWW. The MSHA is comprised of five scoring subcategories, including land use, riparian zone, instream zone substrate, instream zone cover, and channel morphology, which are summed for a total possible score of 100 points.

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for physical habitat as a candidate cause for impairment.

Applicable standards

There are no applicable standards for physical habitat.

3.2.4 High suspended sediment

Background

Total suspended solids is a measurement of the weight of suspended mineral (e.g., soil particles) or organic (e.g., algae) sediment per volume of water. Although sediment delivery and transport are important natural processes for all stream systems, excess sediment can result in the loss of habitat (e.g., embeddedness of coarse substrate), in addition to the direct harm to aquatic organisms. As described in a review by Waters (1995), high suspended sediment can cause harm to fish and macroinvertebrates through two major pathways: 1) direct, physical effects (e.g., clogged nets or filtering apparatuses) and 2) indirect effects (e.g., loss of visibility and increase in sediment oxygen demand). High suspended sediment can also reduce the penetration of sunlight and thus impede photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for high suspended sediment as a candidate cause for impairment.

Applicable standards

The state TSS standard for waters in the Northern River Region is 15 mg/L; this includes all of the biologically impaired reaches in the LOWW.

3.2.5 Low dissolved oxygen

Background

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Oxygen diffuses into water from the atmosphere (turbulent flow enhances this diffusion) and from aquatic plants during photosynthesis. The concentration of DO changes 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. Low or highly fluctuating DO concentrations can cause adverse effects (e.g., avoidance behavior, reduced growth rate, and fatality) for many fish and macroinvertebrate species (Allan, 1995; Davis, 1975; Marcy, 2007; Nebeker et al., 1992; EPA, 2012). Many species of fish avoid areas where DO concentrations are below 5.0 mg/L (Raleigh et al., 1986). According to Heiskary et al. (2010), DO flux of between 2.0 to 4.0 mg/L is typical in a 24-hour period.

Low DO can be an issue in streams with slow currents, excessive temperatures, high biological oxygen demand, and/or high groundwater seepage (Hansen, 1975). The critical conditions for DO usually occur during the late summer, when the water temperature is high and stream flow is low. Additionally, eutrophication (i.e., increased phosphorus) can cause excessive aquatic plant and algal growth, which can ultimately result in a decline in daily minimum DO concentrations and an increase in the magnitude of daily DO concentration fluctuations.

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for dissolved oxygen as a candidate cause for impairment.

Applicable standards

The state DO standard for Class 2B waters is 5.0 mg/L as a daily minimum; this includes all of the biologically impaired reaches in the LOWW.

3.3 Causal analysis – Profile of individual biologically impaired reaches

3.3.1 Williams Creek (AUID 501)

Physical setting

This reach represents Williams Creek (Figure 5), which extends from its headwaters, situated southwest of Williams, to its outlet to East Branch Zippel Creek; a total length of 13 miles. The reach has a subwatershed area of 31 square miles (19,957 acres). The subwatershed contains 13 miles of intermittent drainage ditch, 12 miles of perennial drainage ditch, 11 miles of intermittent stream, and 2 miles of perennial stream (DNR, 2015). According to the MPCA (2013), 71% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including approximately 9 miles of AUID 501. The NLCD 2011 (USGS, 2011) lists wetlands (70%) as the predominant land cover in the subwatershed. Notable minor land cover groups in the subwatershed included cultivated crops (12%), hay/pasture (5%), forest (5%), developed (4%), and herbaceous (3%).

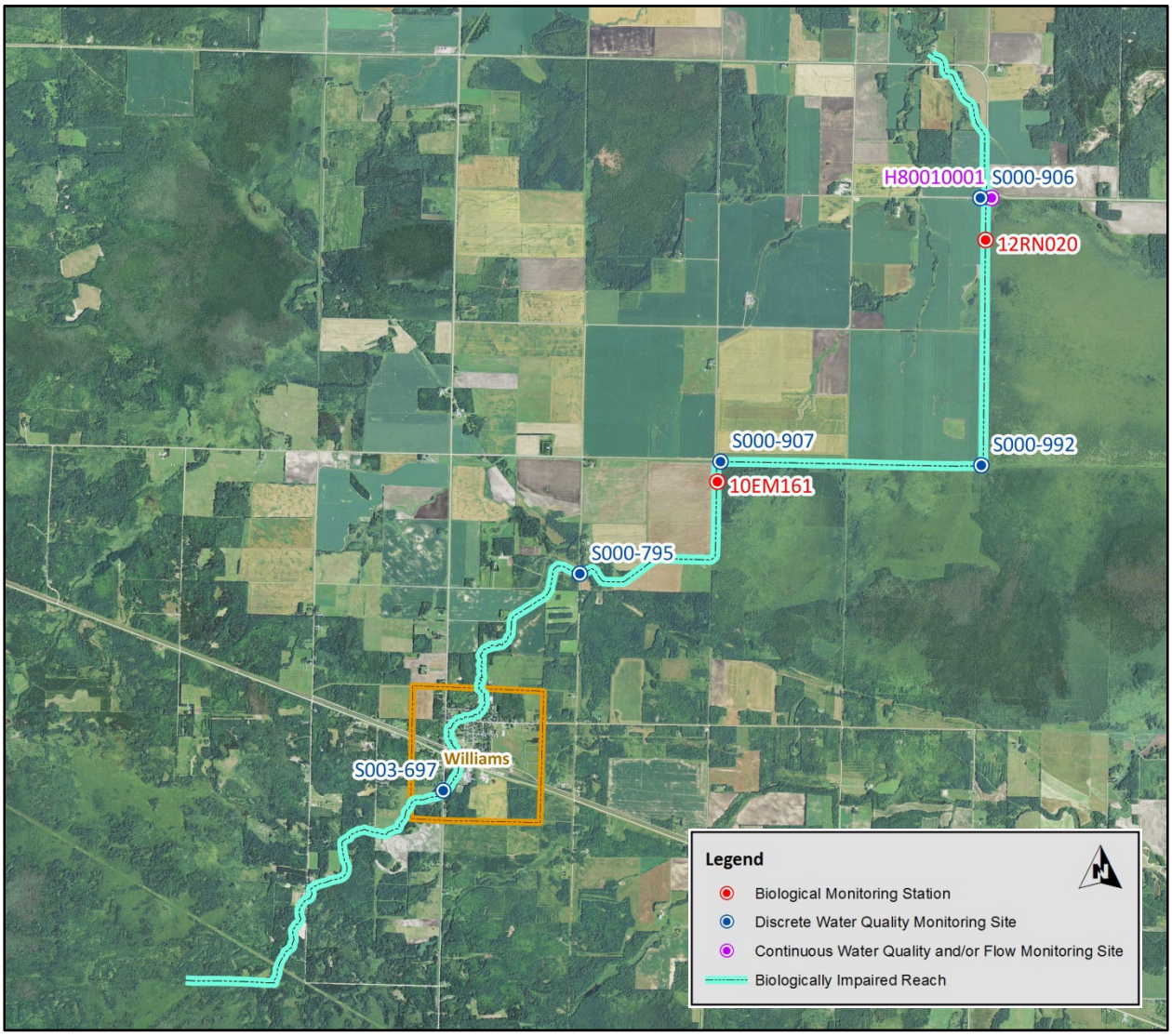
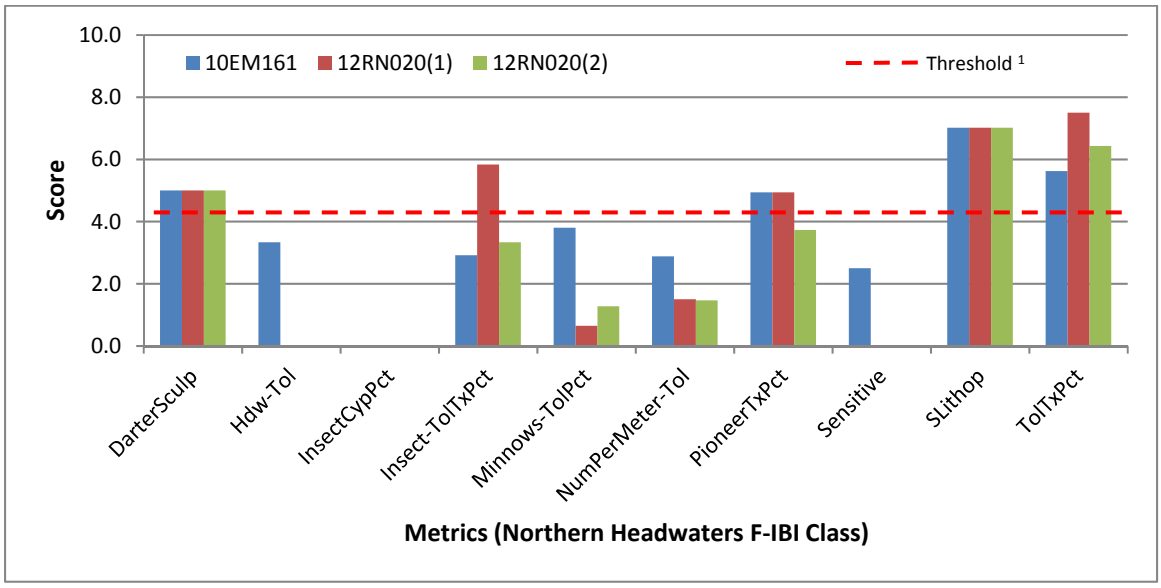


Figure 5. Map of AUID 501 and associated biological monitoring stations and water quality/flow monitoring site (2013 National Agriculture Imagery Program (NAIP) aerial image).

Biological impairments

Fish (F-IBI)

The fish community of AUID 501 was monitored at Station 10EM161 (0.2 mile upstream of 24th Street NW) on June 23, 2010; and Station 12RN020 (0.3 mile upstream of the County State Aid Highway (CSAH) 12 crossing) on June 14, 2012(1) and July 12, 2012(2). The relative location of the stations is shown in Figure 5. The stations were designated as General Use within the Northern Headwaters F-IBI Class. Accordingly, the impairment threshold for the stations is an F-IBI score of 42. Both stations scored below the impairment threshold. Station 10EM161 had an F-IBI score of 38, while Station 12RN020 had F-IBI scores of 32 and 28. According to Figure 6, seven individual metrics for Stations 10EM161 and/or 12RN020 scored below the mean value needed to meet the impairment threshold (i.e., Hdw-Tol, InsectCypPct, Insect-TolTxPct, Minnows-TolPct, NumPerMeter-Tol, PioneerTxPct, and Sensitive). A description of each metric is provided in the *Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014a). Overall, the fish assemblage of the stations was dominated by tolerant taxa, specifically brook stickleback, central mudminnow, Johnny darter, and white sucker.

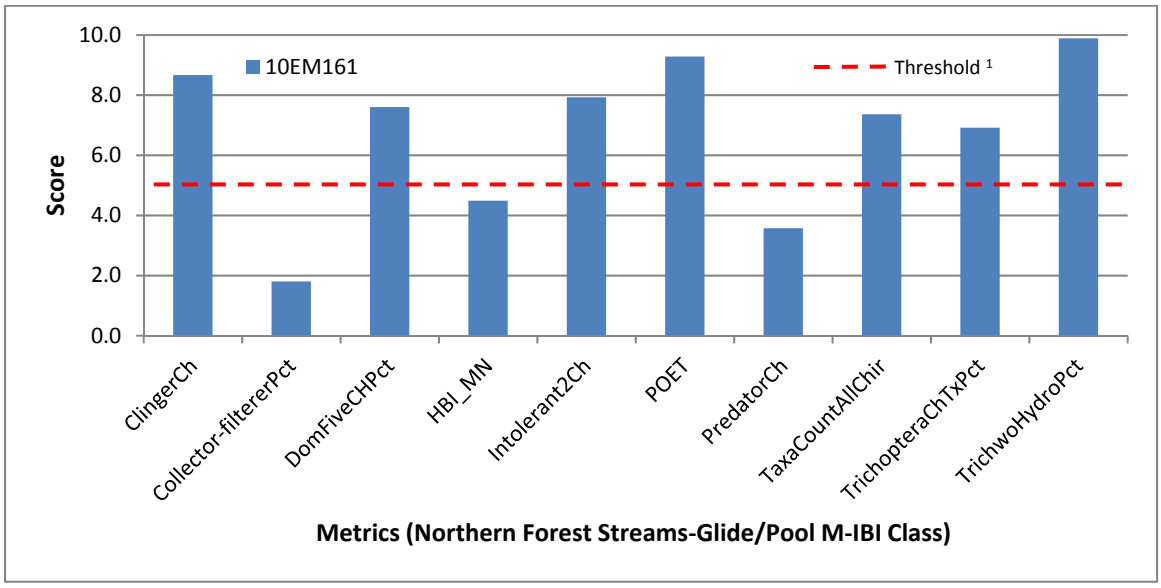


[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 6. Indvividual F-IBI metric scores for Stations 10EM161 and 12RN020 along AUID 501.

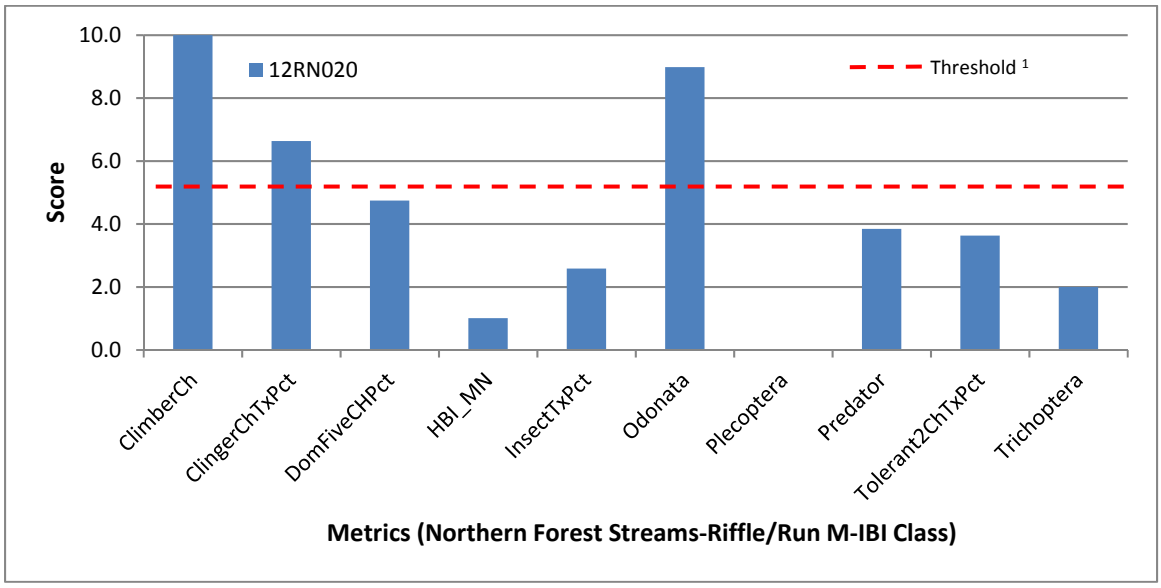
Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 501 was monitored at Station 10EM161 on August 31, 2010; and Station 12RN020 on July 31, 2012. Station 10EM161 was designated as General Use within the Northern Forest Streams-Glide/Pool M-IBI Class, while Station 12RN020 was designated as General Use within the Northern Forest Streams-Riffle/Run M-IBI Class. Accordingly, the impairment threshold for the stations is an M-IBI score of 51 and 53, respectively. Station 10EM161 (M-IBI=67) scored above its impairment threshold, while Station 12RN020 (M-IBI=43) scored below its impairment threshold. According to Figure 7, three individual metrics for Station 10EM161 scored below the mean value needed to meet the impairment threshold (i.e., Collector-filtererPct, HBI_MN, and PredatorCh). Seven metrics for Station 12RN020 (Figure 8) failed to meet the same criterion (i.e., DomFiveCHPct, HBI_MN, InsectTxPct, Plecoptera, Predator, Tolerant2ChTxPct, and Trichoptera). A description of each metric is provided in the *Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014b). Overall, the macroinvertebrate assemblage of the stations was dominated by moderately tolerant to tolerant taxa, including *Caenis* (mayflies), *Dubiraphia* (riffle beetles), *Hyalella* (amphipods), and *Physa* (snails).



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 7. Individual M-IBI metric scores for Station 10EM161 along AUID 501.



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 8. Individual M-IBI metric scores for Station 12RN020 along AUID 501.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Stations 10EM161 and 12RN020 along AUID 501. According to the DNR (2011), there are no man-made dams on the reach. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. A perched culvert (Figure 9) was documented at the County Road (CR) 61 crossing. The downstream end of the culvert was

elevated approximately two feet above the creek. The perched culvert likely obstructs connectivity during low and, likely, moderate flow conditions. In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No additional connectivity-related issues were identified in the photo.

Figure 9. Photos of a perched culvert (left) and its associated plunge pool (right) at the CR 61 crossing along AUID 501.

Biotic response – fish

There is inconclusive evidence of a causal relationship between a loss of longitudinal connectivity and the F-IBI impairment associated with AUID 501. The aforementioned perched culvert is located approximately two miles upstream of the nearest biological monitoring station (i.e., Station 10EM161) and there are no known obstructions to connectivity between Stations 10EM161 and 12RN020 and Lake of the Woods; several of fish species sampled along the reach likely migrate from the lake to spawn (e.g., northern pike). None of the metrics for Stations 10EM161 and 12RN020 (Appendix A) exhibited a correlation to this candidate cause. However, there is insufficient information to determine if culverts along the reach are impeding fish passage during high flow conditions (i.e., creating a velocity barrier).

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of longitudinal connectivity and the M-IBI impairment associated with AUID 501. Macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by longitudinal connectivity barriers.

Insufficient base flow

Available data

The MPCA biological monitoring staff encountered minimal flow during the July 12, 2012, fish monitoring visit at Station 12RN020 (Figure 10). The MPCA has conducted continuous flow monitoring at Site H80010001 (CSAH 12 crossing); the relative location of the site is shown in Figure 5. Figure 11 presents a flow duration curve for the site that was created based upon available discharge data (2000, 2001, 2009, and 2014). The highest mean daily peak flow during these years was 302.4 cfs, while the lowest flow was 0.0 cfs. Approximately 20% of the total mean daily flow values were less than 1.0 cfs. A discharge of less than 1.0 cfs or less was recorded during each year. Additionally, the MPCA flow monitoring staff documented minimal flow at the site during the summer of 2007 (Figure 10). The MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and noted flow conditions. Staff observed very minimal flow at the County Road 12 crossing on August 4, 2015 (Figure 10), as well as lentic conditions at the County Road 8 crossing on September 16, 2015 (Figure 10). According to local water resource managers in the LOWW (MPCA, 2015), the reach has a “flashy” flow regime, with

high and quick peak flows, along with prolonged periods of low discharge. Overall, the available data suggest that the reach experiences frequent periods of minimal to no flow.

Figure 10. Photos of lentic and minimal flow conditions along AUID 501, including Station 12RN020 on July 12, 2012 (upper left); the County Road 12 crossing during the summer of 2007 (upper right); the County Road 12 crossing on August 4, 2015 (lower left); and the County Road 8 crossing on September 16, 2015 (lower right).

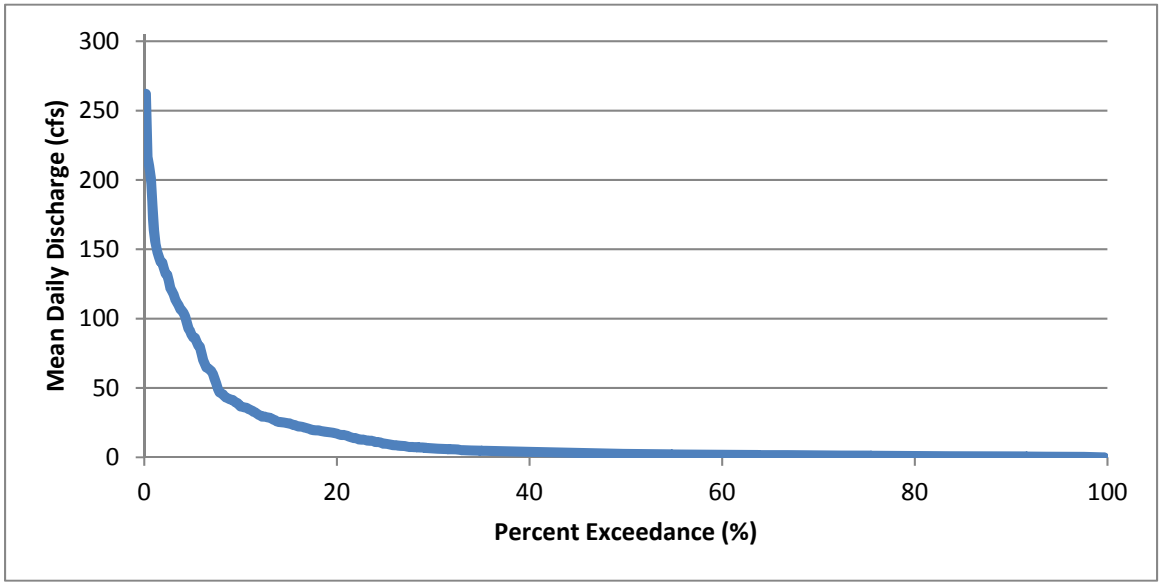


Figure 11. Flow duration curve for Site H80010001 (2000, 2001, 2009, and 2014) along AUID 501.

Biotic response – fish

Evidence of a causal relationship between insufficient base flow and the F-IBI impairment associated with AUID 501 is provided by the following metric responses (Appendix A):

- Above state class average (>80%) combined relative abundance of the three most abundant taxa (DomThreePct) at Station 10EM161 (83%)
- Above state class average (>41%) relative abundance of taxa that are generalists (GeneralTxPct) at Stations 10EM161 (50%) and 12RN020(1)(2) (50/57%)
- Above state class average (>84%) relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct) at Stations 10EM161 (99%) and 12RN020(2) (93%)
- Below state class average (<0.52) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN020(1)(2) (0.27/0.27)
- Above state class average (>20%) relative abundance of taxa that are pioneers (PioneerTxPct) at Stations 10EM161 (25%) and 12RN020(1)(2) (25/29%)
- Below state class average (<2) taxa richness of sensitive species (Sensitive) at Stations 10EM161 (1) and 12RN020(1)(2) (0/0)
- Above state class average (>57%) relative abundance of taxa that are tolerant (TolTxPct) at Station 10EM161 (63%)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are trophic generalists, early maturing, pioneering, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient base flow and the M-IBI impairment associated with AUID 501 is provided by the following metric responses (Appendix B):

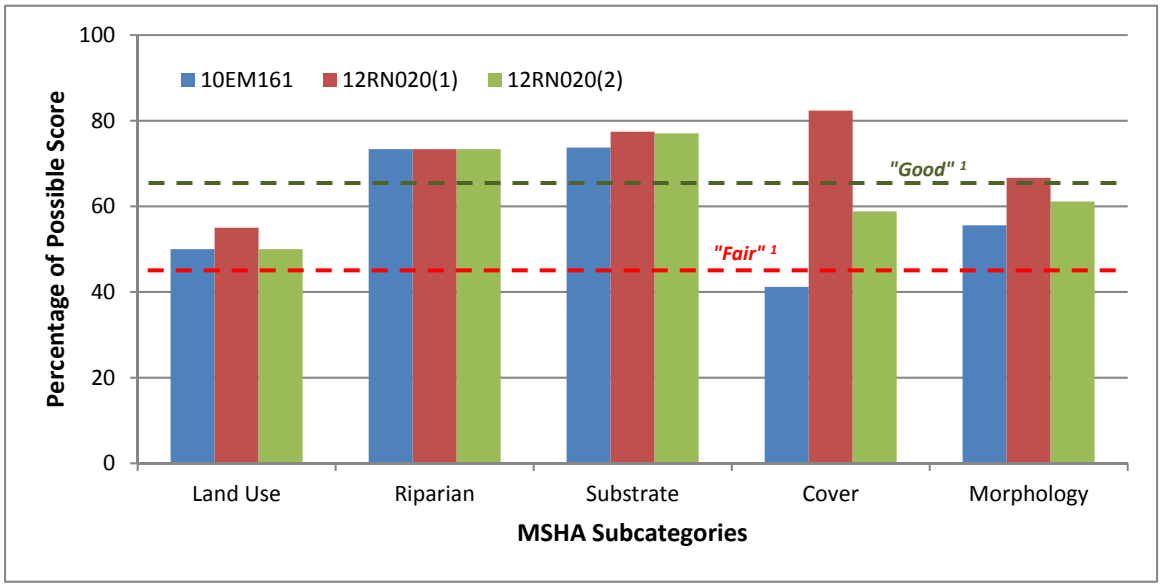
- Below state class average (<27/18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Stations 10EM161 (7%) and 12RN020 (5%)
- Above state class average (>51%) relative abundance of the dominant five taxa in a subsample (DomFiveCHPct) at Station 12RN020 (59%)
- Below state class average (<4) taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch) at Station 12RN020 (0)
- Below state class average (<9%) relative abundance of long-lived individuals (LongLivedPct) at Station 12RN020 (8%)
- Below state class average (<19) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN020 (11)
- Below state class average (<51) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN020 (44)
- Above state class average (>58%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN020 (77%)

Frequent and/or prolonged periods of minimal to no flow tends to limit macroinvertebrate diversity, specifically taxa belonging to the orders of Plecoptera, Ephemeroptera, and Trichoptera (many of which are collector-filterers), and favor taxa that are tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; EPA, 2012). Overall, the macroinvertebrate assemblage of the stations was dominated by taxa that are adapted to lentic conditions (i.e., *Caenis*, *Dubiraphia*, *Hyalella*, and *Physa*).

Insufficient physical habitat

Available data

The physical habitat of AUID 501 was evaluated at Stations 10EM161 and 12RN020 using the MSHA. Both stations are located along ditched segments of the reach (MPCA, 2013). Station 12RN020 (MSHA=73/"good" and 66/"fair") yielded the highest scores along the reach, while Station 10EM161 (MSHA=60/"fair") scored slightly lower. Figure 12 displays the MSHA subcategory results for the stations. The land use subcategory scores were limited by the predominance of agricultural row crops in the vicinity of the stations. The stations scored uniformly well in the riparian zone and substrate subcategories. Both stations had an "extensive" riparian width and no bank erosion. Also, both stations offered riffle habitat and coarse substrate (e.g., boulders, cobble, and gravel), with "light" embeddedness. Station 10EM161 had only a "sparse" amount of cover and subsequently scored substantially lower in the cover subcategory than Station 12RN020, which had a "moderate" to "extensive" amount of cover. The stations provided similar cover types, including boulders, macrophytes (emergent and submergent), and overhanging vegetation. Lastly, the channel morphology subcategory scores for the stations were slightly limited by "poor" sinuosity. However, both stations offered "moderate/high" channel stability and "good" channel stability.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Figure 12. MSHA subcategory results for Stations 10EM161 and 12RN020 along AUID 501.

On October 19, 2015, Vinje et al. (2017) performed a geomorphic assessment of Stations 10EM161 and 12RN020 (Appendix C). Below is a summary of the results:

> *"The Pfankuch rating for [Station 10EM161] on October 19, 2015 was 67, which is good (stable) for an E5 stream type. A good, or stable, rating for E5 stream types ranges from 50-75. Almost all Pfankuch categories ranked as excellent or good, with only bank rock content ranking as poor. The upper banks were well vegetated with grasses and forbs, but there were no trees or shrubs located on either the upper or lower banks. There was also no evidence of mass wasting in the upper banks. The lower banks were well vegetated with some cutting, but no deposition. The substrate appeared to be stable and was made up of sand, with some small gravel mixed in. Overall, the bed did not seem to be either aggrading or degrading."*

"The Pfankuch rating for [Station 12RN020] on October 19, 2015 was 52, which is good (stable) for an E5 stream type. A good, or stable, rating for E5 stream types ranges from 50-75. All of the Pfankuch categories ranked from fair to excellent, with no poor categories observed. The upper banks were well vegetated with grasses and forbs, and on the right bank (looking downstream) there were willow saplings growing on both the upper and lower banks. There was no evidence of mass wasting on the upper banks. The lower banks were well vegetated with no cutting or deposition. Unlike upstream site 10EM161, this site had rip-rap lining the lower banks. The substrate appeared to be stable and was made up of sand, with some small gravel mixed in. Overall, the bed did not seem to be either aggrading or degrading."

In summary, the available data suggest that past channelization has limited the diversity and amount of cover present along the reach.

Biotic response – fish

There is no evidence of a causal relationship between insufficient physical habitat and the F-IBI impairment associated with AUID 501. None of the metrics for Stations 10EM161 and 12RN020 (Appendix A) exhibited a correlation to this candidate cause.

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient physical habitat and the M-IBI impairment associated with AUID 501 is provided by the following metric responses (Appendix B):

- Below state class average (<19) taxa richness of clingers (ClingerCh) at Station 12RN020 (16)
- Above state class average (>40%) relative abundance of legless individuals (LeglessPct) at Station 12RN020 (44%)
- Above state class average (>15/23%) relative abundance of sprawler individuals (SprawlerPct) at Stations 10EM161 (32%) and 12RN020 (25%)

Clinger taxa require clean, coarse substrate or other objects to attach themselves to, while legless and sprawler macroinvertebrates are tolerant of degraded benthic habitat.

High suspended sediment

Available data

The reach has a TSS impairment that will be included on the proposed 2016 Impaired Waters List. The MPCA biological monitoring staff collected a discrete water quality sample at Stations 10EM161 and 12RN020 along AUID 501 at the time of each fish monitoring visit. The samples were analyzed for several parameters, including TSS. The stations had TSS concentrations ranging from 4 to 11 mg/L. Table 7 summarizes all available discrete TSS data for Sites S000-795 (CR 61 crossing), S000-906 (CSAH 12 crossing), and S003-697 (CSAH 2 crossing); the relative location of these sites is shown in Figure 5. Collectively, the sites had a high proportion of total exceedances of the 15 mg/L standard (22%). However, most of the exceedances occurred at Site S000-906 (79%). Additionally, the LOWW HSPF model estimates that the reach had a TSS concentration in excess of the standard 9% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of high suspended sediment.

Table 7. Discrete TSS data for Sites S000-795, S000-906, and S003-697 along AUID 501.

Site	Date Range	*n*	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Exceedances (#)
S000-795	1981-2010	25	1	68	8	4
S000-906	1982-2013	65	1	150	16	19
S003-697	2004	18	1	26	4	1

Biotic response – fish

There is no evidence of a causal relationship between high suspended sediment and the F-IBI impairment associated with AUID 501. None of the metrics or related data for Stations 10EM161 and 12RN020 (Appendix A) exhibited a correlation to this candidate cause.

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 501 is provided by the following metric and data responses (Appendix B):

- Below state class average (<27/18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Stations 10EM161 (7%) and 12RN020 (5%)
- Above state class average (>7 mg/L) TSS TIV at Station 12RN020 (10 mg/L)
- Below state class average (<8) taxa richness of high TSS intolerant macroinvertebrates at Station 12RN020 (5)

Collector-filterers utilize specialized mechanisms (e.g., silk nets) to strain organic material from the water column. High suspended sediment can interfere with these mechanisms (Arruda et al., 1983; Barbour et al., 1999; Lemley, 1982; Strand and Merritt, 1997).

Low dissolved oxygen

Available data

The reach has a DO impairment that will be included on the proposed 2016 Impaired Waters List. The MPCA biological monitoring staff collected a discrete DO measurement at Stations 10EM161 and 12RN020 along AUID 501 at the time of fish and macroinvertebrate monitoring. Only one of the measurements was below the 5.0 mg/L standard; Station 12RN020 had a DO concentration of 4.5 mg/L at the time of the July 12, 2012, fish monitoring visit. Figure 13 displays all available discrete DO data for Sites S000-795 (1981-2011; *n*=89), S000-906 (1982-2013; *n*=122), S000-907 (near 24th Street NW/66th Avenue NW intersection; 1982-2009; *n*=54), S000-992 (near 24th Street NW/58th Avenue NW intersection; 1984-2009; *n*=35), and S003-697 (2004-2009; *n*=55); the relative location of these sites is shown in Figure 5. Collectively, 6% of the DO values for the sites were below the standard; a majority (59%) of the measurements were collected prior to 9:00 a.m. The lowest DO levels were in the months of June, July, and August. The MPCA conducted continuous DO monitoring at Site H80010001 from July 22, 2015, to August 4, 2015. The monitoring results are provided in Table 8, as well as displayed in Figure 14. None of the DO measurements within the monitoring period were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard 9% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of low DO.

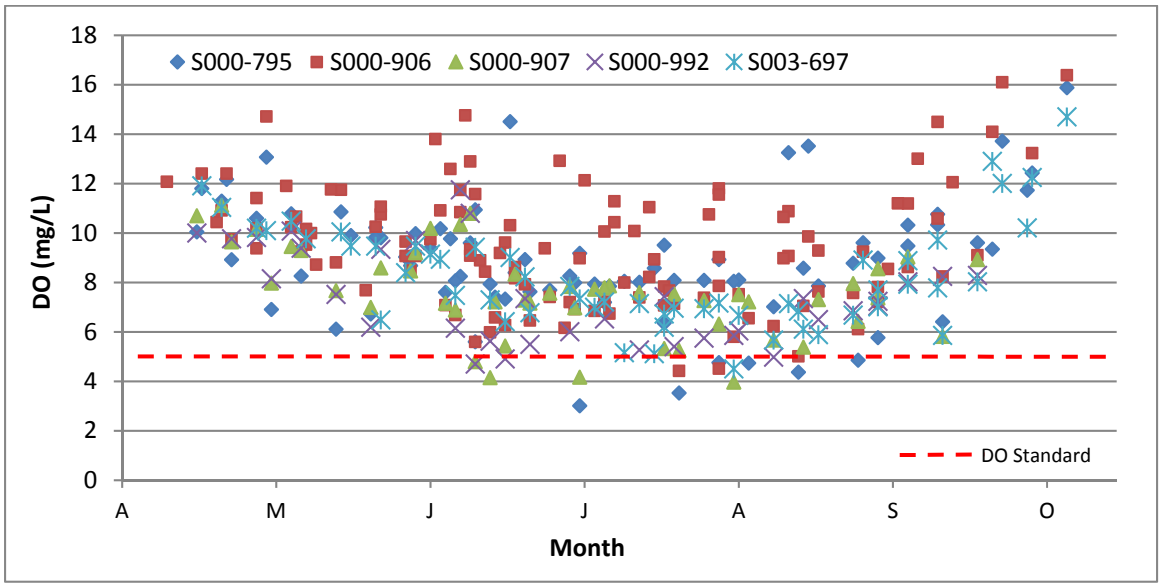


Figure 13. Discrete DO data for Sites S000-795, S000-906, S000-907, S000-992, and S003-697 along AUID 501.

Table 8. Continuous DO data for Site H80010001 along AUID 501.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – August 4, 2015	1250	5.5	10.7	0	0	3.9

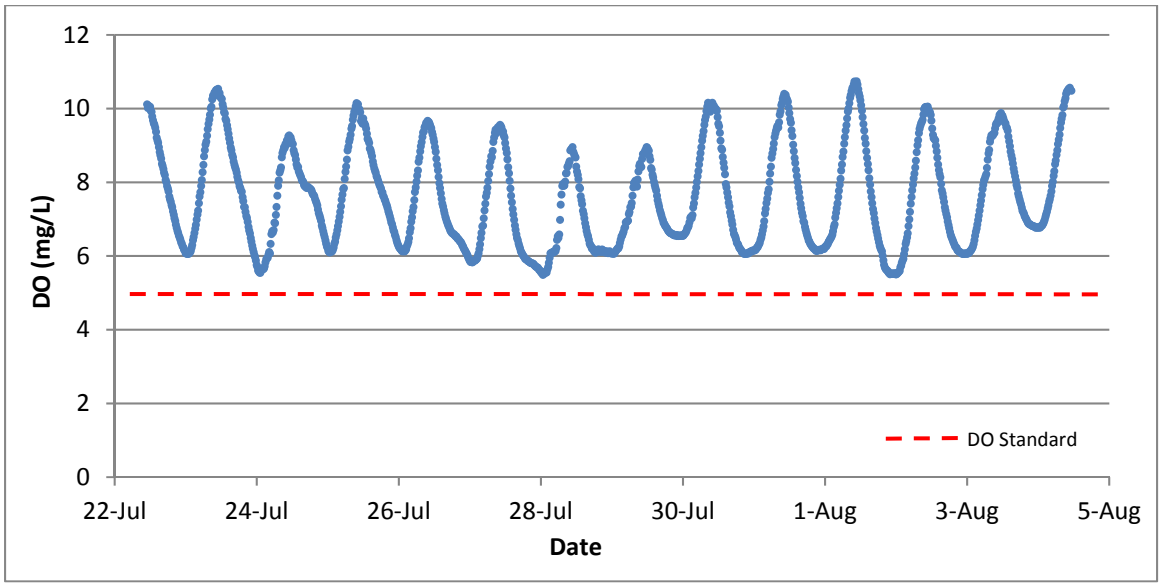


Figure 14. Continuous DO data for Site H80010001 along AUID 501.

Eutrophication-related data for the reach are limited to the following parameters: total phosphorus (TP) and DO flux. Discrete TP data is available for Sites S000-795 (1981-2004; *n*=23), S000-906 (1982-2013; *n*=63), S000-907 (1982-1984; *n*=2), S000-992 (1984; *n*=1), and S003-697 (2004; *n*=18). Collectively, the mean TP concentration for the sites was 52 µg/L, while the highest concentration was 246 µg/L and the lowest concentration was 12 µg/L. Approximately 31% of the values exceeded the 50 µg/L North River

Nutrient Region TP standard. Nearly all of the exceedances occurred at Sites S000-795 and S000-906. The mean daily DO flux documented during continuous DO monitoring at Site H80010001 (Table 8) was 3.9 mg/L, which exceeded the 3.0 mg/L North River Nutrient Region DO flux standard. Overall, the available data suggest that eutrophication is likely contributing to the low DO conditions along the reach.

Additionally, according to local water resource managers in the LOWW, seeps may be discharging low DO groundwater to the reach (MPCA, 2015).

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 501 is provided by the following metric and data responses (Appendix A):

- Below state class average (<0.41) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN020(1)(2) (0.27/0.27)
- Below state class average (<2/1) taxa richness of sensitive species (Sensitive) at Stations 10EM161 (1) and 12RN020(1)(2) (0/0)
- Above state class average (>57%) relative abundance of taxa that are tolerant (TolTxPct) at Station 10EM161 (63%)
- Below state class average (<6.6 mg/L) DO TIV at Station 10EM161 (6.5 mg/L)
- Below state class average (<30%) probability of meeting the DO standard at Station 10EM161 (27%)

Low DO often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012).

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 501 is provided by the following metric and data responses (Appendix B):

- Above state class average (>6) Hilsenhoff's Biotic Index value (HBI_MN) at Station 12RN020 (8)
- Below state class average (<19) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN020 (11)
- Below state class average (<51) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN020 (44)
- Above state class average (>58%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN020 (77%)
- Below state class average (<7.0 mg/L) DO TIV at Station 12RN020 (6.4 mg/L)
- Above state class average (>11%) relative abundance of low DO tolerant individuals at Station 12RN020 (41%)
- Below state class average (<10) taxa richness of low DO intolerant macroinvertebrates at Station 12RN020 (2)

Low DO often limits the taxa richness of macroinvertebrates, particularly members of the orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera, and favors taxa that are tolerant (Weber, 1973; EPA, 2012).

Strength-of-evidence analysis

Table 9 presents a summary of the SOE scores for the various candidate causes associated with AUID 501. The evidence suggests that insufficient base flow is the primary stressor contributing to the F-IBI impairment. Low DO also appears to be marginally affecting the fish community. Additionally, the evidence indicates that the M-IBI impairment is the collective result of the following primary stressors: insufficient base flow, high suspended sediment, and low DO. There is also limited evidence that

suggests that the macroinvertebrate community is adversely affected by insufficient physical habitat. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 9. SOE scores for candidate causes associated with AUID 501.

Types of Evidence	SOE Scores per Candidate Cause[1]									
	Loss of Longitudinal Connectivity		Insufficient Base Flow		Insufficient Physical Habitat		High Suspended Sediment		Low Dissolved Oxygen	
	Biological Impairment									
	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI
Types of Evidence that Use Data from the Case										
Spatial/Temporal Co-Occurrence	0	--	++	++	-	+	0	++	+	++
Temporal Sequence	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response Relationship	0	--	++	++	-	+	0	++	+	++
Causal Pathway	0	--	++	++	-	+	0	++	+	++
Evidence of Exposure/Bio-Mechanism	0	--	++	++	-	+	0	++	+	++
Manipulation of Exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Symptoms	0	--	++	++	-	+	0	++	+	++
Types of Evidence that Use Data from Elsewhere										
Mechanistically Plausible Cause	+	-	+	+	+	+	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	++	NE	++	++	++	++	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Multiple Lines of Evidence										
Consistency of Evidence	**0**	**--**	**++**	**++**	**-**	**+**	**0**	**++**	**+**	**++**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor, **0** *neither supports nor weakens* the case for the candidate cause as a stressor, **-** *somewhat weakens* the case for the candidate cause as a stressor, **--** *strongly weakens* the case for the candidate cause as a stressor, **---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

3.3.2 East Branch Warroad River (AUID 504)

Physical setting

This reach represents the East Branch Warroad River (Figure 15), which extends from its headwaters in the Beltrami Island State Forest, to its confluence with the Warroad River; a total length of 34 miles. The reach has a subwatershed area of 54 square miles (34,719 acres). The subwatershed contains 31 miles of river, 14 miles of intermittent drainage ditch, 10 miles of intermittent stream, 6 miles of perennial drainage ditch, and 4 miles of perennial stream (DNR, 2015). According to the MPCA (2013), 33% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including 1% of AUID 504. The NLCD 2011 (USGS, 2011) lists wetlands (76%) as the predominant land cover in the subwatershed. The majority of wetlands are located within the Beltrami Island State Forest. Notable minor land cover groups in the subwatershed included hay/pasture (9%), cultivated crops (5%), and forest (4%).

