Grand Marais Creek Watershed Stressor Identification Report

A study of the stressors limiting the aquatic biological communities in the Grand Marais Creek Watershed.

Minnesota Pollution Control Agency

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Cover Photo

Grand Marais Creek outlet restoration

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Acronyms

AUID – Assessment Unit Identification

BEHI – Bank Erosion Hazard Index

BMP – Best Management Practice

CADDIS – Causal Analysis/Diagnosis Decision Information System

CD – County Ditch

CR – County Road

CSAH – County State Aid Highway

DO – Dissolved Oxygen

GMCW – Grand Marais Creek Watershed

HSPF – Hydrological Simulation Program - FORTRAN

HUC – Hydrologic Unit Code

IBI – Index of Biological Integrity

IWM – Intensive Watershed Monitoring

MDNR – Minnesota Department of Natural Resources

MPCA – Minnesota Pollution Control Agency

MSHA – MPCA Stream Habitat Assessment

MSTRWD – Middle-Snake-Tamarac Rivers Watershed District

NAIP – National Agriculture Imagery Program

NBS – Near Bank Stress

NLCD – National Land Cover Database

RLWD – Red Lake Watershed District

SI – Stressor identification

SOE – Strength-of-Evidence

TALU – Tiered Aquatic Life Use

TIVs – Tolerance Indicator Values

TMDL – Total Maximum Daily Load

TSS – Total Suspended Solids

USEPA – United States Environmental Protection Agency

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 81 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. In 2012, the MPCA conducted biological monitoring at several stations in the Grand Marais Creek Watershed (GMCW). 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. A stream segment with a low IBI score(s) (i.e., below an established threshold) is considered "impaired" or unable to support its designated beneficial use for aquatic life. Three reaches were determined to have a F-IBI and/or M-IBI impairment in the GMCW: County Ditch 2, County Ditch 43 and Judicial Ditch 75.

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 physical connectivity, lack of base flow, lack of instream 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 ranks the stressors identified for each reach in the GMCW by the strength of supporting evidence.

Table 1. Summary of the stressors associated with the biologically impaired reaches in the GMCW.

AUID Suffix	Reach Name	Biological Impairment(s)	Candidate Causes[1]				
			Loss of Physical Connectivity	Lack of Base Flow	Lack of Instream Habitat	High Suspended Sediment	Low Dissolved Oxygen
515	County Ditch 2	F-IBI	++	+++	++		+
		M-IBI		+++	++	+	+
517	County Ditch 43	F-IBI	++	+++	++	+	+
		M-IBI		+++	++	+	+
520	Judicial Ditch 75	F-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.

A lack of base flow is a prominent stressor for all three reaches and associated biological impairments. The reaches are prone to extended periods of intermittency, particularly in the latter summer months. The reaches also inherently lack instream habitat due to their construction (i.e., traditional, trapezoidal design) and physiographic setting (i.e., lake plain). All of the reaches are prone to periods of low DO, which appear to coincide with low flow conditions. High suspended sediment is contributing to the M-IBI impairments in the watershed. Lastly, a loss of physical connectivity is a stressor for the F-IBI impairments in the watershed.

Introduction

Stressor identification (SI) is a formal and rigorous methodology for determining the causes, or "stressors", that are likely contributing to the biological impairment of aquatic ecosystems (USEPA, 2000). The initial step in the SI 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 SI 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.

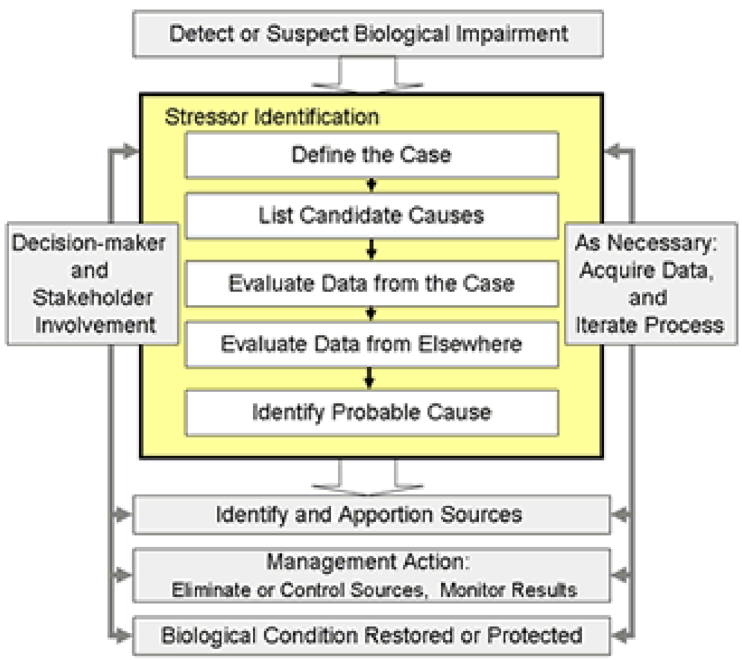


Figure 1. Conceptual model of the SI process (USEPA 2012).

Section 1: Watershed overview

1.1 Physical setting

The Grand Marais Creek Watershed (GMCW), United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 09020306, is situated in northwestern Minnesota and is part of the larger Red River of the North Basin. The GMCW has a drainage area of 592 square miles and encompasses portions of the following counties, listed in order of the percentage of watershed area: Polk (85%), Marshall (12%), and Pennington (3%). The City of Oslo is the only incorporated community in the watershed.

1.2 Surface water resources

The Grand Marais Creek is the prominent surface water feature in the GMCW and extends from its headwaters, situated southeast of East Grand Forks, to its confluence with the Red River of the North, located south of the City of Oslo. The GMCW contains 69 miles of perennial stream and river (e.g., Grand Marais Creek), 147 miles of intermittent stream, one mile of perennial drainage ditch, and 352 miles of intermittent drainage ditch (MDNR, 2003). According to the MPCA (2013), 70% of the watercourses in the GMCW have been hydrologically altered (i.e., channelized, ditched, or impounded). There are no lakes in the watershed.

1.3 Geology and soils

The GMCW intersects the beach ridges and lake plain physiographic regions. The beach ridges region encompasses approximately the eastern one-third of the watershed. The region represents the ancient shorelines of glacial Lake Agassiz. The soils of this region are generally coarse textured and derived from sand and gravel deposits. The western portion of the watershed represents the lake plain of Glacial Lake Agassiz. This region is characterized by an extremely flat topography (0-1% slope) and very fine textured soils derived from lacustrine sediments.

1.4 Land use and ecoregions

The predominant land use in the GMCW is agricultural crop production. According to the National Land Cover Database (NLCD) 2011 (USGS, 2011), cultivated crops comprised 91% of the watershed. Notable minor land cover groups in the watershed included developed areas (4%), open water (1%), wetlands (1%), and forest (1%). The entire watershed is located within the Lake Agassiz Plain ecoregion.

1.5 Ecological health

The Minnesota Department of Natural Resources (MDNR) 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 GMCW. The mean health score for the watershed was 42. The overall score was limited by the individual mean component scores for biology

(34) and connectivity (18). Specifically, the watershed scored poorly for the following component indices: at-risk species richness (40), aquatic connectivity (34), water quality assessments (25), riparian connectivity (20), storage (11), perennial cover (3), terrestrial habitat connectivity (1), climate vulnerability (0), and terrestrial habitat quality (0).

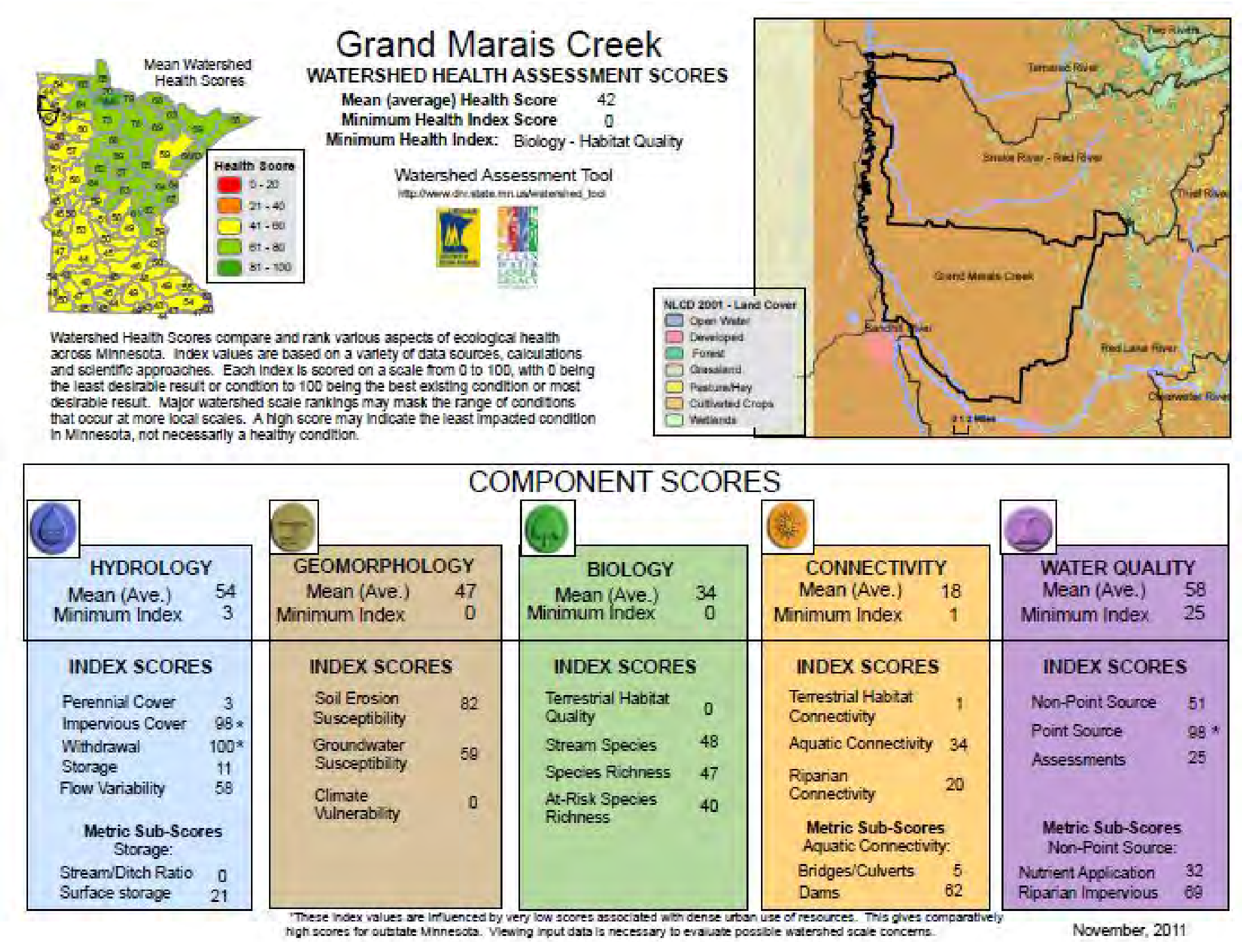


Figure 2. Watershed health assessment scores for the GMCW.

1.6 Hydrological Simulation Program – FORTRAN (HSPF) Model

A Hydrological Simulation Program – FORTRAN (HSPF) model was developed for the GMCW 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. It is the only comprehensive model of watershed hydrology and water quality that 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 81 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. In 2012, the MPCA conducted biological monitoring at several stations throughout the GMCW. 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 GMCW are the focus of this SI report. The results of the SI 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.

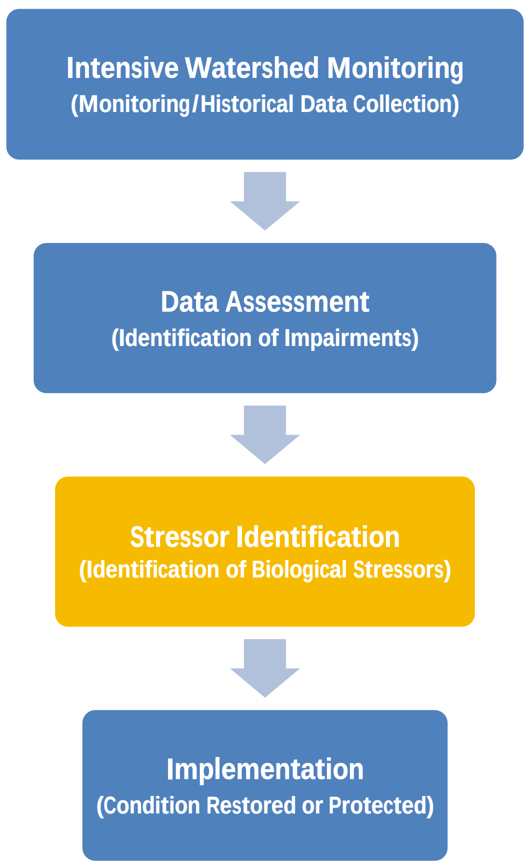


Figure 3. Conceptual model of the watershed approach processes.

2.2 Monitoring stations

Table 2 lists the seven biological monitoring stations that were sampled for fish and/or macroinvertebrates in the GMCW. The stations are situated along four 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 GMCW.

AUID Suffix	AUID	Reach Name	Monitoring Station(s)
512	09020303-512	Grand Marais Creek	12RD097
515	09020303-515	County Ditch 2	05RD098, 12RD100
517	09020303-517	County Ditch 43	12RD087, 12RD089, 07RD023
520	09020303-520	Judicial Ditch 75	12RD098

2.3 Monitoring results

Table 3 provides the F-IBI and M-IBI scores for each of the biological monitoring stations in the GMCW. All of the stations scored below their respective F-IBI impairment threshold, while five of the stations scored below their respective 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 GMCW.

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)
512	12RD097	SS (MU)	35	18	512	Not Sampled (Insufficient Flow)			
515	05RD098	SS (MU)	35	29	515	05RD098	PS (MU)	22	15
515	12RD100	SS (MU)	35	19	515	12RD100	PS (MU)	22	11
517	07RD023	NH (MU)	23	0	517	07RD023	PS (MU)	22	14
517	12RD087	SS (MU)	35	13	517	12RD087	PS (MU)	22	5
517	12RD089	SS (MU)	35	13	517	12RD089	PS (MU)	22	13
520	12RD098	SS (MU)	35	0	520	12RD098	PS (MU)	22	32

[1] F-IBI Classes: Northern Headwaters (NH) and Southern Streams (SS)
[2] M-IBI Class: Prairie Streams-Glide/Pool Habitats (PS)
[3] Tiered Aquatic Life Use (TALU) Framework Designation: Modified Use (MU)

2.4 Assessments and impairments

The biological monitoring results for the GMCW were formally assessed as part of the development of the *Grand Marais Creek Watershed Monitoring and Assessment Report* (MPCA, 2015) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 4, three 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 GMCW.

AUID Suffix	AUID	Reach Name	Description	Length (mi)	Biological Impairment(s)
512	09020306-512	Grand Marais Creek	County Ditch 2 to Red River of the North	2	Not Assessed
515	**09020306-515**	**County Ditch 2**	**County Ditch 66 to Grand Marais Creek**	**11**	**F-IBI/M-IBI**
517	**09020306-517**	**County Ditch 43**	**Unnamed Ditch to County Ditch 7**	**24**	**F-IBI/M-IBI**
520	**09020306-520**	**Judicial Ditch 75**	**County Ditch 7 to Red River of the North**	**13**	**F-IBI**

In addition to biological impairments, there are two reaches in the GMCW that were included on the 2012 Impaired Waters List for water quality impairments affecting aquatic life (Table 5). AUID 507 was listed for low dissolved oxygen, high pH, and high turbidity. AUID 512 was listed for high turbidity; AUID 515 is a tributary of this reach.

Table 5. Water quality impairments associated with reaches in the GMCW (2012 Impaired Waters List).

AUID Suffix	AUID	Reach Name	Description	Water Quality Impairment(s)
507	09020306-507	Grand Marais Creek	Headwaters to CD 2	Dissolved Oxygen, pH, Turbidity[1]
512	09020306-512	Grand Marais Creek	CD 2 to Red River of the North	Turbidity[1]

[1] The MPCA has replaced the turbidity standard with a total suspended solids standard.

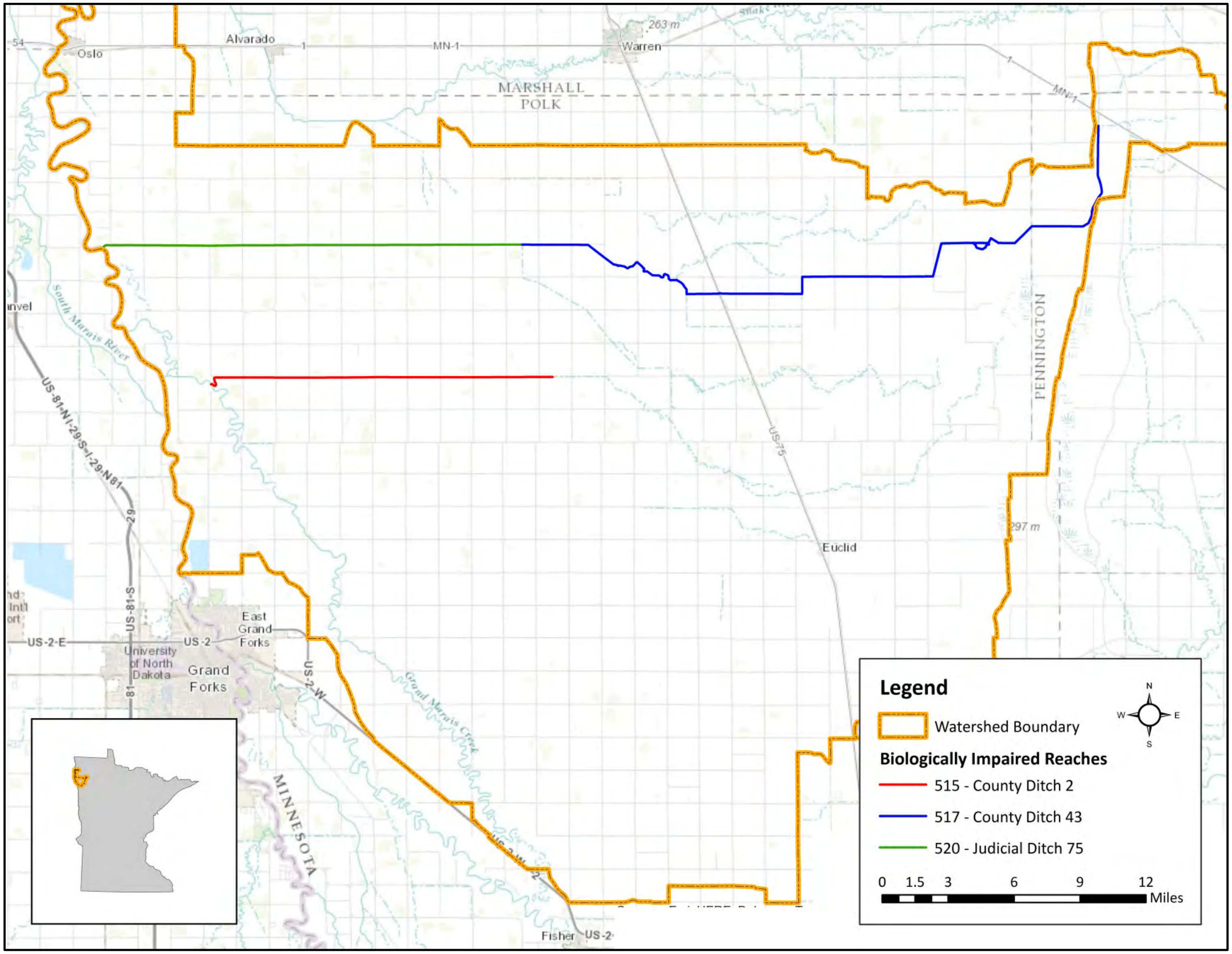


Figure 4. Map of the GMCW and associated biologically impaired reaches.

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" (USEPA, 2012). Identification of a set of candidate causes is an important early step in the SI process and provides the framework for gathering key data for causal analysis. Table 6 lists the nine common biotic stressors that were considered as potential candidate causes in the GMCW. The list was developed based upon the results of the *Red River Valley Biotic Impairment Assessment* (EOR, 2009) and other completed SI reports in the state. The credibility of each stressor as a candidate cause 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 *Grand Marais Creek Watershed Monitoring and Assessment Report* (MPCA, 2015), the *Middle-Snake-Tamarac Rivers Watershed District's Ten Year Watershed Management Plan* (MSTRWD, 2011), and the *Red Lake Watershed District's 10-Year Comprehensive Plan* (RLWD, 2006). 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 GMCW.

