Clearwater River Watershed Stressor Identification Report

A study of stressors limiting the aquatic biological communities in the Clearwater River Watershed

Minnesota Pollution Control Agency

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Acronyms

AUID – Assessment Unit Identification

BMP – Best Management Practice

CADDIS – Causal Analysis/Diagnosis Decision Information System

CD – County Ditch

cfs – cubic feet per second

CR – County Road

CSAH – County State Aid Highway

DNR – Minnesota Department of Natural Resources

DO – Dissolved Oxygen

EPA – United States Environmental Protection Agency

HSPF – Hydrological Simulation Program - FORTRAN

HUC – Hydrologic Unit Code

IBI – Index of Biological Integrity

IWM – Intensive Watershed Monitoring

MPCA – Minnesota Pollution Control Agency

MSHA – MPCA Stream Habitat Assessment

NAIP – National Agriculture Imagery Program

NLCD – National Land Cover Database

RLWD – Red Lake Watershed District

SI – Stressor Identification

SOE – Strength-of-Evidence

TALU – Tiered Aquatic Life Use

TIV – Tolerance Indicator Value

TMDL – Total Maximum Daily Load

TP – Total phosphorus

TSS – Total suspended solids

TSVS – Total suspended volatile solids

USGS – United States Geological Survey

WHAF – Watershed Health Assessment Framework

Executive summary

The Minnesota Pollution Control Agency (MPCA) follows a watershed approach to systematically monitor and assess surface water quality in each of the state's 80 major watersheds. A key component of this approach is the Intensive Watershed Monitoring (IWM) program, which includes biological (fish and macroinvertebrate) monitoring to evaluate overall stream health. In 2014, 2015, and 2016 the MPCA conducted biological monitoring at several monitoring stations throughout the Clearwater River watershed. An Index of Biological Integrity (IBI) score was then calculated for the fish (F-IBI) and macroinvertebrate (M-IBI) communities sampled from each station. The biological monitoring results for the watershed were assessed to identify individual stream reaches, referred to using Assessment Unit Identification (AUID) numbers that were not supporting a healthy fish and/or macroinvertebrate population. A reach with low IBI scores (i.e., below an established threshold) is usually considered "impaired" for aquatic life.

A total of eight reaches, or AUIDs, in the Clearwater River watershed were determined to have an aquatic life impairment, including segments of County Ditch 23, Beau Gerlot Creek, Poplar River, Tributary to the Poplar River Diversion Ditch, Hill River, Lost River, and Silver Creek.

The Lost River AUID 646 (Section 4.8) was investigated because the M-IBI score at site 05RD046 was lower during the 2015 sampling event than during the 2005 sampling event. The AUID passed the fish and macroinvertebrate IBI; however, signs of biological community change were evident in the macroinvertebrate community. Lower Badger Creek was also investigated during the stressor identification process. Originally, the AUID was failing for fish and full support for macroinvertebrates. Additional information was collected in 2016 that placed this AUID in the Modified Use category based on an updated MSHA score. The fish are now meeting the standard. This AUID is discussed later in the report (Section 4.10). This report identifies six candidate causes, or "stressors," that are likely contributing to the nine aquatic life impairments throughout the Clearwater River watershed. Those candidate causes are: low dissolved oxygen (DO), flow alteration, lack of physical habitat, eutrophication (elevated phosphorus levels combined with high daily DO flux), and lack of longitudinal connectivity (prohibiting fish passage). A causal analysis procedure was performed to evaluate connections between each of the six candidate causes and the aquatic life impairments. Table 1 provides a summary of the stressors identified in the biologically impaired reaches of the Clearwater River watershed.

Table 1. Summary of stressors identified in the Clearwater River Watershed

Name (AUID suffix)	Biological impairment(s)	Candidate causes				
		Low dissolved oxygen	Flow alteration	Lack of physical habitat	Elevated nutrients	Lack of longitudinal connectivity
County Ditch 23 (658)	F-IBI		X	X		X
Beau Gerlot Creek (652)	F-IBI/M-IBI		X	X		X
Poplar River (518)	F-IBI/M-IBI	X	X	X		X
Hill River (539)	F-IBI	X		X		X
Hill River (656)	F-IBI	X		X		X
Tributary to Poplar River Diversion Ditch (561)	F-IBI	X	X	X		X
Lost River (645)	F-IBI	X	X	X	X	X
Silver Creek (527)	M-IBI	X	X		X	

Modeling results from the Hydrologic Simulation Program - FORTRAN (HSPF) model indicate that low flow periods are a source of stress to the biologically impaired reaches in the watershed. Many of the reaches experience extended periods of low to no flow throughout the modeled record of 1999 through 2009. Also, the model results show that very high flows are routinely experienced in these reaches. High flows, if not alleviated by connection to a floodplain, can have enough shear stress to physically dislodge and move macroinvertebrates and fish downstream. Historical changes in land cover (e.g., native vegetation to cropland) and drainage patterns (e.g., ditching and channelization) are the primary anthropogenic factors contributing to this flow regime instability. Additional runoff detention/retention is needed throughout the watershed to attenuate peak flows and augment base flows, thus stabilizing the flow pattern.

The habitat quality of several reaches have been degraded because of flow pattern alterations, hence “lack of physical habitat” and “flow alteration” were the most common stressors found in the watershed. Low DO is a stressor in three of the impaired reaches. The severity of low DO varies among reaches, with the lowest concentrations generally coinciding with low flow and lentic conditions occurring in late summer. Base flow augmentation appears to be the primary means of alleviating the three primary stressors, lack of physical habitat, flow alteration, and low DO.

Introduction

Stressor identification is a formal and rigorous methodology for determining the causes, or "stressors", that are likely contributing to the biological impairment of aquatic ecosystems (EPA, 2000). The initial step in the 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 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 analysis is used to determine the probable stressors for the biological impairment(s). Confidence in the final stressor identification results often depends on the quality of data available to the process. In some cases, additional data collection may be necessary to conclusively identify the stressors.

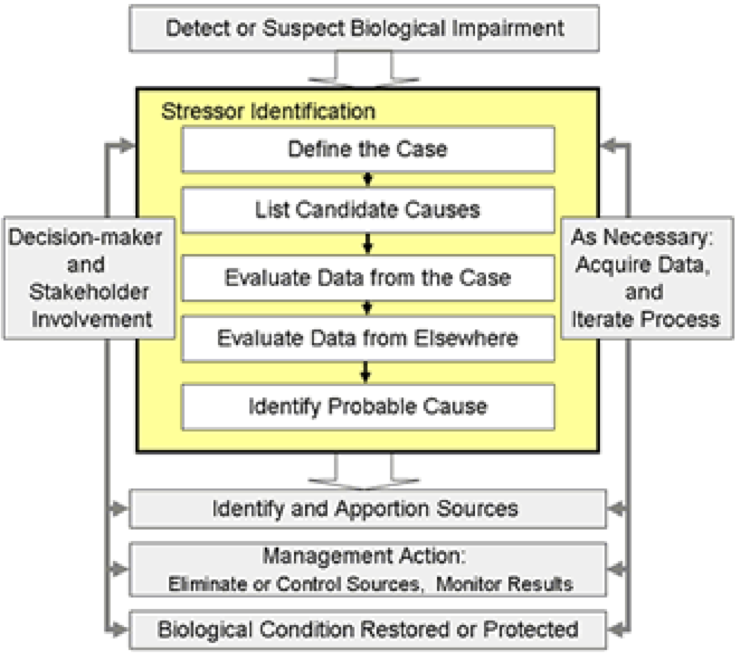


Figure 1. Conceptual model of the stressor identification process (EPA 2012b).

Section 1: Watershed overview

1.1 Physical setting

The Clearwater River watershed (United States Geological Survey Hydrologic Unit Code: 09020305) is situated in northwestern Minnesota and is part of the larger Red River of the North Basin. The watershed has a drainage area of 1,359 square miles and encompasses portions of the following counties, listed in order of the percentage of watershed area: Clearwater (36%), Polk (35%), Red Lake (21%), Pennington (4%), Beltrami (3%) and Mahnomen (1%). Some cities within the watershed include Red Lake Falls, Bagley, McIntosh, Clearbrook, and Erskine.

1.2 Surface water resources

The Clearwater River and its three main associated tributaries (Lost River, Poplar River, and Hill River) are the prominent water features in the Clearwater River watershed. The Clearwater River outlets to the Red Lake River approximately two miles northwest of the city of Red Lake Falls. The Clearwater River watershed contains 483 miles of natural stream channel, 1,009 miles of altered stream or drainage ditch network, 20.4 miles of impounded stream channel, and 362 miles of undefinable stream channel. According to the MPCA (2013), 74% of the watercourses in this watershed have been hydrologically altered (i.e., channelized, ditched, or impounded). There are numerous natural lakes in the southern portion of the watershed, among the largest lakes are Whitefish Lake and Turtle Lake (east of Fosston), Pine Lake (west of Clearbrook), and Spring Lake (south of Lengby).

1.3 Geology and soils

Two distinct physiographic regions are represented in the Clearwater River watershed. Approximately the one-fourth of the western portion of the watershed is comprised of the drift plain/beaches ridges region, which includes glacial drift deposits that were modified by glacial Lake Agassiz, and the ancient shorelines of glacial Lake Agassiz. The drift plain/beaches region is characterized by an undulating topography (1-8% slope) and soils of varying textures (sand to clay loam). There are also large inclusions of organic soils scattered throughout the region. The eastern portion of the watershed is characterized by till plain or lake plain features. The till plain and lake plain regions feature an extremely flat topography (0-1% slope) and very fine textured soils (clay and silt) derived from lacustrine sediments deposited by glacial Lake Agassiz.

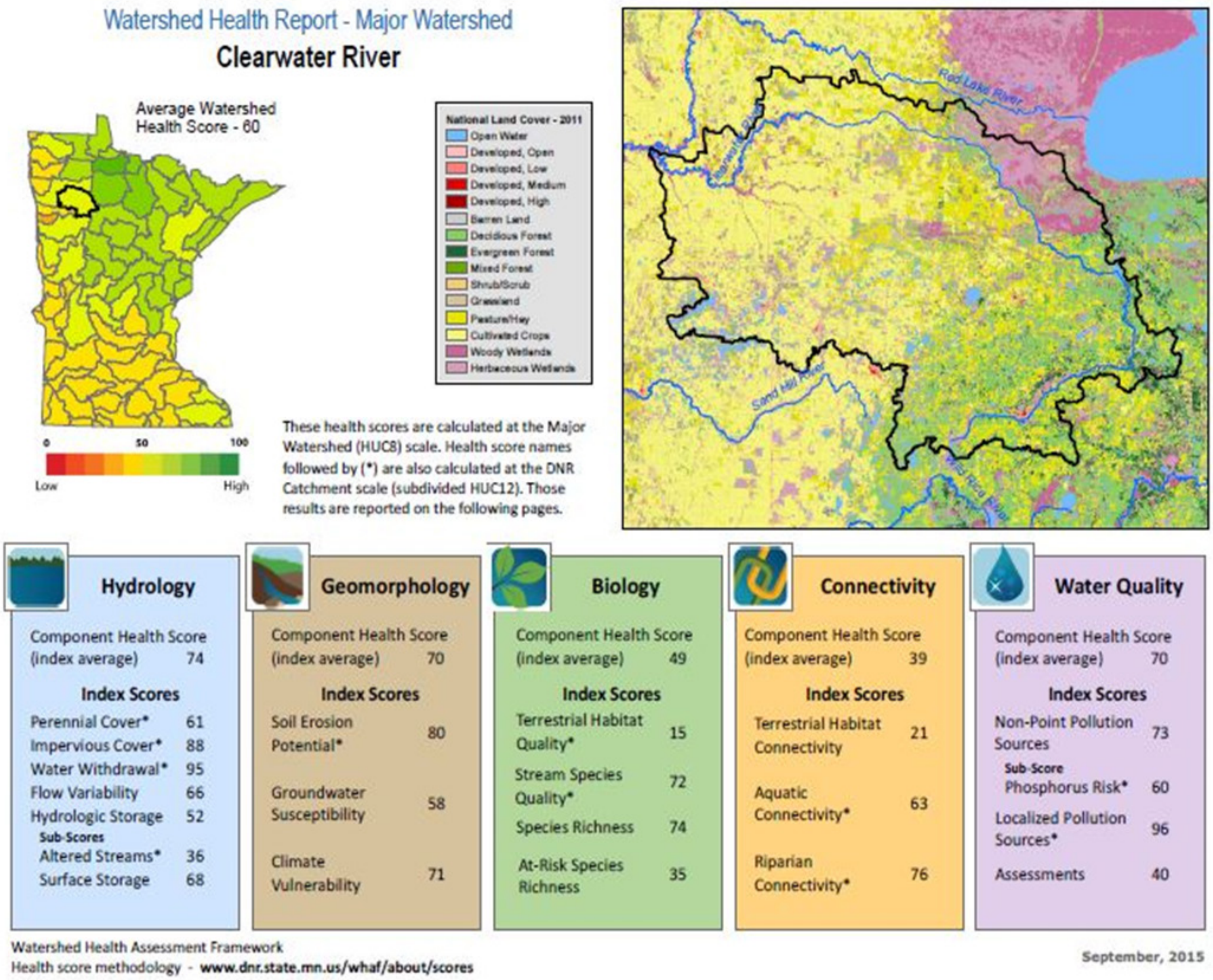
1.4 Land use and ecoregions

The predominant land use in the Clearwater River watershed is agricultural crop production. According to the National Land Cover Database of 2011, cultivated crops comprised 51% of the watershed (USGS, 2011). Other notable land cover groups in the watershed included forest (22%), wetlands (16%), prairie/shrub (4%), and developed (4%). There are two ecoregions represented in the watershed: Lake Agassiz Aspen Parklands - Minnesota Morainal, and Laurentian Mixed Forest (EPA, 2012a). A majority (79%) of the watershed is located within the Lake Agassiz and Minnesota Morainal ecoregion. The Laurentian Mixed Forest ecoregion (20%) is isolated to the northeastern and southeastern portions of the watershed.

1.5 Ecological health

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

Figure 2 presents the watershed health scorecard for the Clearwater River watershed. The mean health score for the watershed was 60. The overall score was limited by the individual mean component scores for connectivity (39) and biology (49). Specifically, the watershed scored poorly for the following component indices: terrestrial habitat quality (15), terrestrial habitat connectivity (21), at-risk species (35), altered streams (36), water quality assessments (40), and hydrologic storage (52).



Watershed Health Report - Major Watershed

Clearwater River

These health scores are calculated at the Major Watershed (HUC8) scale. Health score names followed by (*) are also calculated at the DNR Catchment scale (subdivided HUC12). Those results are reported on the following pages.

Hydrology

Component Health Score (index average)	74
Index Scores	
Perennial Cover*	61
Impervious Cover*	88
Water Withdrawal*	95
Flow Variability	66
Hydrologic Storage	52
Sub-Scores	
Altered Streams*	36
Surface Storage	68

Geomorphology

Component Health Score (index average)	70
Index Scores	
Soil Erosion Potential*	80
Groundwater Susceptibility	58
Climate Vulnerability	71

Biology

Component Health Score (index average)	49
Index Scores	
Terrestrial Habitat Quality*	15
Stream Species Quality*	72
Species Richness	74
At-Risk Species Richness	35

Connectivity

Component Health Score (index average)	39
Index Scores	
Terrestrial Habitat Connectivity	21
Aquatic Connectivity*	63
Riparian Connectivity*	76

Water Quality

Component Health Score (index average)	70
Index Scores	
Non-Point Pollution Sources	73
Sub-Score	
Phosphorus Risk*	60
Localized Pollution Sources*	96
Assessments	40

Watershed Health Assessment Framework
Health score methodology - **www.dnr.state.mn.us/whaf/about/scores**

September, 2015

Figure 2. Watershed health assessment report for the Clearwater River Watershed.

1.6 Hydrological Simulation Program - FORTRAN (HSPF) Model

A Hydrological Simulation Program – FORTRAN (HSPF) model was developed for the Clearwater River watershed to simulate the hydrology and water quality conditions throughout the watershed on an hourly basis from 1996 to 2009. The HSPF model incorporates a watershed-scale agricultural runoff model and non-point source model into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. The model enables 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 output was considered in the evaluation of several of the candidate causes outlined in this report.

Section 2: Biological monitoring and impairments

2.1 The MPCA's watershed approach

The Minnesota Pollution Control Agency (MPCA) follows a watershed approach to systematically monitor and assess surface water quality in each of the state's 80 major watersheds, one of them being the Clearwater River. A key component of this approach is the Intensive Watershed Monitoring (IWM) program, which includes biological (fish and macroinvertebrate) monitoring to evaluate overall stream health. In 2014, 2015, and 2016 the MPCA conducted biological monitoring at several monitoring stations throughout the Clearwater River watershed. An Index of Biological Integrity (IBI) score was then calculated for the fish (F-IBI) and macroinvertebrate (M-IBI) communities sampled from each station. The biological monitoring results for the watershed were assessed to identify individual stream reaches, referred to using Assessment Unit Identification (AUID) numbers that were not supporting a healthy fish and/or macroinvertebrate population. A reach with failing IBI score(s) (i.e., below an established threshold) is considered "impaired" for aquatic life.

The nine aquatic life impairments found in the Clearwater River watershed are the focus of this stressor identification report. The results of the stressor identification 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.

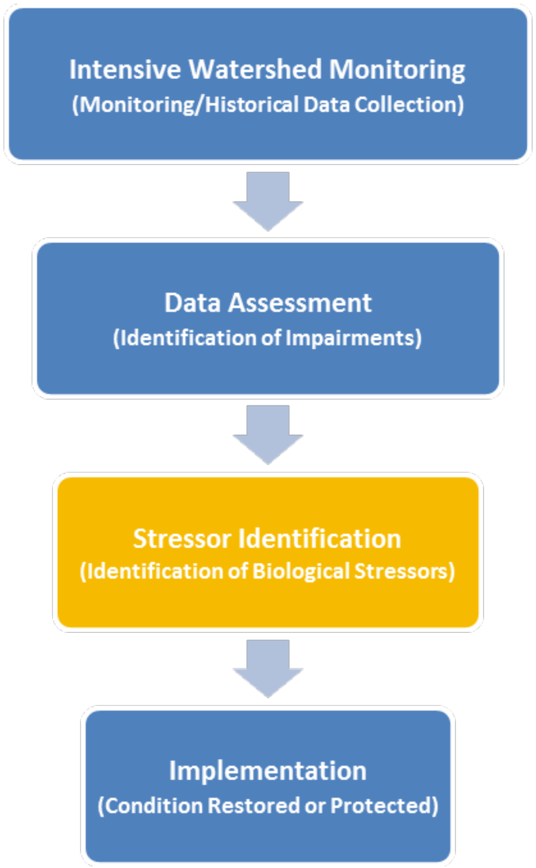


Figure 3. Conceptual model of the watershed approach processes.

2.2 Monitoring stations

Between 2014 and 2016, 52 biological monitoring stations were sampled for fish and/or macroinvertebrates in the Clearwater River watershed. These stations are situated along 27 separate reaches (AUIDs) of the Clearwater River and its tributaries. For the purpose of this report, the individually assessed stream reaches will be referred to by their respective three-digit Assessment Unit Identification (AUID) number suffix. An AUID can have multiple stations on it, and the entire AUID can be classified as impaired for aquatic life even if only one station yields a failing IBI score. Table 2 lists the 52 monitoring stations by the AUID on which they are located. Impaired AUIDs are highlighted in red, and the station that yielded the failing IBI score is also highlighted in red, whereas the stations that yielded a passing score are not highlighted.

2.3 Monitoring results

Table 3 provides the F-IBI and M-IBI scores for each of the biological monitoring stations in the Clearwater River Watershed. A total of 12 stations (24%) out of the 52 scored below their F-IBI impairment threshold, while six stations (12%) scored below their M-IBI impairment threshold. However, more information beyond the IBI scores are considered when determining whether or not an AUID is supporting of fish or macroinvertebrates. Of the 27 AUIDs in the Clearwater River Watershed, eight total have aquatic live impairments (highlighted in red on Table 2): five are nonsupporting of fish, one is nonsupporting of macroinvertebrates, and two are nonsupporting of either population.

Table 2. Summary of F-IBI and M-IBI scores from biological monitoring stations in the Clearwater River Watershed. Failing IBI scores that resulted in a "nonsupport" AUID designation are highlighted in red. Asterisks (*) denote IBI scores that are below the impairment threshold, but other data from the AUID indicated that the AUID is sufficiently supporting the fish and/or macroinvertebrate population.

Location		Fish IBI			Macroinvertebrate IBI		
AUID suffix	**Station**	**F-IBI Class[1] (Use[2])**	**F-IBI impairment threshold**	**F-IBI score (mean)**	**M-IBI Class[3] (Use)**	**M-IBI impairment threshold**	**M-IBI score (mean)**
502	07RD026	NS(G)	47	32.7*	Not Sampled		
502	14RD239	NS(G)	47	49.7	SRR(G)	37	55.5
502	14RD237	NS(G)	47	51	SRR(G)	37	30.6*
504	14RD215	NS(G)	47	73.6	SRR(G)	37	38.1
511	14RD271	NR(G)	38	67.9	PFR(G)	31	50.2
512	14RD230	NS(G)	47	47	PGP(G)	41	49.3
513	05RD101	NH(G)	42	62.6	SRR(G)	37	43.4
513	14RD303	NH(G)	42	60.9	SRR(G)	37	62.0
513	14RD234	NH(G)	42	59.9	SRR(G)	37	34.3*
518	**14RD218**	**NH(G)**	**42**	**23.2**	**SGP(G)**	**43**	**25.7**
518	**05RD078**	**NS(G)**	**47**	**41.3**	SGP(G)	43	57.7

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[1] F-IBI Classes: Low Gradient Streams (LGS), Northern Headwaters (NH), Northern Rivers (NR), Northern Streams (NS), Northern Coldwater (NC), Southern Rivers (SR), Southern Streams (SS)

[2] Tiered Aquatic Life Use (TALU) Framework Designation: General Use (G), Modified Use (M)

[3] M-IBI Class: Prairie Forest Rivers (PFR), Prairie Streams-Glide/Pool Habitats (PGP), Southern Streams-Riffle/Run Habitats (SRR), Northern-Coldwater (NC)

518	**14RD216**	NS(G)	47	58.9	**PGP(G)**	**41**	**27.6**
523	14RD242	NS(M)	35	0*	PGP(M)	22	38.4
523	14RD272	NS(M)	35	56.4	SRR(M)	24	11.9*
523	07RD005	NS(M)	35	48.6	SRR(M)	24	30.6
527	14RD235	NH(G)	42	52.8	SGP(G)	43	50.1
527	15EM098	NH(G)	42	42	SRR(G)	37	60
527	**14RD231**	NH(G)	42	59.7	**SRR(G)**	**37**	**32**
529	15EM066	NH(G)	42	66	PGP(G)	41	74
539	**05RD026**	**NS(G)**	**47**	**33.4**	SGP(G)	43	26.5*
539	**14RD253**	**NS(G)**	**47**	**43.7**	SGP(G)	43	56.4
539	14RD221	NS(G)	47	69.7	SRR(G)	37	68.6
550	14RD241	LG(M)	15	36.7	SGP(M)	22	22
561	**14RD243**	**LG(M)**	**15**	**0**	Not Sampled		
590	07RD004	NH(G)	42	50.7	PGP(G)	41	70.8
592	07RD030	LG(M)	15	5.6*	Not Sampled/Not Assessed		
641	10EM021	NH(M)	23	0*	SGP(M)	30	22.8*
643	14RD228	NH(G)	42	58.7	PGP(G)	41	46.2
645	**07RD024**	**NS(G)**	**47**	**35.9**	PGP(G)	41	54.7
645	**14RD226**	**NS(G)**	**47**	**33.0**	Not Sampled		
646[4]	14RD225	NH(G)	47	50.3	PGP(G)	41	53.9
646	05RD046	NH(G)	47	63	PGP(G)	41	49.2
646	14RD259	NH(G)	47	66.7	SRR(G)	37	43.1
647	14RD207	NS(G)	47	44.2*	PGP(G)	41	50.4
647	05RD012	NS(G)	47	56.6	SRR(G)	37	46.8
647	14RD205	NR(G)	38	41.9	PGP(G)	41	53.9
647	14RD203	NR(G)	38	51.8	SRR(G)	37	37
647	07RD017	NR(G)	38	53.1	PGP(G)	41	50.8
647	14RD200	NR(G)	38	57.1	NFGP(G)	51	60.2
648	14RD262	NR(G)	38	59.2	PFR(G)	31	57.5
648	05RD029	NR(G)	38	56	PFR(G)	31	67.2
648	14RD261	NR(G)	38	67.6	SRR(G)	37	56
649	14RD209	NS(G)	47	56	NGP(G)	53	59.8
650	14RD208	NS(G)	47	60.4	SRR(G)	37	77.1
652	**14RD255**	**NH(G)**	**42**	**6.95**	**SRR(G)**	**37**	**28.9**
653	10RD081	NC(G)	35	48.5	NC(G)	32	49.7
653	14RD273	NC(G)	35	53.8	NC(G)	32	35.3
653	14RD302	NC(G)	35	41.7	NC(G)	32	32
653	09RD065	NC(G)	35	45.7	NC(G)	32	32.1
654	10EM085	NS(G)	47	63	NFGP(G)	51	81.9
656	**14RD246**	**NS(G)**	**47**	**15.7**	SGP(G)	43	53.8
658	**14RD260**	**NH(G)**	**42**	**0**	Not Sampled		

2.4 Assessments and impairments

The biological monitoring results for the Clearwater River watershed were assessed as part of the development of the *Clearwater River Watershed Monitoring and Assessment Report* (MPCA, 2017) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 4,

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[4] AUID 646 (segment of the Lost River) does fully support fish and macroinvertebrates, as of 2016. It is discussed in this report (Section 4.8) because the IBI scores are showing degradation over time at site 05RD046.

10 reaches were determined to be biologically impaired; these reaches are highlighted in red. The relative location of these reaches is displayed in Figure 4.

Table 3. Biological assessment results for stream reaches in the Clearwater River Watershed.

AUID suffix	Name	Description	Length (mi)	Biological impairment(s)
501	Clearwater River	Lower Badger Creek to Red Lake River	7.17	
502	Lower Badger Creek	County Ditch 14 to Clearwater River	12.66	
504	Poplar River	Highway 59 to Lost River	14.25	
511	Clearwater River	Lost River to Beau Gerlot Creek	11.76	
512	Lost River	Pine Lake to Anderson Lake	10.23	
513	Ruffy Brook	Headwaters to Clearwater River	26.41	
518	**Poplar River**	**Spring Lake to Highway 59**	**39.28**	**F-IBI;M-IBI**
523	County Ditch 14	Headwaters (Maple Lake 60-0305-00) to Lower Badger Creek	6.67	
527	**Silver Creek**	**Headwaters to Anderson Lake**	**15.65**	**M-IBI**
529	Lost River	T148 R38W S17, south line to Pine Lake	9.87	
539	**Hill River**	**Hill River Lake to Lost River**	**34.06**	**F-IBI**
550	Judicial Ditch 73	Unnamed ditch to Tamarack Lake	1.7	
561	**Tributary To Poplar River Diversion Ditch**	**Gerdin Lake to Poplar River diversion**	**2.35**	**F-IBI**
590	State Ditch 61	Unnamed ditch to Lost River	1.52	
592	Unnamed Ditch	Unnamed ditch to Unnamed ditch	2.51	Not Assessed/IF
643	Tributary to Lost River	Unnamed ditch to Lost River	1.17	
645	**Lost River**	**Anderson Lake to Unnamed Creek**	**12.27**	**F-IBI**
646	Lost River	Unnamed Creek to Hill River	28.75	
647	Clearwater River	Ruffy Brook to Judicial Ditch 1	34.62	
648	Clearwater River	JD 1 to Lost River	25.1	
649	Clearwater River	Clearwater Lake to Unnamed Creek	4.9	
650	Clearwater River	Unnamed Creek to Ruffy Brook	13.17	
652	**Beau Gerlot Creek**	**-96.1947 47.8413 to Clearwater River**	**2.02**	**F-IBI;M-IBI**
653	Clearwater River	T148 R35W S31, west line to Unnamed Creek	11.84	
654	Clearwater River	Unnamed Creek to Clearwater Lake	5.82	
656	**Hill River**	**Unnamed Creek to Hill River Lake**	**8.18**	**F-IBI**
658	**County Ditch 23**	**-96.1479 47.8855 to Clearwater River**	**1.98**	**F-IBI**

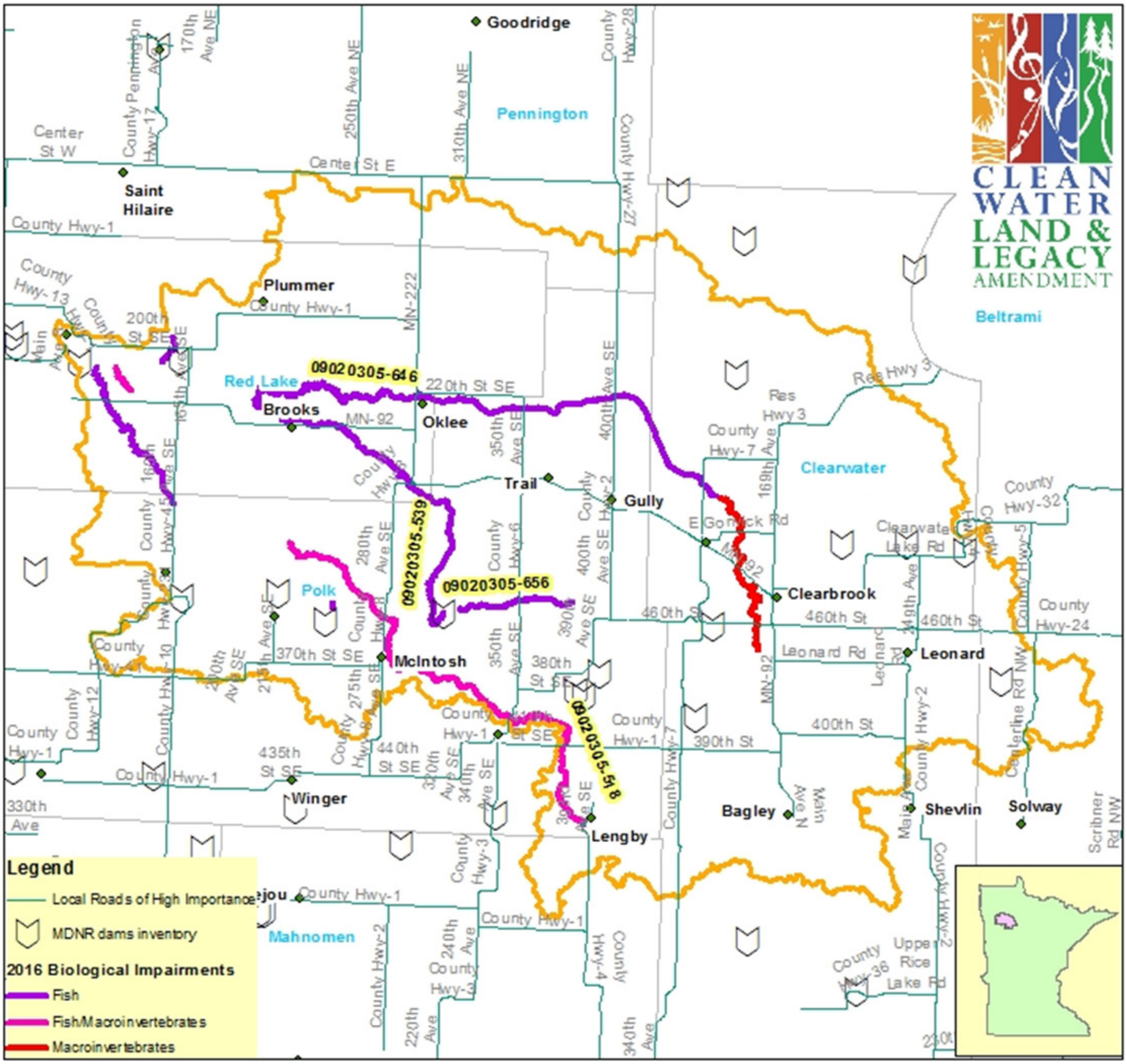

Figure 4. Map of the Clearwater River Watershed and its biological impaired reaches.

2.5 Analysis of biological data

Biological data (the list of taxa sampled and the number of each) form the basis of the assessment of a stream's aquatic life use status. Various metrics can be calculated from the fish or macroinvertebrate sample data. An Index of Biological Integrity, a collection of metrics that have been shown to respond to human disturbance, is used in the assessment process (https://www.pca.state.mn.us/water/index-biological-integrity). Similarly, metrics calculated from biological data can be useful in determining more specifically the cause(s) of a biological impairment. Numerous studies have been done to search for particular metrics that link a biological community's characteristics to specific stressors (Hilsenhoff, 1987); (Griffith M. M.-B., 2009); (Alvarez-Cabria, 2010); (Phelan, et al., 2017); (Anderson & Vondracek, 1999); (Raymond & Vondracek, 2011). This information can be used to inform situations encountered in impaired streams during Minnesota's Watershed Restoration and Protection Strategy (WRAPS) process. This is a relatively new science and much is still being learned regarding the best metric-stressor linkages. Use of metrics gets more complicated if multiple stressors are acting in a stream (Statzner, 2010); (Ormerod, 2010); (Piggott, 2012).

Staff in MPCA's Standards, Biological Monitoring, and Stressor ID programs have worked to find metrics that link biological metrics to stressors; work continues toward this goal. Recently, much work was done in this area to show the impact of nutrients (particularly phosphorus) on biological stream communities when Minnesota's River Nutrient Standards were developed (Heiskary, Bouchard, & Markus, 2013). The Biological Monitoring Units of MPCA have worked to develop Tolerance Indicator Values for many water quality parameters and habitat features for species of fish, and genera of macroinvertebrates. This is a take-off on the well-known work of Hilsenhoff (1987) and the EPA (2006). The Tolerance Indicator Values were calculated for each taxon using the weighted average of each water quality parameter value in the MPCA biological monitoring database. Using those scores, a weighted average community score (a community index) can be calculated for each sample. Using logistical regression, the biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards based on its community index score compared to all other MPCA biological sites to date. Such probabilities are only available for water quality parameters that have developed standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

Some of these stressor-linked metrics and/or community indices are used in this report as contributing evidence of a particular stressor's responsibility in degrading the biological communities in an impaired reach. It is best, when feasible, to include field observations, chemistry samples, and physical data from the impaired reach in determining the stressor(s).

Section 3: Possible stressors to biological communities

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

3.1 Eliminated causes

Initially eight candidate causes were evaluated to address the biological impairments found in the 10 impaired AUIDs in the Clearwater River Watershed. The following sections of the report describe the rationale behind either considering each candidate cause for further analysis or having to just place it into the inconclusive candidate portion of the report. Water quality data was analyzed for the biologically impaired AUIDs, and this analysis led to the elimination of two candidate causes. Pesticide toxicity is an inconclusive stressor because there is no pesticide data for the biologically impaired reaches. Also, pH was eliminated because all reviewed pH values associated with the biologically impaired reaches were within the state standard range (6.5-9.0).

3.2 Inconclusive causes

Elevated stream temperature was deemed inconclusive as a stressor to aquatic life in the Clearwater River Watershed. Warm water streams are not to exceed 30°C on any given day as a daily maximum temperature. Temperature data is readily available throughout much of the Clearwater River Watershed. Most of the temperature data is instantaneous and was collected sporadically over the course of 2002 through 2015. The reviewed temperature data showed no exceedances of the 30°C daily maximum. However, temperature data is limited and a more in-depth analysis of temperature data would be required to conclusively eliminate elevated temperature as a stressor. The highest temperature recorded in 2015 was 28.99 °C in Lost River (S002-133) and 29.37 °C in Silver Creek (S002-082).

Ammonia toxicity can be detrimental to aquatic life when the concentrations of un-ionized ammonia (NH_3) exceed 0.040 mg/L. Currently, there is limited data on both ionized (NH_4) or un-ionized ammonia (NH_3). Additional data collection would be required to adequately assess the impact that ammonia is having on the aquatic life in the Clearwater River Watershed.

3.3 Summary of candidate causes

After an initial data evaluation, the list of candidate causes (stressors) was narrowed down to seven candidates for final analysis in this report. The pH standard is discussed, although it was eliminated as a stressor.

3.3.1 Dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Oxygen diffuses into water from the atmosphere (turbulent flow enhances this diffusion) and from the release of oxygen by aquatic plants during photosynthesis. DO concentrations in streams are driven by several factors. Large-scale factors include climate, topography, and hydrologic pathways. These in turn influence smaller scale factors such as water chemistry, temperature, and biological productivity. As water temperature increases, its capability to hold oxygen is reduced. Low DO is commonly found in streams with slow currents, excessive temperatures, high biological oxygen demand, drainage from wetlands, and/or high groundwater seepage (Hansen, 1975). In most streams and rivers, the critical DO conditions usually occur during the late summer season when water temperatures are at or near the annual high and stream flow volumes and velocities are generally low. DO concentrations change hourly, daily, and seasonally in response to these driving factors.

Human activities can alter many of these driving factors and change the naturally occurring DO concentrations of water resources. Increased nutrient content of surface waters is a nearly ubiquitous human influence, which results in excess aquatic plant growth. This situation often leads to a decline in daily minimum oxygen concentrations and an increase in the magnitude of daily DO fluctuations due to: the decay of excess organic plant material, increased usage of oxygen by plants at night, and the plants' increased daytime oxygen production. Humans may directly add organic material. And thus nutrients, with treated municipal or industrial wastewater effluents. Other human activities that can affect DO concentrations include altering vegetation and flow patterns.

Most aquatic organisms require oxygen for respiration. Inadequate oxygen levels can alter fish behavior, such as moving to the surface to breathe air, or moving to another location in the stream. These behaviors can put fish at risk of predation, or may hinder their ability to obtain necessary food resources (Kramer, 1987). Additionally, low DO levels can significantly affect fish growth rates (Doudoroff and Warren, 1965). Fish species differ in their preferred temperature ranges (Dowling, 1986), so alterations in water temperature (and DO) from the natural condition will alter the composition of fish communities. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975) (Nebeker, 1991). Heiskary et al. (2013) observed several strong negative relationships between fish and macroinvertebrate metrics and higher daily DO fluctuations. Increased water temperature raises the metabolism of organisms, and thus their oxygen needs, while at the same time, the warmer water holds less oxygen. Some aquatic insect species have anatomical features that allow them to access atmospheric air, though many draw their oxygen from the water column. Macroinvertebrate groups (Orders) that are particularly intolerant to low DO levels include mayflies (with a few exceptions), stoneflies, and caddisflies.

For more detailed information on DO as a stressor, go to the EPA Caddis webpage following this link. (U.S.EPA, 2013)

3.3.1.1. Minnesota dissolved oxygen standards

The DO standard (as a daily minimum) is 5 mg/L for class 2B (warm water) streams, and 7 mg/L for class 2A (cold water). Additional stipulations have been recently added to this standard. The following is from the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2009).

Under revised assessment criteria beginning with the 2010 assessment cycle, the DO standard must be met at least 90% of the time during both the 5-month period of May through September and the 7-month period of October through April. Accordingly, no more than 10% of DO measurements can violate the standard in either of the two periods.

Further, measurements taken after 9:00 in the morning during the 5-month period of May through September are no longer considered to represent daily minimums, and thus measurements of > 5 DO later in the day are no longer considered to be indications that a stream is meeting the standard.

A stream is considered impaired if 1) more than 10% of the "suitable" (taken before 9:00) May through September measurements, or more than 10% of the total May through September measurements, or more than 10% of the October through April measurements violate the standard, and 2) there are at least three total violations.

3.3.1.2. Types of dissolved oxygen data

1. **Point measurements**
   Instantaneous (one moment in time) DO data was collected at many locations and used as an initial screening for low DO reaches. Because DO concentrations can vary significantly with changes in flow conditions and time of sampling, conclusions using instantaneous measurements need to be made with caution and are not completely representative of the DO regime at a given site.
2. **Longitudinal (synoptic)**
   This sampling method involves collecting simultaneous (or nearly so) readings of DO from several locations along a significant length of the stream path. It is best to perform this sampling in the early morning in order to capture the daily minimum DO readings.
3. **Diurnal (continuous)**Short interval, long time period sampling using deployed YSI™ water quality sondes (a submerged electronic sampling devise) provides a large number of measurements to reveal the magnitude and pattern of diurnal DO fluctuation at a site. This sampling captures the daily minimum DO concentration, and when deployed during the peak summer water temperature period allows an assessment of the annual low DO levels in a stream system.

3.3.1.3. Sources and causal pathways model for low dissolved oxygen

Dissolved oxygen concentrations in streams are driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the DO regime of a waterbody. Agricultural and urban land uses, impoundments (dams), and point source discharges are just some of the anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. The conceptual model for low DO as a candidate stressor is shown in EPA CADDIS website by following this link: Dissolved oxygen simple conceptual diagram | CADDIS: Sources, Stressors & Responses | US EPA.

3.3.2 Flow alteration

Flow alteration is the change of a stream's flow volume and/or flow pattern caused by anthropogenic activities, which include channel alteration, water withdrawals, land cover alteration, wetland drainage, agricultural tile drainage, and impoundment. Changes in landscape vegetation, impervious surfaces, and drainage can increase how fast rainfall runoff reaches stream channels. This creates a stronger pulse of flow, followed later by decreased baseflow levels. According to the authors of a review on flow effects (Poff, 1997), "Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems. Indeed, streamflow, which is strongly correlated with many critical physicochemical characteristics of rivers, such as water temperature, channel geomorphology, and habitat diversity, can be considered a 'master variable'..."

Reduced flow or baseflow reduction

Fish and macroinvertebrate species have many habits and traits that can either be helpful or detrimental in different flow conditions and will either respond positively or negatively with reduced flow. Across the conterminous U.S., Carlisle et al. (2011) found that there is a strong correlation between diminished streamflow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to decreased wetted width, cross sectional area, and water depth. Flows that are reduced beyond normal baseflow decrease living space for aquatic organisms and competition for resources increases. Pollutant concentrations can increase when flows are lower than normal, increasing the exposure dosage to organisms. Tolerant organisms can out-compete others in such limiting situations and will thrive. Low flows of prolonged duration lead to macroinvertebrate and fish communities comprised of generalist species or that have preference for standing water (U.S.EPA, 2012a). Changes in fish community can occur related to factors such as species' differences in spawning behavior (Becker, 1983), flow velocity preference (Carlisle et al., (2011)), and body shape (Blake, 1983). When baseflows are reduced, nest-guarding fish species increase and simple nesters, which leave eggs unattended, are reduced (Carlisle et al., (2011)). Nest guarding increases reproductive success by protecting eggs from predators and providing "continuous movement of water over the eggs, and to keep the nest free from sediment" (Becker, 1983). Active swimmers, such as the green sunfish, contend better under low velocity conditions (Carlisle et al., (2011)). In their review paper on low-flow effects on macroinvertebrates, Dewson et al. (2007) found that responses were complex, and not easy to generalize. Some cited studies showed increased density, and others decreased. More often, the behavior called drift (using the current to be transported to a new location) increased. Many studies reported that species composition changed, and taxonomic richness generally decreased in streams experiencing prolonged low flows. Those invertebrates that filter food particles from the water column have shown negative responses to low flows. EPA's CADDIS website (U.S.EPA, 2012a) lists the responses of reduced flow as lower total stream productivity, elimination of large fish, changes in taxonomic composition of fish communities, fewer migratory species, and fewer fish per unit area, and more-concentrated aquatic organisms, potentially benefiting predators.

Increased flow or channelization

Increasing surface water runoff and seasonal variability in stream flow have the potential for both indirect and direct effects on fish populations (Schlosser, 1990). Indirect effects include alteration in habitat suitability, nutrient cycling, production processes, and food availability. Direct effects include decreased survival of early life stages and potentially lethal temperature and oxygen stress on adult fish (Bell, 2006). Increased flow volume increases channel shear stress, which results in increased scouring and bank destabilization. This subsequently has a negative impact on the fish and macroinvertebrate communities via loss of habitat, including habitat smothering by excess sediment. High flows and the associated increased flow velocities can cause displacement of fish and macroinvertebrates downstream, and mobilization and possible removal to the floodplain of habitat features such as woody debris, which are important as flow refugia for fish and living surfaces for clinging invertebrates. Macroinvertebrate types may shift from those species having long life cycles to shorter ones; species that can complete their life history within the bounds of the recurrence interval of the elevated flow conditions (U.S.EPA, 2012a). Fish species that have streamlined body forms experience less drag under high velocities and will have advantage over non-streamlined fish species (Blake, 1983).

Increased flows may directly impair the biological community or may contribute to additional stressors. Increased channel shear stresses, associated with increased flows, often cause increased scouring and bank destabilization. With these stresses added to the stream, the fish and macroinvertebrate community may be influenced by the negative changes in habitat and sediment. To learn more about flow alteration as a stressor go to the EPA CADDIS webpage here.

The following is an excerpt from a DNR (Missouri River Watershed Hydrology, Connectivity, and Geomorphology Assessment Report., 2014) publication and contains a more detailed discussion on various aspects of connectivity and flow alteration effects:

Lateral connectivity represents the connection between a river and its floodplain. The dynamic relationship amongst terrestrial and aquatic components of a river's floodplain ecosystem comprises a spatially complex and interconnected environment (Ickes et al. 2005). The degree to which lateral connectivity exists is both a time-dependent phenomenon (Tockner, 1999) and dependent upon the physical structure of the channel. Rivers are hydrologically dynamic systems where their floodplain inundation relates to prevailing hydrologic conditions throughout the seasons. Riverine species have evolved life history characteristics that exploit flood pulses for migration and reproduction based on those seasonally predictable hydrologic conditions that allow systems to access their floodplains (Weclomme 1979, McKeown 1984, Scheimer 2000). When a system degrades to a point where it can no longer access its floodplain, the system's capacity to dissipate energy is lost. Without dissipation of energy through floodplain access, sheer stress on streambanks builds within the channel causing channel widening. Channel widening reduces channel stability and causes loss of integral habitat that in turn reduces biotic integrity of the system until the stream can reach a state of equilibrium once again.