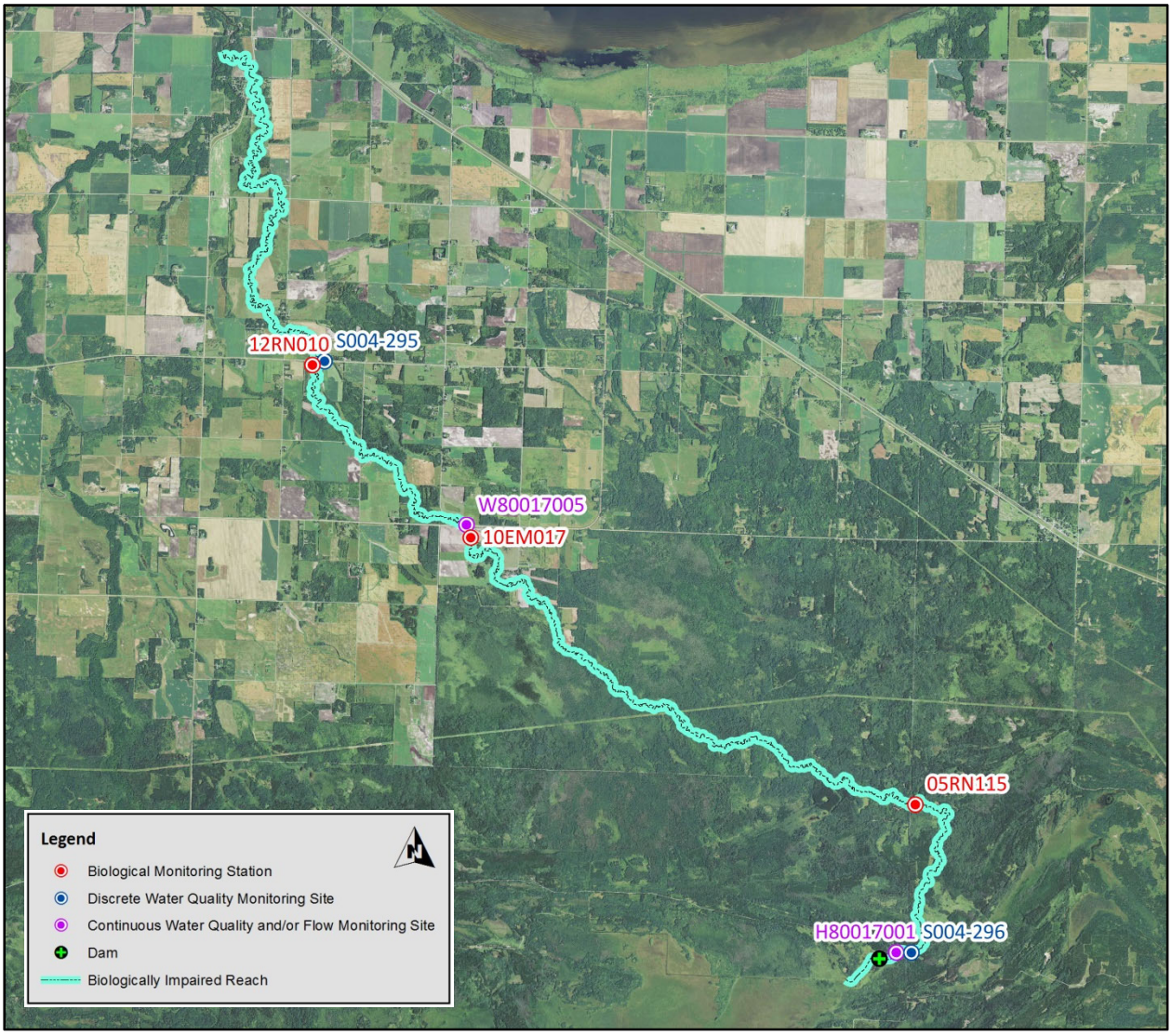
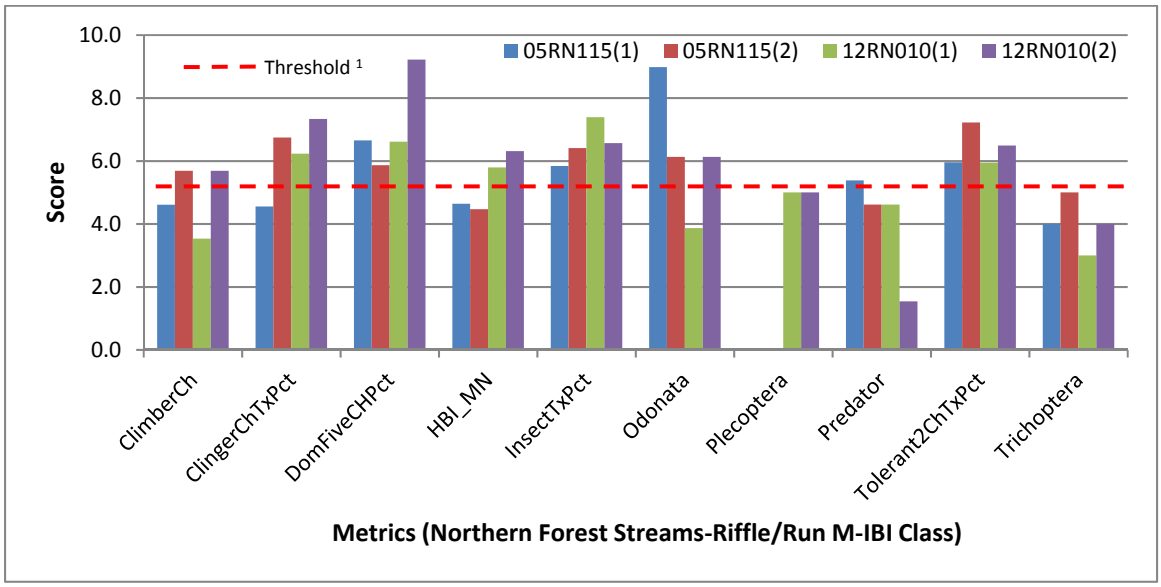


Figure 15. Map of AUID 504 and associated biological monitoring stations and water quality/flow monitoring sites (2013 NAIP aerial image).

Biological impairment

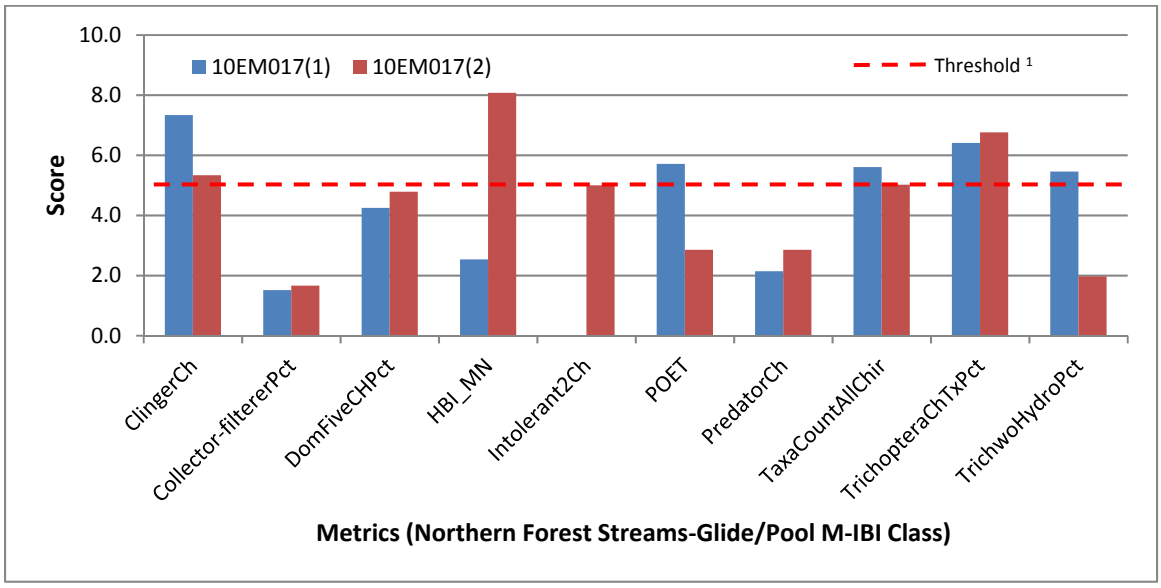
Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 504 was monitored at Station 05RN115 (0.1 mile upstream of the Norris Roosevelt Road crossing) on August 16, 2005(1) and August 27, 2014(2); Station 10EM017 (0.2 mile upstream of the CSAH 2 crossing) on September 1, 2010(1) and August 1, 2012(2); and Station 12RN010 (0.1 mile upstream of the CSAH 12 crossing) on August 1, 2012. Station 12RN010 was sampled twice on the same date. The relative location of the stations is shown in Figure 15. Stations 05RN115 and 12RN010 were designated as General Use within the Northern Forest Streams-Riffle/Run M-IBI Class, while Station 10EM017 was designated as General Use within the Northern Forest Streams-Glide/Pool M-IBI Class. Accordingly, the impairment threshold for the stations is an M-IBI score of 53 and 51, respectively. The scores for Stations 05RN115 (M-IBI=51 and 52) and 10EM017 (M-IBI=41 and 44) were all below their applicable impairment threshold. Station 12RN010 (M-IBI=52 and 58) had one score above and one score below its threshold. According to Figure 16, seven individual metrics for Stations 05RN115 and/or 12RN010 scored below the mean value needed to meet the impairment threshold (i.e., ClimberCh, ClingerChTxPct, HBI_MN, Odonata, Plecoptera, Predator, and Trichoptera). Eight metrics for Station 10EM017 (Figure 17) failed to meet the same criterion (i.e., Collector-filtererPct, DomFiveCHPct, HBI_MN, Intolerant2Ch, POET, PredatorCh, TaxaCountAllChir, and TrichwoHydroPct). A description of each metric is provided in the *Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014b). Overall, the macroinvertebrate assemblage of the stations was dominated by moderately tolerant to tolerant taxa, including Hydrobiidae (snails), *Microtendipes* (midges), *Physa* (snails), *Procloeon* (mayflies), and *Rheotanytarsus* (midges).



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 16. Individual M-IBI metric scores for Stations 05RN115 and 12RN010 along AUID 504.



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 17. Individual M-IBI metric scores for Station 10EM017 along AUID 504.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Stations 05RN115, 10EM017, and 12RN010 along AUID 504. According to the DNR (2011), the Bednar Dam (Figure 15) is located near the headwaters of the reach in the Beltrami Island State Forest. The dam is owned and operated by the DNR, and was constructed in 1982 for the purpose of providing wildlife habitat. The structure has an associated impoundment and is likely a complete barrier to connectivity. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. No obstructions to connectivity were identified (e.g., perched culverts and beaver dams). In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No additional connectivity-related issues were identified in the photo.

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of longitudinal connectivity and the M-IBI impairment associated with AUID 504. Macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by longitudinal connectivity barriers.

Insufficient base flow

Available data

The MPCA biological monitoring staff did not encounter any flow-related issues during fish and macroinvertebrate sampling at Stations 05RN115, 10EM017, and 12RN010 along AUID 504. The DNR has conducted continuous flow monitoring at Site H80017001 (Norris Roosevelt Road crossing), which is located 0.4 mile downstream of the Bednar Dam, since 2012; the relative location of the site is shown in Figure 15. A flow duration curve for the site (2012-2015) is provided in Figure 18. The highest mean daily peak flow during the period of record was 104.0 cfs, while the lowest flow was 0.0 cfs. A discharge of 0.1 cfs or less was recorded during each year. Approximately 28% of the total mean daily flow values were

less than 1.0 cfs. The MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and documented flow conditions. Staff observed lentic conditions at the Tangnes Road and Norris Roosevelt Road crossings (Figure 19), which are located in the vicinity of Station 05RN115. Overall, the available data suggest that at least the headwaters segment of the reach, which includes Station 05RN115, experiences frequent periods of minimal to no flow.

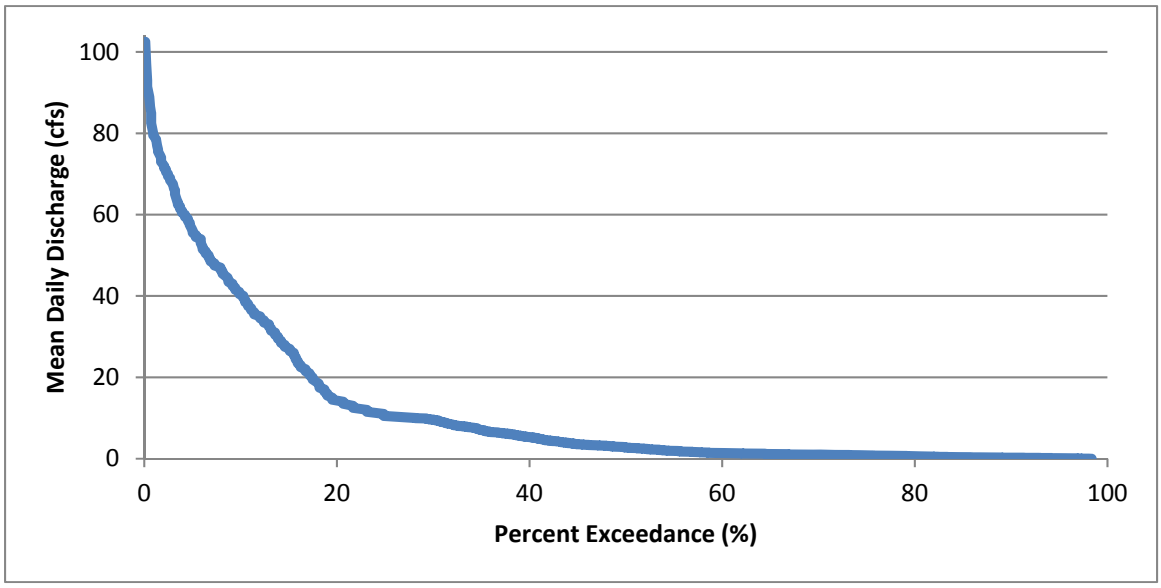


Figure 18. Flow duration curve for Site H80017001 (2012-2015) along AUID 504.

Figure 19. Photos of lentic conditions along AUID 504 on September 16, 2015, including the Tangnes Road crossing (left) and the Norris Roosevelt Road (right).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient base flow and the M-IBI impairment associated with AUID 504 is provided by the following metric responses (Appendix B):

- Below state class average (<27/18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Stations 10EM017(1)(2) (6/8%) and 12RN010(1)(2) (20/19%)
- Above state class average (>51/61%) relative abundance of the dominant five taxa in a subsample (DomFiveCHPct) at Stations 05RN115(1)(2) (52/55%), 10EM017(1)(2) (71/68%), and 12RN010(1) (52%)

- Below state class average (<4/1) taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch) at Stations 05RN115(1)(2) (0/1), 10EM017(1) (0), and 12RN010(1)(2) (3/1)
- Below state class average (<9/5%) relative abundance of long-lived individuals (LongLivedPct) at Stations 05RN115(1)(2) (2/2%) and 10EM017(1)(2) (2/2%)
- Below state class average (<19/11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Stations 05RN115(1)(2) (16/14), 10EM017(2) (6), and 12RN010(1)(2) (12/14)
- Below state class average (<51/43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Stations 05RN115(1)(2) (50/40), 10EM017(1)(2) (42/37), and 12RN010(1)(2) (48/41)
- Above state class average (>58/68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Stations 05RN115(1)(2) (70/60%), 10EM017(2) (73%), and 12RN010(1)(2) (67/63%)

Frequent and/or prolonged periods of minimal to no flow tends to limit macroinvertebrate diversity, specifically taxa belonging to the orders of Plecoptera, Ephemeroptera, and Trichoptera (many of which are collector-filterers), and favor taxa that are tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; EPA, 2012).

Insufficient physical habitat

Available data

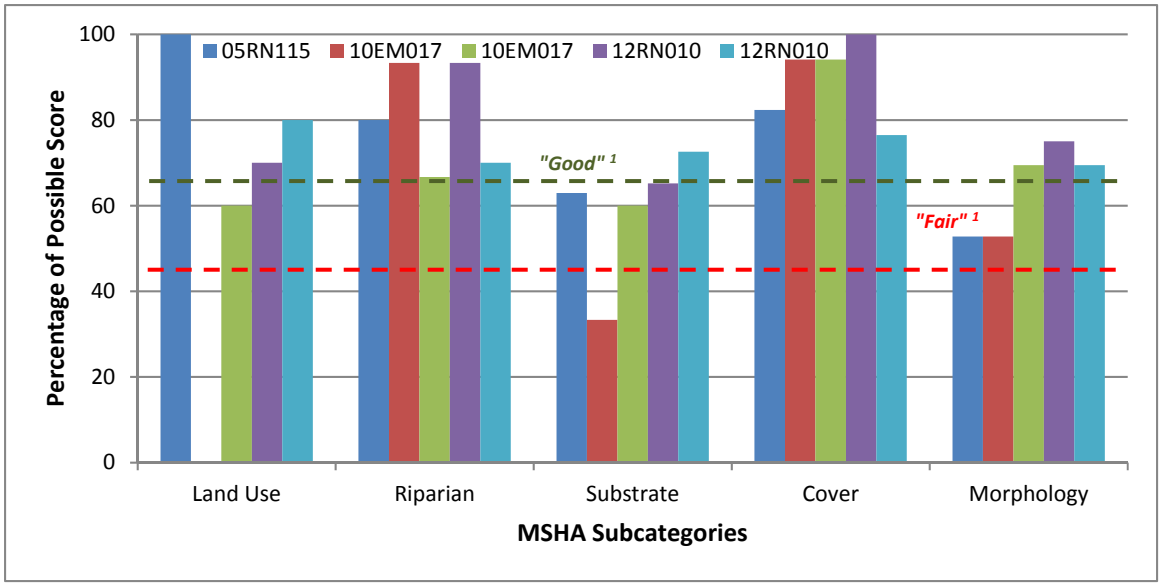
The physical habitat of AUID 504 was evaluated at Stations 05RN115, 10EM017, and 12RN010 using the MSHA. All of the stations are located along natural segments of the reach (MPCA, 2013). Station 12RN010 (MSHA=79/"good" and 72/"good") yielded the highest scores along the reach, while Stations 05RN115 (MSHA=67/"good") and 10EM017 (MSHA=58/"fair" and 70/"good") scored slightly lower. Figure 20 displays the MSHA subcategory results for the stations. Station 10EM017 scored substantially lower in the land use subcategory than the other stations due to the predominance of agricultural row crops immediately surrounding the station. The stations scored uniformly well in the riparian zone subcategory, with a "wide" or "extensive" riparian width. However, "moderate" bank erosion was noted at Station 12RN010. While all of the stations offered riffle habitat and coarse substrate (e.g., cobble and gravel), the substrate subcategory scores for Station 10EM017 was limited due to a "moderate" level of embeddedness. The stations also scored uniformly well in the cover subcategory due to the diversity and "extensive" amount of cover present. Common cover types noted along the reach included boulders, deep pools, macrophytes, overhanging vegetation, rootwads, undercut banks, and woody debris. Lastly, the stations shared many of the channel morphology characteristics, including "moderate/high" channel stability and "fair" to "good" channel development.

On October 20, 2015, Vinje et al. (2017) performed a geomorphic assessment of Stations 05RN115 and 12RN010 (Appendix C). Below is a summary of the results:

> *"The Pfankuch rating for [Station 05RN115] was 63, which is good (stable) for an E5 stream type. A good, or stable, rating for E5 stream types ranges from 50-75. Almost all Pfankuch categories ranked as excellent or good, with only bank rock content ranking as poor. The upper banks at this site were well vegetated with mature trees and there were no signs of mass erosion. The lower banks were also well vegetated, primarily with grasses, sedges, and scattered alder and dogwood. The lower banks showed minimal signs of cutting and no deposition. The substrate at this site was sand and silt, but there were cobble and boulders in the channel where the river had cut into the valley wall near the biological monitoring site. Even though the substrate was primarily sand, the bottom appeared stable and did not appear to be either aggrading or degrading."*

"The Pfankuch rating for [Station 12RN010] was 88, which is fair (moderately unstable) for an E4/C4 stream type. A fair, or moderately unstable, rating for E4 stream types is 76-96. Most Pfankuch categories ranked as either poor, fair, or good for this site. The upper banks were well vegetated with mature trees, but the landform slope ranked poorly because of incision; however, there was no evidence of mass erosion. The lower banks generally ranked in the fair to poor category because of incision and moderate amounts of debris jams. There was significant cutting occurring on the lower banks with some enlargement of point bars. The bottom through this reach generally ranked in the good range. The substrate was primarily gravel with areas of cobble. There were also areas of gravel and cobble over soft clay and areas of sand deposition."

In summary, the MSHA data suggest that the physical habitat of the reach is slightly limited by the embeddedness of coarse substrate at Station 10EM017. Additionally, Vinje et al. (2017) noted that the predominately sand and silt substrate at the Station 05RN115, as well as lack of pool depth and holding cover at Station 12RN010, were adversely affecting the habitat of the reach.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Figure 20. MSHA subcategory results for Stations 05RN115, 10EM017, and 12RN010 along AUID 504.

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient physical habitat and the M-IBI impairment associated with AUID 504 is provided by the following metric responses (Appendix B):

- Below state class average (<38%) relative percentage of clinger taxa (ClingerChTxPct) at Stations 05RN115(1) (32%) and 12RN010(1)(2) (35/37%)
- Above state class average (>40/51%) relative abundance of legless individuals (LeglessPct) at Stations 05RN115(1)(2) (59/67%), 10EM017(1)(2) (89/86%), and 12RN010(1)(2) (48/50%)

Clinger taxa require clean, coarse substrate or other objects to attach themselves to, while legless macroinvertebrates are tolerant of degraded benthic habitat.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Stations 05RN115, 10EM017, and 12RN010 along AUID 504 at the time of each fish monitoring visit. The samples were

analyzed for several parameters, including TSS. The stations had TSS concentrations ranging from 2 to 4 mg/L. Table 10 summarizes all available discrete TSS data for Site S004-295 (CSAH 12 crossing); the relative location of the site is shown in Figure 15. The site had no exceedances of the 15 mg/L standard. Additionally, the LOWW HSPF model estimates that the reach had a TSS concentration in excess of the standard between 5 and 10% of the time during the period of 1996 to 2009. The aforementioned MSHA results indicate that the deposition of excess fine sediment has caused the "moderate" level of embeddedness of coarse substrate documented at Station 10EM017. Overall, the available data suggest that the reach experiences at least occasional periods of high suspended sediment.

Table 10. Discrete TSS data for Site S004-295 along AUID 504.

Site	Date Range	*n*	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Exceedances (#)
S004-295	2012	11	2	5	4	0

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 504 is provided by the following metric and data responses (Appendix B):

- Below state class average (<27/18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Stations 10EM017(1)(2) (6/8%) and 12RN010(1)(2) (20/19%)
- Above state class average (>19%) relative abundance of high TSS tolerant individuals at Stations 05RN115(1) (30%), 05RN115(2) (32%), and 12RN010(2) (20%)
- Below state class average (<8/4) taxa richness of high TSS intolerant macroinvertebrates at Stations 05RN115(1) (4), 05RN115(2) (3), 10EM017(1) (3), 12RN010(1) (7), and 12RN010(2) (5)

Collector-filterers utilize specialized mechanisms (e.g., silk nets) to strain organic material from the water column. High suspended sediment can interfere with these mechanisms (Arruda et al., 1983; Barbour et al., 1999; Lemley, 1982; Strand and Merritt, 1997).

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Stations 05RN115, 10EM017, and 12RN010 along AUID 504 at the time of fish and macroinvertebrate monitoring. Only one of the measurements was below the 5.0 mg/L standard; Station 10EM017 had a DO concentration of 4.6 mg/L at the time of the August 1, 2010, macroinvertebrate monitoring visit. Figure 21 displays all available discrete DO data for Sites S004-295 (2003-2013; *n*=68) and S004-296 (Norris Roosevelt Road crossing; 2003-2012; *n*=52); the relative location of the sites is shown in Figure 15. Collectively, 4% of the DO values for the sites were below the standard; however, only one of the DO measurements was collected prior to 9:00 a.m. Generally, the lowest DO levels were in the months of July and August. The MPCA conducted continuous DO monitoring at Site W80017005 (CSAH 2 crossing) from July 22, 2015, to August 4, 2015; the relative location of the site is shown in Figure 15. The monitoring results are provided in Table 11, as well as displayed in Figure 22. None of the DO measurements within the monitoring period were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard between 2 and 9% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences at least occasional periods of low DO.

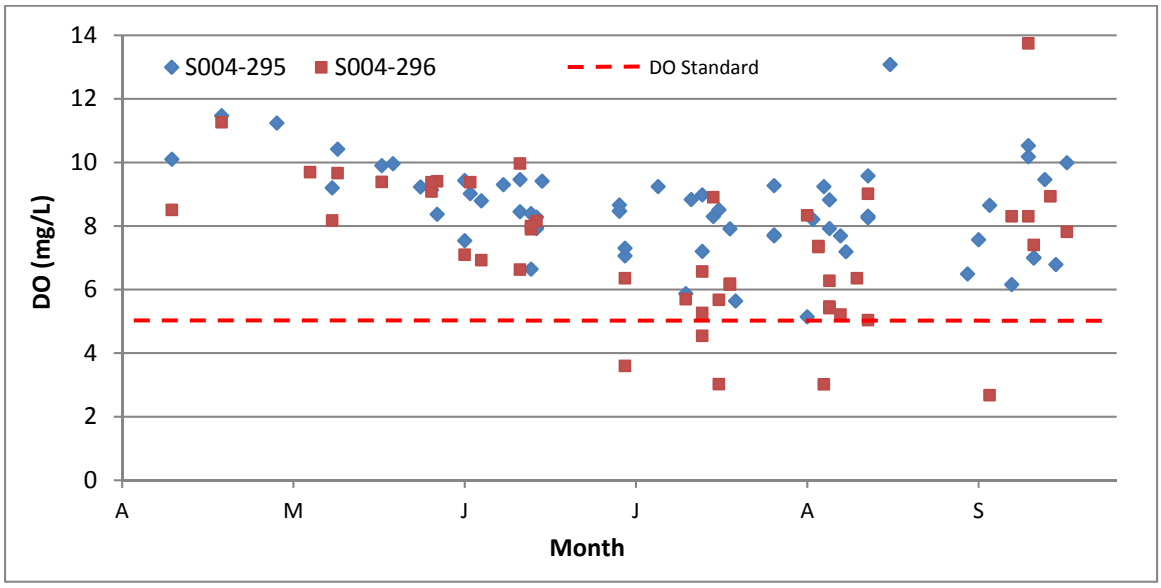


Figure 21. Discrete DO data for Sites S004-295 and S004-296 along AUID 504.

Table 11. Continuous DO data for Site W80017005 along AUID 504.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – August 4, 2015	1234	6.6	9.2	0	0	1.1

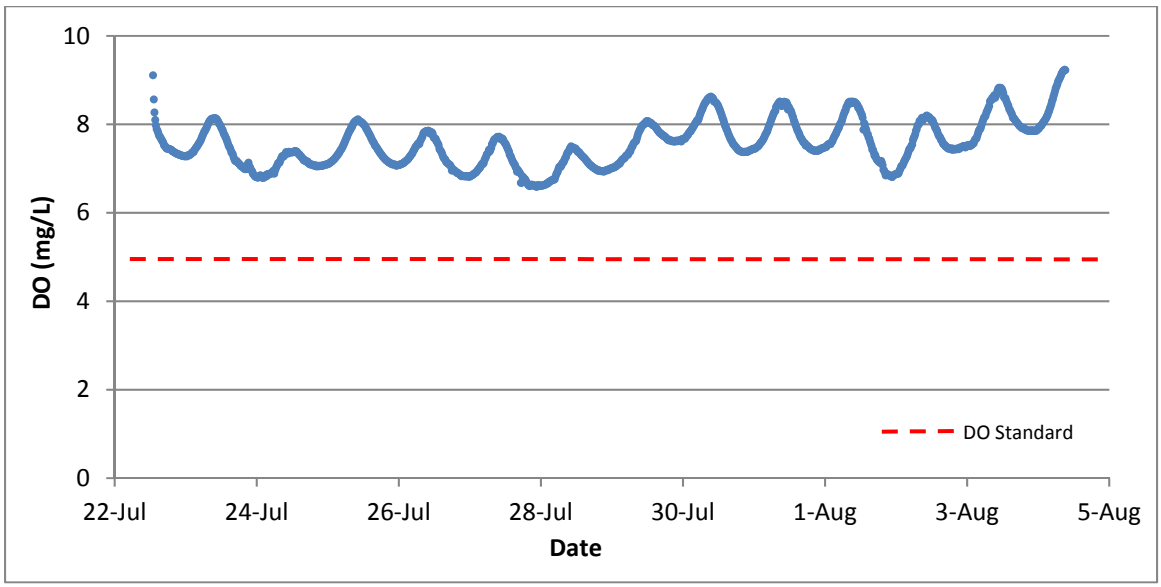


Figure 22. Continuous DO data for Site W80017005 along AUID 504.

Eutrophication-related data for the reach are limited to the following parameters: total phosphorus (TP) and DO flux. Discrete TP data is available for Sites S004-295 (2003-2012; *n*=62), S004-296 (2003-2012; *n*=57), and S005-678 (2009; *n*=1). Collectively, the mean TP concentration for the sites was 26 µg/L, while the highest concentration was 400 µg/L and the lowest concentration was 3 µg/L. Approximately 5% of the values exceeded the 50 µg/L North River Nutrient Region TP standard. The mean daily DO flux

documented during continuous DO monitoring at Site W80017005 (Table 11) was 1.1 mg/L, which is well below the 3.0 mg/L North River Nutrient Region DO flux standard. Overall, the available data suggest that eutrophication is not substantially contributing to the low DO conditions along the reach.

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 504 is provided by the following metric and data responses (Appendix B):

- Above state class average (>6/7) Hilsenhoff's Biotic Index value (HBI_MN) at Stations 05RN115(1)(2) (7/7) and 10EM017(1) (8)
- Below state class average (<19/11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Stations 05RN115(1)(2) (16/14), 10EM017(2) (6), and 12RN010(1)(2) (12/14)
- Below state class average (<51/43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Stations 05RN115(1)(2) (50/40), 10EM017(1)(2) (42/37), and 12RN010(1)(2) (48/41)
- Above state class average (>58/68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Stations 05RN115(1)(2) (70/60%), 10EM017(2) (73%), and 12RN010(1)(2) (67/63%)
- Below state class average (<7.0 mg/L) DO TIV at Station 12RN010(1)(2) (6.9/6.9 mg/L)
- Below state class average (<10/3) taxa richness of low DO intolerant macroinvertebrates at Stations 05RN115(1)(2) (7/4), 10EM017(2) (0), and 12RN010(1)(2) (6/5)

Low DO often limits the taxa richness of macroinvertebrates, particularly members of the orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera, and favors taxa that are tolerant (Weber, 1973; EPA, 2012).

Strength-of-evidence analysis

Table 12 presents a summary of the SOE scores for the various candidate causes associated with AUID 504. The evidence suggests that the M-IBI impairment is the collective result of the following stressors, each marginally affecting the macroinvertebrate community: insufficient base flow, insufficient physical habitat, high suspended sediment, and low DO. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 12. SOE scores for candidate causes associated with Reach 504.

Types of Evidence	SOE Scores per Candidate Cause[1]				
	Loss of Longitudinal Connectivity	Insufficient Base Flow	Insufficient Physical Habitat	High Suspended Sediment	Low Dissolved Oxygen
	Biological Impairment				
	M-IBI	M-IBI	M-IBI	M-IBI	M-IBI
Types of Evidence that Use Data from the Case					
Spatial/Temporal Co-Occurrence	-	+	+	+	+
Temporal Sequence	NE	NE	NE	NE	NE
Stressor-Response Relationship	-	+	+	+	+
Causal Pathway	-	+	+	+	+
Evidence of Exposure/Bio-Mechanism	-	+	+	+	+
Manipulation of Exposure	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE
Symptoms	-	+	+	+	+
Types of Evidence that Use Data from Elsewhere					
Mechanistically Plausible Cause	-	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	NE	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE
Multiple Lines of Evidence					
Consistency of Evidence	**-**	**+**	**+**	**+**	**+**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor**, 0** *neither supports nor weakens* the case for the candidate cause as a stressor**, -** *somewhat weakens* the case for the candidate cause as a stressor**, --** *strongly weakens* the case for the candidate cause as a stressor**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

3.3.3 Willow Creek (AUID 505)

Physical setting

This reach represents Willow Creek (Figure 23), which extends from its headwaters, situated south of Roosevelt, to its outlet to Lake of the Woods; a total length of 15 miles. The reach has a subwatershed area of 28 square miles (17,704 acres). The subwatershed contains 13 miles of intermittent stream, 12 miles of perennial stream, and 6 miles of intermittent drainage ditch (DNR, 2015). According to the MPCA (2013), 30% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including 1% of AUID 505. The NLCD 2011 (USGS, 2011) lists wetlands (57%) as the predominant land cover in the subwatershed. Other notable land cover groups in the subwatershed included cultivated crops (20%), hay/pasture (8%), forest (6%), developed (4%), herbaceous (3%), and shrub/scrub (2%).

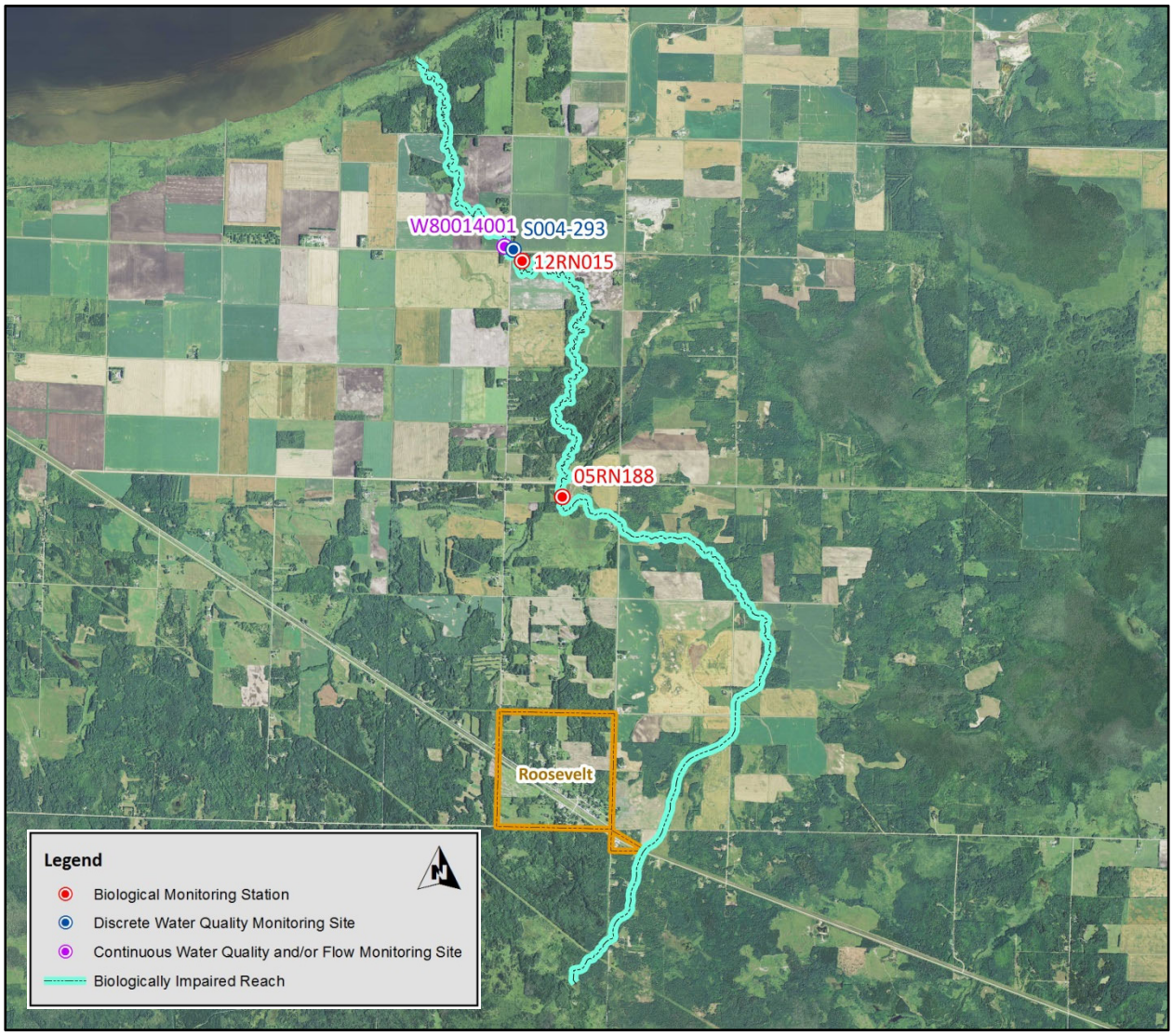
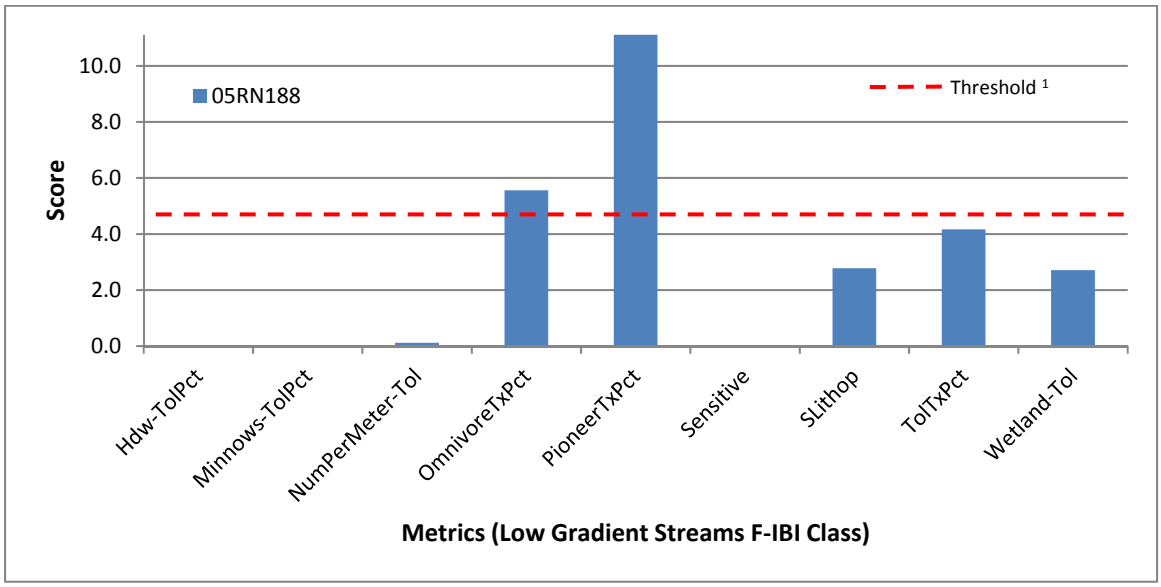


Figure 23. Map of AUID 505 and associated biological monitoring station and water quality monitoring site (2013 NAIP aerial image).

Biological impairment

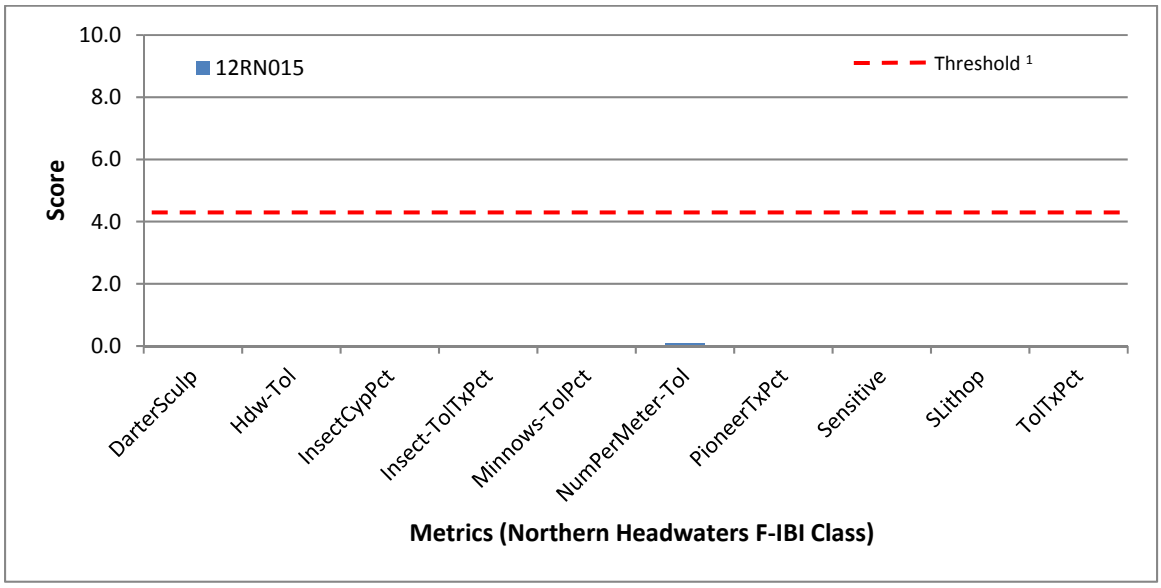
Fish (F-IBI)

The fish community of AUID 505 was monitored at Station 05RN188 (0.1 mile upstream of the CSAH 34 crossing) on June 19, 2006; and Station 12RN015 (0.2 mile upstream of the CSAH 12 crossing) on June 18, 2013. The relative location of the stations is shown in Figure 23. Station 05RN188 was designated as General Use within the Low Gradient Streams F-IBI Class, while Station 12RN015 was designated as General Use within the Northern Headwaters F-IBI Class. Accordingly, the impairment threshold for the stations is an F-IBI score of 42. Both stations scored substantially below their applicable impairment threshold; Station 05RN188 had an F-IBI score of 26, while Station 12RN015 had an F-IBI score of zero. According to Figure 24, seven individual metrics for Station 05RN188 scored below the mean value needed to meet the impairment threshold (i.e., Hdw-TolPct, Minnows-TolPct, NumPerMeter-Tol, Sensitive, SLithop. TolTxPct, and Wetland-Tol). Station 12RN015 (Figure 25) had a score of zero for each of its metrics. A description of each metric is provided in the *Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014a). Overall, the fish assemblage of the stations was dominated by tolerant taxa, specifically brook stickleback, central mudminnow, fathead minnow, and white sucker.



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 24. Individual F-IBI metric scores for Station 05RN188 along AUID 505.



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 25. Individual F-IBI metric scores for Station 12RN015 along AUID 505.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Stations 05RN188 and 12RN015 along AUID 505. According to the DNR (2011), there are no man-made dams on the reach. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. The remnants of a beaver dam was noted immediately upstream of the 32nd Street NW crossing. The remaining portion of the beaver dam was not impeding connectivity as the time of discovery. In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No connectivity-related issues were identified in the photo.

Biotic response – fish

There is inconclusive evidence of a causal relationship between a loss of longitudinal connectivity and the F-IBI impairment associated with AUID 505. There are no known obstructions to connectivity along the reach. Additionally, none of the metrics for Stations 05RN188 and 12RN015 (Appendix A) exhibited a correlation to this candidate cause. However, there is insufficient information to determine if culverts along the reach are impeding fish passage during high flow conditions (i.e., creating a velocity barrier).

Insufficient base flow

Available data

The MPCA biological monitoring staff encountered minimal flow conditions during the June 19, 2006, fish monitoring visit at Station 05RN188 (Figure 26) and the July 31, 2012, macroinvertebrate monitoring visit at Station 12RN015 (Figure 26). There is no flow monitoring data for the reach. The MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and documented flow conditions. Staff observed minimal flow (estimated <0.5 cfs) and/or lentic conditions along the reach on August 4, 2015 and September 16, 2015 (Figure 26).

According to the Roseau County Local Water Management Plan (2010), the reach "can dry down to little or no flow during summer and into fall". Overall, the available data suggest that the reach experiences frequent periods of minimal to no flow.

Figure 26. Photos of lentic conditions along AUID 505, including Station 05RN188 on June 19, 2006 (upper left); Station 12RN015 on July 31, 2012 (upper right), the CSAH 8 crossing on September 16, 2015 (lower left), and the CSAH 12 crossing on September 12, 2015 (lower right).

Biotic response – fish

Evidence of a causal relationship between insufficient base flow and the F-IBI impairment associated with AUID 505 is provided by the following metric responses (Appendix A):

- Above state class average (>80/84%) combined relative abundance of the three most abundant taxa (DomThreePct) at Stations 05RN188 (99%) and 12RN015 (100%)
- Above state class average (>84/82%) relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct) at Stations 05RN188 (88%) and 12RN015 (100%)
- Below state class average (<0.52/0.41) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Stations 05RN188 (0.02) and 12RN015 (0.01)
- Above state class average (>20%) relative abundance of taxa that are pioneers (PioneerTxPct) at Station 12RN015 (33%)
- Below state class average (<2/1) taxa richness of sensitive species (Sensitive) at Stations 05RN188 (0) and 12RN015 (0)

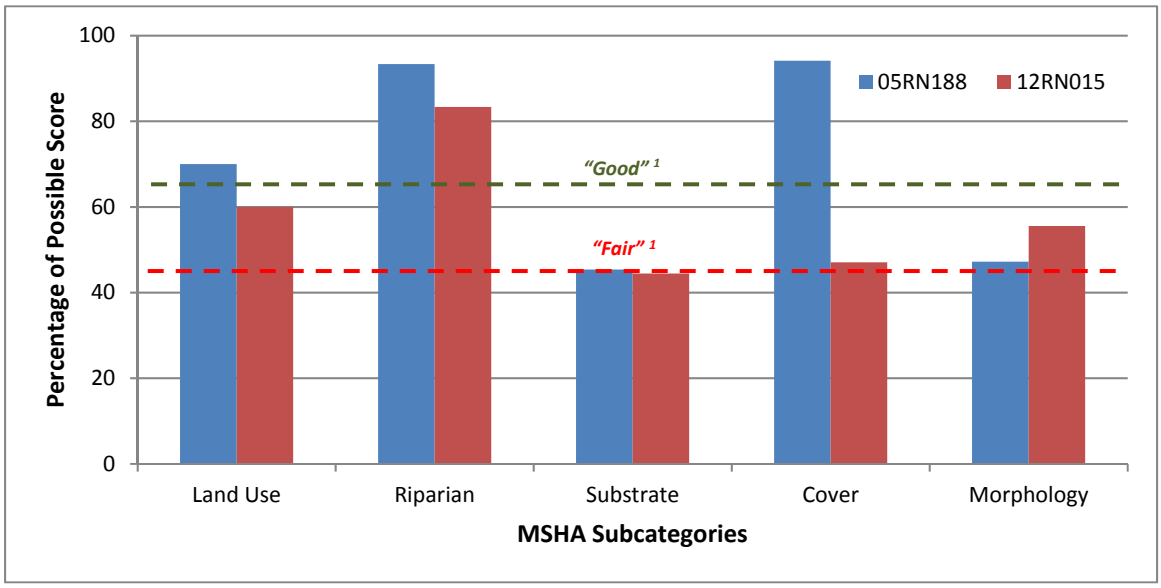
- Above state class average (>57/59%) relative abundance of taxa that are tolerant (TolTxPct) at Stations 05RN188 (75%) and 12RN015 (67%)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are early maturing, pioneering, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010).