Stressor	Candidate Cause Identification - GMCW Biologically Impaired Reaches	
	Summary of Available Information	Candidate Cause (Yes/No)
Loss of Physical Connectivity	Several of the biologically impaired reaches have connectivity barriers (e.g., dams and beaver dams) that are potentially limiting fish passage.	Yes
Lack of Base Flow	Many of the biologically impaired reaches are prone to periods of intermittency.	Yes
Lack of Instream Habitat	Several of the biologically impaired reaches have insufficient instream habitat for aquatic biota.	Yes
High Suspended Sediment	Several of the biologically impaired reaches are prone to periods of high suspended sediment that are above the level expected to cause stress to aquatic biota.	Yes
Low Dissolved Oxygen	Many of the biologically impaired reaches are prone to periods of low dissolved oxygen that are below the level expected to cause stress to aquatic biota.	Yes
High Nitrate	Nitrate concentrations associated with the biologically impaired reaches were low and below the level expected to cause stress to aquatic biota.	No
Temperature Regime Alteration	Temperature values associated with the biologically impaired reaches were within a range that is not expected to cause stress to aquatic biota.	No
pH	Values for pH associated with the biologically impaired reaches were within a range that is not expected to cause stress to aquatic biota.	No
Pesticide Toxicity	There is no pesticide data for the biologically impaired 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 physical 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 MDNR (2014a), 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 (or perched) above the stream level can limit the ability of fish to migrate throughout the stream. A similar phenomenon can occur naturally with beaver dams acting as barriers to fish migration.

Applicable standards

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

3.2.2 Lack of 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).

In the Red River of the North Basin, evapotranspiration generally exceeds precipitation by two to ten inches on an annual basis (EOR, 2009). As a result, streams in the basin are inherently prone to intermittency (EOR, 2009). Additionally, the natural flow regime of many streams in the basin 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; EOR, 2009).

Fish and macroinvertebrates vary in their preferences for flow characteristics. A lack of base flow tends to favor taxa that are adapted to lentic conditions, while often reducing stream productivity and species diversity (USEPA, 2012). Generally, fish take longer to recover from the effects of extreme low flow conditions than macroinvertebrates (Griswold et al., 1982).

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

Applicable standards

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

3.2.3 Lack of instream habitat

Background

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community (USEPA, 2012). Healthy biotic communities have diverse instream habitat, enabling fish and macroinvertebrate habitat specialists to prosper. Instream 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 (USEPA, 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 GMCW. 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 USEPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for lack of instream habitat as a candidate cause for impairment.

Applicable standards

There are no applicable standards for instream habitat.

3.2.4 High suspended sediment

Background

Total suspended solids (TSS) is a measurement of the weight of suspended mineral (e.g., soil particles) or organic (e.g., algae) sediment per volume of water. Klimetz and Simon (2008) indicated that streams in the Red River of the North Basin had the highest median suspended sediment concentration of any region in Minnesota, with the exception of the Western Corn Belt Plains ecoregion (e.g., the Minnesota River Basin). Soil erosion from agricultural fields is believed to be the largest source of sediment to streams in the basin (Lauer et al., 2006). Modified headwater (i.e., first and second order) streams convey much of this sediment to receiving waters (EOR, 2009). The majority of the annual suspended sediment load associated with the streams in the basin is discharged between the months of March and May, when agricultural fields are particularly vulnerable to erosion (EOR, 2009).

According to Waters (1995), high suspended sediment can cause harm to fish and macroinvertebrates through two major pathways: 1) direct, physical effects (e.g., abrasion of gills and avoidance behavior) 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 USEPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for high suspended sediment as a candidate cause for impairment.

Applicable standards

All of the biologically impaired reaches in the GMCW are located in the Southern River TSS Region. The state TSS standard for this region is 65 mg/L.

3.2.5 Low dissolved oxygen

Background

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. 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). 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. In most streams and rivers, the critical conditions for DO usually occur during the late summer, when the water temperature is high and stream flow is low. Low DO can also be an issue in streams with high biological oxygen demand and high groundwater seepage (Hansen, 1975).

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

Applicable standards

The state water quality standard for DO is 5.0 mg/L as a daily minimum for Class 2B and 2C waters; this includes all of the biologically impaired reaches of the GMCW. For additional information regarding this standard, refer to the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List.

3.3 Causal analysis – Profile of individual biologically impaired reaches

3.3.1 County Ditch 2 (AUID 515)

Physical setting

This reach represents County Ditch (CD) 2 (Figure 5), which extends from its confluence with CD 66, to its outlet to Grand Marais Creek; a total length of 11 miles. The reach has a subwatershed area of 104 square miles (66,600 acres). Although the reach is entirely located in the lake plain region of the GMCW, the eastern half of its subwatershed lies within the beach ridges region. The subwatershed contains 46 miles of intermittent stream, 31 miles of intermittent drainage ditch (e.g., AUID 515), and less than one mile perennial stream (MDNR, 2003). 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 515. The NLCD 2011 (USGS, 2011) lists cultivated crops (92%) as the predominant land cover in the subwatershed. Notable minor land cover groups in the subwatershed included developed areas (5%), wetlands (1%), forest (1%), and open water (1%).

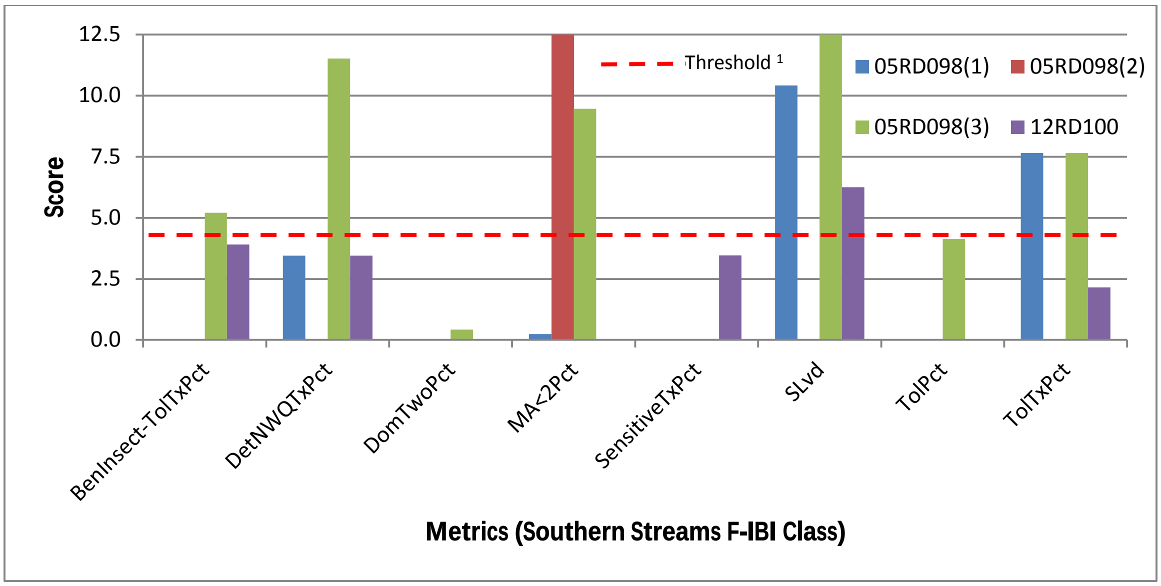
Figure 5. Map of AUID 515 and associated biological monitoring stations and water quality monitoring site (2010 National Agriculture Imagery Program (NAIP) aerial image).

Biological impairments

Fish (F-IBI)

The fish community of AUID 515 was monitored at Station 05RD098 (0.1 mile upstream of the State Highway 220 crossing) on August 23, 2005(1), July 18, 2012(2), and August 16, 2012(3); and Station 12RD100 (0.1 mile upstream of the 410th Avenue NW crossing) on June 14, 2012. The relative location of the stations is shown in Figure 5. The stations were designated as Modified Use within the Southern Streams F-IBI Class. Accordingly, the impairment threshold for the stations is an F-IBI score of 35. Both stations yielded F-IBI scores below the impairment threshold; Station 05RD098 had a mean score of 29, while Station 12RD100 had a score of 19.

Figure 6 provides the individual F-IBI metric scores for the fish monitoring stations along AUID 515; a description of each metric is provided in Appendix A. Station 05RD098 had at least one sampling event that scored below the threshold score for each of the metrics. Additionally, the station had three metrics that scored below the threshold score for all three sampling events (i.e., DomTwoPct, SensitiveTxPct, and TolPct). Station 12RD100 had seven metrics that scored below the threshold score (i.e., BenInsect-TolTxPct, DetNWQTxPct, DomTwoPct, MA<2Pct, SensitiveTxPct, TolPct, and TolTxPct). Overall the fish assemblage of both stations was dominated by tolerant species (e.g., black bullhead and fathead minnow).



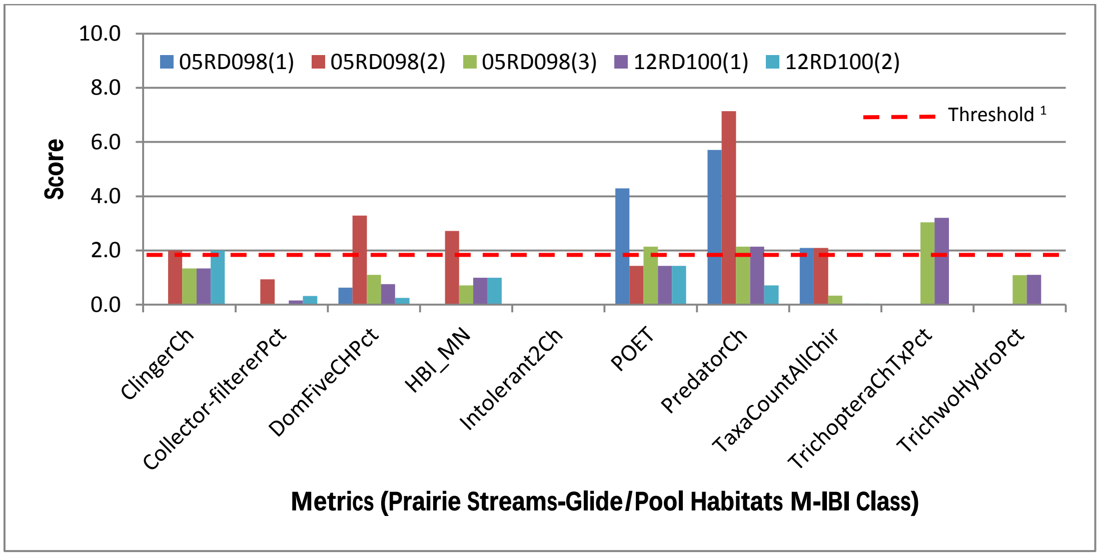
[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 6. Individual F-IBI metric scores for Stations 05RD098 and 12RD100 along AUID 515.

Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 515 was monitored at Station 05RD098 on September 12, 2005(1), September 27, 2005(2), and August 8, 2012(3); and Station 12RD100 on August 1, 2012. Station 12RD100 was sampled twice on the same date. Both of the stations were designated as Modified Use within the Prairie Streams-Glide/Pool Habitats M-IBI Class. Accordingly, the impairment threshold for the stations is an M-IBI score of 22. Monitoring of the stations yielded M-IBI scores below the impairment threshold; Station 05RD098 had a mean score of 15 and Station 12RD100 had a mean score of 11.

Figure 7 provides the individual M-IBI metric scores for the macroinvertebrate monitoring stations along AUID 515; a description of each metric is provided in Appendix B. Both stations scored below the threshold score for five metrics (i.e., ClingerCh, Collector-filtererPct, Intolerant2Ch, TaxaCountAllChir, and TrichwoHydroPct). The macroinvertebrate assemblage of the stations was dominated by tolerant taxa, specifically Coenagrionidae (damselflies) and *Gyraulus* (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 Stations 05RD098 and 12RD100 along AUID 515.

Candidate causes

Loss of physical connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues during the sampling of Stations 05RD098 and 12RD100 along AUID 515. According to the MDNR (2014b), there are no man-made dams on the reach. On September 24, 2014, MPCA SI staff conducted a connectivity assessment along the reach. A large rock check dam (Figure 8) was documented within the channel immediately upstream of the confluence with the Grand Marais Creek. Based upon aerial photo reconnaissance, the rock check dam was presumably installed between June 23, 2010 and September 6, 2011. The rocks obstruct connectivity along the reach during low and, likely, moderate flow conditions. On July 30, 2014, staff viewed the site nine days after a large storm event and the rocks did not appear to be obstructing connectivity at that time (Figure 8). In addition to the assessment, MPCA SI staff performed a detailed review of an April 2, 2012, aerial photo of the reach; the photo was acquired approximately two months prior to fish sampling at Station 12RD100. No additional connectivity-related issues were identified in the photo.

Figure 8. Photos of a rock check dam along AUID 515 immediately upstream of its confluence with the Grand Marais Creek on July 30, 2014 (left) and September 24, 2014 (right).

Biotic response – fish

Evidence of a causal relationship between a loss of physical connectivity and the F-IBI impairment associated with AUID 515 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 05RD098 and 12RD100:

- Low relative abundance of individuals with a female mature age of equal to or greater than three years (MA>Pct)
- Low relative abundance of individuals that are migratory (MgrPct)

Late maturing and migratory fish species require well-connected environments in order to access the habitats and resources necessary to complete their life history. On August 23, 2005, Station 05RD098 was sampled and the fish assemblage included several late maturing and migratory fish species (i.e., channel catfish, freshwater drum, and walleye). The station was subsequently sampled on July 18, 2012 and August 16, 2012, which was after the presumed installation of the rock check dam, and the fish assemblage did not include any of these fish species. However, the fish assemblage of Station 12RD100 included young-of-the-year white sucker, which suggests that adult fish of this species were able to migrate upstream of the rock check dam, likely during high flow conditions, to spawn. White sucker commonly migrate up into the headwater region of waterways to reproduce (Paulson and Hatch, 2004). The influence of culverts along the reach on fish passage during high flow periods is unknown.

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of physical connectivity and the M-IBI impairment associated with AUID 515. Macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by physical connectivity barriers.

Lack of base flow

Available data

The MPCA biological monitoring staff did not encounter any flow-related issues during fish and macroinvertebrate sampling at Stations 05RD098 and 12RD100 along AUID 515. The RLWD and/or MPCA conducted continuous flow monitoring at Site S004-131 (410th Avenue NW crossing) in 2006 (Figure 9) 2007 (Figure 10), 2013 (Figure 11), and 2014 (Figure 12); the relative location of the site is shown in Figure 5. Collectively, the highest peak flow was 1264 cubic feet per second (cfs), while the lowest flow was 0 cfs. No flow represented 70% of the period of record in 2006, 61% of the period of record in 2007, 69% of the period of record in 2013, and 24% of the period of record in 2014. The GMCW HSPF model estimates that the reach had minimal (<1 cfs) to no flow approximately 27% of the time during the period of 1996 to 2009. The MPCA SI staff conducted reconnaissance along the reach on four separate dates (i.e., July 2, 2014, July 23, 2014, July 30, 2014, and September 24, 2014) and documented flow conditions. Staff observed intermittent flow conditions (i.e., interspersed pools of stagnant water) along the reach at the time of the last visit (Figure 13). Overall, the available information suggests that the reach is prone to frequent periods of minimal to no flow.

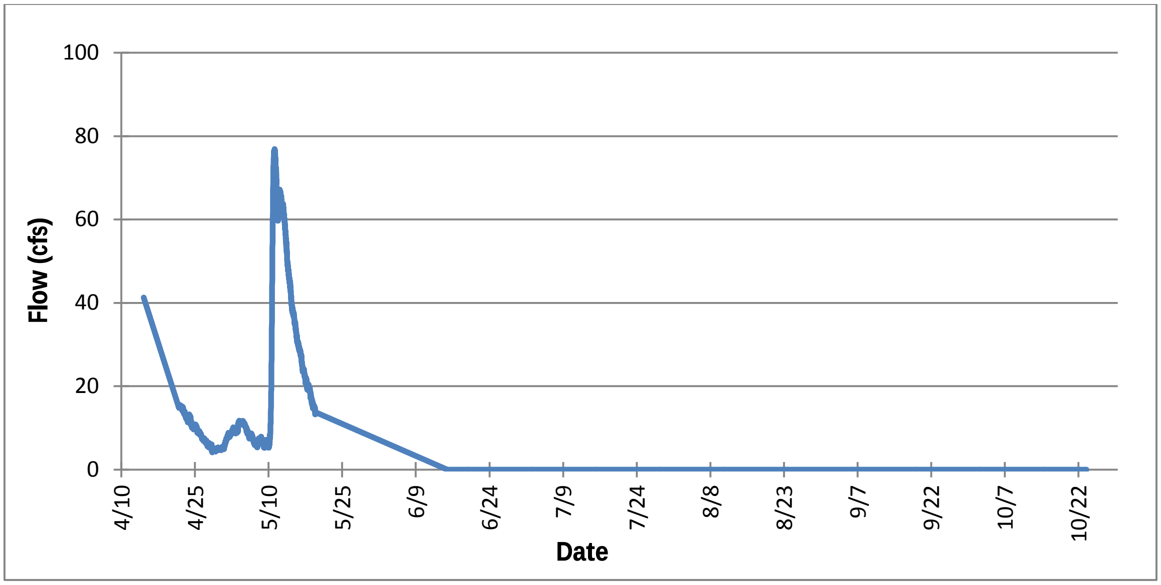


Figure 9. Continuous flow data (April 14, 2006, to October 23, 2006) for Site S004-131 along AUID 515.

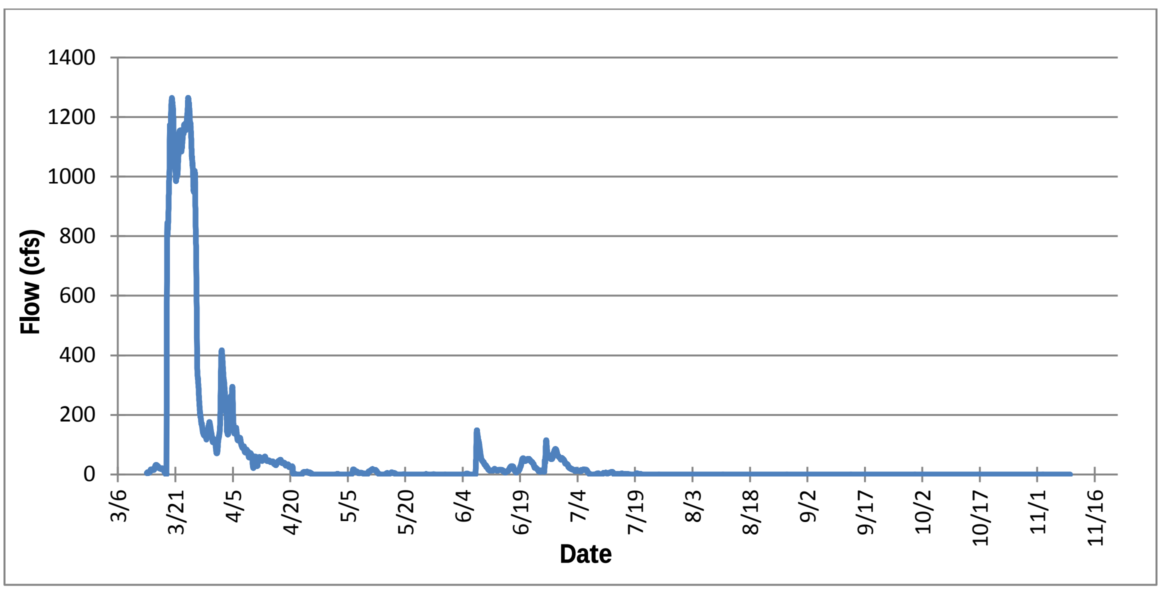


Figure 10. Continuous flow data (March 13, 2007, to November 9, 2007) for Site S004-131 along AUID 515.