Types of flow alteration data

Stream gaging stations are located in each major watershed of the state. The stations have differing lengths of monitoring history, and some are very new. If there is sufficient monitoring data, detailed hydrologic analysis can be used to help analyze for flow alteration. In addition, hydrologic models can be used to predict flows in a watershed or subwatershed when measured data are not available. An indirect determination of flow alteration can be found via geomorphological measurements, as channel form and dimensions are related to flow volumes.

3.3.3 Suspended sediment (TSS)

Sediment and turbidity have been shown to be among the leading pollutant issues affecting stream health in the United States (U.S.EPA, 2012a). Recent studies in Minnesota have demonstrated that human activities on the landscape have dramatically increased the sediment entering our streams and rivers since European settlement (Triplet, 2009);(Engstrom, 2009). Sediment can come from land surfaces (e.g., exposed soil), or from unstable stream banks. The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently vegetated pastures. Human actions on the landscape, such as channelization of waterways, riparian land cover alteration, and increased impervious surface area can cause stream bank instability leading to sediment input from bank sloughing. Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess suspended sediment or lack of sediment) can be detrimental to aquatic organisms.

As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (i.e., abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (i.e., loss of visibility, increase in sediment oxygen demand). Elevated total suspended solids (TSS) concentrations can reduce the penetration of sunlight and can thwart photosynthetic activity and limit primary production (Munawar et al., 1991; Murphy et al., 1981). Sediment can also cause increases in water temperature, as darker (turbid) water will absorb more solar radiation.

Organic particles (including algae) can also contribute to TSS. Testing for Total Suspended Volatile Solids (TSVS) allows for the determination of the particle type, and provides information on the source of the problem. High percentages of TSVS in relation to TSS concentrations can be indicative of excess nutrients (causing algal growth) and an unstable DO regime. Determining the type of suspended material (mineral vs organic) is important for proper conclusions about the stressor and source (erosion vs. nutrient enrichment vs. a wastewater discharge). More information on sediment effects can be found on EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_sed_int.html.

Water quality standards

The new TSS standard in Minnesota is stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. For the central region, the TSS standard has been set at 30 mg/L and in the southern region; the TSS standard has been set at 65 mg/L for warm water streams and 10 mg/L for cold water streams. For assessment, this concentration is not to be exceeded in more than 10% of samples within a 10-year data window. There is currently no standard for TSVS in Minnesota.

Types of suspended sediment data

Particles suspended in the water column can be either organic or mineral. Generally, both are present to some degree and measured as TSS. Typically, fine mineral matter is more concerning and comes from soil erosion of land surfaces or stream banks. TSS is determined by collecting a stream water sample and having the sample filtered and weighed to determine the concentration of particulate matter in the sample. To determine the mineral component of the suspended particles, a second test is run using the same procedure except to burn off the organic material in an oven before weighing the remains, which are only mineral material.

Sources and causal pathways model for suspended sediment

High TSS occurs when heavy rains fall on unprotected soils, dislodging the soil particles, which are transported by surface runoff into the rivers and streams (MPCA and MSUM, 2009). The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently vegetated land. Decreases in bank stability may also lead to sediment loss from the stream banks, often caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration, and increases in impervious surfaces.

Rangeland and pasture are also common landscape features in Minnesota. In some areas, the riparian corridor has been cleared for pasture and is heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect streambanks and provide shading. Exposures of these areas to weathering, trampling, and shear stress (water friction) from high flow events are increasing the quantity and severity of bank erosion. Additional causes and potential sources for increases in sediment are modeled at EPA's CADDIS Sediments webpage.

3.3.4 Physical habitat

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. This section will focus on the physical habitat structure including geomorphic characteristics and vegetative features (Griffith, Rashleigh, & Schofield, 2010). Physical habitat is often interrelated to other stressors (e.g., sediment, flow, dissolved oxygen).

Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe & MacDonald, 1991). Aquatic macroinvertebrates are generally affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg & Wiens, 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky, 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman, 1988); and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985); (Gray & Ward, 1982).

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on our landscape by way of resource extraction, agriculture, forestry, silviculture, urbanization, and industry. These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat; or reduced habitat quality, such as embedded gravel substrates. Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (Griffith, Rashleigh, & Schofield, 2010). Fish species that are simple lithophilic spawners require clean, coarse substrate for reproduction. These fish do not construct nests for depositing eggs, but rather broadcast them over the substrate. Eggs often find their way into interstitial spaces among gravel and other coarse particles in the streambed. Increased sedimentation can reduce reproductive success for simple lithophilic spawning fish, as eggs become smothered by sediment and become oxygen deprived. In the past, it was common to remove large woody debris (LWD) from stream channels for various reasons. It has now been shown (Gurnell, 1995); (Cordova, 2006); and (Magilligan F.J., 2008) that LWD is very important in creating habitat (causes scour pools, provides cover for fish and creates pockets of protection from faster currents, and a living surface for macroinvertebrates that cling to hard objects).

Degraded physical habitat is a leading cause of impairment in streams on 303(d) lists. According to the EPA CADDIS website, six attributes are the main features of physical habitat structure provided by a stream: *stream size and channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, vegetation cover and structure in the riparian zone, and channel-riparian interactions*. Just like for terrestrial settings and those animals, aquatic population and community changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (U.S.EPA, 2012a). To learn more about physical habitat go to the EPA CADDIS webpage here.

Water quality standards

There is no standard for physical habitat.

Types of physical habitat data

MPCA biological survey crews conduct a qualitative habitat assessment using the MPCA Stream Habitat Assessment (MSHA) protocol for stream monitoring sites. The MSHA protocol can be found here. MSHA scores can be used to review habitat conditions at biological sampling locations and compare those conditions against similar size streams and a variety of IBI scores.

MPCA and DNR partners are collecting stream channel dimension, pattern and profile data at select stream locations of various sizes and biological condition. This data can be used to compare channel departure from a reference condition. Habitat features can be analyzed to determine if a stream is lacking pool depth, pool spacing, adequate cross sectional area to convey discharge, and various other physical habitat features. The applied river morphology method created by (Rosgen, 1996) is the accepted method of data collection by the MPCA and DNR.

Deposited sediment is visually estimated by measuring the degree to which fine material surrounds rock or woody substrate within the channel (embeddedness). Deposited sediment is also analyzed by randomly measuring numerous substrate particles (pebble count) and calculating the D_{50} particle size.

Sources and causal pathways for physical habitat

Alterations of physical habitat, defined here as changes in the structural geomorphic or vegetative features of stream channels, can adversely affect aquatic organisms. Many human activities and land uses can lead to myriad changes in in-stream physical habitat. Mining and resource extraction, agriculture, forestry and silviculture, urbanization, and industry can contribute to increased sedimentation (e.g., via increased erosion) and changes in discharge patterns (e.g., via increased stormwater runoff and point effluent discharges), as well as lead to decreases in streambank habitat and instream cover, including large woody debris (see the Sediment and Flow modules for more information on sediment- and flow-related stressors).

Direct alteration of stream channels also can influence physical habitat, by changing discharge patterns, changing hydraulic conditions (water velocities and depths), creating barriers to movement, and decreasing riparian habitat. These changes can alter the structure of stream geomorphological units (e.g., by increasing the prevalence of run habitats, decreasing riffle habitats, and increasing or decreasing pool habitats).

Typically, physical habitat degradation results from reduced habitat availability (e.g., decreased snag habitat, decreased riffle habitat) or reduced habitat quality (e.g., increased fine sediment cover). Bedded and deposited sediments are closely related to suspended sediments. Decreases in bank stability lead to sediment loss from the stream-banks, causing sediment loads in the water column, and deposition on the streambed. Bank instability is often caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration (e.g., loss of buffer vegetation), and increases in impervious surfaces. Decreases in habitat availability or habitat quality may contribute to decreased condition, altered behavior, increased mortality, or decreased reproductive success of aquatic organisms; ultimately, these effects may result in changes in population and community structure and ecosystem function. Narrative and conceptual model can be found on theEPA CADDIS webpage here.

3.3.5 Eutrophication (phosphorus)

Phosphorus (P), an important plant nutrient, is typically in short supply in natural systems, but human presence and activity on the landscape often exports phosphorus to waterways, which can impact stream organisms. Nutrient sources can include urban stormwater runoff, agricultural runoff, animal waste, fertilizer, industrial and municipal wastewater facility discharges, and non-compliant septic system effluents. Phosphorus exists in several forms; the soluble form, orthophosphorus, is readily available for plant and algal uptake. While phosphorus itself is not toxic to aquatic organisms, it can have detrimental effects via other follow-on phenomena when levels are elevated above natural concentrations. Increased nutrients cause excessive aquatic plant and algal growth, which alters physical habitat, food resources, and oxygen levels in streams. Excess plant growth increases DO during daylight hours and saps oxygen from the water during the nighttime. Additionally, DO is lowered as bacterial decomposition occurs after the abundant plant material dies. Streams dominated with submerged macrophytes experience the largest swings in DO and pH (Wilcox R. a., 2001). In some cases, oxygen production leads to extremely high levels of oxygen in the water (supersaturation), which can cause gas bubble disease in fish. The wide daily fluctuations in DO caused by excess plant growth are also correlated to degradation of aquatic communities (Heiskary, Bouchard, & Markus, 2013). More information on the effects of phosphorus can be found on EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_nut_int.html.

Water quality standards

The MPCA has developed standards for phosphorus designed to protect aquatic life (Heiskary, Bouchard, & Markus, 2013). Total Phosphorus (TP) criteria were developed for three geographic regions (Table 5). The TP standard is a maximum concentration also requiring at least one of three related stressors above its threshold.

Table 4. River eutrophication criteria ranges by River Nutrient Region for Minnesota. The biologically impaired AUIDs of the Clearwater River Watershed are in the Central Region.

Region	TP µg/L	Related Stressor		
		Chl-a µg/L	DO flux mg/L	BOD_5 mg/L
North	≤ 50	≤ 7	≤ 3.0	≤ 1.5
Central	≤ 100	≤ 20	≤ 3.5	≤ 2.0
South	≤ 150	≤ 35	≤ 4.5	≤ 2.0

Types of phosphorus data

Water samples were collected from streams and rivers throughout the state. The most common data is for TP, though orthophosphorus samples have also been collected in many cases. Related stressor parameters (Chl-a, DO flux, BOD) are analyzed in conjunction with TP to understand potential impacts and connections.

Sources and causal pathways for phosphorus

Phosphorus is delivered to streams by wastewater treatment facilities, urban stormwater, agricultural runoff, and direct discharges of sewage. Phosphorus bound to sediments in the river channel could be contributing to concentrations; however, there is no data available. Orthophosphorus is the form of phosphorus that is readily available for plant and algal uptake, and can influence excess algae growth. While orthophosphates occur naturally in the environment, river and stream concentrations may become elevated with additional inputs from wastewater treatment plants, noncompliant septic systems, and fertilizers in urban and agricultural runoff. The causes and potential sources for excess phosphorus are modeled at EPA's CADDIS Phosphorus webpage.

3.3.6 Nitrogen (nitrate)

Nitrate (NO_3) and nitrite (NO_2) forms of nitrogen are components of the natural nitrogen cycle in aquatic ecosystems. NO_2 anions are naturally present in soil and water, and are readily converted to NO_3 by microorganisms as part of the denitrification process of the nitrogen cycle. As a result, nitrate is far more abundant than nitrite. Although the water test commonly used measures both nitrate and nitrite, because a very large percent is nitrate, this report will refer to this data as being nitrate. Nitrogen is commonly applied as a crop fertilizer. Nitrogen transport pathways can be different depending on geology and hydrology of the watershed. When water moves quickly through the soil profile (as in the case of watersheds with karst geology and heavily tiled watersheds) nitrate transport can become very significant.

A statewide nitrogen study in Minnesota found that the breakdown of cropland nitrogen sources was: 47% commercial fertilizer application, 21% from cropland legume fixation, 16% from manure application, and 15% from atmospheric deposition (MPCA, 2013). These land applications can reach waterways through surface runoff, tile drainage, and leaching to groundwater, with tile drainage being the largest pathway (MPCA, 2013). Other nitrogen sources are non-compliant septic systems and municipal wastewater discharges. For more information on the sources and effects of nitrate, see the EPA's CADDIS webpages: http://www.epa.gov/caddis/ssr_nut_int.html.

Apart from its function as a biological nutrient, some levels of nitrate can become toxic to organisms. Nitrate toxicity is dependent on concentration and exposure time, as well as the sensitivity of the individual organisms. The intake of nitrate by aquatic organisms converts oxygen-carrying pigments into forms that are unable to carry oxygen, thus inducing a toxic effect on fish and certain macroinvertebrates (Grabda et al., 1974). Certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity according to Camargo and Alonso (2006), who cited a maximum level of 2.0 mg/L nitrate N as appropriate for protecting the most sensitive freshwater species and nitrate-N concentrations under 10.0 mg/L to protect several other sensitive fish and aquatic invertebrate taxa. For toxic effects of chemicals, see EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_tox_int.html.

Water quality standards

Minnesota currently does not have an aquatic life use nitrate standard, though MPCA is actively developing an aquatic life standard for nitrate toxicity.

Minnesota's Class 1 waters, designated for domestic consumption, have a nitrate water quality standard of 10 mg/L (Minn. Stat. 7050.0222 subp. 3).

Types of nitrogen data

Stream and river water samples are collected at various locations throughout the 8-HUC. Samples are sent to a state certified laboratory and analyzed for a number of water quality parameters including nutrients. Laboratory analytical data is then stored in the EQuIS database and can be accessed via the MPCA webpage here.

Sources and causal pathways for nitrogen

The conceptual model for nitrogen as a candidate stressor is modeled at EPA's CADDIS Nitrogen webpage. Lefebvre et al. (2007) determined that fertilizer application and land-cover were the two major determinants of nitrate signatures observed in surface water and that nitrate signatures in surface waters increased with fertilization intensity. Nitrogen is commonly applied as a crop fertilizer, predominantly for corn. A statewide nitrogen study found that cropland commercial fertilizers make up 47% of nitrogen added to the landscape, 21% occurs through cropland legume fixation, 16% from manure application, and 15% from atmospheric deposition (MPCA, 2013). These land applications can reach waterways through surface runoff, tile drainage, and leaching to groundwater, with tile drainage being the largest pathway (MPCA, 2013).

3.3.7 pH

Acidity is measured on a scale called pH, ranging from 0 to 14, with values of 0 to 6.99 being acidic, 7.0 neutral and above 7.0 being basic. Human effects on pH values can result from agricultural runoff, urbanization, and industrial discharges. Some geology produces naturally high hydrogen ions that can leach into surface water, but it would be rare for this to be the only cause when pH is a stressor. Photosynthesis from unnaturally abundant plants or algae removes carbon dioxide from the water, causing a rise in pH. As pH increases, unionized ammonia (the toxic form of ammonia) increases, and may reach toxic concentrations (U.S.EPA, 2012a). Low pH values contribute to elevated ionic strength of water (more dissolved minerals). High or low pH effects on biology include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Values of pH outside the range of 6.5 – 9.0 or highly fluctuating values are stressful to aquatic life (U.S.EPA, 2012a). For additional information on pH as a stressor, see EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_ph_int.html#highph.

Water quality standards

The pH standard for Class 2B (warmwater) streams is within the range of 6.5 as a daily minimum and 9.0 as a daily maximum (Minn. Stat. 7050.0222 subp. 4).

Types of pH data

Like DO, pH readings can be collected by deployed devices at defined time intervals, or a single, instantaneous reading taken during a site visit.

Sources and causal pathways for pH

The conceptual model for pH as a candidate stressor is modeled at EPA's CADDIS pH webpage. Human effects on pH values can result from agricultural runoff, urbanization, and industrial discharges. Some geology has naturally high hydrogen ions that can leach into surface water, but it would be rare for this to be the only cause. Photosynthesis of overabundant macrophytes and algae can remove carbon dioxide from the water, causing a higher pH. Effects on biology include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Concentrations of nutrients (especially nitrogen) also play a significant part in pH dynamics, as nitrification and respiration both produce hydrogen ions (U.S.EPA, 2013).

3.3.8 Physical connectivity (fish passage)

Connectivity in river ecosystems refers to how water features are linked to each other on the landscape or how locations within a feature (i.e., a stream) are connected. Connectivity also pertains to locations adjacent to a stream, such as a stream's connectivity to its floodplain, or the groundwater system.

Humans can alter the degree of connectivity within stream systems. In Minnesota, there are more than 800 dams on streams and rivers for a variety of purposes, including flood control, maintenance of lake levels, wildlife habitat, and hydroelectric power generation. Dams change stream habitat by altering streamflow, water temperature, and sediment transport (Cummins M.J., 1979); (Waters, 1995). Dams also directly block fish migration. Both mechanisms can cause changes in fish and macroinvertebrate communities and greatly reduce or even extirpate local populations (Brooker, 1981); (Tiemann, Gillette, Wildhaber, & Edds, 2004).

The DNR has conducted numerous dam removal projects in recent years, which have demonstrated benefits to fish populations. A more detailed presentation of the effects of dams on water quality and biological communities can be found in the DNR publication "Reconnecting Rivers: Natural Channel Design in Dam Removals and Fish Passage" (Aadland, 2010).

Culverts at road crossings can also be significant barriers to fish passage if they are installed or sized incorrectly. Culverts can be perched above the downstream water level, have too high an angle, resulting in high velocity flow, which many species cannot traverse, or be undersized for the stream size, which also results in high velocity within the culvert. An excellent review of studies regarding culvert impacts to fish migration, including information specifically from Minnesota, has been conducted by the Minnesota Department of Transportation (MNDOT, 2013).

The following is an excerpt from a DNR (2014) publication and contains a more detailed discussion on various aspects of connectivity:

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes within a river system (Annear 2004). Connectivity is thus the water-mediated transfer of energy, materials, and organisms across the hydrological landscape (Pringle 2003). The transport of these integral components within a river travel in four dimensions: longitudinal, upstream and downstream; lateral, channel to floodplain; vertical, hyporheic to groundwater zones; and temporal, continuity of transport over time (Annear 2004). Due to the objectives of this study, vertical connectivity was not directly assessed.

Longitudinal connectivity of flowing surface waters is of the utmost importance to fish species. Many fish species' life histories employ seasonal migrations for reproduction or overwintering. Physical barriers such as dams, waterfalls, perched culverts and other instream structures disrupt longitudinal connectivity and often impede seasonal fish migrations. Disrupted migration not only holds the capacity to alter reproduction of fish, it also impacts mussel species that utilize fish movement to disperse their *offspring. Structures, such as dams, have been shown to reduce species richness of systems, while also increasing abundance of tolerant or undesirable species* (Winston, 1991), (Santucci V.A., 2005).

Longitudinal connectivity of a system's immediate riparian corridor is an integral component within a healthy watershed. Continuous corridors of high quality riparian vegetation work to sustain stream stability and play an important role in energy input and light penetration to surface waters. Riparian connectivity provides habitat for terrestrial species as well as spawning and refuge habitat for fish during periods of flooding. Improperly sized bridges and culverts hinder the role of riparian connectivity as they reduce localized floodplain access, disrupt streambank vegetation, and bottle neck flows that can wash out down stream banks and vegetation.

Water quality standards

There is no applicable water quality standard for connectivity impacts, though new design guidelines for culverts have been developed by Minnesota Department of Transportation for fish passage http://www.dot.state.mn.us/research/TRS/2013/TRS1302.pdf.

Types of physical connectivity data

Locations for dams are available on DNR GIS coverage. Aerial photos are viewed for unknown structures. Culverts are visited to determine their organism passage capability.

Section 4: Causal analysis-discussion of individual aquatic life impairments by AUID

4.1 County Ditch 23 (AUID 658) – non-support of fish/no data for macroinvertebrates

4.1.1 Physical setting

This 2.96-mile reach, AUID 658, represents a segment of Red Lake County Ditch 23 that originates at latitude -96.1479 and longitude 47.8885, and outlets at the Clearwater River. AUID 658 is located approximately 6.2 miles east of Red Lake Falls, Minnesota (Figure 5). This natural channel functions as the outlet of the County Ditch 23 (CD 23) drainage system. This reach also receives drainage from Red Lake County Ditch 17.

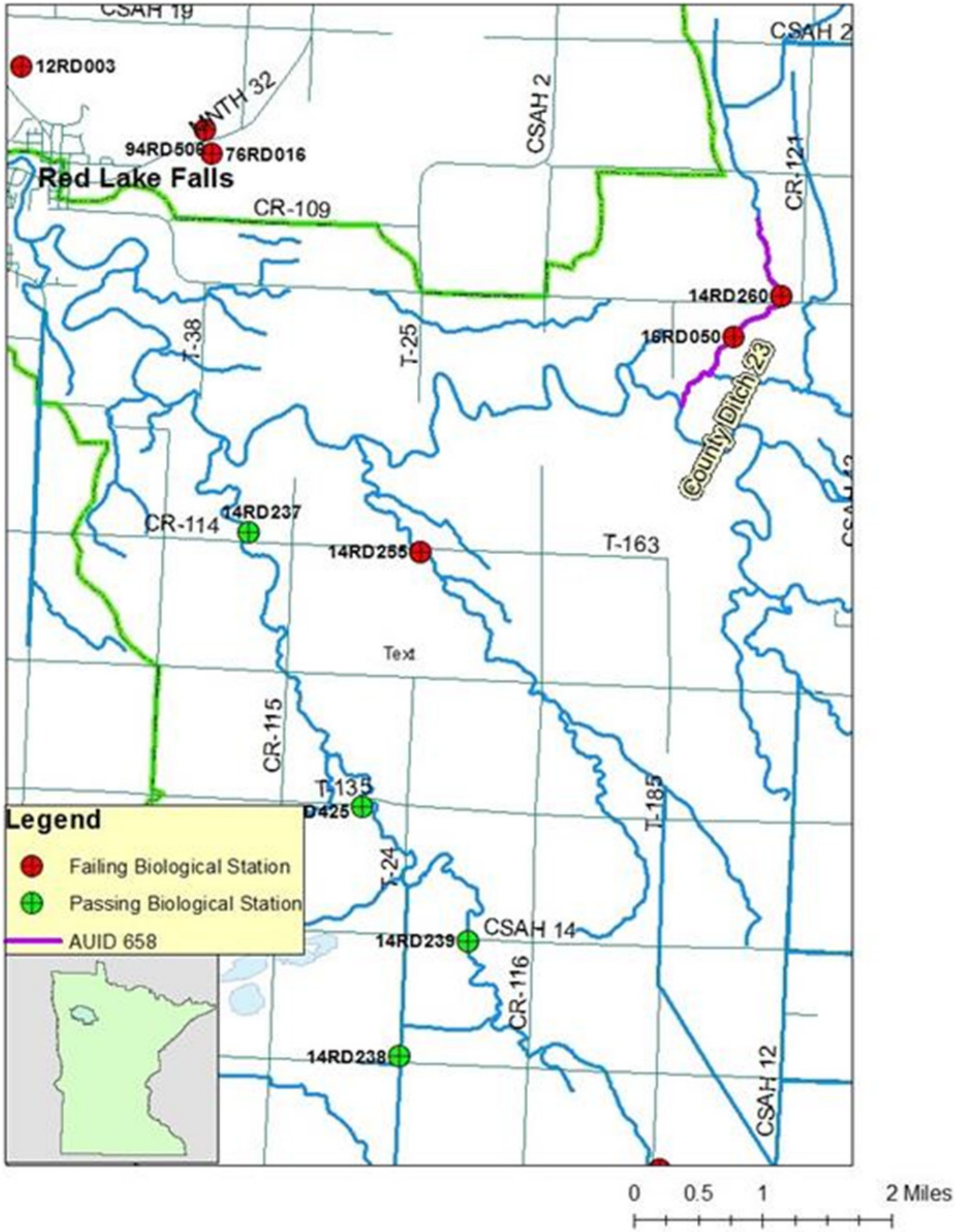

Figure 5. Map of AUID 09020305-658 (County Ditch 23) and the Clearwater River Watershed biological monitoring stations. Part of the Clearwater River Watershed boundary can be seen on this map highlighted in green.

4.1.2 Biological impairments

Two biological monitoring stations exist in this AUID: 14RD260 and 16RD050 (Figure 5). Both stations yielded failing F-IBI scores for their General Use designations, thus AUID 658 is impaired for aquatic life. Macroinvertebrates were not sampled in this AUID due to low flows during attempted sample visits.

Station 14RD260 was sampled for fish on June 23, 2014 and scored a zero on the F-IBI. The MPCA Stream Habitat Analysis (MSHA) was also conducted during this visit and yielded a score of 55/100, which, combined with other site information, places this AUID in the General Use category, where it must meet an F-IBI threshold of 42 to avoid being impaired for aquatic life.

Later that year, on August 5, 2014, the stream was visited again to sample for macroinvertebrates, but the flows were too low to collect a sample.

The section of stream that was sampled in 2014 has a natural channel and is part of a 1.98-mile natural segment. The upstream, contributing reaches represent approximately 3.9 miles of channelized stream. The small drainage area likely has flashy flows, and does not maintain sufficient baseflow to support biological communities throughout the year. Figure 6 shows the size and aerial image for the small drainage area (~8.5 mi^2) above sites 14RD260 and 16RD050.

Station 16RD050, which is downstream of 14RD260, was sampled for fish on June 23, 2016, and scored an F-IBI of six, which is a failing score. This sample confirmed the aquatic life impairment that was detected with the fish data in 2014.

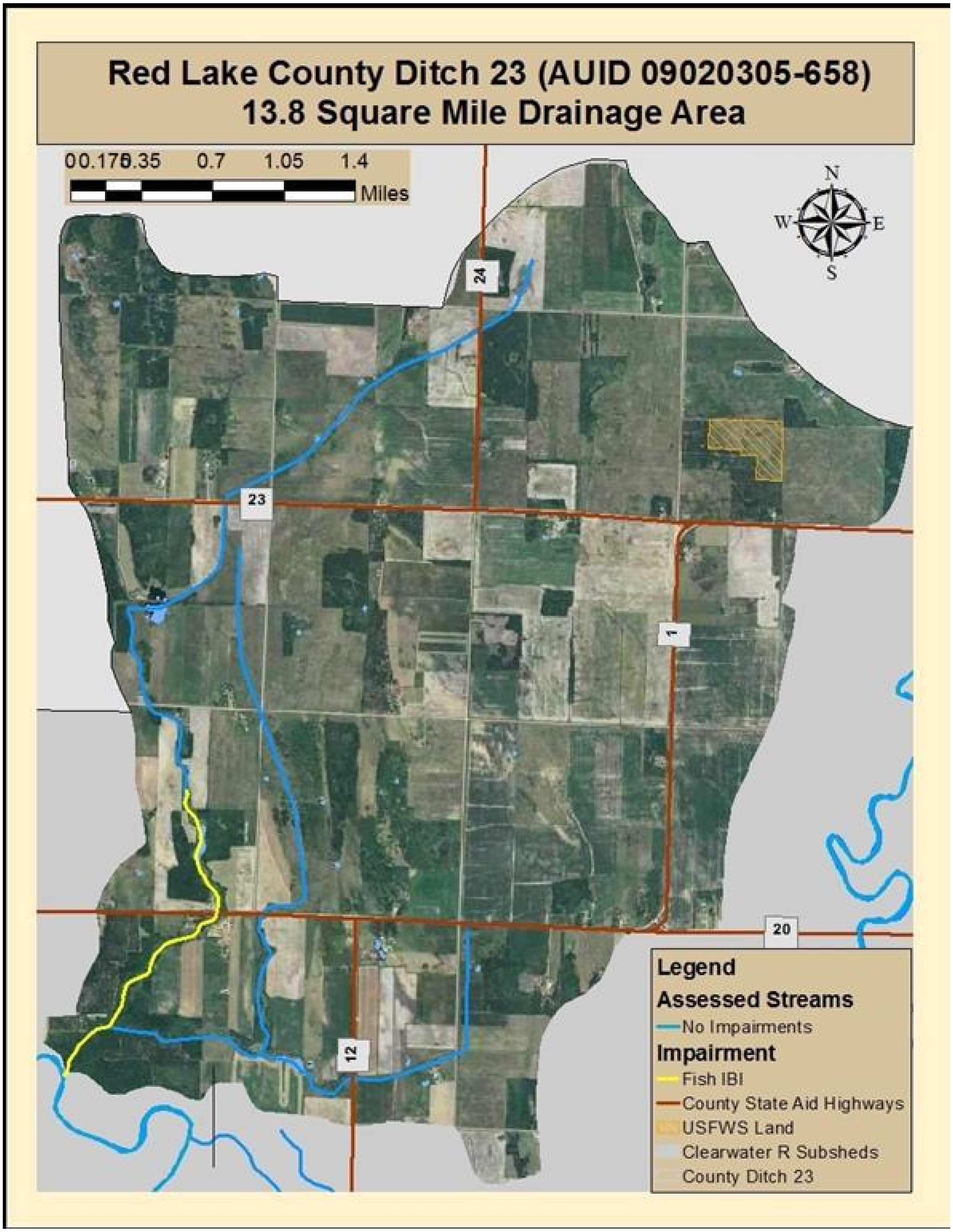

Figure 6. Aerial image of the drainage area encompassing site 14RD260. The majority of the contributing area to AUID 658 is channelized.

4.1.3 Candidate causes

Summary

Of the six candidate causes evaluated (see sections below), the predominant stressors identified in this AUID were flow alteration (lack of base flow), lack of habitat, and lack of connectivity due to a culvert (Figure 9). Although it is possible that the other candidate causes, especially low DO, are stressing the biological communities in County Ditch 23, but not enough data was available to make a conclusive determination.

Elevated nutrients

Limited water chemistry data was available to conclusively evaluate whether or not elevated nutrient levels are stressing the biological communities in AUID 658. However, the various water quality samples that were collected by the MPCA and the Red Lake Watershed District (RLWD) did not yield nutrient measurements that exceed the threshold for impairment (Table 6). There is currently no evidence to suggest that either phosphorus or nitrogen is stressing the fish community.

One water quality sample was collected during the MPCA fish visit on June 23, 2014. A second sample collection was attempted on August 5, 2014, along with the macroinvertebrate visit, but the stream had insufficient flow. In 2016, the RLWD collected six additional samples at this stream location to better understand the in-stream concentrations of phosphorus and nitrogen throughout the growing season. The average total phosphorus (TP) concentration threshold for impairment for the Central Region is 0.100 mg/L, comprised of at least twelve samples. If the TP threshold is exceeded, the AUID must *also* exceed one of the following average concentration thresholds to be considered impaired for eutrophication: chlorophyll-a = 0.18 mg/L, DO flux = 0.35 mg/L/day, or biological oxygen demand (BOD_5)= 2.0mg/L. Because less than twelve TP samples were available for use in the average TP calculation, an impairment decision cannot be made. Table 6 shows that the average TP from five sample dates in 2016 was 0.093 mg/L, which is below the threshold. Additionally, DO flux did not exceed the 3.5 mg/L threshold (Figure 7); chlorophyll-a and BOD_5 were not measured.

In all seven instances in which samples from CD 23 have been analyzed for ammonia nitrogen, the concentration has been lower than the reporting limit (typically <0.04 mg/L). Therefore, all unionized ammonia concentrations were also lower than the 0.04 mg/L impairment threshold.

Table 5: Nutrient data collected from AUID 658 (County Ditch 23) by the MPCA and RLWD.

Date collected	Time collected	TP[5] [mg/L]	ORP[6] [mg/L]	NOx[7][mg/L]	NH4 [mg/L]	TSS[8] [mg/L]	TSVS[9] [mg/L]
6/23/2014	6:15PM	0.093	-	0.46	0.10	4.0	4.0
6/7/2016	1:10PM	0.062	0.049	0.045	<0.04	<1	-
7/21/2016	11:10AM	0.116	0.103	<.03	<0.04	2	-
8/8/2016	3:25AM	0.126	0.117	0.099	<0.04	2	-
8/22/2016	2:35PM	0.097	0.078	0.060	<0.04	2	-
9/29/2016	4:00PM	0.062	0.062	0.181	<0.04	<1	-
9/29/2016	4:01PM	0.063	0.062	0.182	<0.04	<1	-
2016 Average[10]		0.093	0.066	0.077	<0.04[11]	0.24[12]	-

Low dissolved oxygen (DO)

Prior to 2017, very little monitoring data, outside of biological monitoring efforts, had been collected along this reach. In 2016, the RLWD deployed a continuous DO sampling device in CD 23 from July 11 through August 22. DO measurements were taken every thirty minutes throughout the time frame, producing 1,913 DO measurements. Figure 7 displays the daily DO maximum, minimum, and flux for the deployed record. The average concentration for the entire record was 6.50 mg/L. The average daily minimum was 5.79 mg/L, and the average daily flux was 1.82 mg/L/day.

A method for estimating the probability that a site will meet its DO standard based on the fish community sampled there was developed by Sandberg (MPCA 2012). These metrics allow the stressor identification staff the chance to compare the fish community at a site to every other fish community ever sampled by the MPCA. The results produced from such an estimate of probability can serve as guiding clues and suggestions toward what may be stressing the biology in an AUID, but this evidence alone is not strong enough to reach conclusive stressor identification decisions. Analysis of the fish community sampled at 14RD027 in 2014 suggests that the AUID had only a 31% chance of meeting the DO standard, suggesting that low DO concentrations may be stressing the fish. However, the continuous DO data collected in 2016 suggests that was not the case in 2016 (Figure 7). DO did drop below the standard (5.0 mg/L) during the deployment of the sampling device, but this appears to have been short-lived. Continuous DO data was not collected prior to 2016.

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[5] Total phosphorus
[6] Orthophosphate
[7] Nitrogen as nitrate(NO_3)+nitrite(NO_2)
[8] Total suspended solids
[9] Total suspended volatile solids
[10] Both samples collected on 9/29/2016 were averaged and counted as one sample for calculations of the 2016 Average.
[11] Measurements below the detection limit (those equaling <0.04 mg/L) were counted as 0 mg/L for the average.
[12] Measurements below the detection limit (those equaling <1 mg/L) were counted as 0 mg/L for the average calculation.

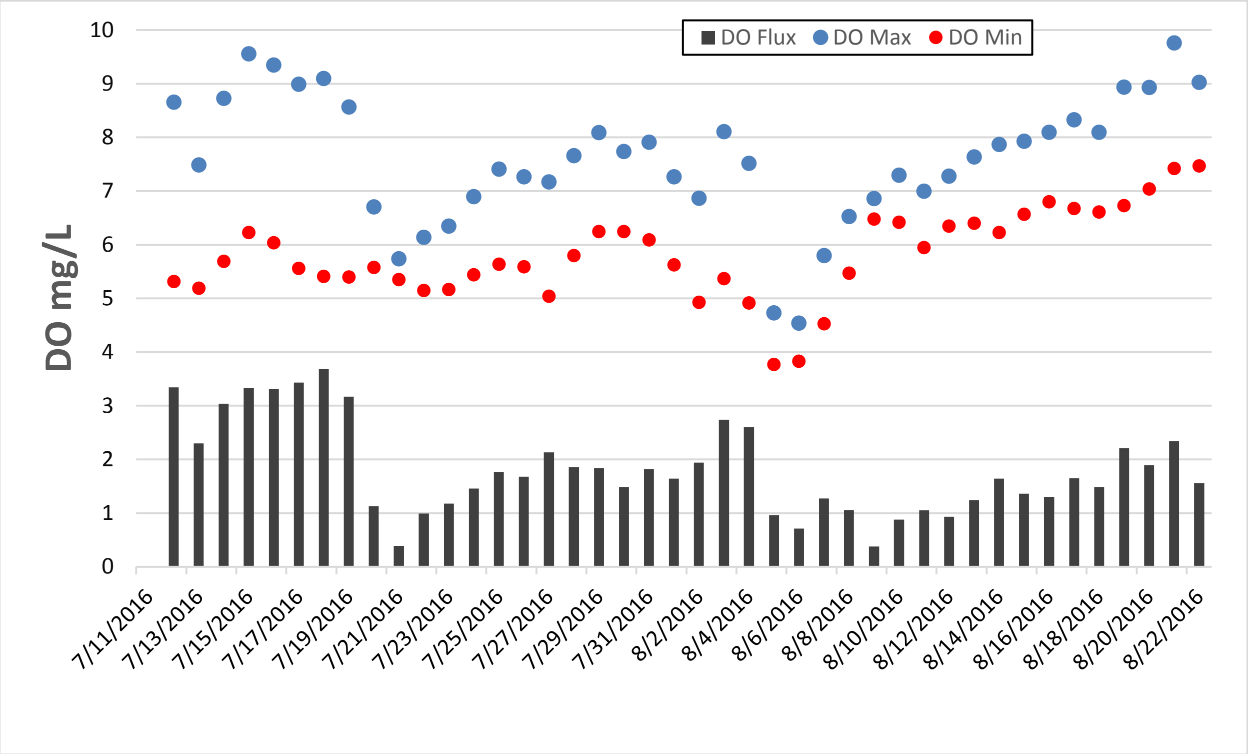


Figure 7. Continuous DO daily maximum, minimum, and flux for the 2016 summer season, monitored by the RLWD.

Flow alterations

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Simulated 1996-2009 flow data for the CD 23 sub-basin from the Clearwater River HSPF model was analyzed to evaluate the flow regime and its possible effects on the biological communities. The drainage area of CD 23 is approximately 13.8 mi^2. The results of the model show that land use and drainage improvements in the CD 23 watershed are causing flashy flows. The peak discharge modeled was 163 cubic feet per second (cfs), with an average of 3.2 cfs and a minimum of 0 cfs. The model estimated that for 84 % of the record, CD 23 had a discharge of less than 5 cfs, and 43% of the record had a discharge of less than 1 cfs. Conversely, discharges greater than 13 cfs occurred for 5% of the record. Overall, the modeling data suggest that the reach is prone to extended periods of very low to zero flow. Lack of base flow is a stressor to the biological communities of CD 23. Low flows will also limit fish passage past minor and temporary barriers in addition to limiting DO levels.

Biological response - fish

Additional evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 658 is provided by the following individual F-IBI metric responses, calculated using the 2014 sample from 14RD027 only (Appendix A). These specific metrics have not yet been prepared using the 2016 sample from 16RD050.

- Above average (>80%) combined relative abundance of the three most abundant taxa (100%)
- Above average (>44%) relative abundance of individuals that are short-lived (56%)
- Above average (>66%) relative abundance of individuals that are tolerant (100%)
- Above average (>20%) relative abundance of taxa that are pioneers (67%)
- Below average (<23%) relative abundance of taxa that are sensitive (0%)

Total suspended sediment (TSS)

Measurements of total suspended sediment (TSS) in the stream are an evaluation of stream clarity, or lack thereof, caused by organic or inorganic solids, rather than by other culprits, such as chlorophyll-a. When water clarity is low, feeding habits of fish and macroinvertebrates can be altered or completely inhibited. Also, high levels of TSS can affect respiration of some fish and macroinvertebrates, plus pollutants such as phosphorus and metals wind up in waterways by attaching to sediments.

The RLWD measured TSS on five days in the summer of 2016 (Table 6). The average TSS found was well below the water quality standard for impairment in the Central Region (TSS > 30 mg/L). Although, more water chemistry data is needed to conclusively dismiss TSS as a stressor to the aquatic life in AUID 658. The 2016 samples were all 2 mg/L or less, which is good. The fish data collected in 2014 (9 total fish) did not yield any fish species that are known to be either tolerant or intolerant of high TSS levels. More clues about a possible biological response from the fish to elevated TSS concentrations will be uncovered after the 2016 fish data has been analyzed further.

Lack of habitat

After each fish sample was taken, habitat was evaluated using the MSHA. The MSHA score (55) for the June 23, 2014, sampling event at station 14RD260 places habitat in the fair category. The MSHA score (79.5) for the June 23, 2016, sampling event at station 16RD050, a little ways downstream, places habitat in the “good” category.

In 2014, channel morphology and substrate categories scored less than 50% of the potential maximum attainable value, which weighed the total MSHA score down. Little diversity was noted in the channel development section. Ninety percent of the sampled reach was marked as “run” habitat, and 10% was “pool.” Both the run and pool categories were dominated by sand substrate and included some silt. Six in-stream “cover” (habitat) types were present in the reach but in moderate amounts (25-50%).

In 2016, channel morphology and substrate scored nearly 73% of their combined maximum attainable value. More velocity types, habitat cover types, and substrate types were noted than in 2014 at 14RD260. Also, seven species of beneficial aquatic vegetation were observed in the reach, whereas in 2014 only three were seen at the upstream station. Yet again, only a moderate amount of in-stream cover was observed in 2016.

The DNR Clean Water Specialists conducted a Pfankuch inventory of the stream reach near site 14RD260. The results of this stability rating was a 73, which is near moderately unstable for an E5 stream type. The Pfankuch stability rating looks at three stream channel zones: the upper bank, the lower bank and stream bottom. Each zone analyzed had at least one subcategory that was rated fair. Many of the subcategories rated “good to excellent.” In the upper bank zone, bank slope was 40-60%. In the lower bank zone, the bank material is composed of small size rock and non-cohesive material, making the banks susceptible to erosion. The stream bottom also scored “fair” in the category of rock angularity. Stream bottom rocks were rounded on two sides, indicating that the stream rocks are being moved along the channel bottom and rolled. The Pfankuch stability rating does suggest that channel instability could be affecting the in-stream habitat features through channel deposition and the potential for bank failure due to the bank material present. In the pasture downstream of CSAH 1, it appears that trampling of streambanks by livestock has caused portions of the stream to become wider and shallower. Much of the riparian woody vegetation has been removed in the pastured area.

Biological response-fish

Evidence of a causal relationship between channel instability and the F-IBI impairment associated with AUID 658 is provided by the following individual F-IBI metric responses using the 2014 fish data (Appendix A):

- Below average (<5%) relative abundance of individuals that are benthic insectivores (0%)
- Above average (>66%) relative abundance of individuals that are tolerant (100%)
- Above average (>67%) relative abundance of the dominant two species of fish (78%)
- Below average (<8) relative abundance of taxa that are darter, sculpin, and round bodied suckers (0%)

The MSHA information and fish metrics analyzed do show that a lack of habitat is affecting the fish community at 14RD260.

Lack of connectivity

The road crossing on 200th Street SE appears that it may be causing fish passage issues during both low and high flow periods. The August 5, 2014, site visit shows the culvert bottom with low flow such that it appears to be inhibiting all fish passage. The HSPF model estimated that 43% of daily average flows were like this or lower (<1 cfs).

Figure 8: **Picture of culvert at road crossing on 200th Street SE on County Ditch 23, showing less than 0.10 feet of water.**

This culvert appears much smaller in diameter than the cross section of the stream. This constriction is possibly causing the higher flow days to have velocities that would impede fish passage. Only three species of fish were sampled upstream of this culvert: fathead minnows, creek chub and white sucker.

Improper culvert placement/sizing is also evidenced by aerial photo review. A Google Earth aerial image dated April 14, 2015, shows a large scour pool on the downstream side of the 200th Street SE road crossing. This large scour pool and the fact that the channel is wider upstream of the road crossing than downstream indicates that the road crossing is holding back some water and is probably perched in relation to the channel bottom (Figure 9). There are additional private stream crossings that could be creating fish passage issues downstream. The entire reach of the stream has not been explored to see if there are any portions near the downstream end of the reach where fish passage is hindered by the steep gradient. Additional exploration of the downstream portions of the reach is recommended.

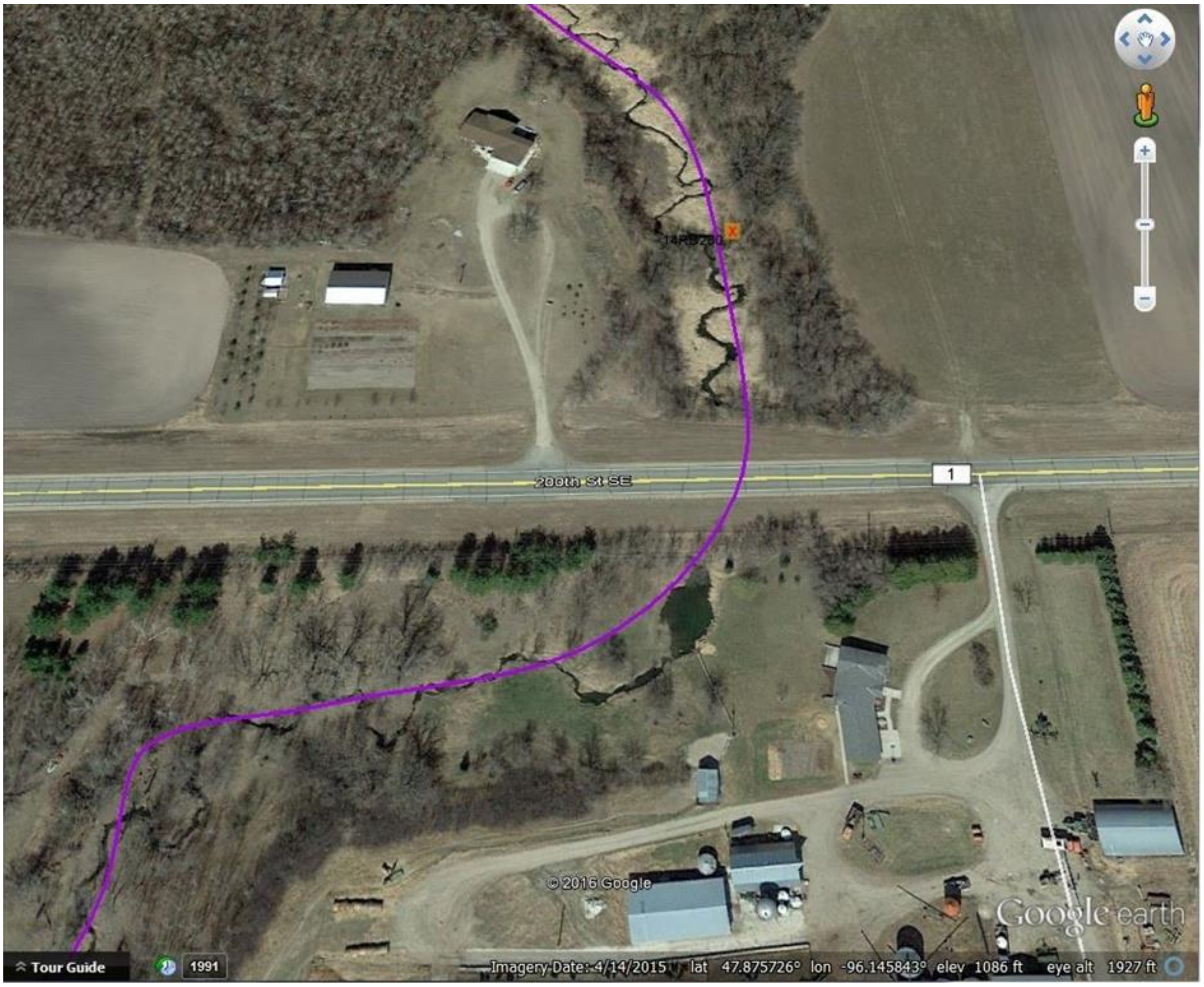


Figure 9: Google Earth aerial image of the road crossing on AUID 658 at 200th Street SE. The downstream side of the crossing has a large scour (yellow arrow), indicating improperly sized and/or placed crossing.