Insufficient physical habitat

Available data

The physical habitat of AUID 505 was evaluated at Stations 05RN188 and 12RN015 using the MSHA. Both stations are located along natural segments of the reach (MPCA, 2013). Station 05RN188 yielded a MSHA score of 63 ("fair"), while Station 12RN015 had a MSHA score of 56 ("fair"). Figure 27 displays the MSHA subcategory results for the stations. Station 12RN015 scored slightly lower in the land use subcategory than Station 05RN188 due to the predominance of agricultural fields in the vicinity of the station. Both stations scored uniformly well in the riparian subcategory and had an "extensive" riparian zone width. However, Station 12RN015 had "moderate" bank erosion. Both stations scored the lowest in the substrate subcategory. Station 05RN188 had limited coarse substrate, with a "moderate" level of embeddedness, while Station 12RN015 offered no coarse substrate. Station 12RN015 had only a "sparse" amount of cover and subsequently scored substantially lower in the cover subcategory than Station 05RN188, which had an "extensive" amount of cover. However, the stations provided similar cover types, including deep pools, macrophytes, overhanging vegetation, undercut banks, and woody debris. Lastly, the stations had similar scores in the channel morphology subcategory; the stations had "moderate" to "moderate/high" channel stability and "fair" channel development.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Figure 27. MSHA subcategory results for Stations 05RN188 and 12RN015 along AUID 505.

On October 20, 2015, Vinje et al. (2017) performed a geomorphic assessment of Stations 05RN188 and 12RN015 (Appendix C). Below is a summary of the results:

> *"The Pfankuch rating for [Station 05RN188] was 83, which is fair (moderately unstable) for an E5 stream type. A fair, or moderately unstable, rating for E5 stream types ranges from 76-96. Most Pfankuch categories ranked as fair, with only bank rock content ranking as poor. The upper banks at this site were well vegetated with mature trees and grasses and there were no signs of mass erosion.*

The lower banks had some cutting and deposition, as well as moderately frequent obstructions to flow which appeared to be primarily from old beaver dams. The predominant substrate type through the reach appeared to be sand with areas of silt and small gravel. The bottom appeared to be fairly stable but there were areas of deposition, especially near the biological monitoring station waypoint. Both the deposition and channel width appeared to decrease in the downstream direction."

"The Pfankuch rating for [Station 12RN015] was 98, which is poor (unstable) for an E6 stream type. A poor, or unstable, rating for E6 stream types is 87 and above. Most Pfankuch categories ranked as either fair or poor for this site. The upper banks were well vegetated with mature trees near the biological monitoring station waypoint, but downstream 150 feet the upper banks were vegetated with reed canary grass for a length of approximately 300' to the road crossing. Because of incision, the upper banks were also very steep and showed evidence of both present and future mass erosion potential. Incision was also causing the lower banks to have significant cutting and was confining the channel. The substrate through this reach was primarily silt/clay, and it appeared the bottom had degraded or was in the process of degrading."

Overall, the available data suggest that the physical habitat of the reach is primarily limited by bank erosion, a lack of quality substrate, and spare cover.

Biotic response – fish

Evidence of a causal relationship between insufficient physical habitat and the F-IBI impairment associated with AUID 505 is provided by the following metric responses (Appendix A):

- Below state class average (<12/10%) relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct) at Stations 05RN188 (0%) and 12RN015 (0%)
- Below state class average (<1/1) taxa richness of darter and sculpin species (DarterSculp) at Stations 05RN188 (0) and 12RN015 (0)
- Above state class average (>17/20%) relative abundance of taxa that are detritivorous (DetNWQTxPct) at Stations 05RN188 (25%) and 12RN015 (33%)
- Below state class average (<9/5%) relative abundance of individuals that are insectivorous Cyprinids (InsectCypPct) at Stations 05RN188 (0%) and 12RN015 (0%)
- Below state class average (<24/21%) relative abundance of taxa that are insectivorous, excluding tolerant species (Insect-TolTxPct) at Stations 05RN188 (0%) and 12RN015 (0%)
- Below state class average (<2) taxa richness of simple lithophilic spawning species (SLithop) at Station 12RN015 (0)

Insectivores (e.g., darters and sculpins) and simple lithophilic spawners require quality benthic habitat (e.g., clean, coarse substrate) for feeding and/or reproduction purposes, while detritivores utilize decomposing organic matter (i.e., detritus) as a food resource and, therefore, are less dependent upon the quality of instream habitat (Aadland et al., 2006).

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Stations 05RN188 and 12RN015 along AUID 505 at the time of each fish monitoring visit. The samples were analyzed for several parameters, including TSS. Station 05RN188 had a TSS concentration of 20 mg/L, while Station 12RN015 had a TSS concentration of 4 mg/L. Table 13 summarizes all available discrete TSS data for Site S004-293 (CSAH 12 crossing); the relative location of the site is shown in Figure 23. The site had no exceedances of the 15 mg/L standard. Additionally, the LOWW HSPF model estimates that the reach had TSS concentration in excess of the standard 11% of the time during the period of 1996 to 2009. The

aforementioned MSHA results indicate that the deposition of excess fine sediment has caused the "moderate" level of embeddedness of coarse substrate documented at Station 05RN188. Overall, the available data suggest that the reach experiences at least occasional periods of high suspended sediment.

Table 13. Discrete TSS data for Site S004-293 along AUID 505.

Site	Date Range	*n*	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Exceedances (#)
S004-293	2012	11	2	9	5	0

Biotic response – fish

Evidence of a causal relationship between high suspended sediment and the F-IBI impairment associated with AUID 505 is provided by the following data responses (Appendix A):

- Above state class average (>14 mg/L) TSS TIV at Station 12RN015 (17 mg/L)
- Below state class average (<75%) probability of meeting the TSS standard at Station 12RN015 (66%)

Additionally, the deposition of suspended sediment has caused the aforementioned embeddedness of coarse substrate and the related biotic response associated with Station 05RN188.

Low dissolved oxygen

Available data

The reach has an existing DO impairment that was included on the 2012 Impaired Waters List. The MPCA biological monitoring staff collected a discrete DO measurement at Stations 05RN188 and 12RN015 along AUID 505 at the time of fish and macroinvertebrate monitoring. Only Station 12RN015 had measurements below the 5.0 mg/L standard. The station had a DO concentration of 2.7 mg/L at the time of the June 18, 2013, fish monitoring visit, as well as a DO concentration of 0.7 mg/L at the time of the July 31, 2012, macroinvertebrate monitoring visit. Figure 28 displays all available discrete DO data for Site S004-293 (2003-2013; *n*=63). Approximately 37% of the DO values for the site were below the standard; however, only one of the DO measurements was collected prior to 9:00 a.m. Generally, the lowest DO levels were in the months of July, August, and September. The MPCA conducted continuous DO monitoring at Site W80014001 (CSAH 12 crossing) from July 22, 2015, to August 4, 2015; the relative location of the site is shown in Figure 23. The monitoring results are provided in Table 14, as well as displayed in Figure 29. None of the DO measurements within the monitoring period were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard 39% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of low DO.

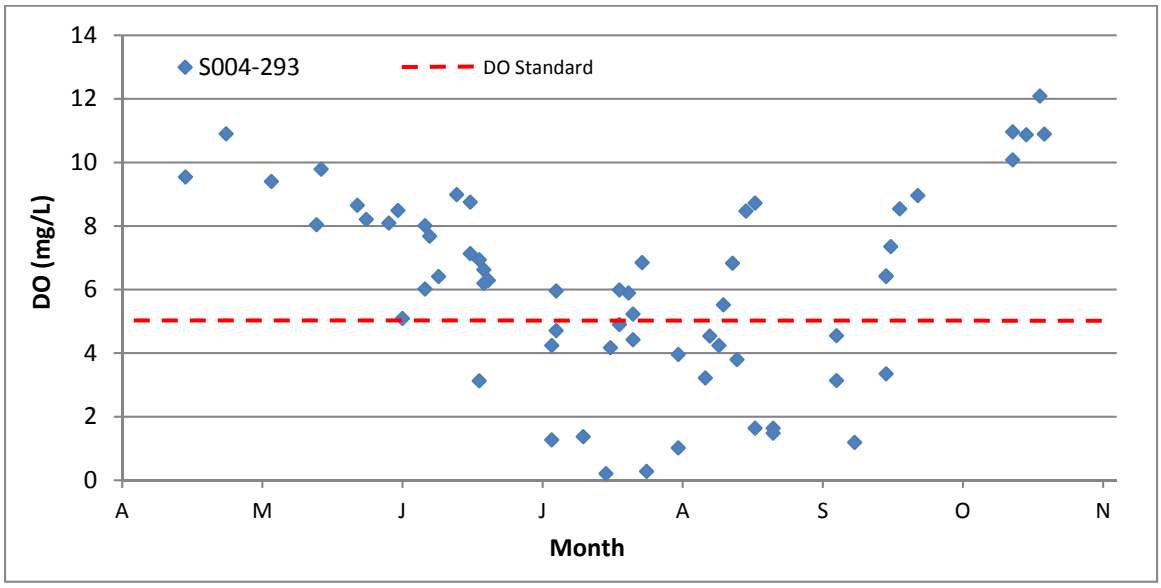


Figure 28. Discrete DO data for Site S004-293 along AUID 505.

Table 14. Continuous DO data for Site W80014001 along AUID 505.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – August 4, 2015	1241	5.2	8.2	0	0	1.5

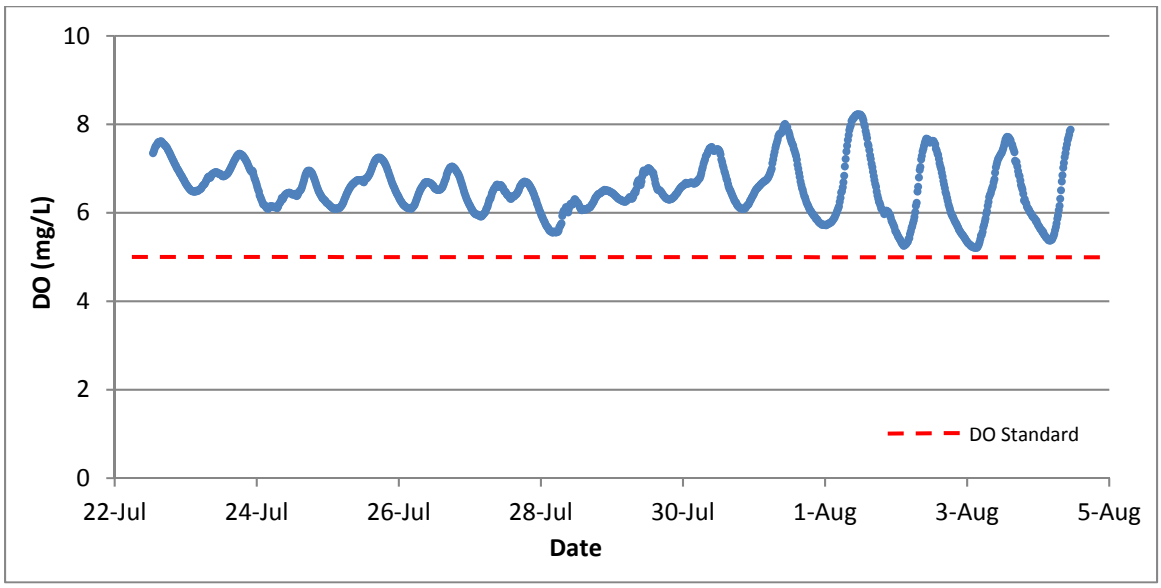


Figure 29. Continuous DO data for Site W80014001 along AUID 505.

Eutrophication-related data for the reach are limited to the following parameters: total phosphorus (TP) and DO flux. Discrete TP data is available for Sites S004-293 (2003-2012; *n*=57). The mean TP concentration for the site was 150 µg/L, while the highest concentration was 510 µg/L and the lowest concentration was 13 µg/L. Approximately 95% of the values exceeded the 50 µg/L North River Nutrient Region TP standard. The mean daily DO flux documented during continuous DO monitoring at Site

W80014001 (Table 14) was 1.5 mg/L, which is well below the 3.0 mg/L North River Nutrient Region DO flux standard. Overall, the reach has an extremely high percentage of exceedances of the TP standard, but the limited DO flux data does not suggest that eutrophication is contributing to the low DO conditions along the reach.

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 505 is provided by the following metric and data responses (Appendix A):

- Below state class average (<0.52/0.41) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Stations 05RN188 (0.02) and 12RN015 (0.01)
- Below state class average (<2/1) taxa richness of sensitive species (Sensitive) at Stations 05RN188 (0%) and 12RN015 (0%)
- Above state class average (>57/59%) relative abundance of taxa that are tolerant (TolTxPct) at Stations 05RN188 (75%) and 12RN015 (67%)
- Below state class average (<6.6/6.3 mg/L) DO TIV at Stations 05RN188 (5.8 mg/L) and 12RN015 (6.3 mg/L)
- Below state class average (<30/22%) probability of meeting the DO standard at Stations 05RN188 (6%) and 12RN015 (13%)

Low DO often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012).

Strength-of-evidence analysis

Table 15 presents a summary of the SOE scores for the various candidate causes associated with AUID 505. The evidence suggests that the F-IBI impairment is the collective result of the following primary stressors: insufficient base flow, insufficient physical habitat, and low DO. High suspended sediment also appears to be marginally affecting the fish community. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 15. SOE scores for candidate causes associated with Reach 505.

Types of Evidence	SOE Scores per Candidate Cause[1]				
	Loss of Longitudinal Connectivity	Insufficient Base Flow	Insufficient Physical Habitat	High Suspended Sediment	Low Dissolved Oxygen
	Biological Impairment				
	F-IBI	F-IBI	F-IBI	F-IBI	F-IBI
Types of Evidence that Use Data from the Case					
Spatial/Temporal Co-Occurrence	-	++	++	+	++
Temporal Sequence	NE	NE	NE	NE	NE
Stressor-Response Relationship	-	++	++	+	++
Causal Pathway	-	++	++	+	++
Evidence of Exposure/Bio-Mechanism	-	++	++	+	++
Manipulation of Exposure	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE
Symptoms	-	++	++	+	++
Types of Evidence that Use Data from Elsewhere					
Mechanistically Plausible Cause	+	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	++	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE
Multiple Lines of Evidence					
Consistency of Evidence	**-**	**++**	**++**	**+**	**++**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor**, 0** *neither supports nor weakens* the case for the candidate cause as a stressor**, -** *somewhat weakens* the case for the candidate cause as a stressor**, --** *strongly weakens* the case for the candidate cause as a stressor**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

3.3.4 West Branch Zippel Creek (AUID 515)

Physical setting

This reach represents West Branch Zippel Creek (Figure 30), which extends from its headwaters, to its outlet to Zippel Bay; a total length of six miles. The reach has a subwatershed area of 39 square miles (24,973 acres). The subwatershed contains 21 miles of intermittent drainage ditch, 11 miles of intermittent stream,8 miles of perennial drainage ditch, and 6 miles of perennial stream (DNR, 2015). According to the MPCA (2013), 74% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including 53% of AUID 515. The NLCD 2011 (USGS, 2011) lists wetlands (65%) as the predominant land cover in the subwatershed. Other notable land cover groups in the subwatershed included cultivated crops (21%), hay/pasture (7%), forest (3%), developed (2%), and herbaceous (2%).

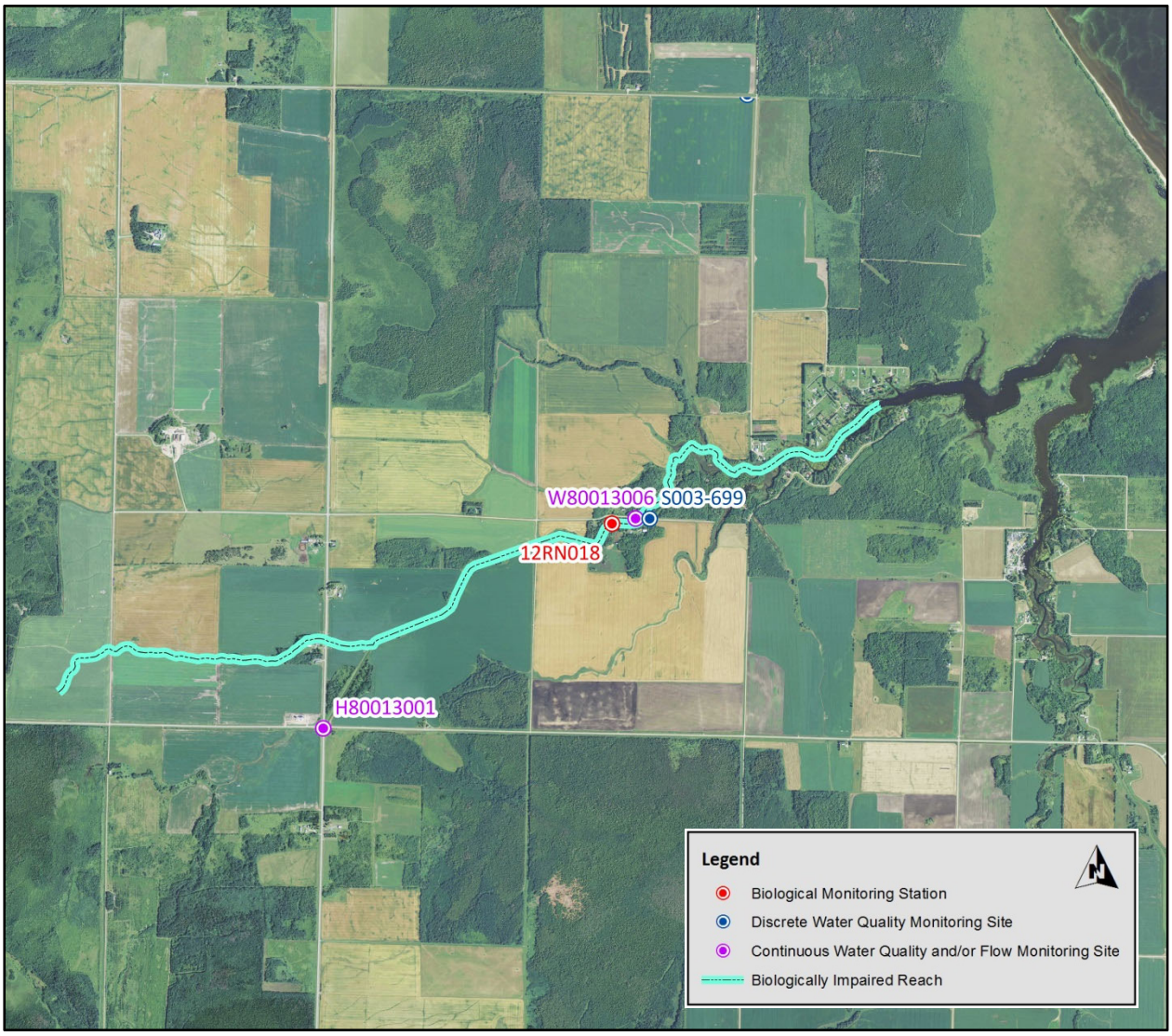
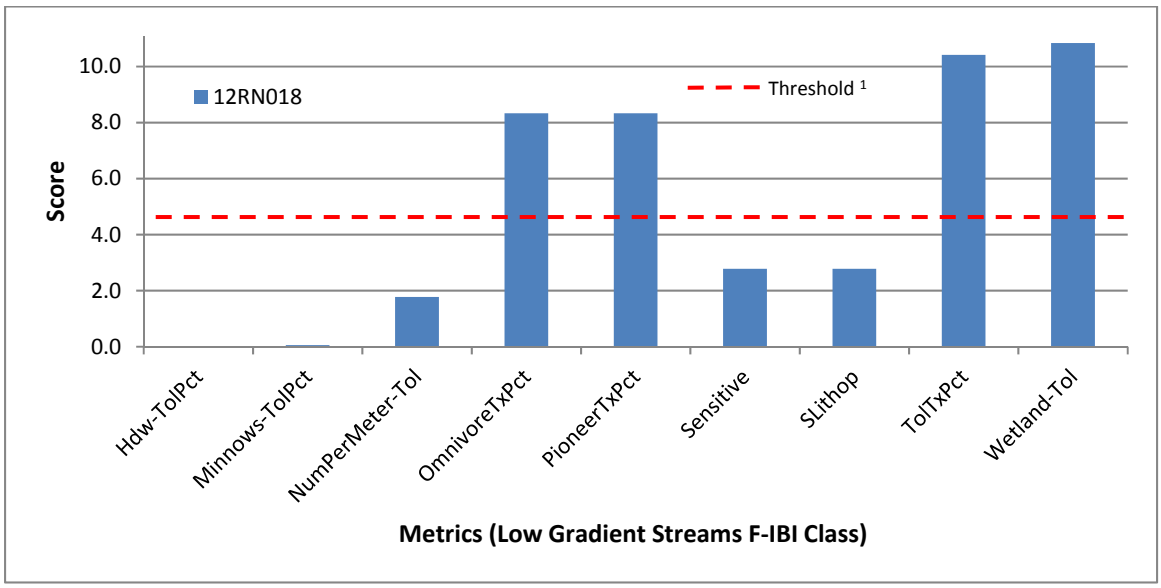


Figure 30. Map of AUID 515 and associated biological monitoring stations and water quality monitoring sites (2013 NAIP aerial image).

Biological impairments

Fish (F-IBI)

The fish community of AUID 515 was monitored at Station 12RN018 (0.1 mile upstream of the 40th Street NW crossing) on June 26, 2012. The relative location of the station is shown in Figure 30. The station was designated as General Use within the Low Gradient Streams F-IBI Class. Accordingly, the impairment threshold for the station is an F-IBI score of 42. The monitoring results for the station yielded an F-IBI score (45) slightly above the threshold. According to Figure 31, five individual metrics for Station 12RN018 scored below the mean value needed to meet the impairment threshold (i.e., Hdw-TolPct, Minnows-TolPct, NumPerMeter-Tol, Sensitive, and SLithop). A description of each metric is provided in the *Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014a). Overall, the fish assemblage of the stations was largely comprised of tolerant taxa, specifically central mudminnow.

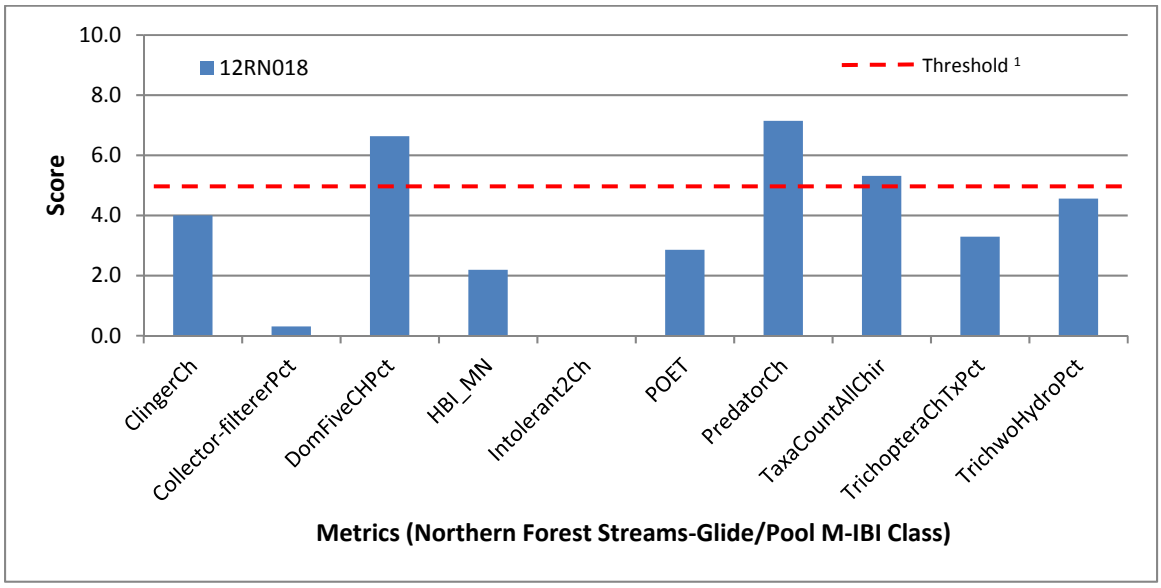


[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 31. Individual F-IBI metric scores for Station 12RN018 along AUID 515.

Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 515 was monitored at Station 12RN018 on July 31, 2012. The station was designated as General Use within the Northern Forest Streams-Glide/Pool M-IBI Class. Accordingly, the applicable impairment threshold for the station is an M-IBI score of 51. The monitoring results for the station yielded an M-IBI score (36) below the threshold. According to Figure 32, seven individual metrics for Station 12RN018 scored below the mean value needed to meet the impairment threshold (i.e., ClingerCh, Collector-filtererPct, HBI_MN, Intolerant2Ch, POET, TrichopteraChTxPct, and TrichwoHydroPct). A description of each metric is provided in the *Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014b). Overall, the macroinvertebrate assemblage of the station was dominated by tolerant taxa, specifically *Caenis* (mayflies), Coenagrionidae (damselflies), and *Hyalella* (amphipods).



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 32. Individual M-IBI metric scores for Station 12RN018 along AUID 515.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Station 12RN018 along AUID 515. According to the DNR (2011), there are no man-made dams on the reach. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. No obstructions to connectivity were identified (e.g., perched culverts and beaver dams). In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No connectivity-related issues were identified in the photo.

Biotic response – fish

There is inconclusive evidence of a causal relationship between a loss of longitudinal connectivity and the F-IBI impairment associated with AUID 515. There are no known obstructions to connectivity along the reach. Additionally, none of the metrics for Station 12RN018 (Appendix A) exhibited a correlation to this candidate cause. However, there is insufficient information to determine if culverts along the reach are impeding fish passage during high flow conditions (i.e., creating a velocity barrier).

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of longitudinal connectivity and the M-IBI impairment associated with AUID 515. There are no known obstructions to connectivity along the reach. Additionally, macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by longitudinal connectivity barriers.

Insufficient base flow

Available data

The MPCA biological monitoring staff did not note any flow-related issues during fish and macroinvertebrate sampling at Station 12RN018. There is no flow monitoring data for the reach;

however, the MPCA has conducted flow monitoring at Site H80013001 (CSAH 2/CSAH 8 intersection) along County Ditch 1 (Figure 30). The ditch is a major tributary to the reach. Figure 33 presents a flow duration curve for the site that was created based upon available discharge data (2000, 2001, 2004-2009, and 2011-2014). The highest mean daily peak flow during these years was 314.5 cfs, while the lowest flow was 0.0 cfs. Approximately 35% of the total mean daily flow values were less than 1.0 cfs. A discharge of less than 1.0 cfs or less was recorded in eight of the years represented. The MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and documented flow conditions. Staff observed low flow (estimated <1.0 cfs) conditions along the reach on September 16, 2015 (Figure 34). Overall, the available data suggest that the reach experiences at least occasional periods of minimal to no flow.

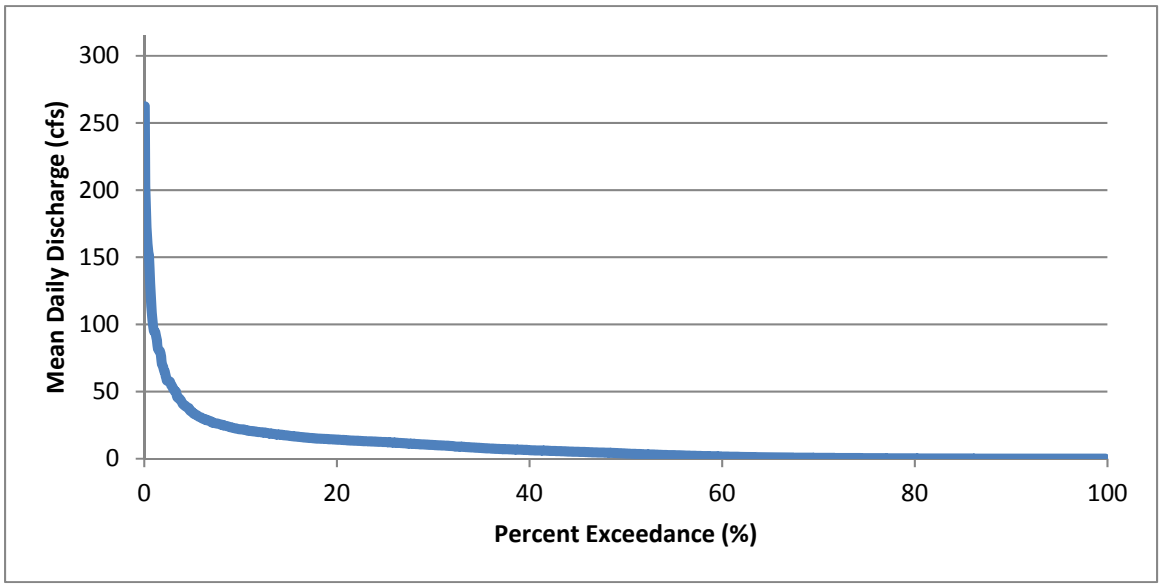


Figure 33. Flow duration curve for Site H80013001 (2000, 2001, 2004-2009, and 2011-2014) along County Ditch 1.

Figure 34. Photos of minimal flow conditions along AUID 515 on September 16, 2015, including the 40th Street NW crossing (left) and the 70th Avenue NW crossing (right).

Biotic response – fish

Evidence of a causal relationship between insufficient base flow and the F-IBI impairment associated with AUID 515 is provided by the following metric responses (Appendix A):

- Above state class average (>84%) combined relative abundance of the three most abundant taxa (DomThreePct) at Station 12RN018 (94%)
- Above state class average (>82%) relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct) at Station 12RN018 (86%)
- Below state class average (<0.41) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN018 (0.30)
- Above state class average (>2) taxa richness of species that utilize wetland habitats, excluding tolerant species (Wetland-Tol) at Station 12RN018 (4)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are early maturing, wetland oriented, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient base flow and the M-IBI impairment associated with AUID 515 is provided by the following metric responses (Appendix B):

- Below state class average (<18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN018 (2%)
- Below state class average (<1) taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch) at Station 12RN018 (0)
- Below state class average (<5%) relative abundance of long-lived individuals (LongLivedPct) at Station 12RN018 (4%)
- Below state class average (<11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN018 (6)
- Below state class average (<43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN018 (38)
- Above state class average (>68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN018 (92%)

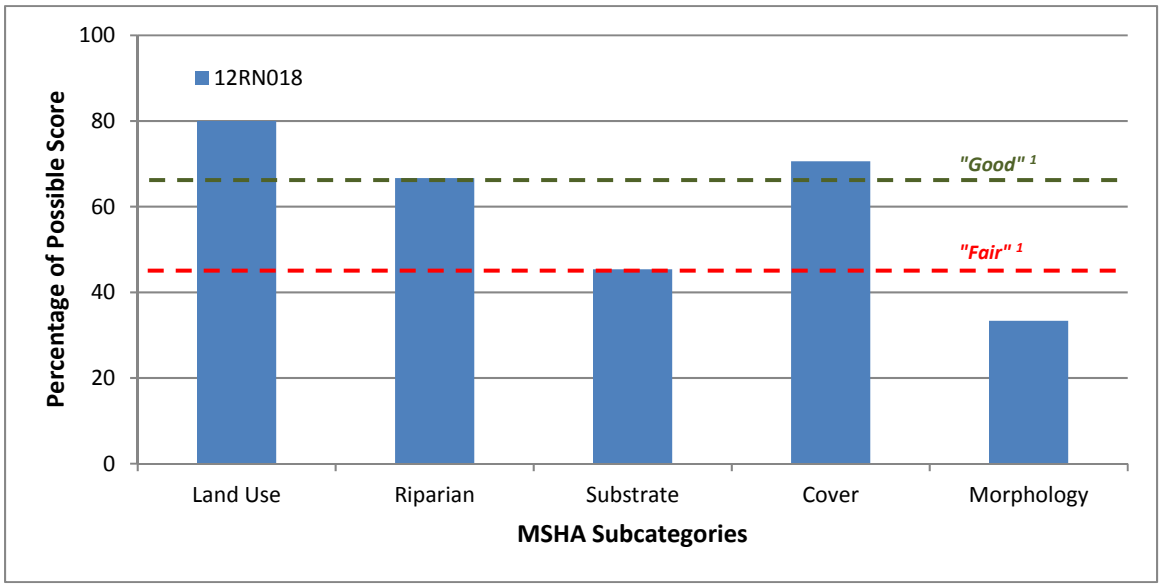
Frequent and/or prolonged periods of minimal to no flow tends to limit macroinvertebrate diversity, specifically taxa belonging to the orders of Plecoptera, Ephemeroptera, and Trichoptera (many of which are collector-filterers), and favor taxa that are tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; EPA, 2012). Overall, the macroinvertebrate assemblage of the station was dominated by taxa that are adapted to lentic conditions (i.e., *Caenis*, Coenagrionidae, and *Hyalella*).

Insufficient physical habitat

Available data

The physical habitat of AUID 515 was evaluated at Station 12RN018 using the MSHA. The station is located along a channelized segment of the reach (MPCA, 2013). The station yielded a MSHA score of 50 (“fair”). Figure 35 displays the MSHA subcategory results for the station. The total MSHA score for the station was most limited by the substrate and channel morphology subcategories. The land use immediately adjacent to the station was largely forest/wetlands. The width of the riparian zone was characterized as “extensive”. No bank erosion was noted at the station. The station offered no riffle habitat or coarse substrate. The amount of cover present at the station was considered “moderate” and consisted of deep pools, macrophytes (emergent, floating leaf, and submergent), overhanging

vegetation, undercut banks, and woody debris. Lastly, the station had “moderate” channel stability, “fair” sinuosity, and “fair” channel development.



[1] The minimum percentage of each subcategory score needed for the station to achieve a “fair” and “good” MSHA rating.

Figure 35. MSHA subcategory results for Station 12RN018 along AUID 515.

On October 19, 2015, Vinje et al. (2017) performed a geomorphic assessment of Station 12RN018 (Appendix C). Below is a summary of the results:

> *“The Pfankuch rating for [Station 12RN018] was 67, which is good (stable) for a C5 stream type. A good, or stable, rating for C5 stream types ranges from 70-90. Almost all Pfankuch categories ranked as excellent or good, with only bank rock content ranking as poor. The upper banks were well vegetated with mature trees (primarily on right bank), reed canary grass (primarily on left bank), and scattered shrubs. There was also no evidence of mass wasting in the upper banks. The lower banks were well vegetated with no evidence of cutting or deposition. The substrate at this location was sand and silt, and there was likely some deposition occurring from an undersized culvert approximately 450 feet downstream of the biological station site waypoint. There was also abundant aquatic vegetation throughout the reach.”*

Overall, the available data suggest that the physical habitat of the reach is limited by a lack of coarse substrate and riffle habitat. Additionally, Vinje et al. (2017) noted that past channelization has adversely affected the diversity and amount of cover present along the reach.

Biotic response – fish

There is no evidence of a causal relationship between insufficient physical habitat and the F-IBI impairment associated with AUID 515. None of the metrics for Station 12RN018 (Appendix A) exhibited a correlation to this candidate cause.

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient physical habitat and the M-IBI impairment associated with AUID 515 is provided by the following metric responses (Appendix B):

- Below state class average (<11) taxa richness of clingers (ClingerCh) at Station 12RN018 (8)
- Above state class average (>23%) relative abundance of sprawler individuals (SprawlerPct) at Station 12RN018 (40%)

Clinger taxa require clean, coarse substrate or other objects to attach themselves to, while sprawler macroinvertebrates are tolerant of degraded benthic habitat.

High suspended sediment

Available data

The reach has a TSS impairment that will be included on the proposed 2016 Impaired Waters List. The MPCA biological monitoring staff collected a discrete water quality sample at Station 12RN018 along AUID 515 at the time of the fish monitoring visit. The sample was analyzed for several parameters, including TSS. The station had a TSS concentration of 10 mg/L. Table 16 summarizes all available discrete TSS data for Site S003-699 (40th Street NW crossing); the relative location of the site is shown in Figure 30. The site had a high proportion of total exceedances of the 15 mg/L standard (16%). Additionally, the LOWW HSPF model estimates that the reach had a TSS concentration in excess of the standard 4% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of high suspended sediment.

Table 16. Discrete TSS data for Site S003-699 along AUID 515

Site	Date Range	*n*	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard Exceedances (#)
S003-699	2004-2013	51	1	84	9	8

The *Bostic and Zippel Creeks Watershed Assessment* (USDA, 2013) was conducted to evaluate the sources and transport of sediment through these systems to Zippel and Bostic Bays. Sedimentation of the bays has created flooding, water quality, and fish/wildlife habitat degradation concerns. The assessment concluded that a "significant portion" of the sediment reaching West Zippel Bay via the West Branch Zippel Creek is from the ephemeral erosion of agricultural land.

Biotic response – fish

There is no evidence of a causal relationship between high suspended sediment and the F-IBI impairment associated with AUID 515. None of the metrics or related data for Station 12RN018 (Appendix A) exhibited a correlation to this candidate cause.

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 515 is provided by the following metric and data responses (Appendix B):

- Below state class average (<18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN018 (2%)
- Above state class average (>14%) relative abundance of high TSS tolerant individuals at Station 12RN018 (27%)
- Below state class average (<4) taxa richness of high TSS intolerant macroinvertebrates at Station 12RN018 (1)

Collector-filterers utilize specialized mechanisms (e.g., silk nets) to strain organic material from the water column. High suspended sediment can interfere with these mechanisms (Arruda et al., 1983; Barbour et al., 1999; Lemley, 1982; Strand and Merritt, 1997).

Low dissolved oxygen

Available data

The reach has a DO impairment that will be included on the proposed 2016 Impaired Waters List. The MPCA biological monitoring staff collected a discrete DO measurement at Station 12RN018 along AUID 515 at the time of fish and macroinvertebrate monitoring. The station had a DO concentration of 5.6 mg/L at the time of the June 26, 2012, fish monitoring visit, as well as a DO concentration of 4.2 mg/L at the time of the July 31, 2012, macroinvertebrate monitoring visit. Figure 36 displays all available discrete DO data for Site S003-699 (2004-2013; *n*=87). Approximately 7% of the DO values for the site were below the standard; 34% of the measurements were collected prior to 9:00 a.m. Generally, the lowest DO levels were in the months of July and August. The MPCA conducted continuous DO monitoring at Site W80013006 (40th Street NW crossing) from July 22, 2015, to August 4, 2015; the relative location of the site is shown in Figure 30. The monitoring results are provided in Table 17, as well as displayed in Figure 37. While only 4% of the total values were below the standard, 31% of the daily minimum values were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard 8% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of low DO.

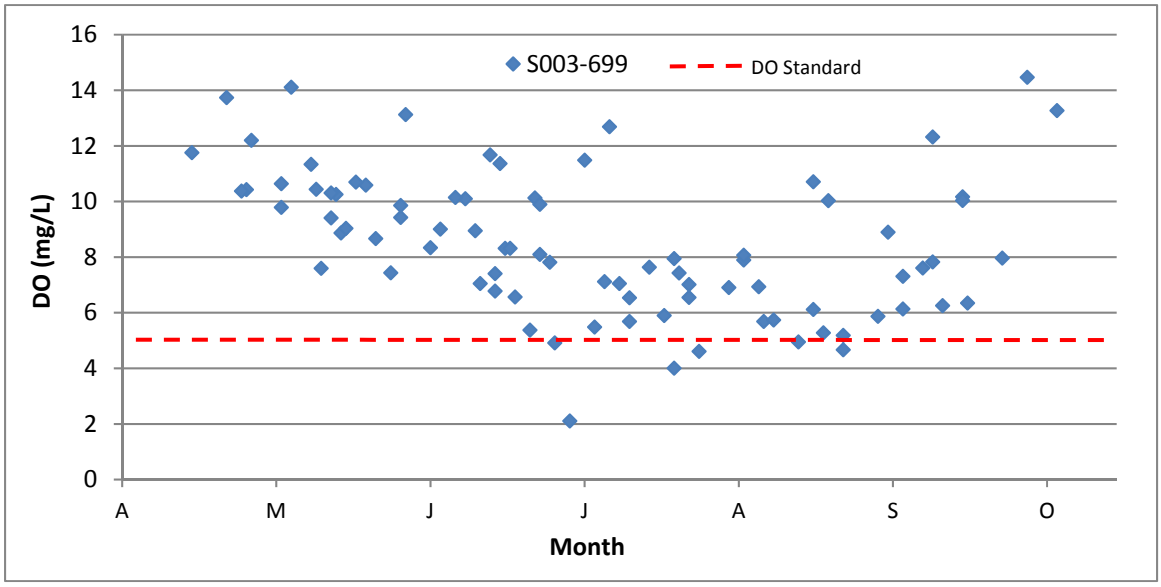


Figure 36. Discrete DO data for Site S003-699 along AUID 515.

Table 17. Continuous DO data for Site W80013006 along AUID 515.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – August 4, 2015	1250	4.2	14.3	4	31	8.2

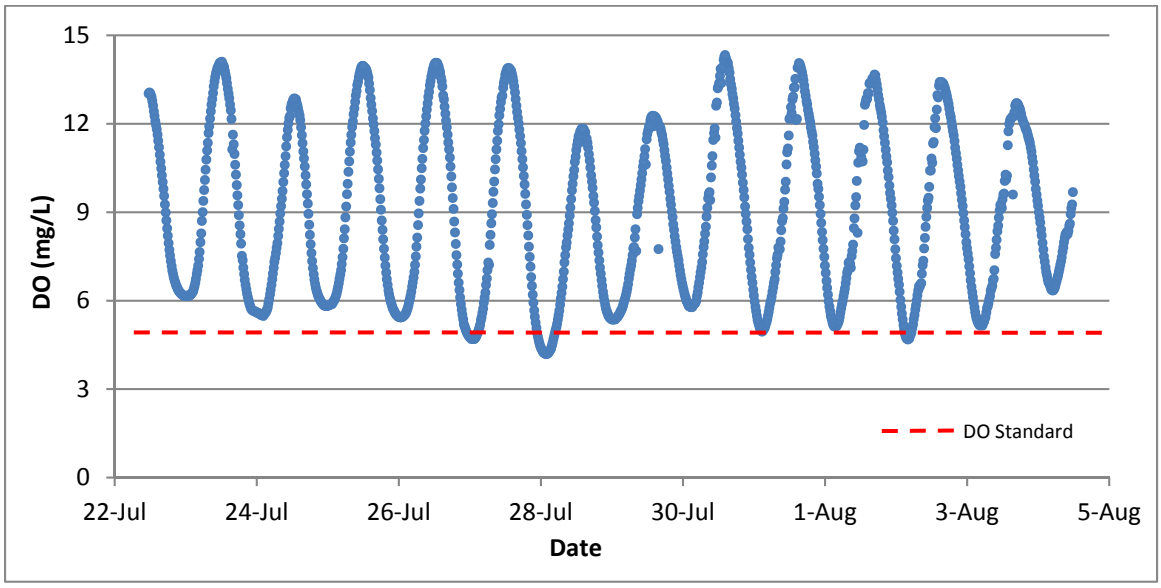


Figure 37. Continuous DO data for Site W80013006 along AUID 515.

Eutrophication-related data for the reach are limited to the following parameters: total phosphorus (TP) and DO flux. Discrete TP data is available for Sites S003-699 (2004-2013; *n*=50). The mean TP concentration for the site was 54 µg/L, while the highest concentration was 246 µg/L and the lowest concentration was 3 µg/L. Approximately 26% of the values exceeded the 50 µg/L North River Nutrient Region TP standard. The mean daily DO flux documented during continuous DO monitoring at Site W80014001 (Table 17) was 8.2 mg/L, which is substantially above the 3.0 mg/L North River Nutrient Region DO flux standard. Overall, the available data suggest that eutrophication is likely contributing to the low DO conditions along the reach.

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 515 is provided by the following metric and data responses (Appendix A):

- Below state class average (<0.41) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN018 (0.30)
- Below state class average (<6.3 mg/L) DO TIV at Station 12RN018 (5.9 mg/L)
- Below state class average (<22%) probability of meeting the DO standard at Station 12RN018 (8%)

Low DO often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012).