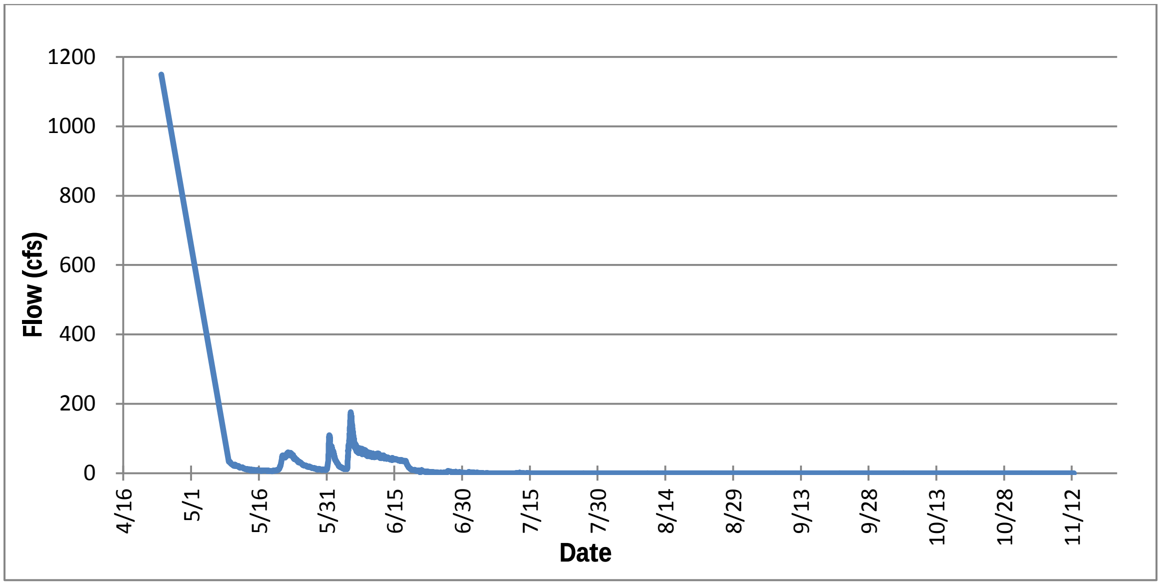


Figure 11. Continuous flow data (April 24, 2013, to November 12, 2013) for Site S004-131 along AUID 515.

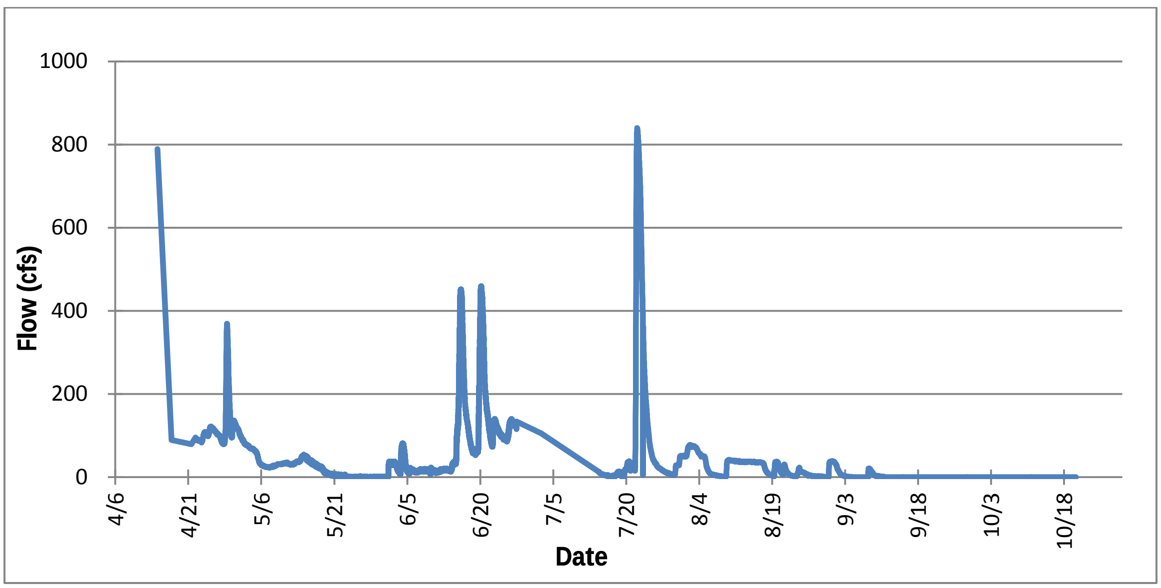


Figure 12. Continuous flow data (April 14, 2014, to October 20, 2014) for Site S004-131 along AUID 515.

Figure 13. Photos of intermittent flow conditions along AUID 515 on September 24, 2014, including the 360th Avenue NW crossing (upper left), the 370th Avenue NW crossing (upper right), the 380th Avenue NW crossing (lower left), and the 440th Avenue NW (lower right).

Biotic response – fish

Evidence of a causal relationship between a lack of base flow and the F-IBI impairment associated with AUID 515 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 05RD098 and 12RD100:

- High combined relative abundance of the two most abundant taxa (DomTwoPct)
- High relative abundance of taxa that are generalists (GeneralTxPct)
- High relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct)
- Low number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are trophic generalists, early maturing, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). According to Figure 6, five of the aforementioned individual metrics (i.e., DomTwoPct, MA<2Pct, SensitiveTxPct, TolPct, and TolTxPct) were used in the calculation of the F-IBI score(s) for Stations 05RD098 and 12RD100. Both stations had a “low” score(s) for each of these metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach.

Biotic response – macroinvertebrate

Evidence of a causal relationship between a lack of base flow and the M-IBI impairment associated with AUID 515 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 05RD098 and 12RD100:

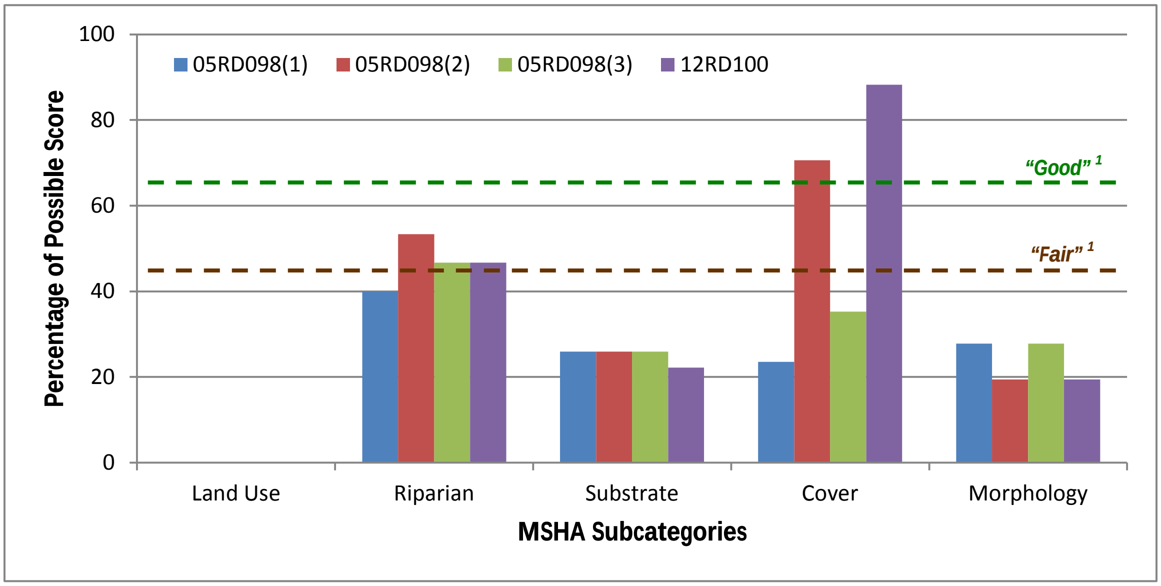
- Low relative abundance of collector-filterer individuals (Collector-filtererPct)
- High relative abundance of the dominant five taxa in a subsample (DomFiveCHPct)
- Low taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch)
- Low relative abundance of long-lived individuals (LongLivedPct)
- Low taxa richness of Plecoptera (Plecoptera)
- Low taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET)
- Low total taxa richness of macroinvertebrates (TaxaCountAllChir)
- High relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

Frequent and/or prolonged periods of minimal to no flow tends to limit species 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 (USEPA, 2012; Klemm et al., 2002, Poff and Zimmerman, 2010). According to Figure 7, seven of the aforementioned individual metrics (i.e., Collector-filtererPct, DomFiveCHPct, Intolerant2Ch, POET, TaxaCountAllChir, TrichopteraChTxPct, and TrichwoHydroPct) were used in the calculation of the M-IBI scores for Stations 05RD098 and 12RD100. Both stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. Overall, the macroinvertebrate assemblage of the stations was dominated by taxa that are adapted to lentic conditions (e.g., Coenagrionidae and *Gyraulus*).

Lack of instream habitat

Available data

The instream habitat of Stations 05RD098 and 12RD100 was evaluated during each fish sampling event using the MSHA. Total MSHA scores for Station 05RD098 ranged from 27 to 34, while Station 12RD100 had a score of 35; each of these scores is rated as "poor". According to Figure 14, the MSHA scores for the stations were generally limited by the land use, substrate, and channel morphology subcategories. The land use adjacent to the stations was dominated by row crop agriculture (e.g., corn and sugar beets). In addition, the stations lacked riffle habitat, had no coarse substrate, and had "poor" sinuosity and channel development.



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

Figure 14. MSHA subcategory results for Stations 05RD098 and 12RD100 along AUID 515.

Biotic response – fish

Evidence of a causal relationship between a lack of instream habitat and the F-IBI impairment associated with AUID 515 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 05RD098 and 12RD100:

- Low relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct)
- High relative abundance of taxa that are detritivorous (DetNWQTxPct)
- Low relative abundance of individuals that are insectivorous Cyprinids (InsectCypPct)
- Low relative abundance of taxa that are insectivorous, excluding tolerant species (Insect-TolTxPct)
- Low taxa richness of simple lithophilic spawning species (SLithop)

Benthic insectivores 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). According to Figure 6, two of the aforementioned individual metrics (i.e., BenInsect-TolTxPct and DetNWQTxPct) were used in the calculation of the F-IBI score(s) for Stations 05RD098 and 12RD100. Both stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach.

Biotic response – macroinvertebrate

Evidence of a causal relationship between a lack of instream habitat and the M-IBI impairment associated with AUID 515 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 05RD098 and 12RD100:

- Low taxa richness of clinger taxa (ClingerCh)
- Low relative abundance of collector-filterer individuals in a subsample (Collector-filtererPct)
- High relative abundance of legless individuals (LeglessPct)

Clinger taxa, including many collector-filterers, require clean, coarse substrate or other objects to attach themselves to, while legless macroinvertebrates are tolerant of degraded benthic habitat. According to Figure 7, two of the aforementioned individual metrics (i.e., ClingerCh and Collector-filtererPct) were used in the calculation of the M-IBI scores for Stations 05RD098 and 12RD100. Both stations had "low" scores for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a water quality sample at Stations 05RD098 and 12RD100 along AUID 515 at the time of fish sampling. Each sample was analyzed for several parameters, including TSS. The sample collected at Station 05RD098 on August 16, 2012 had the highest TSS concentration (146 mg/L). All of the other samples collected at the stations had a low TSS concentration (≤28 mg/L). Table 7 summarizes discrete TSS data for Site S004-131. Only 6.2% of the total values exceeded the 65 mg/L TSS standard. Additionally, the GMCW HSPF model estimates that the reach had a TSS concentration in excess of the standard seven percent of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to occasional periods of high suspended sediment.

Table 7. Discrete TSS data for Site S004-131 along AUID 515.

Site	Date Range	*n*	Min	Max	Mean	% Total Values Above Standard
S004-131	2006-2014	64	1	165	19	6.2

EOR and Lenhart (2014) conducted a geomorphic assessment of Stations 05RD098 and 12RD100. Station 05RD098 (E6 stream type) had a "moderate" Bank Erosion Hazard Index (BEHI) rating, a "moderate" Near Bank Stress (NBS) rating, and a "poor" Pfankuch stability rating. Station 12RD100 (Bc stream type) had a "moderate" BEHI rating, a "low" NBS rating, and a "poor" Pfankuch stability rating. While the instability documented at the stations is likely a source of suspended sediment, the overall contribution of this source is believed to be minor compared to field and gully erosion (Lauer et al., 2006; EOR, 2009). The most influential factor on channel stability in the GMCW is likely ditch maintenance (EOR and Lenhart, 2014).

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 individual F-IBI metrics for Stations 05RD098 and 12RD100 exhibited a correlation to this candidate cause. Additionally, due to its intermittent flow regime, the reach is unlikely to support a year round fish community and is frequently recolonized by fish originating from the Grand Marais Creek and Red River of the North during high flow conditions. According to Paakh et al. (2006), the Grand Marais Creek and the Red River of the North typically have very high suspended sediment. The mean TSS concentration of Site S002-113 (2002-2014; *n*=277), which is located on the Red River of the North at East Grand Forks, was 194 mg/L. Therefore, the fish community of the reach is inherently adapted to high suspended sediment.

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 individual M-IBI metric responses (Appendix D) for Stations 05RD098 and 12RD100:

- Low relative abundance of collector-filterer individuals in a subsample (Collector-filtererPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

Collector-filterers, including several members of the order Trichoptera, 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). According to Figure 7, each of these individual metrics was used in the calculation of the M-IBI scores for Stations 05RD098 and 12RD100. Both stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. Additionally, the MPCA calculated TSS Tolerance Indicator Values (TIVs), which provide a means of comparing the relative tolerance of sampled taxa, for the stations (Appendix D). Both stations had a high percentage of high TSS tolerant taxa and a low number of high TSS intolerant taxa.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Stations 05RD098 and 12RD100 along AUID 515 at the time of fish and macroinvertebrate sampling. None of the measurements were below the 5.0 mg/L standard. Figure 15 displays discrete DO data for Site S004-131 (2006-2014; n=126). Only five percent of the DO values for the site were below the standard; however, only one measurement was taken 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 S004-131 from July 2, 2014, to July 13, 2014 and from July 23, 2014, to July 30, 2014. Table 8 provides a summary of the monitoring results. None of the DO measurements for the initial monitoring period were below the standard. The second monitoring period, which occurred two days after an approximately four inch rainfall, had 50% of the daily minimum DO values that were below the standard. The level of mean daily DO flux was nominal for both monitoring periods. Additionally, the GMCW HSPF model estimates that the reach had a DO concentration below the standard less than one percent of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to occasional periods of low DO.

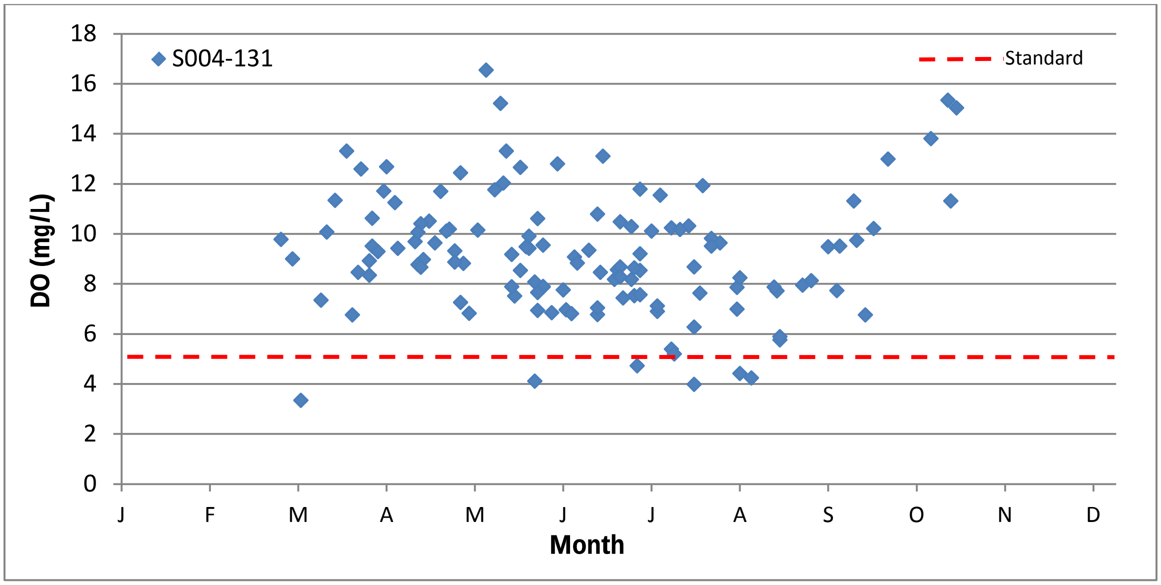


Figure 15. Discrete DO data for Site S004-131 (2006-2014; *n*=126) along AUID 515.

Table 8. Continuous DO data for Site S004-131 along AUID 515.

Site	Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Daily Min. Values Below Standard	% Total Values Below Standard	Mean Daily Flux (mg/L)
S004-131	July 2, 2014 - July 13, 2014	1036	5.6	9.2	0.0	0.0	1.5
S004-131	July 23, 2014 - July 30, 2014	668	4.0	8.6	50.0	32.2	1.4

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 individual F-IBI metric responses (Appendix C) for Stations 05RD098 and 12RD100:

- Low number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Low DO often results in a limited fish community that is dominated by tolerant taxa (USEPA, 2012). According to Figure 6, three of these individual metrics (SensitiveTxPct, TolPct, and TolTxPct) were used in the calculation of the F-IBI score(s) for Stations 05RD098 and 12RD100. Both stations had a “low” score(s) for each of these metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach. Sandberg (2014) utilized TIVs to estimate the likelihood of each station meeting the DO standard based upon its sampled fish assemblage (Appendix C). Both stations had a relatively low probability (5-20%) of meeting the standard.

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 individual M-IBI metric responses (Appendix D) for Stations 05RD098 and 12RD100:

- High Hilsenhoff's Biotic Index value (HBI_MN)
- Low taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch)
- Low taxa richness of Plecoptera (Plecoptera)
- Low taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET)
- Low total taxa richness of macroinvertebrates (TaxaCountAllChir)
- High relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

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 (USEPA, 2012; Weber, 1973). According to Figure 7, six of these individual metrics (HBI_MN, Intolerant2Ch, POET, TaxaCountAllChir, TrichopteraChTxPct, and TrichwoHydroPct) were used in the calculation of the M-IBI scores for Stations 05RD098 and 12RD100. Both stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. Additionally, the MPCA calculated DO TIVs for the stations (Appendix D). Both stations had a high percentage of low DO tolerant taxa and lacked low DO intolerant taxa.

Strength-of-evidence analysis

Table 9 presents a summary of the SOE scores for the various candidate causes associated with AUID 515. The evidence suggests that the F-IBI impairment is likely attributed to the following stressors: loss of physical connectivity, lack of base flow, lack of instream habitat, and low DO. Additionally, the evidence indicates that the M-IBI impairment is likely the result of the following stressors: lack of base flow, lack of instream 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 9. SOE scores for candidate causes associated with AUID 515.

Types of Evidence	SOE Scores for Candidate Causes[1]									
	Loss of Physical Connectivity		Lack of Base Flow		Lack of Instream Habitat		High Suspended Sediment		Low Dissolved Oxygen	
	Biological Impairment(s)									
	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.

3.3.2 County Ditch 43 (AUID 517)

Physical setting

This reach represents CD 43 (Figure 16), which extends from its confluence with an unnamed ditch, to its confluence with CD 7; a total length of 24 miles. The reach has a subwatershed area of 65 square miles (41,292 acres). The reach and its subwatershed are primarily situated in the beach ridges region of the GMCW; however, approximately the western one-third of the reach and its subwatershed lies in the lake plain region. The subwatershed contains 36 miles of intermittent drainage ditch (e.g., AUID 517), 24 miles of intermittent stream, and less than one mile of perennial drainage ditch and stream (MDNR, 2003). According to the MPCA (2013), 85% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including the entire length of AUID 517. The NLCD 2011 (USGS, 2011) lists cultivated crops (91%) as the predominant land cover in the subwatershed. Notable minor land cover groups in the subwatershed included developed areas (5%), forest (2%), wetlands (1%), and hay/pasture (1%).