4.2 Beau Gerlot Creek (AUID 652) – non-support of fish/non-support of macroinvertebrates

4.2.1 Physical setting

This AUID (652) represents a segment of Beau Gerlot Creek approximately 3.1 miles southeast of Red Lake Falls, Minnesota that runs from latitude -96.1947, longitude 47.8413 to the Clearwater River (Figure 10). During the 2016 assessment process, Beau Gerlot Creek, which was AUID 520 at the time, was split into two segments. The upstream segment, AUID 651, has been channelized. The downstream segment, AUID 652, remains a natural channel.

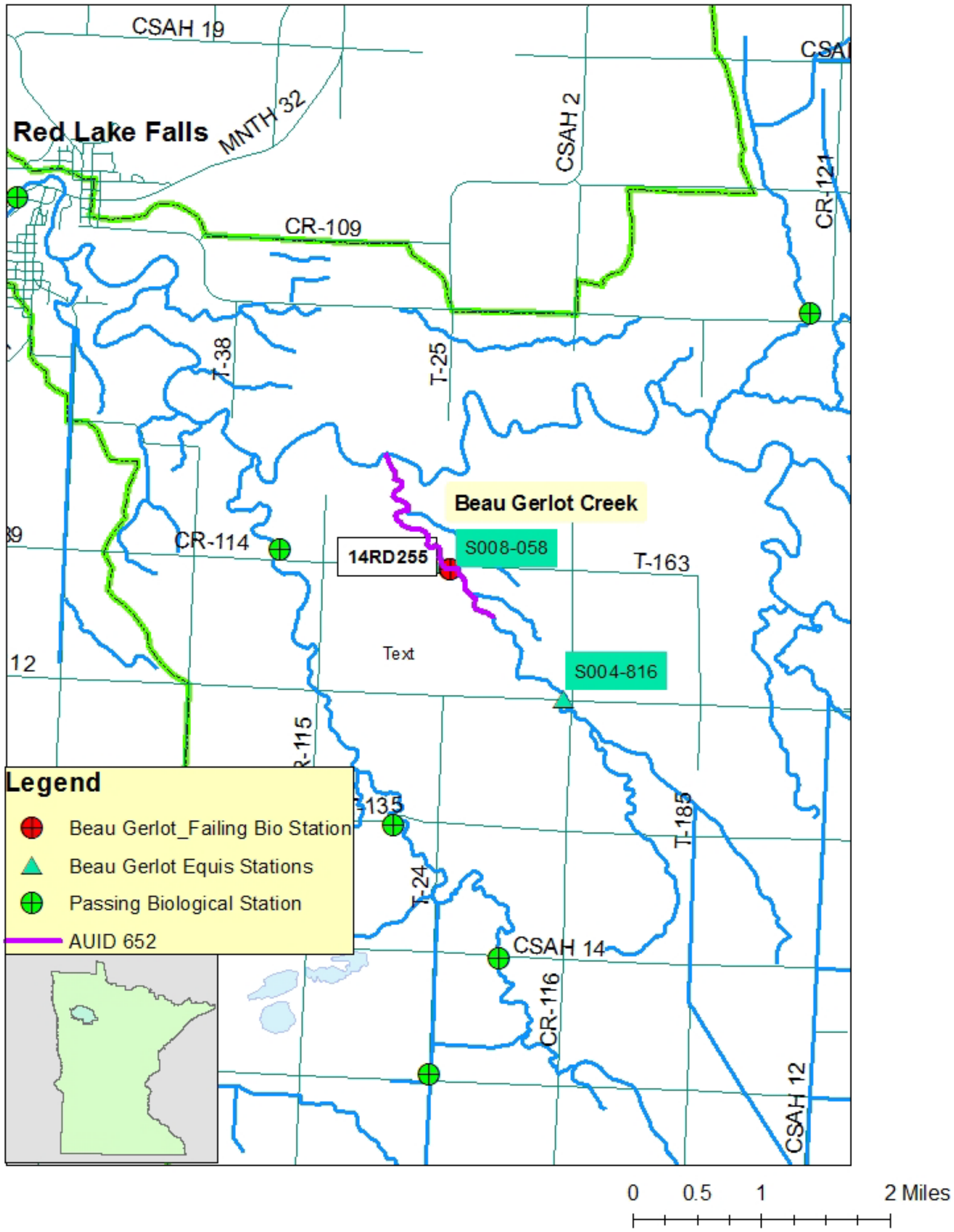


Figure 10: Map of AUID 652 (Beau Gerlot Creek) and the Clearwater River watershed biological monitoring stations. Part of the Clearwater River watershed boundary can be seen on this map highlighted in green.

4.2.2 Biological impairments

There is one monitoring station, 14RD255, in this AUID. It was sampled for fish and macroinvertebrates in 2014 and 2015.

On July 17, 2014, the fish community was sampled at station 14RD255 and scored a 14 on the F-IBI, which is 28 points below the impairment threshold (42). During this site visit, creek chub and central mud minnow were the two dominant fish species found. On June 23, 2015, the fish were sampled again and scored an F-IBI of zero. On this visit, two smallmouth bass and one central mud minnow was sampled; a total of three fish were collected. Field notes indicated that habitat was “great”, but just these few fish were observed, plus one northern pike that was not caught.

On July 29, 2014, the macroinvertebrate community failed to meet the impairment threshold (37), scoring an M-IBI of 26.8. The sample was dominated by *Simulium* (blackfly) species. The sample had little population richness as 88.4% of the sample was comprised of the same two taxa. Then, on August 5, 2015, another macroinvertebrate sample was collected, scoring an M-IBI of 31, which again failed to meet the impairment threshold (37).

4.2.3 Candidate causes

Summary

Of the six candidate causes analyzed, the primary stressors to aquatic life in AUID 652 (Beau Gerlot Creek) are flow alterations, lack of connectivity, and lack of habitat.

Records of DO, nutrient, and TSS levels indicate that water quality conditions should be good enough to support aquatic life within Beau Gerlot Creek, though physical characteristics of the stream are limiting aquatic life. Flow alterations (increased flashiness and insufficient base flow) can exacerbate other stressors like minor fish passage barriers and habitat. Stagnant conditions can cause occasional periods of low DO. This is a case in which biological sampling identified a problem with the support of aquatic life that could not be identified through water chemistry monitoring alone.

Elevated nutrients

All of the rivers and streams in the Clearwater River watershed, thus including Beau Gerlot Creek, must meet the eutrophication standards for the Central region (see *Elevated nutrients* under section 4.1.3 for more information on eutrophication standards).

Evaluation of the nutrient dataset available from 2015 and 2016 (nine samples) suggests that AUID 652 may not have had a eutrophication problem in those years, and that nitrate levels were generally low with summertime spikes seen in both years (Figure 11); however, more data is needed to conclusively determine if excess nutrients are stressing the biology.

Data from a nearby site (S004-816) on the upstream AUID, 651, is applicable to this biological impairment as S004-816 and S008-058 are consecutive crossings of Beau Gerlot Creek. The data from S004-816 on AUID 651 yield similar water quality statistics as those on AUID 652. The combined summer average TP concentration between the two sites is 0.04 mg/l, which suggests that elevated nutrients are not stressing the biological communities in AUID 652.

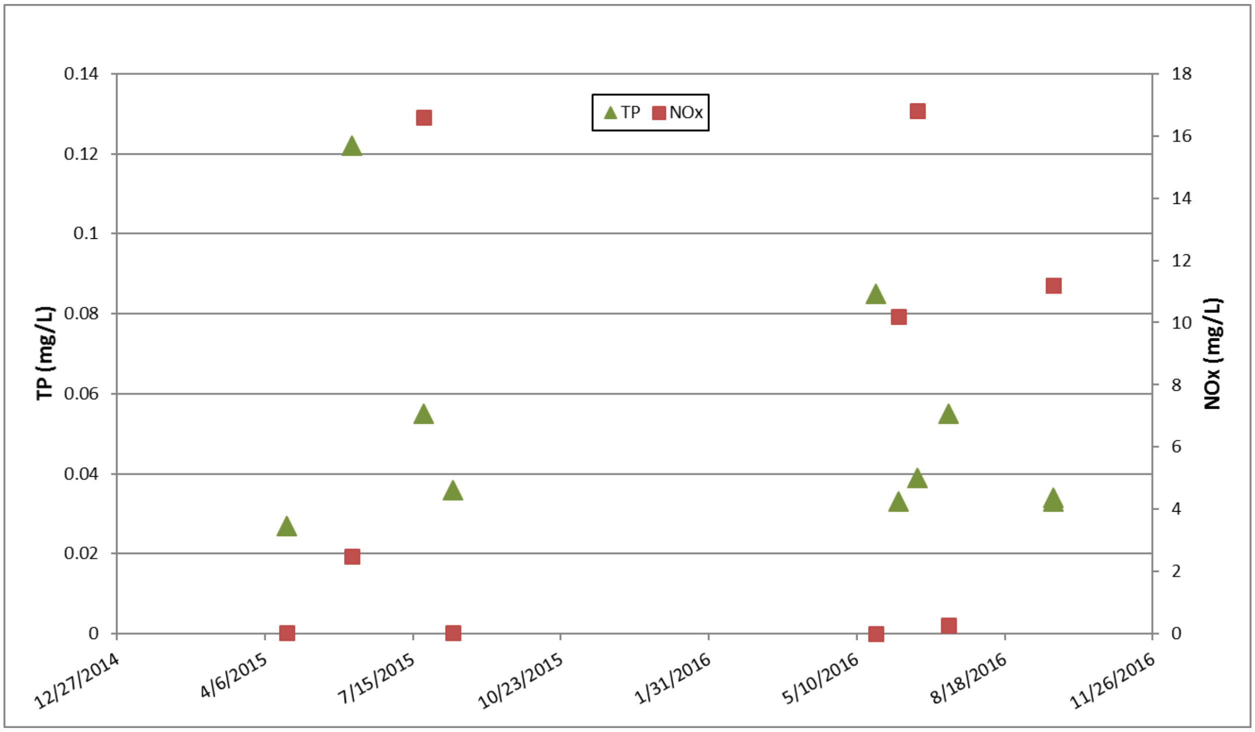


Figure 11: Total phosphorus (TP) and nitrate-nitrite (NOx) data from samples taken in 2015 and 2016 at EQuIS site S008-058 on Beau Gerlot Creek.

Of note, the DO flux data provides some evidence that eutrophication may have been occurring in this AUID in 2015. Daily DO flux exceeded the 3.5 mg/L standard for 41% of continuous measurements taken in the summer of 2015 (Figure 12). This might be indicative of excessive algal growth within the channel, however it is more likely that the high DO flux is the result of zero-flow conditions and stagnant water. When the DO flux values from summer days with an average flow greater than 0 cfs are averaged, the result is 1.84 mg/L, and the stream meets the Central Region standard for DO flux. Although more data is needed to conduct an individual, formal assessment of AUID 652, the existing data from Beau Gerlot Creek suggest that the water chemistry is suitable for aquatic life as long as there is measurable flow in the stream.

Low dissolved oxygen

The Red Lake Watershed District collected continuous DO data from Beau Gerlot Creek (EQuIS site S008-058) from July 16, 2015, through August 31, 2015, (Figure 12). The continuous DO data has 44 days of record. Of the 44 days, only three data points were below the 5 mg/L standard. Each of the three violations of the standard occurred on a day in which the average rate of flow was 0 cfs. The violations were not extreme. The lowest DO concentrations that was recorded during the DO logger deployments was 4.57 mg/L.

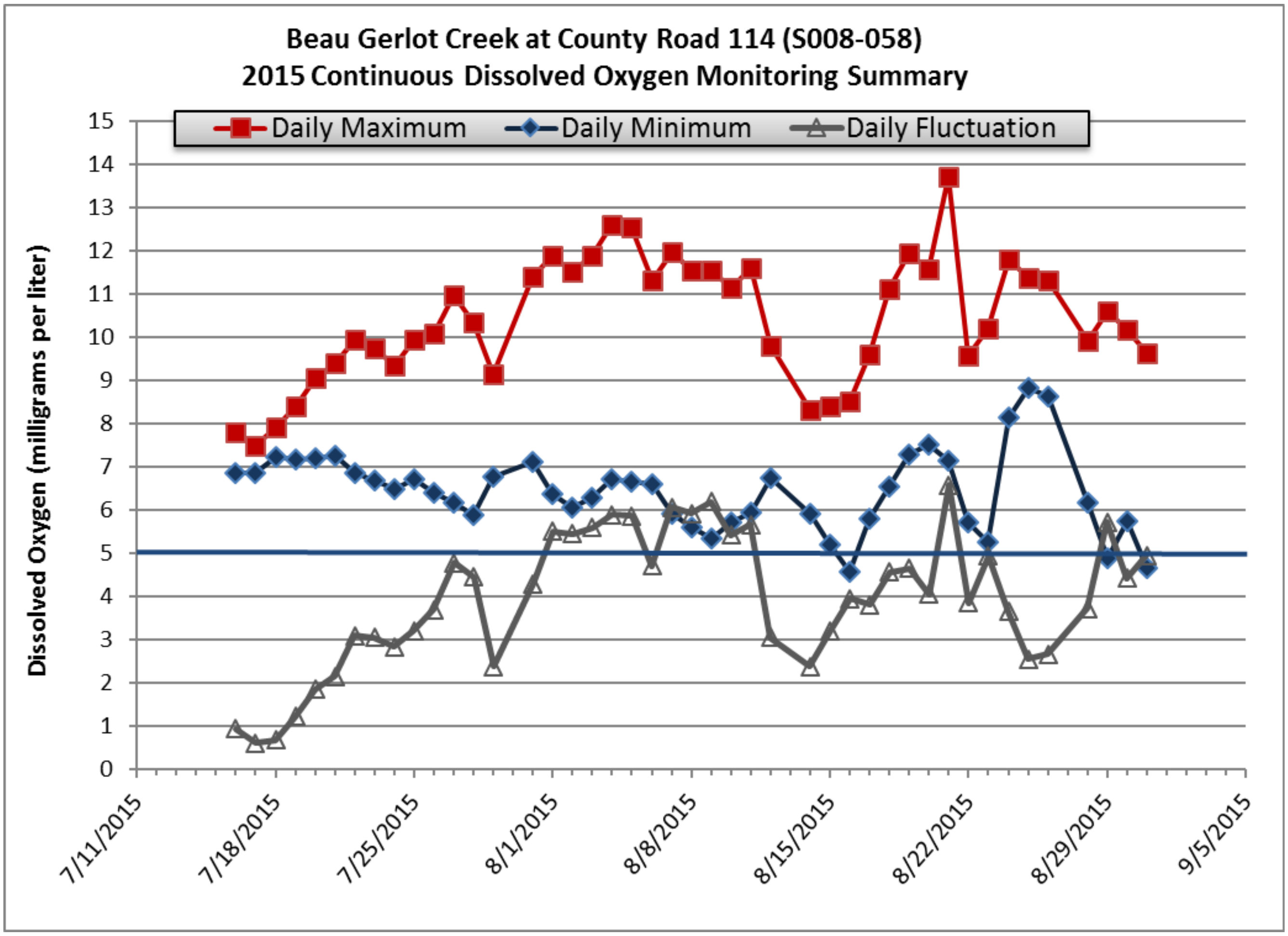


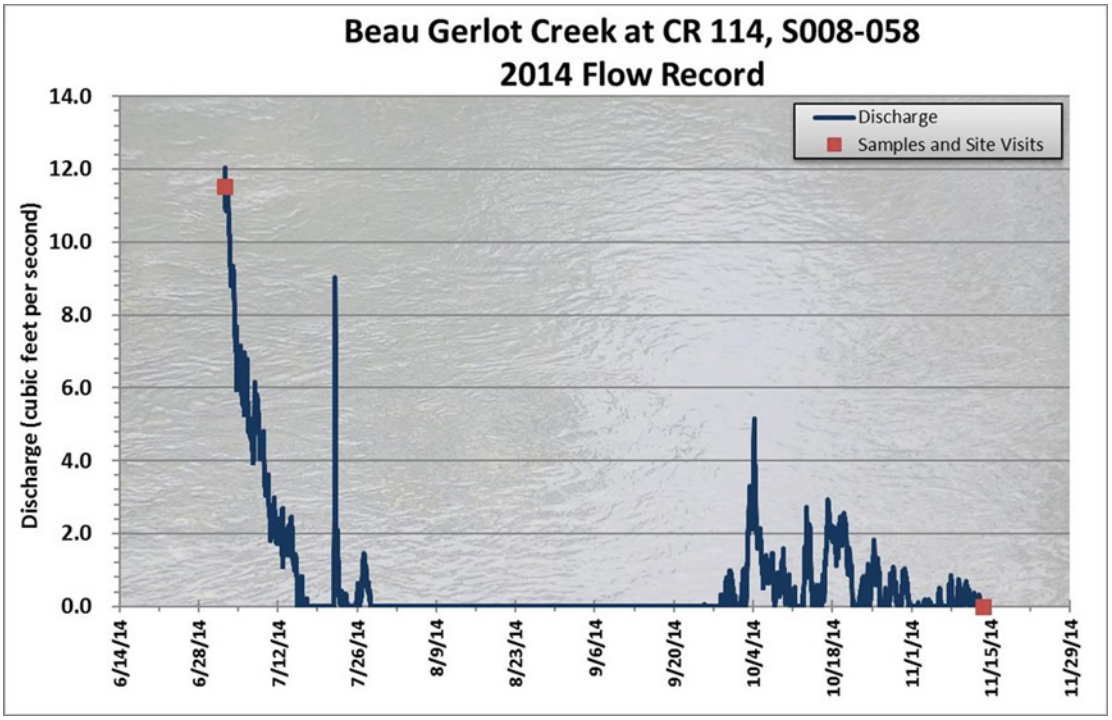
Figure 12: Continuous DO data collected from 7/16/2015 through 8/31/2015. The horizontal blue line highlights the 5mg/L minimum DO standard, and the gray line indicates the 3.5mg/L daily DO flux standard (only applies under certain TP conditions).

Biological sampling data does not indicate that low DO levels are a stressor. Using the MPCA's community index values (discussed in Section 4.1.3 under *Low dissolved oxygen (DO)*), it was estimated that this AUID would likely (52% chance) meet the DO standard. The macroinvertebrate community sampled in 2014 also indicates that low DO was not a main stressor since the sample had more taxa that are intolerant to low DO than those that can tolerate low DO.

Flow alterations

An HSPF hydrologic model was built for Beau Gerlot Creek. This model was developed for a period from 1996-2009 and ran on an hourly time step. The results show that the discharge in Beau Gerlot Creek is flashy and there are periods of extreme high and low flow. The summary statistics for the reach are: maximum discharge of 556 cfs, mean discharge of 21.5 cfs and minimum discharge of 0.10 cfs. The percent of the discharge that is estimated at 1 cfs or below is 6% and 43.6% the stream has a discharge that is less than 5 cfs. Higher flows occurred 5.3 % of the time using 86 cfs as a measure, which is 4 times the mean discharge for the record. Overall, the available data suggest that the reach is prone to extended periods of minimal to no flow.

Continuous stage/discharge measurements were recorded from 2014-2016 and include summer-early winter of 2014 and spring-early winter of 2015-2016 (Figure 13). From this data, a total of 664 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was low (less than 1.0 cfs) and extremely low (less than 0.1 cfs). Although spanning different time periods, the HSPF model results are quite different than those based on the continuous measurements. Where the modeling results show that Beau Gerlot Creek yields a discharge less than 1.0 cfs only 6% of its record, the continuous data collected in 2014-2016 show that it was 64-72% of the 664 days, and below 0.1 cfs throughout 54-66% of the sampled record.



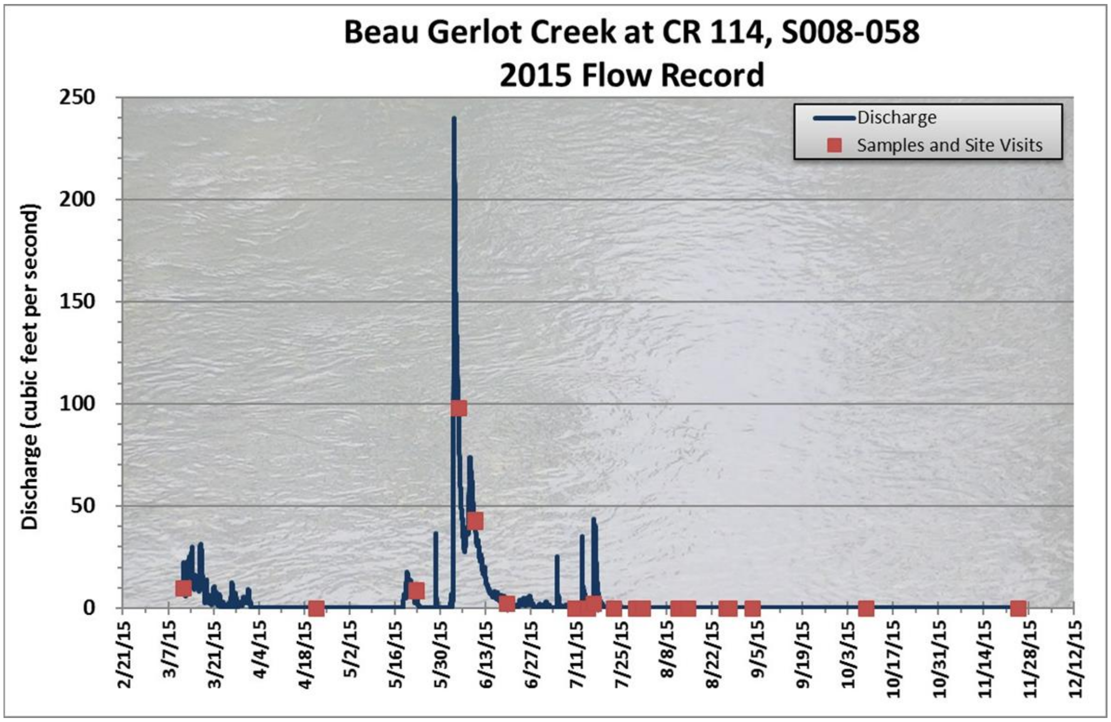


Figure 13: Three hydrographs showing continuous discharge measurements made in 2014, 2015, and 2016 by Red Lake Watershed District, on Beau Gerlot Creek.

The modeled HSPF data, the measured continuous discharge data, and pictures of the channel (Figure 14) all indicate that this AUID suffers from a lack of baseflow and has a highly unstable channel due to flow regime alteration. To further characterize the stability of this channel, the DNR Clean Water Specialists performed multiple geomorphologic surveys and assessments, such as Pfankuch and Rosgen assessments. Based on the entrenchment ratios (~1.5) measured at various locations along AUID 652, the channel is highly entrenched. The high entrenchment ratio means that flood flows cannot reach the floodplain, which increases the shear stress on stream banks and causes bank erosion. A Pfankuch inventory of the stream reach near station 14RD255 resulted in a stability rating of 95, which is moderately unstable for this stream type (type C4). The Pfankuch stability rating looks at three stream channel zones: the upper bank, the lower bank and stream bottom. Each zone analyzed had at least one subcategory that was rated poor. In the upper bank zone, bank slope was greater than 60% and there was a high potential for debris jams. The lower bank zone had significant bank cuts of 12-24 inches in height. The stream bottom also scored poorly in the category of scour and deposition; nearly 50% of the channel bottom is affected by scour or channel deposition. The DNR survey indicated that the reach was lacking in pool depth and holding cover. Aerial photos show that there also are localized areas where stream banks have been damaged by livestock. While the final results of the geomorphologic surveys conducted by DNR will be published with this report at a later date, we can use some of the preliminary information to conclude that Beau Gerlot Creek has an unstable stream channel due to flow alterations, which are stressing the biological communities.

Figure 14: Pictures of Beau Gerlot Creek stream channel, taken in July of 2014, showing excessive in-channel deposition (left) and entrenchment (right).

Upstream of AUID 652, Beau Gerlot Creek has been channelized (AUID 651). The drainage improvements have most likely increased the flashiness of flows in the watershed. Increased peak flows from the channelized portion are likely contributing to instability along the natural channel, particularly within the well-buffered portions. The Red Lake County Ditch 2 system, constructed in 1901, forms the headwaters of Beau Gerlot Creek. LiDAR data and faint meander scars indicate that the system may have diverted water north (near 47°46'44.63"N. & 96° 8'18.85"W) into Beau Gerlot Creek that would have (historically) continued to flow west into Lower Badger Creek. If this is the case, the natural drainage area of Beau Gerlot Creek would have been increased by an estimated 18.84 mi^2, which would increase flows to the channel and overcome its natural ability to maintain baseflow.

Biological response - fish

Additional evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 652 is provided by the following individual F-IBI metric responses, calculated using the 2014 sample from 14RD255 only (Appendix A).

- Above average (>80%) combined relative abundance of the three most abundant taxa (98%)
- Above average (>66%) relative abundance of individuals that are tolerant (98%)
- Above average (>20%) relative abundance of taxa that are pioneers (25%)
- Below average (<23%) relative abundance of taxa that are sensitive (0%)

Flow alteration is a common stressor in watersheds with heavy agricultural use, largely due to channelization, ditching, and other drainage area modifications. The drainage area of Beau Gerlot Creek has undergone excessive modifications in the past and as recently as 2015 (Figure 15).

Figure 15: Aerial imagery from 4/14/2015, showing a newly added ditch that will move water faster than the original natural channel which is still visible on the east side of the new ditch.

Total suspended sediment

While there is always room for improvement, particularly in agricultural or urban watersheds, existing water quality data indicates that Beau Gerlot Creek is meeting expectations for TSS concentrations. TSS intolerant organisms were found. In combined data sets from AUIDs 651 and 652, Beau Gerlot Creek exceeded the 30 mg/L TSS standard in just one sample out of the 31 that were collected. TSS was high on July 22, 2015 due to runoff from a rainfall event that occurred on July 18, 2015. Beau Gerlot Creek met (at 27 mg/L) the 30 mg/L TSS standard on June 4, 2015 after a large runoff event that caused exceedances of the TSS standard in nearby streams (102 mg/L in AUID 502 on Lower Badger Creek).

Lack of connectivity

Six potential fish passage barriers were identified from aerial photography taken in 2015 (Table 7). One of the possible barriers identified is an extensive beaver dam that spans the width of Beau Gerlot Creek and into the floodplain, actively holding water as of April 14, 2015, (Figure 16). The other five potential barriers are either public road crossings or appear to be private, in-field stream crossings. Some of the stream crossings are suspected of being potential barriers due to signs of improperly sized or sloped culverts, such as scour pools on the downstream side. Although, due to the water level on the date the imagery was taken, the crossing may or may not appear to be blocking passage in the figures shown below. These potential barriers would need to be inspected on foot in order to conclusively determine if they are and when they are blocking fish passage.

Table 6: List of potential fish barriers on Beau Gerlot Creek identified using aerial imagery taken in 2015. Potential barriers are listed here going upstream from the creek's outlet to Clearwater River.

Potential Barrier	Description		Latitude, Longitude	Figure
Crossing 1	Upstream of outlet to Clearwater River, between CR 114 and CR 1		47°51'5.01"N 96°12'37.10"W	16
Crossing 2	Upstream of Crossing 1 & downstream of monitoring station 14RD255, between CR 114 and CR 1		47°50'55.75"N 96°12'19.57"W	17
Beaver dam	Upstream of monitoring station 14RD255, between CR 114 and MN 92		47°50'26.92"N 96°11'39.66"W	18
Crossing 3	Upstream of beaver dam, private drive on north side of MN 92 just west of CR 116		47°50'5.34"N 96°11'19.10"W	19
Crossing 4	Upstream of Crossing 3, through field between MN 92 and CR 117, east of CR 116		47°49'35.95"N 96°10'12.31"W	20
Crossing 5	Upstream of Crossing 4, on CR 117 between CR 116 and CR 12		47°49'2.68"N 96° 9'34.37"W	21

Figure 16: Beaver dam on Beau Gerlot Creek. Imagery taken on 4/14/2015.

Figure 17: Crossing 1: potential fish barrier (if white pipe in photo is the only flow path under the road). Imagery taken on 4/14/2015.

Figure 18: Crossing 2: potential fish barrier, especially in low flow conditions. Imagery taken on 4/14/2015.

Figure 19: Crossing 3: potential fish barrier, especially under low flow conditions. Imagery taken on 4/14/2015.

Figure 20: Crossing 4: potential fish barrier, especially under low flow conditions, due to improperly sized or sloped culvert. Imagery taken on 4/14/2015.

Figure 21: Crossing 5: potential fish barrier, especially under low flow conditions. In this photo, there appears to be no water flowing through the culverts. Imagery taken on 4/14/2015.

During the fish sampling of 2014, one individual fish was collected that is considered migratory. The one migratory fish captured was a white sucker that was 1.6 inches long. This may indicate that some adult white suckers made their way upstream to spawn and had left the creek by the July 17, 2014 sampling event. The striking lack of migratory fish species collected at a monitoring station that is relatively close to the Clearwater River indicates that lack of connectivity is likely prohibiting a healthy fish population from thriving in Beau Gerlot Creek.

Lack of habitat

Stream habitat was evaluated using the MSHA during each of the four biological sampling events. The four scores range from 49.1 to 67.6, and the average of the four scores is 56.4. The two most common habitat features that weighed down the total MSHA scores were channel morphology and substrate. These categories scored less than 50% of the total possible in two out of the four MSHAs.

The low channel morphology ratings are indicative of a general lack of channel depth variability, poorly stabilized banks, and a lack of stream velocity variability. Although these poor habitat features were only observed in two out of the four MSHAs, it is suggestive of channel instability, which will degrade habitat even further over time if not addressed. Photographs taken during the four sampling events show that there are significant depositional features located throughout the stream reach. This indicates excess sediment is entering the stream from in-channel erosion and/or overland field runoff. Bank erosion was also evident in the sampling reach. A significant number of downed trees falling in as the banks collapse were evident in the photos. The trees will temporarily provide some new habitat features for both fish and invertebrates; however, channel erosion and over-widening outweigh any benefits provided by the newly imported wood (Figure 22). Also, in some areas on Beau Gerlot Creek, widening and shallowing of the channel has occurred where stream banks have been disturbed by livestock.

Figure 22: Evidence of channel deposition and over widening of channel cross section. As the channel becomes wider, the riparian trees can fall into channel causing even more stress on stream banks, which in turn causes more erosion and deposition.

Aerial photos indicate that the buffer width is acceptable under the requirements of Minnesota's Buffer Law. Much of the riparian buffer is forested, though the quality of the vegetation has been degraded by a livestock operation downstream of CR 114.

Biological response - fish

Additional evidence of a causal relationship between lack of habitat and the F-IBI impairment associated with AUID 652 is provided by the following individual F-IBI metric responses, calculated using the 2014 sample from 14RD255 (Appendix A).

- Below average (<23%) relative abundance of individual lithophilic spawners (5%)
- Below average (<5%) relative abundance of individual benthic insectivores (0%)
- Below average (<8%) relative abundance of taxa that are darters, sculpins, or round-bodied suckers (0%)
- Above average (>57%) relative abundance of taxa that are tolerant (75%)

It appears that the lack of habitat heterogeneity is having a negative effect on the fish community at station 14RD255.

4.3 Poplar River (AUID 518) – non-support of fish/nonsupport of macroinvertebrates

4.3.1 Physical setting

AUID 518 represents a 40-mile long segment of the Poplar River (Figure 23). The Poplar River originates at the outlet of Spring Lake, in Lengby, Minnesota, and enters the Lost River just north of MN-92 near Brooks, Minnesota.

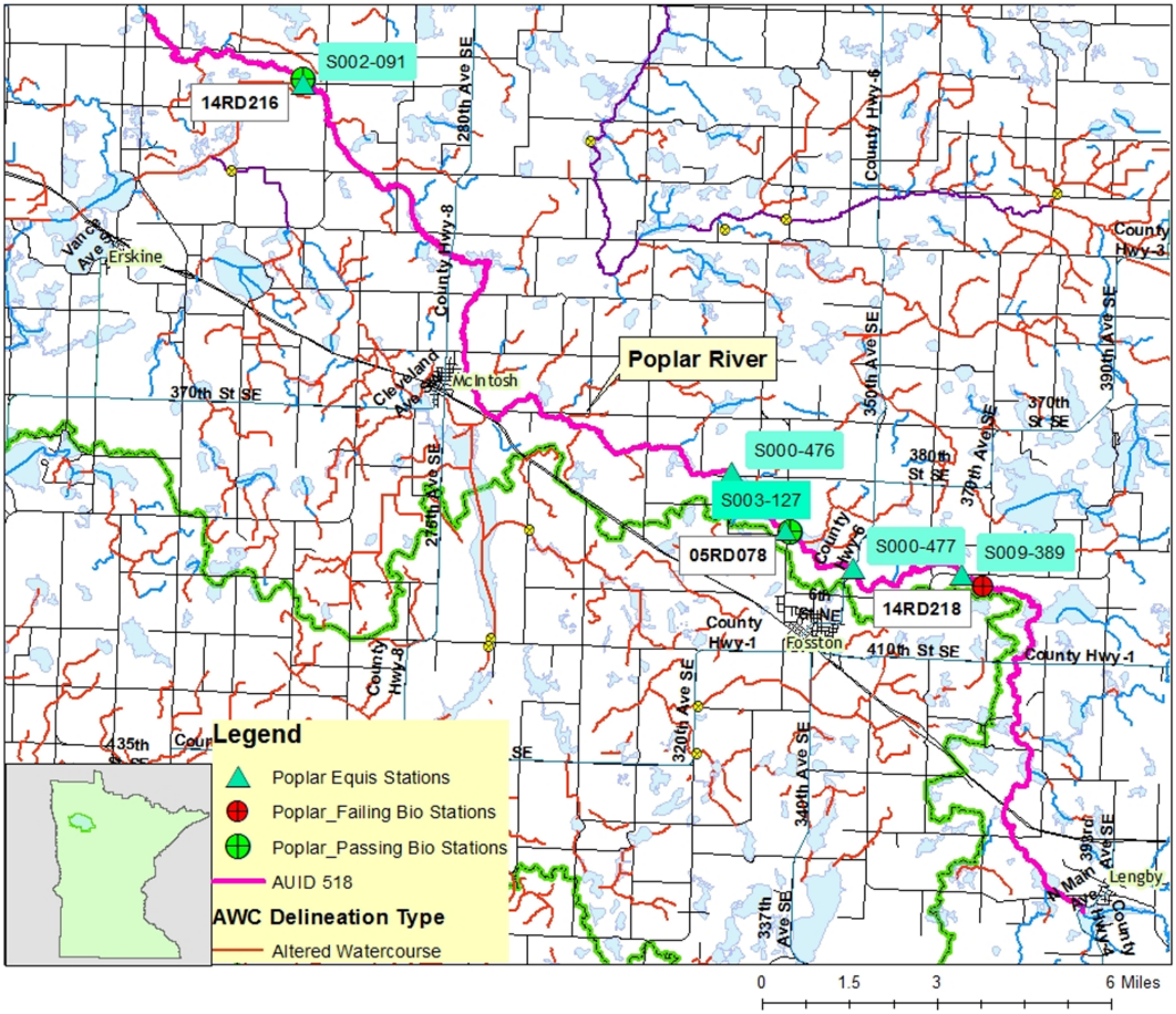


Figure 23: Location of AUID 518 (40 stream miles long) within the Poplar River, and its associated monitoring stations. The map also shows the altered condition of adjacent waters. The Clearwater River watershed boundary is shown in bright green just west of the Poplar River.

4.3.2 Biological Impairments

Since 2005, 10 total samples of fish and/or macroinvertebrates have been collected from three monitoring stations on this AUID (Table 8).

Table 7: Results of MPCA biological monitoring on AUID 518, on the Poplar River. Stations are listed in a downstream to upstream order (based on their location in the AUID). Failing IBI scores are highlighted in red.

Station	Sample date	F-IBI (score/threshold)	M-IBI (score/threshold)
14RD216	8/4/2014	-	27.6/41
	8/5/2014	59/47	-
	8/17/2015	-	67/41
	9/13/2016	-	75.4/41
05RD078	8/9/2005	41/47	-
	8/24/2005	-	57.7/43
14RD218	7/15/2014	23/42	-
	8/6/2014	-	25.7/43
	6/16/2015	23/42	-
	9/14/2016	-	8.8/43

The biological communities in this AUID failed 6 out of 10 IBI analyses, most notably at the most upstream monitoring station, 14RD218. The AUID was deemed as “nonsupport” for both fish and macroinvertebrates. An especially concerning trend in the macroinvertebrate data is the general decrease in IBI scores as the stations move upstream.

4.3.3 Candidate causes

Summary

Of the five candidate causes analyzed, the primary stressors to aquatic life suspected in AUID 518 (Poplar River) are low DO, flow alterations, lack of connectivity, and lack of habitat. Elevated nutrients are an inconclusive stressor at this time. If low DO is causing the release of orthophosphorus, then it is the driver of the high TP concentrations and the primary stressor. All of these stressors are primarily affecting the biological communities in the upstream portion of AUID 518, as the IBI scores improve in a downstream pattern.

Total suspended solids are not closely examined because no exceedances of the standard have been recorded within the 2006-2015, April-September assessment period, nor do the biological data suggest a TSS stressor. Two exceedances of the TSS standard have been recorded at S003-127 on days that fall outside of the assessment period (40 mg/L on 10/18/2007 and 98 mg/L on 7/7/2016). Those high TSS concentrations were associated with discharge from the Fosston WWTF lagoons.

Elevated nutrients

Nutrients were measured at various water chemistry monitoring sites (called EQuIS stations) on this AUID (Figure 23). In sum, TP is suspected to be a problem at three EQuIS stations on AUID 518. Those three stations are S009-389, S000-476, and S002-091.

EQuIS station S009-389 (located at the CSAH 27 crossing) is the furthest upstream water chemistry monitoring station analyzed (Figure 24). This site is nearly co-located with the 14RD218 biological sampling site. Seven TP samples were collected here in 2016 (Figure 25). The TP concentrations in these seven samples averaged 0.111 mg/L, with the July 8th sample being 0.195 mg/L, all of which exceeds 0.100 mg/L TP standard; however, more TP data and DO flux data are needed to determine if eutrophication is occurring at EQuIS station S009-389. On average, orthophosphorus (OP) represented 88% of the TP concentration. This suggests that soluble, inorganic phosphorus is being released from sediment in the stagnant, low-gradient portion of the stream that tangentially flows past Whitefish Lake.

Biological oxygen demand (BOD) concentrations in four samples (too few for a formal assessment) that were collected during the 2016 sampling effort also exceeded 2.0 mg/L standard with an average concentration of 3.22 mg/L. If eutrophication were occurring here, it would likely affect the fish and macroinvertebrates at biological station 14RD218.

The nitrogen samples collected from EQuIS station S009-389 were below concentrations that would stress the biological community. The macroinvertebrate data also suggest that nitrogen is not a stressor here (Table 9). In 2016, five nitrogen samples were collected at this station, and all five samples had concentrations that were below the detection limit.

Figure 24: Looking up stream at the Poplar River/CSAH 27 crossing (AUID 518), where EQuIS station S009-389 is located. Photograph taken on 5/3/2007.

Table 8: Macroinvertebrate indices at the three sampling locations. Site 14RD216 is a Class 7, and other two sites are in Class 6.

	Low DO intolerant taxa	Low DO tolerant taxa	TSS intolerant taxa	TSS tolerant taxa	Nitrogen intolerant taxa	Nitrogen tolerant Taxa
14RD216	1	3	2	4	2	11
05RD078	6	9	1	14	5	23
14RD218	0	3	2	3	3	8

After S009-389, the next downstream water chemistry station is S000-477 at the CSAH 6 crossing. At this station, TP and nitrogen samples were collected 22 times between 2001 and 2014 (Figure 25). The TP concentration data from this site suggest that elevated TP concentrations do not appear to be a major issue. Almost all of the TP concentrations were below the 0.100 mg/L Central region eutrophication standard. DO flux, a response variable to eutrophication, was monitored at this station during 2014.

None of the 29 DO flux measurements exceeded the 3.5 mg/L/day standard. The average DO flux (1.67 mg/L) from the 2014 deployments were less than half of the amount allowed by the impairment threshold. Data suggests that the Poplar River has recovered from the conditions that are causing high TP and low DO levels at S009-389, and eutrophication does not appear to be occurring at EQuIS station S000-477.

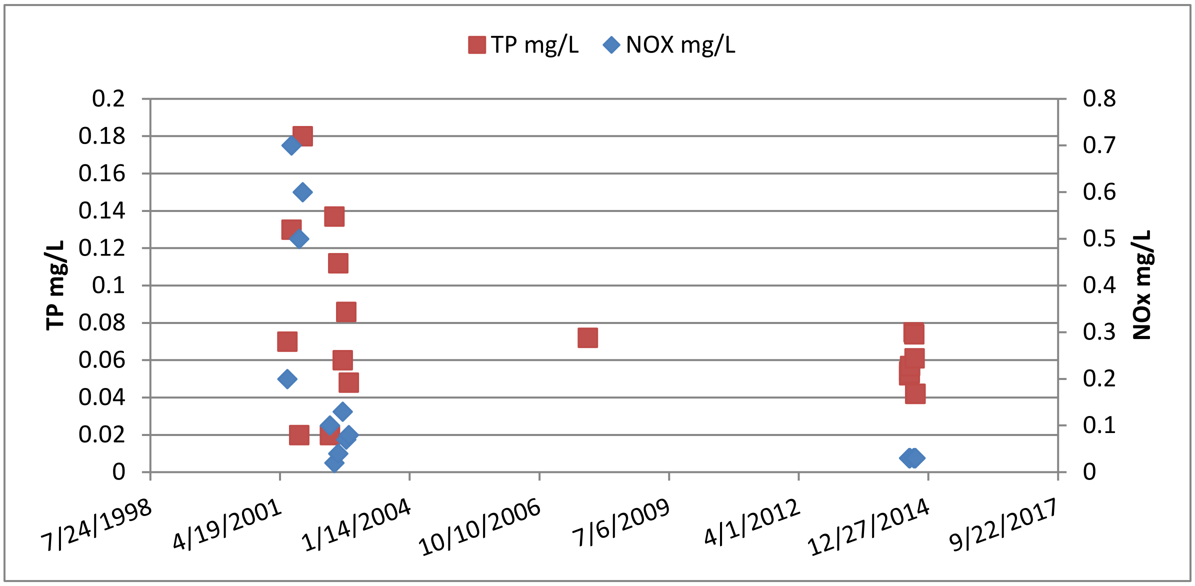


Figure 25: Water chemistry data collected from EQuIS site S000-477 near biological station 05RD078. TP concentrations are generally below the eutrophication standard and NOx concentrations are all below 1 mg/L for the sampling record.

After S000-477, the next downstream station is S003-127. This site is co-located with the 05RD078 biological monitoring site. The city of Fosston wastewater ponds (Figure 26) are located upstream of biological monitoring stations 14RD216 and 05RD078 and immediately upstream of the S003-127 water chemistry monitoring site. Very high concentrations of nutrients have been recorded during discharge from the Fosston lagoons on 10/18/2007 (2.39 mg/L TP and 32 mg/L BOD) and 7/7/2016 (6.74 mg/L TP, 143 mg/L BOD, and 27.6 mg/L TKN). However, the entire record of available TP data from 05RD078 and S003-127 does not suggest that elevated TP is a chronic problem (0.076 mg/L summer average). Nitrate-nitrite (NOx) concentrations averaged 0.07 mg/L (maximum of 0.5 mg/L), indicating that NOx is not a stressor to the biological community at stations 14RD216 and 14RD218.

After S003-127, the next downstream station is S000-476. In 2014, eleven TP and nitrogen samples were collected from this site, averaging 0.119 mg/L for TP and 0.040 mg/L for NOx. In 2016, one nutrient sample was taken on August 3, yielding 0.454 mg/L of TP. There is enough evidence of elevated TP concentrations to warrant an investigation into the response variables of DO flux, Chl-a, and/or BOD_5. Some continuous DO data was collected in 2014 (see the next section, *Low dissolved oxygen (DO)*), but more is needed to conclusively determine if eutrophication is affecting the biological communities near station S000-476.

Lastly, the most downstream water chemistry monitoring station is EQuIS station S002-091, where 36 water chemistry samples were collected from spring to fall between the years of 2007 and 2015. These samples were analyzed for TP, NOx and NH_4. During this period, all TP concentrations averaged 0.244 mg/L, and 89% of the individual TP measurements exceeded the eutrophication standard of 0.100 mg/L. When considering only those samples that were taken in June through September (a total of 19 samples), the average concentration is 0.285 mg/L, which does exceed the TP standard; however, a response variable such as DO flux, Chl-a, or BOD_5, would also have to exceed the standard for this AUID to be listed as impaired for eutrophication. None of those three response variables were measured at this location. However, 14 BOD samples from S002-091 are relevant to the 2016 assessment. Using simple numerical results from EQuIS, the average is 2.14 mg/L, which exceeds the 2 mg/L standard. However, nine of those values are actually "<2 mg/L," so the true average is significantly less than 2.14 mg/L and the site is likely not exceeding the BOD standard.

Additional monitoring should be conducted to determine if elevated TP is affecting stream biology, especially DO monitoring near site S002-091.