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 515 is provided by the following metric and data responses (Appendix B):

- Above state class average (>7) Hilsenhoff's Biotic Index value (HBI_MN) at Station 12RN018 (8)
- Below state class average (<11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN018 (6)
- Below state class average (<43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN018 (38)
- Above state class average (>68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN018 (92%)
- Below state class average (<6.5 mg/L) DO TIV at Station 12RN018 (6.0 mg/L)

- Above state class average (>29%) relative abundance of low DO tolerant individuals at Station 12RN018 (68%)
- Below state class average (<3) taxa richness of low DO intolerant macroinvertebrates at Station 12RN018 (0)

Low DO often limits the taxa richness of macroinvertebrates, particularly members of the orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera, and favors taxa that are tolerant (Weber, 1973; EPA, 2012).

Strength-of-evidence analysis

Table 18 presents a summary of the SOE scores for the various candidate causes associated with AUID 515. The evidence suggests that low DO is the primary stressor contributing to the F-IBI impairment. There is also limited evidence that suggests that the fish community is adversely affected by insufficient base flow. Additionally, the evidence indicates that the M-IBI impairment is the collective result of the following primary stressors: insufficient base flow, high suspended sediment, and low DO. Insufficient physical habitat also appears to be marginally affecting the macroinvertebrate community. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 18. SOE scores for candidate causes associated with AUID 515.

Types of Evidence	SOE Scores per Candidate Cause[1]									
	Loss of Longitudinal Connectivity		Insufficient Base Flow		Insufficient Physical Habitat		High Suspended Sediment		Low Dissolved Oxygen	
	Biological Impairment									
	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI
Types of Evidence that Use Data from the Case										
Spatial/Temporal Co-Occurrence	0	--	+	++	-	+	0	++	++	+++
Temporal Sequence	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response Relationship	0	--	+	++	-	+	0	++	++	+++
Causal Pathway	0	--	+	++	-	+	0	++	++	+++
Evidence of Exposure/Bio-Mechanism	0	--	+	++	-	+	0	++	++	+++
Manipulation of Exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Symptoms	0	--	+	++	-	+	0	++	++	+++
Types of Evidence that Use Data from Elsewhere										
Mechanistically Plausible Cause	+	-	+	+	+	+	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	++	NE	++	++	++	++	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Multiple Lines of Evidence										
Consistency of Evidence	**0**	**--**	**+**	**++**	**-**	**+**	**0**	**++**	**++**	**+++**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor**, 0** *neither supports nor weakens* the case for the candidate cause as a stressor**, -** *somewhat weakens* the case for the candidate cause as a stressor**, --** *strongly weakens* the case for the candidate cause as a stressor**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

3.3.5 Unnamed ditch (AUID 523)

Physical setting

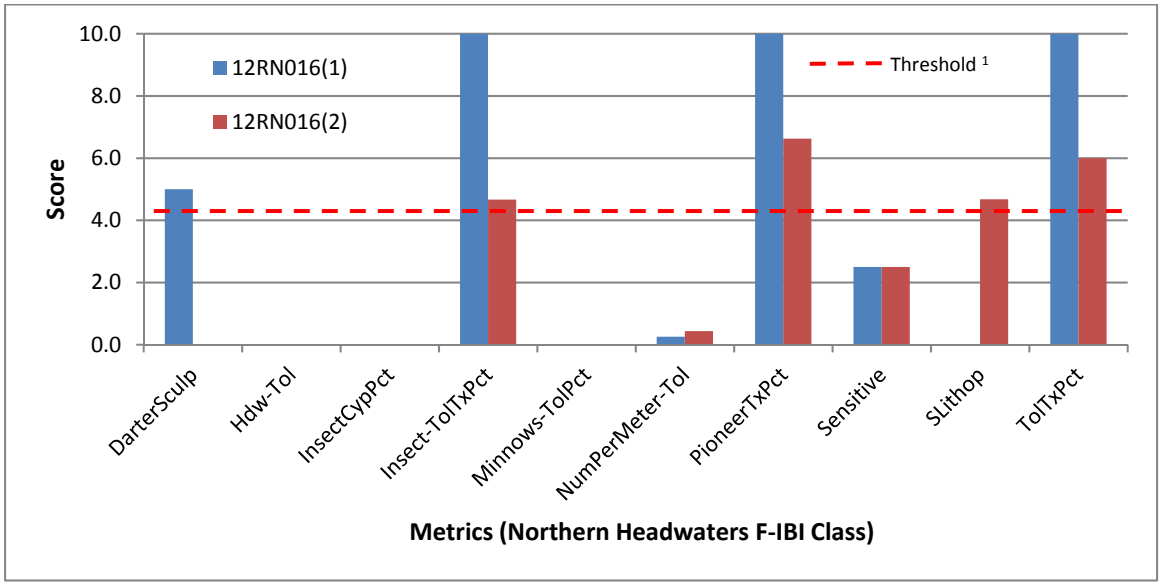
This reach represents an unnamed ditch (Figure 38), which extends from immediately upstream of the CSAH 17 crossing, to its confluence with an unnamed ditch along 56th Street NW; a total length of one mile. The reach has a subwatershed area of 16 square miles (10,088 acres). The subwatershed contains 20 miles of intermittent drainage ditch (e.g., AUID 523) and four miles of intermittent stream (DNR, 2015). According to the MPCA (2013), 83% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including the entire length of AUID 523. The NLCD 2011 (USGS, 2011) lists wetlands (56%) as the predominant land cover in the subwatershed. Other notable land cover groups in the subwatershed included cultivated crops (21%), hay/pasture (11%), herbaceous (3%), forest (3%), developed (3%), and shrub/scrub (1%).

Figure 38. Map of AUID 523 and associated biological monitoring stations and water quality monitoring sites (2013 NAIP aerial image).

Biological impairments

Fish (F-IBI)

The fish community of AUID 523 was monitored at Station 12RN016 (0.1 mile downstream of the CSAH 17 crossing) on July 11, 2012(1) and August 27, 2014(2). The relative location of the station is shown in Figure 38. The station was designated as General Use within the Northern Headwaters F-IBI Class. Accordingly, the impairment threshold for the station is an F-IBI score of 42. The monitoring results for the station yielded F-IBI scores (38 and 25) below the threshold. According to Figure 39, seven individual metrics for Station 12RN016 scored below the mean value needed to meet the impairment threshold (i.e., DarterSculp, Hdw-Tol, InsectCypPct, Minnows-TolPct, NumPerMeter-Tol, Sensitive, and SLithop). A description of each metric is provided in the *Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014a). Overall, the fish assemblage of the stations was largely comprised of tolerant taxa (i.e., central mudminnow and white sucker).

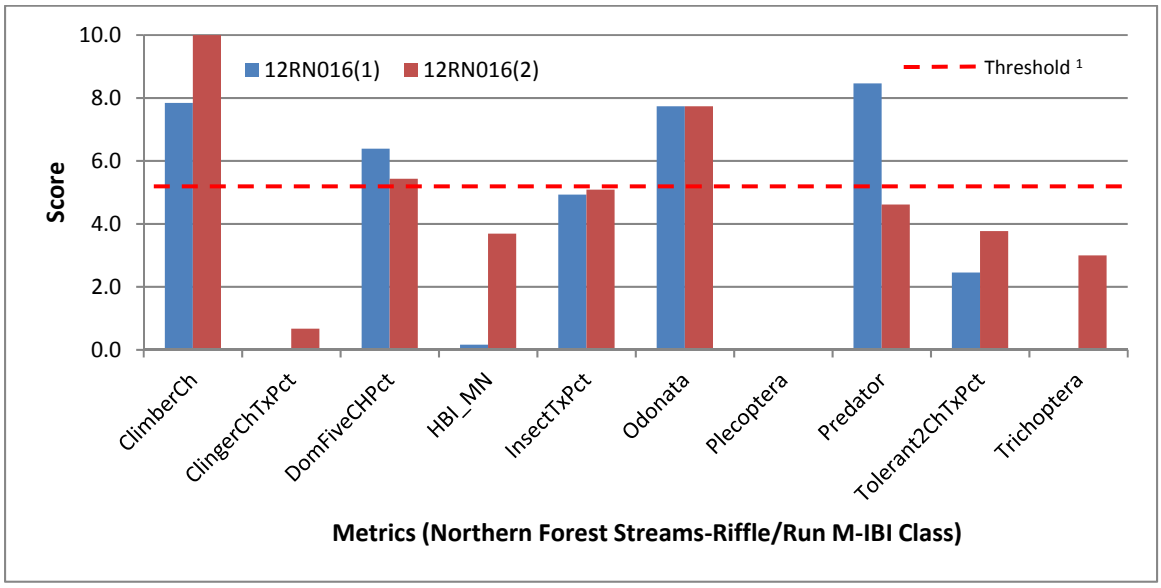


[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 39. Individual F-IBI metric scores for Station 12RN016 along AUID 523.

Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 523 was monitored at Station 12RN016 on July 31, 2012 and August 26, 2014. The station was designated as General Use within the Northern Forest Streams-Riffle/Run M-IBI Class. Accordingly, the impairment threshold for the station is an M-IBI score of 53. The station (M-IBI=38 and 44) scored below the threshold. According to Figure 40, seven individual metrics for Station 12RN016 scored below the mean value needed to meet the impairment threshold (i.e., ClingerChTxPct, HBI_MN, InsectTxPct, Plecoptera, Predator, Tolerant2ChTxPct, and Trichoptera). A description of each metric is provided in the *Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014b). Overall, the macroinvertebrate assemblage of the station was dominated by tolerant taxa, including Coenagrionidae (damselflies), *Dicrotendipes* (midges), *Micropsectra* (midges), Oligochaeta (worms). *Paratanytarsus* (midges), and *Physa* (snails).



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 40. Individual M-IBI metric scores for Station 12RN016 along AUID 523.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Station 12RN016 along AUID 523. According to the DNR (2011), there are no man-made dams on the reach. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. No obstructions to connectivity were identified (e.g., perched culverts and beaver dams). In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No connectivity-related issues were identified in the photo.

Biotic response – fish

There is inconclusive evidence of a causal relationship between a loss of longitudinal connectivity and the F-IBI impairment associated with AUID 523. There are no known obstructions to connectivity along the reach. Additionally, none of the metrics for Station 12RN016 (Appendix A) exhibited a correlation to this candidate cause. However, there is insufficient information to determine if culverts along the reach are impeding fish passage during high flow conditions (i.e., creating a velocity barrier).

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of longitudinal connectivity and the M-IBI impairment associated with AUID 523. There are no known obstructions to connectivity along the reach. Additionally, macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by longitudinal connectivity barriers.

Insufficient base flow

Available data

The MPCA biological monitoring staff encountered low flow conditions during the July 11, 2012, fish monitoring visit at Station 12RN016 (Figure 41). There is no flow monitoring data for the reach. The

MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and documented flow conditions. Staff observed minimal flow (estimated <0.5 cfs) and lentic conditions along the reach on September 16, 2015 (Figure 41). According to the DNR (2015), the reach has an intermittent flow regime. Overall, the available data suggest that the reach experiences frequent periods of minimal to no flow.

Figure 41. Photos of minimal flow and lentic conditions along AUID 523, including Station 12RN016 on July 11, 2012 (upper left); the CSAH 11 crossing on September 16, 2015 (upper right); the CSAH 17 crossing on September 16, 2015 (lower left); and near 56th Street NW on September 16, 2015 (lower right).

Biotic response – fish

Evidence of a causal relationship between insufficient base flow and the F-IBI impairment associated with AUID 523 is provided by the following metric responses (Appendix A):

- Above state class average (>80%) combined relative abundance of the three most abundant taxa (DomThreePct) at Station 12RN016(1)(2) (89/88%)
- Above state class average (>41%) relative abundance of taxa that are generalists (GeneralTxPct) at Station 12RN016(2) (43%)
- Above state class average (>84%) relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct) at Station 12RN016(1) (89%)
- Below state class average (<0.52) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN016(1)(2) (0.05/0.08)
- Below state class average (<2) taxa richness of sensitive species (Sensitive) at Station 12RN016(1)(2) (1/1)

- Above state class average (>57%) relative abundance of taxa that are tolerant (TolTxPct) at Station 12RN016(2) (60%)
- Above state class average (>2) taxa richness of species that utilize wetland habitats, excluding tolerant species (Wetland-Tol) at Station 12RN016(1) (3)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are trophic generalists, early maturing, wetland oriented, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient base flow and the M-IBI impairment associated with AUID 523 is provided by the following metric responses (Appendix B):

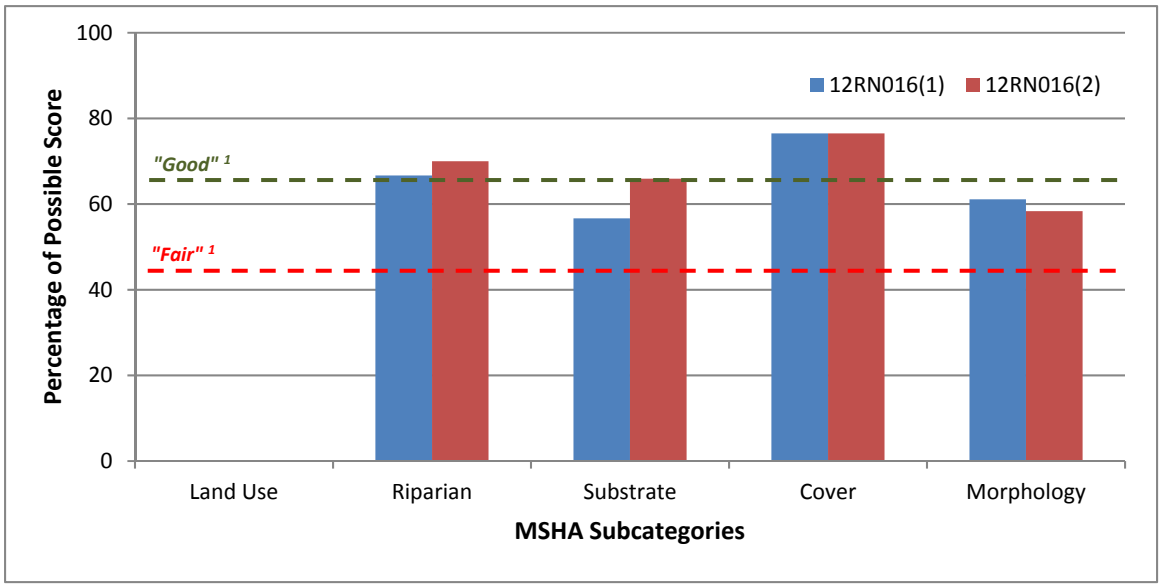
- Below state class average (<27%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN016(1)(2) (1/26%)
- Above state class average (>51%) relative abundance of the dominant five taxa in a subsample (DomFiveCHPct) at Station 12RN016(1)(2) (53/56%)
- Below state class average (<4) taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch) at Station 12RN016(1)(2) (0/0)
- Below state class average (<9%) relative abundance of long-lived individuals (LongLivedPct) at Station 12RN016(1)(2) (7/3%)
- Below state class average (<19) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN016(1)(2) (6/11)
- Below state class average (<51) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN016(1)(2) (46/46)
- Above state class average (>58%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN016(1)(2) (83/76%)

Frequent and/or prolonged periods of minimal to no flow tends to limit macroinvertebrate diversity, specifically taxa belonging to the orders of Plecoptera, Ephemeroptera, and Trichoptera (many of which are collector-filterers), and favor taxa that are tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; EPA, 2012). Overall, the macroinvertebrate assemblage of the station was dominated by taxa that are adapted to lentic conditions (e.g., Coenagrionidae, *Dicrotendipes*, Oligochaeta, *Paratanytarsus*, and *Physa*).

Insufficient physical habitat

Available data

The physical habitat of AUID 523 was evaluated at Station 12RN016 using the MSHA. The station is located along a ditched segment of the reach (MPCA, 2013). The station yielded MSHA scores of 60 (“fair”) and 62 (“fair”). Figure 42 displays the MSHA subcategory results for the station. The total MSHA scores for the station were most limited by the land use, substrate, and channel morphology subcategories. The land use immediately adjacent to the station was largely agricultural row crops. The width of the riparian zone was characterized as “very narrow” to “moderate”. No bank erosion was noted at the station. The station offered riffle habitat and coarse substrate (i.e., gravel); however, the substrate had “light” to “moderate” embeddedness. The amount of cover present at the station was considered “moderate” and consisted of deep pools, macrophytes (emergent and submergent), overhanging vegetation, undercut banks, and woody debris. Lastly, the station had “moderate/high” channel stability, “poor” sinuosity, and “fair” to “good” channel development.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Figure 42. MSHA subcategory results for Station 12RN016 along AUID 523.

On October 21, 2015, Vinje et al. (2017) performed a geomorphic assessment of Station 12RN016 (Appendix C). Below is a summary of the results:

> *"The Pfankuch rating for [Station 12RN016] was 69, which is good (stable) for an E4 stream type. A good, or stable, rating for E4 stream types is 50-75. Most categories ranked as either good or excellent, with only bank rock content and aquatic vegetation ranking as poor. The upper banks were well vegetated with grasses, forbs, and willow saplings and there was no evidence of mass erosion. The lower banks were also well vegetated and there was very little bank cutting and no deposition on the lower banks. The bottom generally ranked as good, with the substrate being primarily small gravel with areas of silt/clay."*

In summary, the MSHA data suggest that the physical habitat of the reach is primarily limited by the embeddedness of coarse substrate. Additionally, Vinje et al. (2017) noted that past channelization has adversely affected the diversity and amount of cover present along the reach.

Biotic response – fish

Evidence of a causal relationship between insufficient physical habitat and the F-IBI impairment associated with AUID 523 is provided by the following metric responses (Appendix A):

- Below state class average (<12%) relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct) at Station 12RN016(2) (0%)
- Below state class average (<1) taxa richness of darter and sculpin species (DarterSculp) at Station 12RN016(2) (0)
- Above state class average (>17%) relative abundance of taxa that are detritivorous (DetNWQTxPct) at Station 12RN016(2) (40%)
- Below state class average (<9%) relative abundance of individuals that are insectivorous Cyprinids (InsectCypPct) at Station 12RN016(1)(2) (0/0%)
- Below state class average (<24%) relative abundance of taxa that are insectivorous, excluding tolerant species (Insect-TolTxPct) at Station 12RN016(2) (20%)

- Below state class average (<12%) relative abundance of species that predominately utilize riffle habitats (RiffleTxPct) at Station 12RN016(1) (0%)
- Below state class average (<2) taxa richness of simple lithophilic spawning species (SLithop) at Station 12RN016(1) (0)

Insectivores (e.g., darters and sculpins) and simple lithophilic spawners require quality benthic habitat (e.g., clean, coarse substrate and riffles) for feeding and/or reproduction purposes, while detritivores utilize decomposing organic matter (i.e., detritus) as a food resource and, therefore, are less dependent upon the quality of instream habitat (Aadland et al., 2006).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient physical habitat and the M-IBI impairment associated with AUID 523 is provided by the following metric responses (Appendix B):

- Above state class average (>10%) relative abundance of burrowers (BurrowerPct) at Station 12RN016(1) (29%)
- Below state class average (<19) taxa richness of clingers (ClingerCh) at Station 12RN016 (1)(2) (9/10)
- Below state class average (<38%) relative percentage of clinger taxa (ClingerChTxPct) at Station 12RN016(1)(2) (20/22%)
- Above state class average (>40%) relative abundance of legless individuals (LeglessPct) at Station 12RN016(1)(2) (62/62%)
- Above state class average (>15%) relative abundance of sprawler individuals (SprawlerPct) at Station 12RN016(2) (20%)

Clinger taxa require clean, coarse substrate or other objects to attach themselves to, while burrower, legless, and sprawler macroinvertebrates are tolerant of degraded benthic habitat.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Station 12RN016 along AUID 523 at the time of each fish monitoring visit. The samples were analyzed for several parameters, including TSS. The station had TSS concentrations of 4 and 9 mg/L, respectively. Additionally, the LOWW HSPF model estimates that the reach had a TSS concentration in excess of the standard 6% of the time during the period of 1996 to 2009. The aforementioned MSHA results indicate that the deposition of excess fine sediment has caused the “moderate” level of embeddedness of coarse substrate documented at Station 12RN016. Overall, the available data suggest that the reach experiences at least occasional periods of high suspended sediment.

Biotic response – fish

None of the metrics or related data for Station 12RN018 (Appendix A) exhibited a correlation to this candidate cause. However, the deposition of suspended sediment has caused the aforementioned embeddedness of coarse substrate and the related biotic response at Station 12RN018.

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 523 is provided by the following metric and data responses (Appendix B):

- Below state class average (<27%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN016(1)(2) (1/26%)
- Above state class average (>19%) relative abundance of high TSS tolerant individuals at Station 12RN016(1) (33%)

- Below state class average (<8) taxa richness of high TSS intolerant macroinvertebrates at Station 12RN016(1) (2)

Collector-filterers utilize specialized mechanisms (e.g., silk nets) to strain organic material from the water column. High suspended sediment can interfere with these mechanisms (Arruda et al., 1983; Barbour et al., 1999; Lemley, 1982; Strand and Merritt, 1997).

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Station 12RN016 along AUID 523 at the time of each fish and macroinvertebrate monitoring visit. Only one of the measurements was below the 5.0 mg/L standard; the station had a DO concentration of 0.7 mg/L at the time of the July 31, 2012, macroinvertebrate monitoring visit. The MPCA conducted continuous DO monitoring at Site W80007001 (CSAH 17 crossing) from July 22, 2015, to July 31, 2015; the relative location of the site is shown in Figure 38. The monitoring results are provided in Table 19, as well as displayed in Figure 43. While 11% of the total values were below the standard, 67% of the daily minimum values were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard 12% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of low DO.

Table 19. Continuous DO data for Site W80007001 along AUID 523.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – July 31, 2015	860	4.2	15.1	11	67	8.5

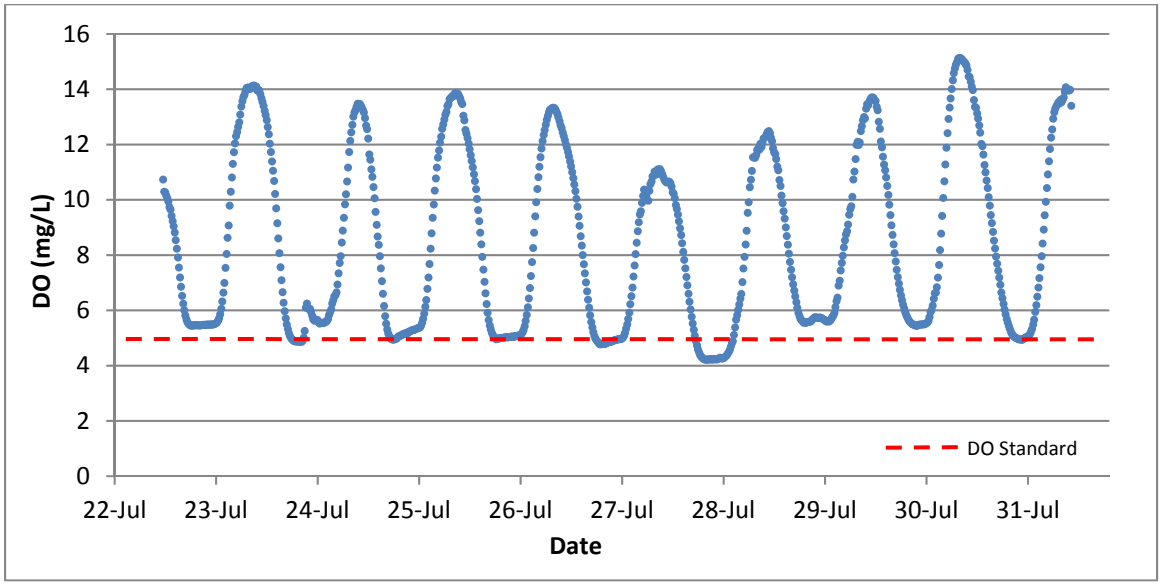


Figure 43. Continuous DO data for Site W80007001 along AUID 523.

Eutrophication-related data for the reach is limited to DO flux. The mean daily DO flux documented during continuous DO monitoring at Site W80007001 (Table 19) was 8.5 mg/L, which is substantially above the 3.0 mg/L North River Nutrient Region DO flux standard. The data suggests that eutrophication may be contributing to the low DO conditions along the reach.

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 523 is provided by the following metric responses (Appendix A):

- Below state class average (<0.52) number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol) at Station 12RN016(1)(2) (0.05/0.08)
- Below state class average (<2) taxa richness of sensitive species (Sensitive) at Station 12RN016(1)(2) (1/1)
- Above state class average (>57%) relative abundance of taxa that are tolerant (TolTxPct) at Station 12RN016(2) (60%)

Low DO often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012).

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 523 is provided by the following metric and data responses (Appendix B):

- Above state class average (>6) Hilsenhoff's Biotic Index value (HBI_MN) at Station 12RN016(1)(2) (8/7)
- Below state class average (<19) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN016(1)(2) (6/11)
- Below state class average (<51) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN016(1)(2) (46/46)
- Above state class average (>58%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN016(1)(2) (83/76%)
- Below state class average (<7.0 mg/L) DO TIV at Station 12RN016(1)(2) (6.0/6.8 mg/L)
- Above state class average (>11%) relative abundance of low DO tolerant individuals at Station 12RN016(1) (63%)
- Below state class average (<10) taxa richness of low DO intolerant macroinvertebrates at Station 12RN016(1)(2) (0/2)

Low DO often limits the taxa richness of macroinvertebrates, particularly members of the orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera, and favors taxa that are tolerant (Weber, 1973; EPA, 2012).

Strength-of-evidence analysis

Table 20 presents a summary of the SOE scores for the various candidate causes associated with AUID 523. The evidence suggests that insufficient base flow and insufficient physical habitat are the primary stressors contributing to the F-IBI impairment. There is also limited evidence that suggests that the fish community is adversely affected by high suspended sediment and low DO. Additionally, the evidence indicates that the M-IBI impairment is the collective result of the following primary stressors: insufficient base flow, insufficient physical habitat, and low DO. High suspended sediment also appears to be marginally affecting the macroinvertebrate community. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 20. SOE scores for candidate causes associated with AUID 523.

Types of Evidence	SOE Scores per Candidate Cause[1]									
	Loss of Longitudinal Connectivity		Insufficient Base Flow		Insufficient Physical Habitat		High Suspended Sediment		Low Dissolved Oxygen	
	Biological Impairment									
	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI	F-IBI	M-IBI
Types of Evidence that Use Data from the Case										
Spatial/Temporal Co-Occurrence	0	--	++	++	++	++	+	+	+	++
Temporal Sequence	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response Relationship	0	--	++	++	++	++	+	+	+	++
Causal Pathway	0	--	++	++	++	++	+	+	+	++
Evidence of Exposure/Bio-Mechanism	0	--	++	++	++	++	+	+	+	++
Manipulation of Exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Symptoms	0	--	++	++	++	++	+	+	+	++
Types of Evidence that Use Data from Elsewhere										
Mechanistically Plausible Cause	+	-	+	+	+	+	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	++	NE	++	++	++	++	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Multiple Lines of Evidence										
Consistency of Evidence	**0**	**--**	**++**	**++**	**++**	**++**	**+**	**+**	**+**	**++**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor**, 0** *neither supports nor weakens* the case for the candidate cause as a stressor**, -** *somewhat weakens* the case for the candidate cause as a stressor**, --** *strongly weakens* the case for the candidate cause as a stressor**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

3.3.6 County Ditch 20 (AUID 560)

Physical setting

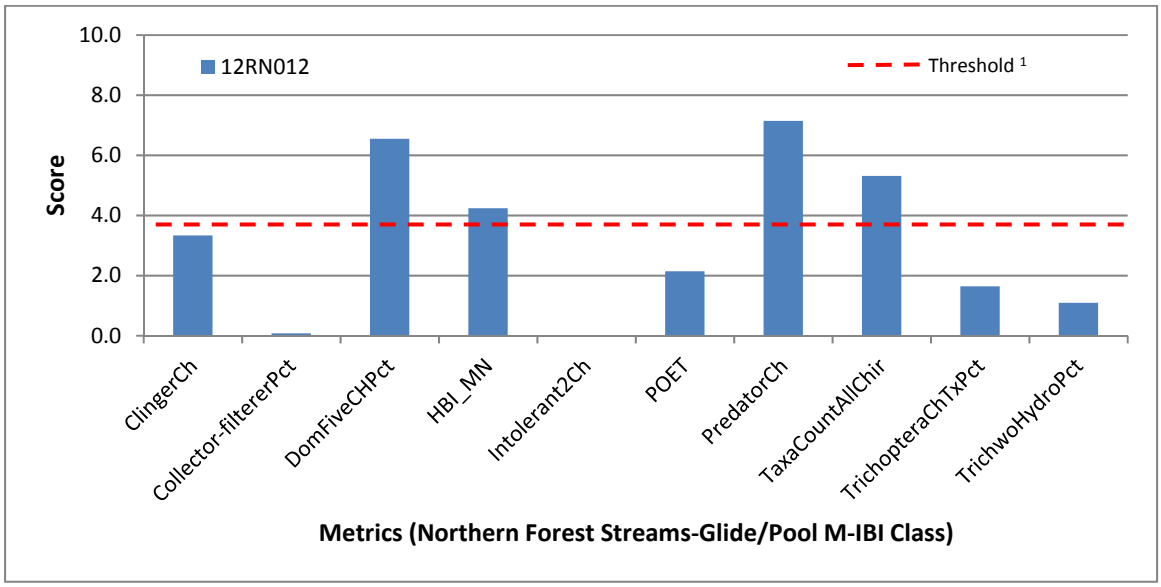
This reach represents County Ditch 20 (Figure 44), which extends from its headwaters, situated near Swift, to its outlet to Lake of the Woods; a total length of 3 miles. The reach has a subwatershed area of 10 square miles (6,228 acres). The subwatershed contains 11 miles of intermittent stream, 3 miles of perennial drainage ditch, and 2 miles of intermittent drainage ditch (DNR, 2015). According to the MPCA (2013), 50% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including the entire length of AUID 560. The NLCD 2011 (USGS, 2011) lists wetlands (55%) as the predominant land cover in the subwatershed. Other notable land cover groups in the subwatershed included hay/pasture (16%), cultivated crops (14%), forest (6%), developed (5%), and herbaceous (3%).

Figure 44. Map of AUID 560 and associated biological monitoring stations and water quality monitoring sites (2013 NAIP aerial image).

Biological impairment

Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 560 was monitored at Station 12RN012 (0.1 mile downstream of the CSAH 12 crossing) on August 1, 2012. The relative location of the station is shown in Figure 44. The station was designated as Modified Use within the Northern Forest Streams-Glide/Pool M-IBI Class. Accordingly, the impairment threshold for the station is an M-IBI score of 37. The monitoring results for the station yielded an M-IBI score (31) below the threshold. According to Figure 45, six individual metrics for Station 12RN012 scored below the mean value needed to meet the impairment threshold (i.e., ClingerCh, Collector-filtererPct, Intolerant2Ch, POET, TrichopteraChTxPct, and TrichwoHydroPct). A description of each metric is provided in the *Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams* (MPCA, 2014b). Overall, the macroinvertebrate assemblage of the station was dominated by tolerant taxa, specifically *Hyalella* (amphipods) and Oligochaeta (worms).



[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 45. Individual M-IBI metric scores for Station 12RN012 along AUID 560.

Candidate causes

Loss of longitudinal connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues at Station 12RN012 along AUID 560. According to the DNR (2011), there are no man-made dams on the reach. On September 16, 2015, MPCA SID staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings on the reach as part of the assessment. A slightly perched culvert was documented at a private road crossing along 645th Avenue. The downstream end of the culvert was elevated approximately four inches above the ditch. The perched culvert likely obstructs connectivity only during very low flow conditions. In addition to the assessment, MPCA SID staff performed a detailed review of a May 17, 2011, aerial photo (courtesy of Google Earth) of the reach. No connectivity-related issues were identified in the photo.

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of longitudinal connectivity and the M-IBI impairment associated with AUID 560. Macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by longitudinal connectivity barriers.

Insufficient base flow

Available data

The MPCA biological monitoring staff did not note any flow-related issues during fish and macroinvertebrate sampling at Station 12RN012. There is no flow monitoring data for the reach. The MPCA SID staff conducted reconnaissance along the reach on three separate dates (i.e., July 22, 2015, August 4, 2015, and September 16, 2015) and documented flow conditions. Staff observed minimal flow (estimated <0.5 cfs) and/or lentic conditions along the reach on each of these dates (Figure 46). According to local water resource managers in the LOWW, the downstream extent of the reach, which includes Station 12RN012, is often affected by backwater from Lake of the Woods (MPCA, 2015). Overall, the available data suggest that the reach experiences frequent periods of minimal to no flow.

Figure 46. Photos of minimal flow and lentic conditions along AUID 560, including the CSAH 12 crossing on August 4, 2015 (upper left); the 320th Street crossing on September 16, 2015 (upper right); the CSAH 12 crossing on September 16, 2015 (lower left); and along CR 147 on September 16, 2015 (lower right).

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient base flow and the M-IBI impairment associated with AUID 560 is provided by the following metric responses (Appendix B):

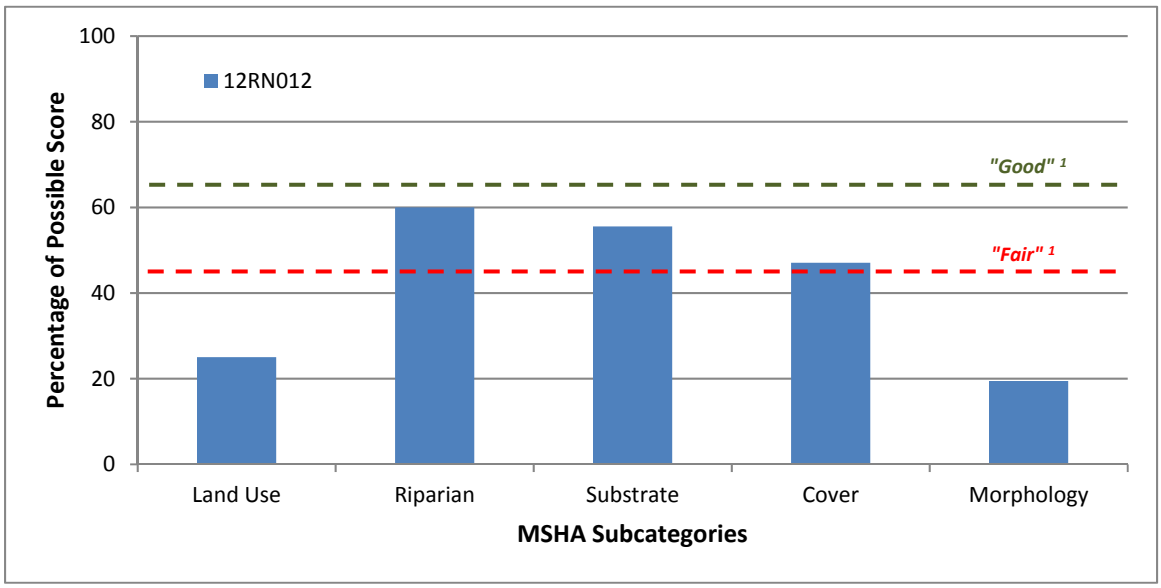
- Below state class average (<18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN012 (1%)
- Below state class average (<1) taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch) at Station 12RN012 (0)
- Below state class average (<5%) relative abundance of long-lived individuals (LongLivedPct) at Station 12RN012 (4%)
- Below state class average (<11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN012 (5)
- Below state class average (<43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN012 (37)
- Above state class average (>68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN012 (81%)

Frequent and/or prolonged periods of minimal to no flow tends to limit macroinvertebrate diversity, specifically taxa belonging to the orders of Plecoptera, Ephemeroptera, and Trichoptera (many of which are collector-filterers), and favor taxa that are tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; EPA, 2012). Overall, the macroinvertebrate assemblage of the station was dominated by taxa that are adapted to lentic conditions (i.e., *Hyalella* and Oligochaeta).

Insufficient physical habitat

Available data

The physical habitat of AUID 560 was evaluated at Station 12RN012 using the MSHA. The station is located along a ditched segment of the reach (MPCA, 2013). The station yielded a MSHA score of 40 (“poor”). Figure 47 displays the MSHA subcategory results for the station. The total MSHA score for the station was most limited by the land use and channel morphology subcategories. The land use immediately adjacent to the station was largely agricultural row crops. The width of the riparian zone was characterized as “very narrow” to “narrow”. No bank erosion was noted at the station. The station offered no riffle habitat or coarse substrate. The amount of cover present at the station was considered “sparse” and consisted of boulders (riprap), macrophytes (emergent and submergent), overhanging vegetation, undercut banks, and woody debris. Lastly, the station had “moderate/high” channel stability, “poor” sinuosity, and “poor” channel development.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Figure 47. MSHA subcategory results for Station 12RN012 along AUID 560.

On October 20, 2015, Vinje et al. (2017) performed a geomorphic assessment of Station 12RN012 (Appendix C). Below is a summary of the results:

> *"The Pfankuch rating for [Station 12RN012] was 56, which is good (stable) for an E6 stream type. A good, or stable, rating for E6 stream types is 40-63. Most Pfankuch categories ranked as either good or excellent. The upper banks were well vegetated with grasses and forbs on the left bank and grasses, forbs, and brush on the right bank. There was no evidence of mass wasting, but the top of the left upper bank is bound by a gravel road that runs the length of the ditch until it outlets into Lake of the Woods. The lower banks were also well vegetated with grasses, forbs, and brush and showed little signs of cutting or deposition. Although determining bankfull at this location was difficult, it did appear that the ditch was at least slightly incised and moderately entrenched. The bottom through this reach ranked primarily as excellent. Substrate through the reach was clay, and there was abundant aquatic vegetation throughout."*

Overall, the available data suggest that the physical habitat of the reach is limited by a lack of coarse substrate and riffle habitat, as well as a sparse amount of cover.

Biotic response – macroinvertebrate

Evidence of a causal relationship between insufficient physical habitat and the M-IBI impairment associated with AUID 560 is provided by the following metric responses (Appendix B):

- Below state class average (<11) taxa richness of clingers (ClingerCh) at Station 12RN012 (7)
- Below state class average (<25%) relative percentage of clinger taxa (ClingerChTxPct) at Station 12RN012 (19%)
- Above state class average (>23%) relative abundance of sprawler individuals (SprawlerPct) at Station 12RN012 (39%)

Clinger taxa require clean, coarse substrate or other objects to attach themselves to, while sprawler macroinvertebrates are tolerant of degraded benthic habitat.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Station 12RN012 along AUID 560 at the time of the fish monitoring visit. The sample was analyzed for several parameters, including TSS. The station had a TSS concentration of 19 mg/L. Additionally, the LOWW HSPF model estimates that the reach had a TSS concentration in excess of the standard 4% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences at least occasional periods of high suspended sediment.

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 560 is provided by the following metric and data responses (Appendix B):

- Below state class average (<18%) relative abundance of collector-filterer individuals (Collector-filtererPct) at Station 12RN012 (1%)
- Above state class average (>10 mg/L) TSS TIV at Station 12RN012 (19 mg/L)
- Above state class average (>14%) relative abundance of high TSS tolerant individuals at Station 12RN012 (27%)
- Below state class average (<4) taxa richness of high TSS intolerant macroinvertebrates at Station 12RN012 (2)

Collector-filterers utilize specialized mechanisms (e.g., silk nets) to strain organic material from the water column. High suspended sediment can interfere with these mechanisms (Arruda et al., 1983; Barbour et al., 1999; Lemley, 1982; Strand and Merritt, 1997).

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Station 12RN012 along AUID 560 at the time of fish and macroinvertebrate monitoring. The station had a DO concentration of 3.5 mg/L at the time of the June 26, 2012, fish monitoring visit, as well as a DO concentration of 5.0 mg/L at the time of the August 1, 2012, macroinvertebrate monitoring visit. The MPCA conducted continuous DO monitoring at Site W80030001 (CSAH 12 crossing) from July 22, 2015, to August 4, 2015; the relative location of the site is shown in Figure 44. The monitoring results are provided in Table 21, as well as displayed in Figure 48. While 16% of the total values were below the standard, 69% of the daily minimum values were below the standard. Additionally, the LOWW HSPF model estimates that the reach had a DO concentration below the standard 71% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach experiences frequent periods of low DO.

Table 21. Continuous DO data for Site W80030001 along AUID 560.

Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Total Values Below Standard	% Daily Min. Values Below Standard	Mean Daily Flux (mg/L)
July 22, 2015 – August 4, 2015	1238	2.5	16.7	16	69	9.3

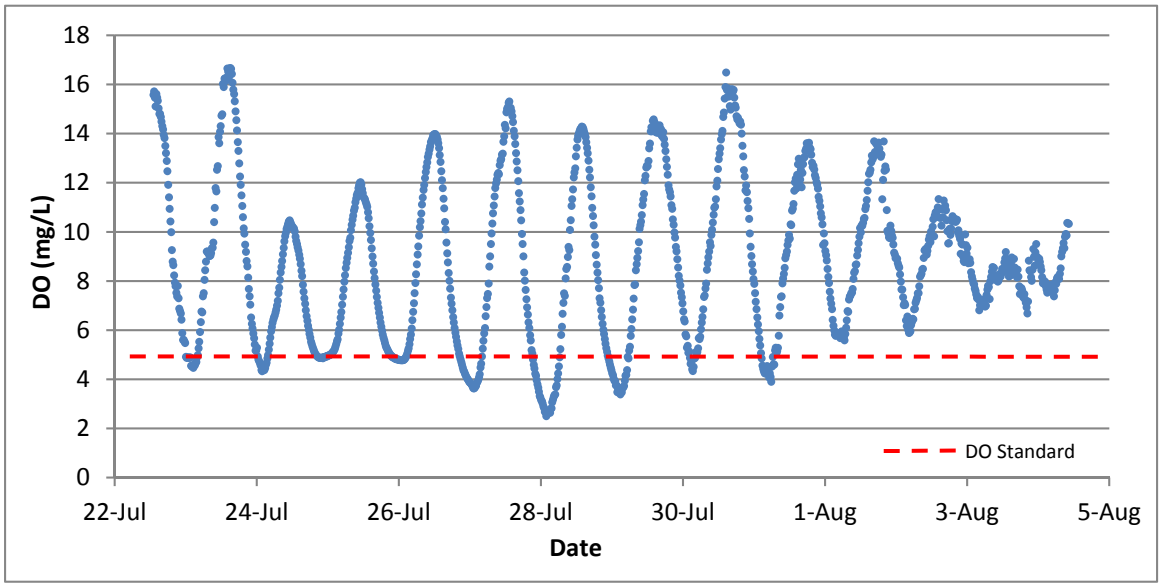


Figure 48. Continuous DO data for Site W80030001 along AUID 560.

Eutrophication-related data for the reach is limited to DO flux. The mean daily DO flux documented during continuous DO monitoring at Site W80030001 (Table 21) was 9.3 mg/L, which is substantially above the 3.0 mg/L North River Nutrient Region DO flux standard. The data suggests that eutrophication may be contributing to the low DO conditions along the reach.

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 560 is provided by the following metric and data responses (Appendix B):

- Above state class average (>7) Hilsenhoff's Biotic Index value (HBI_MN) at Station 12RN012 (8)
- Below state class average (<11) taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET) at Station 12RN012 (5)
- Below state class average (<43) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 12RN012 (37)
- Above state class average (>68%) relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct) at Station 12RN012 (81%)
- Below state class average (<6.5 mg/L) DO TIV at Station 12RN012 (6.0 mg/L)
- Above state class average (>29%) relative abundance of low DO tolerant individuals at Station 12RN012 (66%)
- Below state class average (<3) taxa richness of low DO intolerant macroinvertebrates at Station 12RN012 (0)

Low DO often limits the taxa richness of macroinvertebrates, particularly members of the orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera, and favors taxa that are tolerant (Weber, 1973; EPA, 2012).

Strength-of-evidence analysis

Table 22 presents a summary of the SOE scores for the various candidate causes associated with AUID 560. The evidence suggests that insufficient base flow, insufficient physical habitat, and low DO are the primary stressors contributing to the M-IBI impairment. There is also limited evidence that suggests that the macroinvertebrate community is adversely affected by high suspended sediment. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 22. SOE scores for candidate causes associated with Reach 560.