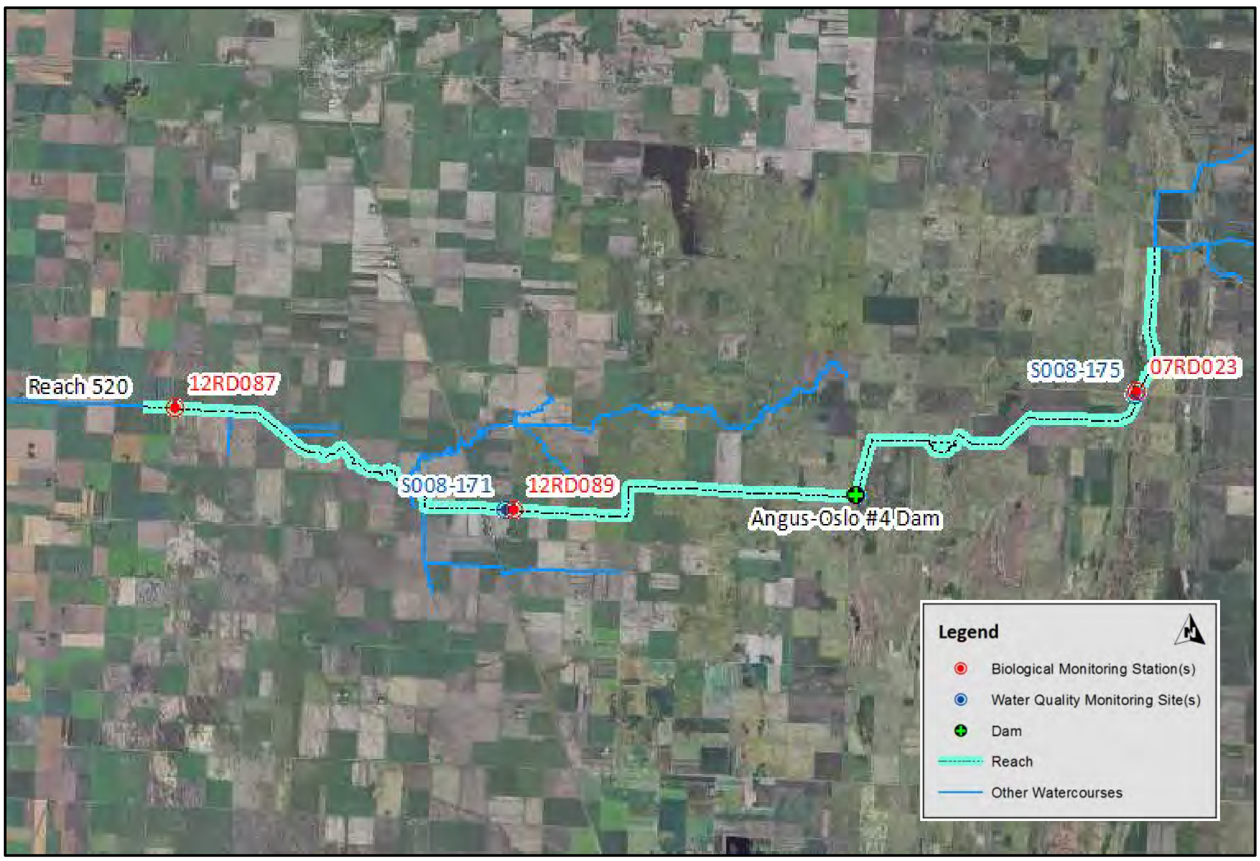


Figure 16. Map of AUID 517 and associated biological monitoring stations and water quality monitoring sites (2010 NAIP aerial image).

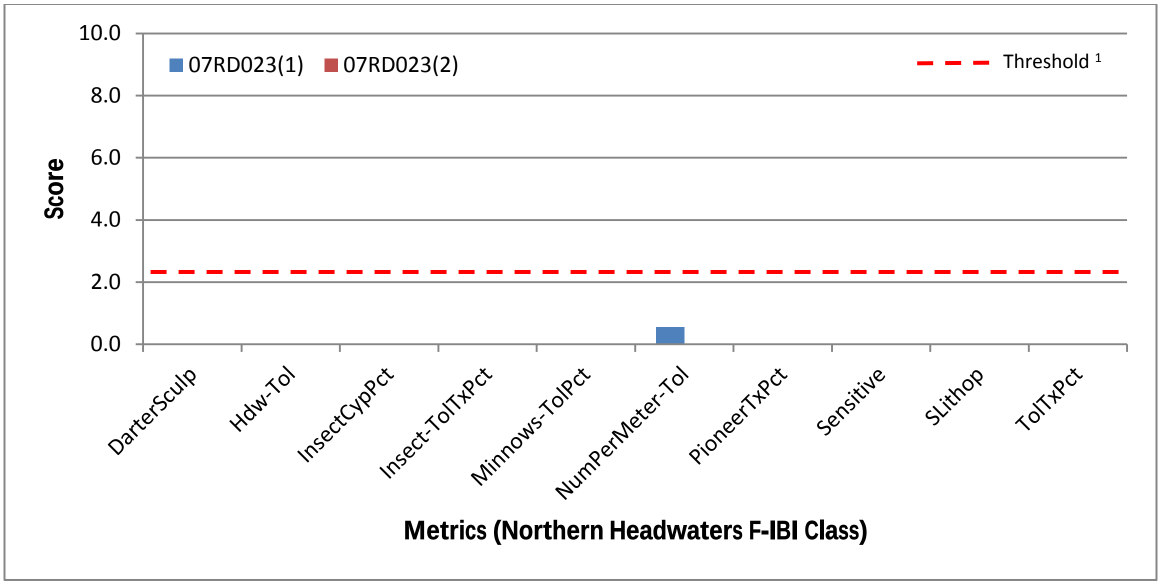
Biological impairments

Fish (F-IBI)

The fish community of AUID 517 was monitored at Station 07RD023 (0.1 mile upstream of the CR 8 crossing) on August 9, 2007(1) and June 13, 2012(2); Station 12RD087 (0.1 mile upstream of the 360th Avenue NW crossing) on July 19, 2012; and Station 12RD089 (0.1 mile upstream of the 300th Avenue NW crossing) on June 13, 2012. The relative location of the stations is shown in Figure 16. Station 07RD023 was designated as Modified Use within the Northern Headwaters F-IBI Class. Stations 12RD087 and

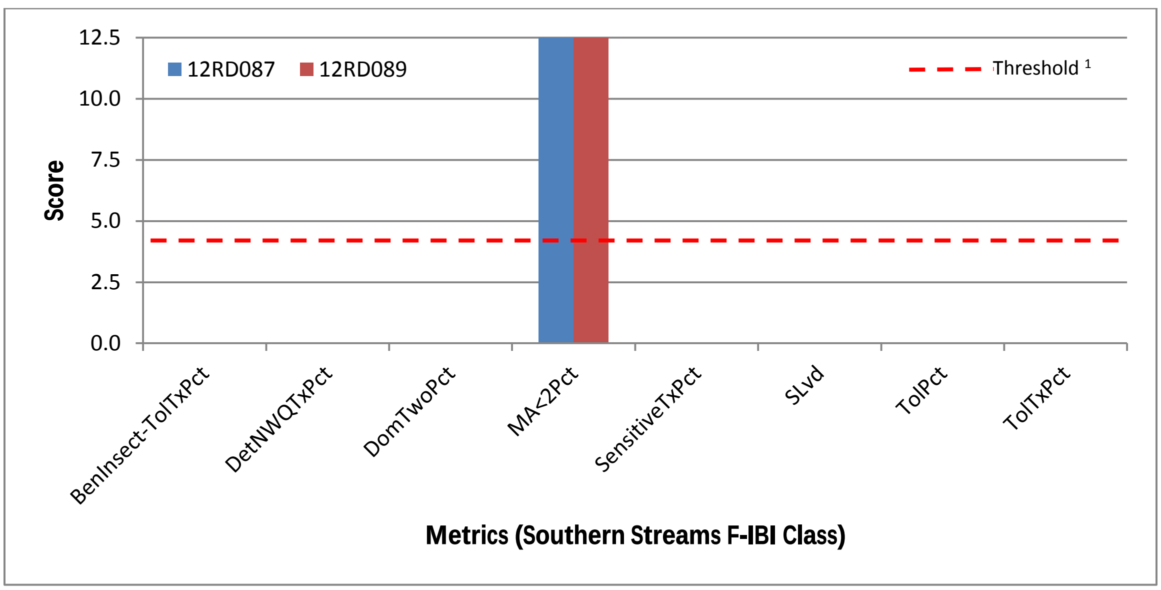
12RD089 were designated as Modified Use within the Southern Streams F-IBI Class. Accordingly, the impairment threshold for the stations is an F-IBI score of 23 and 35, respectively. Monitoring of the stations yielded F-IBI scores below their impairment threshold; Station 07RD023 had a mean score of zero, while Stations 12RD087 and 12RD089 each had a score of 13.

Figures 17 and 18 provide the individual F-IBI metric scores for the three fish monitoring stations along AUID 517; a description of each metric is provided in Appendix A. Station 07RD023 scored below the threshold score for all metrics. Stations 12RD087 and 12RD089 each had seven metrics that failed to meet the same criterion (BenInsect-TolTxPct, DetNWQTxPct, DomTwoPct, SensitiveTxPct, SLvd, TolPct, and TolTxPct). Overall, the fish assemblage of the stations was largely comprised of tolerant taxa (e.g., black bullhead, 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 17. Individual F-IBI metric scores for Station 07RD023 along AUID 517.



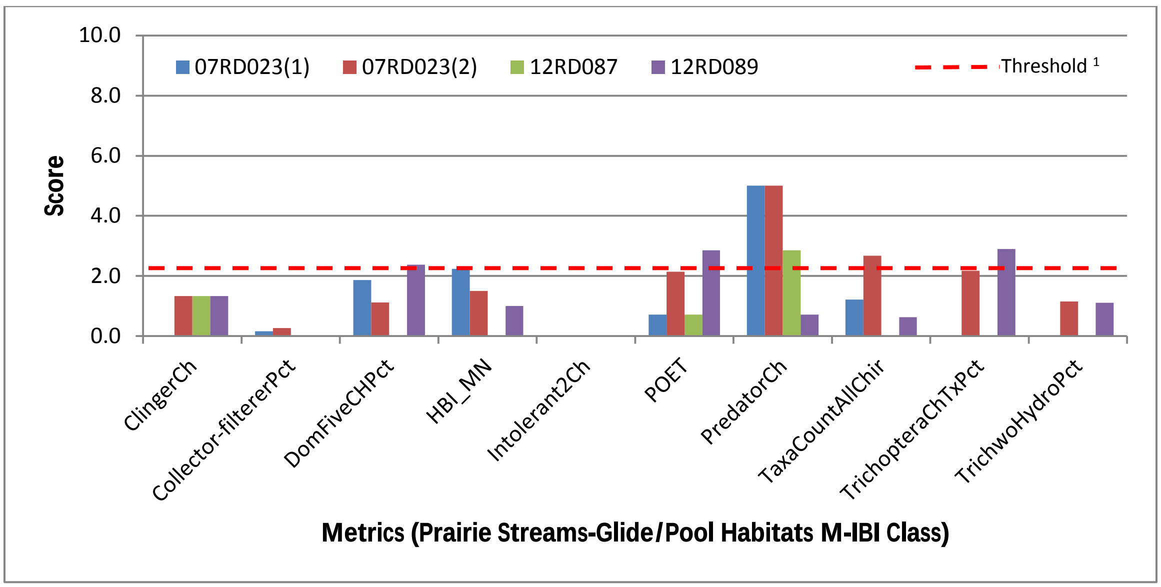
[1] The mean individual metric score needed for the station to meet its applicable impairment (IBI class and use) threshold. An individual metric score below this level is considered "low" and is contributing to the biological impairment.

Figure 18. Individual F-IBI metric scores for Stations 12RD087 and 12RD089 along AUID 517.

Macroinvertebrate (M-IBI)

The macroinvertebrate community of AUID 517 was monitored at Station 07RD023 on August 14, 2007(1) and August 6, 2013(2); Station 12RD087 on August 1, 2012; and Station 12RD089 on August 1, 2012. All of the stations were designated as Modified Use within the Prairie Streams-Glide/Pool Habitats M-IBI Class. Accordingly, the impairment threshold for the stations is an M-IBI score of 22. Monitoring of the stations yielded M-IBI scores below the impairment threshold; Station 07RD023 had a mean score of 14, while Station 12RD087 had a score of 5 and Station 12RD089 had a score of 13.

Figure 19 provides the individual M-IBI metric scores for the macroinvertebrate monitoring stations along AUID 517; a description of each metric is provided in Appendix B. All of the stations scored below the threshold score for four metrics (i.e., ClingerCh, Collector-filtererPct, Intolerant2Ch, and TrichwoHydroPct). The macroinvertebrate assemblage of the stations was dominated by tolerant taxa, specifically, *Gyraulus* (snails), *Hyalella* (amphipods), *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 19. Individual M-IBI metric scores for Stations 07RD023, 12RD087, and 12RD089 along AUID 517.

Candidate causes

Loss of physical connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues during the sampling of Stations 07RD023, 12RD087, and 12RD089 along AUID 517. According to the MDNR (2014b), the Angus-Oslo #4 Dam (Figure 20) is located on the upstream end of the reach, approximately six miles east of the unincorporated community of Angus. The dam, which is owned and operated by the Middle-Snake-Tamarac Rivers Watershed District (MSTRWD), was constructed for purpose of flood control; the dam was completed in 2005. The structure has an associated impoundment and is likely a complete barrier to connectivity. However, the impoundment has an emergency spillway that may re-establish connectivity when in use. On July 2, 2014, MPCA SI staff documented a beaver dam (Figure 20) immediately downstream of Site S008-175 (CR 8 crossing); the relative location of the site is shown in Figure 16. The beaver dam had an associated pool and posed a complete barrier to connectivity at the time of discovery. On September 24, 2014, MPCA SI staff conducted a connectivity assessment along the reach. Staff viewed all of the road crossings along the reach as part of the assessment. No obstructions to connectivity were identified (e.g., perched culverts and beaver dams); the aforementioned beaver dam was not present. In addition to the assessment, MPCA SI staff performed a detailed review of an April 2, 2012, aerial photo of the reach; the photo was acquired approximately two months prior to fish sampling at Stations 07RD023 and 12RD089. A beaver dam (Figure 20) was noted immediately upstream of Site S008-175. The beaver dam had been breached and, therefore, was likely not limiting connectivity.

Figure 20. Photos of connectivity barriers along AUID 517, including a beaver dam immediately upstream of Site S008-175 on April 2, 2012, courtesy of Google Earth (upper left); a beaver dam immediately downstream of Site S008-175 on July 2, 2014 (upper right); the inlet structure of the Angus-Oslo #4 Impoundment on September 24, 2014 (lower left); and the outlet structure of the Angus-Oslo #4 Impoundment on September 24, 2014 (lower right).

Biotic response – fish

Evidence of a causal relationship between a loss of physical connectivity and the F-IBI impairment associated with AUID 517 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 07RD023 and 12RD087:

- Low relative abundance of individuals with a female mature age of equal to or greater than three years (MA>Pct)
- Low relative abundance of individuals that are migratory (MgrPct)

Late maturing and migratory fish species require well-connected environments in order to access the habitats and resources necessary to complete their life history. The fish assemblage of Station 07RD023, which is situated upstream of the Angus-Oslo #4 Dam, did not include any late maturing or migratory fish species. Downstream of the dam, Station 12RD089 had a fish assemblage that was dominated by young-of-the-year white sucker, which suggests that adult fish of this species were able to migrate up into the lower extent of the reach to spawn. White sucker commonly migrate up into the headwater region of waterways to reproduce (Paulson and Hatch, 2004). The influence of culverts along the reach on fish passage during high flow periods is unknown.

Biotic response – macroinvertebrate

There is no evidence of a causal relationship between a loss of physical connectivity and the M-IBI impairment associated with AUID 517. Macroinvertebrates are generally sessile or have limited migration patterns and, therefore, are not readily affected by physical connectivity barriers.

Lack of base flow

Available data

The MPCA biological monitoring staff did not encounter any flow-related issues during fish and macroinvertebrate sampling at Stations 07RD023, 12RD087, and 12RD089. There is no flow monitoring data for the reach. The GMCW HSPF model estimates that the reach had minimal (<1 cfs) to no flow between 23 and 35% of the time during the period of 1996 to 2009. The MPCA SI staff conducted reconnaissance along the reach on three separate dates (i.e., July 2, 2014, July 3, 2014, and September 24, 2014) and documented flow conditions. Staff observed intermittent flow conditions (i.e., interspersed pools of stagnant water) along the reach at the time of the last visit (Figure 21). Overall, the available information suggests that the reach is prone to frequent periods of minimal to no flow.

Biotic response – fish

Evidence of a causal relationship between a lack of base flow and the F-IBI impairment associated with AUID 517 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 07RD023, 12RD087, and 12RD089:

- High combined relative abundance of the two most abundant taxa (DomTwoPct)
- High relative abundance of taxa that are generalists (GeneralTxPct)
- Low number of individuals per meter of stream sampled, excluding tolerant taxa (NumPerMeter-Tol)
- Low taxa richness of sensitive species (Sensitive)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are trophic generalists and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). According to Figure 17, three of the aforementioned individual metrics (i.e., NumPerMeter-Tol, Sensitive, and TolTxPct) were used in the calculation of the F-IBI scores for Station 07RD023. Additionally, three of the individual metrics (i.e., DomTwoPct, SensitiveTxPct, and TolPct) were used in the calculation of the F-IBI score for Stations 12RD087 and 12RD089 (Figure 18). The stations had a “low” score(s) for each of these respective metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach.

Figure 21. Photos of intermittent flow conditions along AUID 517 on September 24, 2014, including Site S008-171 (upper left), the 310th Avenue NW crossing (upper right), the 320th Avenue NW crossing (lower left), and the 330th Avenue NW (lower right).

Biotic response – macroinvertebrate

Evidence of a causal relationship between a lack of base flow and the M-IBI impairment associated with AUID 517 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 07RD023, 12RD087, and 12RD089:

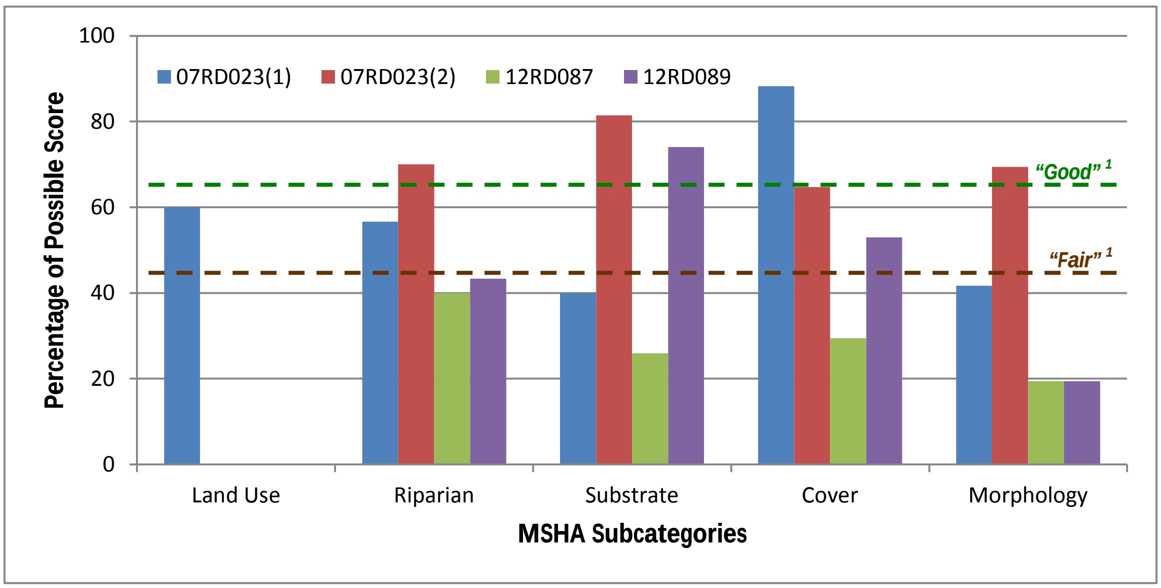
- Low relative abundance of collector-filterer individuals (Collector-filtererPct)
- High relative abundance of the dominant five taxa in a subsample (DomFiveCHPct)
- Low taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch)
- Low relative abundance of long-lived individuals (LongLivedPct)
- Low taxa richness of Plecoptera (Plecoptera)
- Low taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET)
- Low total taxa richness of macroinvertebrates (TaxaCountAllChir)
- High relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

Frequent and/or prolonged periods of minimal to no flow tends to limit species 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 (USEPA, 2012; Klemm et al., 2002, Poff and Zimmerman, 2010). According to Figure 19, seven of the aforementioned individual metrics (i.e., Collector-filtererPct, DomFiveCHPct, Intolerant2Ch, POET, TaxaCountAllChir, TrichopteraChTxPct, and TrichwoHydroPct) were used in the calculation of the M-IBI score(s) for Stations 07RD023, 12RD087, and 12RD089. A majority of the stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. Overall, the macroinvertebrate assemblage of the stations was dominated by taxa that are adapted to lentic conditions (i.e., *Gyraulus*, *Hyalella*, *Paratanytarsus*, and *Physa*).