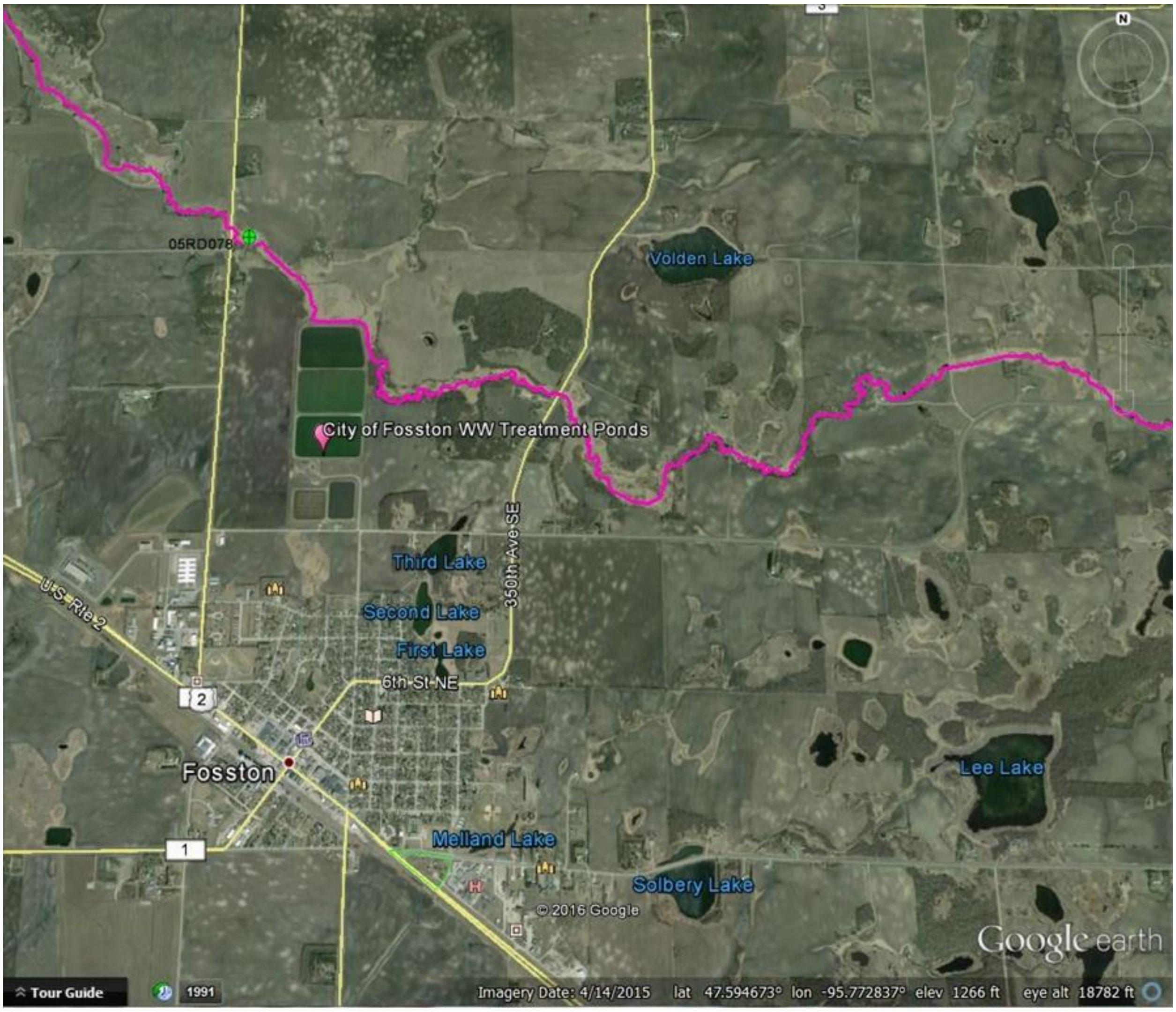


Figure 26: Location of Fosston Wastewater Treatment ponds just upstream of biological site 05RD078.

Low dissolved oxygen

DO was measured at various water chemistry monitoring sites (EQuIS stations) on this AUID (Figure 27). Sufficient data from discrete measurements and/or DO logger deployments were collected at six sites along the AUID from 2006 to 2016. Low DO is suspected to be a problem at six of those seven stations. Those seven stations are (downstream to upstream):

- S002-091 (10.7% below 5 mg/L DO standard), nearest EQuIS station to 14RD216
- S003-126 (66.1% below 5 mg/L, continuous data)

- S000-476 (88.27% below 5 mg/L, continuous data)
- S003-127 (36.7% below 5 mg/L, continuous data), nearest EQuIS station to 05RD078
- S000-477 (2.3% below 5 mg/L, continuous data) = not a concern
- S009-389 (97.9% below 5 mg/L, 2016 continuous data), nearest EQuIS station to 14RD218
- S004-502 (59.4% below 5 mg/L, continuous data)

The poorest DO levels and IBI scores were found near the CSAH 27 crossing of the Poplar River, northeast of Fosston at stations 14RD218 and S009-389. Station S009-389 is the furthest upstream water chemistry monitoring station on AUID 518; it is located downstream of a large wetland complex near the outlet of Whitefish Lake. The land use surrounding this wetland complex is primarily row crop agriculture. During periods of medium to high flow, it is likely that these wetland complexes flush out nutrients that can affect downstream DO concentrations. Nutrient samples collected during this deployment did not show elevated TP or nitrogen concentrations. In 2016, the RLWD collected continuous DO data from this station from July 9 through August 21 (Figure 27). A total of 2,009 DO readings were collected at thirty-minute intervals. The entire sample period recorded DO concentrations below the 5 mg/L standard, ranging from 3.94 mg/L down to 0.01 mg/L. Additionally, more fish and macroinvertebrate taxa that are considered tolerant of low DO conditions were found at this site than taxa that are considered intolerant of low DO. Low DO concentrations in the upstream portion of this AUID are stressing the biological community.

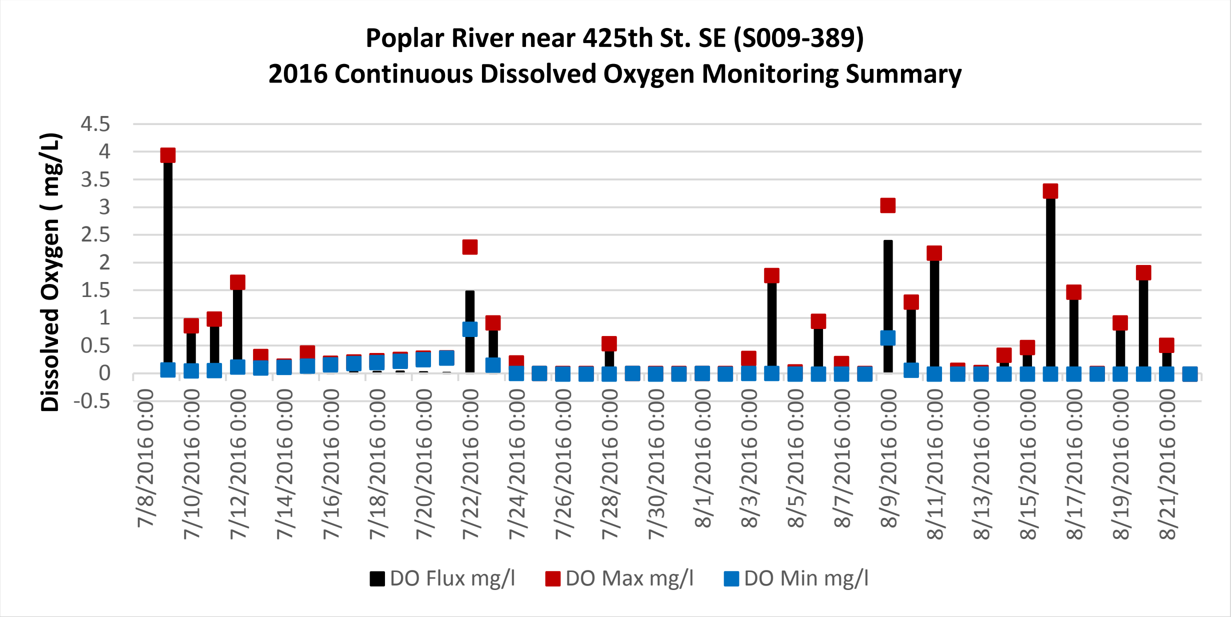


Figure 27: Continuous dissolved oxygen data collected by RLWD at S009-389 near biological station 14RD218.

After S009-389, the next downstream water chemistry monitoring station is EQuIS station S000-477. Instantaneous DO measurements were collected 53 times from 2001 through 2014; no measurements were below the 5 mg/L DO standard (Figure 28). In 2014, the RLWD collected continuous DO measurements, which did not reveal a DO problem that year as nearly all measurements were above the 5 mg/L standard, and daily DO flux stayed below the 3.5 mg/L standard. (Figure 29). Likely due in part to an increased gradient, the DO levels at this site are much improved from the levels found in the river at CSAH 27.

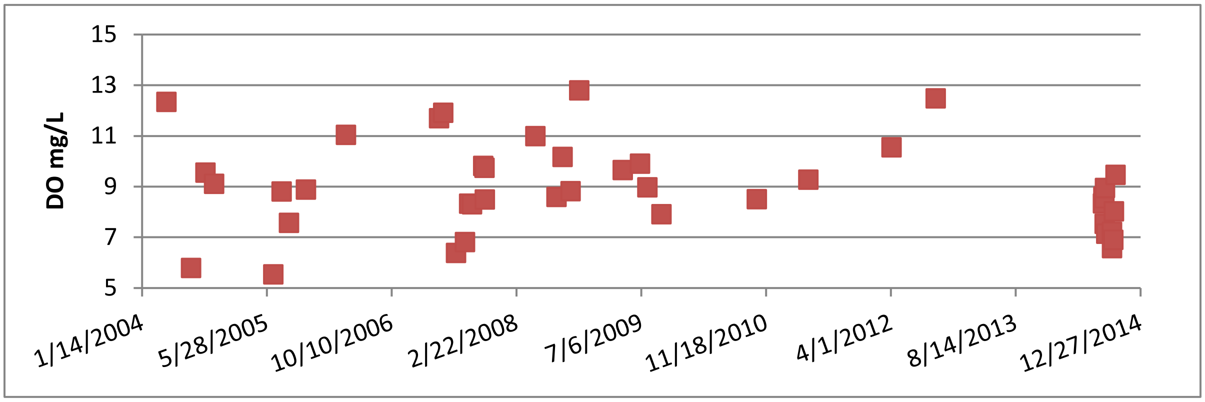


Figure 28: Instantaneous dissolved oxygen data collected from EQuIS station S000-477 from 2004 through 2014.

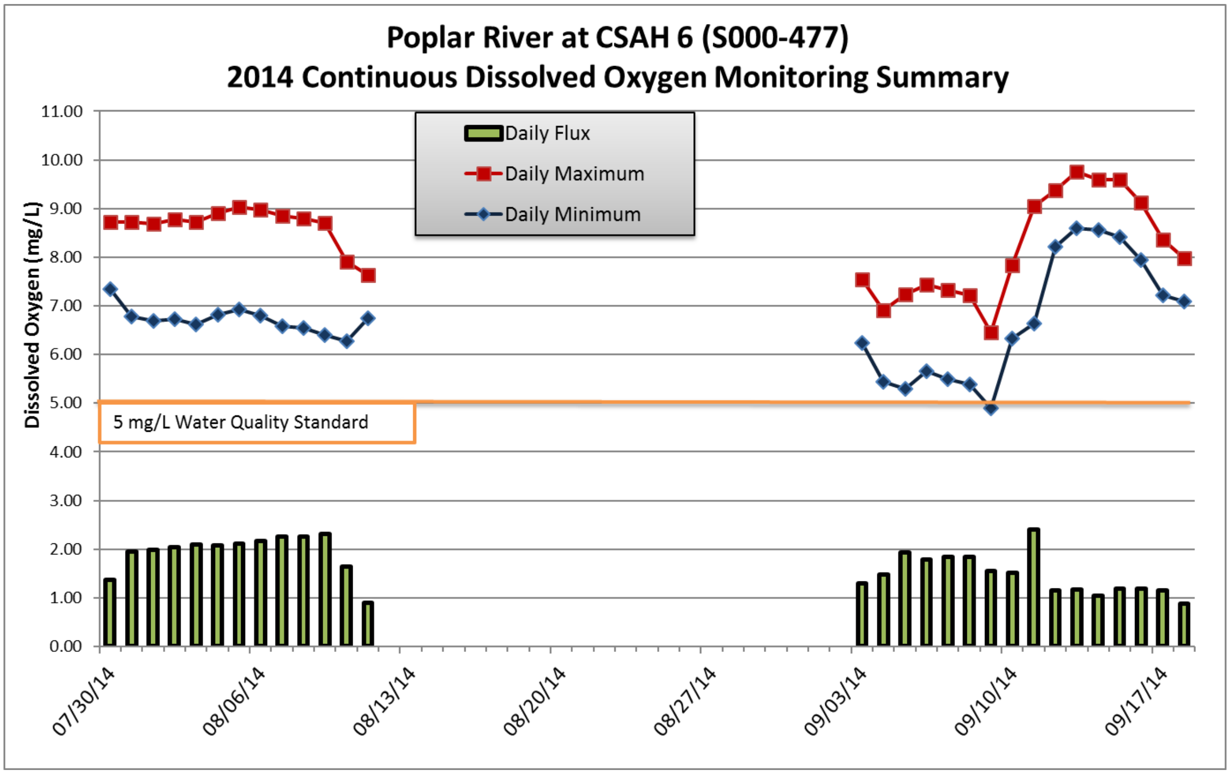


Figure 29: Continuous DO data from EQuIS station S000-477 from 2014.

After S000-477, the next downstream is EQuIS station S003-127. This water chemistry station is co-located with the 05RD076 biological sampling station near the CSAH 30 crossing. This is the first crossing of the Poplar River downstream of the Fosston lagoons. DO loggers were deployed at the site during two full summers: 2007 and 2014. Low daily minimum DO concentrations coincided with low/no flow conditions (especially in August) in both of those summers. In June of 2014, DO levels also seemed to be negatively affected by a significant runoff event. In 2016, DO levels were negatively affected by discharge from the Fosston lagoons.

After S003-127, the next downstream is EQuIS station S000-476. There is a large wetland complex (approximately 116 acres) just upstream, and this site is not far downstream of the City of Fosston wastewater ponds. In 2014, 13 instantaneous DO samples were collected between July 30 and September 18. The minimum DO concentration was 1.71 mg/L, and the maximum was 6.84 mg/L. Six of the 13 samples were below the 5 mg/L standard for DO. Also in 2016, two samples were taken yielding 2.45 mg/L on July 7 and 0.08 mg/L on August 3. The instantaneous data show that the stream does experience low DO concentrations at this site. Wetlands reduce stream velocity and cause pooling of water allowing for biological and chemical oxygen demand (i.e. detrital decomposition) to consume DO. The many wetland complexes along AUID 518 may be reducing stream DO concentrations. The fish community data at the upstream site (14RD218) suggests that low DO is a stressor (Table 10). Continuous DO data were collected from this site in 2014 from July 25 to September 18 (minus the latter half of August); a total of 1,534 measurements were made within 34 days (Figure 30). The daily DO minimums commonly fell below the 5 mg/L standard, and the daily DO flux exceeded the 3.5 mg/L standard 15% of the time.

Table 9: Fish community tolerance to TSS and low DO

Monitoring station	TSS intolerant taxa	TSS tolerant taxa	Probability of passing TSS standard	Low DO intolerant taxa	Low DO tolerant taxa	Low DO tolerant individuals [%]	Probability of passing DO standard
14RD216	0	0	0.82	0	3	15	0.47
05RD078			0.76	0	8	29	0.40
14RD218	0	0	0.88	**0**	**4**	**88**	**0.13**

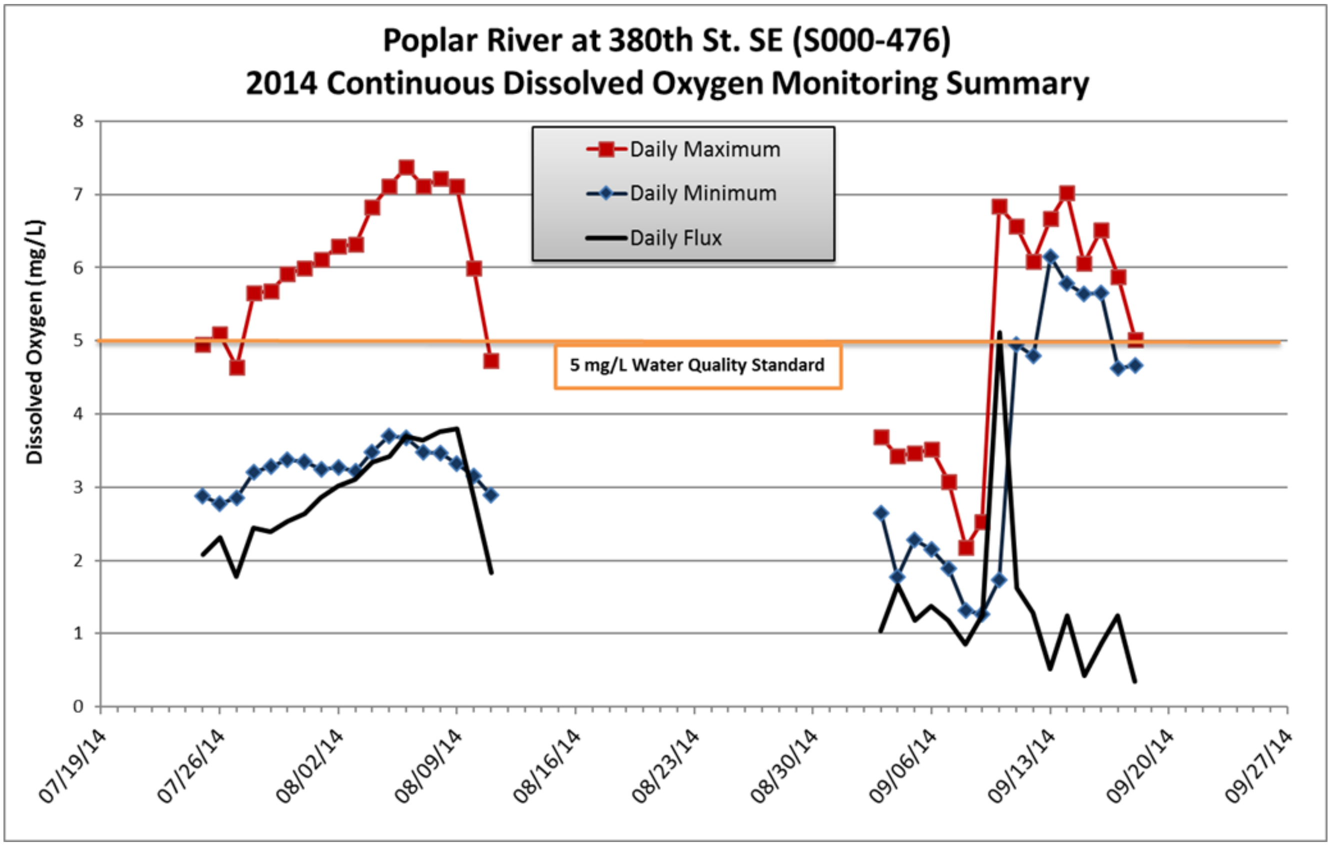


Figure 30: Continuous DO data collected from EQuIS site S000-476 in 2014.

The furthest downstream water chemistry station with sufficient DO data on this AUID (518) is S002-091. Instantaneous DO data was collected from 2006 through 2015. During this period, DO concentrations ranged from 3.42 to 10.68 mg/L. Three of the 29 sample points collected during the months of May through September were below the 5 mg/L standard (10.7%). Also, the number of DO tolerant taxa decrease at this downstream end of the reach compared to the upstream samples. Low DO is not a stressor to the biota at this location.

Continuous DO data was also collected on a different AUID (504), at EQuIS station S007-608, which is located on the farthest downstream reach of Poplar River, just before its confluence with the Lost River at CR 118. Data from the 2014 and 2015 deployments suggest that low DO is a possible stressor to the biological communities in that reach. Of the 60 days of daily minimum DO values recorded, 23% were below the 5 mg/L standard.

Flow alterations

The results of the (HSPF) hydrologic model are summarized as follows: a peak discharge of 1057 cfs, mean discharge of 35.4 cfs and a minimum discharge of 0.22 cfs. The record also shows that 15% of the time, the stream was below 5 cfs, and 4.3% of the time discharge was above 141 cfs, which is 4 times the mean discharge (Figure 31).

In 2007, continuous discharge measurements of the Poplar River were made by the RLWD from May 5 to November 13, and again in 2016 from April 11 to December 5 (Figure 31). These measurements were collected at EQuIS station S003-127, where the river crosses CSAH 30. From this data, a total of 876 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was low (less than 1.0 cfs) and extremely low (less than 0.1 cfs). The results show that the Poplar River yielded a discharge less than 1.0 cfs for 33-41% of the record, and less than 0.1 cfs for 28-39% of the record. The record of flow data at the site displays a pattern in which flows typically drop to zero during the month of August.

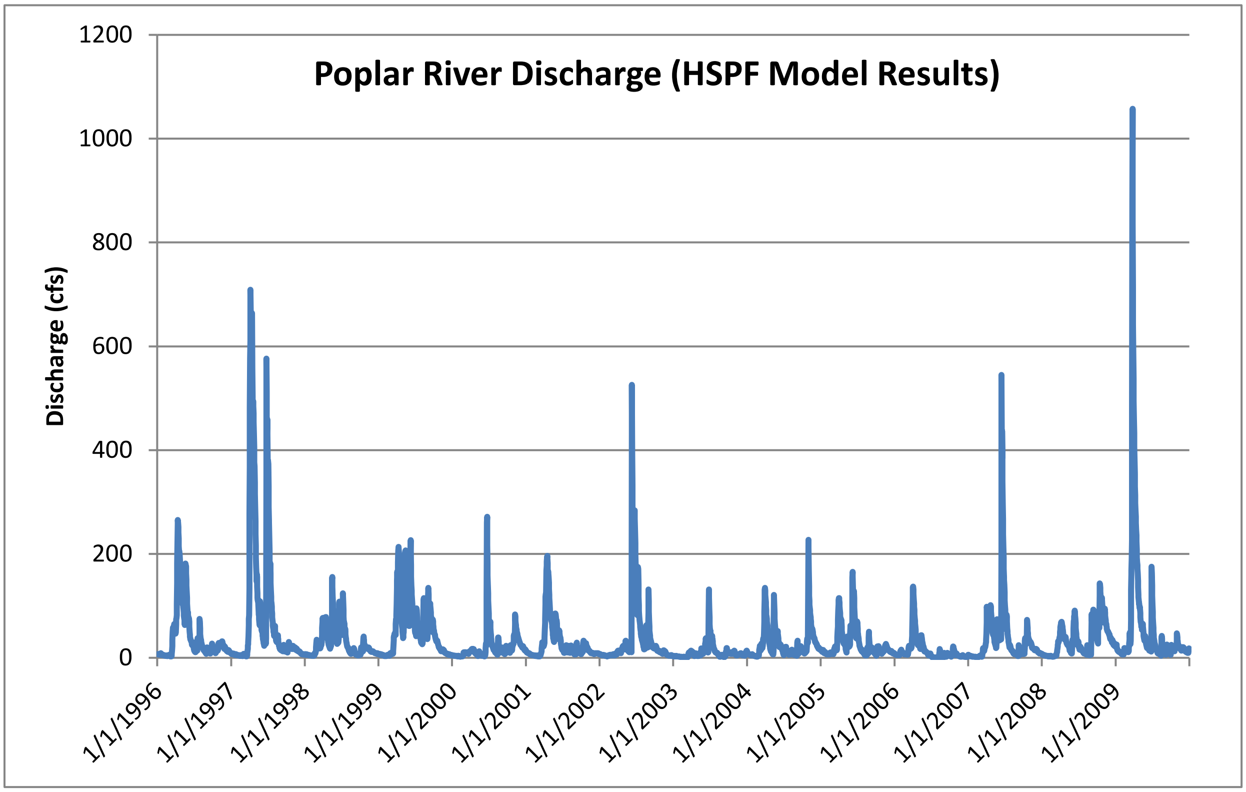


Figure 31: HSPF modeled daily discharge data for AUID 518.

Only small sections of the Poplar River near road crossings have been channelized. Drainage from cultivated agricultural land and stormwater runoff from cities likely cause the abrupt increases in flow that occur during runoff events. There are a large number of wetlands in the watershed that capture some of that runoff, and, based on hydrographs, seem to contribute some through-flow to the Poplar River. Aerial photos reveal that large wetlands in the watershed have been drained and others have been partially drained. So, there is room for improvement. Storage could be improved in the watershed by restoring wetland basins that have been drained or filled with sediment.

Biological response-fish

Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 518 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>80%) combined relative abundance of the three most abundant taxa at station 14RD218 (80%)
- Above average (>66%) relative abundance of individuals that are tolerant at station 05RD078 (78%)
- Above average (>20%) relative abundance of taxa that are pioneers at station 14RD260 (67%)
- Below average (<23%) relative abundance of taxa that are sensitive at stations 14RD216 (18%), 05RD078 (15%), and 14RD218 (0%)

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). A review of the various fish metrics does not indicate a strong correlation between altered hydrology and the lack of fish assemblage at 14RD218 or the remainder of AUID 518. The three most dominant fish species sampled at station 14RD218 on July 15, 2014, were central mud minnow, brown bullhead, and yellow perch. During the June 16, 2015 fish visit, the three most dominant fish species sampled were central mud minnow, white sucker, and northern pike. Central mud minnow are short lived and tolerant, but the other four species are longer lived and not as tolerant.

Biotic response – macroinvertebrates

Evidence of a causal relationship between flow regime instability and the M-IBI impairment associated with AUID 518 is provided by the following individual M-IBI metric responses (Appendix B):

- Above average (>70%/59%) relative abundance of the dominant five taxa in a subsample, (chironomid genera treated individually) at stations 14RD216 (88.5%) and 14RD218 (90%)
- Below average (<4%/6%) relative abundance of long-lived individuals at station 14RD216 (1.3%) and 14RD218 (0%)

Flow regime alteration tends to limit macroinvertebrate diversity and favor taxa that are shorter lived and tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; USEPA, 2012b). *Simulium sp*. (blackflies) dominated the sample at station 14RD218. This taxon is short-lived and highly tolerant of a wide range of environmental conditions. Macroinvertebrate metric data suggest that flow alterations may be a stressor in the upstream portion of AUID 518.

Lack of connectivity

One migratory fish was sampled at the most upstream station, 14RD218, while 18 migratory fish were sampled downstream at 14RD216. Site 14RD216 is the farthest downstream station on this AUID, and thus is closest to the Lost River confluence. Station 05RD078 is located between those two stations and had 44 migratory fish when sampled in 2005. It is very possible that between the 2005 and 2014 sampling events, a road crossing or was replaced or installed that is now limiting the free movement of fish species throughout the reach, or other barriers such as beaver dams have entered the system. The fish data suggests that longitudinal connectivity is inconclusive as a stressor to the fish community.

Using Google Earth aerial imagery, 22 road crossings were identified on this AUID between 14RD216 and 14RD218. Three of those crossings are private (field approach or driveway access). An inventory of some of the crossings was conducted by the DNR Clean Water Specialists to identify potential barriers to fish migration. Two of the most concerning crossings are where the Poplar goes under 310th Avenue SE and

350th Street SE. The concern at these locations are that the culverts may be perched and limiting fish passage during low flows. Two other crossings further upstream in the AUID were identified as possible fish barriers under low and base flow conditions due to insufficient water depths through the culvert. These are where the Poplar goes under 440th St SE and CR 4. The final results of the DNR's entire inventory of crossings will be published with this report at a later date.

Lack of habitat

Overall, the MSHA scores along with the associated response metrics from the biological community indicate that habitat is a limiting factor in this AUID and is stressing the biology.

Four MSHA scores were available for stations 14RD216 and 14RD218; station 05RD078 had an MSHA score calculated once in 2005 (Table 11). The average of the three MSHA scores for station 14RD218 is 55, which places the habitat there in the "fair" category. There is a general lack of stream channel variability within this reach as 90% of the channel is run habitat. This brought the MSHA score below 50% of maximum for this site. Photos taken during sampling events at station 14RD218 show a streambed with large amounts of submerged macrophyte growth along with stable banks. The photos also indicate that the channel can access a floodplain and the width appears to be sufficient to transport sediment through the reach.

Table 10: Results of MSHA on AUID 518, on the Poplar River. Stations listed in an upstream to downstream order.

Station	Sample date	MSHA score
14RD216	8/4/2014 8/5/2014 8/17/2015 9/13/2016	57 53 42 59.5
05RD078	8/9/2005 8/24/2005	71
14RD218	7/15/2014 8/6/2014 6/16/2015 9/14/2016	52 59 52.5 48

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 518 is provided by the following individual F-IBI metric responses (Appendix A):

- Below average (<14%) relative abundance of individuals that are benthic insectivores at station 05RD078 (6%) and 14RD218 (0%)
- Above average (>78%) relative abundance of individuals that are tolerant at station 05RD078 (50%)
- Above average (67%) relative abundance of the dominant two species of fish at station 14RD218 (68%)
- Below average (<8) relative abundance of taxa that are Darters, sculpins, or round bodied suckers at station 14RD218 (0%)

Biological response - macroinvertebrates

Evidence of a causal relationship between habitat availability and the M-IBI associated with AUID 518 is provided by the following individual M-IBI metric responses (Appendix B):

- Below average (<34%) relative abundance of clinger taxa at station 14RD218 (22%)
- Above average (>19%) relative abundance of sprawler taxa at stations 14RD218 (33%)

The DNR Clean Water Specialist conducted a Pfankuch inventory of the stream reach near stations 14RD216, 05RD078, and 14RD218. The results of this inventory were stability ratings of 84, 74, and 59, respectively which rates as stable for a C5 stream type. The C5 stream type represents a slightly entrenched single channel stream with a sand dominated substrate. The Pfankuch stability rating looks at 3 stream channel zones: the upper bank, the lower bank, and stream bottom. Each zone analyzed had at least one subcategory that was rated fair. In the upper bank zone, bank slope was greater than 60% and there was a high potential for debris jams. In the lower bank zone, the bank material was composed of small size rock and in-cohesive material making the banks susceptible to erosion. This is also seen in the bank-cutting category, which scored “fair” at station 14RD218 and has significant bank cuts of 12 inches in height. The stream bottom also scored “good” in all the categories. The Pfankuch stability rating does not show that habitat is a significant problem, however station14RD218 does show higher bank cutting and higher rates of deposition, which could be causing localized habitat issues in that section of the AUID.

4.4 Hill River (AUID 539) – nonsupport of fish/full support of macroinvertebrates

4.4.1 Physical setting

AUID 539 represents a 34-mile segment of the Hill River that extends from the outlet of the Hill River Lake downstream to the confluence with Lost River, just northwest of Brooks, Minnesota (Figure 32).

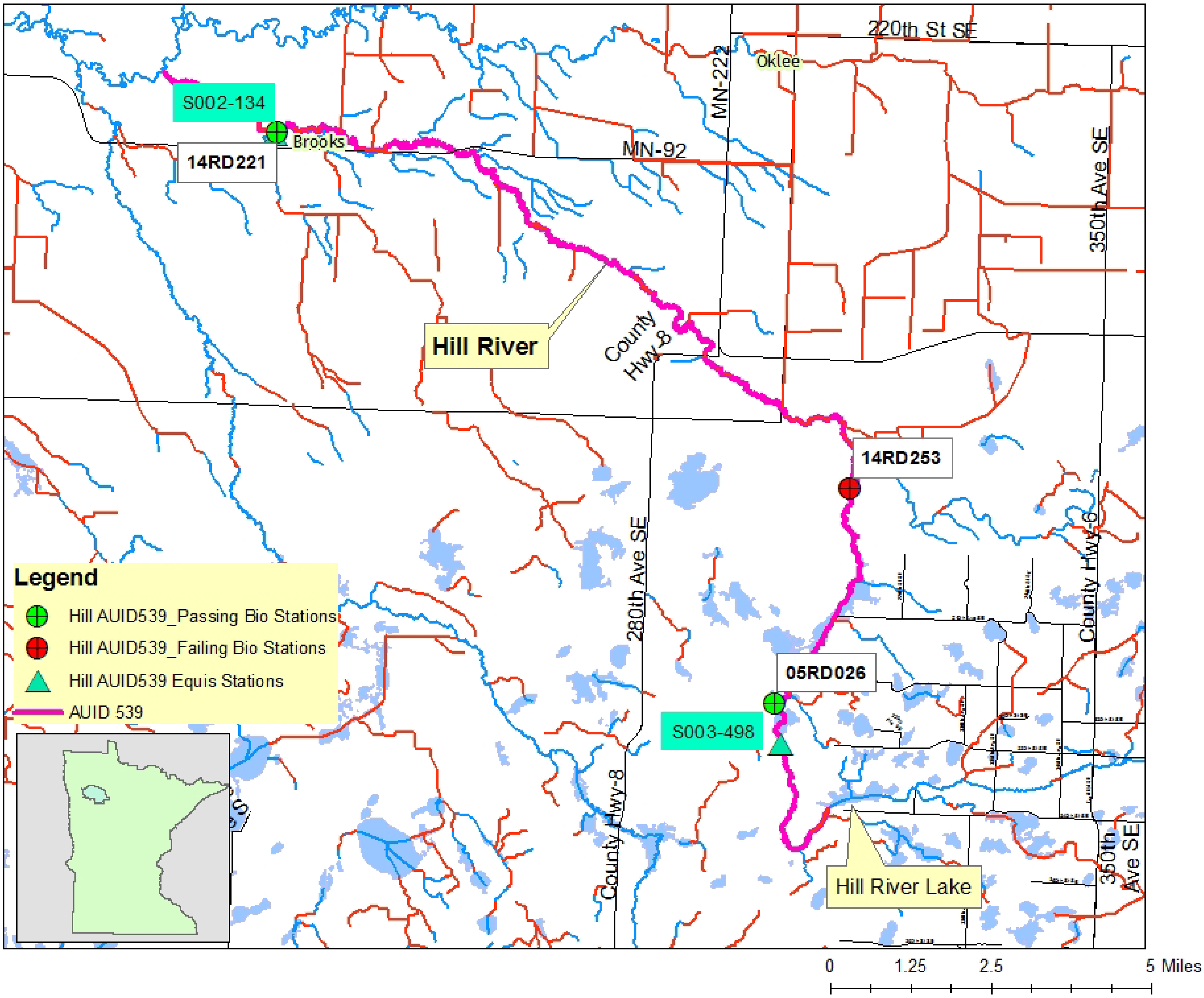


Figure 32: Location of AUID 539 (34 stream miles long) within the Hill River, and its associated monitoring stations. The map also shows the altered condition of adjacent waters.

4.4.2 Biological Impairments

The biological community of AUID 539 was monitored at stations 14RD221, 14RD253, and 05RD026 (Table 12). The 2006 fish sample at 05RD026 yielded a poor F-IBI score of 33; however, this station was positioned between numerous beaver impoundments that may have negatively affected the F-IBI score.

Site 14RD221 was noted as "very good," in field notes, and the F-IBI score was near the "Exceptional Use" class threshold. Numerous lithophilic spawners and sensitive species were found. This site has good habitat and warrants protection. The fish community sampled at site 05RD026 was dominated by trophic generalists and tolerant species. Generally speaking, the IBI scores seem to improve in an upstream to downstream pattern, possibly due to an increase in coarse substrate at the downstream sites.

Table 11: Results of MPCA biological monitoring on AUID 539, on the Hill River. Stations are listed in a downstream to upstream order (based on their location in the AUID). Failing IBI scores are highlighted in red.

Station	Sample date	F-IBI (score/threshold)	M-IBI (score/threshold)
14RD221	7/8/2014 7/29/2014	70/47 -	- 68.6/37
14RD253	7/15/2014 7/30/2014 7/19/2016	44/47 - 38/47	- 56.5/43 -
05RD026	9/27/2005 7/10/2006	- 33/47	26.5/43 -

4.4.3 Candidate causes

Summary

Of the five candidate causes analyzed, the primary stressors to aquatic life suspected in AUID 539 on the Hill River are most evident at (and upstream of) site 05RD026. Those stressors are lack of connectivity, low DO/high daily DO flux, and lack of habitat. Flow alterations was deemed inconclusive as a stressor. Further hydrological investigation is needed to determine if flashiness and lack of base flow are stressing the biota. Also, ground inspections of beaver dams and some road crossings is needed to determine the degree of longitudinal connectivity throughout this AUID. The evidence strongly suggests that fish from the outlet of the Hill River can get to the most downstream site (14RD221), but many cannot get further upstream to site 14RD253 and beyond. Additionally, fish may be prohibited from passing through Hill River Lake due to the elevation of the existing culverts that replaced the dam, and are still effectively damming up the lake. Ground inspections of this site suggest that although one of the culverts was designed to facilitate fish passage, there is a steep gradient through this culvert and water velocities down this slope can be fast enough to prohibit passage of some fish, and can be low enough to prohibit fish passage due to low flow though the culvert.

Elevated nutrients

Between 2001 and 2015, the Hill River was sampled for nutrients 89 times at EQuIS station S002-134, near biological monitoring station 14RD221, downstream of Brooks, Minnesota (Figure 33). The average of all measurements was 0.081 mg/L, with a median of 0.063 mg/L. Of note, the average daily DO flux in 2015 was 3.30 mg/L, just under the 3.5 mg/L standard (Figure 33).

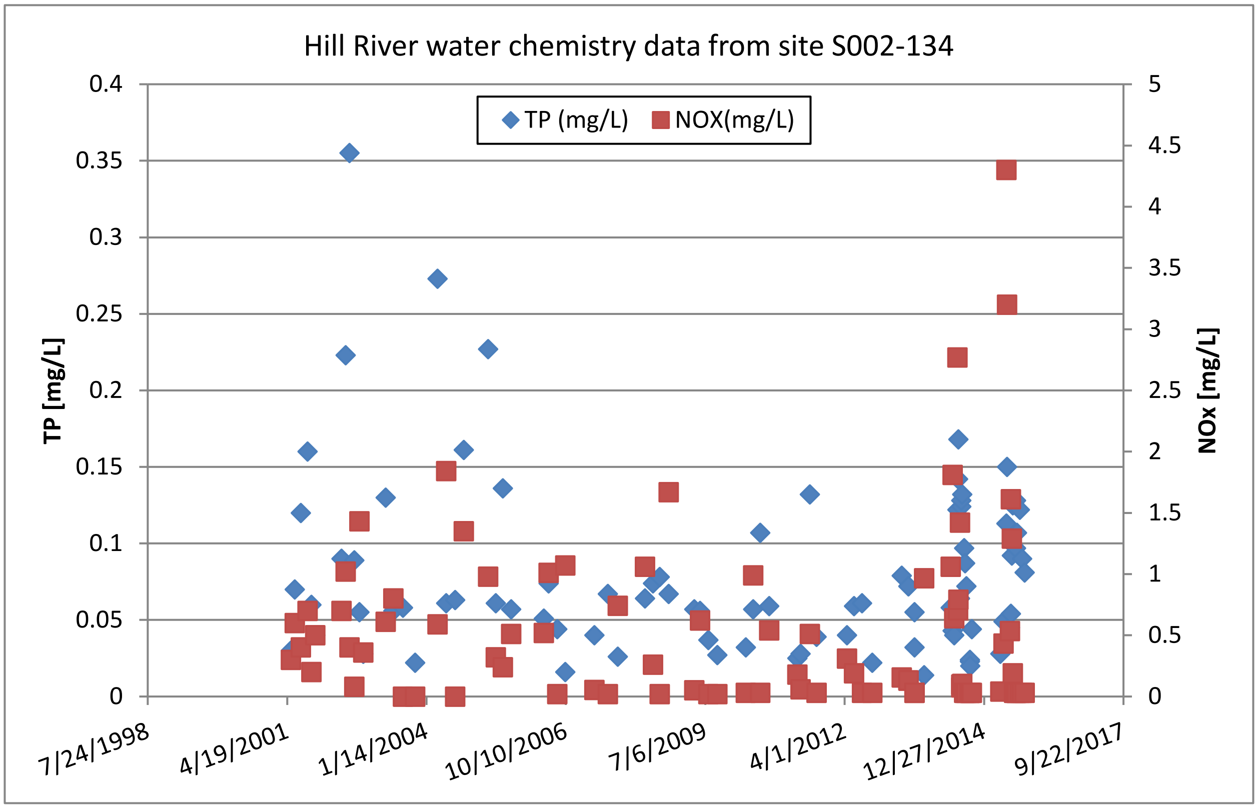


Figure 33: Water chemistry data at EQuIS site S002-134. Data shows elevated TP and nitrogen levels.

Nutrient samples from station S003-498, just upstream of biological site 05RD026, were collected in 2015 and 2016 (Figure 34). Although the average TP concentration was below the 0.100 mg/L standard, it was close at 0.090 mg/L. Also in 2016, five samples were analyzed for BOD (response variables to eutrophication) (Figure 34), and three of the five measurements did exceed the 2.0 mg/L standard, with two quite high measurements of 4 and 8 mg/L. Potential BOD sources (livestock and cultivated agricultural land) exist upstream of S003-498. More TP and DO flux monitoring should be done to conclusively determine if eutrophication is stressing the biological communities near station S003-498, which is suggested by biological samples from the nearest existing station, 05RD026.

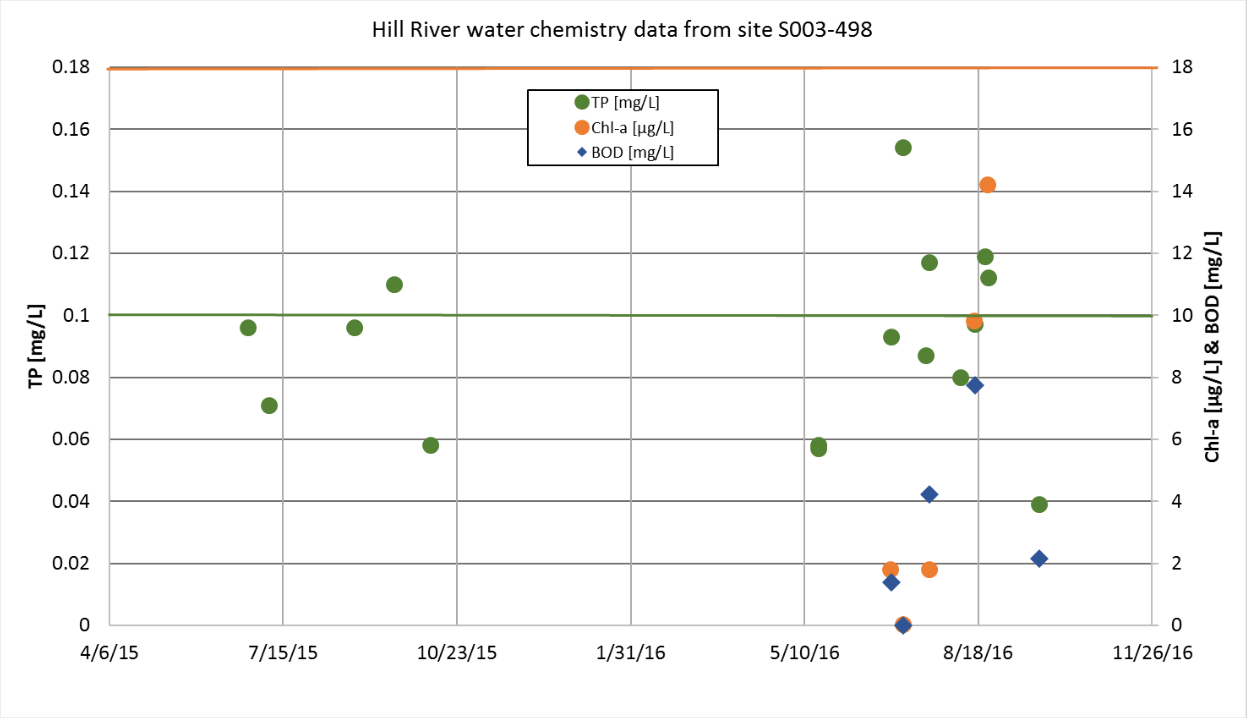


Figure 34: Data from EQuIS station S003-498, collected by the RLWD in 2015 and 2016. Standard concentrations are represented by the colored horizontal lines, colored to match its associated parameter. No Chl-a measurements exceeded the standard (18 µg/L).

The summer average NOx (nitrates and nitrites) concentration at the upstream sampling station, S003-498, was just 0.05 mg/L (2015-2016), which is far below the summer average of 0.49 mg/L (2006-2015) from samples collected at the sampling station near the downstream end of the reach, S002-134. The majority of NOx concentrations (8 out of 13 summer samples) from the upstream station, S003-498, were lower than the laboratory's minimum reporting limit. There is a significant amount of tile drainage in the Hill River and Lost River watersheds. Those two tributaries have higher summer average NOx concentrations (0.45 mg/Lin the Hill River and 0.74 mg/L in the Lost River) than neighboring tributaries of the Clearwater River (0.212 mg/L in the Poplar River) and the Clearwater itself (0.31 mg/L in AUID 511). NOx concentrations as high as 4.3 mg/L have been found in the Hill River. A tile drain within the Hill River watershed was monitored in 2005 and 2006 for the *Red Lake River Watershed Farm to Stream Tile Drainage Water Quality Study*. The average concentration of nitrates from the tile was 21.37 mg/L and the maximum concentration was 25.9 mg/L. The study also found that wetland environments could reduce nitrate concentrations through plant uptake and denitrification. Nitrate concentrations in wild rice paddy tile drainage were very low. IBI scores in the upstream portion of this AUID were low IBI scores despite low nitrate concentrations. The downstream portion of the AUID had high IBI scores despite having relatively high nitrate concentrations. While increasing nitrate concentrations due to increasing tile drainage is a water quality concern, it appears that the nitrate concentrations in the stream are not the cause of the biological impairments.

DO flux can be calculated from continuous DO records that were recorded in 2016 at S003-498 and 2015 at S002-134. The DO flux levels differed significantly between the two sites, but both sites exceeded the standard. The summer average DO flux at the upstream station, S003-498, was 5.55 mg/L. The summer average DO flux at the downstream station, S002-134, was 3.51 mg/L. DO flux is greater near the biological station that had the poorest IBI scores and the lower concentrations of nutrients. Differences in DO flux provide relevant information pertaining to the cause of the IBI impairment.

Low dissolved oxygen

Station S003-498 is just upstream of biological station 05RD026; revealing that as we move upstream toward station 05RD026, the fish samples and DO data suggest that low DO is likely becoming a stressor.