Types of Evidence	SOE Scores per Candidate Cause[1]				
	Loss of Longitudinal Connectivity	Insufficient Base Flow	Insufficient Physical Habitat	High Suspended Sediment	Low Dissolved Oxygen
	Biological Impairment				
	M-IBI	M-IBI	M-IBI	M-IBI	M-IBI
Types of Evidence that Use Data from the Case					
Spatial/Temporal Co-Occurrence	--	++	++	+	++
Temporal Sequence	NE	NE	NE	NE	NE
Stressor-Response Relationship	--	++	++	+	++
Causal Pathway	--	++	++	+	++
Evidence of Exposure/Bio-Mechanism	--	++	++	+	++
Manipulation of Exposure	NE	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE	NE
Symptoms	--	++	++	0	++
Types of Evidence that Use Data from Elsewhere					
Mechanistically Plausible Cause	-	+	+	+	+
Stressor-Response in Lab Studies	NE	NE	NE	NE	NE
Stressor-Response in Field Studies	NE	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE	NE
Manipulation Experiments at Sites	NE	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE	NE
Multiple Lines of Evidence					
Consistency of Evidence	**--**	**++**	**++**	**+**	**++**

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause as a stressor, **++** *strongly supports* the case for the candidate cause as a stressor, **+** *somewhat supports* the case for the candidate cause as a stressor**, 0** *neither supports nor weakens* the case for the candidate cause as a stressor**, -** *somewhat weakens* the case for the candidate cause as a stressor**, --** *strongly weakens* the case for the candidate cause as a stressor**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause as a stressor, and **NE** *no evidence* available.

Section 4: Conclusions and recommendations

4.1 Conclusions

Table 23 presents a summary of the stressors associated with the biologically impaired reaches in the LOWW. Each of the reaches is affected to a varying degree by the following stressors: insufficient base flow, insufficient physical habitat, high suspended sediment, and low DO. Most of the reaches are prone to frequent and extended periods of intermittency, particularly in late summer. Historical changes in land cover (e.g., native vegetation to cropland) and drainage patterns (e.g., ditching and channelization) are the primary anthropogenic factors contributing to this condition. The physical habitat of several of the reaches has been degraded as a result of hydrologic alterations. Excess suspended sediment appears to be having an effect on the biological communities of the reaches. Soil erosion and channel degradation are believed to be the primary sources of this sediment. Lastly, low DO is a stressor for each of the impaired reaches. While the severity of low DO conditions varies amongst the reaches, the lowest concentrations generally coincide with low flow and lentic conditions that occur during the late summer.

Table 23. Summary of the stressors associated with the biologically impaired reaches in the LOWW.

AUID Suffix	Name	Biological Impairment(s)	Candidate Causes[1]				
			Loss of Longitudinal Connectivity	Insufficient Base Flow	Insufficient Physical Habitat	High Suspended Sediment	Low Dissolved Oxygen
501	Williams Creek	F-IBI		++			+
		M-IBI		++	+	++	++
504	East Branch Warroad River	M-IBI		+	+	+	+
505	Willow Creek	F-IBI		++	++	+	++
515	West Branch Zippel Creek	F-IBI		+			++
		M-IBI		++	+	++	+++
523	Unnamed Ditch	F-IBI		++	++	+	+
		M-IBI		++	++	+	++
560	County Ditch 20	M-IBI		++	++	+	++

[1] **Key:** +++ the available evidence *convincingly supports* the case for the candidate cause as a stressor, ++ the available evidence *strongly supports* the case for the candidate cause as a stressor, and + the available evidence *somewhat supports* the case for the candidate cause as a stressor. A blank space indicates that the available evidence *does not* support the case for the candidate cause as a stressor.

4.2 Recommendations

The recommended actions listed below, as well as included in *The Aquatic Biota Stressor and Best Management Practice Selection Guide*, will help to reduce the influence of the stressors that are limiting the fish and macroinvertebrate communities of the watershed.

- Prevent or mitigate activities that will further alter the hydrology of the watershed.
- Consider opportunities and options to reduce peak flows and increase base flows throughout the watershed.
- Incorporate the principles of natural channel design into stream restoration and ditch maintenance activities.
- Increase the quantity and quality of instream habitat throughout the watershed.
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible.
- Implement agricultural BMPs to reduce soil erosion.
- Conduct an inventory of culverts in the watershed and evaluate their impact on fish passage.

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Appendix A: Individual F-IBI Metric and TIVs Data

Percentage of individuals per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics				
				DomThreePct	Hdw-TolPct	InsectCypPct	MA<2Pct	Minnows-TolPct
501	10EM161	23-Jun-10	6	83	1	0	99	20
	12RN020(1)	14-Jun-12	6	63	0	0	72	3
	12RN020(2)	12-Jul-12	6	79	0	0	93	7
505	05RN188	19-Jun-06	7	99	0	0	88	0
	12RN015	18-Jun-13	6	100	0	0	100	0
515	12RN018	26-Jun-12	7	94	0	0	86	0
523	12RN016(1)	11-Jul-12	6	89	0	0	89	0
	12RN016(2)	27-Aug-14	6	88	0	0	35	0
Class 6 Mean (State)				**80**	**10**	**9**	**84**	**18**
Class 7 Mean (State)				**84**	**5**	**5**	**82**	**12**

Taxa richness per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics				
				DarterSculp	Hdw-Tol	Sensitive	SLithop	Wetland-Tol
501	10EM161	23-Jun-10	6	1	1	1	3	1
	12RN020(1)	14-Jun-12	6	1	0	0	3	2
	12RN020(2)	12-Jul-12	6	1	0	0	3	1
505	05RN188	19-Jun-06	7	0	0	0	1	1
	12RN015	18-Jun-13	6	0	0	0	0	1
515	12RN018	26-Jun-12	7	2	0	1	1	4
523	12RN016(1)	11-Jul-12	6	1	0	1	0	3
	12RN016(2)	27-Aug-14	6	0	0	1	2	1
Class 6 Mean (State)				**1**	**1**	**2**	**2**	**2**
Class 7 Mean (State)				**1**	**1**	**1**	**1**	**2**

Percentage of taxa per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics							
				BenInsect-TolTxPct	DetNWQTxPct	GeneralTxPct	Insect-TolTxPct	OmnivoreTxPct	PioneerTxPct	RiffleTxPct	TolTxPct
501	10EM161	23-Jun-10	6	13	13	50	13	13	25	12	63
	12RN020(1)	14-Jun-12	6	13	13	50	25	13	25	12	50
	12RN020(2)	12-Jul-12	6	14	14	57	14	14	29	14	57
505	05RN188	19-Jun-06	7	0	25	25	0	25	0	25	75
	12RN015	18-Jun-13	6	0	33	33	0	33	33	0.	67
515	12RN018	26-Jun-12	7	25	13	25	38	13	13	12	38
523	12RN016(1)	11-Jul-12	6	25	0	0	50	0	0	0	25
	12RN016(2)	27-Aug-14	6	0	40	40	20	40	20	20	60
Class 6 Mean (State)				**12**	**17**	**37**	**24**	**18**	**20**	**12**	**57**
Class 7 Mean (State)				**10**	**20**	**38**	**21**	**22**	**20**	**9**	**59**

.

Catch-Per-Unit-Effort (CPUE) F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metric
				NumPerMeter-Tolerant
501	10EM161	23-Jun-10	6	0.52
	12RN020(1)	14-Jun-12	6	0.27
	12RN020(2)	12-Jul-12	6	0.27
505	05RN188	19-Jun-06	7	0.02
	12RN015	18-Jun-13	6	0.01
515	12RN018	26-Jun-12	7	0.30
523	12RN016(1)	11-Jul-12	6	0.05
	12RN016(2)	27-Aug-14	6	0.08
Class 6 Mean (State)				**0.52**
Class 7 Mean (State)				**0.41**

Fish TIVs data

AUID Suffix	Station	Visit Date	Class	Mean TIV		Probability of Meeting Standard	
				TSS	DO	TSS	DO
501	10EM161	23-Jun-10	6	13	6.5	83	27
	12RN020(1)	14-Jun-12	6	13	7.0	81	41
	12RN020(2)	12-Jul-12	6	13	6.8	84	37
505	05RN188	19-Jun-06	7	16	5.8	85	6
	12RN015	18-Jun-13	6	17	6.3	66	13
515	12RN018	26-Jun-12	7	15	5.9	84	8
523	12RN016(2)	27-Aug-14	6	13	6.7	84	30
Class 6 Mean (State)				**14**	**6.6**	**75**	**30**
Class 7 Mean (State)				**16**	**6.3**	**70**	**22**

Appendix B: Individual M-IBI Metric and TIVs Data

Percentage of individuals per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics							
				BurrowerPct	Collector-filtererPct	DomFiveCHPct	HBI_MN	LeglessPct	LongLivedPct	SprawlerPct	TrichwoHydroPct
501	10EM161	31-Aug-10	4	5	7	55	7	31	23	32	10
	12RN020	31-Jul-12	3	2	5	59	8	44	8	25	5
504	05RN115(1)	16-Aug-05	3	8	47	52	7	59	2	7	3
	05RN115(2)	27-Aug-14	3	7	38	55	7	67	2	9	5
	10EM017(1)	01-Sep-10	4	3	6	71	8	89	2	9	3
	10EM017(2)	01-Aug-12	4	8	8	68	6	86	2	4	1
	12RN010(1)	01-Aug-12	3	9	20	52	6	48	9	13	7
	12RN010(2)	01-Aug-12	3	13	19	41	6	50	13	8	9
515	12RN018	31-Jul-12	4	4	2	59	8	35	4	40	2
523	12RN016(1)	31-Jul-12	3	29	1	53	8	62	7	4	1
	12RN016(2)	26-Aug-14	3	8	26	56	7	62	3	20	1
560	12RN012	01-Aug-12	4	14	1	60	8	32	4	39	0
Class 3 Mean (State)				**10**	**27**	**51**	**6**	**40**	**9**	**15**	**10**
Class 4 Mean (State)				**15**	**18**	**61**	**7**	**51**	**5**	**23**	**4**

Taxa richness per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics									
				ClimberCh	ClingerCh	Intolerant2Ch	Odonata	Plecoptera	POET	Predator	PredatorCh	TaxaCountAllChir	Trichoptera
501	10EM161	31-Aug-10	4	15	16	2	5	0	18	8	11	49	6
	12RN020	31-Jul-12	3	12	16	0	4	0	11	8	11	44	4
504	05RN115(1)	16-Aug-05	3	8	16	0	4	0	16	10	15	50	8
	05RN115(2)	27-Aug-14	3	8	15	1	2	0	14	9	11	40	7
	10EM017(1)	01-Sep-10	4	9	14	0	2	1	12	5	8	42	5
	10EM017(2)	01-Aug-12	4	10	10	1	1	0	6	4	8	37	4
	12RN010(1)	01-Aug-12	3	6	17	3	1	1	12	9	12	48	5
	12RN010(2)	01-Aug-12	3	8	15	1	2	1	14	5	8	41	6
515	12RN018	31-Jul-12	4	11	8	0	2	0	6	10	14	38	2
523	12RN016(1)	31-Jul-12	3	10	9	0	3	0	6	14	18	46	1
	12RN016(2)	26-Aug-14	3	13	10	0	3	0	11	9	15	46	5
560	12RN012	01-Aug-12	4	10	7	0	2	0	5	13	14	37	1
Class 3 Mean (State)				**9**	**19**	**4**	**3**	**2**	**19**	**11**	**14**	**51**	**9**
Class 4 Mean (State)				**9**	**11**	**1**	**3**	**0**	**11**	**9**	**13**	**43**	**4**

Percentage of taxa per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics			
				ClingerChTxPct	InsectTxPct	Tolerant2ChTxPct	TrichopteraChTxPct
501	10EM161	31-Aug-10	4	33	82	55	12
	12RN020	31-Jul-12	3	36	77	77	9
504	05RN115(1)	16-Aug-05	3	32	88	70	16
	05RN115(2)	27-Aug-14	3	38	88	60	18
	10EM017(1)	01-Sep-10	4	33	86	67	12
	10EM017(2)	01-Aug-12	4	27	73	73	11
	12RN010(1)	01-Aug-12	3	35	88	67	10
	12RN010(2)	01-Aug-12	3	37	85	63	15
515	12RN018	31-Jul-12	4	21	74	92	5
523	12RN016(1)	31-Jul-12	3	20	83	83	2
	12RN016(2)	26-Aug-14	3	22	85	76	11
560	12RN012	01-Aug-12	4	19	76	81	3
Class 3 Mean (State)				**38**	**87**	**58**	**17**
Class 4 Mean (State)				**25**	**81**	**68**	**10**

Macroinvertebrate TIVs data

AUID Suffix	Station	Visit Date	Class	Mean TSS TIV	TSS Tolerant Taxa (%)	TSS Intolerant Taxa (#)	Mean DO TIV	DO Tolerant Taxa (%)	DO Intolerant Taxa (#)
501	10EM161	31-Aug-10	4	4	4	5	6.6	12	4
	12RN020	31-Jul-12	3	10	16	5	6.4	41	2
504	05RN115(1)	16-Aug-05	3	4	30	4	7.2	1	7
	05RN115(2)	27-Aug-14	3	4	32	3	7.1	4	4
	10EM017(1)	01-Sep-10	4	4	7	3	6.8	12	4
	10EM017(2)	01-Aug-12	4	4	7	4	6.6	20	0
	12RN010(1)	01-Aug-12	3	4	19	7	6.9	4	6
	12RN010(2)	01-Aug-12	3	4	20	5	6.9	3	5
515	12RN018	31-Jul-12	4	10	27	1	6.0	68	0
523	12RN016(1)	31-Jul-12	3	5	33	2	6.0	63	0
	12RN016(2)	26-Aug-14	3	5	12	2	6.8	10	2
560	12RN012	01-Aug-12	4	19	27	2	6.0	66	0
Class 3 Mean (State)				**7**	**19**	**8**	**7.0**	**11**	**10**
Class 4 Mean (State)				**10**	**14**	**4**	**6.5**	**29**	**3**

DEPARTMENT OF NATURAL RESOURCES

Lake of the Woods Watershed Geomorphology Report

Ecological and Water Resources Division
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DEPARTMENT OF NATURAL RESOURCES

CLEAN WATER LAND & LEGACY AMENDMENT

Contents

List of Acronyms

BEHI	Bank Erosion Hazard Index
CD	County Ditch
CFS	Cubic Feet per Second
CR	County Road
CSG	Cooperative Stream Gaging
CWL	Clean Water Legacy
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
JD	Judicial Ditch
LOWW	Lake of the Woods Watershed
LiDAR	Light Detection and Ranging
MN DNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
NLCD	National Land Cover Dataset
NWI	National Wetland Inventory
NWR	National Wildlife Refuge
NRCS	Natural Resources Conservation Service
SNA	Scientific and Natural Area
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WMA	Wildlife Management Area

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Introduction

Healthy watersheds are biologically diverse and connected ecosystems. Healthy watersheds also produce other ecosystem services and products that contribute to the state's economic and social vitality (e.g., habitat, fish, wildlife, timber, and recreation). The Department of Natural Resources (DNR) uses a five component framework to describe watersheds as systems: biology, hydrology, fluvial geomorphology, connectivity, and water quality.

Understanding the interplay between these components will make it easier to identify the root cause of an issue that is impairing one aspect of a healthy watershed. For example, if land use changes increase the flashiness of river flows this may lead to an unstable stream condition. To adjust to these changes, the river may down cut and the banks erode as it attempts to find a new equilibrium with the changes to hydrology. As a result of this instability, variables like instream and overhead cover, substrate composition, pool quality, holding cover velocity, temperature, oxygen, spawning habitat, habitat diversity, and Index of Biological Integrity (IBI) scores would all be expected to degrade. In contrast, an evolution or restoration from the unstable form to a stable river form would result in a reversal of these negative consequences.

This report is primarily focused on fluvial geomorphology, but it also provides some general watershed characteristics and information on hydrology. Connectivity is included to a lesser degree; specifically, culverts were assessed immediately upstream or downstream of studied sites.

Altered Hydrology

Altered hydrology is noted as a stressor in many of the watersheds in Minnesota. An assessment of the climate and hydrologic data in a watershed helps provide an understanding of the current hydrologic conditions and how they have changed over time. The composition, structure, and function of aquatic, wetland, and riparian ecosystems within a watershed are largely a reflection of the watershed's hydrologic regime (Richter et al. 1996; National Research Council 1992). Developing a better understanding of the hydrologic conditions and trends in a watershed will help identify issues and opportunities and establish goals and objectives for various watershed planning efforts.

Previous investigations in Minnesota have established that temperature, precipitation, and streamflow have changed substantially during the last century. Recent climate trends in Minnesota include warmer winters, higher minimum temperatures, greater frequency of tropical dew points, greater annual precipitation, more days with rain, and more frequent heavy rains (Seeley 2003; Seeley 2012). Increasing annual precipitation, most notably in May and June, has also been documented in Minnesota (Yuan and Mitchell 2014).

Changes in streamflow have been associated with these observed changes in precipitation. Mean annual flow, maximum daily streamflow from rainfall, seven-day low flow during open water, seven-day low flow during winter, frequency of high flow days, and frequency of low flow days have all changed significantly throughout Minnesota (Novotny and Stefan 2007). In addition, the ratio of runoff to precipitation (runoff coefficient) has significantly increased in the Red River and

Minnesota River basins and slightly increased in the Lake Superior, Rainy River, and St. Croix river basins (Vandegrift and Stefan 2010). While precipitation changes are known to have a strong influence on changes in stream flow (Sankarasubramanian et al. 2001), land use changes including intensive drainage have also played a key role in increasing runoff, particularly in the agricultural regions of the state (Lenhart et al. 2011; Schottler et al. 2013).

Previous Studies

Sediment deposition in Bostic and Zippel Bays on Lake of the Woods has been a recent issue in the watershed. Several studies and associated reports were conducted. This sediment deposition interferes with navigation for many resorts and businesses on the lake, potentially impacting local tourism and industry in the region. Looking for a solution for this sediment problem, several studies were conducted in the Bostic and Zippel Creek portions of the Lake of the Woods Watershed. A report by Reavie and Baratono (2007) verified highly accelerated sediment accumulations in Zippel Bay due to human activities.

A Natural Resources Conservation Service report (NRCS 2013) documented terrain and soil analysis throughout the landscape and estimated in-channel erosion of representative reaches. The report also summarizes previous cross-section studies conducted in 2009 on ditches throughout these sub-watersheds. Cross-sections were compared to original "as-built" surveys from original ditch construction. The study found in-channel erosion contributed the majority of sediment to Bostic and South Branch Zippel Creek, while erosion associated with cropland contributed the majority of sediment to West Branch Zippel Creek.

In 2012, a report by DNR Fisheries investigated geomorphology within the Warroad River subwatershed. Several sites within the Warroad River were assessed for channel stability using Bank Erosion Hazard Index (BEHI) methodology. Three of six sites had high erosion potentials. The results are shown below in Table 1 (Andvik 2012).

Table 1. BEHI scores and associated bank erosion potential for sampling stations on the Warroad River (From DNR Fisheries 2012).

Station number	Station name	River branch	BEHI score	Bank erosion potential
1	Warroad River 1	West	36.5	High
2	Warroad River 2	Main/East	36	High
2[1]	Warroad River 2	Main/East	30.5	High
3	Warroad River 3	Main/East	19.5	Low
4[2]	Warroad River 4	West	29	Moderate
4	Warroad River 4	West	20	Moderate

[1] Within Station 2 (Warroad River 2) there were two banks that looked dramatically different; consequently, a second BEHI was conducted.

[2] Within Station 4 (Warroad River 4) there were two banks that looked dramatically different; consequently, a second BEHI was conducted.

Fluvial Geomorphology

In the context of "healthy watersheds", fluvial geomorphology is considered good when watercourses are stable. Watercourse stability means that a channel does not aggrade or degrade because it is able to transport the water and sediment from its watershed and maintain its dimension, pattern, and profile. Stability depends on maintaining a natural equilibrium between sediment supply (both size of particles and quantity), channel slope, channel length, and stream flow (Lane 1955, Leopold 1994). An alteration of the conditions of equilibrium through tectonic changes or by changes in the hydrological regimen, including changes in sediment and water yield, will result in altering the floodplain and lead to degradation and terrace formation, or to aggradation. This is referred to as channel evolution (Figure 1; Simon and Rinaldi 2006).

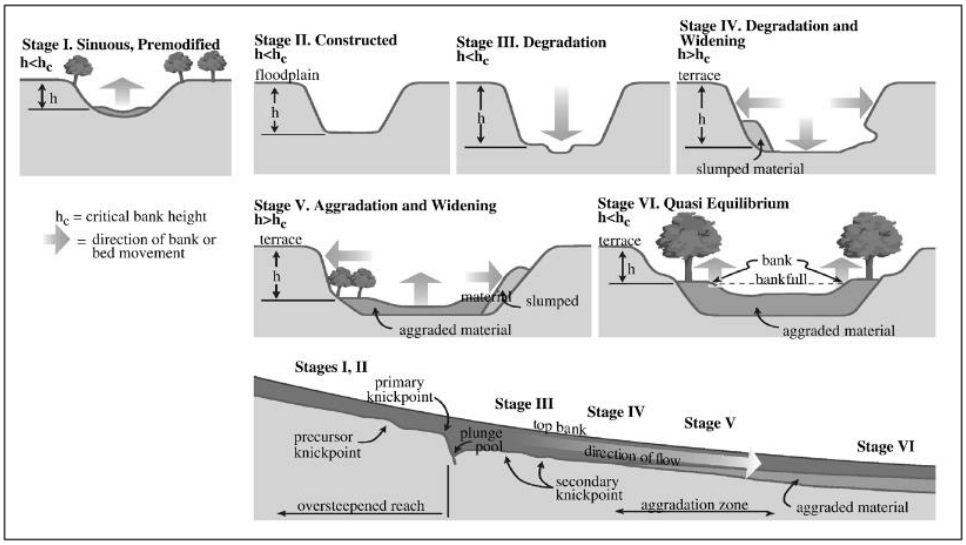

Figure 1. Stages of channel evolution (Source: Simon and Rinaldi 2006; Simon and Hupp 1986).

For this study, fluvial geomorphology was assessed using the modified Pfankuch Stability Index at specific Minnesota Pollution Control Agency (MPCA) biological monitoring sites to assist with the MPCA's Stressor Identification process. To complete this assessment, a channel stability rating was created by evaluating the upper bank, lower bank, and channel bed using Pfankuch Stability Index, modified by stream type (Rosgen 1996). Nine (9) sites were visited by MN DNR staff in October of 2015 (Figure 2). Pfankuch Stability Index was developed by Dale Pfankuch (US Forest Service) with methods created in 1975 (Pfankuch 1975).

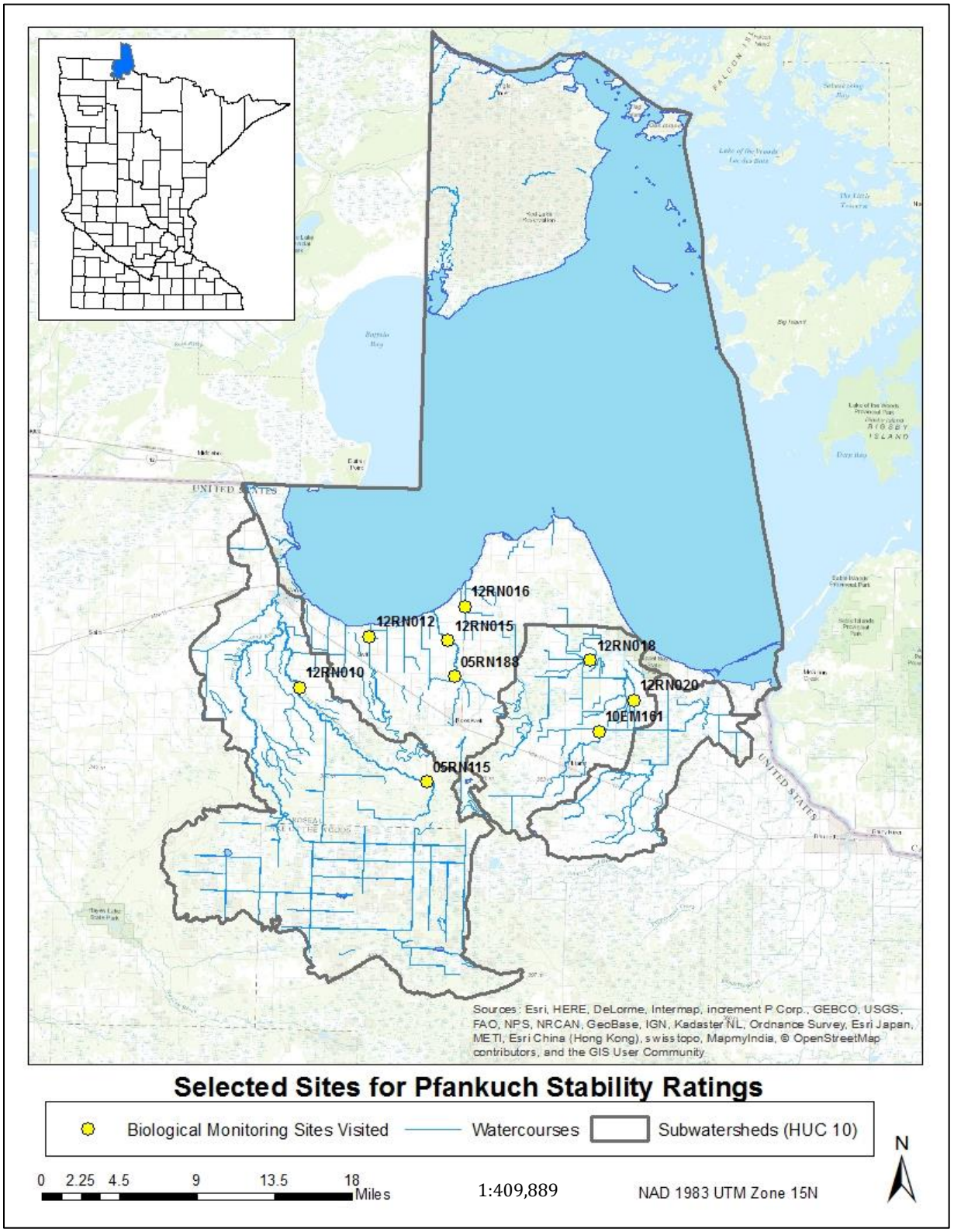

Figure 2. MPCA biological monitoring sites where Pfankuch stability ratings were completed.

Dale Pfankuch developed this "semi-quantitative" assessment to systemize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recover from potential changes in flow or increases to sediment production (Pfankuch 1975). Years later, Dave Rosgen modified the final rating scale to be tiered by Rosgen stream type (Rosgen 1996). The rating is created by answering 15 questions, related to the upper banks, lower banks, and channel bottom (Table 2). Final scores range from 38 (most stable) to 152 (least stable). The individual ratings of each question provide information about the capacity of streams to adjust and recover from potential changes in flow and/or increases in sediment production. The final summed score, with the Rosgen stream type, creates a rating of stable, moderately unstable, or unstable. If the assessed watercourse has become unstable and started a process of channel evolution, it is important to acknowledge that the existing form is not in equilibrium and report the modified Pfankuch score as the highest potential stream type, not the existing type.

A few of the individual Pfankuch metrics consistently ranked as *poor* or *fair* within the Lake of the Woods Watershed, specifically "bank rock content" on the lower banks and "rock angularity" on the channel bottom. In this watershed, stream types observed at the nine selected sites were dominated by sand or silt/clay (two were gravel). The Pfankuch scoring categorized by stream type adjusts the final adjective rating to account for these types of expected differences. To resolve the discrepancies inherent in different stream classes and sediment sizes, some studies modified the original form or only used a subset of the metrics. Death (1995) used only the channel bottom metrics and found the summed score to be strongly correlated with benthic invertebrates. Asmus (2011) found the specific metrics associated with the degree of substrate mobility and aggradation explained a significant portion of the variation in fish Index of Biotic Integrity (IBI) in two watersheds in Minnesota.

Table 2. Modified Pfankuch stability worksheet (Rosgen 2009).

Stream:			Location:		Landscape Type:		Observers:		Date:	
Loca-tion	Key	Category	Excellent		Good		Fair		Poor	
			Description	Rating	Description	Rating	Description	Rating	Description	Rating
Upper banks	1	Landform slope	Bank slope gradient <30%.	2	Bank slope gradient 30–40%.	4	Bank slope gradient 40–60%.	6	Bank slope gradient > 60%.	8
	2	Mass erosion	No evidence of past or future mass erosion.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly yearlong.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense, soil-binding root mass.	3	70–90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50–70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species and less vigor indicating poor, discontinuous, and shallow root mass.	12
Lower banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. Width/depth ratio departure from reference width/depth ratio = 10. Bank-Height Ratio (BHR) = 10.	1	Bankfull stage is contained within banks. Width/depth ratio departure from reference width/depth ratio = 10–12. Bank-Height Ratio (BHR) = 10–11.	2	Bankfull stage is not contained. Width/depth ratio departure from reference width/depth ratio = 12–14. Bank-Height Ratio (BHR) = 11–13.	3	Bankfull stage is not contained; over-bank flows are common with flows less than bankfull. Width/depth ratio departure from reference width/depth ratio > 14. Bank-Height Ratio (BHR) > 13.	4
	6	Bank rock content	> 65% with large angular boulders. 12"+ common.	2	40–65%. Mostly boulders and small cobbles 6–12".	4	20–40%. Most in the 3–6" diameter class.	6	<20% rock fragments of gravel sizes, 1–3" or less.	8
	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12–24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges. Surfaces smooth and flat.	2	Corners and edges well-rounded in two dimensions.	3	Well-rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark, or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, i.e., 35–65% mixture range.	3	Predominantly bright, > 65%, exposed or scoured surfaces.	4
	12	Consolidation of particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom size distribution	No size change evident. Stable material 80–100%.	4	Distribution shift light. Stable material 50–80%.	8	Moderate change in sizes. Stable materials 20–50%.	12	Marked distribution change. Stable materials 0–20%.	16
	14	Scouring and deposition	<5% of bottom affected by scour or deposition.	6	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30–50% affected. Deposits and scour at obstructions, constrictions, and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent Total =		Good Total =		Fair Total =		Poor Total =	

Stream type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable)	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+
Stream type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**		
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107		
Fair (Mod. unstable)	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120		
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+		

Grand Total =	
Existing Stream Type =	
*Potential Stream Type =	
Modified channel stability rating =	

*Rating is adjusted to *potential* stream type, not existing stream type

General Watershed Characteristics

Lake of the Woods watershed lies on the United States-Canadian border and is situated in the Laurentian Mixed Forest Ecological Province of Northern Minnesota. Water within this watershed enters primarily from the Rainy River, collects in Lake of the Woods, and empties into the Winnipeg River in Kenora, Ontario, Canada. All water in this watershed eventually makes its way to the Hudson Bay. Approximately 79% of the watershed is located within Canada, though the majority of development and agriculture occurs within the United States. The total watershed is 5,305 square miles in size, including portions of the watershed within Canada. Within the United States, there are 1,133 square miles of watershed located in Roseau and Lake of the Woods counties.

For the purpose of this report the study area will consist only of the United States portions of the watershed. Sub-watersheds (HUC 10) that occur within the United States include Bostic Creek, Lake of the Woods, Warroad River, and Zippel Creek. Erosion within the Bostic and Zippel Creek sub-watersheds and associated sedimentation of bays in Lake of the Woods has been identified as a significant resource concern by local government, natural resources agencies, land owners, and other business interests (NRCS 2013).

Surface waters

Lake of the Woods is the dominant water feature within this watershed, covering 1,679 square miles in Minnesota and Canada, with the majority of the lake in Canada. The lake comprises approximately 47% (538 square miles) of the Lake of the Woods Watershed within the United States. A large reservoir, Lake of the Woods has been controlled since 1916 at approximately 2.5 to 3 feet higher than natural levels (From Lake of the Woods County Water Plan 2010). Dams in International Falls, U.S.A. and Kenora, Canada control the inflow and outflow of water in accordance with international agreements. Three main river systems reside within the United States portions of the watershed: Bostic Creek, Zippel Creek, and Warroad River. These river systems flow north and make their way into the Lake of the Woods basin.

Table 3 breaks the Lake of the Woods Watershed (LOWW) into HUC 10 subwatersheds and shows the corresponding watercourse types. A review using GIS analysis of the watershed found ditched systems (perennial or intermittent) comprising almost half of the miles of watercourse (49.5%). Natural stream or ditched, the majority of the watercourses are classified intermittent (51%). Though management of water levels on Lake of the Woods has a significant impact on streams closest to the lake, impounded streams are not identified through inventory and were thus not tallied.

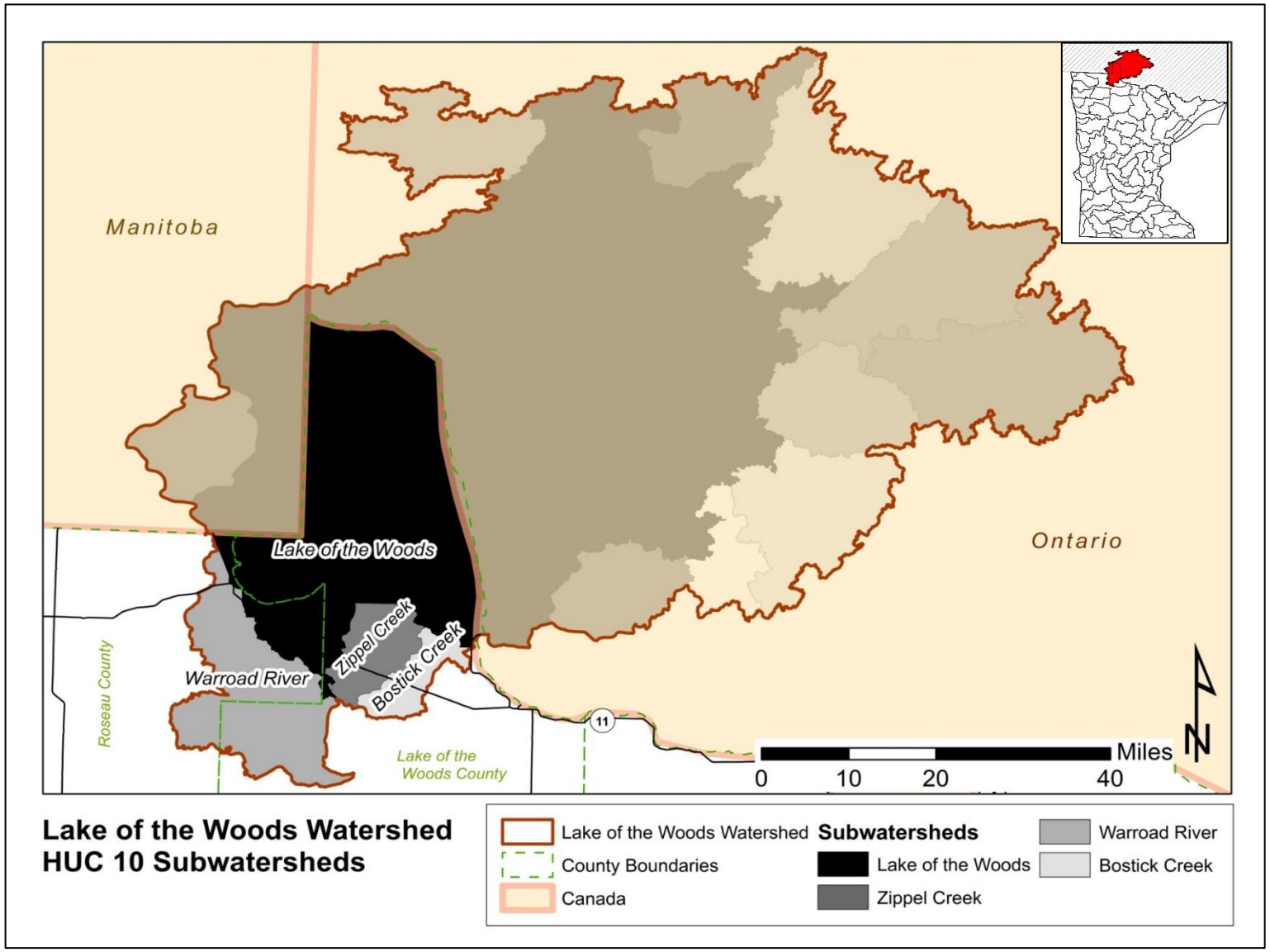

Figure 3. Lake of the Woods watershed, including the portion that is located in Canada.

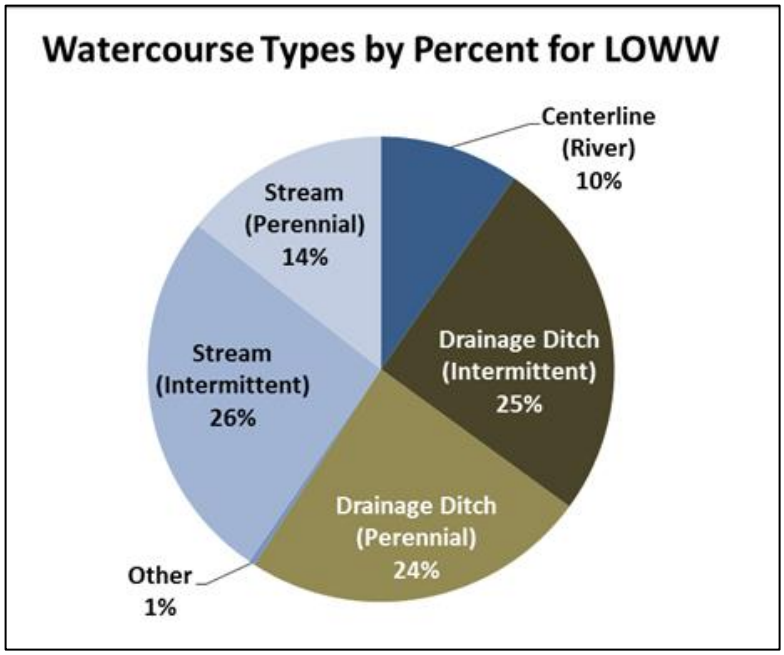

Figure 4. Percentages of watercourse types for the United States portion of Lake of the Woods HUC 8 watershed.

Approximately 50% (332 miles) of watercourses are classified as natural streams or rivers. Fourteen percent (14%) of those are perennial stream channels (94.8 miles), twenty six percent (26%) are intermittent streams (172.3 miles), and ten percent (10%) are rivers (64 miles) (Figure 4).

The Warroad River subwatershed has the most miles of watercourse (298 miles), while Bostic Creek has the lowest number of miles (74.5 miles) (Table 3). Bostic Creek subwatershed has the highest percentage of natural watercourses (65%) and Zippel Creek subwatershed has the highest percentage of ditched watercourses (58%). Zippel Creek also had the highest percentage of intermittent watercourses (66%), most of which are ditched. Warroad River was the only subwatershed with a watercourse classified as a river (Figure 5). These rivers are the East and West Branches of the Warroad River. The relatively few large rivers within the watershed are a testament to the peatland hydrology of the overall watershed. Water moves through landscape in a more dispersed pattern, with much of the water movement beneath the surface (Figure 6).

Table 3. Miles of watercourse type broken down by subwatershed within the United States portion of Lake of the Woods watershed.

	Subwatersheds (HUC10)									
	Full Watershed		Bostic Creek		Lake of the Woods		Warroad River		Zippel Creek	
Surface water type	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent
Centerline (River)	63.83	9.67	0.00	0.00	0.00	0.00	63.83	21.41	0	0
Connector (Wetland)	1.22	0.18	0.00	0.00	0.00	0.00	1.22	0.41	0.00	0.00
Drainage Ditch (Intermittent)	167.53	25.38	17.01	22.85	69.95	37.26	43.49	14.59	41.66	37.57
Drainage Ditch (Perennial)	159.16	24.11	8.97	12.05	14.40	7.67	115.10	38.61	22.67	20.44
Drainage Ditch (Undifferentiated)	1.14	0.17	0.00	0.00	0.00	0.00	0.41	0.14	0.73	0.66
Stream (Intermittent)	172.31	26.10	29.74	39.95	48.51	25.84	62.65	21.02	31.41	28.32
Stream (Perennial)	94.82	14.36	18.73	25.16	54.8599	29.22	11.40	3.83	14.27	12.87
Stream (Unknown)	0.15	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.13
TOTAL	660.16	100.00	74.45	100.00	187.72	100.00	298.10	100.00	110.90	100.00

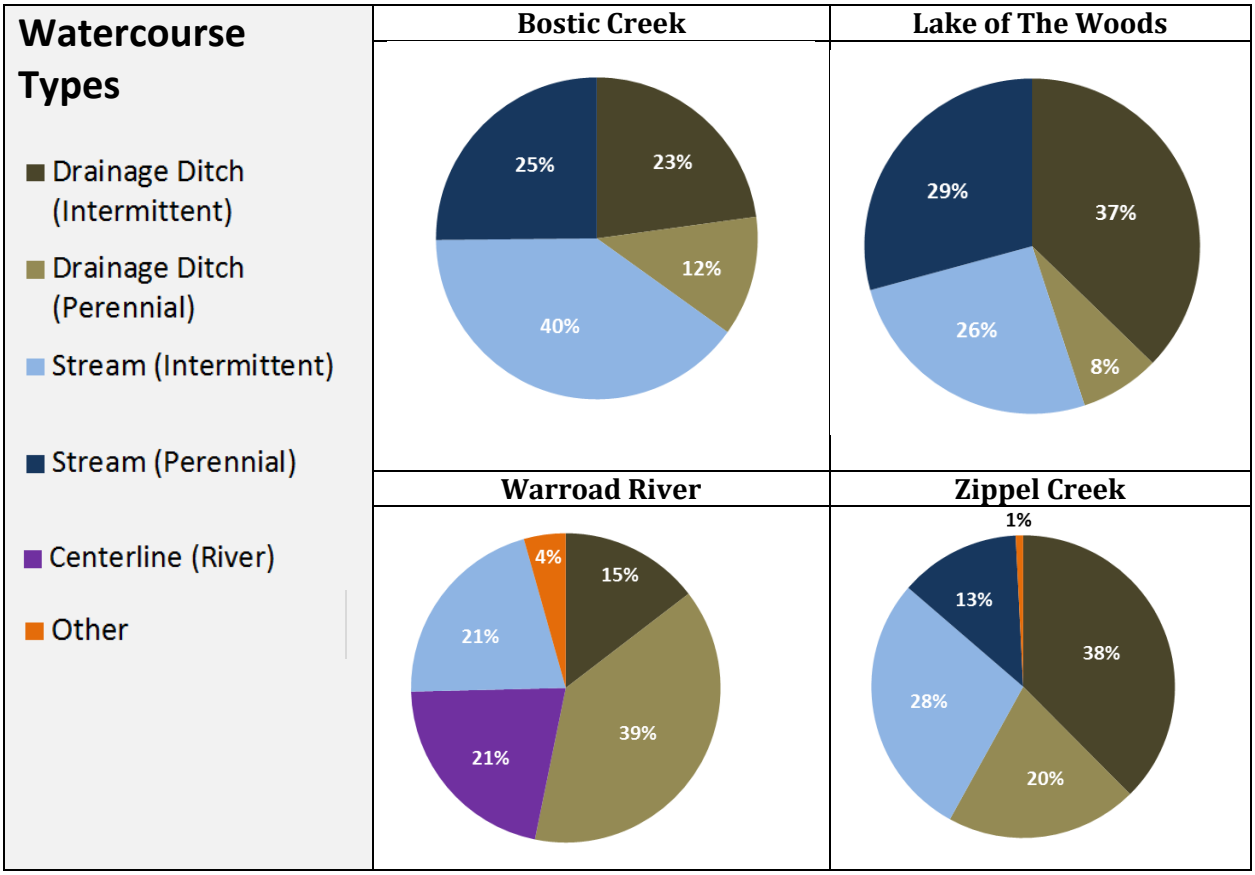

Figure 5. Percentage of each watercourse type in each of the HUC 10 subwatersheds within the United States.