Lack of instream habitat

Available data

The instream habitat of Stations 07RD023, 12RD087, and 12RD089 was evaluated during each fish sampling event using the MSHA. Total MSHA scores for Station 07RD023 were 52 ("fair") and 68 ("good"), while Station 12RD087 had a score of 25 ("poor") and Station 12RD089 had a score of 42 ("poor"). According to Figure 22, the MSHA scores for Stations 12RD087 and 12RD089 were generally limited by the land use, riparian zone, and channel morphology subcategories. The land use adjacent to the stations was dominated by row crop agriculture (e.g., corn and sugar beets). The stations also had a "very narrow" riparian width and "poor" channel development. Additionally, Stations 07RD023 and 12RD089 each offered coarse substrate; however, the substrate at Station 07RD023 had "light" to "moderate" embeddedness. Station 12RD087 had no coarse substrate or riffle habitat.



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

Figure 22. MSHA subcategory results for Stations 07RD023, 12RD087, and 12RD089 along AUID 517.

Biotic response – fish

Evidence of a causal relationship between a lack of instream habitat and the F-IBI impairment associated with AUID 517 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 07RD023, 12RD087, and 12RD089:

- Low relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct)
- Low taxa richness of darter and sculpin species (DarterSculp)

- High relative abundance of taxa that are detritivorous (DetNWQTxPct)
- Low relative abundance of individuals that are insectivorous Cyprinids (InsectCypPct)
- Low relative abundance of taxa that are insectivorous, excluding tolerant species (Insect-TolTxPct)
- Low taxa richness of simple lithophilic spawning species (SLithop)

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). According to Figure 17, four of the aforementioned individual metrics (i.e., DarterSculp, InsectCypPct, Insect-TolTxPct, and SLithop) were used in the calculation of the F-IBI scores for Station 07RD023. Additionally, two of the individual metrics (i.e., BenInsect-TolTxPct and DetNWQTxPct) were used in the calculation of the F-IBI score for Stations 12RD087 and 12RD089 (Figure 18). The stations had a score(s) of zero for each of these respective metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach.

Biotic response – macroinvertebrate

Evidence of a causal relationship between a lack of instream habitat and the M-IBI impairment associated with AUID 517 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 07RD023, 12RD087, and 12RD089:

- Low taxa richness of clinger taxa (ClingerCh)
- Low relative abundance of collector-filterer individuals in a subsample (Collector-filtererPct)
- High relative abundance of legless individuals (LeglessPct)

Clinger taxa, including many collector-filterers, require clean, coarse substrate or other objects to attach themselves to, while legless macroinvertebrates are tolerant of degraded benthic habitat. According to Figure 19, two of the aforementioned individual metrics (i.e., ClingerCh and Collector-filtererPct) were used in the calculation of the M-IBI score(s) for Stations 07RD023, 12RD087, and 12RD089. The stations had a “low” score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a water quality sample at Stations 07RD023, 12RD087, and 12RD089 along AUID 517 at the time of fish sampling. Each sample was analyzed for several parameters, including TSS. The TSS concentration of the samples ranged from 8 to 38 mg/L. The GMCW HSPF model estimates that the reach had a TSS concentration in excess of the 65 mg/L standard between 9 and 27% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to occasional periods of high suspended sediment.

EOR and Lenhart (2014) conducted a geomorphic assessment of Stations 07RD023 and 12RD087. Station 07RD023 (E6 stream type) had a “moderate” BEHI rating, a “low” NBS rating, and a “good” Pfankuch stability rating. Station 12RD098 (E6 stream type) had a “low” BEHI rating, a “moderate” NBS rating, and a “good” Pfankuch stability rating. The geomorphic data for the stations indicates that channel instability is not a likely source of suspended sediment along the reach.

Biotic response – fish

There is no evidence of a causal relationship between high suspended sediment and the F-IBI impairment associated with AUID 517. None of the individual F-IBI metrics for Stations 07RD023, 12RD087, and 12RD089 exhibited a correlation to this candidate cause. Additionally, due to its intermittent flow regime, the reach is unlikely to support a year round fish community and is frequently recolonized by fish originating from the Red River of the North via JD 75 during high flow conditions. According to Paakh et al. (2006), the Red River of the North typically has very high suspended sediment. The mean TSS concentration of Site S002-113 (2002-2014; *n*=277), which is located on the Red River of the North at East Grand Forks, was 194 mg/L. Therefore, the fish community of the reach is inherently adapted to high suspended sediment. However, the deposition of suspended sediment has resulted in the embeddedness of coarse substrate and the associated biotic response at Station 07RD023.

Biotic response – macroinvertebrate

Evidence of a causal relationship between high suspended sediment and the M-IBI impairment associated with AUID 517 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 07RD023, 12RD087, and 12RD089:

- Low relative abundance of collector-filterer individuals in a subsample (Collector-filtererPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

Collector-filterers, including several members of the order Trichoptera, 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). According to Figure 19, each of these individual metrics was used in the calculation of the M-IBI score(s) for Stations 07RD023, 12RD087, and 12RD089. A majority of the stations had a “low” score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. The MPCA also calculated TSS TIVs for the stations (Appendix D). The stations had a low percentage of high TSS tolerant taxa, but a low number of high TSS intolerant taxa. Additionally, the deposition of suspended sediment has resulted in the embeddedness of coarse substrate and the associated biotic response at Station 07RD023.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Stations 07RD023, 12RD087, and 12RD089 along AUID 517 at the time of fish and macroinvertebrate sampling. One measurement was below the 5.0 mg/L standard; Station 07RD023 had a DO concentration of 4.6 mg/L at the time of fish sampling on August 9, 2007. The MPCA conducted continuous DO monitoring at Site S008-171 (0.1 mile downstream of the 300th Avenue NW crossing) from July 2, 2014, to July 17, 2014 and Site S008-175 from July 3, 2014, to July 17, 2014. Table 10 provides a summary of the results for the sites. None of the daily minimum DO values for Site S008-171 were below the standard, while 67% of the daily minimum DO values for Site S008-175 were under the standard. Both sites had an elevated level of mean daily DO flux (6.1 and 4.8 mg/L). Additionally, the GMCW HSPF model estimates that the reach had a DO concentration below the standard between one and three percent of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to occasional periods of low DO.

Table 10. Continuous DO data for Sites S008-171 and S008-175 along AUID 517.

Site	Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Daily Min. Values Below Standard	% Total Values Below Standard	Mean Daily Flux (mg/L)
S008-171	July 2, 2014 - July 17, 2014	1428	5.1	17.0	0.0	0.0	6.1
S008-175	July 3, 2014 - July 17, 2014	1356	1.0	14.9	66.7	33.5	4.8

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 517 is provided by the following individual F-IBI metric responses (Appendix C) for Stations 07RD023, 12RD087, and 12RD089:

- Low number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol)
- Low taxa richness of sensitive species (Sensitive)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Low DO often results in a limited fish community that is dominated by tolerant taxa (USEPA, 2012). According to Figure 17, two of the individual metrics (i.e., NumPerMeter-Tol and Sensitive) were used in the calculation of the F-IBI scores for Station 07RD023. Additionally, three of the individual metrics (i.e., SensitiveTxPct, TolPct, and TolTxPct) were used in the calculation of the F-IBI score for Stations 12RD087 and 12RD089 (Figure 18). The stations had a “low” score(s) for each of these respective metrics, thereby negatively affecting the overall F-IBI scores and directly contributing to the biological impairment of the reach. Sandberg (2014) utilized TIVs to estimate the likelihood of each station meeting the DO standard based upon its sampled fish assemblage (Appendix C). Stations 07RD023 and 12RD087 had a relatively low probability (5 and 13%) of meeting the standard. Conversely, Station 12RD089 had a relatively high probability (58%) of meeting the standard.

Biotic response – macroinvertebrate

Evidence of a causal relationship between low DO and the M-IBI impairment associated with AUID 517 is provided by the following individual M-IBI metric responses (Appendix D) for Stations 07RD023, 12RD087, and 12RD089:

- High Hilsenhoff’s Biotic Index value (HBI_MN)
- Low taxa richness of macroinvertebrates with tolerance values less than two (Intolerant2Ch)
- Low taxa richness of Plecoptera (Plecoptera)
- Low taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET)
- Low total taxa richness of macroinvertebrates (TaxaCountAllChir)
- High relative percentage of taxa with tolerance values equal to or greater than six (Tolerant2ChTxPct)
- Low relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct)
- Low relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct)

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 (USEPA, 2012; Weber, 1973). According to Figure 19, six of these individual metrics (HBI_MN, Intolerant2Ch, POET, TaxaCountAllChir, TrichopteraChTxPct, and TrichwoHydroPct) were used in the calculation of the M-IBI score(s) for Stations 07RD023, 12RD087, and 12RD089. A majority of the stations had a "low" score(s) for each of these metrics, thereby negatively affecting the overall M-IBI scores and directly contributing to the biological impairment of the reach. Additionally, the MPCA calculated DO TIVs for the stations (Appendix D). Stations 07RD023 and 12RD089 had a high percentage of low DO tolerant taxa. All of the stations had a low number of low DO intolerant taxa.

Strength-of-evidence analysis

Table 11 presents a summary of the SOE scores for the various candidate causes associated with AUID 517. The evidence suggests that the F-IBI impairment is likely attributed to the following stressors: loss of physical connectivity, lack of base flow, lack of instream habitat, high suspended sediment, and low DO. Additionally, the evidence indicates that the M-IBI impairment is likely the result of the following stressors: lack of base flow, lack of instream 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 11. SOE scores for candidate causes associated with AUID 517.

Types of Evidence	SOE Scores for Candidate Causes[1]									
	Loss of Physical Connectivity		Lack of Base Flow		Lack of Instream Habitat		High Suspended Sediment		Low Dissolved Oxygen	
	Biological Impairment(s)									
	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	++	--	+++	+++	++	++	+	+	+	+
Temporal Sequence	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-Response Relationship	++	--	+++	+++	++	++	+	+	+	+
Causal Pathway	++	--	+++	+++	++	++	+	+	+	+
Evidence of Exposure/Bio-Mechanism	++	--	+++	+++	++	++	+	+	+	+
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	++	--	+++	+++	++	++	+	+	+	+
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	**++**	**--**	**+++**	**+++**	**++**	**++**	**+**	**+**	**+**	**+**

[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 Judicial Ditch 75 (AUID 520)

Physical setting

This reach represents JD 75 (Figure 23), which extends from its confluence with CD 7, to its outlet to the Red River of the North; a total length of 13 miles. The reach has a subwatershed area of 106 square miles (67,821 acres). Although the reach is entirely located in the lake plain region of the GMCW, approximately the eastern half of its subwatershed lies within the beach ridges region. The subwatershed contains 59 miles of intermittent drainage ditch (e.g., AUID 520), 49 miles of intermittent stream, and less than one mile of perennial drainage ditch and stream (MDNR, 2003). According to the MPCA (2013), 84% of the watercourses in the subwatershed have been hydrologically altered (i.e., channelized, ditched, or impounded), including the entire length of AUID 520. The NLCD 2011 (USGS, 2011) lists cultivated crops (92%) as the predominant land cover in the subwatershed. Notable minor land cover groups in the subwatershed included developed areas (4%), forest (2%), wetlands (1%), and hay/pasture (1%).

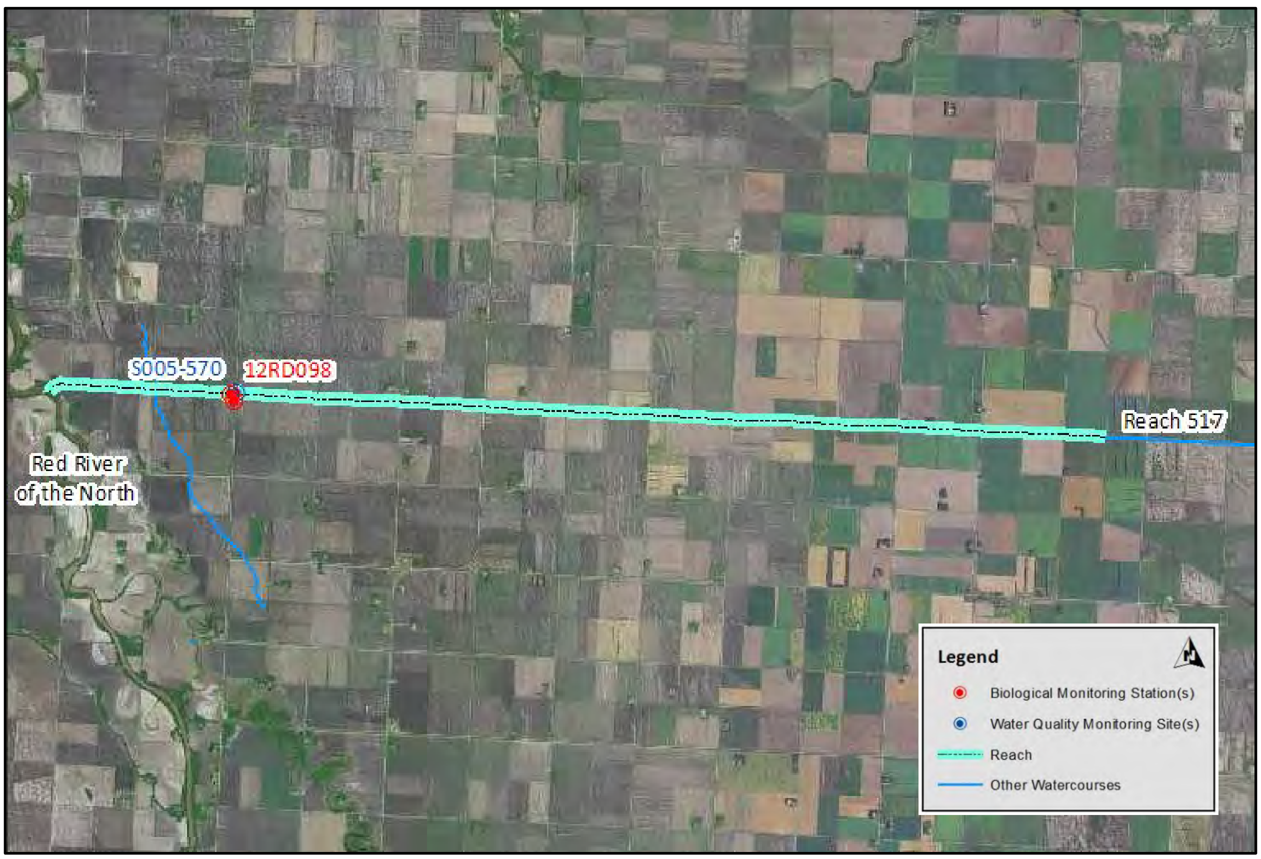
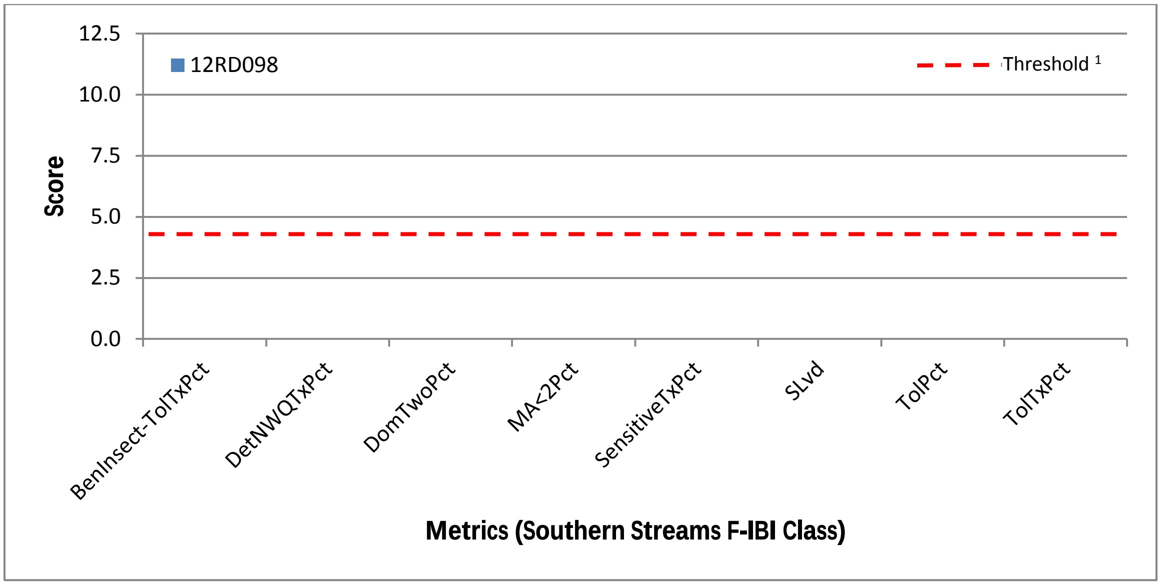


Figure 23. Map of AUID 520 and associated biological monitoring station and water quality monitoring site (2010 NAIP aerial image).

Biological impairment

Fish (F-IBI)

The fish community of AUID 520 was monitored at Station 12RD098 (0.1 mile downstream of the CR 22 crossing) on June 19, 2012. The relative location of the station is shown in Figure 23. The station was designated as Modified Use within the Southern Streams F-IBI Class. Accordingly, the impairment threshold for the station is an F-IBI score of 35. The station had an F-IBI score of zero. Correspondingly, all of the individual metrics associated with the station had a score of zero (Figure 24). Overall, the station had a very limited sample population (<25 individuals) that was comprised of tolerant species (i.e., brook stickleback 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 12RD098 along AUID 520.

Candidate causes

Loss of physical connectivity

Available data

The MPCA biological monitoring staff did not encounter any connectivity-related issues during the sampling of Station 12RD098 along AUID 520. According to the MDNR (2014b), there are no man-made dams on the reach. On November 5, 2013, MPCA monitoring staff documented a beaver dam (Figure 25) at the State Highway 220 crossing. The beaver dam had an associated pool and posed a complete barrier to connectivity at the time of discovery. On September 24, 2014, MPCA SI staff conducted a connectivity assessment along the reach. Staff noted a series of four metal grade control structures (Figure 25) near the outlet of the reach to the Red River of the North. Based upon aerial photo reconnaissance, the structures were installed prior to April 19, 1991. The structures obstruct connectivity during low and, likely, moderate flow conditions. Staff also noted a beaver dam (Figure 25) immediately downstream of the confluence of the reach and CD 7. The beaver dam had an associated pool and was obstructing connectivity at the time of discovery. There are no culverts along the reach; all of the road crossings are bridges. In addition to the assessment, MPCA SI staff performed a detailed review of an April 2, 2012, aerial photo of the reach; the photo was acquired approximately two months prior to fish sampling at Station 12RD098. No additional connectivity-related issues were identified in the photo. The aforementioned beaver dams were not present in the photo.

Figure 25. Photos of connectivity barriers along AUID 520, including a beaver dam at the State Highway 220 crossing on November 5, 2013 (upper left); a beaver dam immediately downstream of the confluence with CD 7 on September 24, 2014 (upper right); and grade control structures immediately upstream of the confluence with the Red River of the North on September 24, 2014 (lower left and lower right).

Biotic response – fish

The grade control structures are obstructing fish passage during low and, likely, moderate flow conditions, thereby limiting the fish community of AUID 520. The fish assemblage of Stations 12RD098 and 12RD089 (AUID 517) included young-of-the-year white sucker, which suggests that adult fish of this species were able to migrate upstream of the grade control structures, likely during high flow conditions, to spawn. White sucker commonly migrate up into the headwater region of waterways to reproduce (Paulson and Hatch, 2004).

Lack of base flow

Available data

The MPCA biological monitoring staff did not encounter any flow-related issues during fish and macroinvertebrate sampling at Station 12RD098. The RLWD conducted continuous flow monitoring at Site S005-570 (CR 22 crossing) in 2013 (Figure 26); the relative location of the site is shown in Figure 23. The highest peak flow was 394 cfs, while the lowest flow was 0 cfs. No flow represented 20% of the total values. The GMCW HSPF model estimates that the reach had minimal (<1 cfs) to no flow 68% of the time during the period of 1996 to 2009. The MPCA SI staff conducted reconnaissance along the reach on four separate dates (i.e., July 2, 2014, July 23, 2014, July 30, 2014, and September 24, 2014) and documented flow conditions. Staff observed intermittent flow conditions (i.e., pools of stagnant water) along the reach at the time of the last visit (Figure 27). Overall, the available information suggests that the reach is prone to frequent periods of minimal to no flow.