In 2015, five instantaneous DO readings were taken at station S003-498; all five were above the 5 mg/L standard. In 2016, the RLWD deployed a continuous DO sensor at this station from July 6 through August 22. During this deployment, 2,054 measurements were taken. The mean DO concentration was 4.49 mg/L, with a median concentration of 3.85 mg/L, and a range of 1.02-13.11 mg/L. Daily minimum DO concentrations fell below the 5 mg/L standard in all 46 of the 46 days in which a DO logger was deployed at the site. Data from this location on the Hill River does suggest that low DO is a stressor to both the fish and macroinvertebrate communities. The fish community at station 05RD026 indicates that the probability that this reach will meet the DO standard is 26% (Table 13). The macroinvertebrate data also support that low DO is a stressor at station 05RD026, where zero taxa were found that are intolerant to low DO, and nine were found that can tolerate low DO (Table 14).

Table 12: Analysis of AUID 539 fish community metrics to predict the probability of passing the TSS and DO water quality standards.

Station number	Probability of passing TSS standard	Probability of passing DO standard
14RD221	0.78	0.53
14RD253	0.82	0.68
05RD026	0.74	0.26

Table 13: Macroinvertebrate taxa metrics comparing the number of taxa that are intolerant and tolerant to a select group of stressors.

Station number	DO index	DO intolerant taxa	DO tolerant taxa	TSS index	TSS intolerant taxa	TSS tolerant taxa
14RD221	6.41	6	6	12	7	16
14RD253	7.11	17	2	4	5	7
05RD026	6.14	0	9	54	1	7

In 2015, continuous DO was collected from May 8 through September 24 at the far downstream station (S002-134) in the reach. During the deployment, there were no data points below the 5 mg/L standard, but 41.7% of the daily DO flux readings exceeded the 3.5 mg/L/day standard. In this reach of the Hill River, IBI scores are good where DO levels are good, and IBI scores are poor where DO levels are poor. Low DO and DO flux are not stressors in the lower section of this AUID; however, they are stressors at and upstream of site 05RD026.

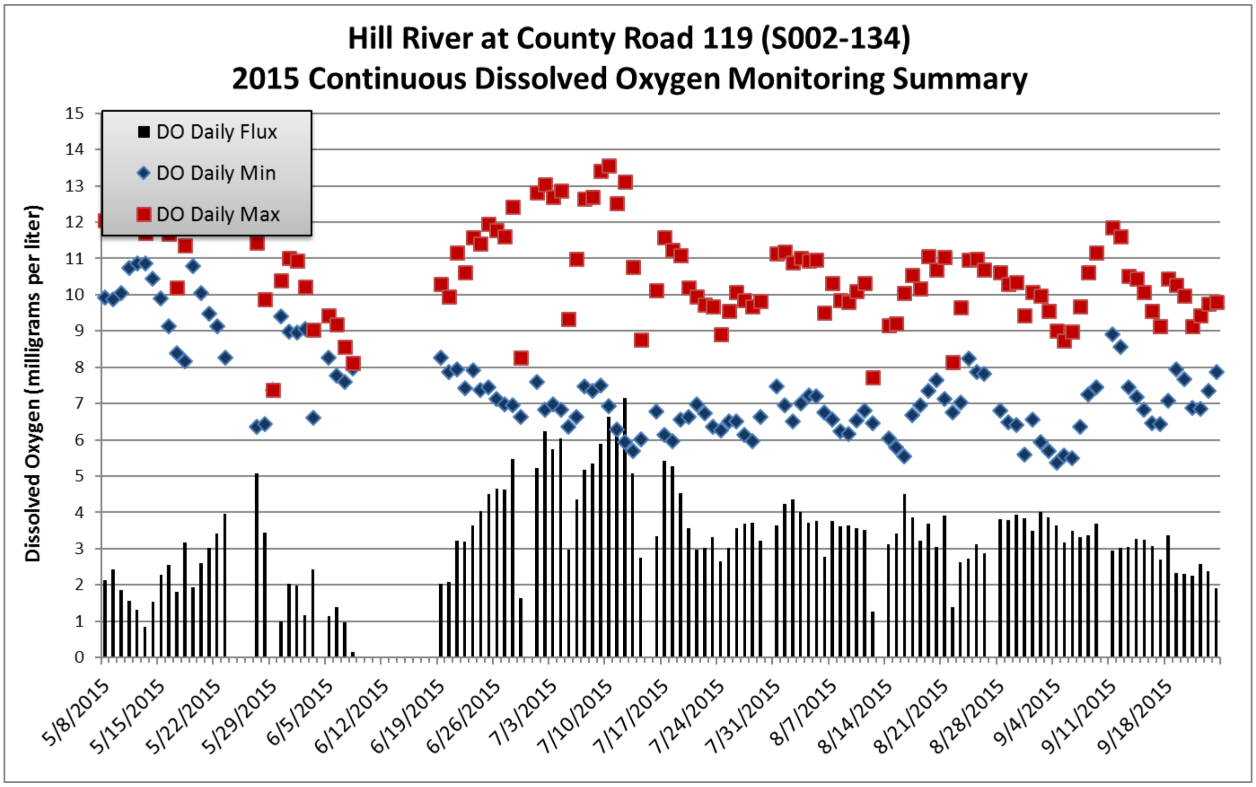


Figure 35: Continuous DO data with DO daily flux at site S002-134 which is located downstream on the Hill River near Brooks, Minnesota.

Low DO concentrations below the 5 mg/L standard are common in 2016 at site S003-498. The daily average minimum DO concentration during the 46-day deployment was 2.13 mg/L. The maximum daily minimum was 4.13 mg/L. For every day during the 2016 deployment, the daily minimum DO concentration was below the 5 mg/L standard. The daily flux of DO averaged 5.55 mg/L/day. This is above the central river DO flux concentration of 3.5 mg/L. The minimum daily flux was 2.03 and the maximum daily flux was 11.21 mg/L. The upstream portion of AUID 539 is being stressed by low DO concentrations and elevated daily DO flux swings. Of note, a series of beaver dams along the north-south section of the stream can be seen in aerial photos. There is a lower gradient along this section that may allow the beaver dams to influence longer reaches.

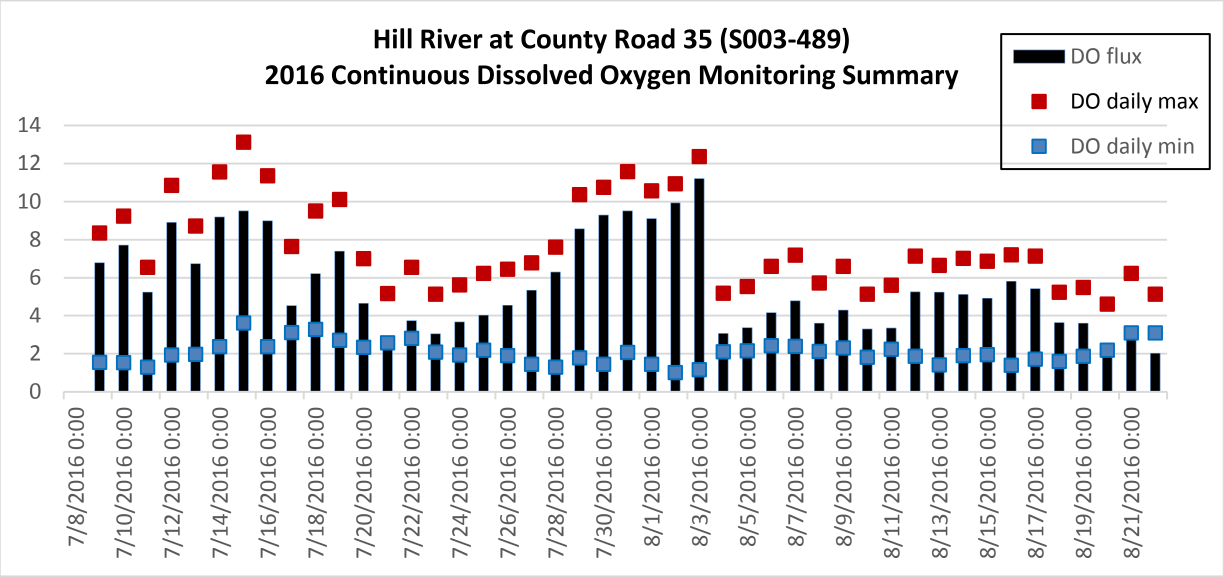


Figure 36: Dissolved oxygen daily maximum, minimum, and DO flux concentrations at site S003-489 collected in 2016.

Flow alterations

The hydrologic model (HSPF) results indicate that during the modeled time period (1996-2009), discharge in the Hill River is flashy and periods of extreme high and low flow occur. The model summary discharge statistics show a peak discharge of 1039 cfs, mean discharge of 44.7 cfs and a minimum discharge of 0.29 cfs. The record also reveals that the stream is below 5 cfs for 11% of the period and above 178 cfs (4x the mean discharge) for 4.5% of the record period. Overall, the available data suggest that the reach is prone to extended periods of minimal to no flow. The reach also rapidly reaches peak flow and quickly returns to low flow (Figure 38).

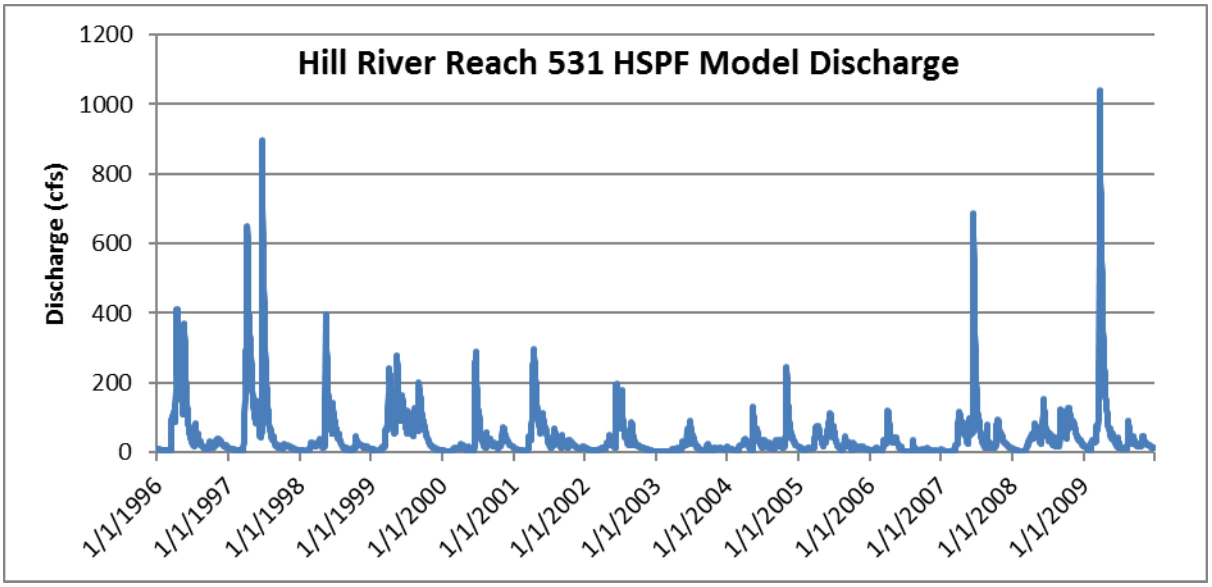


Figure 37: HSPF modeled daily discharge data for AUID 539 on the Hill River.

From 2012-2015, continuous discharge measurements of the Hill River on this AUID (539) were made generally from spring to late fall. These measurements were collected at EQuIS station S002-134, where the river crosses CR119. From this data, a total of 895 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was low (less than 1.0 cfs) and extremely low (less than 0.1 cfs). The results show that at this location on the Hill River, a discharge less than 1.0 cfs was measured for 21-31% of the record, and less than 0.1 cfs for 18-26% of the record. Flows at S002-134 during the July 2014 sampling effort ranged from 19 cfs to 45 cfs.

Biological response - fish

Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 539 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>72%) combined relative abundance of the three most abundant taxa at station 14RD253 (78%)
- Above average (>50%) relative abundance of individuals that are tolerant at station 14RD253 (79%)
- (Almost) above average (>17%) relative abundance of taxa that are pioneers at station 14RD253 (16%)
- Below average (<23%) relative abundance of taxa that are sensitive at station 14RD253 (15%)
- Below average (<9%) relative abundance of individuals that are insectivorous Cyprinids at stations 14RD221 (6%) and 14RD253 (0.2%)
- Below average (<20%) relative abundance of taxa that are insectivorous, excluding tolerant species at stations 14RD253 (15%)

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Review of the various fish metrics does show a strong correlation to flow alterations and the lack of fish assemblage at 14RD253 in the upstream portion of AUID 539. The three most dominant fish taxa sampled at 14RD253 on July 14, 2014 were blacknose dace, creek chub and white sucker. All three of these species are moderately tolerant to environmental disturbance. Flow alterations may be a stressor to the fish community, but it is inconclusive at this time.

Lack of connectivity

There are 24 stream crossings and many beaver dams that were identified using Google Earth aerial imagery from 2015. From site 14RD221 upstream to site 14RD253, nine fish species were lost, especially riverine obligates like the three redhorse species. Many barriers to fish passage were found between these sites, such as various debris jams and five beaver dams. Additionally, between sites 14RD253 (17.25% migratory species) and 05RD026 (4% migratory species), two more fish species were lost and at least four beaver dams were identified. Although the sample from site 05RD026 was sampled in 2006, some Google Earth imagery from 2006 and earlier suggests that there were potential beaver dam barriers affecting that fish sample.

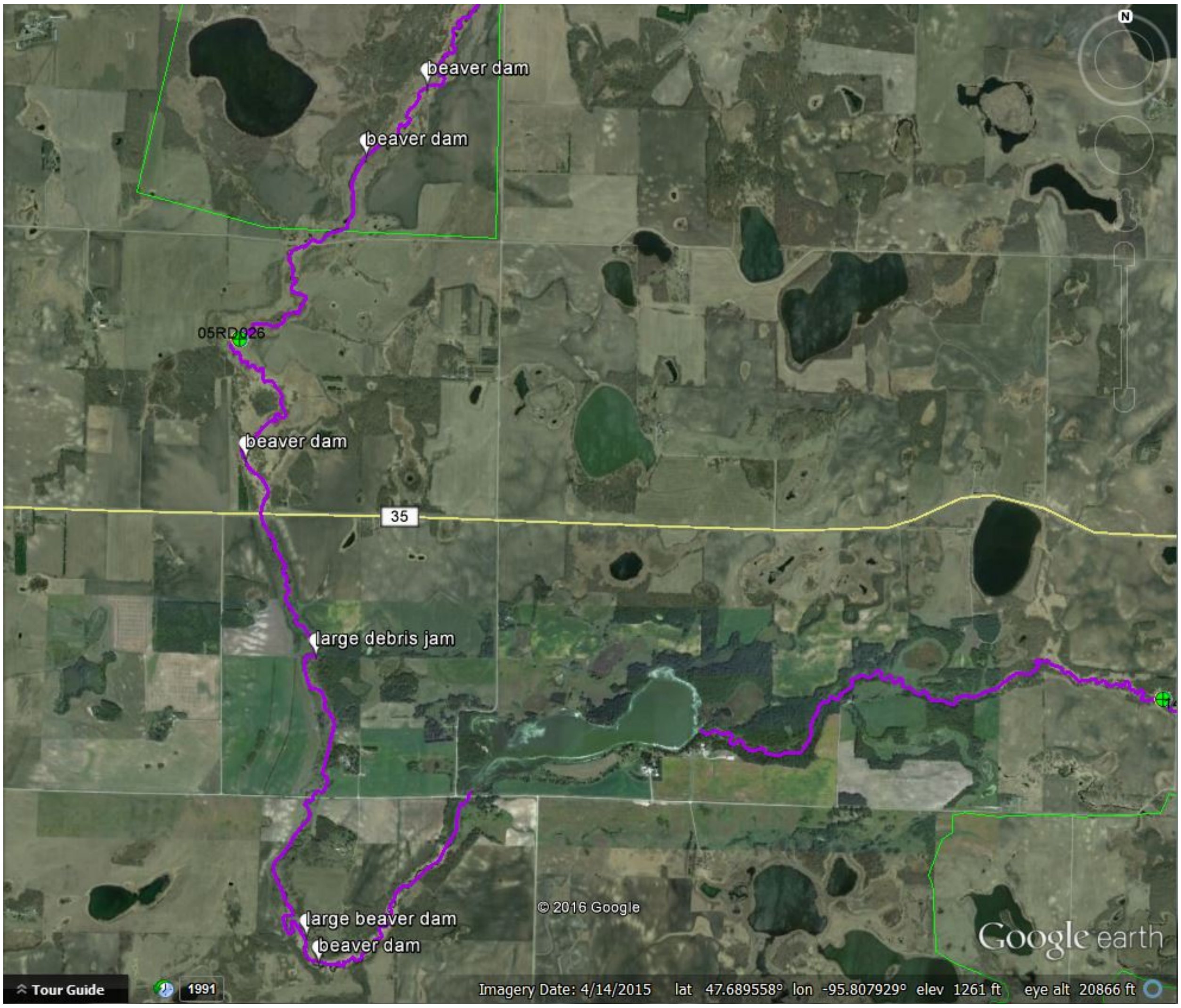


Figure 38: Some potential fish barriers between 05RD026 and Hill River Lake outlet.

Historically, there was a dam located on the outlet of Hill River Lake that was six feet high, and would have prevented fish from passing from AUID 539 to 656 (section of Hill River upstream of Hill River Lake), and based on anecdotal evidence, was the site of frequent yet minor fish kills. There have been three documented time periods of severe winter fish kills between the 1930's and 1990's in Hill River Lake. The dam was modified around 2007, yet more investigation is necessary to determine if the new culverts are a barrier to fish movement during various flow regimes.

Lack of habitat

MSHA scores were calculated twice for sites 14RD221 and 14RD253. The sites averaged a 62 and 61, which places them near the top of the "fair" category. Channel development scores were less than 50% of the possible score, indicating that there were some missing stream habitat features and stream velocity variability. Both sites were dominated by run and had less than 30% pool features. There were essentially no riffles documented at either site.

Photos taken during sampling events at 14RD253 (farthest upstream site) show a stream bed with large amounts of submerged macrophyte growth along with stable banks. The photos also indicate that the channel can access a floodplain and the width appears to be sufficient to transport any sediment through the reach. Eighty percent of the channel is run.

Station 14RD221 was dominated by a wooded riparian corridor that is shading the channel. There are far fewer submerged macrophytes growing in this reach, and the photos taken suggest that the channel is slightly incised. The substrate appears to be predominantly sand. This brought the MSHA score below 50% of maximum for this site. Overall, the MSHA score along with the associated response metrics from the biological community show that habitat is a limiting factor in this reach of the AUID and is stressing the biology.

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 539 is provided by the following individual F-IBI metric responses (Appendix A):

- Below average (<14%) relative abundance of individuals that are benthic insectivores at stations 14RD221 (10%) and 14RD253 (2%)
- Above average (>50%) relative abundance of individuals that are tolerant at station 14RD253 (79%)
- Above average (60%) relative abundance of the dominant two species of fish at station 14RD253 (61%)
- Below average (<15%) relative abundance of taxa that are Darter, sculpin, or round bodied suckers at station 14RD253 (7.7%)

4.5 Hill River (AUID 656) – nonsupport of fish/full support of macroinvertebrates

4.5.1 Physical setting

This reach represents an eight mile long segment of the Hill River from Unnamed creek downstream to Hill River Lake, approximately five miles northeast of McIntosh, Minnesota.

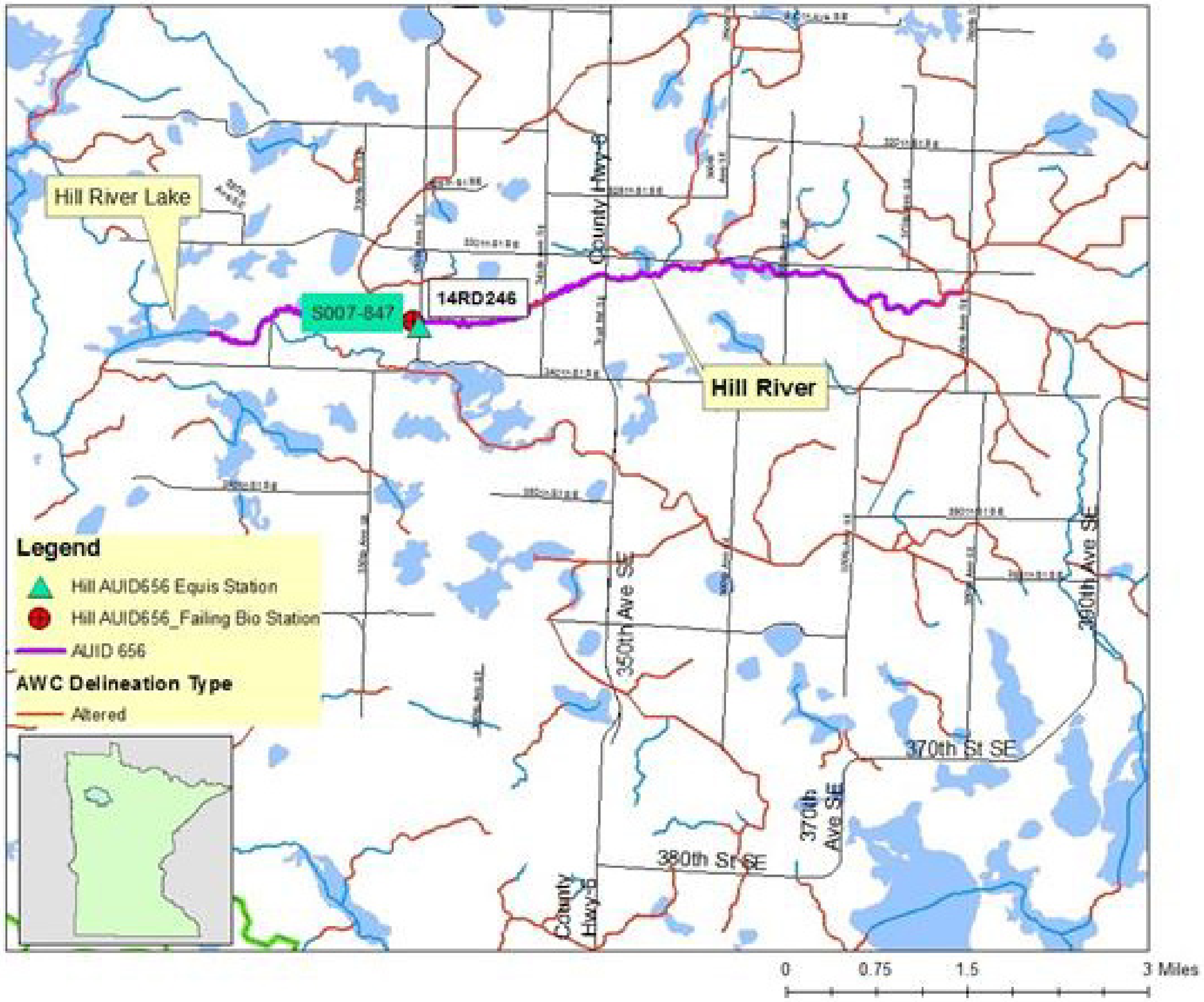


Figure 39: Location of AUID 656 (8 stream miles long) within the Hill River, and its associated monitoring stations. The map also shows the altered condition of adjacent waters.

4.5.2 Biological impairments

There is one biological monitoring station on AUID 656, station 14RD246, located in the lower third of the AUID reach, downstream of the 335th Avenue SE crossing. Station 14RD246 was sampled twice for fish (2014 and 2015) and once for macroinvertebrates (2014) (Table 15).

Both fish samples had low overall abundance of fish and many of the species collected were lake-oriented species, likely due to the site's proximity to Hill River Lake. The three main fish species sampled were black crappie, bluegill, and common shiner in 2014 sampling event. In 2015, the only four fish species sampled (8 individuals total) were bluegill (4), northern pike (1), central mud minnow (1), and johnny darter (2). In 2014, the macroinvertebrate community scored a 53.8 with a threshold of 43 for its class, so the score does pass the IBI, though the sample had a noteable quantity of *Simulium* (blackfly) species and other tolerant taxa.

Table 14. Results of MPCA biological monitoring on AUID 656, on the Hill River. Failing IBI scores are highlighted in red.

Station	Sample date	F-IBI (score/threshold)	M-IBI (score/threshold)
14RD246	6/10/2014	31/47	-
	7/30/2014	-	53.8/43
	7/14/2015	0/47	-

4.5.3 Candidate causes

Summary

Of the five stressors evaluated, the primary stressors identified in this AUID (656) of the Hill River are lack of connectivity, and likely low DO and daily DO flux (possibly due to elevated nutrient levels and/or natural drainage of wetlands). Lack of habitat due to lack of coarse substrate/sedimentation is also suspected as a stressor.

Elevated nutrients

Nutrient samples were collected in this AUID at EQuIS station S007-847, located where the river crosses 335th Avenue SE, near the biological station. Between 2014 and 2015, 21 stream samples were collected for TP, with measurements ranging from 0.032 to 0.200 mg/L (Figure 41). Seventy-one percent of the samples collected were above the TP eutrophication standard, which is 0.100 mg/L. The summer average TP concentration within the 2006-2015 assessment period was 0.148 mg/L, which exceeds the standard. On average, orthophosphorus (OP) has represented nearly 74% of the summer TP concentrations.

Six BOD samples were collected in 2015, one of which exceeded the 2.0 mg/L response variable standard for eutrophication. Also, DO flux was monitored at this station from May 1 through September 24 of 2015. Of the 147 DO flux readings collected, 46% exceeded the standard of 3.5 mg/L/day. Based on the TP and DO flux data, it is possible that elevated phosphorus levels are spurring excessive in-channel primary production; however, further investigation is needed to determine if this is occurring at a level that will stress the biota. Elevated TP levels could be due to recent/current phosphorus inputs to the stream, or could be driven by the release of OP under low DO conditions despite a lack of recent/current phosphorus inputs.

It is important to note that the Hill River upstream of this station does receive drainage from some wetlands, which can be naturally higher in phosphorus content than other types of land cover drainage. Additionally, the Lindberg Slough appears to have been partially drained, which would reduce the storage capacity of the wetland and negatively affect storage and base flow. During runoff events, the ditched channel would flush organic material from the wetland.

NOx was measured 21 times during 2014 and 2015. All sample concentrations were at or below the detection limit except the June 17, 2014 concentration, which was 1.29 mg/L (flow was relatively high). NOx is not a stressor to the biology in this reach.

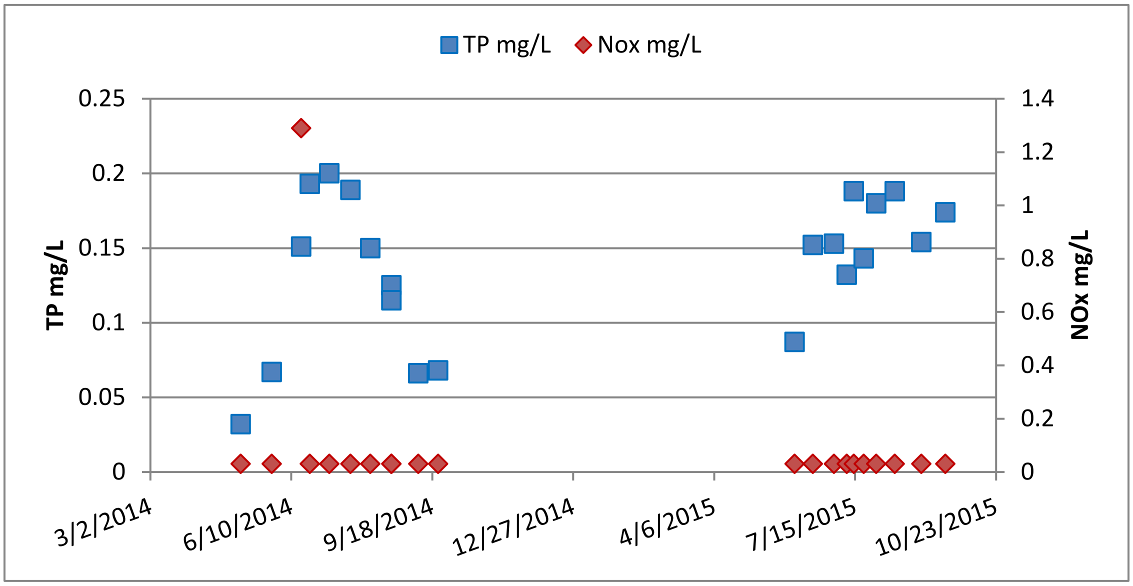


Figure 40: Water chemistry data collected from EQuIS station S007-847 on AUID 656 of the Hill River.

Low dissolved oxygen

At EQuIS station S007-847 there were 34 instantaneous DO readings collected in 2014 and 2015. One reading was below the 5 mg/L standard for Class 2B waters. Continuous DO was measured at this station by the Red Lake Watershed District from May 1 through September 24 of 2015 (Figure 42). A total of 147 days were measured; 29% had a daily minimum below the 5 mg/L standard. Overall, 27.7% of the May-September daily minimum DO concentrations from the 2006-2015 assessment period fell below 5 mg/l. Daily DO flux was also analyzed to determine if the flux exceeded the 3.5 mg/L standard. DO flux exceed the standard for 46% of the sampled record. Based on this information, it would appear that DO minimums may be a stressor, but the high DO flux is a greater concern.

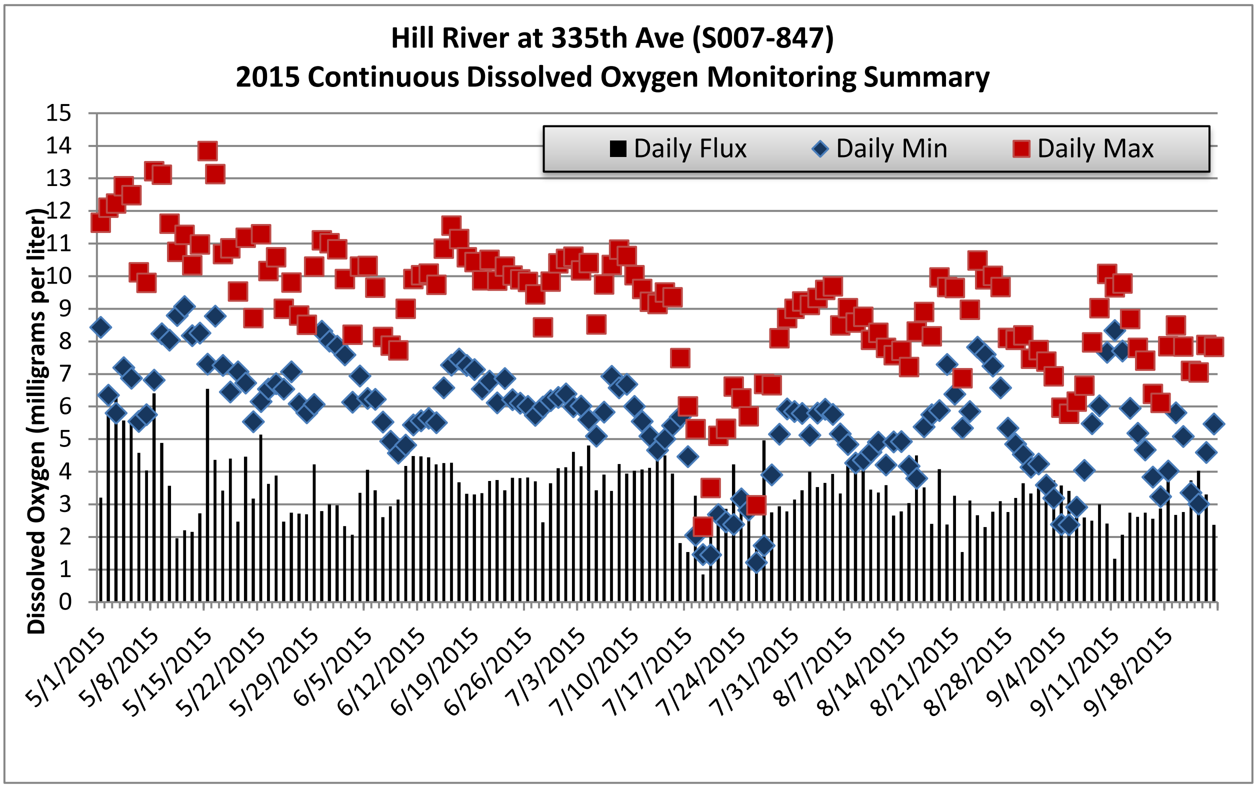


Figure 41: Continuous DO data collected by RLWD during the summer of 2014 at EQuIS station S007-847.

The fish community samples were analyzed using the tolerance indicator values developed by MPCA, which suggests that the probability this AUID will meet the DO standard is 36%, suggestive of a DO stressor (Table 16).

Table 15: Fish community tolerance metrics viewing the probability of passing the TSS and DO standards based on the fish community sampled at 14RD246.

Field Number	Sample date	Probability of passing TSS standard	Probability of passing DO standard
14RD246	6/10/2014	0.79	0.36
14RD246	7/14/2015	0.83	0.32

The macroinvertebrate sample scored a passing IBI value in this AUID, though the individual metrics can still be useful in an analysis of stressors. Site 14RD246 is a Class 6 Stream for macroinvertebrates. Table 17 shows the number of taxa that are both intolerant and tolerant to three main water quality stressors. However, the macroinvertebrates do not show a strong relationship to any of these three stressors, including low DO.

Table 16: Macroinvertebrate taxa metrics for a select number of potential stressors to the biological community in AUID 656.

Station number	Sample date	DO Index	DO Intolerant Taxa	DO Tolerant Taxa	TSS Index	TSS Intolerant Taxa	TSS Tolerant Taxa	Nitrogen Index	Nitrogen Intolerant Taxa	Nitrogen Tolerant Taxa
14RD246	7/30/2014	7.23	3	4	4	4	11	0.05	4	14

Flow alterations

The hydrologic model (HSPF) results indicate that during the modeled time period (1996-2009), discharge in this AUID of the Hill River is flashy and periods of extreme high and low flow occur. The model summary discharge statistics show a peak discharge of 915 cfs, mean discharge of 26.9 cfs, and a minimum discharge of 0.0 cfs. The record also shows that 22% of the time the stream is below 5 cfs, and 4% of the record shows discharge above 108 cfs, which is 4 times the mean discharge. Low flows of less than 1 cfs were also estimated to occur 3.2% of the record. Overall, the available data suggest that the reach is prone to extended periods of minimal to no flow, and has periods of high flow that occur rapidly and return to low flows quickly (Figure 43).

Photos taken during sampling events at 14RD246 on June 10, 2014 indicate that there were very high flows, evidenced by debris stuck in the branches of trees on the banks that were overhanging the stream channel (Figure 44). Other pictures from the sampling events also show bank erosion in the sampling reach (Figure 45). Portions of the Hill River have been channelized upstream of this reach. Wetlands, including some large basins, have been drained with ditches. The channelization and wetland drainage would increase flashiness and reduce base flow.

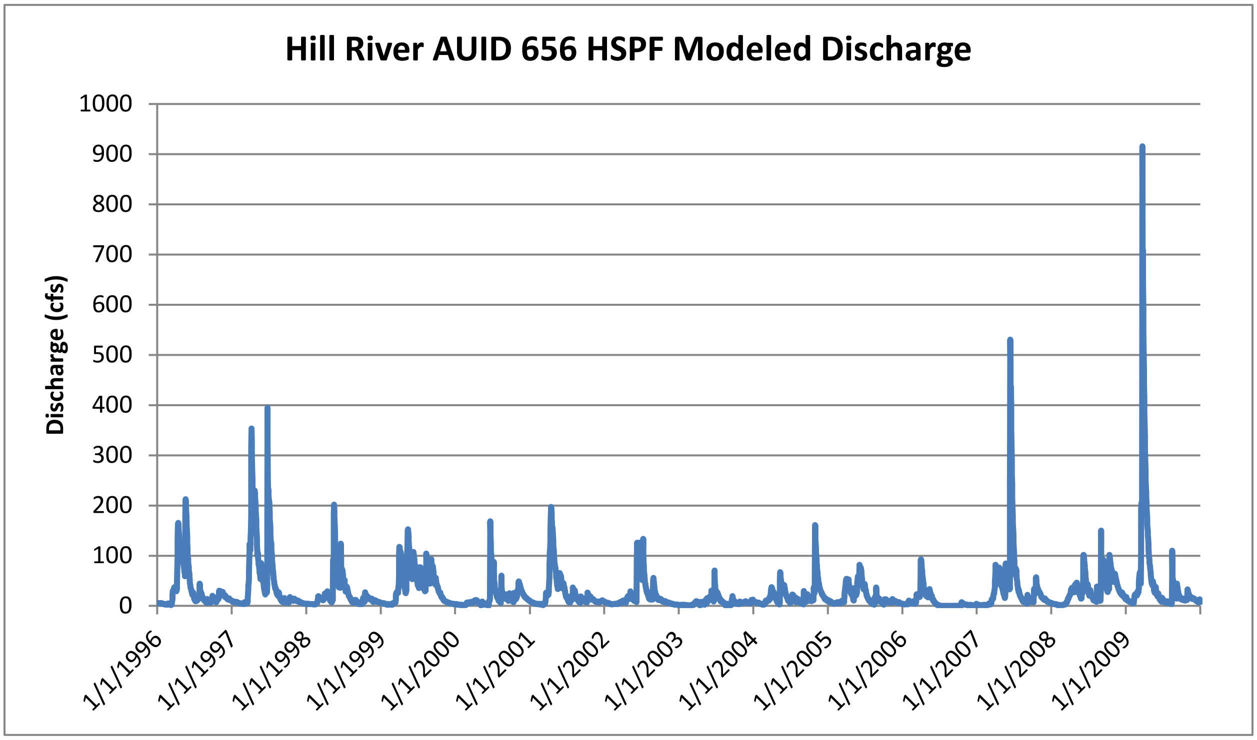


Figure 42: HSPF modeled daily discharge data for AUID 656 of the Hill River.

Figure 43: Pictures from biological station 14RD246, showing debris on trees well above the current water level. This shows the flashy nature of the flow regime. Pictures taken June 10, 2014.

Figure 44: Picture from biological station 14RD246, taken on June 10, 2015, showing bank erosion on the Hill River.

Biological response - fish

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Review of the various fish metrics does show a correlation to flow alterations and the lack of fish assemblage at 14RD246 in AUID 656. Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 656 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>72%) combined relative abundance of the three most abundant taxa at station 14RD246 in 2014 (75%) and 2015 (87%)
- Above average (>17%) relative abundance of taxa that are pioneers at station 14RD245 in 2015 (25%)
- Below average (<21%) relative abundance of taxa that are sensitive at station 14RD246 in 2014 (0%) and 2015 (0%)
- Below average (<8%) relative abundance of individuals that are insectivorous Cyprinids at station 14RD246 in 2014 (0%)
- Below average (<33%) relative abundance of taxa that are insectivorous-nontolerant at station 14RD246 in 2014 (28%) and 2015 (0%)

In 2016 (a relatively “wet” year for the area), continuous discharge measurements of the Hill River on this AUID (656) were made from March 22 to December 5. These measurements were collected at EQuIS station S007-847, where the river crosses 335th Avenue SE. From this data, a total of 259 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was low (less than 1.0 cfs) and extremely low (less than 0.1 cfs). The results show that at this location on the Hill River, a discharge less than 1.0 cfs was measured for 11-18% of the record, and less than 0.1 cfs for 3-8% of the record.

Lack of connectivity

Using 2015 Google Earth aerial imagery, no road crossings or beaver dams were identified between Hill River Lake and site 14RD246. Longitudinal connectivity does not appear to be a problem in the lower portion of this AUID. However, the fish population in this entire AUID is not connected to the rest of the Clearwater River system and may be suffering due to lack of sufficient refuges and spawning habitat.

At Station 14RD246, there was only one migratory fish sampled. The station located on the downstream side of Hill River Lake, station 14RD253 on AUID 539, had 109 migratory fish sampled. There is a lack of connectivity on the Hill River somewhere between station 14RD253 and station 14RD246, which also means a lack of connectivity between station 14RD246 and the rest of the Clearwater River system that is negatively affecting the F-IBI scores. One possible explanation are the beaver dams (Figure 39) identified above in Section 4.4.3 *Lack of Connectivity*, and the dam at the outlet of Hill River Lake.

Furthermore, upstream of station 14RD253, several active beaver dams were identified using 2015 Google Earth aerial imagery, as well as some through-stream crossings that may be blocking fish during low flows.

Lack of habitat

Stream habitat was measured using the MSHA, calculated three times for station 14RD246, once during each of the three biological sampling visits. The MSHA scores are: 67.2 (6/10/2014), 50.5 (7/30/2014), and 61 (7/14/2015), with an average of 59.5. The 59.5 average score places the habitat in the “fair” category, though substrate is a likely stressor at this site. Furthermore, if the riverbed upstream of this site is equally as unstable, even if fish can get past the beaver dams and other barriers to spawn, some species may be finding sufficient substrate.

The main areas of difference between the highest score of 67.2 (6/10/2014) and the lowest score of 50.5, assigned just seven weeks later, are found in the following categories: channel morphology (60% of the difference) and substrate (25% of the difference), specifically regarding substrate size and channel development. The crew in June noted the presence of a riffle with gravel size substrate whereas the crew in July noted zero riffles. In fact, the crew in July even noted the presence of silt in pools and runs whereas the June crew did not note any silt. Additionally, the crew in June rated channel development as “fair” (3 points) rather than “excellent” (9 points). Lastly, another notable difference between the analyses of the two crews in 2014 is that in June the crew noted some forest/wetland/prairie/shrub in addition to row crop in the surrounding land use, whereas the July crew noted only row crop, a 2.5-point difference.

The difference in substrate observed by the two crews of 2014 suggests that there is a moving streambed due to channel instability. The theory of a moving streambed is supported by the macroinvertebrate data sampled at this site on 7/30/2014. Of the total taxa found, 68% were filterers and 63.6% of the sample was made up of *Simulium* and *Polypedilum* species, which are tolerant organisms. Also, the crew noted that woody debris has replaced rock as the primary coarse substrate. Further evidence of channel instability is provided by pictures of severe bank erosion and frequent channel damage from the many livestock access points throughout the river.

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 656 is provided by the following individual F-IBI metric responses (Appendix A):

- Below average (<14%) relative abundance of individuals that are benthic insectivores at station 14RD246 in 2014 (10%), but not in 2015 (25%)
- Above average (60%) relative abundance of the dominant two species of fish at station 14RD246 in 2015 (65%) and 2015 (75%)
- Below average (<15%) relative abundance of taxa of Darter, sculpin, and round bodied suckers at station 14RD246 in 2014 (14%) but not in 2015 (25%)

The MSHA scores along with the associated response metrics from the biological community show that, overall, habitat is inconclusive as a biological stressor in this AUID, although substrate size is a concern. Pfankuch or other geomorphic assessments are recommended to determine if channel instability is causing a sediment supply issue.

4.6 Tributary to the Poplar River Diversion Ditch (AUID 561) – nonsupport of fish/no data for macroinvertebrates

4.6.1 Physical setting

This reach represents a segment of an unnamed, man-made ditch, which flows from Gerdin Lake to the Poplar River Diversion Ditch, which is also man-made. The site is located approximately 2.2 miles northeast of Erskine, Minnesota.

4.6.2 Biological impairments

The fish community of AUID 561 was monitored at station 14RD243. The first fish sample was taken on June 10, 2014 and scored an IBI of zero, which is 15 points below the threshold for this stream, which is a Class 7 Modified Use Stream. The site was visited again on August 5, 2014, and determined to have insufficient flow to sample fish or macroinvertebrates; macroinvertebrates have not been sampled from this AUID.

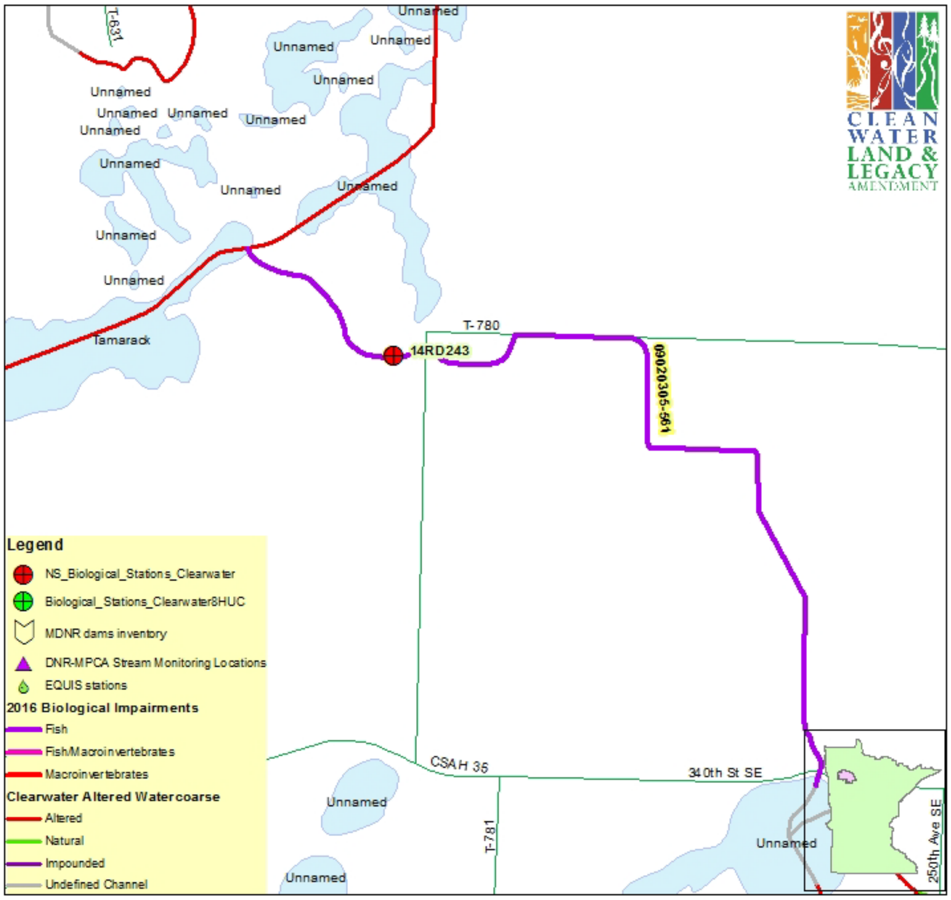


Figure 45: Location map for AUID 561 (Tributary to Poplar River Diversion) along with biological sampling location 14RD243.