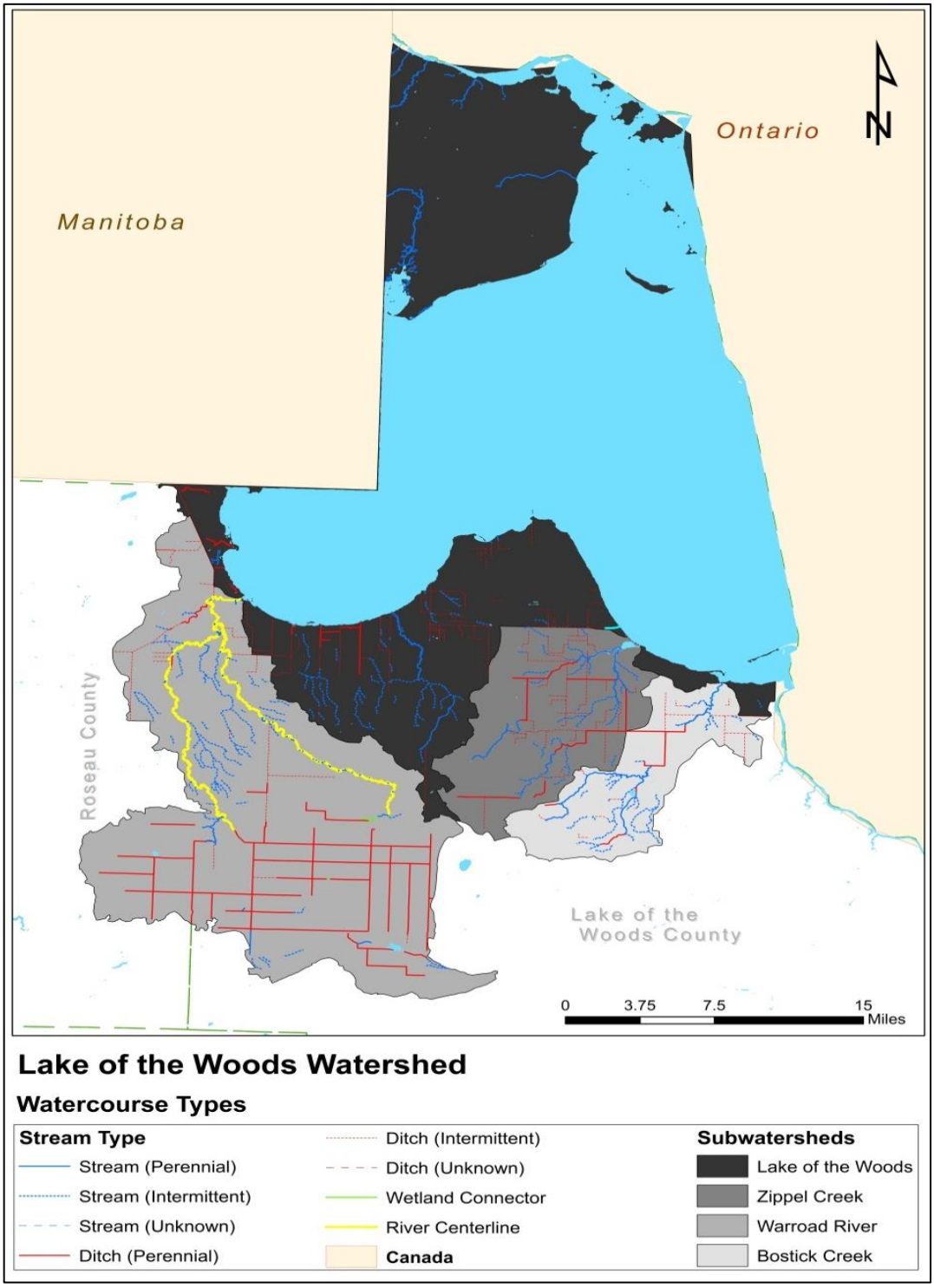

Figure 6. Watercourses within the Lake of the Woods watershed

Figure 7 shows the National Wetland Inventory (NWI) for the LOWW. The NWI breaks out the type of wetlands into 8 classifications (i.e. wet meadow, bog, deep marsh, etc.). The majority of the larger bodies of water/wetlands found within the watershed fall into the category of open water, bog, or shrub swamp. There are many wetlands in the northern and southern portions of the watershed within the United States boundary that are protected by DNR Forestry (State Forests), Scientific and Natural Areas (SNAs) or the Red Lake Nation tribal lands. These peatlands are most prominent in the Warroad River and northern half (in the Northwest Angle) of the Lake of the Woods subwatersheds.

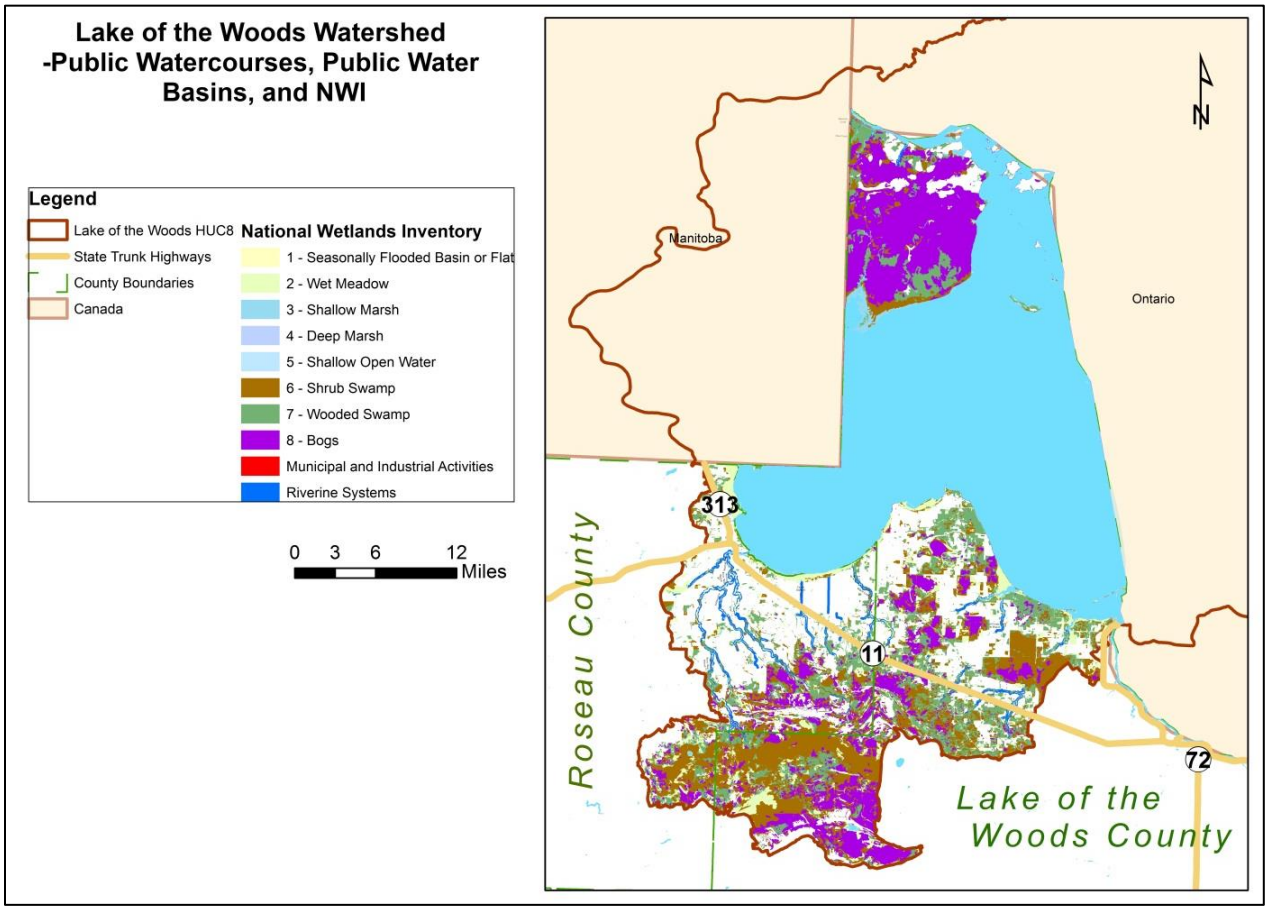

Figure 7. National Wetland Inventory (NWI) for Lake of the Woods watershed

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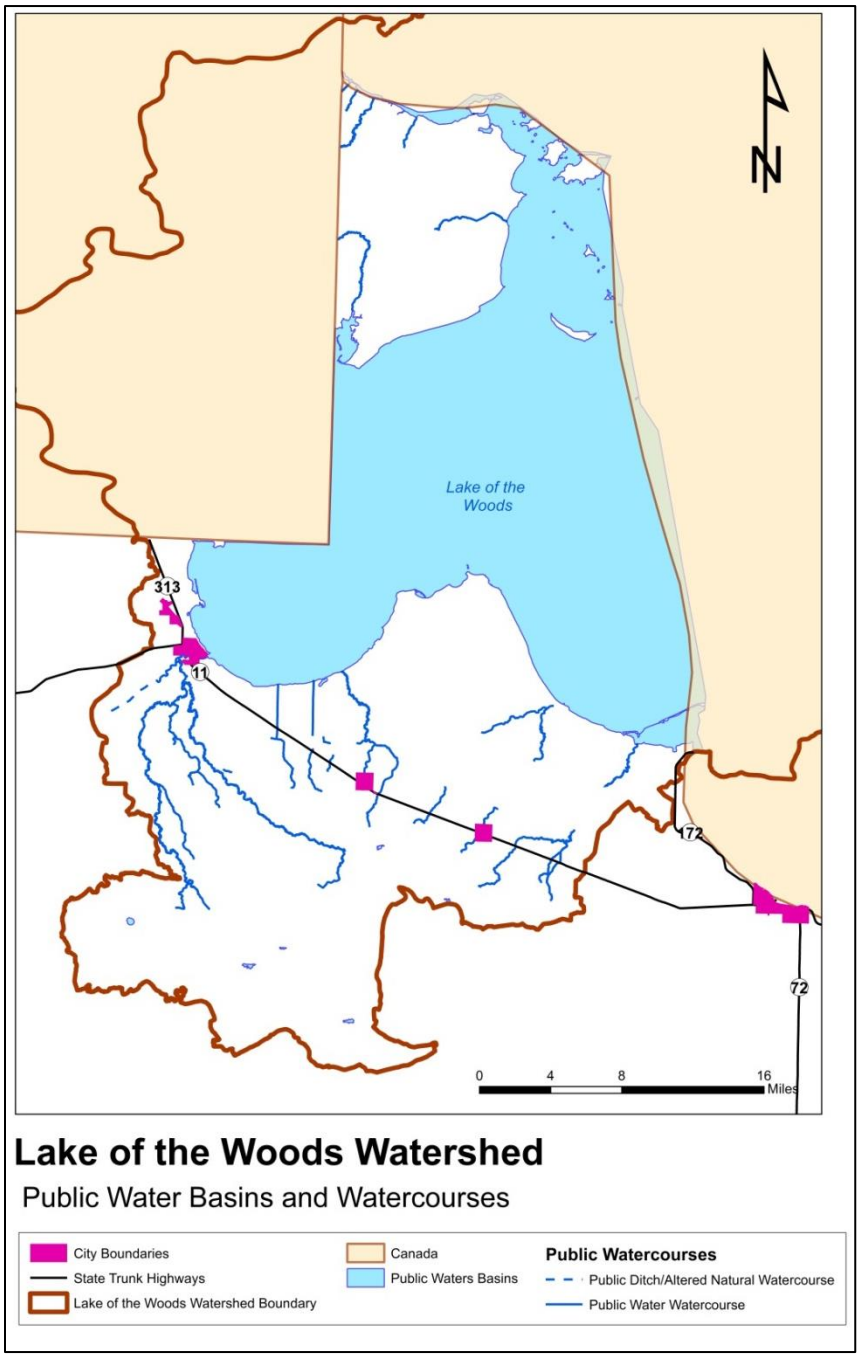

Figure 8. Public water basins within LOW Watershed, U.S. portion.

Lake of the Woods is primarily the only public water basin in the LOW watershed within the United States portion. Relatively few public water courses occur throughout the watershed. The primary watercourses are the Warroad River, Willow Creek, Zippel Creek (Figure 8). All watercourses drain into the Lake of the Woods basin.

Land Use

Management of land within a watershed has the ability to change sediment supply as well as the quantity and timing of water inflows to a river channel. River channel stability is dependent on this equilibrium between sediment supply and quantity/timing of water. The quantity and size of sediment being delivered to a river channel is a product of the geologic history, present day soil types, and land use changes over time. Responses that can be measured within the river channel include changes to the width-to-depth ratio, channel bottom elevation, channel slope, and size of particles found within the channel. When river channels become unstable, they will go through a series of adjustments until they reach a new equilibrium. These changes not only impact channel stability, they can also have a direct impact on habitat and water quality.

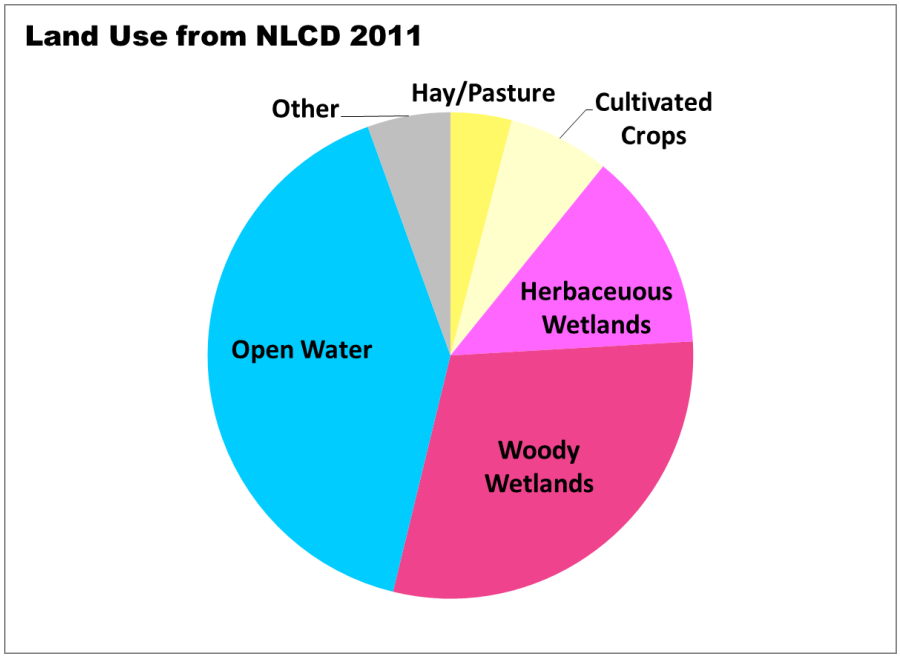

Figure 9. Lake of the Woods watershed landuse (NLCD 2011)

In LOWW, geology plays a major role in the distribution of land use. The largest land use within the watershed, by far, is open water and wetlands (84%, Figure 9). A large portion of the watershed consists of peatlands (identified as "woody wetlands" and "herbaceous wetlands"). These vast areas are largely naturally vegetated and undisturbed for vast expanses with the exception of ditches, roads, and a few scattered farms. Higher ridges of glacial till allow for more development and agricultural production. Agriculture, both hay and pasture, comprise only 11% of the watershed

The 2012 Lake of the Woods Watershed Conditions Report (Houston Eng. 2012) notes there appears to be a decrease in cultivated lands and an increase in pasture throughout the watershed from the last inventory in 1992 (Table 4). However, the 2013 NRCS report of Bostic and Zippel Creek subwatersheds reported an increase from livestock based agriculture to cash crop operations such as soy and corn over time since 1940 (Figure 10). This trend is occurring throughout the watershed but particularly in Bostic and Zippel Creek subwatersheds. It is also possibly occurring in the Warroad River subwatershed where a significant amount of tillable uplands are found. Row cropping cash crops such as corn and soy is also associated with an increase of subsurface tile drainage systems. Though no formal inventory of drain tile installation exists, anecdotally resource professionals have noted the increase of drain tile installation throughout the watershed.

Table 4. Change in land use from 1992 - 2006 (2012 Watershed Conditions Report).

General Land Category	% of Project Area by NLCD Layer	
	1992	2006
Water/Wetlands	60.5%	67.2%
Forest	11.3%	5.3%
Cultivated	19.7%	13.8%
Pasture/open	7.8%	11.0%
Urban	0.6%	2.7%

Less than two percent of the land is classified as developed within the U.S. portion of the watershed (Figure 11). Those developed lands are primarily due to the cities of Warroad and Roosevelt.

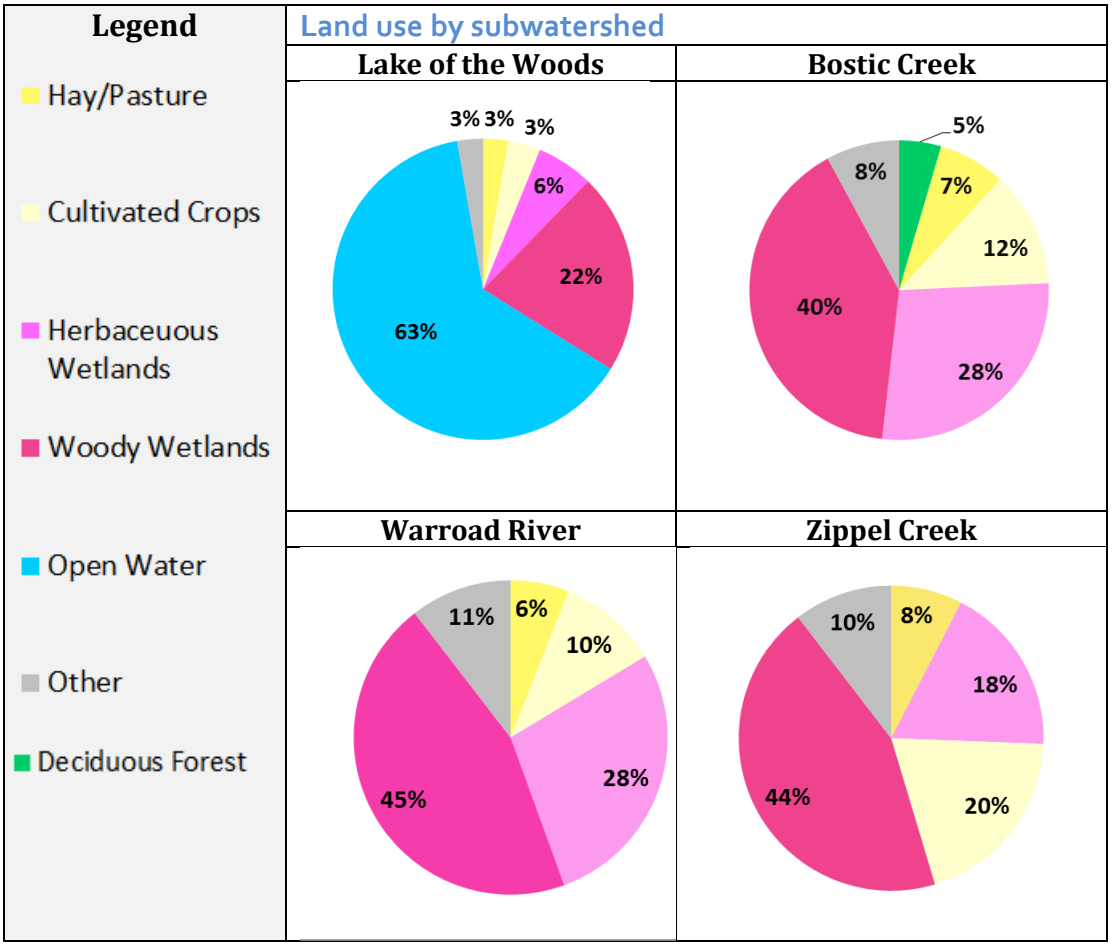

Figure 10. Lake of the Woods HUC 10 subwatershed landuse (NLCD 2011)

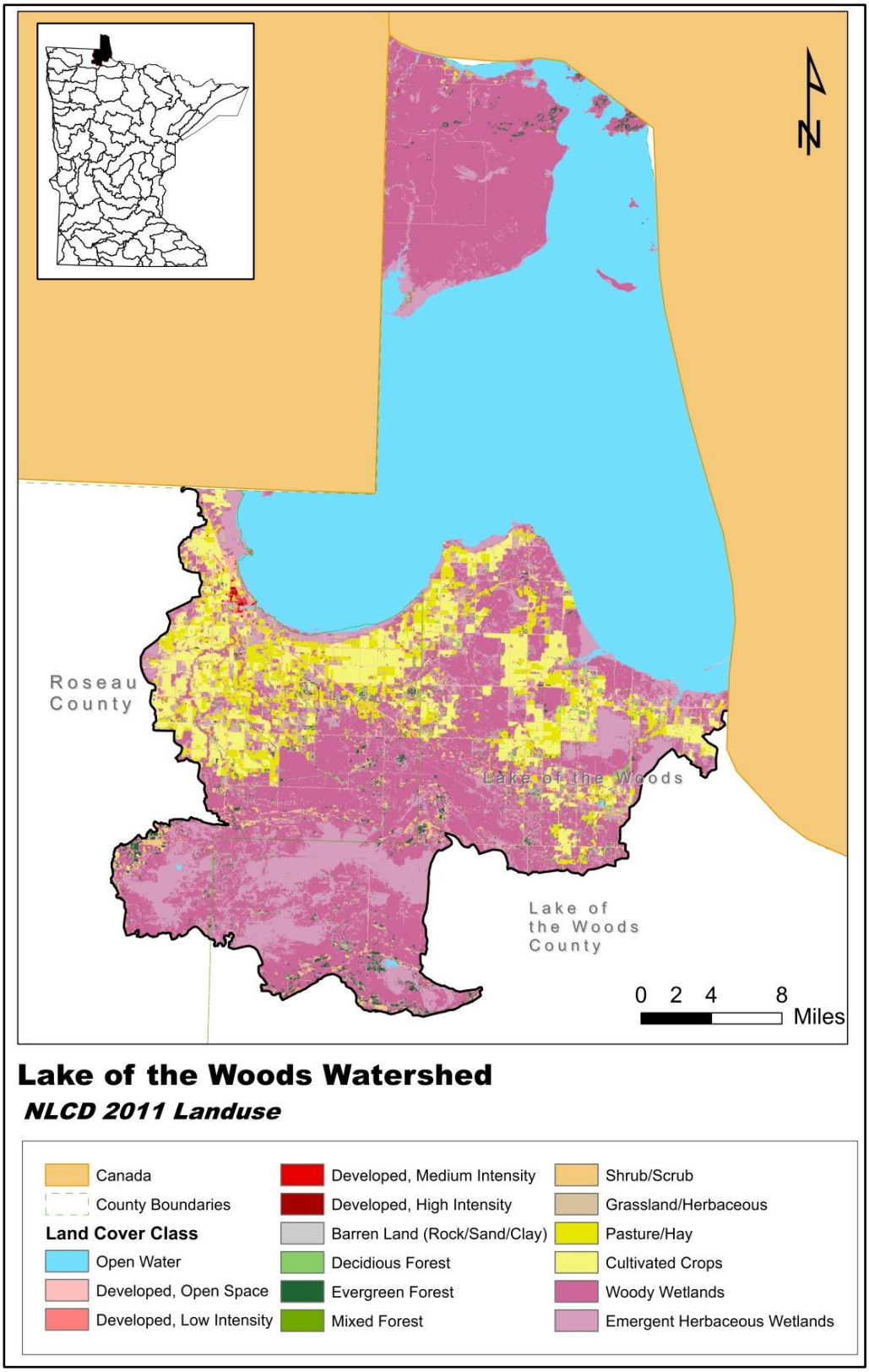

Figure 11. Lake of the Woods watershed landuse (NLCD 2011).

Subwatersheds

Within the Lake of the Woods Watershed, four subwatersheds were delineated at the HUC 10 catchment level by MN DNR. The four subwatersheds are Lake of the Woods, Bostic Creek, Warroad River and Zippel Creek subwatershed.

Lake of the Woods subwatershed is the largest of the four subwatersheds. It is dominated by the Lake of the Woods Basin on the U.S. portion of the watershed, with the basin comprising 63% of the total subwatershed. The northern most portion of the watershed is accessible in summer only by boat or through Canada and has little development or agriculture. This portion of the watershed is also almost entirely wetland. The southernmost portion of the watershed contains the majority of the LOWW developed and agricultural lands (Figure 12). The cities of Warroad and Roosevelt are found in this watershed, giving it the highest number of acres of developed land than any other subwatershed. This subwatershed also has the highest number of acres in agricultural production.

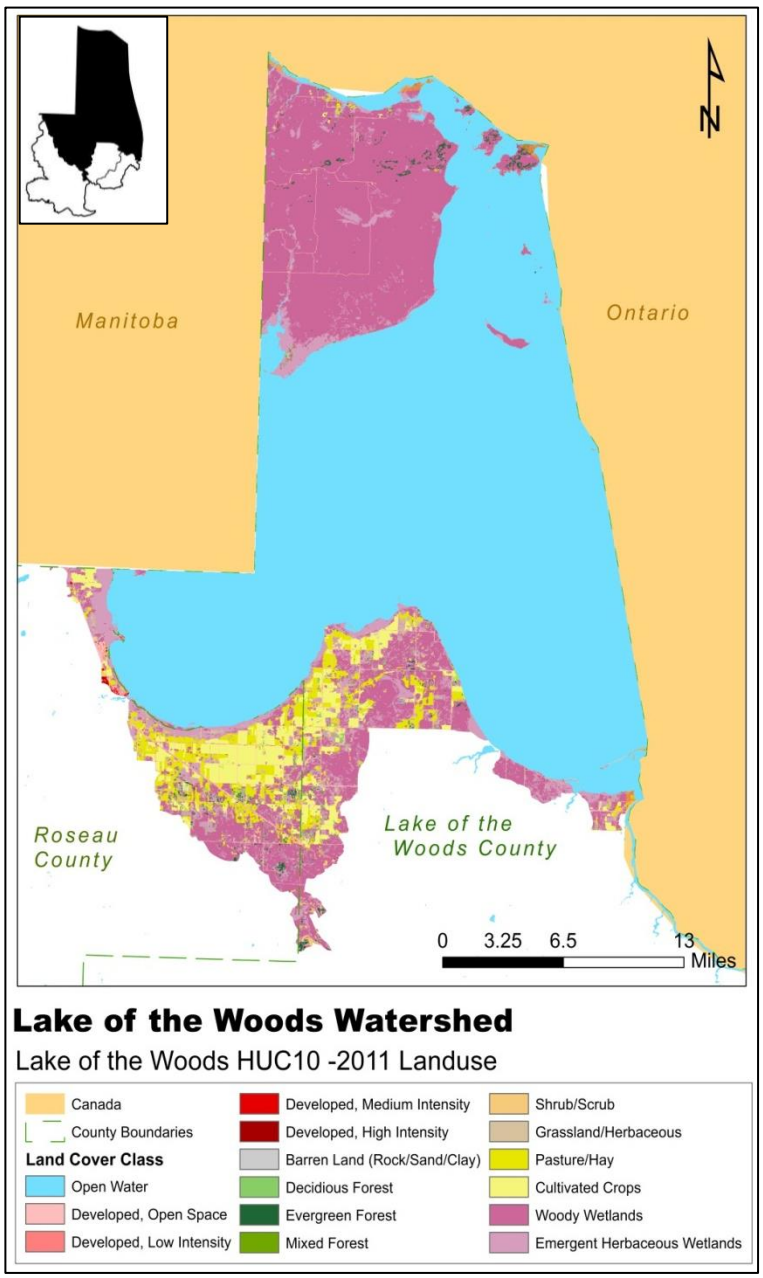

Figure 12. Lake of the Woods subwatershed landuse (NLCD 2011).

Bostic Creek Subwatershed

Over two thirds (68%) of this watershed consists of woody and emergent wetlands (Figure 13). The next highest landuse is agricultural production, much of which is concentrated along an upland ridge paralleling the shores of Lake of the Woods.

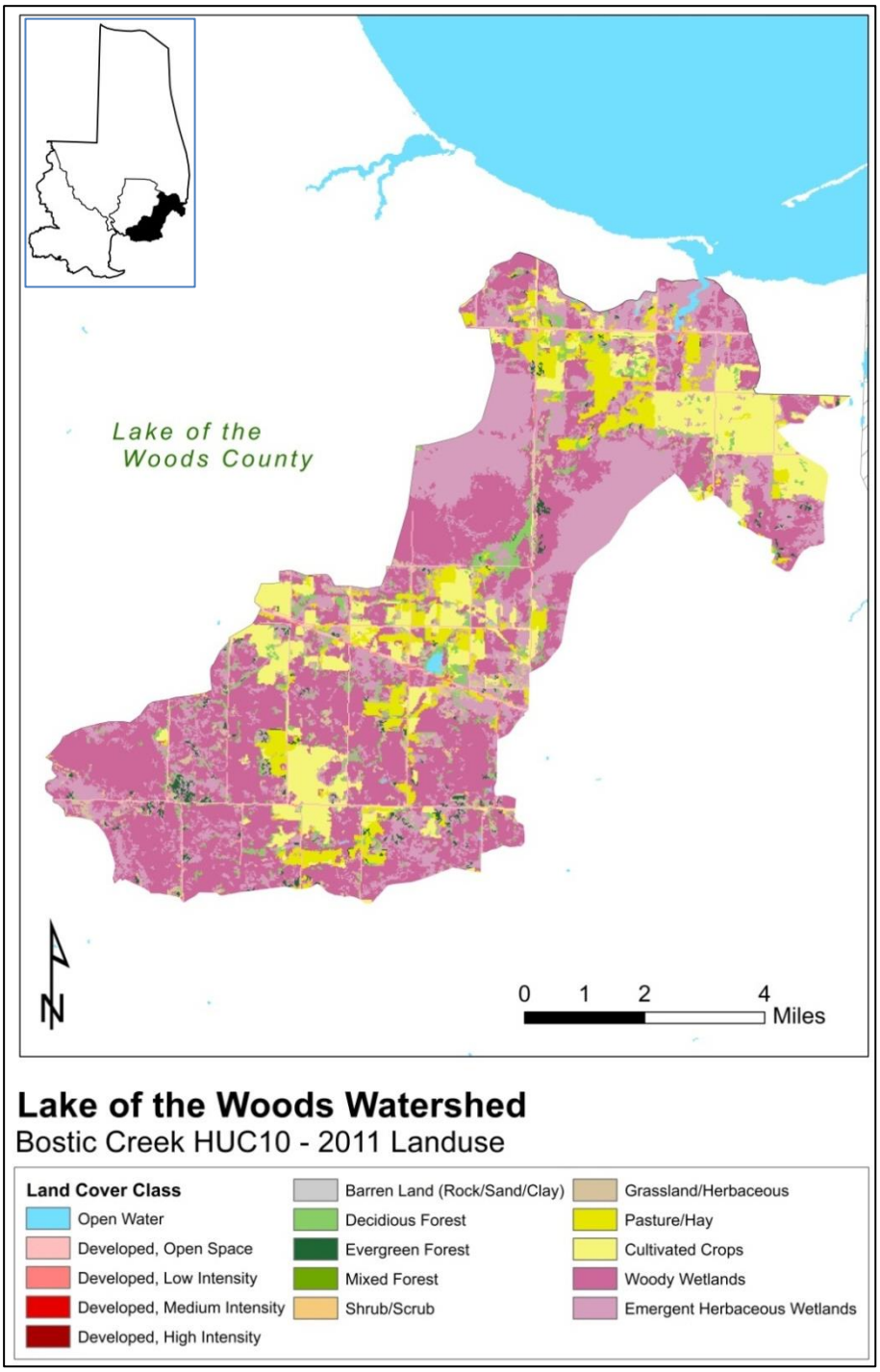

Figure 13. Bostic Creek subwatershed landuse (NLCD 2011).

Warroad River Subwatershed

The landuse distribution in this watershed is divided in half from north to south (Figure 14). Glacial till on the northern half of the watershed enables agricultural production along the Warroad River (East and West Branches). In the southern half, extensive peatlands prevent development. Just under three-quarters of this watershed consists of woody and emergent wetlands (73%).

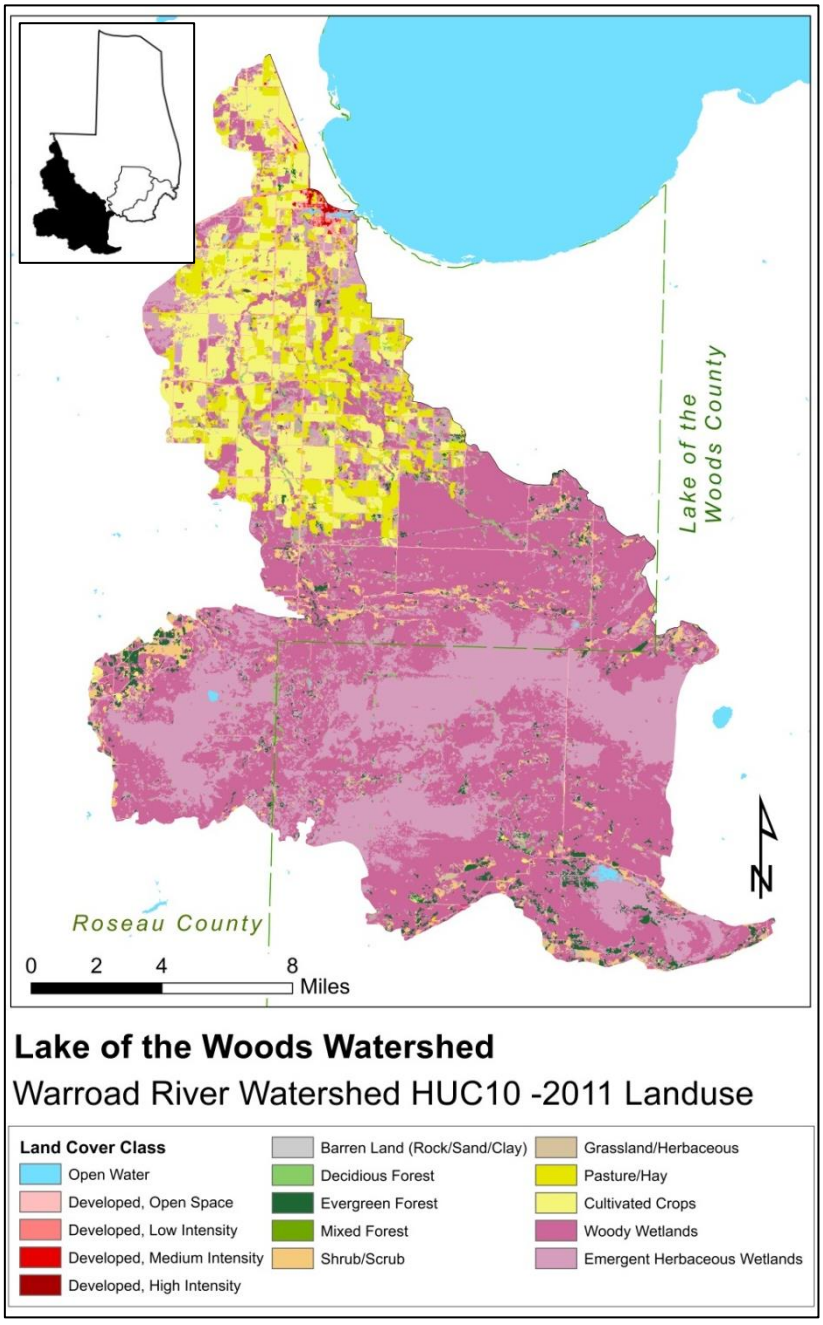

Figure 14. Warroad River subwatershed landuse (NLCD 2011).

Zippel Creek Subwatershed

Over half of this watershed (62%) is dominated primarily by woody wetlands (Figure 15). The remainder of the watershed is used for agricultural production. This watershed has the highest percentage of cropland (20%).

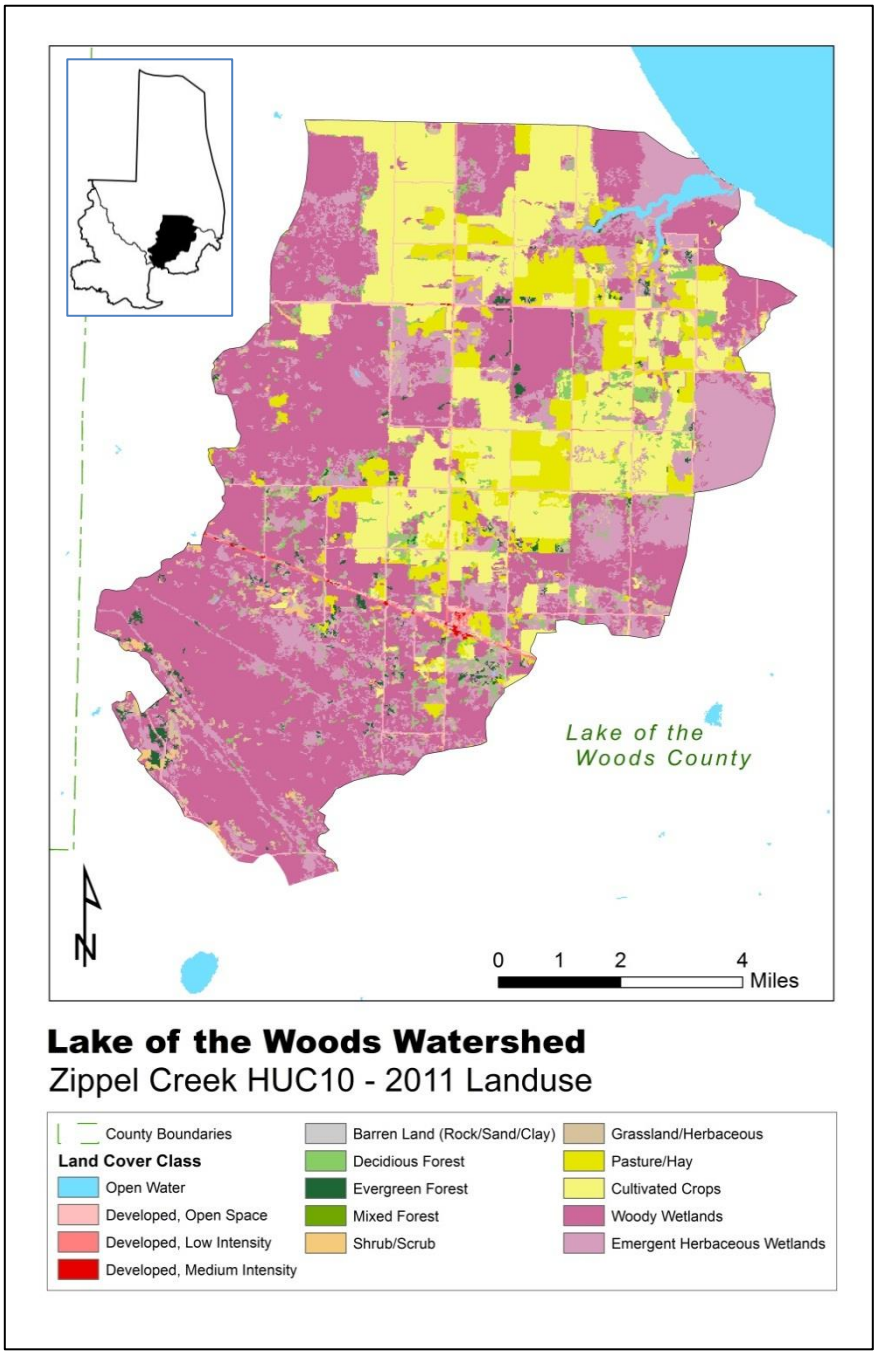

Figure 15. Zippel Creek subwatershed landuse (NLCD 2011).

Geology and Soils

Glaciers played a significant role in the landscape of northern Minnesota, disappearing relatively recently in geologic time. Geologists refer to the most recent time period as the Quaternary Period. It is divided into the Pleistocene Epoch (2 million to 10,000 years ago) and the Holocene (10,000 years ago to present) (Lusardi 1997). The bedrock geology of northwestern Minnesota is largely buried beneath as much as 150 m of glacial deposits, the thickest glacial cover in the state (Ojakangas and Matsch 1982).

During the Pleistocene, the Laurentide Ice Sheet covered much of northern North America. Figure 16 shows generalized coverage by specific glacial lobes of advancement. The most recent glacier to cross the state was the Des Moines Lobe. It extended from the current day Red River Basin to Des Moines, Iowa. The material deposited by this glacial advancement is gray to brown, loamy clay and distinctive because it contained Cretaceous shale pushed south from North Dakota and Canada (Lusardi 1994). Approximately 12,000 years ago, glacial Lake Agassiz occupied the area now delineated for Lake of the Woods Watershed.

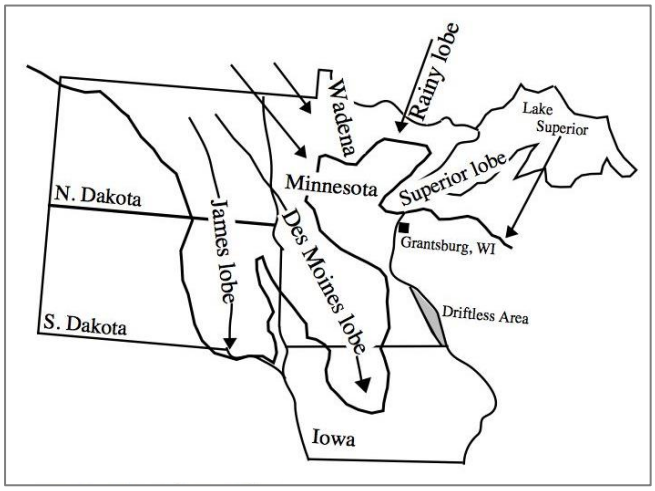

Figure 16. Simplifed drawing of ice lobes about 14,000 years ago. Source: Lusardi 1994.

Glacial Lake Agassiz was the largest glacial lake to form from the melt water of receding glaciers (Lusardi 1994). At its largest extent, the lake may have covered 170,000 square miles. The surface deposits of the areas mapped as Lake Agassiz have a lacustrine, or lake, source. Lake sedimentation produces areas of level sediment and other areas with a rolling to undulating topography due to nearshore wave action and beach formation.

The lowlands created by Glacial Lake Agassiz are virtually level and dominated by peat as reflected by the drainage network. About 40% of the soils within LOWW are peat, most predominantly in the southern portion of the basin and the northern-most portion. Closer to Lake of the Woods, soils become dominated by Lake-modified till (38% of the watershed) and the remaining soils predominantly as sand and gravel ridges (21%) interspersed throughout the peatlands in the southern half of the watershed (Figure 17).

As noted earlier, extensive ditching of the peatlands was done in the earlier part of this century in an effort to promote agricultural development of the region. Native plant communities included in this area are sedge fen, black spruce-sphagnum bog, and white cedar-black ash swamp. There were

also low moraines and beach ridges dominated by jack pine forest or quaking aspen-paper birch forest.

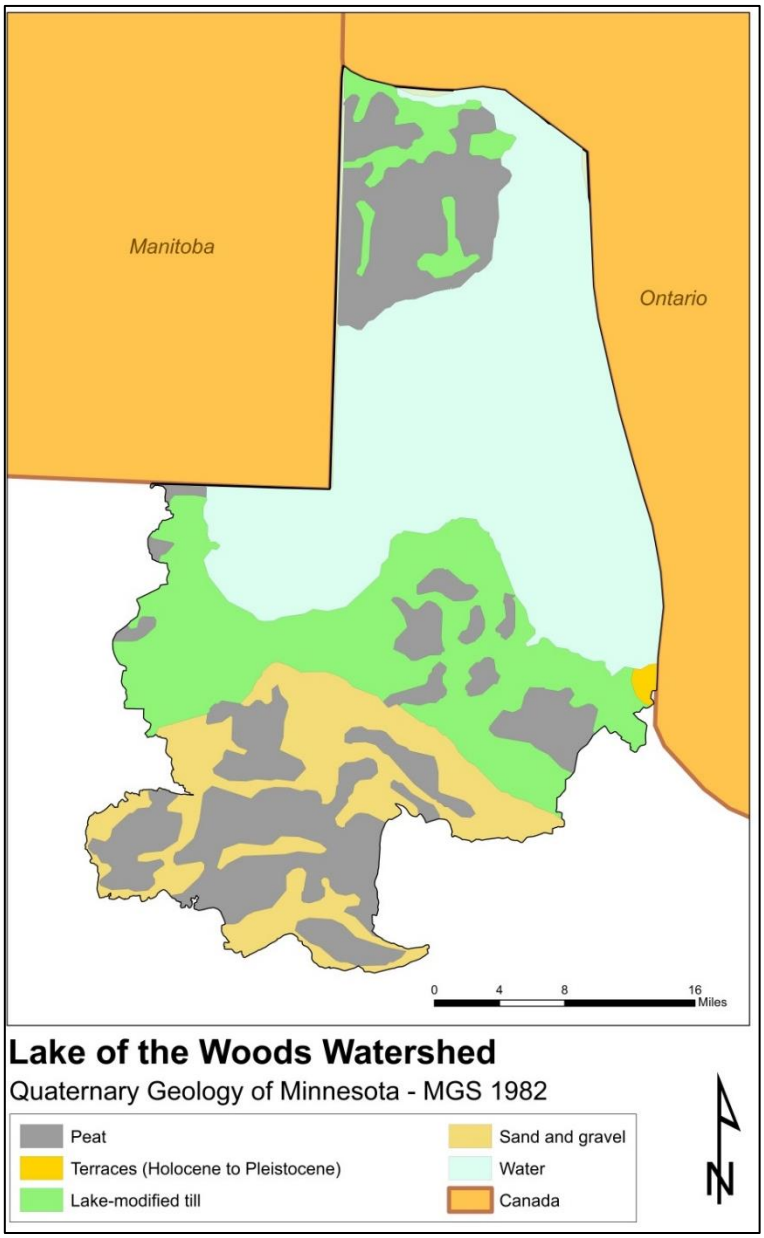

Figure 17. Lake of the Woods watershed quaternary geology

Hydrology

In the early 20th century in LOWW extensive ditch systems were put in place for logging access and agricultural production. Ditching focused on improving drainage within the peat bog areas where the natural hydrology excluded streams and rivers. Almost half (49%) of the watercourses throughout the watershed are ditched systems (Figure 18). Naturally, peatland hydrology is more of a slow sheet-flow system, with water generally under, but near, the surface. Absorption and

release of water throughout the system is slow. Ditching has a significant impact on hydrology and vegetation of these peatlands. Typically, spoil from when a ditch was constructed is placed adjacent to the ditch. This spoil compacts soil and acts as a dam for groundwater flow when constructed perpendicular to groundwater flow. A recent hydrological study on the ditched peatlands at Winter Road Peatland SNA verified this damming effect by ditch spoil piles. In addition, hydrological data showed ditches to be removing water from the peatlands. The study also revealed water is removed faster from the peatland when water levels are low (MN DNR 2015).