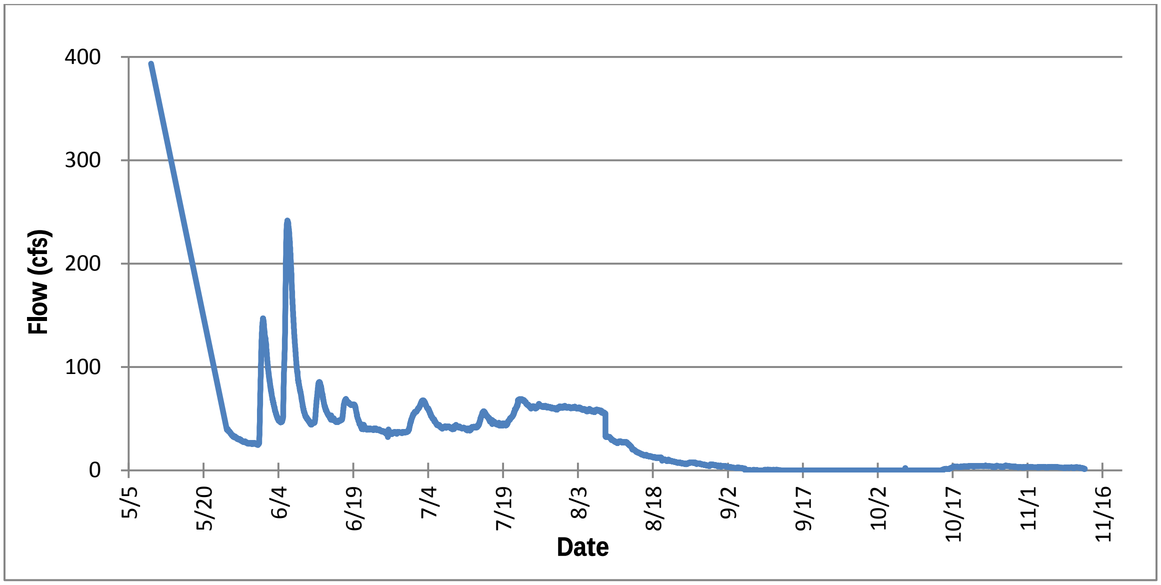


Figure 26. Continuous flow data (May 9, 2013, to November 12, 2013) for Site S005-570 along AUID 520.

Figure 27. Photos of intermittent flow conditions along AUID 520 on September 24, 2014, including the 370th Avenue NW crossing (upper left), the 390th Avenue NW crossing (upper right), Site S005-570 (lower left), and the State Highway 220 crossing (lower right).

Biotic response – fish

Evidence of a causal relationship between a lack of base flow and the F-IBI impairment associated with AUID 520 is provided by the following individual F-IBI metric responses (Appendix C) for Station 12RD098:

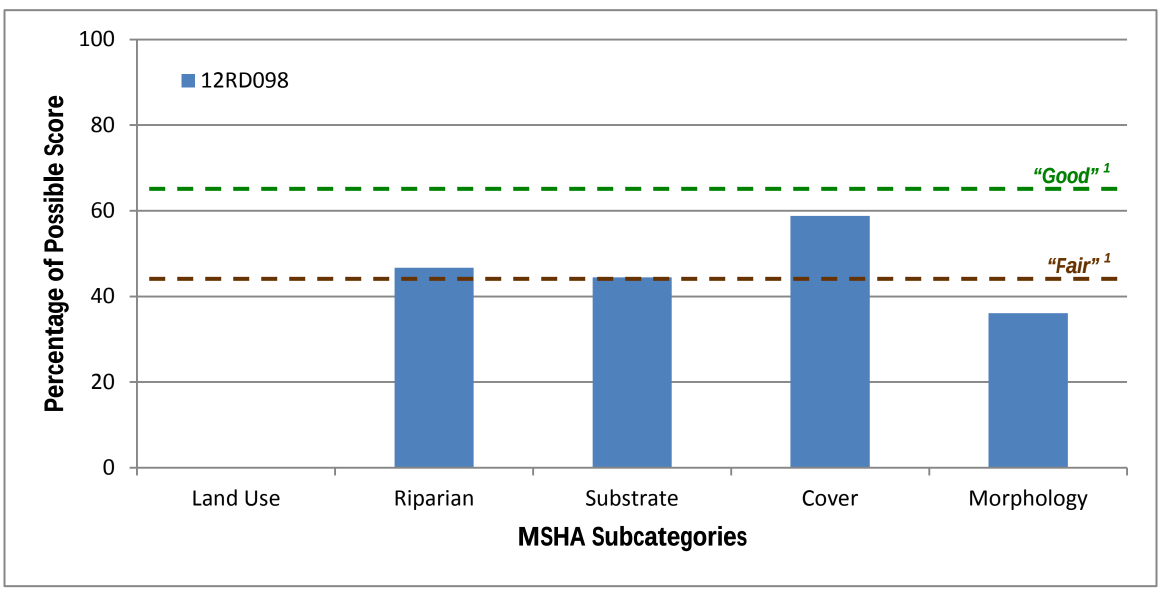
- High combined relative abundance of the two most abundant taxa (DomTwoPct)
- High relative abundance of taxa that are generalists (GeneralTxPct)
- Low number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High taxa richness of short-lived species (SLvd)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Frequent and/or prolonged periods of minimal to no flow tends to limit species diversity and favor taxa that are trophic generalists, short-lived, and/or tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). According to Figure 24, five of the aforementioned individual metrics (i.e., DomTwoPct, SensitiveTxPct, SLvd, TolPct, and TolTxPct) were used in the calculation of the F-IBI score for Station 12RD098. The station had a score of zero for each of these metrics, thereby negatively affecting the overall F-IBI score and directly contributing to the biological impairment of the reach.

Lack of instream habitat

Available data

The instream habitat of Station 12RD098 was evaluated at the time of fish sampling using the MSHA. The station yielded a total MSHA score of 42 (“poor”). According to Figure 28, the MSHA score for the station was limited by the land use, substrate, and channel morphology subcategories. The land use adjacent to the station was dominated by row crop agriculture (e.g., corn and sugar beets). In addition, the station lacked riffle habitat, had very limited coarse substrate, and had “poor” sinuosity and channel development.



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

Figure 28. MSHA subcategory results for Station 12RD098 along AUID 520.

Biotic response – fish

Evidence of a causal relationship between a lack of instream habitat and the F-IBI impairment associated with AUID 520 is provided by the following individual F-IBI metric responses (Appendix C) for Station 12RD098:

- Low relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct)
- Low taxa richness of darter and sculpin species (DarterSculp)
- High relative abundance of taxa that are detritivorous (DetNWQTxPct)
- Low relative abundance of individuals that are insectivorous Cyprinids (InsectCypPct)
- Low relative abundance of taxa that are insectivorous, excluding tolerant species (Insect-TolTxPct)
- Low taxa richness of simple lithophilic spawning species (SLithop)

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). According to Figure 24, two of the aforementioned individual metrics (i.e., BenInsect-TolTxPct and DetNWQTxPct) were used in the calculation of the F-IBI score for Station 12RD098. The station had a score of zero for each of these metrics, thereby negatively affecting the overall F-IBI score and directly contributing to the biological impairment of the reach.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a water quality sample at Station 12RD098 along AUID 520 at the time of fish sampling. The sample was analyzed for several parameters, including TSS. The sample had a low TSS concentration (11 mg/L). Table 12 summarizes discrete TSS data for Site S005-570. Nearly 18% of the total values exceeded the 65 mg/L TSS standard. Additionally, the GMCW HSPF model estimates that the reach had a TSS concentration in excess of the standard 12% of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to periods of high suspended sediment.

Table 12. Discrete TSS data for Site S005-570 along AUID 520.

Site	Date Range	*n*	Min	Max	Mean	% Total Values Above Standard
S005-570	2009-2013	34	1	1310	122	17.6

EOR and Lenhart (2014) conducted a geomorphic assessment of Station 12RD098. The station (B6c stream type) had a “moderate” BEHI rating, a “low” NBS rating, and a “good” Pfankuch stability rating. The geomorphic data for the station indicates that channel instability is not a likely source of suspended sediment along the reach.

Biotic response – fish

There is no evidence of a causal relationship between high suspended sediment and the F-IBI impairment associated with AUID 520. None of the individual F-IBI metrics for Station 12RD098 exhibited a correlation to this candidate cause. Additionally, due to its intermittent flow regime, the reach is unlikely to support a year round fish community and is frequently recolonized by fish originating from the Red River of the North during high flow conditions. According to Paakh et al. (2006), the Red River of the North typically has very high suspended sediment. The mean TSS concentration of Site S002-113 (2002-2014; *n*=277), which is located on the Red River of the North at East Grand Forks, was 194 mg/L. Therefore, the fish community of the reach is inherently adapted to high suspended sediment.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Stations 12RD098 along AUID 520 at the time of fish and macroinvertebrate sampling. None of the measurements were below the 5.0 mg/L standard. Figure 29 displays discrete DO data for Site S005-570 (2009-2014; *n*=56). Only two percent of the DO values for the site were below the standard; however, none of the measurements were taken 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 S005-570 during four separate periods in July 2014. Table 13 provides a summary of the monitoring results. Only the July 23, 2014, to July 26, 2014 monitoring period, which occurred two days after an approximately four inch rainfall, had DO values below the standard; all of the values were below this threshold. The level of mean daily DO flux was nominal (≤2.8 mg/L) for all monitoring periods. Additionally, the GMCW HSPF model estimates that the reach had a DO concentration below the standard five percent of the time during the period of 1996 to 2009. Overall, the available data suggest that the reach is prone to occasional periods of low DO.

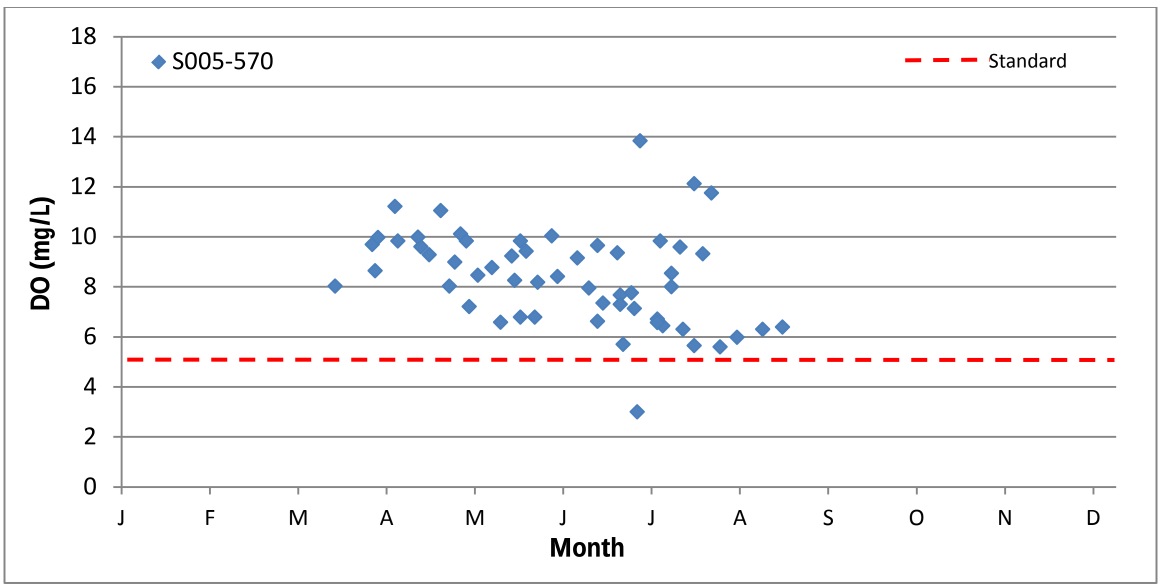


Figure 29. Discrete DO data for Site S005-570 (2009-2014; *n*=56) along AUID 520.

Table 13. Continuous DO data for Site S005-570 along AUID 520.

Site	Start Date - End Date	*n*	Min. (mg/L)	Max. (mg/L)	% Daily Min. Values Below Standard	% Total Values Below Standard	Mean Daily Flux (mg/L)
S005-570	July 2, 2014 - July 8, 2014	566	5.0	10.3	0.0	0.0	2.8
S005-570	July 14, 2014 - July 17, 2014	292	5.5	11.2	0.0	0.0	2.8
S005-570	July 23, 2014 - July 26, 2014	314	2.3	3.9	100.0	100.0	0.6
S005-570	July 28, 2014 - July 30, 2014	191	5.4	7.9	0.0	0.0	1.6

Biotic response – fish

Evidence of a causal relationship between low DO and the F-IBI impairment associated with AUID 520 is provided by the following individual F-IBI metric responses (Appendix C) for Station 12RD098:

- Low number of individuals per meter of stream sampled, excluding tolerant species (NumPerMeter-Tol)
- Low taxa richness of sensitive species (Sensitive)
- Low relative abundance of taxa that are sensitive (SensitiveTxPct)
- High relative abundance of individuals that are tolerant (TolPct)
- High relative abundance of taxa that are tolerant (TolTxPct)

Low DO often results in a limited fish community that is dominated by tolerant taxa (USEPA, 2012). According to Figure 24, three of these individual metrics (SensitiveTxPct, TolPct, and TolTxPct) were used in the calculation of the F-IBI score for Stations 12RD098. The station had a score of zero for each of these metrics, thereby negatively affecting the overall F-IBI score and directly contributing to the biological impairment of the reach. Sandberg (2014) utilized TIVs to estimate the likelihood of the station meeting the DO standard based upon its sampled fish assemblage (Appendix C). Station 12RD098 had a 31% probability of meeting the standard, which is identical to the basin average.

Strength-of-evidence analysis

Table 14 presents a summary of the SOE scores for the various candidate causes associated with AUID 520. The evidence suggests that the F-IBI impairment is likely attributed to the following stressors: loss of physical connectivity, lack of base flow, lack of instream habitat, and low DO. For additional information regarding the SOE scoring system, refer to the USEPA's CADDIS Summary Table of Scores.

Table 14. SOE scores for candidate causes associated with Reach 520.

Types of Evidence	SOE Scores for Candidate Causes[1]				
	Loss of Physical Connectivity	Lack of Base Flow	Lack of Instream Habitat	High Suspended Sediment	Low Dissolved Oxygen
	Biological Impairment(s)				
	F-IBI	F-IBI	F-IBI	F-IBI	F-IBI
Types of Evidence that Use Data from the Case					
Spatial/Temporal Co-Occurrence	++	+++	++	0	+
Temporal Sequence	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
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	++	++	++	++	++
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	**++**	**+++**	**++**	**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.

Section 4: Conclusions and recommendations

4.1 Conclusions

Table 15 presents a summary of the stressors associated with the biologically impaired reaches in the GMCW. A lack of base flow, lack of instream habitat, and low DO were identified as stressors for all of the biological impairments. All of the reaches are ditch systems and are subject to frequent periods of minimal to no flow. The lack of instream habitat associated with reaches is attributed their construction (i.e., traditional, trapezoidal design) and physiographic setting (i.e., lake plain). All of the reaches are prone to periods of low DO, which appear to coincide with low flow conditions. High suspended sediment is contributing to the M-IBI impairments in the watershed. Lastly, a loss of physical connectivity is a stressor for the F-IBI impairments in the watershed.

Table 15. Summary of the stressors associated with the biologically impaired reaches in the GMCW.

AUID Suffix	Reach Name	Biological Impairment(s)	Candidate Causes[1]				
			Loss of Physical Connectivity	Lack of Base Flow	Lack of Instream Habitat	High Suspended Sediment	Low Dissolved Oxygen
515	County Ditch 2	F-IBI	++	+++	++		+
		M-IBI		+++	++	+	+
517	County Ditch 43	F-IBI	++	+++	++	+	+
		M-IBI		+++	++	+	+
520	Judicial Ditch 75	F-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 biologically impaired reaches of the GMCW have the potential to support healthier fish and macroinvertebrate communities. The recommended management actions specified below and included in the MPCA's *Aquatic Biota Stressor and Best Management Practice Selection Guide* (Appendix E) will help to reduce the influence of the stressors that are limiting these communities. Whenever possible, actions should be implemented progressing from upstream to downstream.

- 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.
- Remove or retrofit physical connectivity barriers to enable fish passage at a greater range of flow conditions.
- Conduct an inventory of culverts in the watershed that are limiting fish passage.

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Appendices

Appendix A

4.2. Southern Streams

Table 7. Metrics selected for the Southern Streams F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
BenthicInsectivore-Tol_TxPct	TXPct	Percent benthic insectivore taxa (excludes tolerant species)	trophic	positive	<0.001	3.64	0.00	40.00
Sensitive_TxPct	TXPct	Percent sensitive taxa	tolerance	positive	<0.001	6.58	0.00	45.11
Detritivore_TxPct	TXPct	Percent detritivorous taxa	trophic	negative	<0.001	2.66	14.13	46.38
ShortLived	Richness	Short-lived taxa	life history	negative	<0.001	3.06	1.00	7.00
Tolerant_TxPct	TXPct	Percent tolerant taxa	tolerance	negative	<0.001	5.55	27.99	84.81
MatureAge<2_Pct	IndPct	Percent early-maturing individuals	reproductive	negative	<0.001	2.74	29.68	97.68
Tolerant_Pct	IndPct	Percent tolerant individuals	tolerance	negative	0.060	9.23	27.93	75.00
DominanceTwoTaxa_Pct[1]	IndPct	Combined relative abundance of the two most abundant taxa	composition	negative			34.00	75.00
FishDELT_Pct[2]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance

[2] metric included based on conceptual importance, scored discretely

A total of 76 metrics failed either the Range or Signal-to-Noise Test in the Southern Streams class. No metrics in this class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 79 non-responsive metrics, leaving a total of 82 metrics that met all testing criteria. Nine metrics spanning five metric categories were selected for inclusion in the final Southern Streams IBI (Table 6). Two of these metrics were included based on their conceptual importance. The TolPct metric was included despite showing only moderately strong differences between least- and most-disturbed sites (Responsiveness p-value 0.06). The conceptual importance of the proportion of tolerant individuals, coupled with the high Signal-To-Noise ratio observed for this metric, justified its inclusion. We observed a moderate correlation between F-IBI and HDS, and weak correlations between F-IBI, watershed area, and stream gradient (Table 4). “Low End Scoring” criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 6 taxa are captured.

4.6. Northern Headwaters

Table 11. Metrics selected for the Northern Headwaters F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Sensitive	Richness	Sensitive taxa	tolerance	positive	<0.001	9.97	0.00	4.00
Minnow-Tol_Pct	IndPct	Percent cyprinid individuals (excludes tolerant species)	composition	positive	<0.001	2.50	0.00	51.48
Insectivore-Tol_TxPct	TXPct	Percent insectivorous taxa (excludes tolerant species)	trophic	positive	<0.001	3.36	0.00	42.87
NumPerMeter-Tol	CPUE	Number of fish per meter (excludes tolerant species)	composition	positive	<0.001	2.00	0.01	1.82
InsectivorousCyprinid_Pct	IndPct	Percent insectivorous cyprinid individuals	trophic	positive	<0.001	2.27	0.00	20.85
HeadwaterSpecialist-Tol	Richness	Headwater taxa (excludes tolerant taxa)	habitat	positive	<0.001	6.88	0.00	3.00
DarterSculpin	Richness	Darter and sculpin taxa	composition	positive	<0.001	3.57	0.00	2.00
SimpleLithophil	Richness	Simple lithophilic taxa	reproductive	positive	<0.001	7.84	0.00	4.28
Tolerant_TxPct	TXPct	Percent tolerant taxa	tolerance	negative	<0.001	5.55	33.33	80.00
Pioneer_TxPct	TXPct	Percent pioneer taxa	life history	negative	0.002	2.97	10.00	33.33
FishDELT_Pct[1]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance, scored discretely

A total of 73 metrics failed either the Range or Signal-to-Noise Test in the Northern Headwaters class. No metrics in the Northern Headwaters class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 75 metrics, leaving a total of 89 metrics that met all testing criteria. Eleven metrics spanning seven metric categories were selected for inclusion in the final Northern Headwaters IBI (Table 10). One metric was included based on its conceptual importance. Northern Headwaters F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed a strong correlation between F-IBI and HDS, a moderate correlation between F-IBI and watershed area, and a weak correlation between F-IBI and stream gradient (Table 4). “Low End Scoring” criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 4 taxa are captured.