4.6.3 Candidate causes

Elevated nutrients

Water samples were collected in 2016 by the RLWD to help quantify the concentrations of phosphorus and nitrogen in in this AUID. Seven water quality samples were collected in June through September of 2016 to evaluate the amount of total phosphorus and various nitrogen derivatives. EQuIS site S009-371 was established for the collection of water chemistry data and the deployment of a continuously recording DO meter to analyze the daily maximum; minimum and daily DO flux of the impaired reach. Table 15 below shows the results of the 2016 sampling at site S009-371. The average TP concentration during the sampling was 0.104 mg/L; this is slightly above the 0.100 mg/L standard for eutrophication. Daily DO flux is also considered during the eutrophication assessment. Based on the available data, it does not appear that eutrophication was stressing the biological communities in this ditch in 2016. However, there is a problem with low DO, and DO flux is exceptionally high, indicating a possibility of excessive plant or algal growth in the channel.

Nitrogen parameters were low during the 2016 sampling period, and nitrogen does not appear to be stressing the biological communities.

Table 17: Summary of 2016 water quality data collected at S009-371 on the Tributary to Poplar River Diversion Ditch.

EQuIS Station	Date	Tape-down	TP [mg/L]	OP [mg/L]	NH3 [mg/L]	TKN [mg/L]	NOx [mg/L]
S009-371	6/21/2016	3.71					
S009-371	6/29/2016	3.49	0.058	0.036	<0.04	0.366	<.03
S009-371	7/6/2016	3.46	0.052	0.027	<0.04	0.52	<.03
S009-371	7/7/2016	3.48					
S009-371	7/20/2016	2.45	0.101	0.074	<0.04	1.17	0.202
S009-371	7/21/2016	2.10	0.147	0.1	<0.04	1.28	0.569
S009-371	7/22/2016	2.08					
S009-371	8/8/2016	1.29	0.178	0.109	<0.04	1.64	<.03
S009-371	8/9/2016	1.31					
S009-371	8/17/2016	1.67	0.154	0.093	0.063	1.5	<.03
S009-371	8/22/2016	2.19	0.102	0.057	<0.04	1.38	<.03
S009-371	9/29/2016	2.53	0.046	0.022	0.065	1.18	0.054
mean			0.10475	0.06475	0.064	1.1295	0.275

Low dissolved oxygen

Continuous DO data was collected in 2016 by the RLWD from June 21 through August 22 at site S009-389. All data from August 4 through August 22 was below 1.9 mg/L of DO, and it appears that the probe was possibly either out of the water or malfunctioned during this period. This data was not analyzed due to this likely condition. The previous data from June 21 through August 4 appeared to operate correctly and is discussed below. A total of 2,033 records were analyzed, and the mean concentration during this period was 5.62 mg/L. The minimum during this time was 0.02 mg/L and the maximum was 21.72 mg/L. Average DO flux during this period was 10.29 mg/L, well above the 3.5 mg/L standard. Figure 46 graphically displays the continuous DO data collected during the 2016 deployment. The data shows that the daily DO minimums are well below the 5 mg/L standard and that low DO is a significant source of stress to the fish community in this AUID.

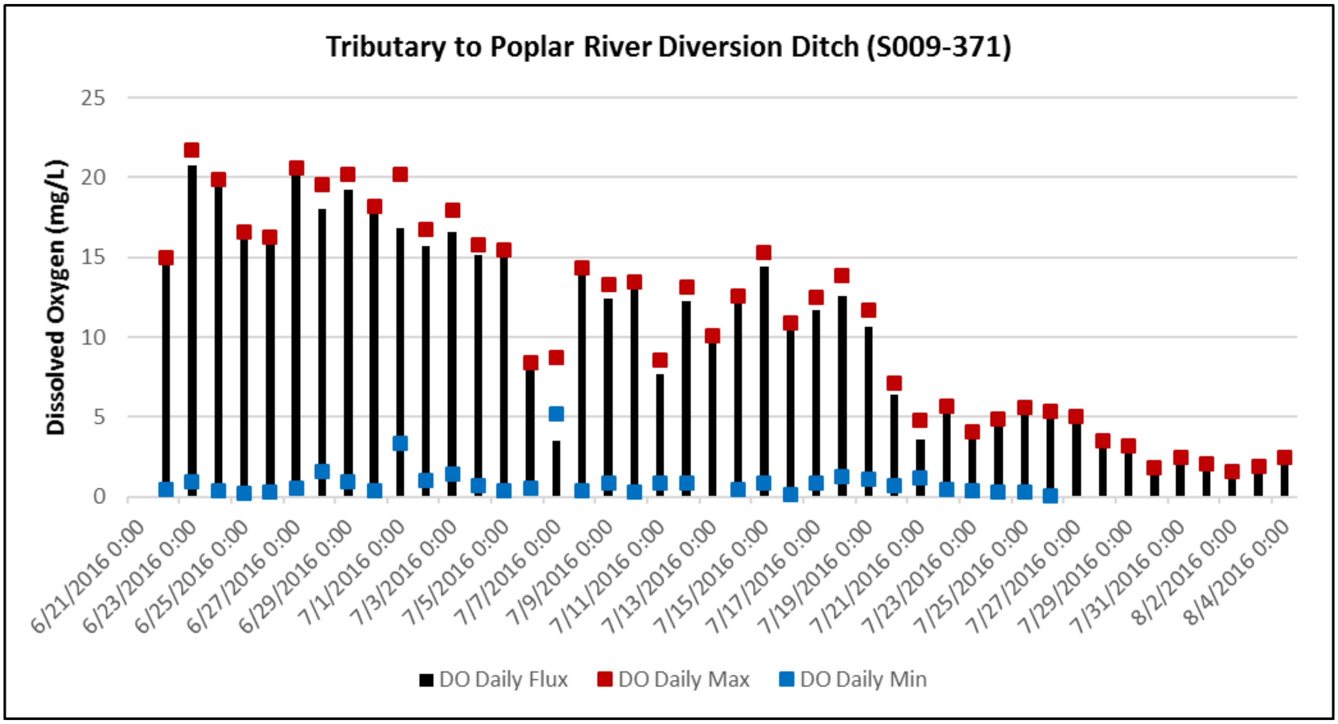


Figure 46: Continuous DO data collected by RLWD during 2016. Data shows the daily DO maximum, minimum, and DO flux from June 21 through August 4, 2016.

The sampled fish community also showed that there is a 96% chance of the DO standard not being met based on the fish captured (Table 16), using Tolerance Indicator Values. These two lines of evidence show that low DO is a stressor to the fish community when water is present. The only fish species sampled at 14RD243 were central mud minnows that are extremely tolerant to low DO concentrations.

Table 18: Probability of meeting the TSS and DO standards based on the fish community sampled based on Tolerance Indicator Values.

Field Number	Waterbody Name	Probability of passing TSS standard	Probability of passing DO standard
14RD243	Trib. to Poplar River Diversion Ditch	0.86	0.04

Flow alterations

Simulated 1996-2009 flow data for the Tributary to the Poplar River sub-basin from the Clearwater River HSPF model was analyzed to evaluate the flow regime and its possible effects on the biological communities. The results of the model show that the discharge in the Tributary to the Poplar River Diversion Ditch is flashy and there are periods of extreme high and low flows. The model summary discharge statistics for this subwatershed show a peak discharge of 296 cfs, mean discharge of 9.9 cfs and a minimum discharge of 0.03 cfs. The record also shows that 17% of the time the stream is below 1 cfs and 5.1% of the record shows discharge above 40 cfs, which is four times the mean discharge. Low flows of less than 5 cfs were estimated to occur 64% of the record. Overall, the available data suggest that the reach is prone to extended periods of minimal to no flow and periods of high flow that occur rapidly and return to low flows quickly (Figure 47). Low base flows will limit fish passage past barriers.

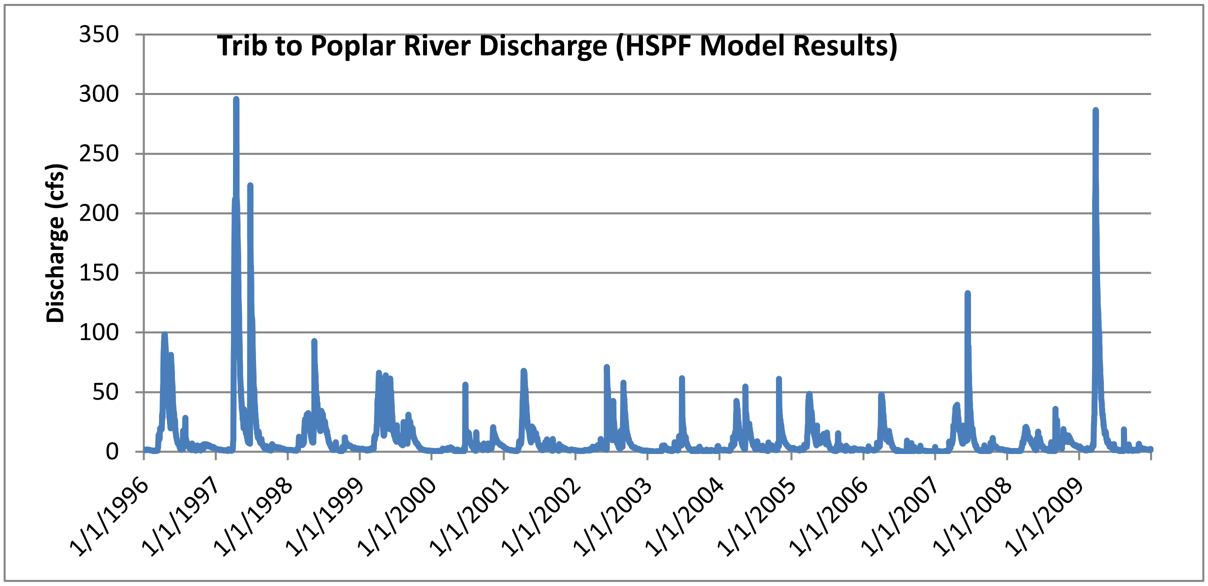


Figure 47: HSPF modeled daily discharge data for AUID 561 (Tributary to Poplar River Diversion Ditch).

Biological response - fish

Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 561 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>92%) combined relative abundance of the three most abundant taxa (DomThreePct) at Station 14RD243 (100%) (Only one taxon was sampled)
- Above average (>82%) relative abundance of individuals that are tolerant (TolPct) at Station 14RD243 (100%) (Sample only found central mud minnow, very tolerant)
- Below average (<18%) relative abundance of taxa that are sensitive (SensitiveTXPct) at Station 14RD243 (0%)

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Review of the various fish metrics does show a strong correlation to flow alterations and the lack of fish assemblage at 14RD243 in AUID 561. Also, the modeled hydrograph shows that 17% of the record shows flows that are near 0 cfs, which would eliminate any potential for fish survival.

Lack of connectivity

Relative abundance of migratory fish species is generally reviewed to determine if longitudinal connectivity is an issue in the AUID. If a barrier is present, often there will be a lack of migratory fish above the barrier. Site 14RD243 did not have any individual fish sampled that were migratory; the sample scored a zero and was also poor in all other aspects of the fish community. The only fish sampled were central mud minnow, which are tolerant to low DO, poor habitat, and can survive in extremely poor conditions. There is not enough information to determine if the wetlands downstream of this AUID are preventing fish from migrating up to AUID 561 or if the conditions are poor enough that fish are not migrating upstream.

Lack of habitat

Stream habitat is measured using the MSHA calculated score for each sampling location. Station 14RD243 was sampled for MSHA scores one time. The site scored a 28.5. This score was below the required score to assess the stream as General Use and placed the stream in the Modified Use category. It also places the habitat in the poor category even for a Modified Use stream. Channel development scores were less than 95% of the possible score indicating that there are some missing stream features and stream velocity was not variable within the reach. The site was dominated by run (100%). The photos also indicate that the reach is channelized and most photos show heavy algal and macrophyte growth within the channel. Substrate also scored very low as the channel substrate is dominated by fine sediments. Overall, the MSHA score along with the associated response metrics from the biological community show that lack of habitat is a stressor and a limited factor in this AUID to the fish community.

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 561 is provided by the following individual F-IBI metric responses (Appendix A):

- Below average (<2.4%) relative abundance of individuals that are benthic insectivores (BenInsectPct) at Station 14RD243 (0%)
- Above average (>82%) relative abundance of individuals that are tolerant (TolPct) at Station 14RD243 (100%)
- Above average (84%) relative abundance of the dominant two species of fish (DomTwoPct) at Station 14RD243 (100%)
- Below average (<4) relative abundance of taxa of Darter, sculpin, and round bodied suckers (DarterSculpSucTxPct) at Station 14RD243 (0%)

This site only had one species of fish sampled (central mud minnow).

4.7 Lost River (AUID 645) - nonsupport of fish/full support of macroinvertebrates

4.7.1 Physical setting

The Lost River begins at the outlet of Anderson Lake (northwest of Clearbrook, Minnesota) and flows northwest, meeting up with the Hill and Poplar Rivers just before it enters to the Clearwater River near Terrebonne, Minnesota. AUID 645 represents a segment (12.27 stream miles) of the Lost River just north of Gully, Minnesota that runs from Anderson Lake to Unnamed Creek, where the river crosses 270th Street SE. AUID 645 is an entirely altered watercourse, mostly channelized for drainage.

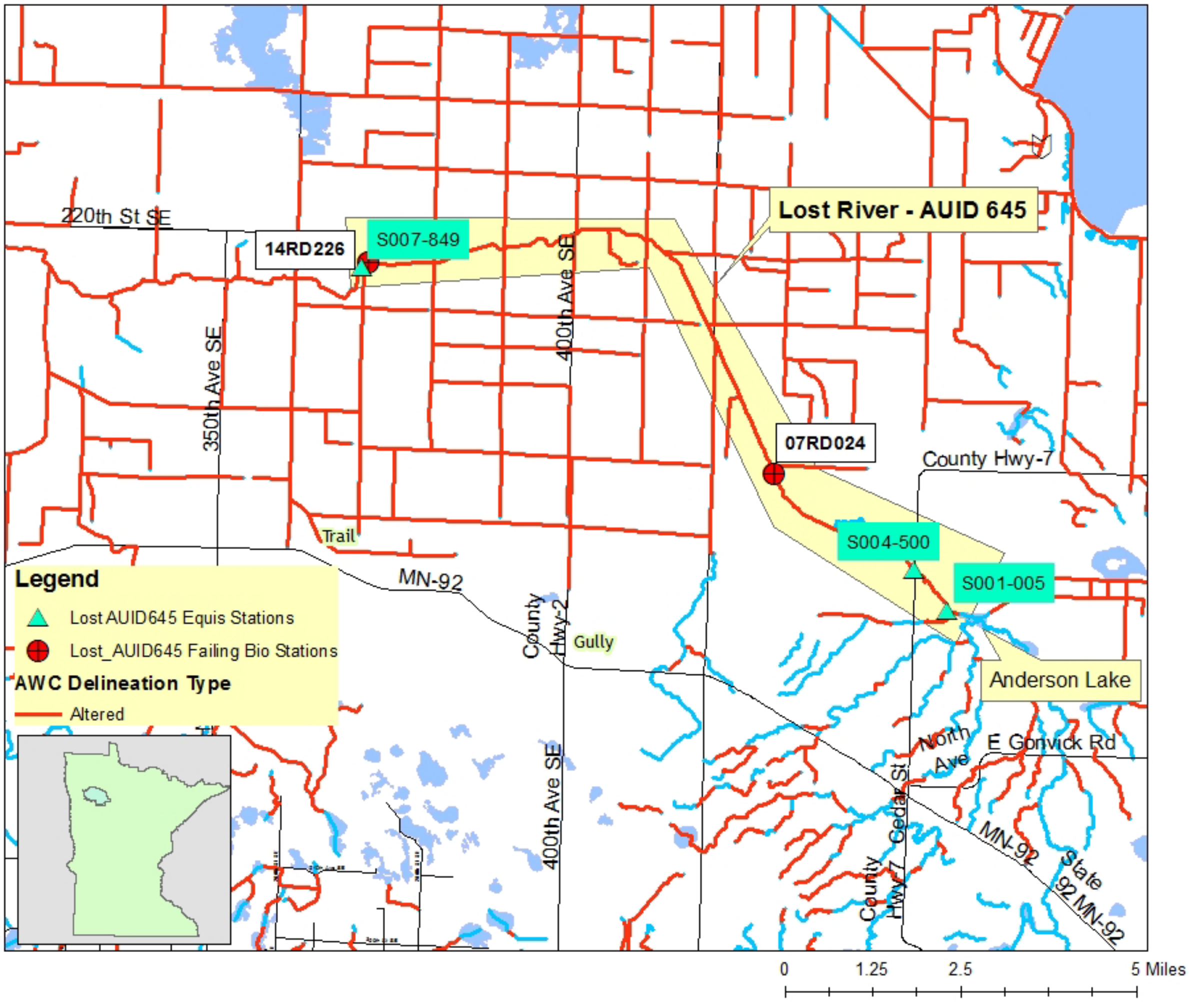


Figure 48: Location of AUID 645 (12.27 stream miles long) within the Lost River, and its associated monitoring stations. Because the entire length of AUID 645 is altered, the stream itself is represented with a red line like the other altered watercourses, so the AUID 645 reach location is highlighted by the tan polygon, starting at Anderson Lake and flowing northwest to site 14RD226. The map also shows the altered condition of adjacent waters.

4.7.2 Biological impairments

The fish community of AUID 645 was monitored at stations 14RD226 and 07RD024, and macroinvertebrates were monitored only at 07RD024.

Table 19: Results of MPCA biological monitoring on AUID 656, on the Hill River. Failing IBI scores are highlighted in red.

Station	Sample date	F-IBI (score/threshold)	M-IBI (score/threshold)
14RD226	8/10/2015	33/47	-
07RD024	8/8/2007	28/47	-
	8/14/2007	-	57.5/41 & 66/41
	7/8/2014	44/47	-
	7/29/2014	-	45.7/41

During the fish sampling of site 14RD226 on August 10, 2014, the field crew noted that a large beaver dam was located downstream of this site (just upstream of the CSAH 28 bridge) during sampling which may have partially been acting as a fish barrier. The macroinvertebrate community was not sampled during the August 26, 2014 visit because of the impacts of the downstream beaver impoundment at site 14RD226 (Figure 50).

Figure 49: Beaver impoundment at site 14RD226 photographed on 8/10/2014 (left) and again on 8/18/2014 (right). This dam may have been prohibiting some fish passage as well as diminishing flows that could then trigger a decrease in DO.

Macroinvertebrates were sampled three times at 07RD024, with two on the same day. The first sampling visit occurred on August 14, 2007 and scored a 57.5. The second event occurred the same day and scored a 66. The water was shallower during the 2007 sampling events, and dense algal growth is pictured in the channel (Figure 51).

Figure 50: Left - dense algal growth at station 07RD024 on 8/14/2007. Right – Same station (07RD024) on 4/10/2015, showing disturbed unstable stream banks.

However, the results suggest that this was not a stressor to the macroinvertebrate community sampled that day. The third macroinvertebrate sampling visit was on July 29, 2014, and scored a 45.7. The macroinvertebrate community shows full support for this AUID, though the 2014 IBI score decreased considerably (~26%) since 2007.

4.7.3 Candidate causes

Summary

Of the five stressors analyzed for AUID 645, the primary stressors found were low DO/high DO flux, flow alterations (causing lack of baseflow and driving low DO – e.g. stagnant water upstream of CSAH 28), and lack of habitat. Lack of connectivity was deemed inconclusive.

Elevated nutrients

Nutrient samples were collected at site S007-849 (co-located with station 14RD226) in 2014 and 2015 to evaluate the level of eutrophication occurring at the downstream end of the AUID. All but two of the TP samples collected were below the 0.10 mg/L standard (Figure 46). The summer average TP concentration was 0.068 mg/L. The nitrogen data also was below a concentration that would affect the biological community. The two highest NOx concentrations were 0.85 mg/L collected in June and September of 2014. River eutrophication is not a stressor to biology at this location, near 14RD226.

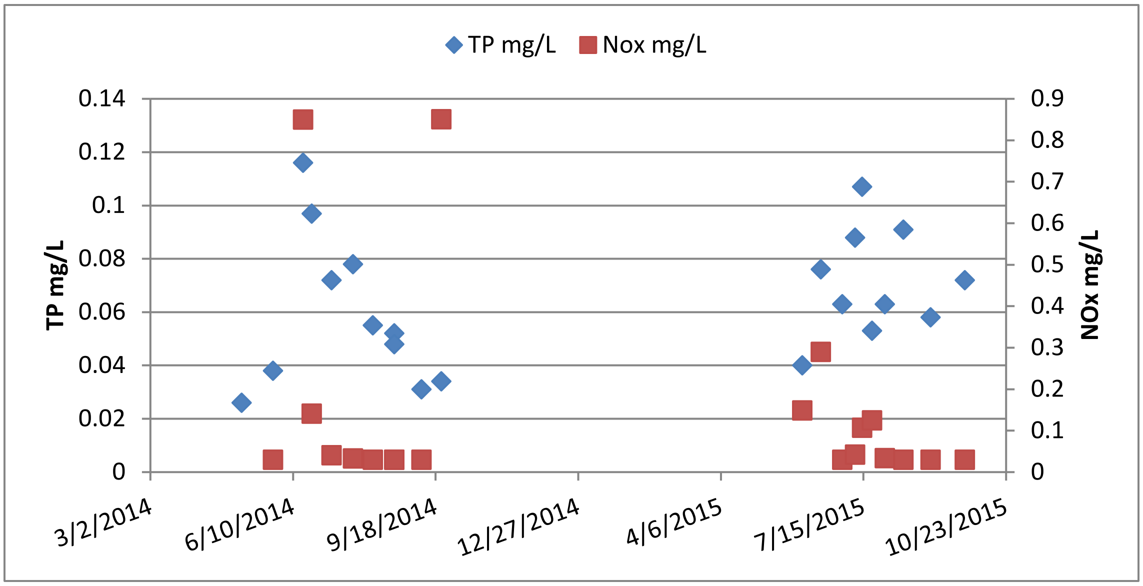


Figure 51: Water quality sample data from S007-849 on the downstream end of AUID 645 on Lost River. Nutrients samples included total phosphorus and nitrate-nitrite (NOx).

However, photos taken during the site sampling events for biology indicate that river eutrophication is occurring in this AUID near station 07RD026. In 2007, the modeled peak discharge was lower than the 2014 peak discharge and mean daily discharge was lower in 2007, which may explain the elevated periphyton growth in the channel during the 2007 sampling event. The stream is experiencing excessive growth of periphyton at site 07RD024 (Figure 53). Although, the photo taken during the July 29, 2014 sampling event at the same location does not document extensive periphyton growth, it was taken shortly after a major rain event that could have scoured and washed any periphyton downstream.

The RLWD collected limited discharge data in 2014 at the downstream end of the AUID, near S007-849. On June 17, 2014, the discharge was 2,332 cfs. During the July 29, 2014 sampling event, discharge was 146 cfs. Discharge remained above 100 cfs for the remainder of the 2014-monitored period, which ended on September 21, 2014. The 2007 sampling event occurred under a lower summer flow regime that in 2014. The sample was collected when flow was 19 cfs and the July flow in 2007 averaged 22 cfs. Thus, conditions were more favorable in 2007 for periphyton growth.

Figure 52: Site 07RD026. Photo on left is from the August 8, 2007 sampling event and photo on the right is same station on July 29, 2014. Both photos are located in middle of reach looking upstream.

Low dissolved oxygen

Dissolved oxygen was collected during site visits in 2014 and 2015 at EQuIS station S007-849. Numerous readings were below the 5 mg/L DO standard (Figure 48). Early morning is typical of the daily minimum DO values. Most instantaneous DO readings were collected in mid-morning to mid-afternoon after the daily minimum has occurred for DO, which skews the dataset to show some of the highest of the daily DO concentrations.

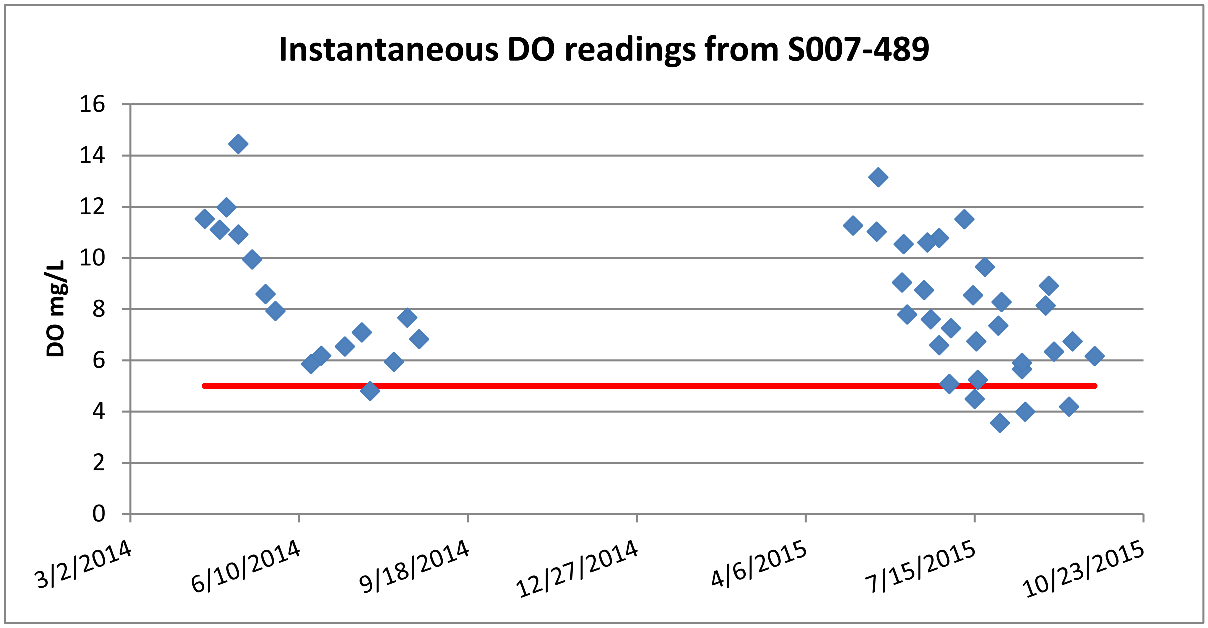


Figure 53: Instantaneous DO data collected at site S007-849 near the downstream end of AUID 645 on Lost River. The red line highlights the 5.0 mg/L minimum DO standard.

In 2015, continuous DO data was collected by the RLWD using a sonde deployed at S007-849, which is located near 14RD226 (Figure 55). The sonde was deployed from May 4 through September 24 (126 days). The DO fell below the 5 mg/L standard for 54% of the daily minimums and the DO flux exceeded the 3.5 mg/L standard 62% of the days sampled (4.67 mg/L summer average). With the high daily DO flux any increase in phosphorus, concentrations above the 0.100 mg/L standard would cause an even greater potential for periphyton growth. This reach of the Lost River should be monitored for phosphorus in the future and phosphorus export bmp's (best management practices) should be investigated to minimize phosphorus export.

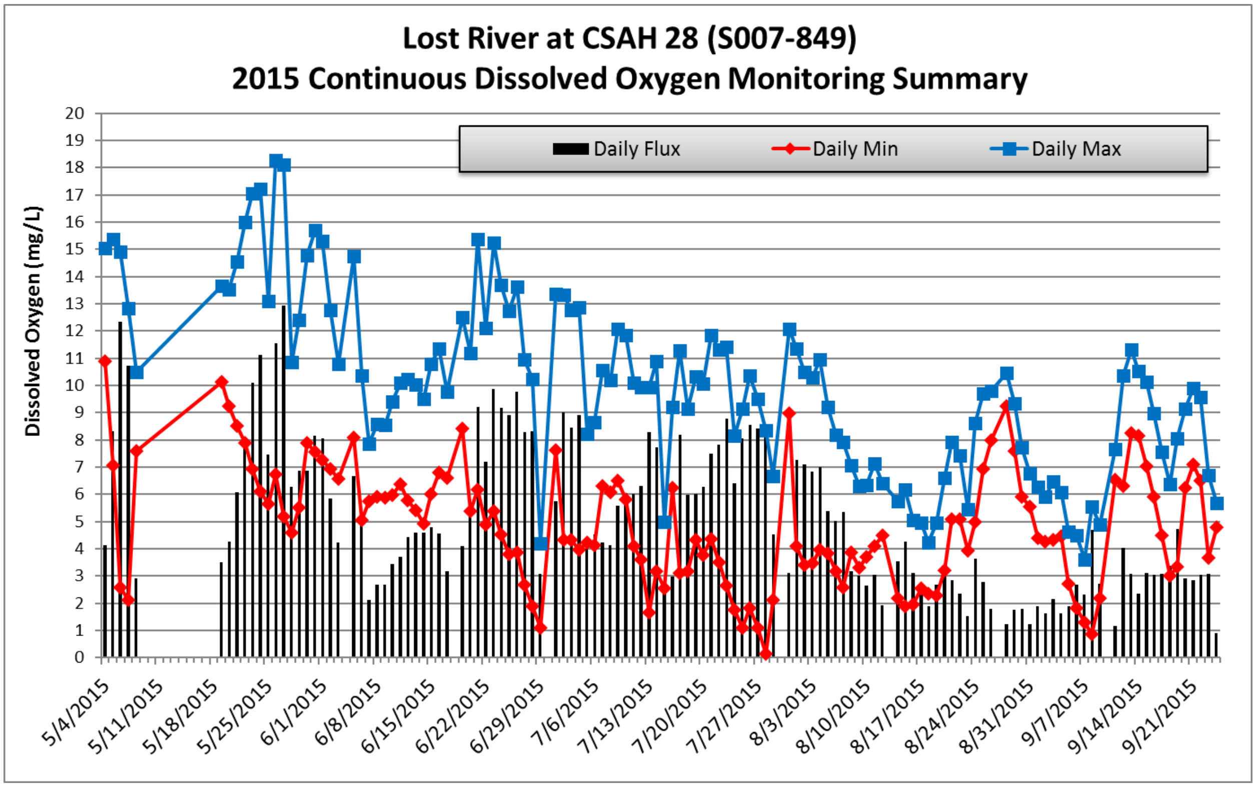


Figure 54: Continuous DO data collected by RLWD from May through September of 2015. The 5.0 mg/L DO standard is highlighted by the red horizontal line. The 3.5 mg/L/day DO flux standard is highlighted by the orange horizontal line.

Nine applicable DO measurements were available for station S004-500 at the CSAH 7 crossing near the upstream end of the AUID. The minimum DO reading from that site was 5.75 mg/L; zero of the nine measurements failed to meet the DO standard. Additional continuous DO monitoring is recommended for the upper portions of the reach and areas where flow is not stagnant. At the CSAH 28 Bridge, which is downstream of station 07RD027, the water flows over a rock structure underneath the bridge, and then flows through a cross-vein weir (Figure 56). The poorest scores for fish occurred within the ponded area upstream of CSAH 28.

Figure 55: View upstream (left photo) and downstream (right photo) of the Lost River at CSAH 28 (S007-849).

The fish and macroinvertebrate TIV scores (MPCA 2012) were analyzed to estimate the probability that this AUID would meet the DO or TSS standards (Table 18).

Table 20: Probability of AUID 645 passing the TSS and DO standard based on the sampled fish community. Values of concern are highlighted in red (strong relationship) and orange (relationship possible).

Field Number	Waterbody Name	Probability of passing TSS standard	Probability of passing DO standard
14RD226	Lost River	0.46	0.19
07RD024	Lost River	0.82	0.35
07RD024	Lost River	0.83	0.48

Generally speaking, if a site has a probability of passing a standard that falls below 30%, there is very likely a relationship between that stressor and the observed community. If a site has a passing probability above 70%, there is a good chance that the stressor is negligible. Based on the data from station 14RD226 and even 07RD024, there is a strong relationship with low DO concentrations and the fish community.

Although the macroinvertebrate samples did not yield a failing IBI score, reviewing the sampled community data can help explain stressors on the fish community, and possibly those not detected by the IBI metrics. Table 19 below shows some select macroinvertebrate metrics against averages from other samples of the same "class" (Class 7).

Table 21: Macroinvertebrate data showing select taxa metrics related to three main stressors to biology.

	DO intolerant taxa	DO tolerant taxa	TSS intolerant taxa	TSS tolerant taxa	Nitrogen intolerant taxa	Nitrogen tolerant taxa
07RD024	2	9	3	16	5	19
07RD024	2	12	3	17	5	21
07RD024	3	3	4	7	6	13

Based on the fish and macroinvertebrate community TIV scores and the low DO readings, low DO is a stressor to the fish community, and high daily DO flux needs to be investigated.

Additionally, six BOD samples were taken at S007-849 in 2015, the average of which (1.93 mg/L) was approaching the 2.0 mg/L standard. Although the available TP data does not violate any standards, the dense periphyton growth documented in 2007 and excessive DO flux documented in 2016 suggests that eutrophication is occurring and may be a driver of the DO stressor. A lack of riparian shading can induce eutrophication even with relatively low TP concentrations.

Flow alterations

The entire AUID and all of the tributaries to the AUID are channelized. This channelization will alter the rate and timing of the water delivery during precipitation events. Runoff will enter and move through the system quicker with the channelization. Base flow will be diminished during periods of little precipitation.

The HSPF modeled results (developed for a period from 1996-2009, ran on hourly time step) show that discharge in the Lost River is flashy and there are periods of extreme high and low flows. The model summary discharge statistics show a peak discharge of 1,343 cfs, mean discharge of 46.3 cfs, and a minimum discharge of 0.8 cfs. The record also shows that 8% of the time the stream is below 5 cfs and 4.8% of the record shows discharge above 184 cfs, which is four times the mean discharge. Low flows of less than 1 cfs were also estimated to occur 0.09% of the record. Overall, the available data suggest that the reach is prone to extended periods of minimal flow and has periods of high flow that occur rapidly and return to low flows quickly (Figure 50).

The RLWD collected stream discharge data for portions of 2014 through 2016. In 2014, the average daily discharge was 103 cfs. In contrast, 2015 averaged 27 cfs and 2016 averaged 23.5 cfs. Daily discharge data collected in 2014 covered 126 days, and ran continuously from July 16 through November 13. The daily discharge record for 2015 runs from March 13 through November 25, and in 2016 the discharge record runs from March 22 through December 5. The data shows that 2014 was a much wetter year than 2015 and 2016 and peak recorded daily discharge in 2014 was 10 times higher than peak recorded discharge in 2015 and 2016.

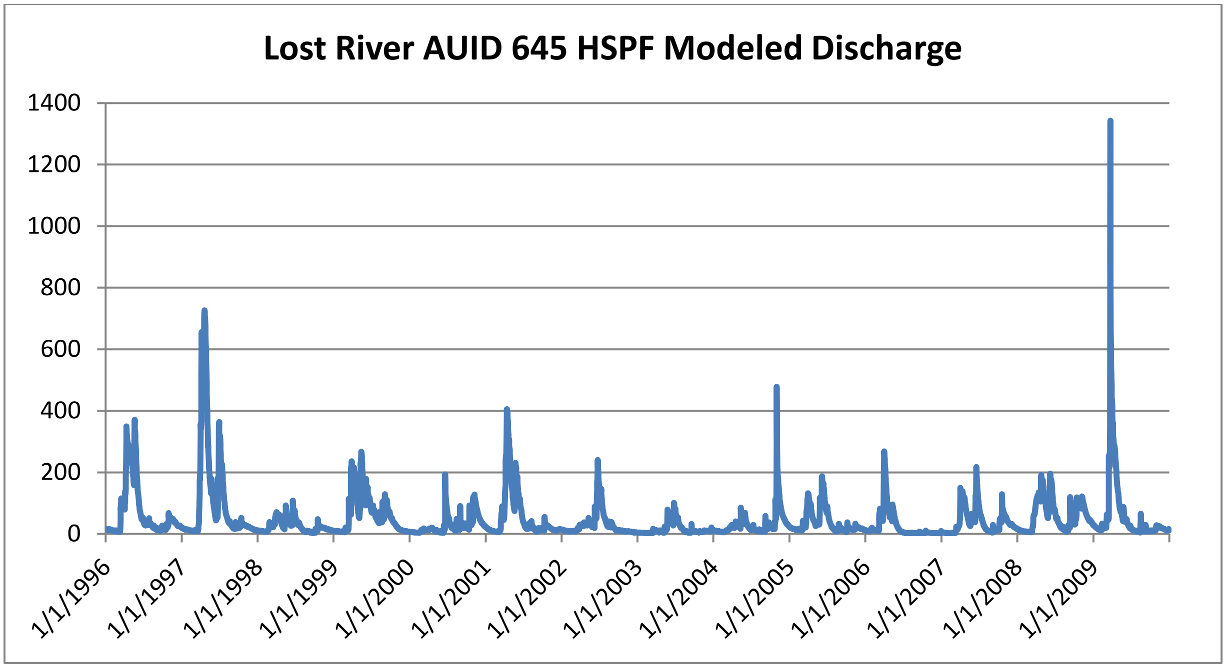


Figure 56: HSPF modeled daily discharge data for AUID 645 of the Lost River.

Biological response - fish

Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 645 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>72%) combined relative abundance of the three most abundant taxa at stations 14RD226 (89%) and 07RD024 (76%)
- Above average (>50%) relative abundance of individuals that are tolerant at station 14RD226 (53%)
- Above average (>17%) relative abundance of taxa that are pioneers at stations 14RD226 (20%) and 07RD024 in 2007 (17%) and 2014 (16%)
- Below average (<21%) relative abundance of taxa that are sensitive at station 07RD024 in 2007 (11%) and 2014 (21%)
- Below average (<8%) relative abundance of individuals that are insectivorous Cyprinids at stations 14RD226 (2%) and 07RD024 (2%)

Review of the various fish metrics does show a correlation to flow alterations and the lack of fish assemblage at 14RD226 in the upstream portion of AUID 645. Lack of baseflow is a stressor to the fish community in AUID 645.

Lack of connectivity

A visual inspection of the stream's connectivity was conducted using Google Earth (4/14/2015 imagery). Six beaver dams and one through-stream fence were identified in AUID 645. The longitudinal connectivity is diminished in this reach by these barriers. Not all beaver dams are impediments to fish movement; however, the aerial interpretation showed that the existing dams are large enough and numerous enough to partially block fish passage. Figure 51 below shows the through-stream fence that appears to be a significant fish passage barrier.

The entire AUID is channelized, which also poses a fish passage barrier during high flow. When spring snowmelt or heavy rains occur, there is little flow velocity refuge for fish, so the high velocity and lack of in-stream habitat variability can cause the fish to be blown out of the stream channel and forced downstream.

Figure 57: Fence across Lost River on AUID 645. It appears that debris may be piling up here, and that this is a significant barrier to fish passage. Picture from Google Earth imagery on 4/14/2015.

The sampled fish community at station 07RD024 shows that migratory fish individuals make up 9% of the sample. This is an increase from the downstream AUID 646 where station 14RD225 has only 4% of the fish individuals were migratory. The evidence in this AUID is inconclusive as to whether barriers are affecting the fish community.

Lack of habitat

Habitat in AUID 645 was analyzed using the MSHA once at station 14RD226 (47.5) and three times at station 07RD024 (low = 42, high = 54.5, and average = 50.3). Both sites scored near the bottom of the fair category and have very low channel development and instream cover scores. The land use scores were also low as the riparian land use is predominantly row crop. Channel development scores were less than 60% of the possible score, indicating that there are some missing stream features and stream velocity was not variable within the reach. The site was dominated by run habitat (80-100%). The photos also indicate that the reach is actively channelized, and most photos show heavy algal and macrophyte growth within the channel. Overall, the MSHA score along with the associated response metrics from the biological community show that lack of habitat is a stressor and a limiting factor in this AUID.

The DNR Clean Water Specialists conducted a Pfankuch inventory of the stream reach near sites 14RD226 and 07RD024. The results of the stability rating were a 76 and 73, respectively, which rates as moderately unstable for this stream type (B4). The B4 stream type represents a moderately entrenched single channel stream with a gravel-dominated substrate. The Pfankuch stability rating looks at three stream channel zones: the upper bank, the lower bank, and stream bottom. Each zone analyzed had at least one subcategory that was rated fair or poor. In the upper bank zone, bank slope was greater than 60% and there was a moderate potential for debris jams. In the lower bank zone, the bank material is composed of small size rock and incohesive material, making the banks susceptible to erosion. The stream bottom scored "good" in all the categories. The Pfankuch stability rating does not show that habitat is a significant problem, however site 14RD226 does show lower percentage of stable bottom material, which indicates that the bottom could be in a state of flux and increased rates of deposition and scour, which could be causing localized habitat issues in that section of the AUID.

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 645 is provided by the following individual F-IBI metric responses (Appendix A):

- Below average (<14%) relative abundance of individuals that are benthic insectivores at stations 14RD226 (1.2%) and 07RD024 in 2007 (5%) and 2014 (13%)
- Above average (>50%) relative abundance of individuals that are tolerant at station 14RD226 (53%)
- Above average (>60%) relative abundance of the dominant two species of fish at stations 14RD226 (88%) and 07RD024 in 2007 (69%) and 2014 (58%)
- Below average (<15%) relative abundance of taxa of Darter, sculpin, and round bodied suckers at stations 14RD226 (7%) and 07RD024 in 2007 (11%) and 2014 (11%)

4.8 Lost River (AUID 646) – full support of fish/full support of macroinvertebrates

4.8.1 Physical setting

This reach represents a 28.75-mile long segment of Lost River, immediately downstream of AUID 645 that flows into the Hill River northwest of Brooks, Minnesota. The AUID begins at the Lost River's confluence with Branch 6 of Judicial Ditch 72 (Br6 JD72). Br6 JD72 is an artificial watercourse that enters the Lost River on the east side of CSAH 28, north of Trail. The Lost River flows west through the town of Oklee. The downstream end of this AUID is the point where the Hill River joins with the Lost River, northwest of Brooks. Much of the reach has been channelized, as indicated by the red-colored portion of the Lost River channel in Figure 58.

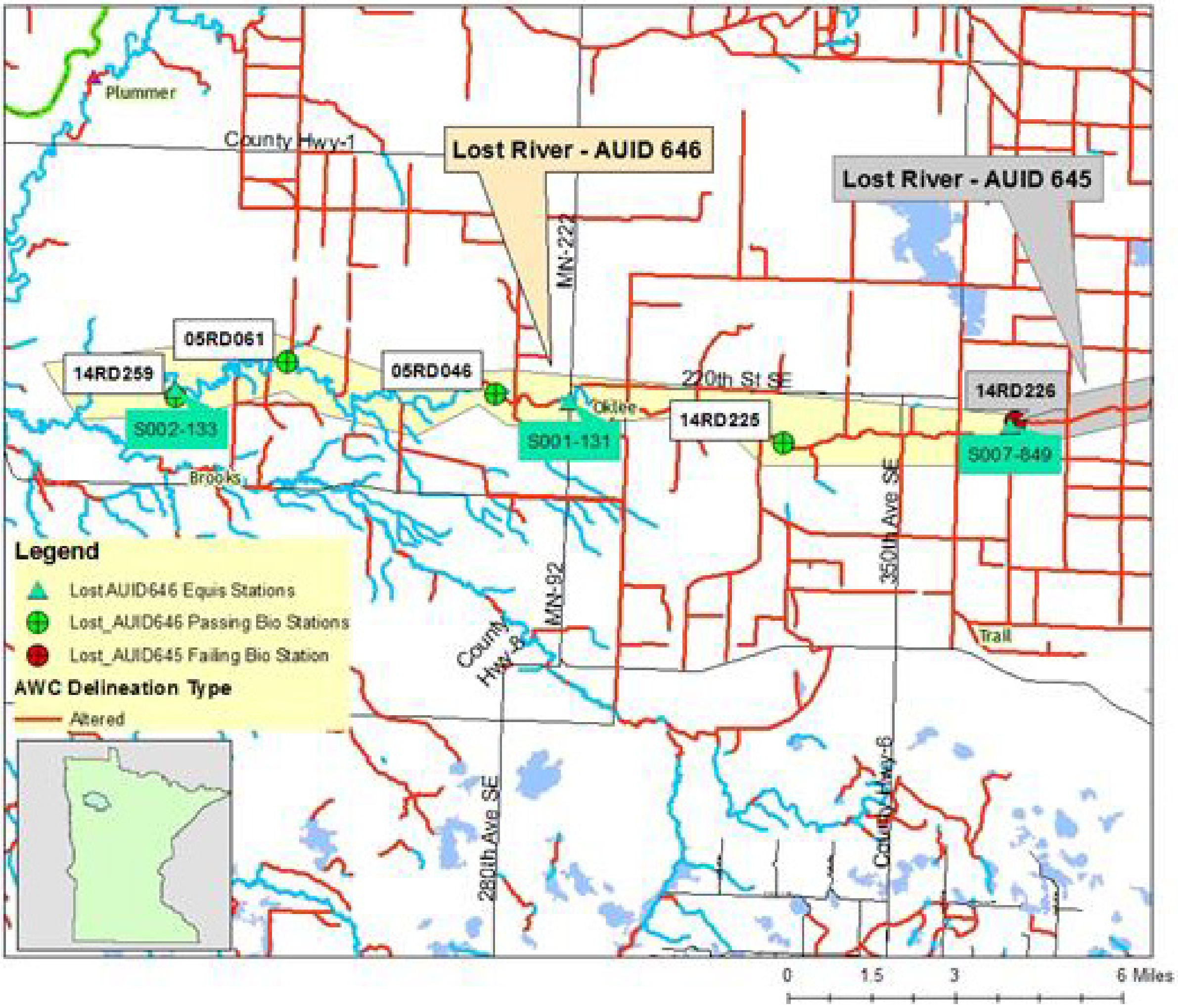


Figure 58: Location map of AUID 646 on Lost River (yellow) and associated monitoring stations. The lower part of AUID 645 is shown for context (grey). The biological communities on AUID 646 all have passing IBI scores. However, site 05RD046 is a concern due to a seemingly degrading biological community between samples collected in 2005-2006 and those collected in 2015.