The manipulation of water levels in Lake of the Woods via dams has also had an impact on the hydrology of tributary streams. Specifically, maintaining water levels 2.5 to 3 feet higher than pre-dam levels has raised the local base level of streams, thereby reducing the gradient and flow velocities, leading to increased deposition. Erosion of lakeshore and backwater areas of tributaries has also occurred due to inundation and wave impacts, which is also a result of increased lake levels.

Stream gages

Stream gages are generally lacking in the Lake of the Woods watershed. There are currently two active DNR/MPCA cooperative stream gaging stations in the watershed; one station is on the East Branch of the Warroad River, off of Forest Road 59, near Roosevelt, and one station is on the West Branch of the Warroad River, off of CSAH 5, near Warroad (Figure 18). However, both gages have short periods of record, with data available from September 2012 to present, so an analysis of gage data is not available at these sites.

There are also two gages in the watershed that monitor Lake of the Woods water levels. The gages are located near Warroad and Springsteel Island, and are operated by the United States Army Corps of Engineers (USACE). The Springsteel Island gage has a period of record from June 1985 to present, and the Warroad gage has a period of record from January 1978 to present. There were also three stream gages near Warroad that were operated by the United States Geological Survey (USGS), but that have been discontinued. One gage was located on the West Branch of the Warroad River, and was active from April 1946 to September 1980. The two other discontinued gages were on the East Branch of the Warroad River and Bulldog Run, and both were active from April 1946 to September 1977 (Figure 18). Maintaining long-term, active stream gages is vital to understanding hydrologic conditions in the watershed and being able to describe average conditions, long-term variations, and trends in flow and discharge.

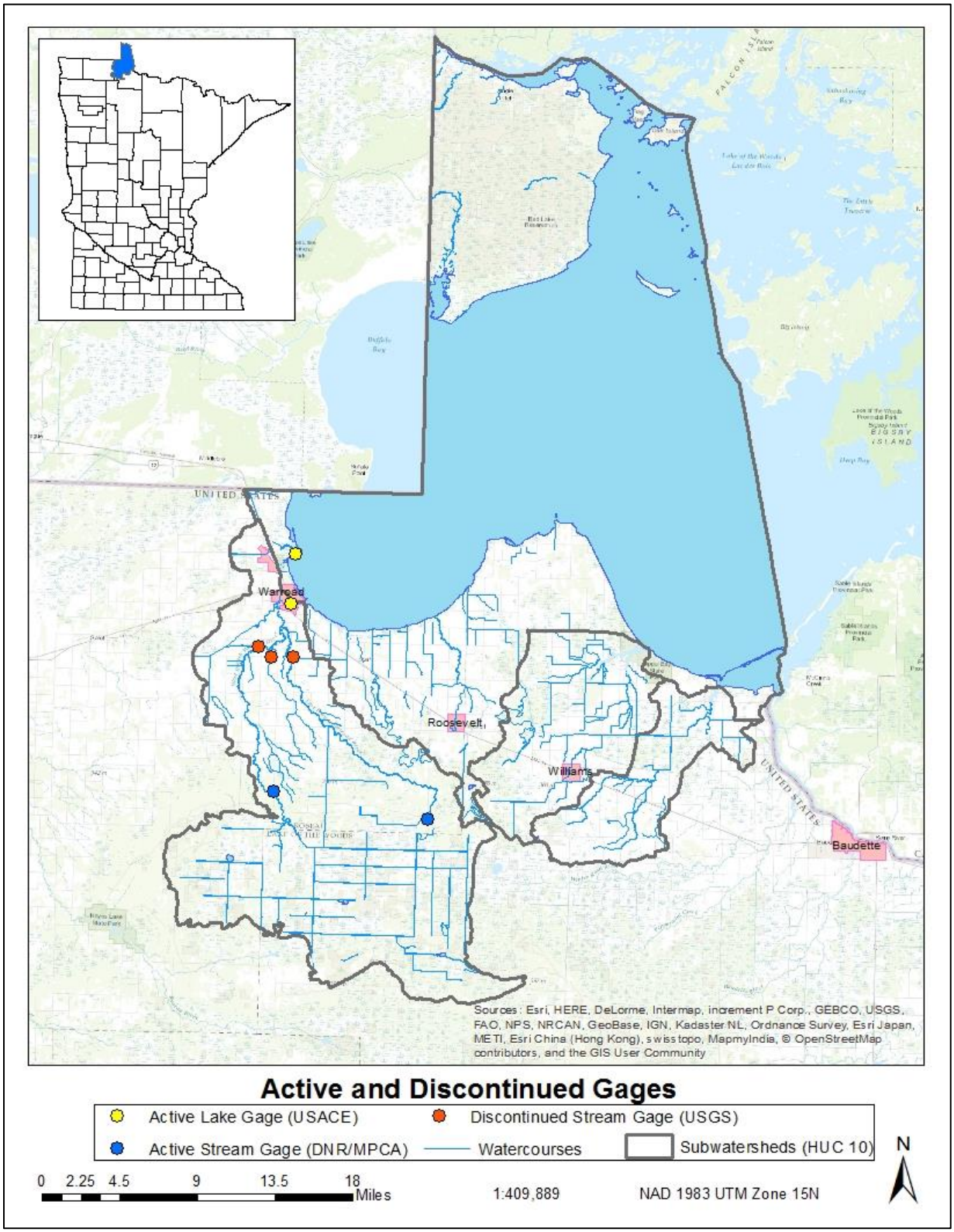

Figure 18. Active and discontinued stream and lake gages in the Lake of the Woods watershed.

Precipitation

Average annual precipitation, measured from 1901-2000 for North Central Minnesota was 24.85 inches. The majority of the precipitation occurs as rainfall, (3.4-3.98 inches/month) during the months of June, July, and August. Regional climate data retrieved from NOAA, National Centers for Environmental Information on April 4, 2016 (http://www.ncdc.noaa.gov/cag/time-series/us) indicates an average increase in annual precipitation of 0.15 inches/decade (Figure 19). This increase in precipitation is expected to continue with climate change.

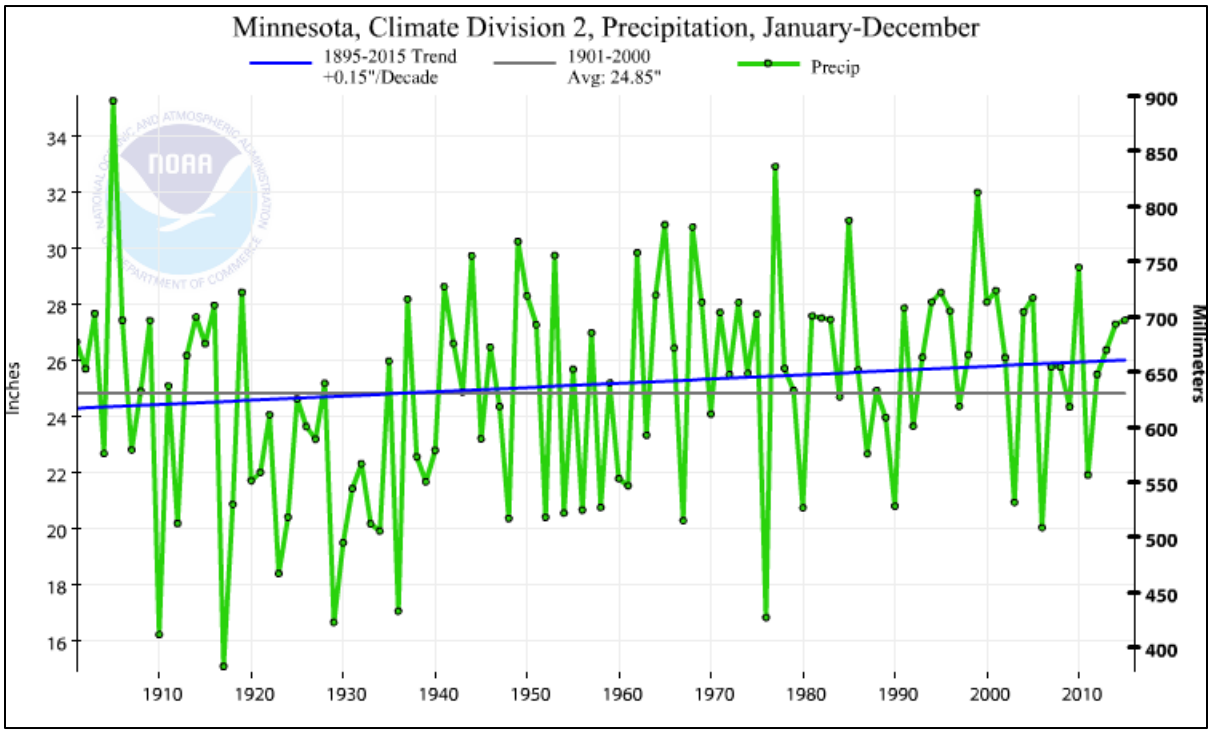

Figure 19. Average annual precipitation for North Central Minnesota.

Pfankuch Stability Ratings at MPCA Biological Monitoring Sites

In order to determine stream type at each site, bankfull channel dimensions were estimated by measuring a rough cross-section at a riffle near the biological monitoring site. Bankfull determinations were made by walking the reach and looking for the lowest depositional flat area on point bars or areas where streams had access to their floodplains. Survey rods and a laser range finder were used to measure bankfull width, bankfull mean depth, and width of the flood prone area (channel width at two times the maximum bankfull depth). Width-to-depth and entrenchment ratios were then calculated to arrive at Rosgen stream type for each site. Pebble counts were not conducted, so the dominant substrate at each site was estimated after walking the reach and conducting the Pfankuch survey. Incised channels were identified where the lowest depositional banks were higher than the bankfull elevation. Entrenched channels were identified where the

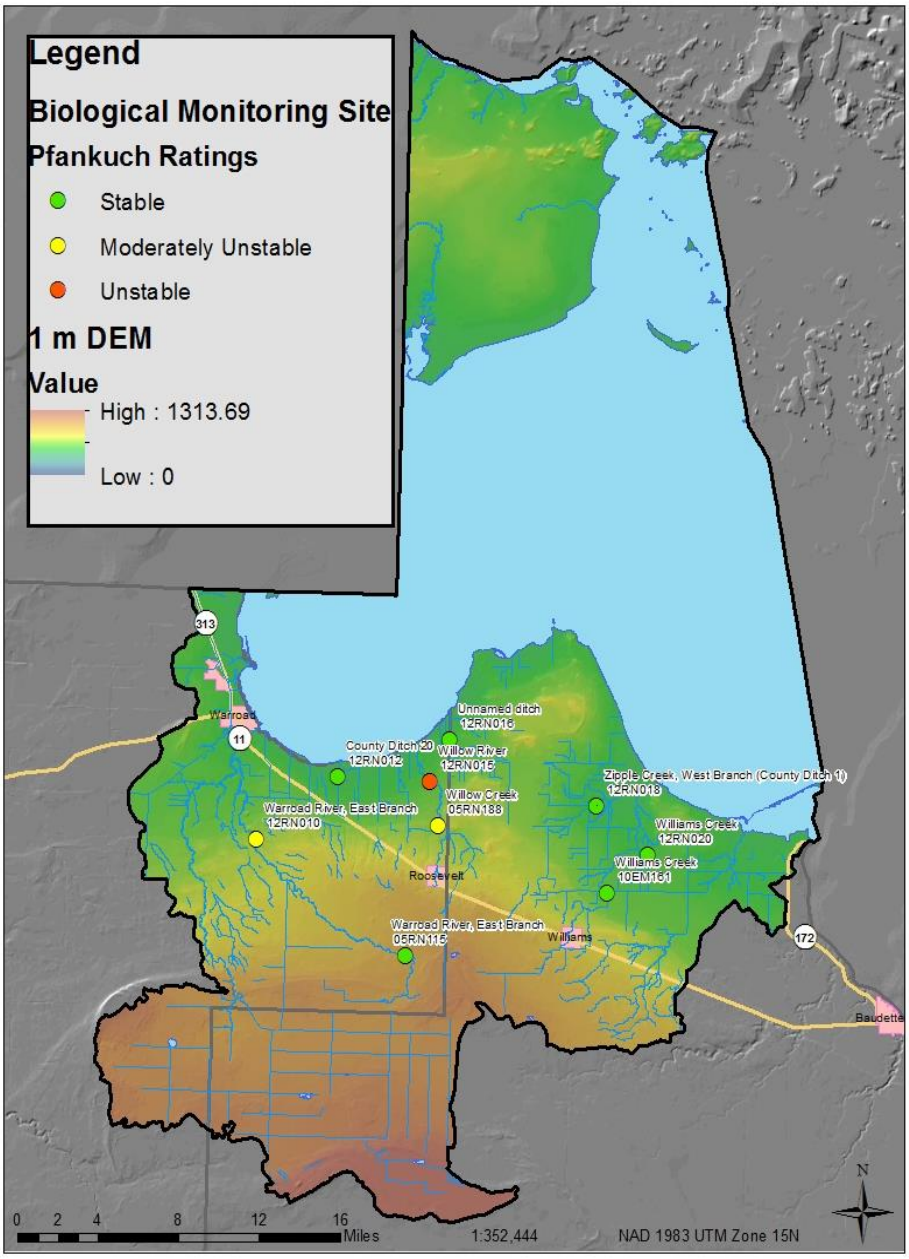

Figure 20. Lake of the Woods Watershed showing biological monitoring sites and Pfankuch stability ratings.

waterbody did not have access to a floodplain at two times the maximum depth at a riffle cross section.

Culverts immediately downstream of biological monitoring station sites were assessed for size and placement to determine whether or not they were barriers to fish passage. Culvert invert elevations were not measured, so it was not possible to determine if culverts were potential velocity barriers at high flows.

Figure 20 shows the locations of the nine biological monitoring sites that were visited and their associated Pfankuch stability ratings. The Pfankuch stability ratings are also included in Table 5, along with stream types and channel morphological parameters. All sites appeared to be at their potential stable stream type, so no adjustment from current to potential stream type was needed.

Table 5. Biological monitoring station Pfankuch stability ratings, stream types, and morphological parameters.

Stream Name	MPCA Biological Station	Drainage Area (sq mi)	Bankfull Width (ft)	Bankfull Mean Depth (ft)	Flood Prone Area Width (ft)	Width/Depth Ratio	Entrenchment Ratio	Stream Type	Pfankuch Stability Rating
Williams Creek	10EM161	18	13	2.96	70	4.4	5.4	E5	Stable
Williams Creek	12RN020	27.8	15	2.42	60	6.2	4	E5	Stable
Zipple Creek, West Branch	12RN018	25.2	34	2.1	200	16.2	5.88	C5	Stable
Warroad River, East Branch	05RN115	12.8	22	2.6	200	8.46	9.1	E5	Stable
Warroad River, East Branch	12RN010	44.2	27	2.35	200	11.49	7.4	E4/C4	Moderately Unstable
Willow Creek	05RN188	21.6	23	2.03	150	11.3	6.5	E5/C5	Moderately Unstable
Willow Creek	12RN015	24.3	15	2.6	32	5.78	2.13	E6	Unstable
Unamed Ditch	12RN016	12	7	1.97	40	3.55	5.7	E4	Stable
County Ditch 20	12RN012	9.43	22	2.77	50	7.94	2.05	E6	Stable

Williams Creek (10EM161)

MPCA biological monitoring station 10EM161 is on Williams Creek, upstream (south) of 24th Street NW near the intersection with 66th Avenue NW, approximately 2.5 miles northeast of Williams. According to USGS StreamStats, the contributing drainage area to this location is 18 square miles (Figure 2). Based on National Land Cover Database (NLCD) 2011 data, the dominant land cover types within this drainage area are emergent herbaceous wetlands (18.7%) and woody wetlands (58%). In the lower reaches of the drainage area, cultivated crops and pasture/hay make up 6% and 3.5% of the land cover, respectively.

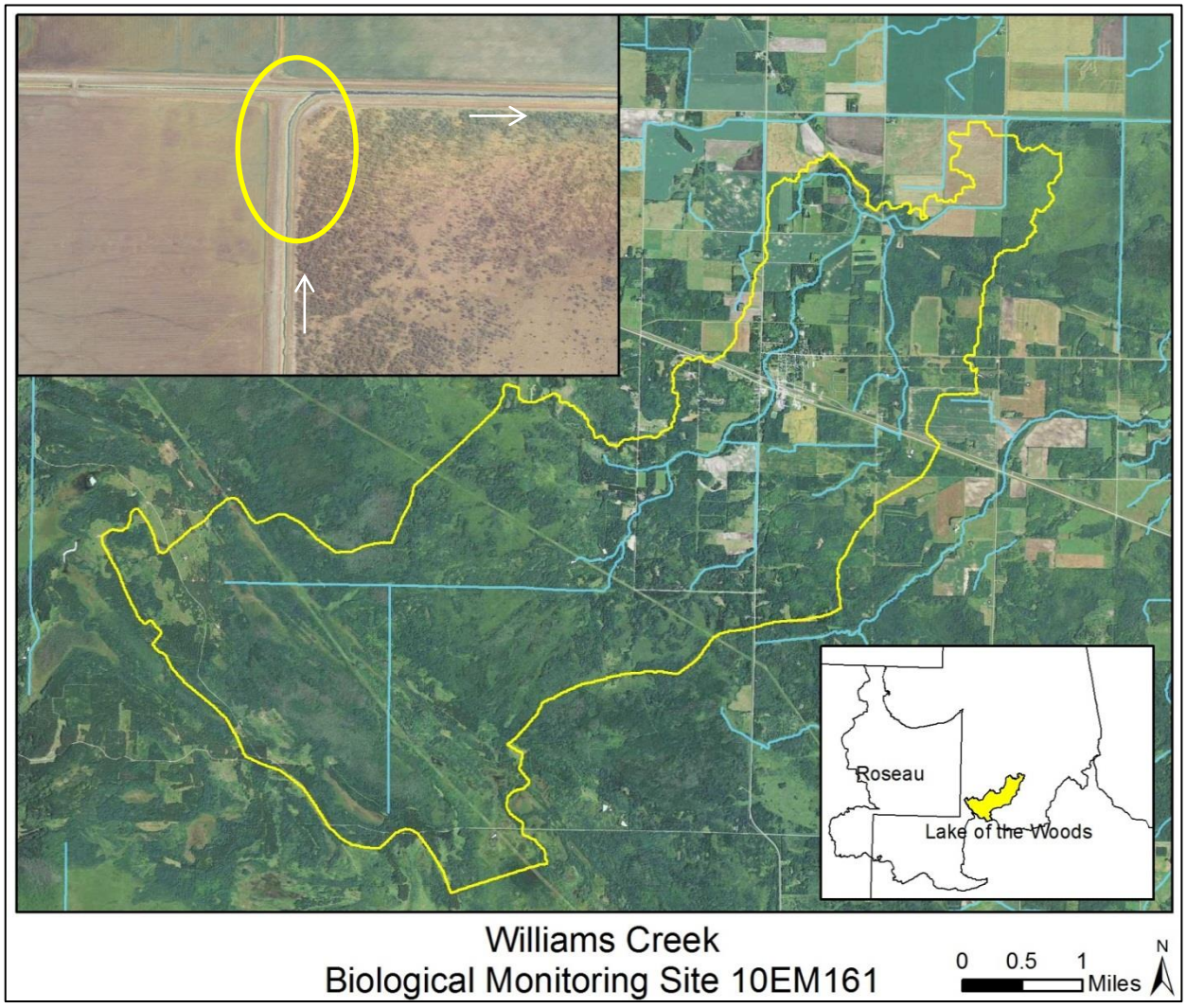

Figure 21. Williams Creek (site 10EM161) drainage area and aerial close-up view.

The Pfankuch rating for this site on 10/19/2015 was 67, which is *good* (stable) for an E5 stream type. A *good*, or stable, rating for E5 stream types ranges from 50-75. Almost all Pfankuch categories ranked as *excellent* or *good*, with only *bank rock content* ranking as *poor*. The upper banks were well vegetated with grasses and forbs, but there were no trees or shrubs located on either the upper or lower banks (Figure 23). There was also no evidence of mass wasting in the upper banks. The lower banks were well vegetated with some cutting, but no deposition. The substrate appeared to be stable and was made up of sand, with some small gravel mixed in (Figure 24). Overall, the bed did not seem to be either aggrading or degrading.

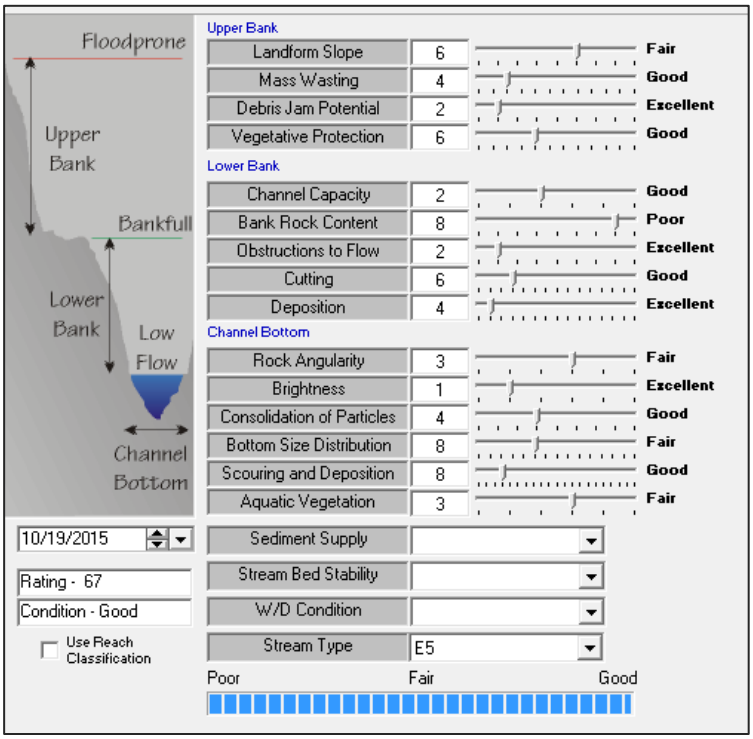

Figure 24. Site 10EM161 Pfankuch score.

Figure 23. Site 10EM161 (photo taken on 10/19/15).

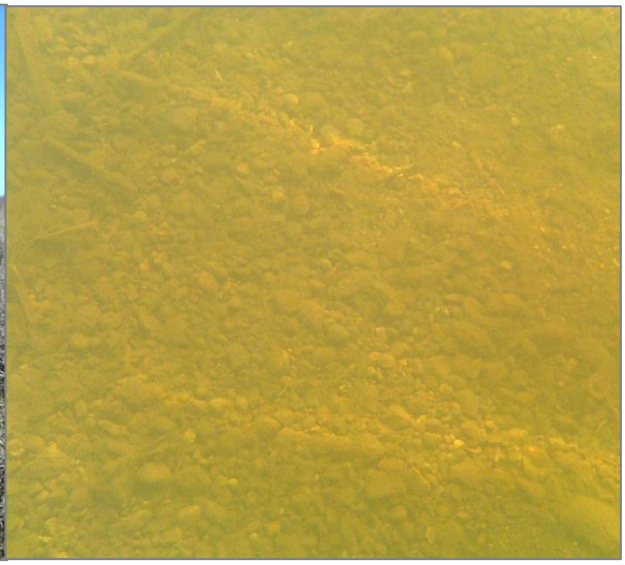

Figure 22. Substrate at site 10EM161 (photo taken on 10/19/15).

Discussion

Although this reach of Williams Creek is stable, it has been channelized and is generally lacking in facets/habitat, which is likely the main stressor for this site (Figure 25). Even though the site is lacking in habitat, it does seem to have sufficient base flow. Additionally, connectivity does not appear to be a stressor here. There are six crossings between the site and Lake of the Woods, with the nearest crossing being approximately 0.6 miles downstream. An assessment of aerial photography does not appear to indicate any barriers to fish passage; however, this assumption should be confirmed during flood flows to ensure there are no velocity barriers.

Figure 25. Site 10EM161 (photo taken on 10/19/15).

Williams Creek (12RN020)

MPCA biological monitoring station 12RN020 is located on Williams Creek, adjacent to 58th Avenue NW, on the northwest side of Graceton Wildlife Management Area. According to USGS StreamStats, the contributing drainage area to this location is 27.8 square miles (Figure 26). Based on National Land Cover Database (NLCD) 2011 data, the dominant land cover types within this drainage area are cultivated crops (11.9%), emergent herbaceous wetlands (19.7%), and woody wetlands (49.9%).

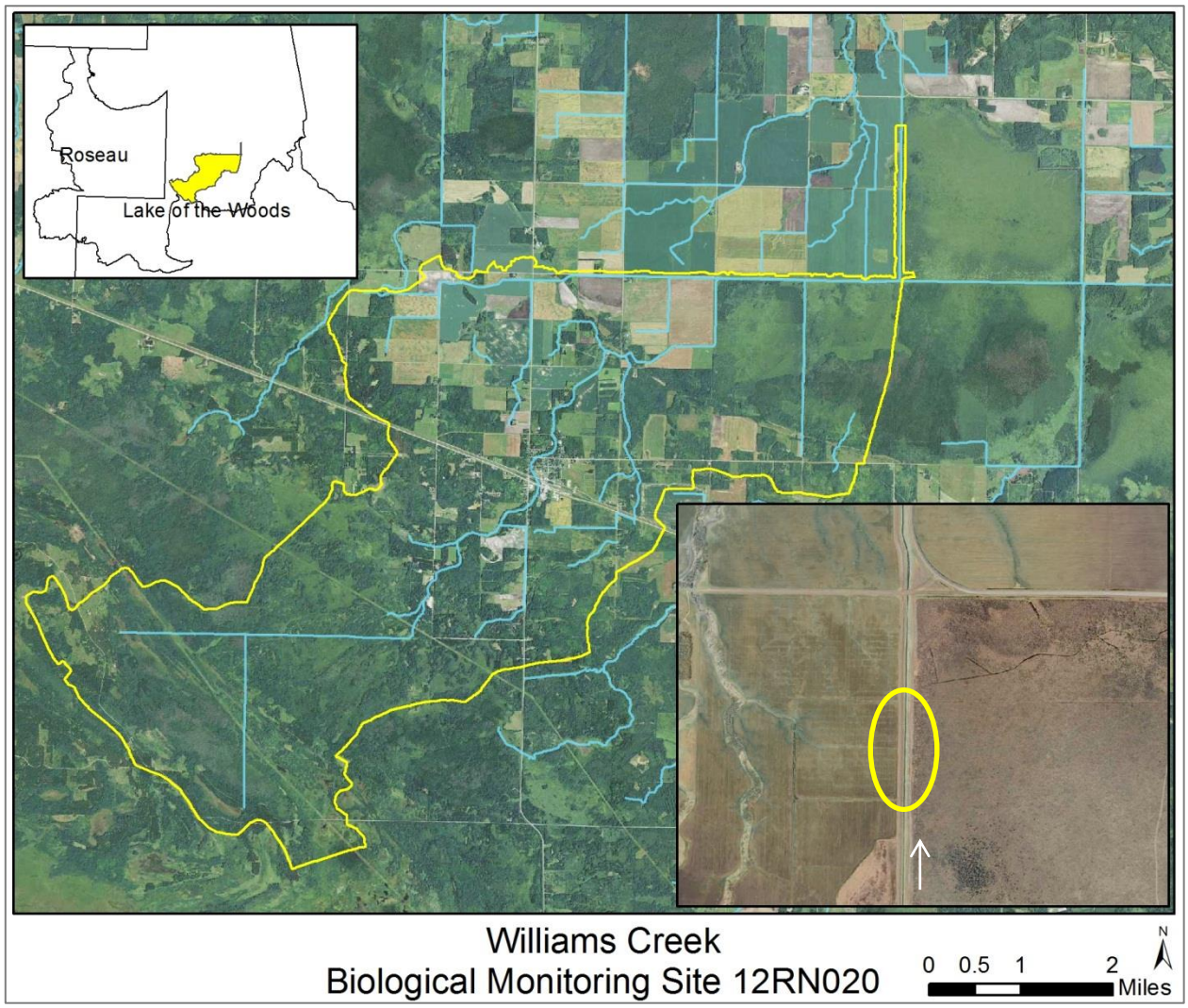

Figure 26. Williams Creek (site 12RN020) drainage area and aerial close-up view.

The Pfankuch rating for this site on 10/19/2015 was 52, which is *good* (stable) for an E5 stream type. A *good*, or stable, rating for E5 stream types ranges from 50-75. All of the Pfankuch categories ranked from *fair* to *excellent*, with no *poor* categories observed (Figure 27). The upper banks were well vegetated with grasses and forbs, and on the right bank (looking downstream)

there were willow saplings growing on both the upper and lower banks (Figure 28). There was no evidence of mass wasting on the upper banks. The lower banks were well vegetated with no cutting or deposition. Unlike upstream site 10EM161, this site had rip-rap lining the lower banks. The substrate appeared to be stable and was made up of sand, with some small gravel mixed in. Overall, the bed did not seem to be either aggrading or degrading.

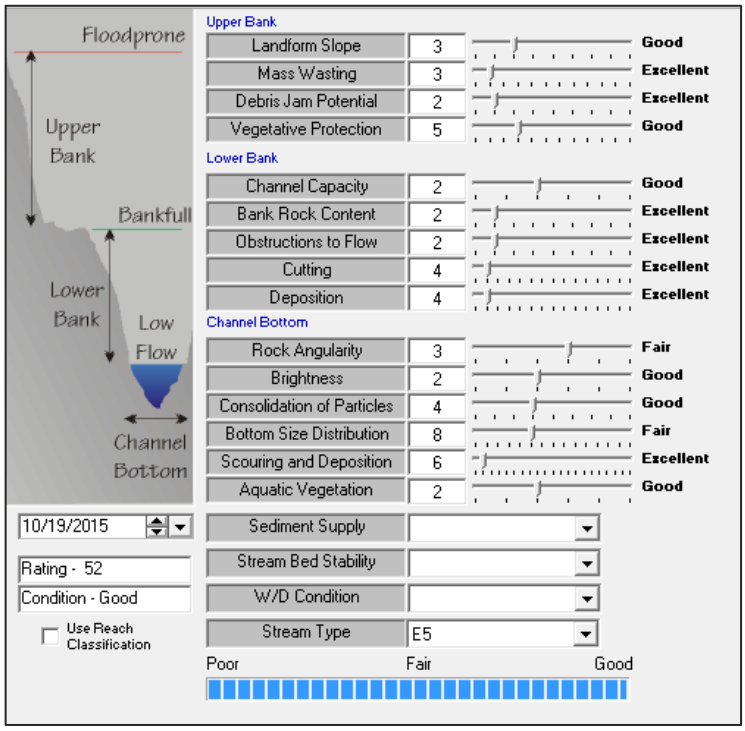

Figure 27. Site 12RN020 Pfankuch score.

Discussion

Although this reach of Williams Creek is stable, it has been channelized and is generally lacking in facets/habitat, which is likely a main stressor for this site. Even though the site is lacking in habitat, it does seem to have sufficient base flow. Additionally, connectivity does not appear to be a stressor here. There are three crossings between the site and Lake of the Woods, with the nearest crossing being approximately 0.3 miles downstream. An assessment of aerial photography does not appear to indicate any barriers to fish passage; however, this assumption should be confirmed during flood flows to ensure there are no velocity barriers.

Figure 28. Site 12RN020 (photos taken on 10/19/15).

Zipple Creek West Branch (12RN018)

MPCA biological monitoring station 12RN018 is located on the West Branch of Zipple Creek, upstream of 40th St NW, approximately six miles northeast of Williams. According to USGS StreamStats, the contributing drainage area to this location is 25.2 square miles (Figure 29). Based on National Land Cover Database (NLCD) 2011 data, the dominant land cover types within this drainage area are cultivated crops (11.1%), emergent herbaceous wetlands (14.8%), and woody wetlands (61%).

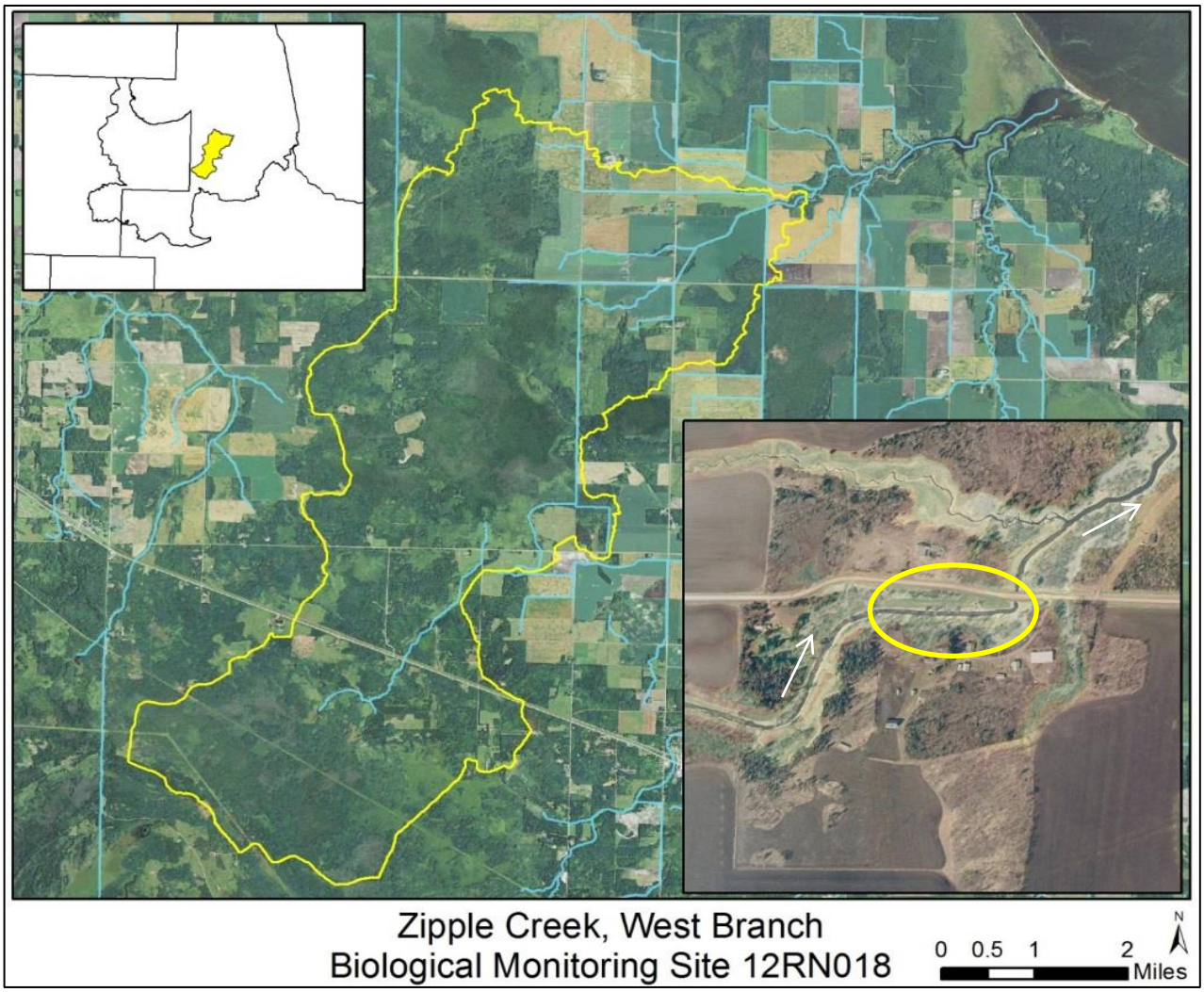

Figure 29. Zipple Creek (site 12RN018) drainage area and aerial close-up view.

The Pfankuch rating for this site was 67, which is *good* (stable) for a C5 stream type. A *good*, or stable, rating for C5 stream types ranges from 70-90. Almost all Pfankuch categories ranked as *excellent* or *good*, with only *bank rock content* ranking as *poor* (Figure 30). The upper banks were well vegetated with mature trees (primarily on right bank), reed canary grass (primarily on left bank), and scattered shrubs (Figure 31). There was also no evidence of mass wasting in the upper banks. The lower banks were well vegetated with no evidence of cutting or deposition. The substrate at this location was sand and silt, and there was likely some deposition occurring from an undersized culvert approximately 450 feet downstream of the biological station site waypoint. There was also abundant aquatic vegetation throughout the reach.

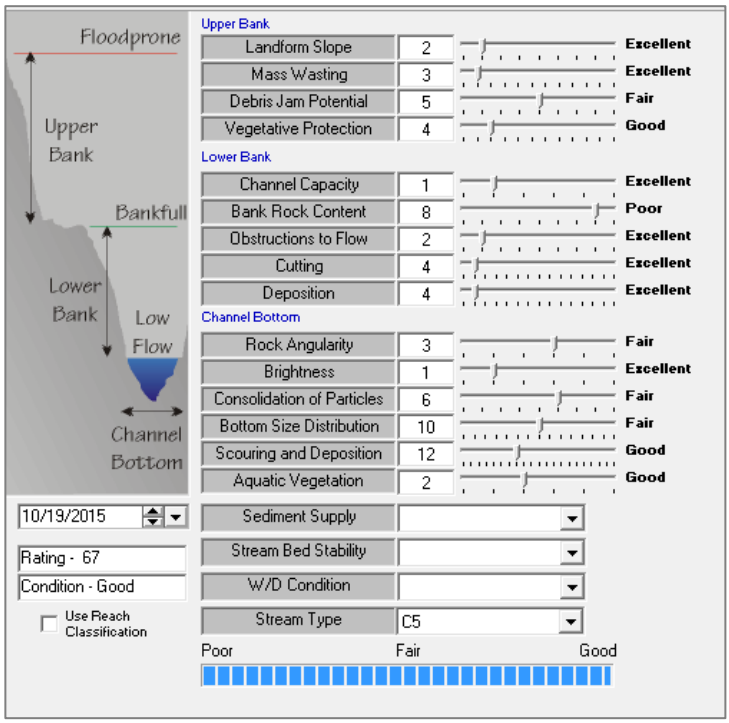

Figure 30. Site 12RN018 Pfankuch score.

Figure 31. Site 12RN018 (photos taken on 10/19/15).

Discussion

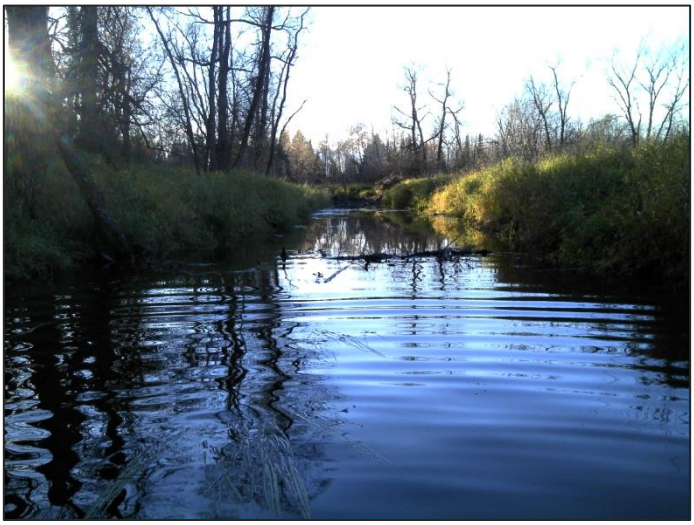

Figure 32. Site 12RN018 (photo taken on 10/19/15).

Although this reach of Zipple Creek is stable, it appears to have been channelized in the past; however, it does have access to a floodplain at this location and does not appear to be incised, and is only slightly entrenched (Figure 32). Likely in part because of the past channelization, this site is generally lacking in facets/habitat, which is a probable candidate for being a primary stressor. Additionally, the sand and silt substrate is also indicative of poor habitat. At the time of assessment the water was stagnant, with virtually no discernable flow, but water depth did not seem to be an issue. Water levels here are likely influenced by Lake of the Woods. There was also a beaver dam upstream of the biological monitoring station waypoint affecting flows, and a nearby landowner indicated that beaver activity in the area is common. With an estimated bankfull width of approximately 34 feet, the downstream concrete box culvert at 40th St NW is undersized at 7.3' high x 14' wide, but it is not a barrier to fish passage; this culvert is the only crossing between the biological monitoring site and Lake of the Woods.

Warroad River, East Branch (05RN115)

MPCA biological monitoring station 05RN115 is located on the East Branch of the Warroad River, upstream of 680th Ave, approximately four miles southwest of Roosevelt, MN. According to USGS StreamStats, the contributing drainage area to this location is 12.8 square miles (Figure 33). Based on NLCD 2011 data, the dominant land cover types within this drainage area are emergent herbaceous wetlands (35.6%) and woody wetlands (56.8%).