Appendix B

4.4 Low Gradient Streams

Table 8. Metrics selected for Statewide Low-Gradient Streams MIBI. This includes the Northern, Prairie, and Southern Low-Gradient stream classes. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
ClimberCh	Taxa richness of climbers	Habitat	Decrease	<.001	2.01	17.0	2.0
Collector-filtererPct	Relative abundance (%) of collector-filterer individuals in a subsample	Trophic	Decrease	<.001	2.37	37.9	0.3
DomFiveChPct	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)	Composition	Increase	<.001	2.49	43.2	90.8
HBI_MN	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	Tolerance	Increase	<.001	5.92	5.8	8.8
Intolerant2Ch	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs	Tolerance	Decrease	<.001	10.88	3.0	0.0
POET	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)	Richness	Decrease	<.001	7.36	16.0	2.0
PredatorCh	Taxa richness of predators	Richness	Decrease	<.001	2.64	18.0	4.0
TaxaCountAllChir	Total taxa richness of macroinvertebrates	Richness	Decrease	<.001	3.69	53.0	19.0
TrichopteraChTxPct	Relative percentage of taxa belonging to Trichoptera	Composition	Decrease	<.001	3.99	16.4	0.0
TrichwoHydroPct	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	Composition	Decrease	<.001	2.32	10.8	2.0

A total of 104 metrics failed either the range or signal-to-noise test in the Low Gradient Streams IBI class. There were no metrics needing correction due to a significant relationship with watershed area or gradient. An additional 14 metrics were removed due to the responsiveness test, leaving 129 metrics that met all testing criteria. Ten metrics in five metric categories were selected for low gradient streams (Table 8). These metrics were used in the Northern Forest Streams, Low Gradient class, the Southern Forest Streams, Low Gradient class, and the Prairie Streams, Low Gradient class. Low gradient streams M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a moderate correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

Appendix C: Individual F-IBI Metric and TIVs Data

Percentage of individuals per selected F-IBI metric

AUID Suffix	Station	Sample Date	F-IBI Metrics[1]							
			DomTwoPct	HerbvPct	InsectCypPct	MA<2Pct	MA>3Pct	MgrPct	Minnows-TolPct	TolPct
515	05RD098	23-Aug-05	91.4	0.0	7.2	96.4	3.60	1.80	0.0	95.5
	05RD098	16-Aug-12	73.6	0.0	0.0	46.2	7.55	11.32	27.4	59.4
	05RD098	18-Jul-12	98.7	0.0	0.0	6.0	0.57	0.57	5.2	94.2
	12RD100	14-Jun-12	95.1	0.0	0.1	98.8	1.03	1.93	0.0	98.2
517	07RD023	09-Aug-07	100.0	0.0	0.0	100.0	0.00	0.00	0.0	15.8
	07RD023	13-Jun-12	100.0	0.0	0.0	100.0	0.00	0.00	0.0	100.0
	12RD087	19-Jul-12	93.2	0.0	0.0	13.6	0.00	0.00	0.0	93.2
	12RD089	13-Jun-12	100.0	0.0	0.0	0.0	100.00	100.00	0.0	100.0
520	12RD098	19-Jun-12	100.0	0.0	0.0	40.0	60.00	60.00	0.0	100.0
Basin Mean Values (2005-2012)			**67.0**	**4.3**	**13.2**	**79.3**	**9.2**	**15.7**	**21.1**	**56.2**
State Mean Values (2005-2012)			**63.5**	**4.4**	**11.2**	**72.8**	**11.6**	**19.9**	**16.2**	**57.8**

[1] Metric response interpretations based upon the criteria outlined in the Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Taxa richness per selected F-IBI metric

AUID Suffix	Station	Sample Date	F-IBI Metrics[1]				
			DarterSculp	Hdw-Tol	Sensitive	SLithop	SIvd
515	05RD098	23-Aug-05	0	0	0	1	2
	05RD098	16-Aug-12	1	0	0	3	0
	05RD098	18-Jul-12	0	0	0	2	1
	12RD100	14-Jun-12	1	0	1	1	4
517	07RD023	09-Aug-07	0	0	0	0	0
	07RD023	13-Jun-12	0	0	0	0	2
	12RD087	19-Jul-12	0	0	0	0	1
	12RD089	13-Jun-12	0	0	0	1	0
520	12RD098	19-Jun-12	0	0	0	1	1
Basin Mean Values (2005-2012)			**1**	**1**	**2**	**3**	**3**
State Mean Values (2005-2012)			**1**	**1**	**3**	**3**	**3**

[1] Metric response interpretations based upon the criteria outlined in the Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Percentage of taxa per selected F-IBI metric

AUID Suffix	Station	Sample Date	F-IBI Metrics[1]						
			BenInsect-TolTxPct	DetNWQTxPct	GeneralTxPct	Insect-TolTxPct	PioneerTxPct	SensitiveTxPct	TolTxPct
515	05RD098	23-Aug-05	0.0	37.5	37.5	12.5	12.5	0.0	50.0
	05RD098	16-Aug-12	16.7	16.7	50.0	16.7	0.0	0.0	50.0
	05RD098	18-Jul-12	0.0	40.0	80.0	0.0	20.0	0.0	60.0
	12RD100	14-Jun-12	12.5	37.5	37.5	12.5	12.5	12.5	75.0
517	07RD023	09-Aug-07	0.0	50.0	50.0	0.0	0.0	0.0	50.0
	07RD023	13-Jun-12	0.0	50.0	50.0	0.0	50.0	0.0	100.0
	12RD087	19-Jul-12	0.0	33.3	66.7	0.0	33.3	0.0	66.7
	12RD089	13-Jun-12	0.0	100.0	100.0	0.0	0.0	0.0	100.0
520	12RD098	19-Jun-12	0.0	50.0	50.0	0.0	0.0	0.0	100.0
Basin Mean Values (2005-2012)			15.1	23.9	34.6	28.9	17.6	17.3	48.8
State Mean Values (2005-2012)			17.7	19.8	36.6	28.5	20.2	19.3	49.8

[1] Metric response interpretations based upon the criteria outlined in the Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

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

AUID Suffix	Station	Sample Date	F-IBI Metrics[1]
			NumPerMeter-Tol
515	05RD098	23-Aug-05	0.05
	05RD098	16-Aug-12	0.23
	05RD098	18-Jul-12	0.22
	12RD100	14-Jun-12	0.07
517	07RD023	09-Aug-07	0.10
	07RD023	13-Jun-12	0.00
	12RD087	19-Jul-12	0.02
	12RD089	13-Jun-12	0.00
520	12RD098	19-Jun-12	0.00
Basin Mean Values (2005-2012)			0.73
State Mean Values (2005-2012)			0.61

[1] Metric response interpretations based upon the criteria outlined in the Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Probability of meeting the TSS and DO standards based upon fish community TIVs

AUID Suffix	Station	Probability of Meeting Standard[1]	
		TSS	DO
515	05RD098	8	20
	05RD098	38	5
	05RD098	65	14
	12RD100	17	16
517	07RD023	23	13
	12RD087	36	5
	12RD089	77	58
520	12RD098	71	31
Basin Mean Values (2005-2012)		**54**	**31**
State Mean Values (2005-2012)		**63**	**37**

[1] Probability interpretations based upon a relative comparison to basin and state mean values.

Appendix D: Individual M-IBI Metric and TIVs Data

Percentage of individuals per selected M-IBI metric

AUID Suffix	Station	Sample Date	M-IBI Metrics[1]					
			Collector-filtererPct	DomFivewoCHPct	HBI_MN	LeglessPct	LongLivedPct	TrichwoHydroPct
515	05RD098	12-Sep-05	0.0	87.8	8.9	85.8	0.0	0.0
	05RD098	27-Sep-05	3.8	57.7	8.0	36.7	3.6	0.0
	05RD098	08-Aug-12	0.0	85.5	8.7	51.1	0.0	0.3
	12RD100	01-Aug-12	0.9	78.7	8.6	69.3	0.3	0.3
	12RD100	01-Aug-12	1.5	84.4	8.6	75.8	0.3	0.0
517	07RD023	14-Aug-07	0.9	81.9	8.2	39.6	2.1	0.0
	07RD023	06-Aug-13	1.3	85.5	8.4	59.7	1.3	0.3
	12RD087	01-Aug-12	0.0	93.7	9.7	89.9	0.3	0.0
	12RD089	01-Aug-12	0.3	53.6	8.6	75.7	0.0	0.3
Basin Mean Values (2005-2012)			**11.6**	**65.2**	**7.5**	**50.1**	**3.9**	**4.7**
State Mean Values (2005-2012)			**18.5**	**63.7**	**7.3**	**46.8**	**4.3**	**5.4**

[1] Metric response interpretations based upon the criteria outlined in the Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Taxa richness per selected M-IBI metric

AUID Suffix	Station	Sample Date	M-IBI Metrics[1]					
			ClingerCh	Intolerant2Ch	Plecoptera	POET	PredatorCh	TaxaCountAllChir
515	05RD098	12-Sep-05	1	0	0	8	12	26
	05RD098	27-Sep-05	5	0	0	4	14	26
	05RD098	08-Aug-12	4	0	0	5	7	21
	12RD100	01-Aug-12	4	0	0	4	7	19
	12RD100	01-Aug-12	5	0	0	4	5	19
517	07RD023	14-Aug-07	1	0	0	3	11	23
	07RD023	06-Aug-13	4	0	0	5	11	28
	12RD087	01-Aug-12	4	0	0	3	8	17
	12RD089	01-Aug-12	4	0	0	6	5	21
Basin Mean Values (2005-2012)			**9**	**0**	**0**	**8**	**10**	**35**
State Mean Values (2005-2012)			**11**	**1**	**0**	**9**	**9**	**36**

[1] Metric response interpretations based upon the criteria outlined in the Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Percentage of taxa per selected M-IBI metric

AUID Suffix	Station	Sample Date	M-IBI Metrics[1]	
			Tolerant2ChTxPct	TrichopteraChTxPct
515	05RD098	12-Sep-05	88.5	0.0
	05RD098	27-Sep-05	73.1	0.0
	05RD098	08-Aug-12	95.2	4.8
	12RD100	01-Aug-12	84.2	5.3
	12RD100	01-Aug-12	89.5	0.0
517	07RD023	14-Aug-07	95.7	0.0
	07RD023	06-Aug-13	89.3	3.6
	12RD087	01-Aug-12	100.0	0.0
	12RD089	01-Aug-12	90.5	4.8
Basin Mean Values (2005-2012)			**80.2**	**7.6**
State Mean Values (2005-2012)			**76.1**	**9.8**

[1] Metric response interpretations based upon the criteria outlined in the Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams, as well as a relative comparison to basin and state mean values.

Macroinvertebrate TIVs data

AUID Suffix	Station	Sample Date	TIVs Data[1]			
			TSS Tolerant Taxa (%)	TSS Intolerant Taxa (#)	DO Tolerant Taxa (%)	DO Intolerant Taxa (#)
515	05RD098	12-Sep-05	9	0	91	0
	05RD098	27-Sep-05	55	1	27	0
	05RD098	08-Aug-12	36	0	86	0
	12RD100	01-Aug-12	36	0	91	0
	12RD100	01-Aug-12	25	0	85	0
517	07RD023	14-Aug-07	11	1	85	0
	07RD023	06-Aug-13	8	1	67	0
	12RD087	01-Aug-12	10	0	11	0
	12RD089	01-Aug-12	11	1	57	1
520	12RD098	12-Sep-05	28	1	56	0
Basin Mean Values (2005-2012)			**30**	**3**	**26**	**3**
State Mean Values (2005-2012)			**26**	**5**	**20**	**6**

[1] TIVs data interpretations based upon a relative comparison to basin and state mean values.

Appendix E

Minnesota Pollution Control Agency
Technical Report
October 2015

The Aquatic Biota Stressor and Best Management Practice Selection Guide

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Introduction

The Aquatic Biota Stressor and Best Management Practice Selection Guide (Guide) was developed to provide an easy-to-use reference table for linking the common stressors to aquatic biota with best management practices (BMPs) that can positively affect them. The Guide was created for use by landowners, local units of government, watershed project managers and natural resource agencies who are working to improve the biological health of aquatic systems.

The Guide was intended for use following the completion of the stressor identification process (USEPA, 2000) although it can be used without this level of rigorous assessment. It is designed to provide BMP selection that specifically targets the stressor(s) to aquatic biota of a stream system under study. The selection of BMPs for implementation on a specific parcel should take into consideration a host of site specific factors, work in conjunction with how the land is operated and will need to meet landowner approval. The comprehensive list of BMP alternatives for addressing stressors can expand the options from which to choose and allow the resource manager and landowner to select the best alternatives for a given situation. BMPs must be properly located, designed, implemented/constructed and maintained in order to be effective.

The Minnesota Pollution Control Agency (MPCA) began implementing the EPA aquatic biota stressor identification process (EPA, 2000) in 2007 in response to bio-monitoring studies that were finding impairments to aquatic life use in Minnesota streams. The work resulted in the development of stressor identification (SID) reports that document the science behind the determination of stressors on bio-impaired stream reaches. The SID reports are written for local resource managers so that they can prioritize protection and restoration work and apply for implementation grant funding.

The development of the Guide began with reviewing various BMP manuals and recording the information regarding practice effectiveness at addressing stressors. Although a literature search was conducted, it was not exhaustive, and focused simply on gathering the necessary information, from credible sources, to build a useful relationship guide that link stressors with BMPs. A table was created to record this information. BMPs for the landuse categories of agriculture, urban, forest and riverine were selected for inclusion in the chart as they generally include the land use categories that have the anthropogenic alterations that typically affect our stream resources.

The literature used in the development of this guide is generally based on work done in Minnesota and the Midwest. Although the BMP stressor relationships indicated in the table should be applicable nationwide, there may be manuals specific to states or regions of the country that may better serve a project in that specific region. In addition, there may be stressors and BMPs unique to a specific area that are not listed within this Guide, or BMPs that have been developed for specific soils or climate that differ from the Midwest.

Most of the literature sources used in this guide ranked the ability of the BMPs for how well they mitigated a stressor. In almost all cases, that ranking was carried through to the table without edit. In some cases, best professional judgment was used to classify the strength of a BMP in addressing a particular stressor. This occurred, in part, due to differences in the ranking systems used in the various papers referenced. In addition, there was on occasion, a need to adjust a rank in order to normalize the ranking when two different sources were cited for a single point in the chart that had different ranks. There were also a couple of instances where the ranking appeared to be suspect or biased.

These few minor edits are not considered an issue because they will have little to no effect on the practical use of this chart. Variability in locations throughout the United States in terms of hydrology, soils, watershed characteristics, biotic response to stressors and landuse intensity will all play into the usefulness of specific BMPs regardless of the rankings presented within this chart. Put another way, the rankings are presented as a guide, and those utilizing this tool will have much more to do with choosing the correct BMPs for a specific application then whether they are ranked high or moderate in their ability to effect change in a stressor on the biota. The purpose of this tool is to present the information in an organized fashion and then get out of the way of the local implementer who can use his/her experience and knowledge to create the most effective treatments, in the right locations for effecting the greatest benefit for a given implementation budget.

Using the Guide

The BMPs listed within this Guide are first organized by land use type (i.e., Agricultural, Riverine, Urban and Forestry), and then by treatment group (e.g., source controls, filtration, settling, nutrient removal, etc.). Each BMP is listed (alphabetically) under the treatment group heading that best characterizes the BMP. The names of the BMPs used in the guide are the names that are used in the United States Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS) Field Office Technical Guide. The NRCS Practice Code numbers, for those BMPs that are found in the Field Office Technical Guide, follow the BMP name in the Guide.

Use of the chart involves picking a stressor from the top of the table and scrolling down the column into the land use type(s) (in the far left column) that apply to the stream reach under study. To find the BMPs within a landuse group that can affect a stressor, one should look for a colored dot in the stressor column and then locate the BMP in the row under column C. Cells within the table are color coded to indicate the relationship that has been identified between the BMP (in the row) and the stressor (in the column). Cells that are marked with a blue or yellow dot indicate that there is documentation in the literature that the BMP can have a positive effect on the stressor. A green dot indicates that there is a strong likelihood that the BMP will have a positive effect on the stressor. A red dot in a cell indicates that the BMP could aggravate the stressor.

The colored dots specifically indicate the following:

(●) Well documented in literature. High confidence that proper implementation of BMP will ameliorate the stressor. The stressor is a primary target of the BMP.
(●) Some study in literature. Moderate confidence that proper implementation of BMP will ameliorate the stressor. The stressor is a secondary or ancillary target of the BMP.
(●) Not identified in literature that was reviewed, however it is reasonable to assume that the BMP will have a positive effect on the stressor. The BMP theoretically has the potential for reducing the stressor.
(●) BMP has potential to aggravate the stressor.

The numbers behind the blue and yellow dots in the Guide are literature reference numbers. Refer to the Literature Cited section to reference the literature used to support the information in the table. The Literature Cited, Credits sheet also contains the names of individuals on the Technical Teams who helped to develop and review the content within specific landuse categories.

Improved BMP Effectiveness

Limited budgets and long lists of impaired waters that require protection and restoration is the reality that resource managers face in Minnesota and likely elsewhere. The need to demonstrate project effectiveness to both funding sources and local stakeholders has increased along with the competition for funding. As resource professionals, we have a responsibility to get the greatest environmental benefit for the public dollars we are entrusted with and this tool can play a part in making that happen.

Two important factors play into BMP effectiveness that should be considered when designing implementation projects. The primary purpose of the Aquatic Biota Stressor and BMP Selection Guide is to specifically select the BMPs that will most effectively mitigate stressors in order to improve biological condition. Those stressors can be identified through both a general assessment of the watershed with assumed stressors or they can be identified through the more rigorous and formal SID process (EPA 2000, www.epa.gov/caddis, Norton et al. 2014).

Figure 1 provides a conceptual table where these two methods are compared against using traditional BMPs (BMPs most commonly used by local Implementers) vs. using this guide to select BMPs specific to the stressors acting on the biology of the stream system under study. Realistic expectations are presented that show that the dollars invested in understanding the stressors play an important role in overall project success measured in environmental results (i.e. if you don't understand the problem, then it's difficult to resolve it). In addition, choosing BMPs that will specifically address the stressors identified will have a greater impact on those stressors verses choosing the standard suite of water quality BMPs commonly used in the area of project.

Figure 1. Realistic expectations of the likelihood of biological stressor reductions (environmental results) from watershed project design decisions.

Rigor /Detail in BMP Selection - Precision of Goal	Simple SID Assessment or Assumptions	Detailed SID Study	BMP Effectiveness at Addressing Aquatic Biota Stressors
General BMP Practice Selection	Poor	Poor to Fair	Poor to Fair
Stressor Targeted BMP Practice Selection	Fair to Good	Good to Excellent	Fair to Excellent
Cost of SID Study	Low to Moderate	Moderate to High	-------

When considering the cost to complete a detailed SID study one should take into consideration that the upfront expense for this work likely has long-term benefits to the project and stream system under study. Effectively protecting and restoring water resources is often an iterative process that is often measured in decades not years. Land use impacts to our waters typically occurred over an extended period of time and addressing those impacts and restoring health to our aquatic resources often requires a well-targeted effort and persistence over time. Conducting a SID study to accurately identify the stressors on the biology can be considered a pre-requisite to implementation if the goal is to accurately focus on the cause of the biological impairments and restore biological integrity. Selecting BMPs that specifically target those stressors will fine tune the implementation strategy so that funds go toward treating the stressors having the greatest impact on the biology.

Conducting protection and restoration planning requires attention to the spatial scales of individual project elements, the sources of the stressors and the watershed. Project size and scope is influenced by many factors including budget and the degree of protection or restoration required to meet project objectives, for example, a low IBI score or a reduction in a pollutant concentration or load. If models have been constructed for the watershed, goals may be the result of model predictions based on a selected scenario that results in the desired future condition. Regardless of the method used to develop the goal, the project team needs to be intentional about scale. On larger systems it may be advantageous to prioritize the protection of high quality tributaries prior to moving into the restoration of impaired reaches that will often require more time, landowner involvement and funds to accomplish.

Figure 2 presents the concept that it is through the proper targeting of BMP location in combination with targeted BMP practice selection that will help to assure the highest net environmental gain for the dollar spent. This chart uses the same “Rigor in BMP Selection” column used in Figure 1 but adds the “BMP Location Selection” variable. The broadcast or random BMP location approach (sign up everyone in the watershed who expresses interest in implementing a BMP) is compared to targeted BMP location. The targeted BMP location approach involves both selecting specific streams that are priority for protection or restoration and then focusing on the proper minor subwatersheds and best parcels for BMP implementation. The cost effectiveness of the options (Net Environmental Gain / $ Spent) is presented to give the reader perspective and help make the point that it is through specific targeting (both in practice selection and location selection) that our projects have the greatest potential to effect positive change. The Location Selection Impact on Project Effectiveness row simply combines the ratings of the two practice selection variables under each of the location selection options to help show the importance of location selection in project effectiveness.