4.8.2 Biological impairments

Data from four biological monitoring stations on this AUID were analyzed, and overall, both fish and macroinvertebrate IBI scores are passing. The issue is that site 05RD046 is showing signs of fish and macroinvertebrate community degradation over time. The field notes from the fish visit indicated that the 2015 fish sample was very different from the 2006 fish sample. Only 10 species were collected in 2015 (compared to 17 species in 2006). Fewer lithophilic spawners and sensitive species were found in 2015. On August 6, 2015, the field notes indicated that flow velocity was slow and there was a buildup of silt and muck along the stream edges.

The macroinvertebrate community also changed at this site between the 2005 and 2015 samples. In 2005, the M-IBI scored 17 points above the threshold; then in 2015, the site scored right at the threshold. The predominant habitat sampled in 2005 was wood, compared to 2015 when both wood and vegetation were sampled, but vegetation was the predominant habitat. The species found on these two dates are fundamentally different; in 2005, 47 taxa were sampled, including some flow-dependent species. In 2015, only 27 taxa were sampled, most of which are strongly associated with aquatic macrophytes and slow flows.

Based on the fish and macroinvertebrate data, it appears that the channel may be aggrading and filling with fine sediment, and suffering from a lack of baseflow. This AUID will require protection at the watershed level to avoid a future aquatic life impairment. Additionally, AUID 529 of the Lost River, which is immediately upstream of Pine Lake, just south of Jonick, Minnesota (thus upstream of both AUIDs 645 and 646 discussed in this report) nearly meet the Exceptional Use category for biology, further warranting protection of the Lost River.

Table 22: Results of MPCA biological monitoring on AUID 646, on the Lost River. Failing IBI scores are highlighted in red.

Station	Sample date	F-IBI (score/threshold)	M-IBI (score/threshold)
14RD225	7/8/2014	47/47	-
	7/29/2014	-	53.9/41
05RD046	8/24/2005	-	58.5/41
	7/11/2006	59/47[13]	-
	8/23/2006	61/47	-
	8/6/2015	65/47	40/41
05RD061	6/22/2006	36/47	-
14RD259	7/17/2014	65/47	43.1/37

4.8.3 Candidate causes

Summary

Five candidate causes were analyzed to determine what might be causing the dramatic decrease in IBI scores seen over time. No conclusive stressors could be identified, although high daily DO flux and flashiness are occurring at various locations throughout the AUID. In general, this AUID warrants protection to prevent the biological communities from degrading further, potentially causing a future aquatic life impairment. This AUID is at risk because it is already showing signs of decline, the reach upstream of this AUID, AUID 645, is nonsupporting of fish, plus, another reach upstream of both AUID 645 and 646 nearly meets Exceptional Use standards for biology and habitat (AUID 529) and needs to be protected.

Elevated nutrients

EQuIS station S001-131, at the CSAH 22 crossing in Oklee, is water chemistry monitoring station located nearest to the biological site of concern, 05RD046. This station had 136 TP and 90 NOx samples collected at varying frequencies from 1984 to 2016. The earliest samples show consistently elevated TP concentrations, and a generally decreasing average is seen over time; TP data from 2006-2016 suggest that elevated TP is not a persisting problem at this location, with an average of 0.0418 mg/L. Of the 90 NOx samples, only seven exceed 1.0 mg/L. Inorganic nitrogen, as measured by NOx, does not appear to have been sampled at elevated concentrations at this station since 1984.

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[13] To reiterate what is discussed in the text: although the F-IBI scores are not decreasing over time, biologists at the MPCA noted a drastic change in assemblage (species type and quantity) from the earlier samples and are concerned that degrading habitat is negatively affecting the fish population.

EQuIS station S002-133 is located just downstream of biological station 14RD259 and the CR119 crossing near Brooks. This site has a water quality record dating from 2001 through 2016. There were 125 TP samples collected over this timeframe and 124 NOx samples. Figure 59 displays the nutrient concentrations found at S002-133.

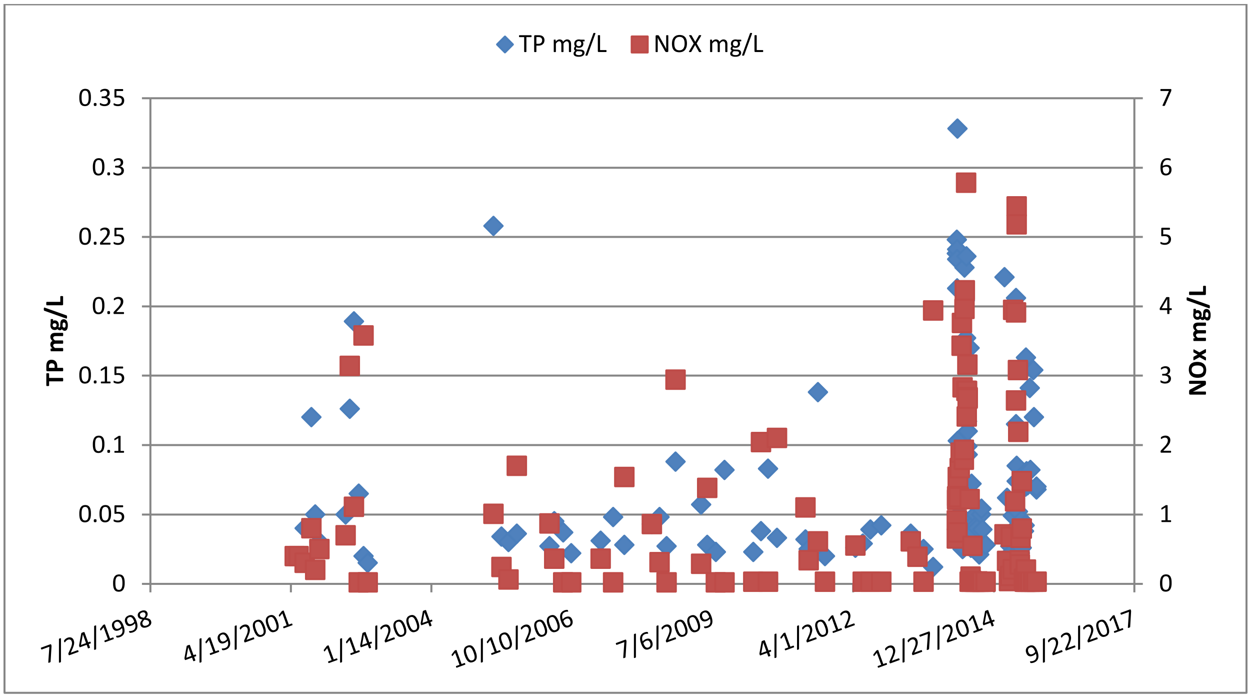

Figure 59: Water chemistry data for nutrients on AUID 646 of the Lost River at EQuIS station S002-133.

The TP samples exceeded the eutrophication standard of 0.100 mg/L in 21.6% of the samples. The majority of the exceedances were observed in 2014 and 2015. Many of the highest TP readings are seen during snowmelt periods and early spring rain events before crops are established. Flows in 2014 were much higher than in 2015. The average monitored discharge on AUID 646 of the Lost River was 103 cfs in 2014 and 27 cfs in 2015. The timing of the high TP concentrations observed concur with the observation of elevated submerged aquatic plant growth in the stream channel at site 05RD046 (Figure 60). This increased plant growth can lead to an elevated DO flux (see Figure 62).

Nitrogen concentrations as measured by NOx are also elevated at this site. Using 1 mg/L as a measure of elevated nitrogen reveals that 36% of the 125 samples collected were above 1 mg/L. The maximum concentration observed was 5.78 mg/L, observed on June 12, 2014; and other concentrations above 5 mg/L occurred in June 2015.

Figure 60: Extensive submerged plant growth in the channel at site 05RD046.

Low dissolved oxygen

Dissolved oxygen was sampled 185 times at station S002-133 from 2001 through 2015. All instantaneous readings were above the Class 2B 5 mg/L standard (Figure 61).

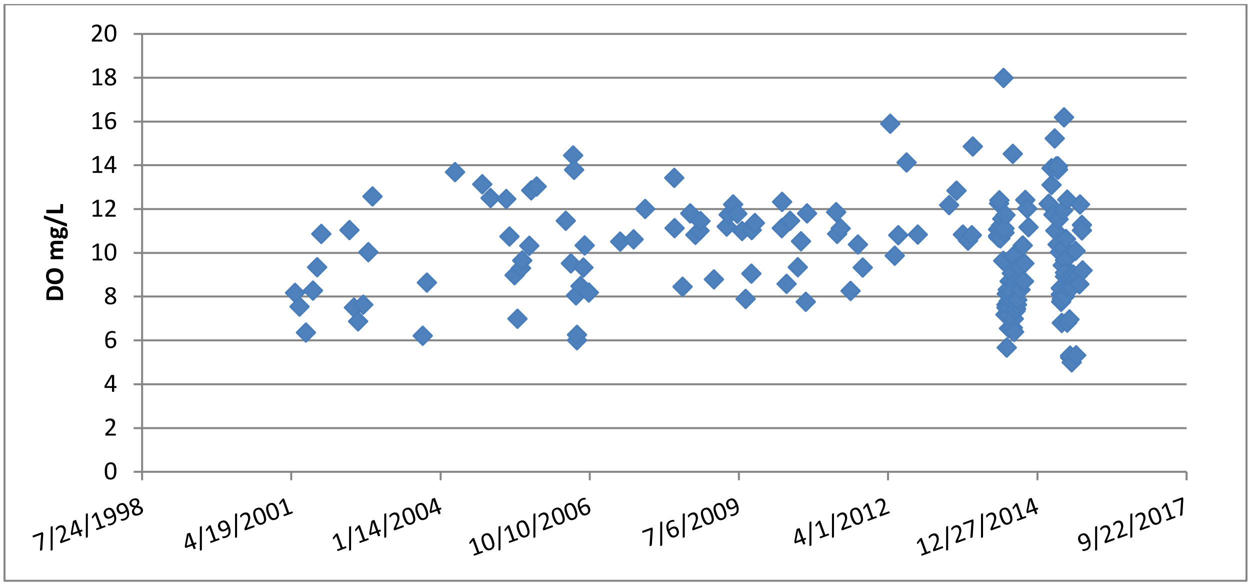

Figure 61: instantaneous DO concentrations collected from site S002-133. All instantaneous DO data is above the 5 mg/L standard.

The fish and macroinvertebrate TIV scores (MPCA 2012) were analyzed to estimate the probability that this AUID would meet the DO or TSS standards (Table 24). Based on these estimates, it is likely that the fish and macroinvertebrate communities are not impacted by low DO or high TSS concentrations. However, the elevated DO flux may be impacting the biology on this AUID. Evidence of eutrophication exists in the elevated plant growth documented within the channel along with the high daily DO flux observed in 2015.

Table 23: Fish community probability of passing the state standards for TSS and DO. Based on this information, lack of DO may have been stressing the fish community at site 05RD046 in 2014. Values of concern are highlighted in red.

Field Number	Waterbody name	Probability of passing TSS standard	Probability of passing DO standard
05RD046	Lost River	0.53	0.56
05RD046	Lost River	0.80	0.38
05RD061	Lost River	0.72	0.57
14RD259	Lost River	0.85	0.56

Continuous DO data was collected by the RLWD at site S002-133 in 2015 from May 4 through July 14, a total of 63 days (Figure 62). DO concentrations were below the 5 mg/L standard for 3.2% of the readings, and the DO flux exceeded the 3.5 mg/L standard for 52% of the sampling time. The summer average DO flux was 5.64 mg/L. Pictures of extensive filamentous algae growth were taken at this station during the deployment, largely explaining the excessive DO flux (Figure 63).

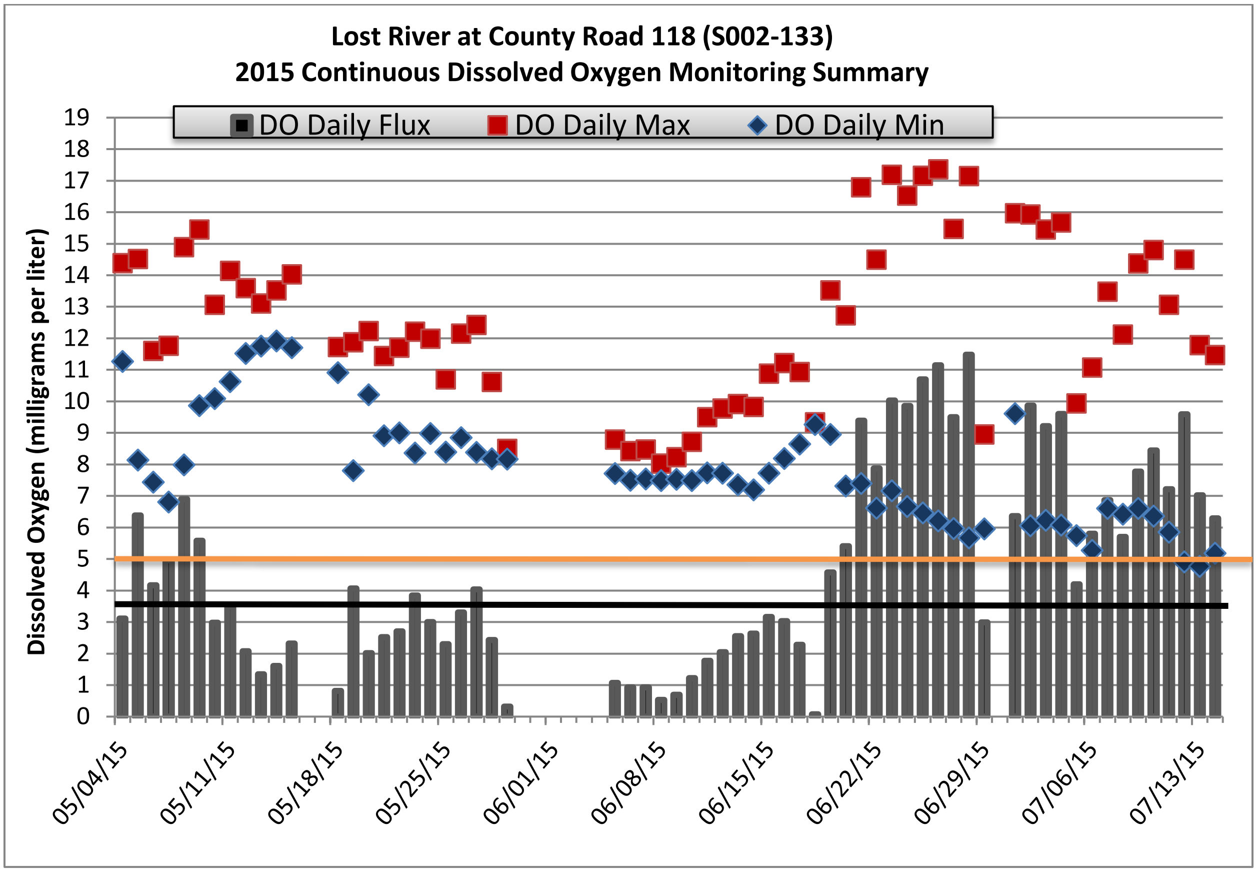

Figure 62: Continuous DO data collected by RRWD from site S002-133 on AUID 646 of the Lost River. Data shows that low DO is not problematic at this reach of stream, though daily DO flux is a concern (standard = 3.5 mg/L, black line).

Figure 63: Filamentous algae growth, photographed at EQuIS station S002-133 (which is co-located with biological station 14RD259) on 6/25/2015. Continuous DO data from this site recorded excessive DO flux, likely caused by the photosynthesis and respiration of the algae.

Although not impaired by TSS, the exceedance rate of the 30 mg/L TSS standard for AUID 646 is relatively close to the impairment threshold (8.1%, 2006-2015 data). The exceedances have been found in samples collected either during spring (April) runoff or during June rainfall events. Zero of the exceedances were found at S001-131. All 10 of the exceedances were discovered at S002-133. A site-specific assessment shows that the river is failing to meet the TSS standard at S002-133. The IBI scores were better where TSS levels were higher, so TSS may not be a primary stressor of biology. However, the site-specific assessment results and the streambank instability in the lower part of this reach should be noted and addressed in the WRAPS for protection purposes.

Flow alterations

The hydrologic model (HSPF) results (developed for 1996-2009, on hourly time step) show that the discharge in the Lost River is flashy and there are periods of extreme high and low flows. The model summary discharge statistics show a peak discharge of 3,744 cfs, mean discharge of 88 cfs and a minimum discharge of 1.6 cfs. The record also shows that 2.6% of the time the stream is below 5 cfs and 4.7% of the record shows discharge above 352 cfs, which is four times the mean discharge.

In 2014-2016, continuous discharge measurements were made generally from spring to early winter. These measurements were collected at EQuIS station S007-849, where the river crosses CSAH 28, which is the furthest upstream end of AUID 646, and therefore does not represent the hydrologic conditions of the entire AUID. From this data, a total of 617 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was low (less than 1.0 cfs) and extremely low (less than 0.1 cfs). The results show that at this location on the Lost River, a discharge less than 1.0 cfs was measured for 11-15% of the record, and less than 0.1 cfs for 7-12% of the record.

To further understand the flow regime and resultant channel stability of AUID 646, the DNR Clean Water Specialists performed a Rosgen Level II survey at biological station 14RD226, as well as Pfankuch stability assessments at sites 14RD226 and 05RD046. The results of that work will be published with this report at a later date. Some preliminary results are discussed below in the *Lack of habitat* section.

Additionally, long-term discharge has been measured on this AUID in Oklee by the USGS and a cooperative stream gauging effort (RLWD/MPCA/DNR) measured discharge at EQuIS station S002-133 from 2013-2016. This data was not analyzed as part of this report, though should be used to inform future decisions, especially the USGS gauge in Oklee since it is located closer to the biological station of concern and has a long-term record.

Lack of connectivity

Eleven road crossings were identified on the AUID using aerial photography. Most of the crossings appear to be bridge crossings and do not pose a threat to fish migration. However, two private crossings were identified that appeared to be culverts. These crossings may pose a barrier to fish migration and should be further investigated. Of the four stations sampled for fish in this AUID, only the farthest upstream station (14RD225) shows a general lack of migratory fish. This station had 4.2% of the sample as migratory. The downstream stations all had between 14.6% and 26% of the sample as migratory individuals. This could indicate that there is some type of a barrier upstream of the city of Oklee that is preventing the free movement of fish in the Lost River. It may be worth investigating the road crossings upstream of Oklee to determine if fish can freely pass upstream.

Lack of habitat

Four MSHA scores were calculated at site 05RD046 between 2006 and 2015, ranging from 41 to 49. All MSHA scores were low in the channel morphology category. According to notes from the biological sampling crews, sedimentation may be occurring based on comparisons between the current MSHAs and a 2006 quantitative habitat assessment. Also, the predominant habitat available for macroinvertebrates changed from wood in 2005 to vegetation in 2015.

There are very low channel development and instream cover scores, which significantly lowers the overall score. The land use scores were also low as the riparian land use is dominated by row crops. Channel development scores were less than 70% of the possible total, indicating that there are some missing stream habitat features and stream velocity was not variable within the reach. The site was dominated by run (85-100%).

The DNR Clean Water Specialists conducted a Pfankuch inventory of the stream reach near site 05RD046. The result was a stability rating of 66, which is considered stable for this stream type (E4). The E4 stream type represents a slightly entrenched, single channel stream with a gravel-dominated substrate. The Pfankuch stability rating looks at three stream channel zones: the upper bank, the lower bank and stream bottom. Each zone analyzed had at least one subcategory that was rated fair. In the upper bank, there was a moderate to heavy potential for debris jams. In the lower bank zone, bank material is composed of small size rock and incohesive material, making the banks susceptible to erosion. The stream bottom scored “fair” in one the category: stream bottom rocks were rounded in two dimensions (an indication of movement of material along the streambed). The Pfankuch stability rating does not show that habitat is a significant problem near site 05RD046.

Biological response - fish

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 646 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>60%) relative abundance of the dominant two species of fish at station 05RD046 (58%)

Biological response - macroinvertebrates

Evidence of a causal relationship between habitat availability and the F-IBI impairment associated with AUID 646 is provided by the following individual M-IBI metric responses (Appendix B):

- Below average (<34%) relative abundance of clinger taxa at station 05RD046 (29%)
- Below average (<19%) relative abundance of sprawler taxa at station 05RD046 (7.4%)

4.9 Silver Creek (AUID 527) - full support of fish/nonsupport of macroinvertebrates

4.9.1 Physical setting

This reach represents a segment of Silver Creek that originates at the headwaters of Silver Creek and outlets at Anderson Lake. The reach is 15.65 miles long. This AUID runs south to north along the west side of the City of Clearbrook, Minnesota. Figure 56 shows the monitoring stations located on AUID 527.

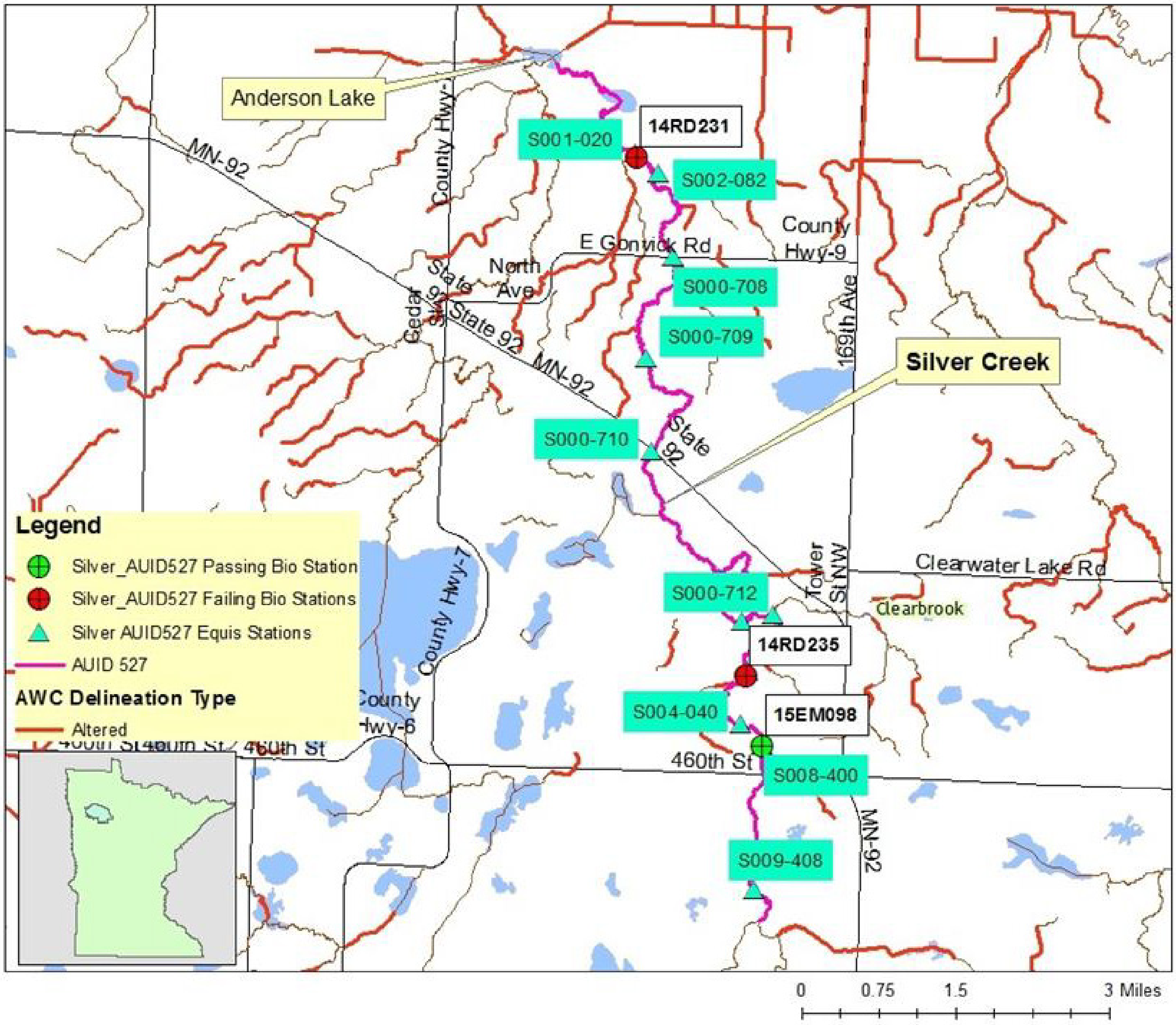

Figure 64: Location map of AUID 527 on Silver Creek.

4.9.2 Biological impairments

Three biological stations are located on AUID 527. The farthest downstream station is 14RD231. This station scored a 58 on the F-IBI and was 16 points above the threshold for a Class 6 Headwater Stream. The station was sampled on July 16, 2014 and sampling notes indicated good habitat and substrate at site. Macroinvertebrates were sampled on July 30, 2014 and scored five points below the Class 5 Southern Stream riffle run stream class. Flow was low during sampling. In 2016, station 14RD231 was sampled again for macroinvertebrates and scored 33.8 out of 37. The mid-reach site 14RD235 was sampled for fish on June 10, 2014 and scored a 52, which is 10 points above the Class 6 threshold. Macroinvertebrate samples were collected on July 30, 2014 and scored seven points above the threshold. Notes from macroinvertebrate sample indicate the landowner stated that stream is normally dry at this point in summer. The farthest upstream station (15EM098) was sampled on June 17, 2014 for fish and was one point below the threshold for class 6 streams. The macroinvertebrate sample was collected on August 5, 2015 and scored a 60, which is 23 points above the threshold for a Class 5 stream. The macroinvertebrate community is showing signs of a loss of taxa and diversity as the sites move downstream. Site photos indicate erosive stream banks and flashy flows in the downstream reaches.

4.9.3 Candidate causes

Elevated nutrients

With the TP dataset available, there does appear to be a eutrophication problem in Silver Creek. The 0.100 mg/L TP standard should reflect an intermediate standard and will be used to assess the stream condition for eutrophication. However, DO flux exceeded the 3.5 mg/L standard 66.4% of the deployment. The DO flux even exceeded the 4.5 mg/L South Region standard for 40.9% of the deployment, indicating eutrophic conditions. From July 1, 2014 through July 31, 2014, the average daily DO flux was 6.12 mg/L/day. This indicates potential excessive algal growth within the channel. The July 1 through July 31, 2014, flow record collected by RLWD shows low flow conditions; however, there was still flow present during this period. The flow record in August and September of 2014 show 0.0 cfs flow conditions at station S002-082 as seen in Figure 64 below.

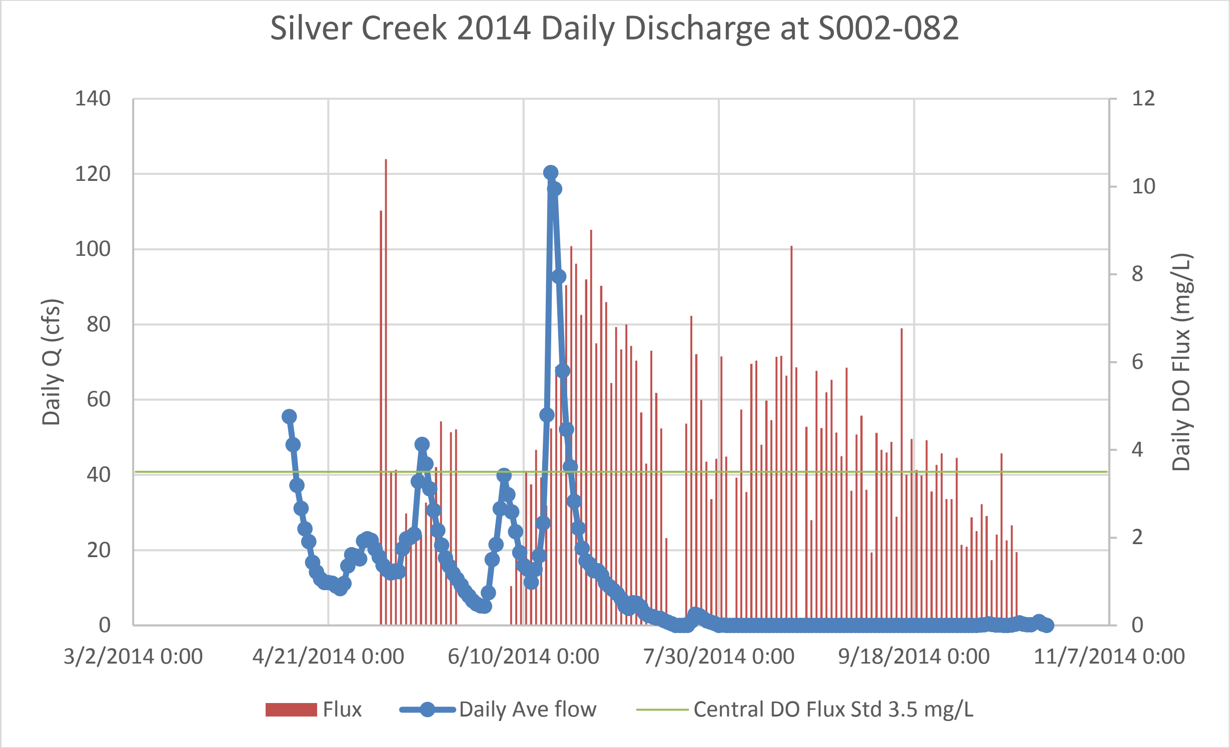

Figure 65: Daily average discharge data in cfs at Site S002-082 on Silver Creek along with the daily DO flux displayed against the Central DO flux standard of 3.5 mg/L/day.

Water chemistry samples were collected at station S002-082 at the downstream end of AUID 527 on CR111 Bridge, two miles east of CSAH-7. Water quality samples were collected and analyzed for Ammonia (NH4), Nitrate (NO3), Inorganic Nitrogen (NOx), Ortho Phosphorus (OP), and Total Phosphorus (TP). The record dates back to 1984, however for this report data from 1996 -2015 will be analyzed and summarized. TP were samples were collected 95 times during this period. The average concentration was 0.113 mg/L, minimum concentration was 0.019 mg/L and the maximum was 0.673 mg/L.

Inorganic nitrogen is measured as NOx. Eighty-three samples were collected with a minimum of 0.0 mg/L, maximum of 1.49 mg/L and an average of 0.17 mg/L. Nitrogen does not appear to be stressing the biology in AUID 527. The number of macroinvertebrate that are tolerant to nitrogen at 15EM098 is 18 (45.8%); intolerant to nitrogen is five (7.7%). At site 14RD235, the number of macroinvertebrate taxa tolerant to nitrogen is 21 (53%) and intolerant is one (0.6%). As we move downstream to site 14RD231, the number of macroinvertebrate taxa tolerant to nitrogen is 18 (60%) and intolerant is three (1.2%) (Table 22). This shows that macroinvertebrate community is tolerant to nitrogen and any increase in nitrogen concentrations may equate to a loss of the few nitrogen intolerant taxa left at the sites. Even though the water chemistry concentrations are well below the 10 mg/L standard, nitrogen does appear to be affecting the macroinvertebrate community and is a stressor.

Table 24: Macroinvertebrate nitrogen data displaying the number of nitrogen tolerant and intolerant taxa

Site	Class	Nitrogen Intolerant taxa	Nitrogen Tolerant taxa	Nitrogen Index score
14RD231	5	3	18	3.873
14RD235	6	1	21	3.214
15EM098	5	5	18	3.382

Low dissolved oxygen

Dissolved oxygen was collected instantaneously 124 times at site S002-082 from 1996 through 2015. The state standard for DO is 5 mg/L for Class 2B waters. Site S002-082 was below the standard 2.4% of the sampling events. Low DO is not stressing the biological communities at S002-082. Since the fish community passes the F-IBI but the macroinvertebrate community fails the M-IBI, a closer look at the community structure is needed. Community tolerance metrics have been developed for both the fish and macroinvertebrate communities. The three biological sampling locations are listed in Table 23 and show that the two sampling sites upstream have an increased number of macroinvertebrate taxa that are tolerant to low DO but also have and increased number of taxa that are intolerant to low DO (meaning they will not flourish in low DO concentrations). The fish community also shows a community that can tolerate low DO conditions, however they pass the IBI score and therefore are not affected by the current low DO conditions observed during the 2014 sampling event.

Table 25: Fish and macroinvertebrate community tolerance and intolerance to low DO.

Site	Class	DO Intolerant taxa	DO Tolerant taxa	DO Index score	Probability of passing the DO 5mg/L standard
14RD231-fish	6	0	4		52.6%
14RD235-fish	6	0	6		30.3%
15EM098-fish	6	0	3		50.7%
14RD231-invert	5	4	2	6.64	
14RD235-invert	6	7	8	6.71	
15EM098-invert	5	7	8	6.64	

Continuous DO data collected by the RLWD from May 29, 2014 through October 3, 2014 recorded 4958 records. Eleven percent of the deployment recorded DO concentrations less than 5 mg/L, which is considered the level where biological organism can become stressed. The DO record also has a flow record that is associated at the same site during the same period. Flow were recorded as 0.0 cfs during the months of August and September which indicates that the continuous DO data collected during that time period was in a pool of water and not measuring a flowing stream during that time. This also is the period when the majority of the DO readings were recorded below 5 mg/L (Figure 58). If we look at the DO record plotted against the Daily flow record, it reveals that the lowest recorded DO records occur at zero or near zero flows. Low DO is not stressing the biology.

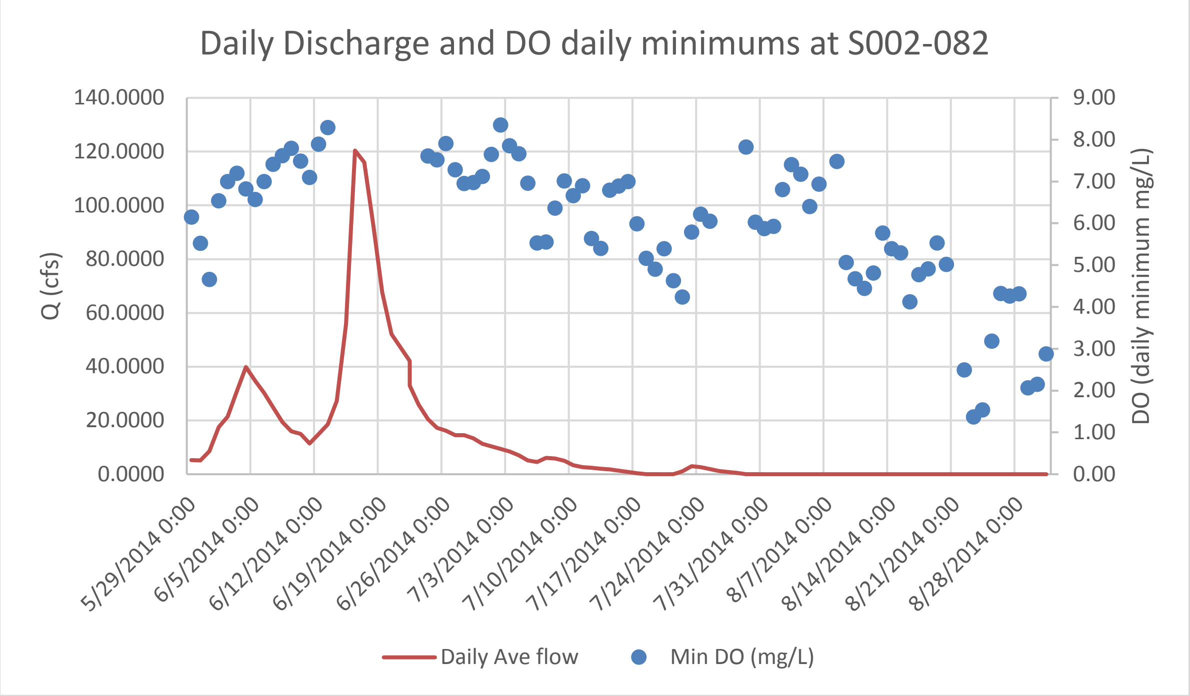

Figure 66: Monitored daily discharge versus daily DO minimums collected by the RLWD. Note that after August 1 stream discharge was at zero or very near 0 cfs. The DO data that was collected during this period is indicative of pool conditions not flowing water.

Total suspended sediment

Total suspended sediment samples were collected 84 times during 2006 through 2015. This data shows that TSS concentrations averaged 6.96 mg/L. The central region TSS standard for streams is 30 mg/L. The recorded values fall well below the TSS standard. The macroinvertebrate community was analyzed to determine the community composition of taxa that are both tolerant and intolerant to TSS. All three samples are dominated by TSS tolerant taxa, however all three sites also have enough intolerant taxa to indicate; along with the TSS concentrations measured that TSS is not stressing the macroinvertebrate community.

Table 26: TSS macroinvertebrate community tolerance to TSS

Site	Class	TSS Intolerant Taxa	TSS Tolerant taxa	TSS Index Score
14RD231	5	2	12	19.42
14RD235	6	2	10	14.72
15EM098	5	6	11	14.63

Flow alterations

The entire AUID and all of the tributaries to the AUID are channelized. This channelization will alter the rate and timing of the water delivery during precipitation events. Runoff will enter the system faster and move through the system quicker with the channelization. Base flow will be diminished during periods of little precipitation. A hydrologic model was built for the Silver Creek using the Hydrologic Simulation Program Fortran model (HSPF). This model was developed for a period from 1996-2009 and ran on an hourly time step. The results show that the discharge in the Silver Creek is flashy and there are periods of extreme high and low flows. The model summary discharge statistics show a peak discharge of 628 cfs, mean discharge of 14 cfs and a minimum discharge of 0.36 cfs. The record also shows that 42% of the time the stream is below 5 cfs and 4.7% of the record shows discharge above 55 cfs, which is four times the mean discharge. The stream is also below 1 cfs during 4.9% of the record. Overall, the available data suggest that the reach is prone to extended periods of minimal to no flow and also has periods of high flow that occur rapidly and return to low flows quickly (Figure 66).

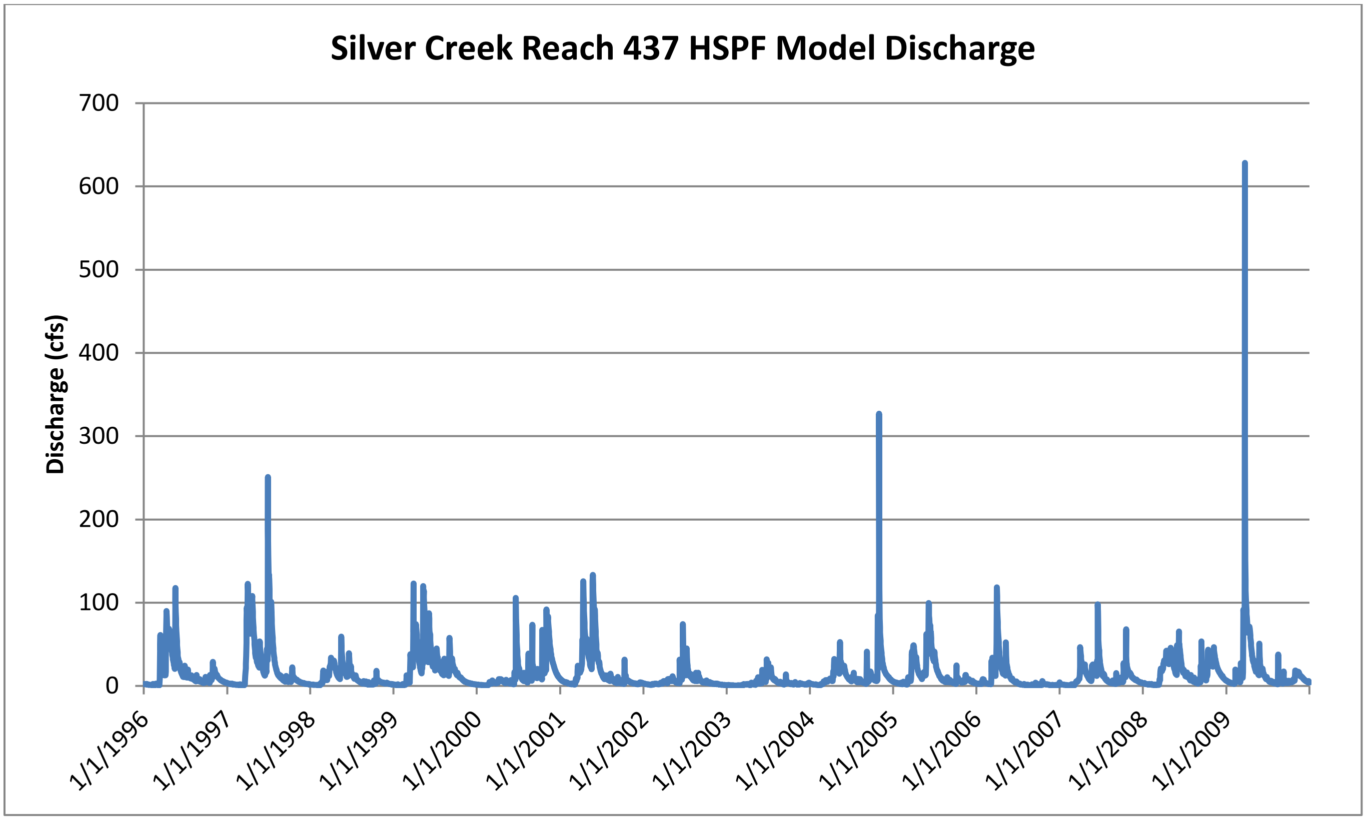

Figure 67: HSPF modeled daily discharge data for AUID 527 Silver Creek

The RLWD also collected continuous discharge at site S002-082 on Silver Creek from 2009 through 2016. The results of this monitoring effort indicate that low flow periods occur at a greater frequency than the HSPF model shows. Documented discharge records from the RLWD show that Silver Creek experienced near zero discharge 30.9 % of the record. Table 25 displays the percent of time for the monitored year that flow was below 0.1 cfs along with the average discharge during the monitoring period.

Table 27: Mean daily discharge data in cubic feet per second (cfs) for the monitoring period of 2009 through 2016. This table also shows the percent of time during each monitoring period that flow was at or below 0.1 cfs. This low of flow would limit available habitat and adversely affect the abundance and diversity of macroinvertebrates.

Year	Mean daily discharge (cfs)	Percent of time discharge is below 0.1 cfs for monitored period
2009	2.17	56
2010	13.72	0
2011	13.64	11
2012	0.98	66
2013	10.84	47
2014	9.72	38
2015	7.37	12
2016	8.17	16

Biological response - fish

Evidence of a causal relationship between flow regime instability and the F-IBI impairment associated with AUID 514 is provided by the following individual F-IBI metric responses (Appendix A):

- Above average (>80%) combined relative abundance of the three most abundant taxa (DomThreePct) at Station 14RD231 (83%)
- Above average (>66%) relative abundance of individuals that are tolerant (TolPct) at Stations 14RD235 (74%) and 15EM098 (70%)
- Above average (>20%) relative abundance of taxa that are pioneers (PioneerTxPct) at Station 15EM098 (25%)
- Below average (<23%) relative abundance of taxa that are sensitive (SensitiveTXPct) at Stations 14RD231 (17%), 14RD235 (18%), and 15EM098 (13%)

Flow regime instability tends to limit species diversity and favor taxa that are short-lived and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010).

Biological response - macroinvertebrates

Evidence of a causal relationship between flow regime instability and the M-IBI impairment associated with AUID 518 is provided by the following individual M-IBI metric responses (Appendix B):

- Above average (>59%) relative abundance of the dominant five taxa in a subsample, chironomid genera treated individually (DomFiveCHPct) at Stations 14RD231 (64%) and 14RD235 (58%)
- Below average (<5%/6%) relative abundance of long-lived individuals (LongLivedPct) at Station 14RD231 (2.4%) and 14RD235 (1.9%) and 15EM098 (22%)
- Below average (<40%) total taxa richness of macroinvertebrates (TaxaCountAllChir) at Station 14RD231 (33%)

Flow regime alteration tends to limit macroinvertebrate diversity and favor taxa that are shorter-lived and tolerant of environmental disturbances (Klemm et al., 2002; Poff and Zimmerman, 2010; USEPA, 2012b).

Macroinvertebrate metric data suggests that flow alterations is a stressor. Lack of baseflow is a stressor.

Lack of habitat

Stream habitat is measured using the MSHA calculated score for each sampling location. Three stations were each sampled twice for MSHA in this AUID. Station 14RD231 was sampled for MSHA scores two times (average score of 65). Station 14RD235 was also evaluated two times for MSHA scores (averaged a 57; low score of 43 and a high score of 71), the farthest upstream Station is 15EM098 (averaged 56.1). The average MSHA score for the three sites place habitat in the fair category for Silver Creek. Channel morphology scores are low indicating that the stream is missing some features and has unstable banks. The land use scores were also low as the riparian land use is dominated by row crops. All three sites had a mixture of pool, riffle, run. Overall, the MSHA score along with the associated response metrics from the biological community show that lack of habitat is not a stressor and a limited factor in this AUID to the fish community. The macroinvertebrate community at Station 14RD231 scored a 31.9, Station 14RD235 scored a 50.1 and 15EM098 scored a 60.0 during the 2014 and 2015 sampling events. Review of select fish and macroinvertebrate metrics that are related to degraded or missing habitat features suggest that the biology is not stressed by habitat.

The DNR Clean Water Specialists conducted a Pfankuch inventory of the stream reach near sites 14RD231, 14RD235 and 15EM098 moving in an upstream direction. The results of this stability rating was a 91,87, and 72 which rates as moderately unstable for a E4-5 stream type at 14RD231 and 14RD235, and stable at 15EM098. The E4 stream type represents a slightly entrenched single channel stream with a gravel-dominated substrate; an E5 is a sand dominated substrate. The Pfankuch stability rating looks at three stream channel zones: the upper bank, the lower bank and stream bottom. Each zone analyzed had at least one subcategory that was rated fair. In the upper bank, there was an elevated bank slope of 40-60%, which can create more potential for bank failure. In the lower bank zone, the bank material is composed of small size rock and in cohesive material making the banks susceptible to erosion. Also in this zone at site 14RD231 there was a significant amount of bank cutting with 24” high bank cuts that occurred almost continuously throughout the lower reach. The stream bottom scored “fair” in one category. That category was stream bottom scour and deposition at site 14RD231 and 14RD235 where pools had some filling and scour occurred at constrictions. The Pfankuch stability rating does not show that habitat is a significant problem throughout the entire reach; however, as we move downstream from site 15EM098 the stream channel does appear to become more unstable. Site 14RD231 shows the most bank cutting and mass wasting as seen in Figure 60.