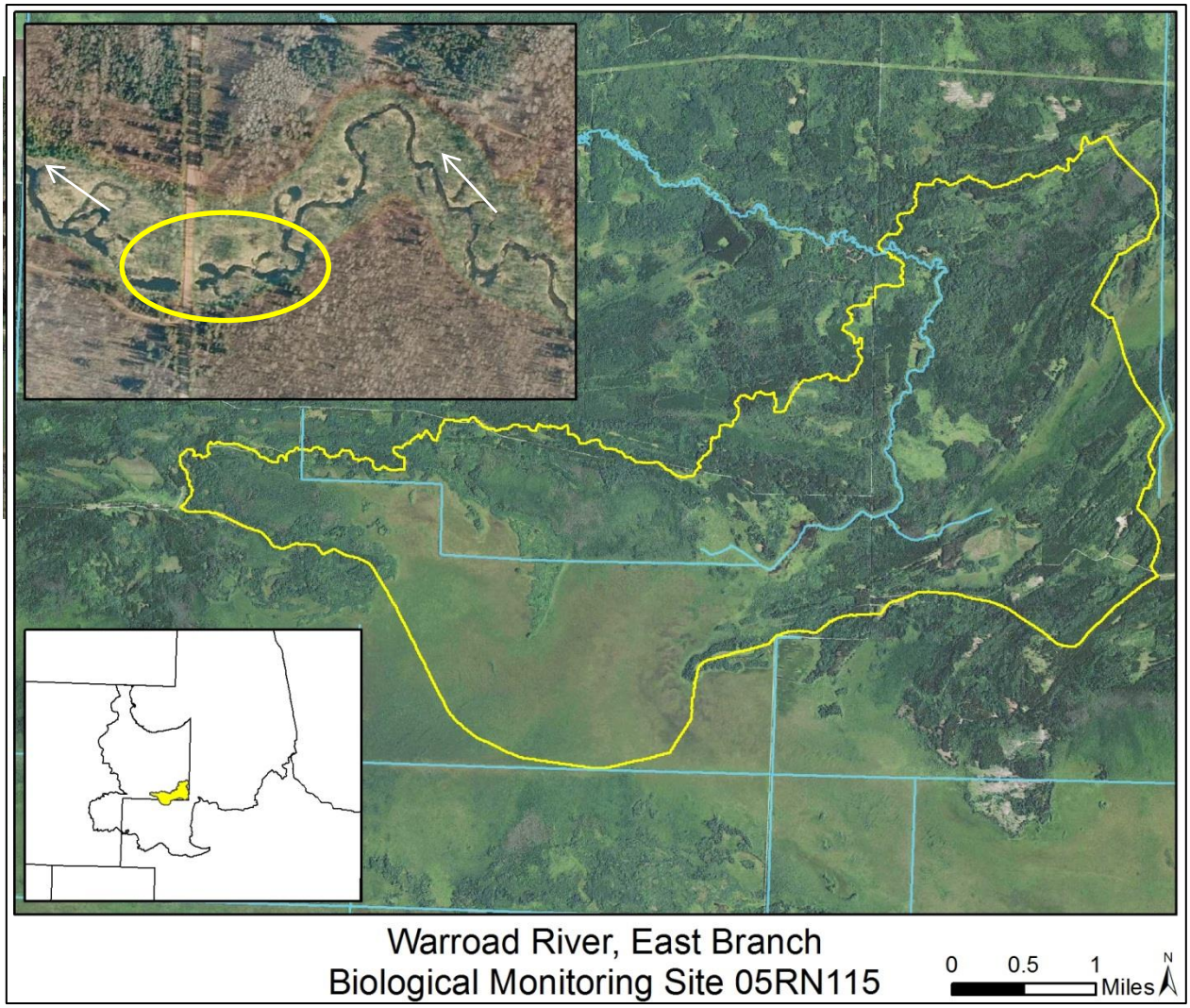

Figure 33. Warroad River, East Branch (site 05RN115) drainage area and aerial close-up view

The Pfankuch rating for this site was 63, which is *good* (stable) for an E5 stream type. A *good*, or stable, rating for E5 stream types ranges from 50-75. Almost all Pfankuch categories ranked as *excellent* or *good*, with only *bank rock content* ranking as *poor* (Figure 34). The upper banks at this site were well vegetated with mature trees and there were no signs of mass erosion. The lower banks were also well vegetated, primarily with grasses, sedges, and scattered alder and dogwood (Figure 35). The lower banks showed minimal signs of cutting and no deposition. The substrate at this site was sand and silt, but there were cobble and boulders in the channel where the river had cut into the valley wall near the biological monitoring site. Even though the substrate was primarily sand, the bottom appeared stable and did not appear to be either aggrading or degrading.

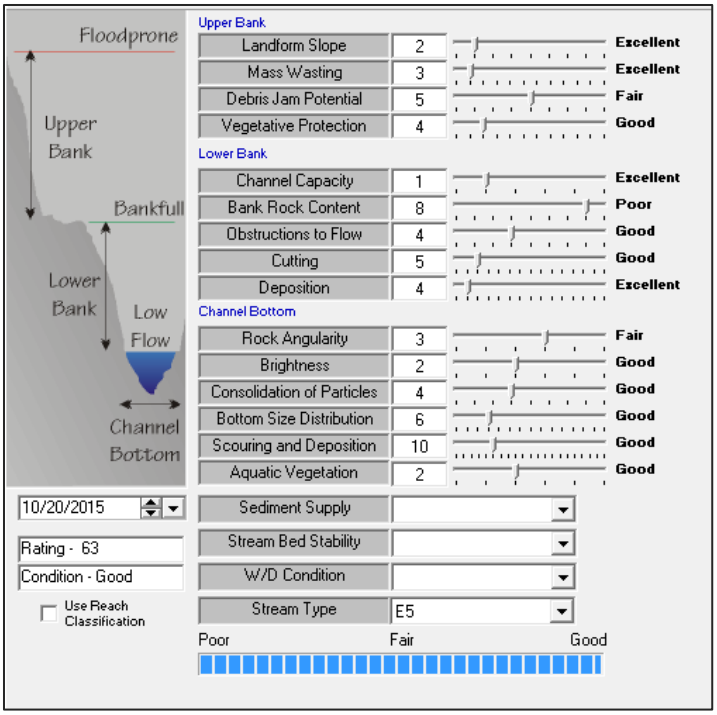

Figure 34. Site 05RN115 Pfankuch score.

Figure 35. Site 05RN115 (photo taken on 10/20/15).

Discussion

Figure 36. Site 05RN115 (photo taken on 10/20/15.

At this location the river had access to a floodplain, was not incised, and was only slightly entrenched. While this location exhibited good riffle-pool sequences, the sand and silt substrate does not provide for good spawning habitat. There also appeared to be sufficient base flows and pool depths to provide for fish holding cover. There is likely beaver activity throughout the reach that could be influencing fish migration, and which appears to be a likely stressor. With a bankfull width of approximately 22 feet, the corrugated metal culvert at the 680th crossing, downstream of the biological monitoring site, is slightly undersized at 9' high x 14' wide; however, the culvert is not perched and does not appear to be a fish passage barrier (Figure 36).

Willow Creek (05RN188)

MPCA biological monitoring station 05RN188 is located on Willow Creek, upstream of the County Road 34 (310th St.) crossing, approximately 2.5 miles north of Roosevelt. According to USGS StreamStats, the contributing drainage area to this location is 21.6 square miles (Figure 37). Based on NLCD 2011 data, the dominant land cover types within this drainage area are cultivated crops (14%), emergent herbaceous wetlands (16%), and woody wetlands (47%).

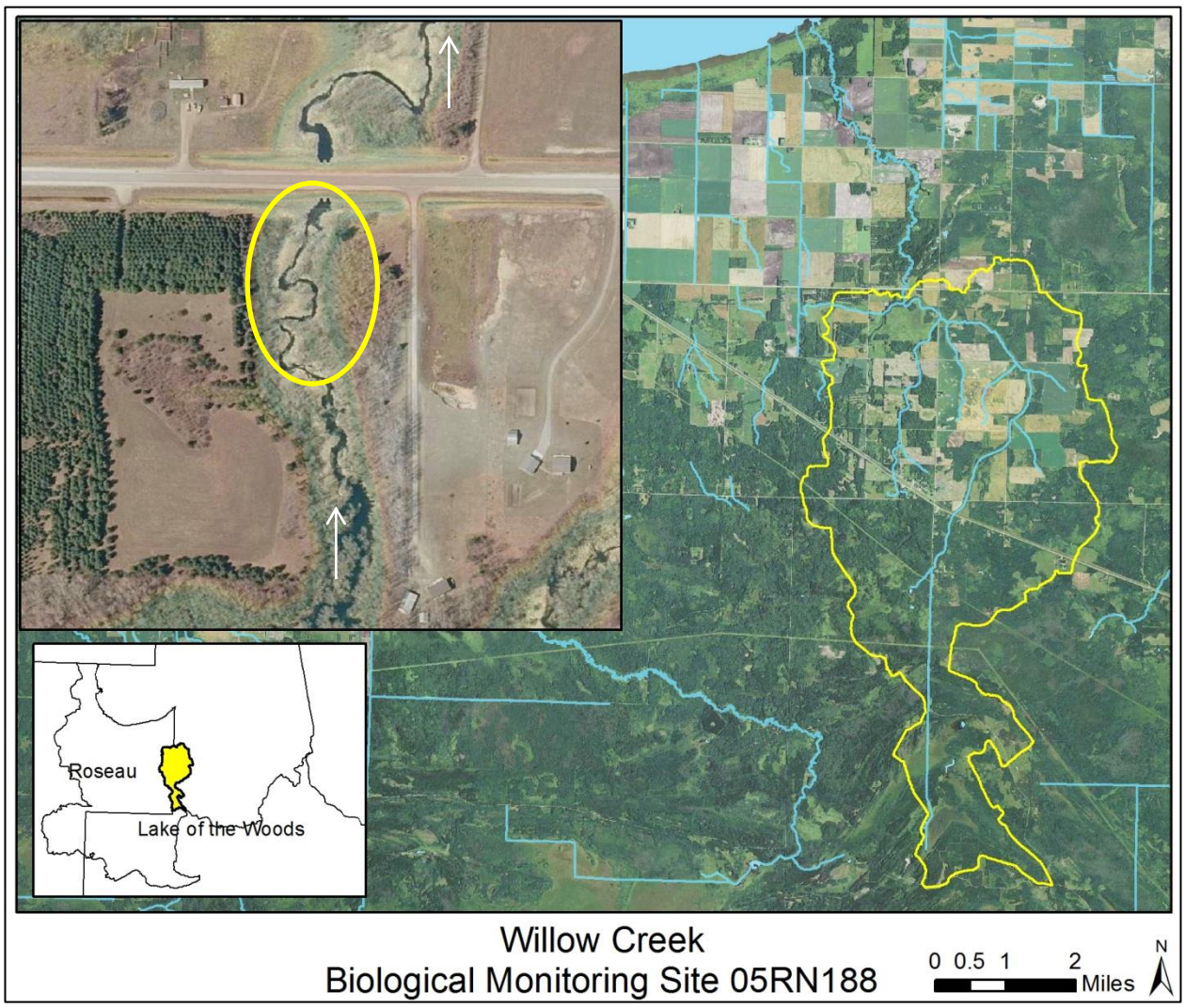

Figure 37. Willow Creek (site 05RN188) drainage area and aerial close-up view.

The Pfankuch rating for this site was 83, which is *fair* (moderately unstable) for an E5 stream type. A *fair*, or moderately unstable, rating for E5 stream types ranges from 76-96. Most Pfankuch categories ranked as *fair*, with only *bank rock content* ranking as *poor* (Figure 38). The upper banks at this site were well vegetated with mature trees and grasses and there were no signs of mass erosion. The lower banks had some cutting and deposition, as well as moderately frequent obstructions to flow which appeared to be primarily from old beaver dams (Figure 39). The predominant substrate type through the reach appeared to be sand with areas of silt and small gravel. The bottom appeared to be fairly stable but there were areas of deposition, especially near the biological monitoring station waypoint. Both the deposition and channel width appeared to decrease in the downstream direction.

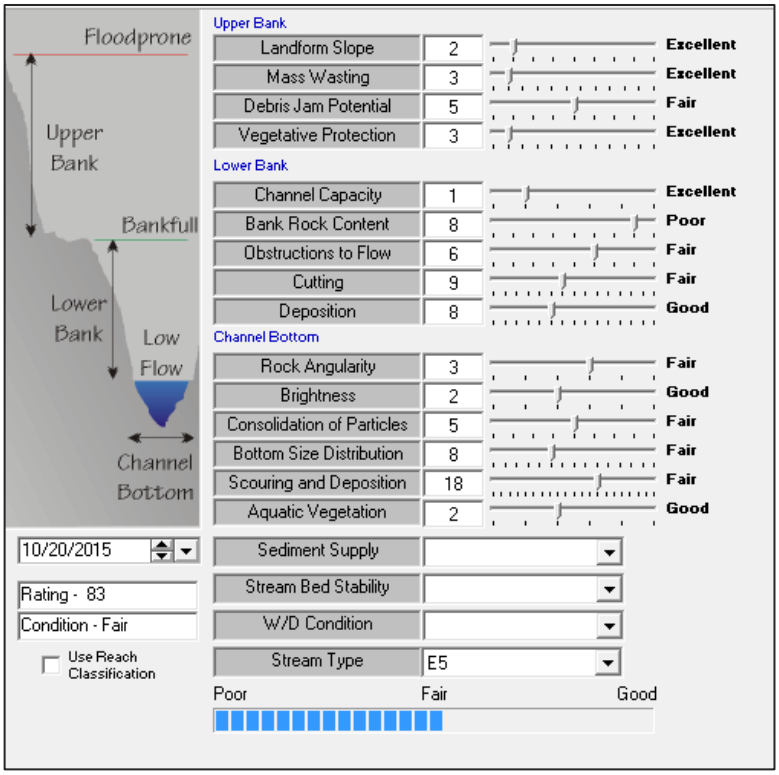

Figure 38. Site 05RN188 Pfankuch score.

Figure 39. Site 05RN188 (photos taken on 10/20/15).

Discussion

At this location the river had access to a floodplain, was not incised, and was only slightly entrenched. With a primarily sand bottom, there was a general lack of quality substrate and habitat. Substrate issues, coupled with a lack of base flow, appear to be the main stressors at this site. Beaver activity is also likely impacting the channel at this location, as remnants of beaver dams were observed through this reach. The channel near the old beaver dams and biological monitoring station was much wider than it was a couple of hundred feet downstream (23 feet versus 15 feet). There were also multiple meander cut-offs in progress, which potentially hint at instability through this reach. The two 6.5' high x 10' wide concrete arch culverts at the County Road 34 road crossing, downstream of the biological monitoring site, appear to be properly sized and are not barriers to fish migration.

Willow Creek (12RN015)

MPCA biological monitoring station 12RN015 is located on Willow Creek, upstream of the County Road 12 and 690th Avenue road crossing, approximately 4.5 miles north of Roosevelt. According to USGS StreamStats, the contributing drainage area to this location is 24.3 square miles (Figure 40). Based on NLCD 2011 data, the dominant land cover types within this drainage area are cultivated crops (14.5%), emergent herbaceous wetlands (16.5%), and woody wetlands (45%).

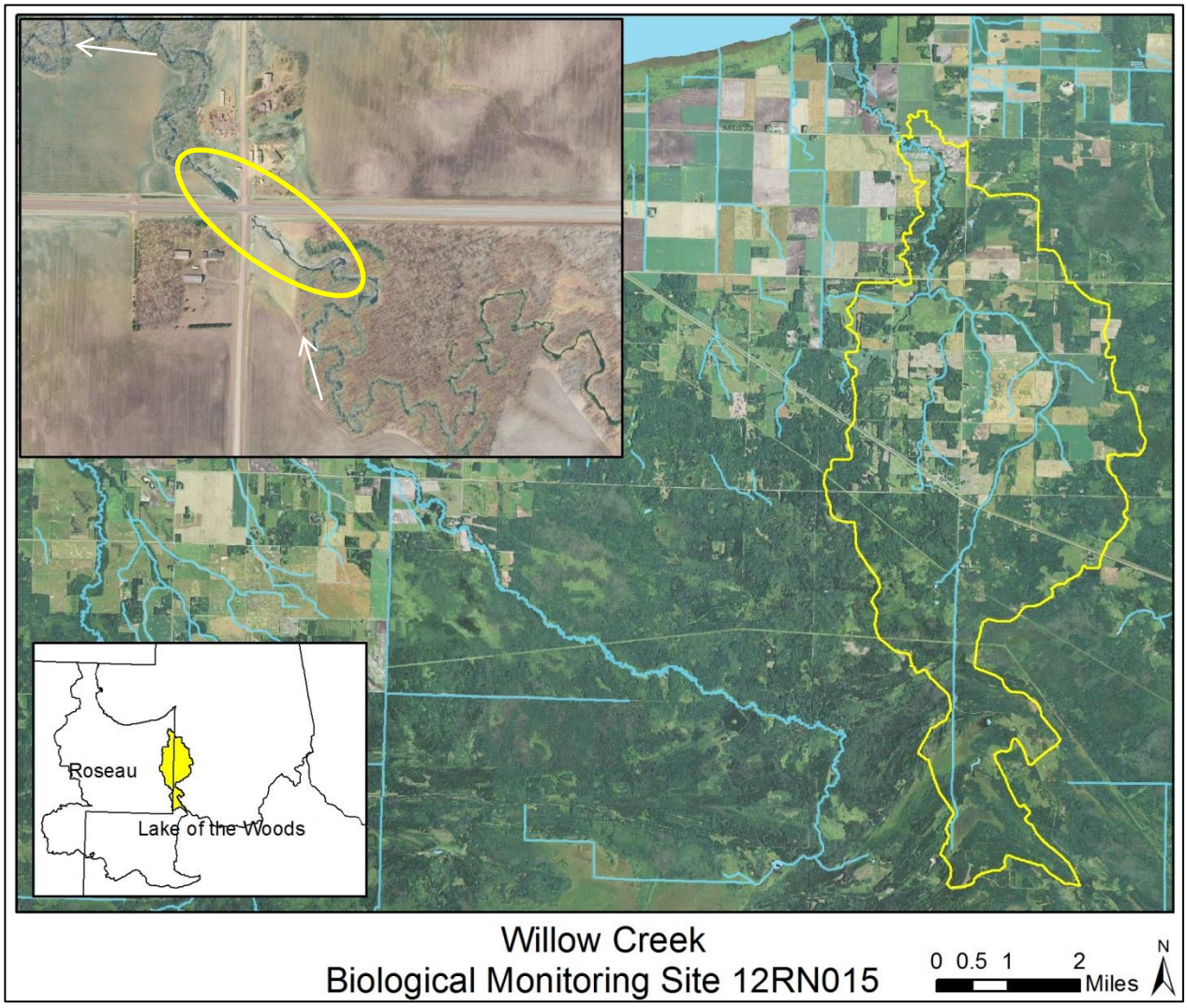

Figure 40. Willow Creek (site 12RN015) drainage area and aerial close-up view.

The Pfankuch rating for this site was 98, which is *poor* (unstable) for an E6 stream type. A *poor*, or unstable, rating for E6 stream types is 87 and above. Most Pfankuch categories ranked as either *fair* or *poor* for this site (Figure 41). The upper banks were well vegetated with mature trees near the biological monitoring station waypoint, but downstream 150 feet the upper banks were vegetated with reed canary grass for a length of approximately 300' to the road crossing. Because of incision, the upper banks were also very steep and showed evidence of both present and future mass erosion potential. Incision was also causing the lower banks to have significant cutting and was confining the channel (Figure 42). The substrate through this reach was primarily silt/clay, and it appeared the bottom had degraded or was in the process of degrading.

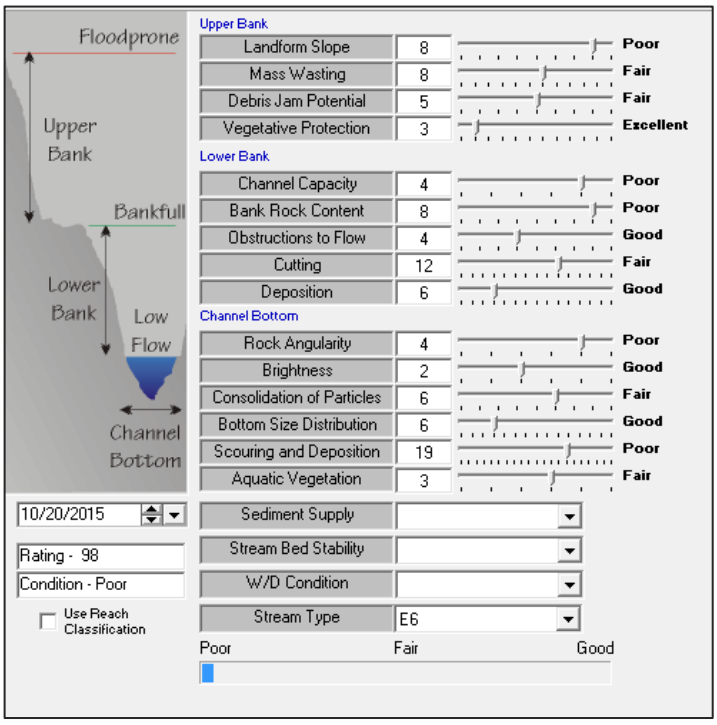

Figure 41. Site 12RN015 Pfankuch score.

Figure 42. Site 12RN015 (photos taken on 10/20/15).

Discussion

In the forested area near the biological monitoring station waypoint, the stream was an unstable E6 (borderline G6), but it appeared to transition to a G6 (gully) downstream through the grassed area. From the road crossing upstream to the biological monitoring station, the stream was both incised and entrenched. Overall, there was a general lack of quality substrate and habitat through this reach. Poor substrate and a lack of base flow (stagnant water was observed) appear to be the main stressors at this site. There was also a beaver dam located just downstream of the biological monitoring station waypoint, so beaver activity could be influencing fish passage throughout this reach (Figure 43). There are two 8.8' high x 14' wide concrete arch culverts at the road crossing. With a bankfull width of approximately 15 feet, this is nearly double the needed capacity, and as a result the right culvert (looking downstream) is completely blocked by sediment; however, the culverts do not appear to be barriers to fish passage.

Figure 43. Site 12RN015 (photo taken on 10/20/15).

Warroad River, East Branch (12RN010)

MPCA biological monitoring station 12RN010 is located on the East Branch of the Warroad River, upstream of County Road 12, approximately five miles south of Warroad. According to USGS StreamStats, the contributing drainage area to this location is 44.2 square miles (Figure 44). Based on NLCD 2011 data, the dominant land cover types within this drainage area are emergent herbaceous wetlands (16.9%) and woody wetlands (68.4%).

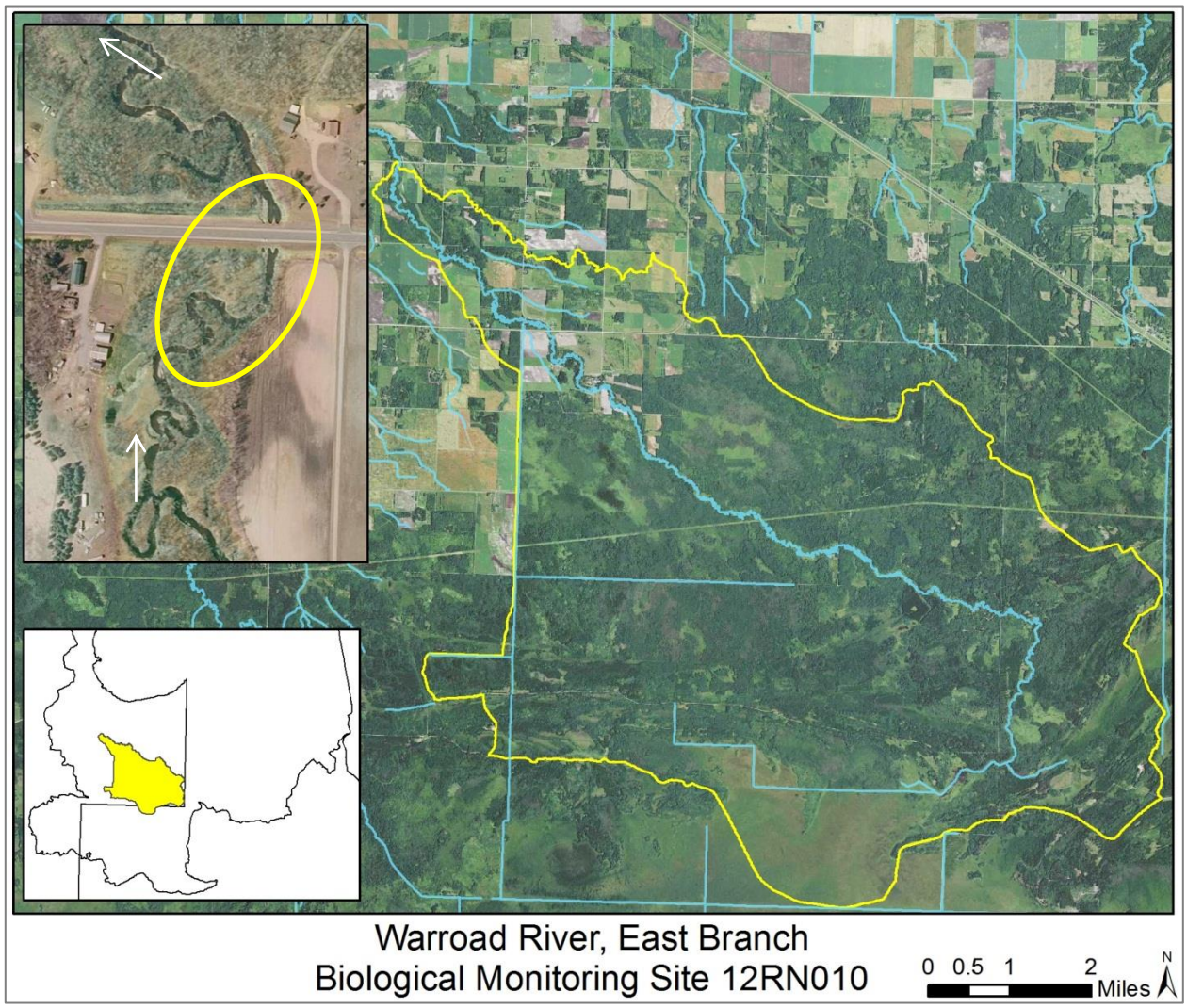

Figure 44. Warroad River, East Branch (site 12RN010) drainage area and aerial close-up view.

The Pfankuch rating for this site was 88, which is *fair* (moderately unstable) for an E4/C4 stream type. A *fair*, or moderately unstable, rating for E4 stream types is 76-96. Most Pfankuch categories ranked as either *poor*, *fair*, or *good* for this site (Figure 45). The upper banks were well vegetated with mature trees, but the *landform slope* ranked poorly because of incision; however, there was no evidence of mass erosion. The lower banks generally ranked in the *fair* to *poor* category because of incision and moderate amounts of debris jams. There was significant cutting occurring on the lower banks with some enlargement of point bars (Figure 46). The bottom through this reach generally ranked in the *good* range. The substrate was primarily gravel with areas of cobble. There were also areas of gravel and cobble over soft clay and areas of sand deposition.

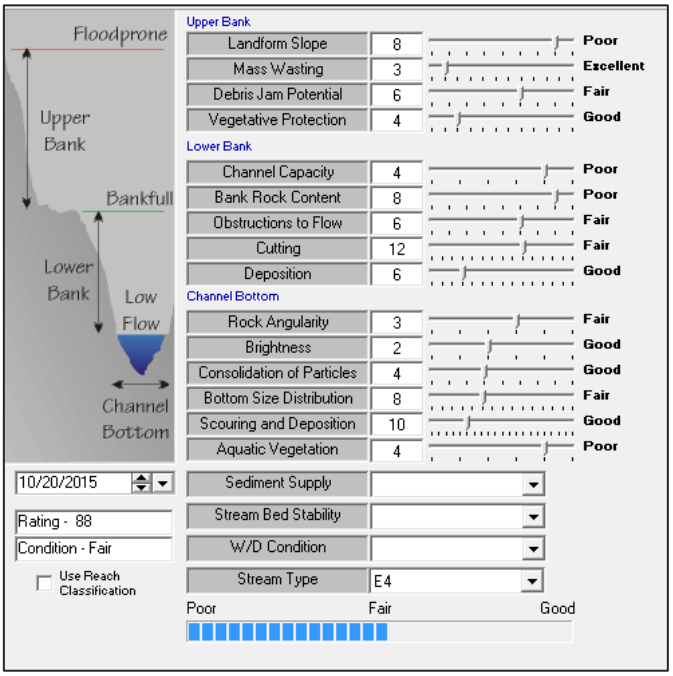

Figure 45. Site 12RN010 Pfankuch score.

Figure 46. Site 12RN010 (photos taken on 10/20/15).

Discussion

The moderately unstable designation for this reach appears to be primarily due to incision; however, the river appears to be only slightly entrenched as there is a wide flood plain at 2x the maximum bankfull depth. There seems to be sufficient base flow and good substrate through this reach, but the pools are lacking in depth and holding cover. There were multiple debris jams observed through this reach, but none that would be barriers to fish passage (Figure 48). The road crossing just downstream of the biological monitoring station has three 8.8' high x 14' wide concrete arch culverts. With an estimated bankfull width of approximately 27 feet there is too much capacity, as evidenced by the left culvert (looking downstream) being completely blocked with sediment (Figure 47).

Figure 48. Site 12RN010 debris jam (photo taken on 10/20/15).

Figure 47. Site 12RN010 culverts (photo taken on 10/20/15).

County Ditch 20 (12RN012)

MPCA biological monitoring station 12RN012 is located on County Ditch 20, just downstream (north) of County Road 12 adjacent to 645th Avenue, approximately five miles southeast of Warroad (Figure 49). According to USGS StreamStats, the contributing drainage area to this location is 9.43 square miles. Based on NLCD 2011 data, the dominant land cover types within this drainage area are cultivated crops (14.7%), pasture/hay (16.8%), emergent herbaceous wetlands (16.8%) and woody wetlands (37.5%).

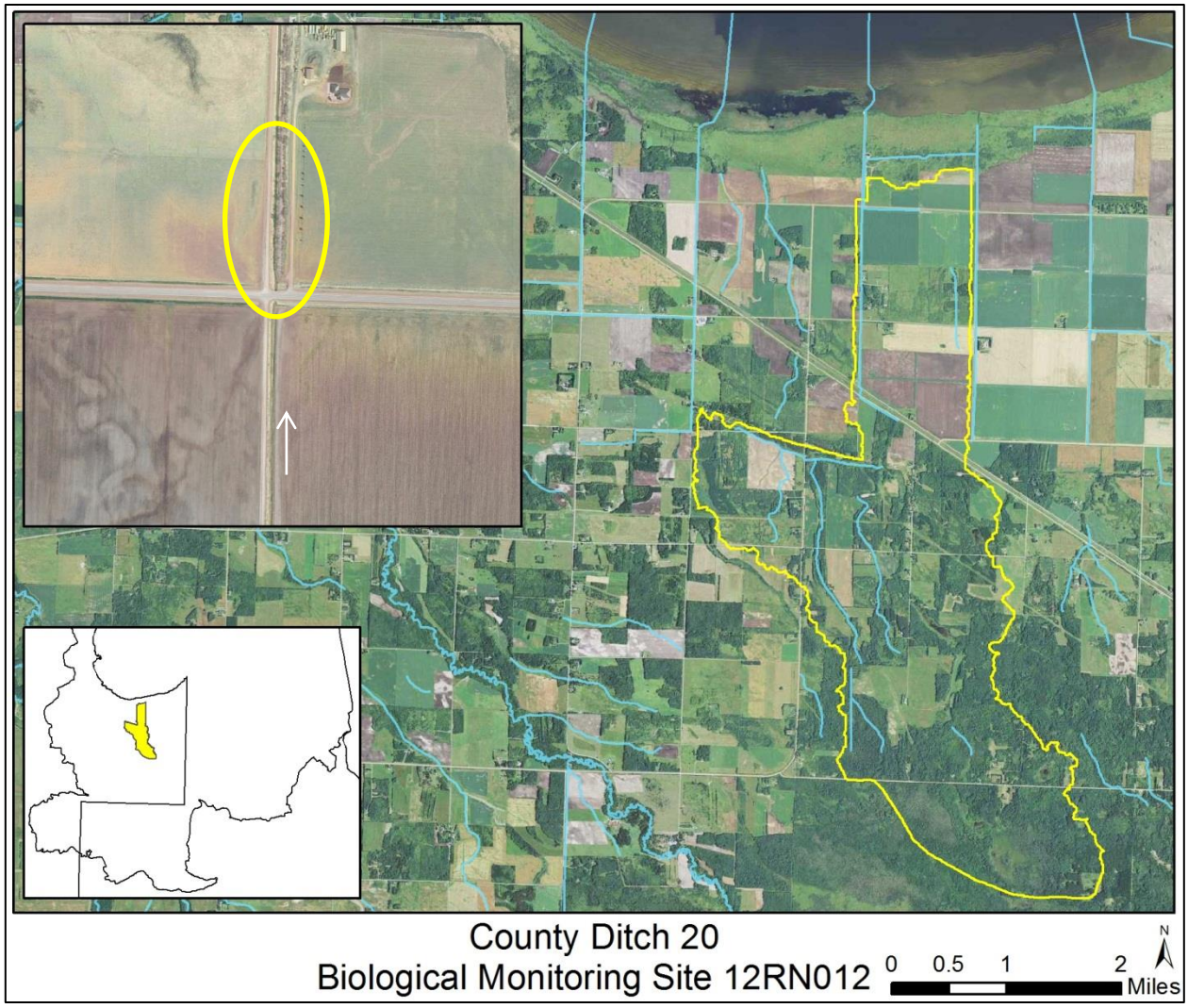

Figure 49. County Ditch 20 (site 12RN012) drainage area and aerial close-up view.

The Pfankuch rating for this site was 56, which is *good* (stable) for an E6 stream type. A *good*, or stable, rating for E6 stream types is 40-63. Most Pfankuch categories ranked as either *good* or *excellent* (Figure 50). The upper banks were well vegetated with grasses and forbs on the left bank and grasses, forbs, and brush on the right bank. There was no evidence of mass wasting, but the top of the left upper bank is bound by a gravel road that runs the length of the ditch until it outlets into Lake of the Woods (Figure 51). The lower banks were also well vegetated with grasses, forbs, and brush and showed little signs of cutting or deposition. Although determining bankfull at this location was difficult, it did appear that the ditch was at least slightly incised and moderately entrenched. The bottom through this reach ranked primarily as *excellent*. Substrate through the reach was clay, and there was abundant aquatic vegetation throughout.

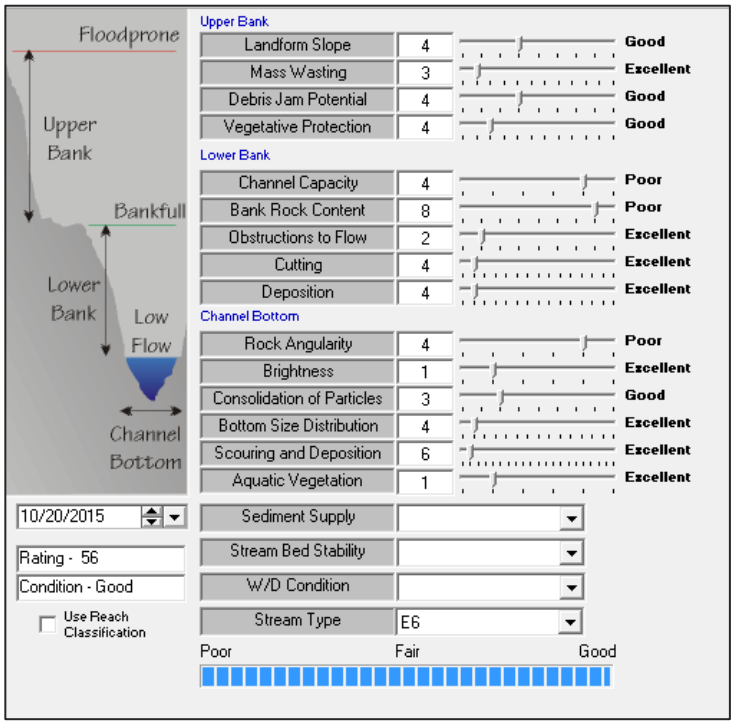

Figure 50. Site 12RN012 Pfankuch score.

Figure 51. Gravel road at site 12RN012 (photo taken on 10/20/15).

Discussion

Although this reach of County Ditch 20 is stable, it is channelized and is generally lacking in facets/habitat, which is likely a stressor for this site (Figure 52). There was no discernable flow at the time of the site visit, likely a result of being in close proximity to Lake of the Woods. Lack of flow could also be contributing to thermal stress in this reach, especially in the absence of vegetation to provide channel shading. There are no crossings or beaver dams between this site and the lake, so fish passage barriers are not an issue.

Figure 52. Site 12RN012 (photo taken on 10/20/15).

Unnamed Ditch (12RN016)

MPCA biological monitoring station 12RN016 is located on an unnamed ditch, just downstream (north) of County Road 17, approximately seven miles north of Roosevelt (Figure 53). According to USGS StreamStats, the contributing drainage area to this location is 12 square miles. Based on the NLCD 2011 data, the dominant land cover types within this drainage area are cultivate crops (17.9%), emergent herbaceous wetlands (19.4%), and woody wetlands (46%).

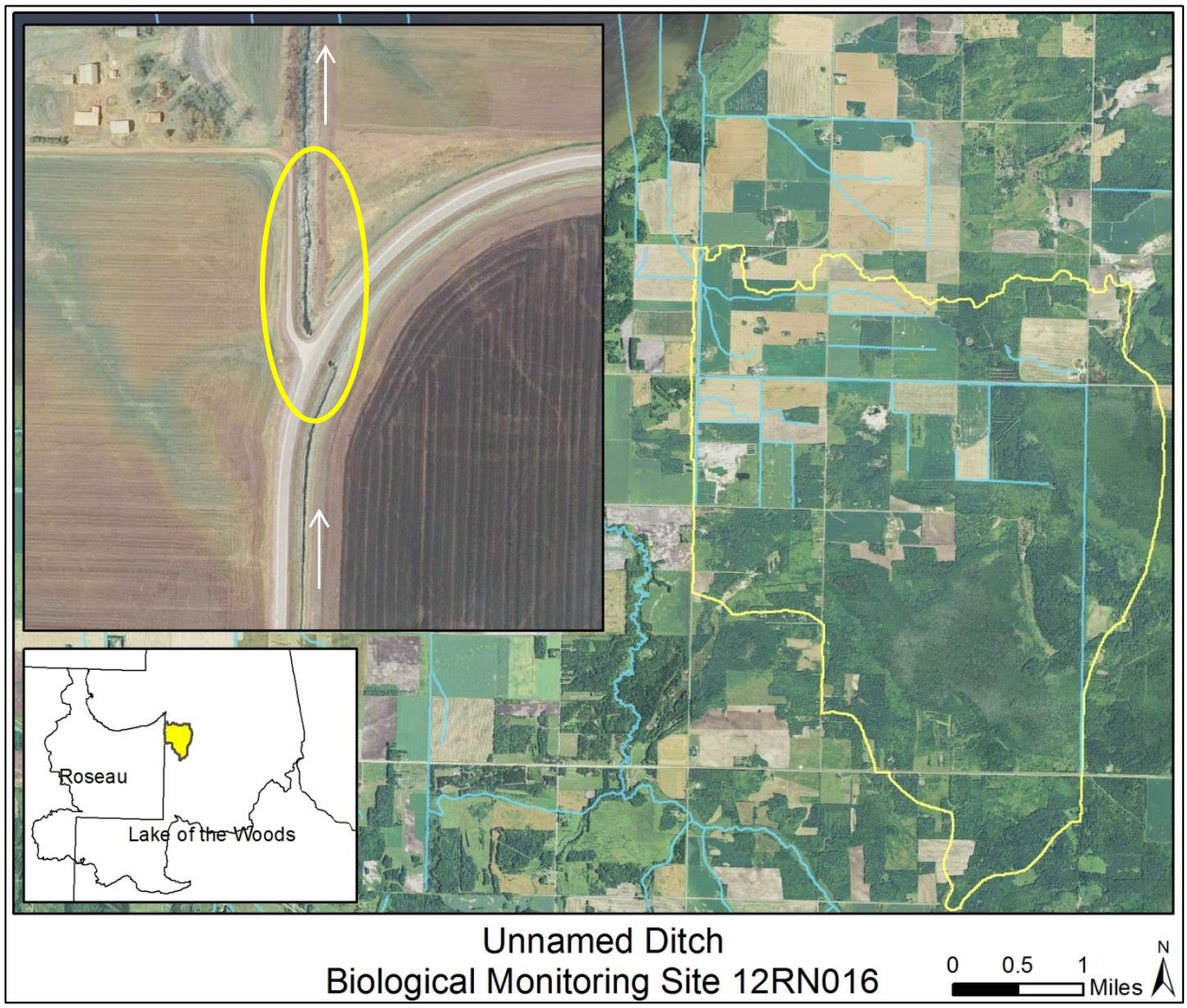

Figure 53. Unnamed Ditch (site 12RN016) drainage area and aerial close-up view.

The Pfankuch rating for this site was 69, which is *good* (stable) for an E4 stream type. A *good*, or stable, rating for E4 stream types is 50-75 (Figure 54). Most categories ranked as either *good* or *excellent*, with only *bank rock content* and *aquatic vegetation* ranking as poor. The upper banks were well vegetated with grasses, forbs, and willow saplings and there was no evidence of mass erosion. The lower banks were also well vegetated and there was very little bank cutting and no deposition on the lower banks (Figure 55). The bottom generally ranked as *good*, with the substrate being primarily small gravel with areas of silt/clay.

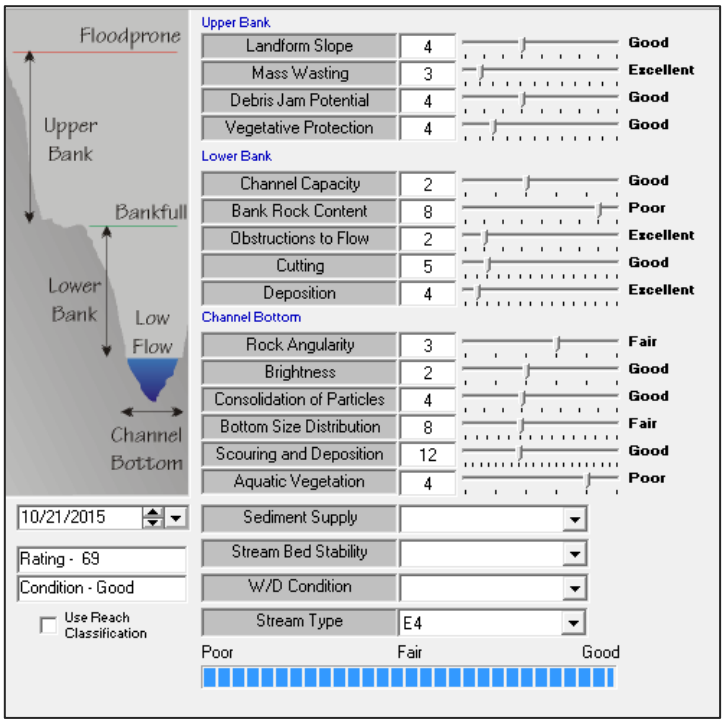

Figure 54. Site 12RN016 Pfankuch score.

Figure 55. Site 12RN016 (photos taken on 10/21/15).

Discussion

This reach of the unnamed ditch is stable, but it is generally lacking in facets/habitat. There was also very little flow at the time of the site visit, which, coupled with the lack of habitat, are likely the primary stressors for this site. Connectivity does not appear to be an issue through this reach, as there is only one crossing approximately 1.25 miles downstream of the biological monitoring station. The crossing appears to be a span-type bridge with no abutments and is not affecting fish passage.

Conclusions

The purpose of the field work component of this report was to assess stream stability at MPCA biological monitoring stations using the modified Pfankuch channel stability rating (Pfankuch 1975; Rosgen 1996). Observations were made at nine biological monitoring stations that are potentially non-supporting for fish and macroinvertebrates. Six out of the nine sites rated as *good* (stable), two rated as *fair* (moderately unstable), and one rated as *poor* (unstable). Interestingly, the *fair* and *poor* rated sites were located in reaches with natural channels that hadn't been ditched; whereas all four of the ditched sites rated as *good*. Even though ditched sites were stable, they were generally lacking in fish habitat and the typical dimension, pattern, and profile of natural, meandering streams.

The Pfankuch stability ratings are only a snapshot of short reaches, and while helpful, do not get at what might be driving instability where it exists. In general, instability can be attributed to land use changes and altered hydrology. Watercourses are formed by the water and sediment that they carry downstream. Changes to either the supplied water (timing and quantity) or sediment (particle size or quantity) drives watercourses toward instability as they adjust. Altered water courses are frequently maintained to maximize their ability to transport water at the expense of efficient sediment transport. It is important to also acknowledge that natural waterways also need to efficiently route sediment downstream. When assessing whether a watercourse is stable, it is important to evaluate its ability to move both water and sediment.

To better assess drivers of instability throughout the watershed, a more comprehensive, watershed-wide geomorphology assessment would be useful. A *Watershed Assessment of River Stability and Sediment Supply* (WARSSS) study (Rosgen 2009) could help to focus in on areas where land use is having an effect on sediment supply and channel stability. The Level II stream classification component of a WARSSS study would also help to establish a baseline of stream conditions in the watershed so that changes can be tracked over time and reference conditions can be documented where they exist.

Additional recommendations would be an assessment of road crossings throughout the watershed, or at least where streams are unstable and appear to not be meeting biological standards, as improperly designed and installed crossings can have a significant impact on stream stability and fish passage. The restoration of ditched and degraded reaches, where feasible, would help to restore proper stream function as it relates to water and sediment conveyance, and thereby improve in-stream fish and macroinvertebrate habitat. Similarly, exploring the restoration of peatlands and other areas of altered land use should improve hydrological function throughout the watershed. Perhaps just as important as restoring degraded areas of the watershed is identifying those areas in the watershed that are worthy of protection.

Finally, having a more robust, long-term set of stream gage data would help to explain how flow and discharge are changing over time in response to changes in precipitation and land use. Throughout the United States portion of the Lake of the Woods watershed, there are two lake gages

(Warroad and Spring Steel Island) and two stream gages (East and West Branches of Warroad River); however, the stream gages have a short period of record dating back only to September 2012. Maintaining these gages, as well as installing others, would provide valuable data and insight into processes occurring in the Lake of the Woods watershed.

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