Figure 2. Impact of BMP targeting (both practice and location) on stressor reduction or environmental effectiveness.

Rigor in BMP Selection	Broadcast or Random BMP Location Selection	Targeted BMP Location Selection	Net Environmental Gain / $ Spent
General BMP Practice Selection	Poor	Fair to Good	Low to Moderate
Targeted BMP Practice Selection	Poor to Fair	Good to Excellent	Moderate to High
Location Selection Impact on Project Effectiveness	Poor to Fair	Fair to Excellent	-------

BMPs can be implemented as stand-alone practices or in series in what is termed "treatment trains." A treatment train approach utilizes a sequence of BMPs that treat pollutants often starting with pollution prevention, then source controls followed by treatments such as filters, settling and infiltration. Utilizing this approach can result in higher rates of pollutant reduction and a more sustainable, lower maintenance set of BMPs. This guide is organized so that the pollution prevention/source control BMPs are listed at the top and the more advanced or follow-up BMPs in the treatment train approach follow in each of the landuse categories.

The use of treatment train method of building BMPs into the landscape is encouraged due to the benefits this approach provides. The concept involves using a set of practices in combination to treat the stressor. An example of using this approach would be a situation where sediment is the stressor and it is determined that it is coming from upland agricultural sources. The sediment is filling in (embedding) coarse gravel substrate and causing poor diversity and IBI scores in the fish community. A treatment train approach could involve an increase in the use of conservation tillage (no till or reduced tillage) in the subwatershed. In addition, cover crops (conservation cover) could be used where possible on fields that are most susceptible to erosion. These BMPs are both found under the Pollution Prevention - Source Controls treatment group under the Agricultural Land Use and are used to reduce the loss of soil/sediment at the source. Grassed waterways (found under the Filtration treatment group) would be a tactic to capture the sediment that makes it way to the field edge. Sediment basins (found under the Settling treatment group) could be used to reduce the sediment levels that make it into the ditch systems serving the fields.

It is the combination of methods in different treatment groups that increase the level of pollutant reduction and protection of the resource. Any one of the practices used would be helpful but by combining several methods the pollutant reduction is increased and the longevity of the practices (especially the downstream grassed waterways and sediment basins) is improved and the required maintenance of these practices reduced as less sediment reach these practices with adequate source controls.

Environmental scientists and watershed managers face some serious challenges in protecting and restoring water resources. There are several relatively new threats to water quality that must be considered when setting realistic expectations for project success. Climate change and the resulting increase in large storm events and increased storm intensity are sending higher pollutant loads into our lakes and streams. The frequency of 3" or greater downpours in the Midwest has doubled since 1964 (Douglas, 2014). The improved drainage efficiency in our urban and agricultural watersheds is another factor that contributes to increased stream flashiness with higher peak flows and an increased rate of stream channel degradation and instream habitat loss. Drainage improvement in the form of agricultural tiling has contributed to prolonged low flow and no-flow conditions in some of our watersheds with associated dissolved oxygen issues and substantial habitat loss. The loss of sensitive set-a-side acres (notably Conservation Reserve Program land) serves another blow to our surface water resources with increased runoff rates and nutrient and sediment loading. As we face these challenges in our watersheds we must bring the best science to the table if we expect to hold ground - let alone make measureable improvement to our stream biology and chemistry.

Setting expectations of environmental improvement is difficult even without the new challenges presented above. Project success is dependent on the proper stressor targeted BMPs being selected in the right combination and density, at the proper scale and in the right locations. It is the cumulative and incremental impact of these actions over time that will affect the desired change to the biology, chemistry and physical condition of the stream. The variability in how biological systems respond to implementation efforts and the time required to generate the biological response must be considered and communicated to bring perspective to the expectations of resource improvement.

Summary

The Aquatic Biota Stressor and BMP Selection Guide fills a void that existed in having an easy to use reference table for selecting BMPs for reducing the impact of stressors affecting aquatic biota. The Guide can assist those working on watershed projects with an initial assessment of protection and restoration options that are available, and their relative effectiveness for improving the health of biologically impaired systems. The most environmentally effective watershed projects will target both practice selection and practice location at specific stressors. Once a suite of options are selected to address a stressor, there are many manuals available that present detailed information regarding BMP design, siting, proper installation and maintenance that can assist in implementing effective protection and restoration.

This guidance tool is new, and as such, it is a candidate for improvement and enhancement by those who study BMPs, stressors or use the table for selecting BMPs for their watershed projects. Ideas that contribute toward improving/revising this table are welcome. Please forward any comment or ideas to Mike Sharp, MPCA. Mike can be reached through his email at michael.sharp@state.mn.us.

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The author thanks the following individuals for their important contributions to the development and review of this guidance tool and technical report. Special thanks to Dr. Susan Norton (USEPA) who encouraged the development of this table to fill the need for a guidance tool that identifies the specific BMPs that are effective at reducing the impact of a stressor acting upon stream biology.

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Minnesota Pollution Control Agency

CLEAN WATER LAND & LEGACY AMENDMENT

Land Use Type	Treatment Group	BMP's	Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
			STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
Agricultural	Education, Training & Regulation	Ag Drainage System Design Training	green		green	green	green	green	green	green	green			green			
		Controlled Tile Ordinance	green														
		Ditch Set-back Ordinance. MN 103E.021			green			green						green			
		Individual Sewage Treatment System Regs & Training						green	green	green	green	green		green		green	green
		MN Shoreland Ordinance - 50' Shoreland Setback			green			green	green	green	green			green	green		
		Restricted Use Pesticide Training (MN)													green		
		Wetland Conservation Act, 401 Certification	green		green			green									
	Pollution Prevention - Source Controls	Biochar Soil Amendment	green		green		green	green	green	green	green				green		
		Conservation Cover (327)	yellow [13]	yellow [1]	yellow [1, 13]			yellow [1, 13]	yellow [13]	blue [1, 13]				yellow [13]	yellow [13]		
		Conservation Crop Rotation (328)			yellow [13]				yellow [13]	blue [1, 13]					yellow [13]		
		Conservation Tillage - No Till (329), Reduced Till (345)			blue [1, 13]			blue [1, 13]	blue [1, 13]	blue [1, 13]					blue [13]		
		Contour Farming (330)			yellow [1, 13]			yellow [1, 13]	yellow [13]	yellow [13]					yellow [13]		
		Cover Crop (340)			blue [1, 13]			yellow [1,13]	yellow [13]	blue [1, 13]					yellow [13]		
		Grade Stabilization Structure (410)	yellow [1]		yellow [1, 13]												
		Grade Stabilization @ Side Inlets (410)			yellow [1]			yellow [1]									
		Nutrient Management (590)			blue [1]			blue [1, 13]	blue [1, 13]	blue [1, 13]	blue [1, 13]			yellow [1]			
		Integrated Pest Management (595)													blue [1, 13]		
		Terrace (600)			blue [1, 13]			yellow [13]	yellow [13]	yellow [13]					yellow [1, 13]		
	Filtration	Contour Buffer Strips (332)			blue [1, 13]			yellow [13]	yellow [13]	yellow [13]					blue [1, 13]	yellow [13]	yellow [13]
		Field Border (386)		green	blue [1, 13]		green	blue [1, 13]	blue [1, 13]	blue [1, 13]	blue [1, 13]				blue [1, 13]		
		Filter Strip (393)		green	blue [1, 13]		green	blue [1, 13]	blue [1, 13]	blue [1, 13]	blue [1, 13]				blue [1, 13]	blue [13]	blue [13]
		Grassed Waterway (412)	yellow [1, 13]		blue [1, 13]	yellow [13]		yellow [13]	yellow [13]	yellow [13]	green				yellow [1, 13]		
		Vegetative Barrier (601)			yellow [13]			yellow [13]	yellow [13]	yellow [13]					yellow [13]		
	Infiltration	Alternative Tile Intakes	yellow [1]		yellow [1]			yellow [1]	yellow [1]				green				
		Structure for Water Control - Controlled Drainage (587)	yellow [1, 13]			green	yellow [13]	yellow [1]	yellow [1]	yellow [1]			green				
		Drainage Water Management (554)						yellow [13]	yellow [13]	red [13]					yellow [13]		
		Irrigation Water Management (449)			yellow [1]			yellow [1, 13]	yellow [13]	yellow [1, 13]					yellow [1, 13]	yellow [13]	yellow [13]
		Tile System Design	yellow [1]							yellow [1]			green				
	Settling	Alternative Side Inlet	yellow [13]		green			green		green	green				green		
		Culvert Downsizing/Road Retention	yellow [1]		yellow [1]			green									
		Sediment Basin (350)	yellow [13]		blue [1, 13]			blue [1, 13]	yellow [13]	yellow [1, 13]	yellow [1, 13]				yellow [13]		
		Water & Sediment Control Basin (638)	yellow [1, 13]		blue [1, 13]			yellow [1]	yellow [1]								
	Nutrient Removal	Saturated Buffers - Vegetated Subsurface Drain (739)	yellow [12, 13]					yellow [12]	yellow [12]	yellow [12, 13]							
		Two Stage Ditch Design	yellow [1]	yellow [1]	yellow [1]		green	green		yellow [1]				green			
		Wetland Creation (658) - Constructed Treatment	yellow [13]	yellow [1]	yellow [1, 13]			yellow [1, 13]	yellow [13]	yellow [1, 13]	blue [7]			yellow [1]	yellow [13]	blue [7]	yellow [13]
		Wetland Enhancement (659)			yellow [13]			yellow [13]	yellow [13]	yellow [13]					yellow [13]		yellow [13]
		Wetland Restoration (657)	yellow [1]	yellow [1]	yellow [1, 13]			yellow [1, 13]	yellow [13]	yellow [1, 13]	blue [7]				yellow [1, 13]	blue [7]	yellow [13]
		Woodchip Bioreactor (Denitrification Beds)						yellow [1]	yellow [1]	yellow [1]					yellow [1]		
	Livestock Management	Constructed Wetland (656)						blue [13]	blue [13]	blue [13]	blue [13]						
		Feedlot Clean Water Diversion			yellow [1, 13]			yellow [1]	yellow [1]	yellow [1]	green		green				
		Fence (382) - Livestock Exclusion		yellow [1]	yellow [1]		yellow [1]	green	green	green	green			green			
		Prescribed Grazing (528) - Rotational			yellow [1, 13]		yellow [1, 13]	yellow [1, 13]	yellow [13]	yellow [1, 13]	yellow [13]				yellow [13]		
		Stream Crossing (578)			yellow [13]			red [13]	red [13]	red [13]	red [13]						
		Vegetated Treatment Area (635) - Feedlot Wastewater I	yellow [13]		blue [1, 13]			blue [1, 13]	blue [1, 13]	blue [1, 13]	blue [13]		green				
		Waste Storage Facility (313) - Manure						blue [1, 13]	blue [13]	blue [1, 13]	blue [13]						

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Riverine	Vegetative Cover	Streambank and Shoreline Protection (580)	🟡[1]	🟡[1, 13]	🟡[1, 13]		🟡[13]	🟡[13]	🟡[13]	🟡[13]							
		Streambank Stabilization with Vegetation	🔵[7]	🔵[7]	🔵[6,7]		🔵[7]	🟡[6]	🟡[6]	🟡[6]	🔵[7]			🔵[7]			
		Re-establish Riparian Trees & Brush	🔵[7]	🔵[7]	🔵[7]		🔵[7]				🔵[7]			🔵[7]		🔵[7]	
		Riparian Forest Buffer (391)			🔵[13]		🔵[13]	🔵[13]	🔵[13]	🔵[13]					🟡[13]		
		Riparian Herbaceous Cover (390)		🟡[1, 13]	🔵[1, 13]		🟡[1, 13]	🔵[1, 13]	🔵[13]	🔵[1, 13]					🟡[13]		
	In-Stream Restoration	Alter Dam Operation to Mimic Natural Conditions	🔵[7]	🔵[7]													
		Dam Removal	🔵[5]	🔵[5]	🔵[7]	🔵[5]	🟢							🔵[5]			
		Grade Control / Drop Structures	🔵[7]	🔵[7]	🔵[7]						🔵[7]			🔵[7]			
		Nature-Like Fish Passage		🔵[11]	🔵[11]	🔵[11]											
		Proper Culvert Sizing or Replace with Bridge	🟢	🟢	🟢	🟢											
		Reset Culverts @ Proper Elevation		🟢		🔵[1]											
		Restore Natural Stream Meander and Complexity	🔵[7]			🔵[11] **								🔵[7]			
		Restore Riffle Substrate		🔵[7]	🔵[7]						🔵[7]			🔵[7]			
		Retrofit Dams with Multilevel Intakes					🔵[7]										
		Stream Habitat Improvement and Management (395)		🟡[13]	🟡[13]	🟡[13]	🟡[13]										
		Terraces				🔵[11] **											
		Two Stage Ditch	🟢	🟢	🟡[1]	🔵[11] **	🟢	🟢	🟢	🟡[1]							

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Urban	Education, Training & Regulation	Erosion & Sediment Control Training		green	blue[2]			yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]			
		Establishing a Buffer Ordinance	blue[2]	green	blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]						
		Establishing an Infiltration Standard(s)	blue[2]		blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]						
		Illicit-Discharge Identification & Risk Reduction						yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]			blue[2]
		Pet Waste Ordinance						yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]			
		Storm Drain Stenciling						yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]		blue[2]	blue[2]
	Pollution Prevention - Source Controls	Park & Open Space Fert/Chem Appl. Programs						yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]	green		
		Composting Programs			yellow[6]			yellow[6]	yellow[6]	yellow[6]	yellow[6]			green			
		Fertilizer Management						green	green	green	green						
		Hazardous Material Storage & Handling													green	blue[2]	blue[2]
		Open Space Design	blue[2]	green	blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]						
		Reducing Impervious Surfaces	blue[2]		blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]	blue[2]				blue[2]	blue[2]
		Residential Waste Collection & Clean-up Programs		green				yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]		blue[2]	
		Septic System Maintenance Programs			blue[2]			yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]			
		Street & Parking Lot Sweeping			blue[2]			yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]			
		Urban Forestry	blue[2]		green		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]					blue[2]	
		Vehicle Washing			yellow[6]			yellow[2]	yellow[2]	yellow[2]	yellow[2]			blue[2]		blue[2]	blue[2]
		Volume Control Using Compost /Soil Amendments	blue[2]		blue[2]			yellow[2]	yellow[2]	yellow[2]	yellow[2]						
		Winter Road Materials Management			blue[2]			yellow[2]	yellow[2]	yellow[2]	yellow[2]	blue[2]	blue[2]			blue[2]	
	Infiltration	Green Roofs	blue[2]		blue[6]		blue[2]	blue[6]	blue[6]	blue[6]	blue[6]					blue[6]	
		Improved Turf			blue[6]			yellow[6]	yellow[6]	yellow[6]	yellow[6]						
		Infiltration Basin/Trench	blue[2]		blue[2]		blue[2]	blue[2,6]	blue[2,6]	yellow[2]	yellow[2]					blue[2]	
		Pervious Pavements	blue[2]		blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]	blue[2]				blue[6]	blue[6]
		Vegetated Swales	green		blue[6]			blue[6]	blue[6]	blue[6]	blue[6]					blue[6]	blue[6]
	Filtration	Bioretention						blue[6]	blue[6]	blue[6]	blue[6]			green		blue[6]	blue[6]
		Dry Swales	blue[2]		blue[2]		blue[2]	blue[6]	blue[6]	blue[6]	blue[6]					blue[6]	blue[6]
		Filter Strips/Buffers	blue[2]		blue[2]		blue[2]	yellow[2]	yellow[2]	yellow[2]	yellow[2]						
		Permeable Pavement with Underdrains	green		green			green									
		Sand Filters						blue[6]									
		Tree Trenches/Boxes	green				green	green	green	green	green						green
		Wet Swales	blue[6]		blue[6]			blue[6]	blue[6]	blue[6]	blue[6]					blue[6]	blue[6]
	Reuse	Rainwater Harvest/Reuse & Rain Barrel Programs	blue[2]		blue[2]			blue[6]	blue[6]	blue[6]	blue[6]	blue[6]			blue[6]	blue[2]	blue[6]
		Underground Storage Systems	green														
	Settling	Constructed Wetland	green		blue[6]			blue[6]	blue[6]	blue[6]	blue[6,7]					blue[6]	blue[6]
		Hydrodynamic Separators			green												green
		Stormwater Ponds	green		green		red[6]	blue[6]	blue[6]	green	green					blue[6]	blue[6]
	Chemical Treatment	Iron & Aluminum Enhanced BMPs			blue[6]			blue[6]	blue[6]	blue[6]	blue[6]					blue[6]	

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Forestry	Pollution Prevention - Source Controls	Avoidance of Logging Residue into Waterbodies		Yellow [3,4]	Yellow [3,4]		Green	Green	Green					Green			
		Careful Pesticide Selection													Yellow [3,4]		
		Erosion Control (water bars, silt fence, etc.)			Green			Green	Green								
		Integrated Pest Management													Yellow [3,4]		
		Minimization of Soil Disturbance			Yellow [3,4]			Green	Green								
		Precautions During Pesticide Use Cycle													Yellow [3,4]		
		Properly Clearing Debris in Rights-of-Way			Yellow [3,4]	Yellow [3,4]											
		Proper Use of Mechanical Site Prep Techniques			Yellow [3,4]												
		Soil Protection/Seeding			Yellow [3,4]			Green	Green								
		Site Reconnaissance/Protect Sensitive Areas	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]	Yellow [3,4]			Yellow [3,4]	Yellow [3,4]		
		Water Diversion Structures	Yellow [3,4]		Yellow [3,4]								Green				
		Wetland Protection	Green	Yellow [3]		Yellow [3]											
	Infrastructure Management	Appropriate Wetland Road Construction	Yellow [3]	Green	Yellow [3,4]			Green	Green								
		Appropriate Winter Road Construction			Yellow [3,4]			Green									
		Closure of Inactive Roads & Post-Harvest	Yellow [3,4]	Green	Yellow [3,4]			Green									
		Forest Road Cross-Drainage			Yellow [3,4]			Green									
		Location & Sizing of Landings			Yellow [3,4]			Green	Green								Green
		Maintaining Active Forest Roads			Yellow [3,4]	Yellow [3,4]		Green									
		Proper Alignment of Forest Roads	Green		Yellow [3,4]	Green		Green									
		Proper Water Crossings	Yellow [3,4]		Yellow [3,4]	Yellow [3,4]		Green									
		Road Construction, Excavation, & Surfacing			Yellow [3,4]			Green	Green								
	Vegetative Cover / Structure	Improving Tree Longevity & Diversity of Composition		Blue [8]		Blue [8]											
		Minimization of Young Forest/Open Area Cover	Blue [9]	Blue [9]	Blue [9]												
		Prescribed Burning		Yellow [3,4,8]	Yellow [3,4,8]	Blue [8]											
		Riparian Management Zone Widths		Blue [8]	Blue [8]	Blue [8]	Blue [8]	Blue [8]	Blue [8]	Blue [8]	Blue [8]			Blue [8]			
		Shade Strips Adjacent to Lakes, Streams & Wetlands		Yellow [3,8]			Yellow [3,8]							Green	Blue [8]		Blue [8]
	Infiltration	Proper Timing of Harvest (minimize compaction) or of Vegetative Treatments	Blue [8,10]	Blue [8,10]	Blue [8,10]			Blue [8,10]	Blue [8,10]	Blue [8,10]	Blue [8,10]						
	Filtration	Filter Strips Adjacent to Lakes, Streams & Wetlands		Yellow [3,4,8]	Yellow [3,4,8]			Yellow [3,4,8]	Yellow [3,4,8]	Yellow [3,4,8]	Yellow [3,4,8]				Yellow [3,4,8]		

Key: A dot in a cell (with the exception of red) indicates the BMP should have a positive affect on the stressor.

Blue	Well Documented. Stressor is primary target of BMP.
Yellow	Some Study. Stressor is secondary target of BMP.
Green	Reasonable to assume stressor affected by BMP.
Red	BMP has potential to aggravate the stressor.
1,2,3...	Literature Cited Supporting the BMP-Stressor Relationship

Notes:

A. * BMPs for Flow Alteration may be included for their impact to reduce the effects of either low and/or high flow.
B. ** Indicates that this BMP addresses lateral connectivity (access to floodplain) rather than longitudinal connect
C. The numbers in parenthesis behind some of the BMPs are the NRCS Conservation Practice (CP) numbers.
D. Habitat for the purposes of this guide refers to the physical, structural attributes of stream habitat.
E. Salts or Ionic Strength is typically measured by conductivity, salinity or total dissolved solids.
F. September, 2015 version.