Figure 68: Station 14RD231, mass wasting shown on left side of photograph.

Figure 69: Station 14RD231 during the July 16, 2014 fish-sampling event. Note bank failure but stream has velocity. Photograph on the right is at the same station on July 30, 2014. Note that the channel has water but there appears to be no velocity as documented by the RLWD stream gage.

4.10 Lower Badger Creek (AUID 502) – full support of fish/full support of macroinvertebrates

4.10.1 Physical setting

This AUID represents a segment of Lower Badger Creek just southeast of Red Lake Falls that runs from County Ditch 14 to the Clearwater River.

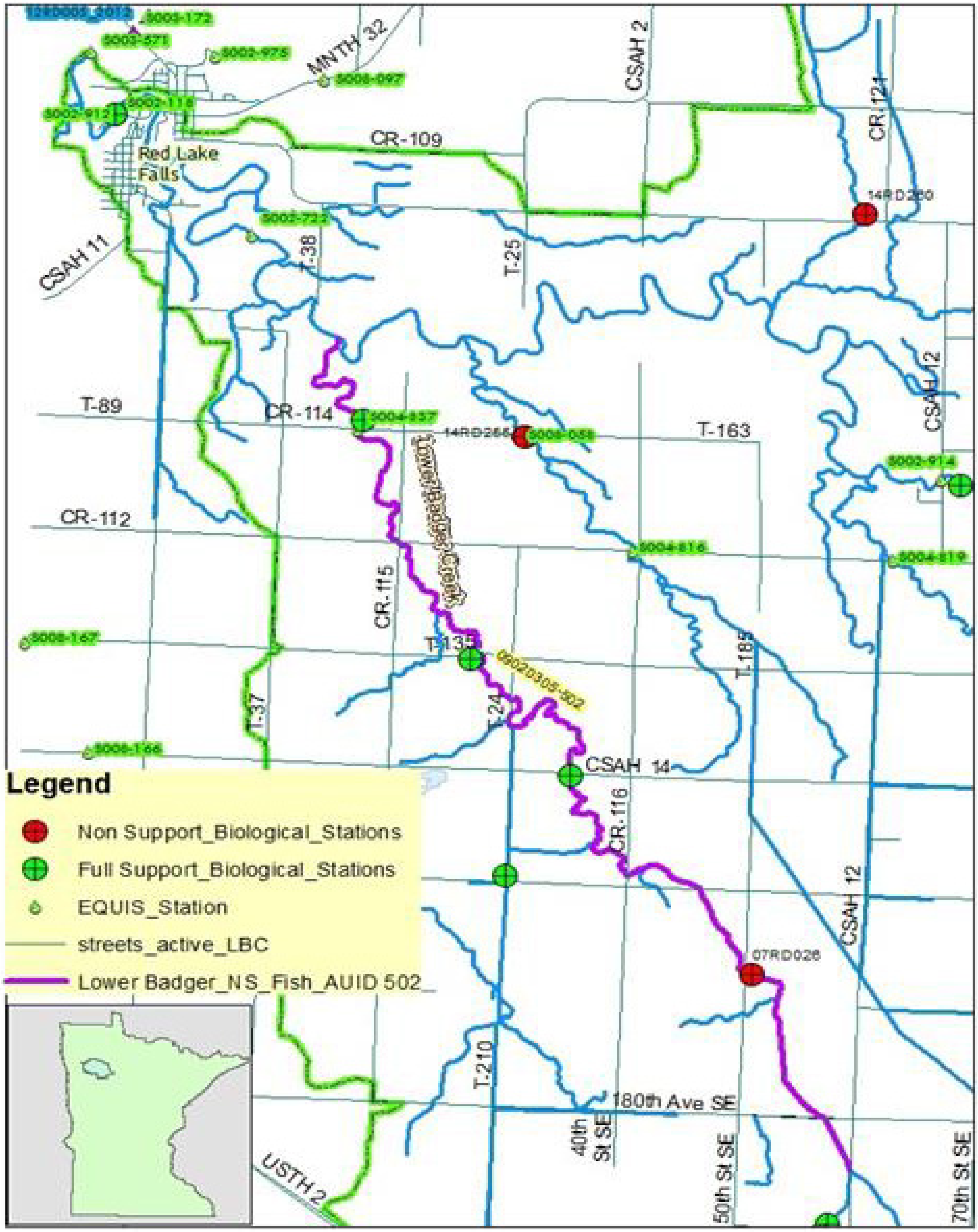

Figure 70: Map of Lower Badger Creek (AUID 502) in the Clearwater River Watershed.

4.10.2 Biological impairments

The fish community of AUID 502 was monitored at stations 07RD026, 14RD239 and 14RD237, listed here as moving in a downstream direction. The fish community at 14RD237 was sampled on June 17, 2015 and scored a 51 on the F-IBI. The F-IBI at this site was four points above the threshold for a Class 5 stream. This is the farthest downstream biological monitoring site on Lower Badger Creek. The macroinvertebrate sample was collected on August 5, 2014 but was not considered valid because of stream flow being lower than baseline flow at the time of sampling. The fish community at 14RD239 was sampled on August 5, 2014 and scored a 51, which is four points above the threshold for a Class 5 General Use Stream. The macroinvertebrate community scored a 55.5 on the M-IBI, which is 18.5 points above the threshold of 37 for a Class 5 Southern Streams (riffle run stream). Thus, the two farthest downstream stations on Lower Badger Creek (14RD239 and 14RD237) both meet the standards for aquatic life. Station 07RD026 was sampled on August 9, 2007 and was listed as a reference ditch in the biomonitoring database, meaning that channelization was present. According to the score of sixty that this site earned on the MPCA Stream Habitat Analysis (MSHA), this site is designated as a General Use stream. Photos of the site taken during sampling suggest that this section of stream should possibly be in the modified use category.

The 2007 F-IBI score was a 33, which is below the general use threshold but slightly above the modified use threshold. In 2016 this site was monitored again for fish (score of 37) and a new MSHA score (42.9) was calculated to determine which class is best represented by the current conditions. The 2016 sample supported the general use designation for fish. Habitat was determined not to be a limiting factor at this location. There was no macroinvertebrate sample collected at 07RD026. Discussion that occurred in March 2017 (with the biological monitoring unit of MPCA) indicate that the AUID is considered as full supporting for fish and macroinvertebrates. Stressor identification was conducted in this AUID to analyze the candidate causes that could be causing the lower fish IBI at 07RD026. Both the downstream stations and the upstream AUID have fish IBI scores that are generally higher than the scores at 07RD026.

No conclusive stressors were identified to explain the difference in F-IBI scores within the reach. It is believed that the area of stream near 07RD026 is lacking stream facet variability and this is affecting the fish community. Both the downstream and upstream biological sites score higher on the F-IBI, which indicates that fish can freely pass through this section of stream but are not residing within the area of 07RD026 and causing the score to be lower. There is documented limited pool and riffle habitat in near 07RD026 and the site is made up of run habitat which is limited the resident fish community.

4.10.3 Candidate causes

Summary

Lower Badger Creek was evaluated as a general use stream during the initial stressor identification phase of the project. Six candidate causes were evaluated to help explain the lack of fish assemblage at site 07RD026. Of the candidate causes analyzed only lack of baseflow was identified as potentially causing issues within the fish community. All sites in the AUID had passing fish scores except site 07RD026. This site was determined that a lack of stream faucet variability may be affecting how fish move through this reach and the fish are likely passing through the stream but not finding suitable habitat to stay near 07RD026. This section of stream is considerably different in habitat than the downstream portion of the AUID.

Elevated nutrients

Nutrient enrichment is a leading cause of eutrophication. Elevated nutrient concentrations can lead to increased growth of algae and aquatic macrophytes in streams. This can cause an abnormal amount of daily DO flux that can impede the biological communities in streams. Minnesota has three regions for river eutrophication standards. Lower Badger Creek is within the central region for river nutrient standards. For a river to be listed as impaired for nutrients, the total phosphorus (TP) concentrations must exceed 0.100 mg/L, *and* the levels of at least one of three response variables, chlorophyll-a (Chl-a), DO fluctuation (DO flux), and biological oxygen demand (BOD_5), must be exceeded (Table 26).

Table 28: River nutrient standards, along with response variables.

	Nutrient Standard	Response variable (stressor)		
Region	TP (mg/L)	Chl-a (mg/L)	DO flux (mg/L)	BOD_5 (mg/L)
Central	0.100	18	3.5	2.0

Nutrient samples were collected at monitoring station S004-837 from 2008 through 2015 (Figure 61). Fifty-seven samples were collected for TP and nitrate-nitrite (NOx). Both nutrients can be responsible for increased plant and algal growth within the stream. The TP during this eight-year period averaged 0.047 mg/L and had a maximum concentration of 0.238 mg/L on June 4, 2015. The average TP for the growing season is 0.55 mg/L. The average is below the TP standard of 0.100 mg/L for the central region. The NOx concentrations averaged 0.41 mg/L with a maximum of 2.72 mg/L that occurred on July 22, 2015. All 4 July 2015 samples were above 1.8 mg/L and were the highest recorded. They are below the 10 mg/L drinking water standard but appear to be increasing over time.

DO flux for the 2016 record was analyzed to determine if eutrophication was a problem in Lower Badger Creek. The average daily DO flux for the 44-day sampling period was 7.40 mg/L, which is significantly higher than the 3.5 mg/L standard for the Central River region. This indicates that photosynthetic activity, driven by nutrient levels, is in turn causing extremely high daily DO fluctuation. The maximum-recorded DO value was 17.8 mg/L, and the minimum recorded was 1.43 mg/L.

There is currently not enough evidence to conclude that eutrophication is a stressor to the biology in Lower Badger Creek. However, the dramatic DO flux and elevated TP concentration in some samples indicate that eutrophication is likely influencing the biology. Reduction in TP may help stabilize the stream DO regime.

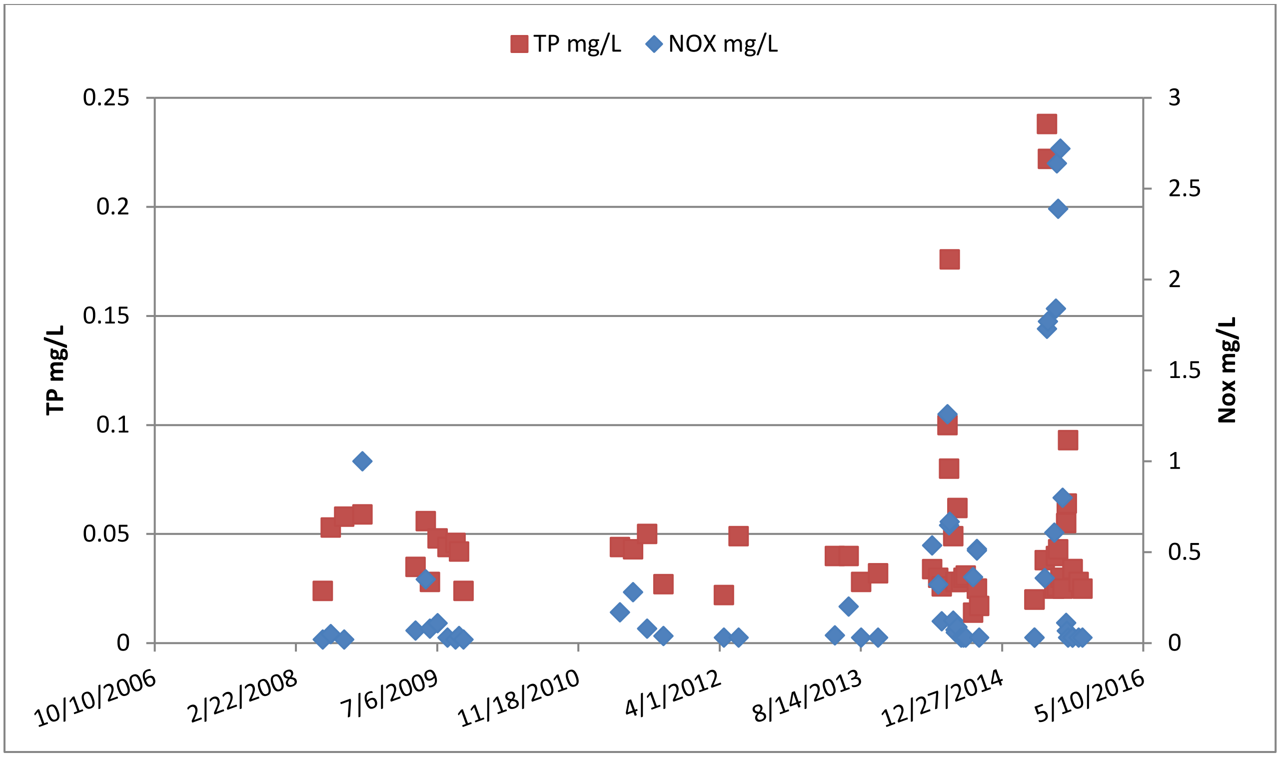

Figure 71: Nutrient concentrations collected from EQuIS site S004-837 from 2008 through 2015.

Low dissolved oxygen

Instantaneous DO data was collected at S004-837 on Lower Badger Creek 98 times between 2008 and 2015. There were no readings below 5 mg/L recorded (Figure 71), suggesting that low DO at the downstream reaches of AUID 502 is not a stressor to the biology. This is evidenced by the DO and the fish community data. Using the MPCA's Tolerance Indicator Values to calculate fish community index scores, we see that the fish community at both site 14RD237 and 14RD239 show a 52% chance of the stream meeting the DO standard. Upstream, at site 07RD026, the fish community shows a 35% probability of the stream meeting the DO standard.

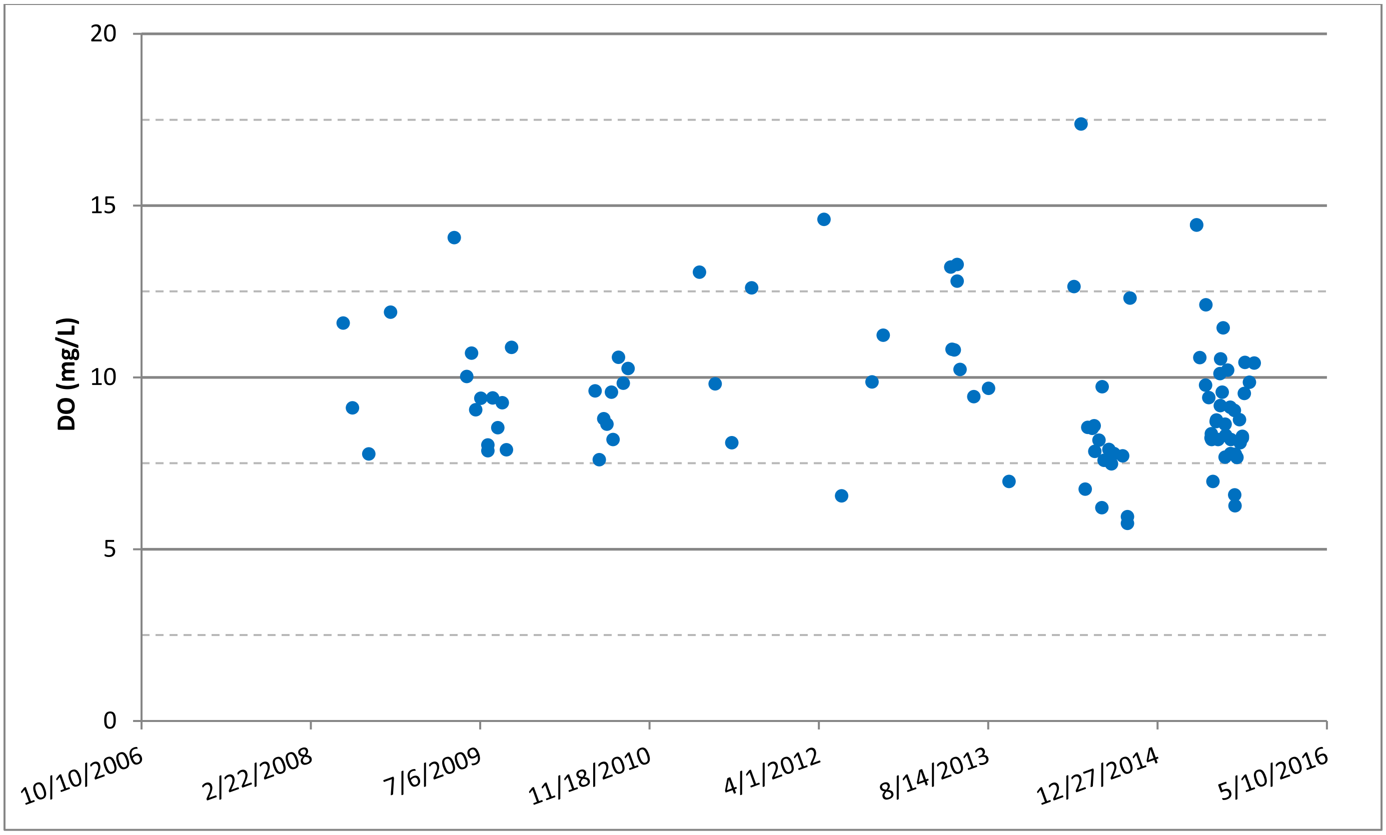

Figure 72: Instantaneous DO concentrations from monitoring station S004-837. No DO measurements were recorded below the 5 mg/L standard.

During 2015, the RLWD collected continuous DO at site S004-837. The sonde was deployed for 126 days and collected 5629 samples at 30-minute intervals. The minimum DO concentration observed during this deployment was 1.98 mg/L and the maximum was 15.82. The DO minimum dropped below the 5 mg/L standard 7.9% of the deployment record in 2015 and the daily DO flux exceeded the 3.5 mg/L standard 35.7% of the record (Figure 72).

The Red Lake Watershed District collected continuous DO data at site S007-837 from May 1, 2015 through July 14, 2015 and again on July 31, 2015 through September 24, 2015. This site is collocated near biological site 14RD237 which is in the downstream section of Lower Badger Creek. The deployment lasted 126 days. During this time, the sonde recorded 10 DO daily minimums below 5 mg/L for a 7.9% exceedance rate. The daily DO flux was also monitored during this timeframe and 25.4% of the deployment had DO flux readings greater than 3.5 mg/L.

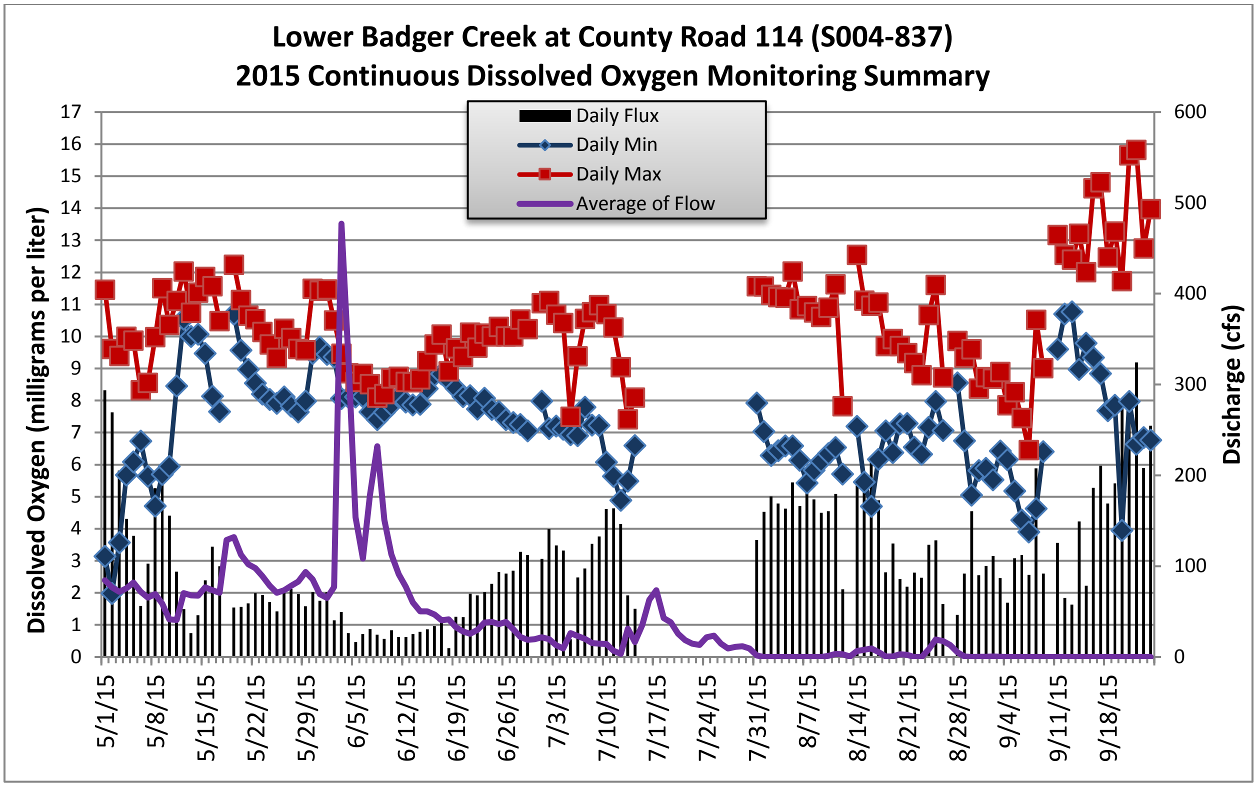

Figure 73: Discharge plotted against the DO continuous deployment record from 2015 at site S004-837.

During 2016, the RLWD collected continuous DO data at Lower Badger Creek on 150th Avenue (near 07RD026) from July 8, 2016 through August 22, 2016. During this sampling period, 2,056 DO measurements were made at thirty-minute intervals. The range of DO concentrations measured was 1.43-17.81 mg/L, with a mean of 7.93 mg/L, and median of 6.88 mg/L. This continuous DO record shows that the DO concentration did drop below the 5 mg/L standard in early July and remained below 5 mg/L until early August of 2016 (Figure 73). The time that low DO was present at this site also is the time that there was minimal or no flow at the site. Flow data was computed by the RLWD during 2012 through 2016 at site S004-837, which shows that the continuous DO sampling period of 2016 started during low flow conditions and captured the intense rains that occurred during July and early August.

The early portion of the sampling period during 2016 shows that the greatest daily DO flux corresponds to low flow conditions in Lower Badger Creek. As flows become higher and wetland areas and drainage, ditches contribute more water to the system, the DO flux decreases with the increase in discharge. As intense rain events increase stream flow to or near flood conditions, the DO flux becomes closer to the 3.5 mg/L threshold, and photosynthetic DO increases appear to be minimized.

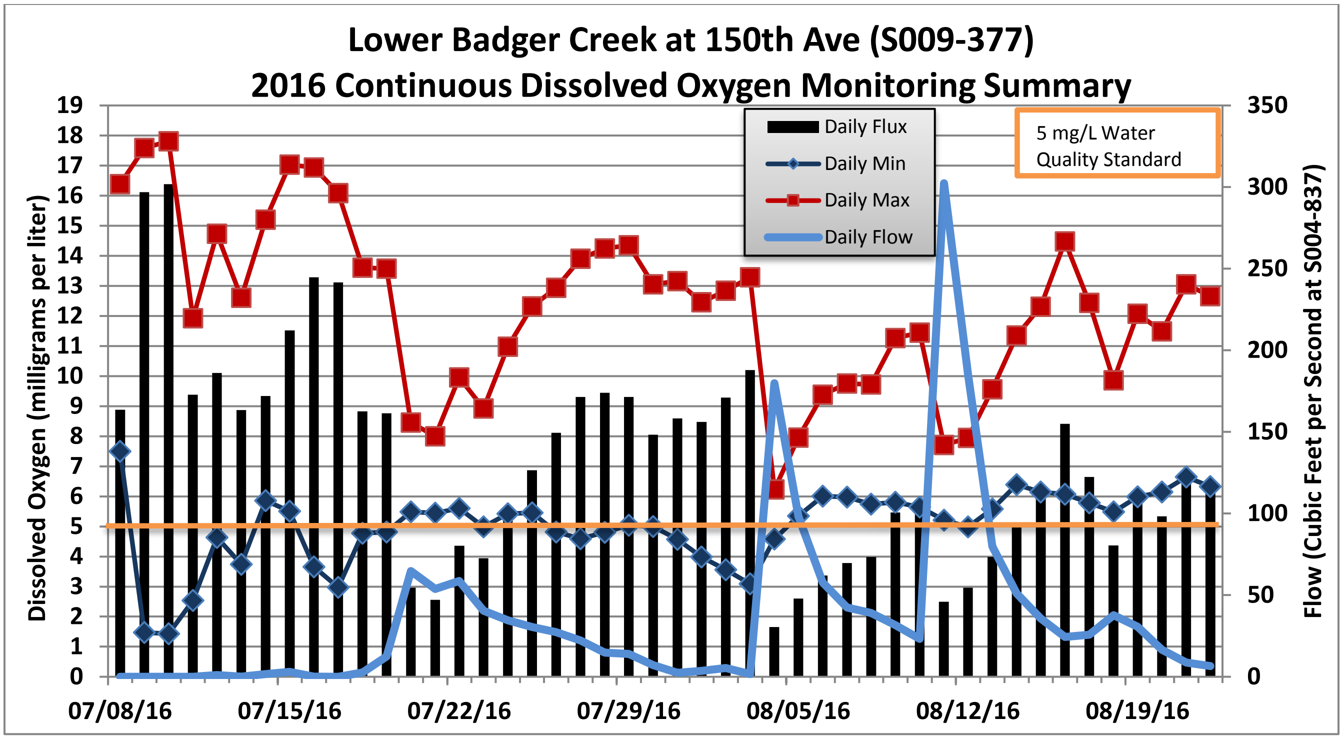

Figure 74: 2016 continuous DO data measured at Lower Badger Creek near 150th Avenue. Gage data is from the RLWD site located at S004-837 on Lower Badger Creek.

Table 29: Displays the number of fish taxa that are tolerant and intolerant to select water quality parameters in Lower Badger Creek (AUID 502).

Monitoring Station	TSS Tolerant Taxa	TSS Intolerant Taxa	Probability of passing TSS standard	DO Tolerant Taxa	DO Intolerant Taxa	Probability of passing DO standard
07RD026	1	0	0.66	3	0	0.35
14RD239	2	0	0.70	5	0	0.56
14RD237	2	1	0.77	4	0	0.56

This AUID has macroinvertebrate data from 14RD237 and 14RD239. The macroinvertebrates pass the M-IBI score however; we can look at macroinvertebrate community characteristics to determine if they agree with the stressors potentially associated with the fish community. The macroinvertebrate community index scores were ranked against all Class 5 sites across the state. The following table shows the relative rank of the two biological sites in this AUID against the rest of Class 5. According to the DO index score, the macroinvertebrate community does not have a DO related problem. Both sites rank near or above the third Quartile (Table 28). This information agrees with the fish community Index scores at sites 14RD237 and 14RD239. There was no macroinvertebrate sample at 07RD026.

Although the biologic data do not suggest that low DO is a dominant stressor in Lower Badger Creek, the extreme DO variability and super saturation is possibly influencing the aquatic biological community. Low DO is an inconclusive stressor to the aquatic life in this AUID.

Table 30: Displays the number of macroinvertebrate taxa that are tolerant and intolerant to select water quality parameters in AUID 502 (Lower Badger Creek).

Site	DO Index	DO Intolerant Taxa	DO Tolerant Taxa	TSS Index	TSS Intolerant Taxa	TSS Tolerant Taxa	Nitrogen Intolerant Taxa	Nitrogen Tolerant Taxa
14RD237	7.679	5	10	14.804	2	9	1	16
14RD239	7.168	6	5	4	6	11	5	23

Suspended sediment

Total suspended solids (TSS) measurements were made 67 times at monitoring station S004-837 between 2008 and 2015. The average TSS concentration was 10.6 mg/L with a maximum of 102 mg/L. The standard for TSS in the Central region is 30 mg/L. The TSS measurements made exceeded the 30 mg/L standard 7.4% of the time, which is below the 10% exceedance required to list the site as impaired for TSS. Data from the fish and macroinvertebrate samples also suggest that the biology is not impacted by elevated TSS levels. Table 27 and 28 show the fish and macroinvertebrate number of tolerant and intolerant taxa to TSS. TSS is not a stressor to the aquatic life in Lower Badger Creek.

Flow alteration

A hydrologic model was built for Lower Badger Creek using the Hydrologic Simulation Program - FORTRAN (HSPF) model, spanning a period from 1996 through 2009. The results of the model show that Lower Badger Creek has flashy flows due to the land use characteristics of the watershed. The peak discharge modeled was 769 cfs, with a minimum of 0.23 cfs and a mean of 27 cfs. The model estimated that 37% of the record yielded a discharge less than 5 cfs, and 7% of the record had a discharge of less than 1 cfs. Discharge greater than 100 cfs occurred for 6.2% of the modeled record.

Continuous stage data was collected from spring to late fall in 2012-2016 on Lower Badger Creek at County Road 114 (S004-837). From this data, a total of 1,078 days, daily average and daily minimum flows were computed to determine what percent of the time discharge was measured below 0.1 cfs and 1.0 cfs (Table 29). Although spanning different time periods, the HSPF model results are quite different than those based on the continuous measurements. Where the modeling results show that Lower Badger Creek yields a discharge less than 1.0 cfs only 7% of the time, the continuous data collected in 2012-2016 show that it was much more often, averaging 33% of the time.

Table 31: Lower Badger Creek low flow summary statistics at S004-837 for discharge collected from 2012 -2016

	Dates in record	Total number of days in record	% Discharge less than 0.1 cfs	% Discharge less than 1.0 cfs	Maximum discharge cfs	
Total discharge record (daily average discharge)	3/30/2012 – 12/8/2016	1078	30.7	33.5	477	
Individual Year stats (daily average discharge)						
2012	3/30/2012 -- 10/27/2012	212	75	78	43	
2013	4/25/2013 -- 8/15/2013	111	27	29	250	
2014	4/8/2014 -- 11/19/2014	226	9.3	8	320	
2015	3/11/2015 -- 11/24/2015	259	39	35	477	
2016	3/14/2016 -- 12/8/2016	270	16	12	302	

Biological response - fish

Flow regime instability tends to limit species diversity and favor taxa that are trophic generalists, early maturing, pioneering, short-lived, and tolerant of environmental disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Some evidence considered in a causal analysis between flow alterations and the F-IBI associated with AUID 502 is provided by the following individual F-IBI metric responses (see Appendix A for more information):

- Above average (>60%) combined relative abundance of the two most abundant taxa (DomTwoPct) at stations 14RD239 (70%) and 07RD026 (54%)
- Above average (>83%) relative abundance of early-maturing individuals with a female mature age equal to or less than two years (MA<2Pct) at stations 14RD237 (91%), 14RD239 (91%), and 07RD026 (71%)
- Above average (>11%) relative abundance of taxa that are pioneers (PioneerTxPct) at stations 14RD237 (18%) and 14RD239 (11%)
- Below average (<21%) relative abundance of taxa that are sensitive (SensitiveTxPct) at stations 14RD237 (18%), 14RD239 (11%) and 07RD026 (9%)
- Above average (>50%) relative abundance of individuals that are tolerant (TolPct) at stations 14RD237 (19%), 14RD239 (61%), and 07RD026 (38%)

However, the fish data that was analyzed for Lower Badger Creek does not indicate a direct link between the fish community and flow alterations, a lack of baseflow during the summer months will directly impact the fish species found in the stream.

Lack of habitat

Habitat was evaluated using the MPCA Stream Habitat Assessment (MSHA). The score for station 14RD237, assessed during the June 17, 2015 sampling event, was 71 out of 100. This places the habitat at this station in the "good" category out of poor, fair, or good possibilities. The MSHA score at site 14RD239, assessed during the August 5, 2014 sampling event, was 63.8. This places habitat at 14RD239 in the "fair" category. Under the MSHA's "Channel morphology" and "Substrate" categories, this site scored only 50/100, which is a primary driver of the overall low score here. Also noted was scant channel diversity in the "Channel development" section, where 85% of the sampled reach was "run," 10% was "pool," and 5% riffle. Two substrate types, gravel and sand dominated all three-habitat types. Five in-stream cover types were present but in moderate amounts. Site 07RD026 was sampled on August 9, 2007, and the MSHA score was 60. This places the habitat in this reach as "fair". The reach had 95% run and 5% pool. Both categories had gravel and sand as the dominant substrate. Site 07RD026 was sampled again on June 22, 2016 for fish, and the MSHA score was 42.9. This score places the habitat in the reach as "poor". The main difference during the two sampling events were a lack of riparian cover, difference in land use score, and significant drop in the channel development score. The fish IBI scores at 07RD026 were nearly identical (33 in 2007 and a 37 in 2016). In 2016, it was noted that the channel was dredged and bank shaping was evident along with only one velocity type and moderate channel stability.

Biological response-fish

Evidence of a causal relationship between lack of habitat and the F-IBI associated with AUID 502 is provided by the following individual F-IBI metric responses (see Appendix A for more information):

- Above average (67%) relative abundance of the dominant two species of fish (DomTwoPct) at Station 14RD239 (70%)

The fish metrics analyzed do not show that a lack of habitat is affecting the fish community at 14RD237, 14RD239 or 07RD026. Based on the MSHA scores and the individual fish metrics analyzed, it is concluded that lack of habitat is not stressing the fish community in Lower Badger Creek.

Lack of connectivity (fish passage)

Lower Badger Creek flows into the Clearwater River 0.4 mi. east of the intersection of T-22 and T-37, just southwest of Red Lake Falls. There are no identified dams on the Clearwater River downstream of the confluence or along the reach of Lower Badger Creek (AUID 502). There are nine road crossings in this AUID, though an aerial photo review suggests that the road crossings are not a problem because there are no visible scour pools on the downstream sides of the crossings. The lack of a scour pool indicates that the culverts are properly sized and sloped, and that fish should be able to pass. There was one identified beaver dam near site 14RD237 that appears to be a partial obstruction to fish passage (Figure 74).

Figure 75: Beaver dam, photographed on August 19, 2014, partially obstructing the channel in the farthest downstream portion of Lower Badger Creek, site 14RD237.

Channelization of this AUID begins at site 14RD239 and the entire AUID upstream of this site has been channelized. A photo taken on August 5, 2014 during a sampling event shows the condition of the current channel near site 14RD239 (Figure 75) and 07RD026 (Figure 76). This photo shows that the channel is incised and cannot gain access to the floodplain during the normal bankfull flow event. This incision can cause excess sheer stress on the banks and cause bank failure along with the introduction of sediment to the streambed. The degree of incision is also seen by review of the flow gage station data. The channels are designed to move water of the landscape quickly thus altering the available water at base flow conditions. Lack of connectivity does not appear to be a stressor. There is no evidence suggesting that fish cannot pass when water is available in the channel.

Figure 76: Site 14RD239 (August 5, 2014). Channelization begins in the AUID at this point, and is significantly altered upstream. Note the heights of the banks. Channel appears incised, not allowing high flows to access the floodplain during the bankfull flow event.

Figure 77: Site 07RD026 on 8/9/2007. Site is channelized. Based on MSHA from 2007, the site meets General Use category. Site will be resampled in 2016 and new MSHA (42.9) to determine its attainable use class.

4.11 Appendix A – Fish data

Relative abundance (%) of individuals per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics												
				BenInsectPct	DetNWQPct	DomThreePct	DomTwoPct	ExoticPct	GeneralPct	HerbvPct	InsectCypPct	Insect-TolPct	IntolerantPct	MA<1Pct	MA<2Pct	MA>3-TolPct
502	07RD026	8/9/07	5	14	7	67	54	0	60	0	16	2	0	10	71	0
	14RD239	8/5/14	5	19	6	81	70	0	71	0	4	2	0	16	91	4
	14RD237	6/17/15	5	18	11	59	45	0	41	0	26	5	3	21	91	7
658	14RD260	6/23/14	6	0	78	10	78	0	10	0	0	0	0	56	78	0
652	14RD255	7/17/14	6	0	2.5	98	95	0	93	0	0	0	0	7.5	98	0
518	14RD216	8/5/14	5	15	5	69	60	0	67	0	0.6	1	0	15	90	5.
	05RD078	8/9/05	5	6	22	59	44	0	69	6	0	9	0	29	81	2
	14RD218	7/15/14	6	0	5	79	68	0	42	0	0	1	0	37	47	11
539	14RD221	7/8/14	5	10	17	56	39	0	56	0	6	1	19	5	60	8
	14RD253	7/15/14	5	2	17	78	61	0	95	1.	0.2	2	0	1.9	81	0.
656	14RD246	6/10/14	5	10	5	75	65	0	15	0	0	4	0	15	60	0
	14RD246	7/14/15	5	25	0	87	75	0	0	0	0	7	0	38	100	0
561	14RD243	6/10/14	7	0	0	10	100	0	0	0	0	0	0	10	100	0
645	14RD226	8/10/15	5	1.2	4	89	88	0	92	0.	2	5	0.4	1.2	46	2.
	07RD024	8/8/07	5	5	8	76	69	0	15	0	2	5	0	4	74	0.
	07RD024	7/8/14	5	13	6.5	67	58	0	55	0.	14	3	0	16	93	4.
646	05RD046	8/6/15	5	74	1.5	72	58	0	5	0	0	7	0	20	83	15
527	14RD231	7/16/14	6	6	18	83	64	0	85	0	3	1	2.3	10	79	1.
	14RD235	6/10/14	6	3	14	58	44	0	54	2.	7	1	0	37	87	0
	15EM098	6/17/15	6	5	5	71	50	0	76	0	2	8	0	21	95	0
Class 7 Basin Average				2.4	27	92	84	1.7	34	5	2.3	6	0.3	76	94	1.
Class 4 Basin Average				36	19	67	54	1	32	1	11	4	7	14	58	30
Class 5 Basin Average				14	20	72	60	1	50	4	8	2	3	33	83	5
Class 6 Basin Average				5	18	80	67	0	45	10	9	1	1	44	91	1

Relative abundance (%) of individuals per selected F-IBI metric (continued)

AUID Suffix	Station	Visit Date	Class	Metrics												
				Minnows-TolPct	NestNoLithPct	SLithopPct	SLvdPct	SSpnPct	TolPct							
502	07RD026	8/9/07	5	39	21	37	8	28	38							
	14RD239	8/5/14	5	15	15	19	2	6	61							
	14RD237	6/17/15	5	49	32	27	7	41	19							
658	14RD260	6/23/14	6	0	56	22	56	56	100							
652	14RD255	7/17/14	6	2.5	0	5	0	0	98							
518	14RD216	8/5/14	5	46	11	58	1.8	0.6	29							
	05RD078	8/9/05	5	13	12	36	22	8	78							
	14RD218	7/15/14	6	0	37	5.3	0	32	47							
539	14RD221	7/8/14	5	28	12	46	0.4	8.6	38							
	14RD253	7/15/14	5	18	3.5	74	42	1.7	79							
656	14RD246	6/10/14	5	10	75	15	0	30	10							
	14RD246	7/14/15	5	0	75	0	0	50	12							
561	14RD243	6/10/14	7	0	0	0	0	0	100							
645	14RD226	8/10/15	5	41	3.7	41	3	3	53							
	07RD024	8/8/07	5	8.3	71	17	2	55	13							
	07RD024	7/8/14	5	60	14	62	8.9	19	19							
646	05RD046	8/6/15	5	3	57	35	0	31	8							
527	14RD231	7/16/14	6	28	3.8	46	1.4	2.8	64							
	14RD235	6/10/14	6	22	8	39	18	2.2	74							
	15EM098	6/17/15	6	25	21	48	36	0	70							
Class 7 Basin Average				**9**	**43**	**5**	**46**	**28**	**82**							
Class 4 Basin Average				**22**	**18**	**55**	**13**	**15**	**23**							
Class 5 Basin Average				**27**	**26**	**37**	**28**	**21**	**50**							
Class 6 Basin Average				**24**	**29**	**23**	**44**	**24**	**66**							

Taxa richness (#) per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics												
				DarterSculp	General	Hdw-Tol	Piscivore	Sensitive	SLithop	SLithopGR1	SLvd	Vtol	Wetland-Tol			
502	07RD026	8/9/07	5	1	3	0	2	1	2	0	2	3	1			
	14RD239	8/5/14	5	3	4	0	3	4	5	0	4	1	3			
	14RD237	6/17/15	5	2	6	0	5	7	8	0	4	3	2			
658	14RD260	6/23/14	6	0	3	0	0	0	1	0	1	1	0			
652	14RD255	7/17/14	6	0	3	0	0	0	2	0	0	1	0			
518	14RD216	8/5/14	5	2	4	0	0	0	4	0	1	1	2			
	05RD078	8/9/05	5	2	6	1	0	2	3	0	6	3	3			
	14RD218	7/15/14	6	0	3	0	2	0	1	0	0	1	3			
539	14RD221	7/8/14	5	2	3	1	5	6	5	0	1	1	4			
	14RD253	7/15/14	5	1	4	1	3	2	3	0	5	1	2			
656	14RD246	6/10/14	5	1	2	0	2	0	2	0	0	1	1			
	14RD246	7/14/15	5	1	0	0	1	0	0	0	0	1	1			
561	14RD243	6/10/14	7	0	0	0	0	0	0	0	0	1	0			
645	14RD226	8/10/15	5	1	7	0	2	4	4	0	4	3	4			
	07RD024	8/8/07	5	2	6	0	2	2	4	0	4	4	2			
	07RD024	7/8/14	5	2	5	1	3	4	5	0	6	3	4			
646	05RD046	8/6/15	5	2	2	0	1	1	4	0	0	1	2			
527	14RD231	7/16/14	6	2	5	0	1	2	4	0	1	2	2			
	14RD235	6/10/14	6	1	4	2	0	2	3	0	4	1	2			
	15EM098	6/17/15	6	1	4	1	0	1	3	0	2	1	1			
Class 7 Basin Average																
Class 4 Basin Average				2	4	0	3	4	6	0	3	2	2			
Class 5 Basin Average				2	4	1	2	3	4	0	4	2	2			
Class 6 Basin Average				1	3	1	0	2	2	0	3	2	2			

Relative abundance (%) of taxa per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics												
				BenInsect-TolTxPct	DarterSculpSucTxPct	DetNWQTxPct	GeneralTxPct	HerbvTxPct	Insect-TolTxPct	PioneerTxPct	RiffleTxPct	SensitiveTxPct	SensitiveTxPctGR1	SensitiveTxPctGR4	SLithopTxPct	SSpnTxPct
502	07RD026	8/9/07	5	9	9	18	27	0	27	9	18	9	0	0	18	36
	14RD239	8/5/14	5	22	17	17	22	0	50	11	17	22	0	0	28	28
	14RD237	6/17/15	5	23	14	23	27	0	45	18	23	2	0	0	36	27
658	14RD260	6/23/14	6	0	0	67	100	0	0	67	33	0	0	0	33	33
652	14RD255	7/17/14	6	0	0	25	75	0	0	25	25	0	0	0	50	0
518	14RD216	8/5/14	5	18	18	9	36	0	36	18	18	18	0	0	36	9
	05RD078	8/9/15	5	15	15	23	46	15	23	23	7.7	15	0	0	23	15
	14RD218	7/15/14	6	0	0	14	43	0	14	14	14	0	0	0	14	14
539	14RD221	7/8/14	5	28	19	4.8	14	0	47	9	19	28	0	0	24	19
	14RD253	7/15/14	5	15	7.7	15	31	15	15	15	7.7	15	0	0	23	23
656	14RD246	6/10/14	5	14	14	14	28	0	28	14	14	0	0	0	29	14
	14RD246	7/14/15	5	25	25	0	0	0	0	25	0	0	0	0	0	25
561	14RD243	6/10/14	7	0	0	0	0	0	0	0	0	0	0	0	0	0
645	14RD226	8/10/15	5	13	7	33	47	7	33	20	13	27	0	0	27	40
	07RD024	8/8/07	5	22	11	17	33	0	33	17	17	11	0	0	22	39
	07RD024	7/8/14	5	16	11	21	26	5	37	16	11	21	0	0	26	37
646	05RD046	8/6/15	5	40	30	10	20	0	60	10	10	10	0	0	40	20
527	14RD231	7/16/14	6	17	17	8	42	0	42	17	17	17	0	0	33	17
	14RD235	6/10/14	6	9	9	18	36	18	27	18	9	18	0	0	27	18
	15EM098	6/17/15	6	13	13	13	50	0	25	25	13	13	0	0	38	0
Class 7 Basin Average				**4**	**4**	**23**	**32**	**10**	**14**	**20**	**5**	**18**	**0**	**0**	**7**	**28**
Class 4 Basin Average				**29**	**23**	**18**	**24**	**2**	**45**	**11**	**18**	**22**	**0**	**-16**	**41**	**18**
Class 5 Basin Average				**19**	**15**	**19**	**33**	**6**	**33**	**17**	**14**	**21**	**0**	**0**	**30**	**22**
Class 6 Basin Average				**9**	**8**	**18**	**37**	**10**	**22**	**20**	**9**	**23**	**0**	**0**	**21**	**25**

Relative abundance (%) of taxa per selected F-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics												
				TolTxPct	VtolTxPct	WetlandTxPct										
502	07RD026	8/9/07	5	45	27	27										
	14RD239	8/5/14	5	28	5.5	22										
	14RD237	6/17/15	5	27	14	18										
658	14RD260	6/23/14	6	10	33	33										
652	14RD255	7/17/14	6	75	25	25										
518	14RD216	8/5/14	5	36	9	27										
	05RD078	8/9/05	5	62	23	54										
	14RD218	7/15/14	6	43	14	57										
539	14RD221	7/8/14	5	19	4.8	29										
	14RD253	7/15/14	5	46	7.7	23										
656	14RD246	6/10/14	5	29	14	29										
	14RD246	7/14/15	5	25	25	50										
561	14RD243	6/10/14	7	10	100	100										
645	14RD226	8/10/14	5	33	20	40										
	07RD024	8/8/07	5	50	22	28										
	07RD024	7/8/14	5	37	16	26										
646	05RD046	8/6/15	5	20	10	30										
527	14RD231	7/16/14	6	42	17	33										
	14RD235	6/10/14	6	54	9	36										
	15EM098	6/17/15	6	63	13	38										
Class 7 Basin Average				**68**	**40**	**78**										
Class 4 Basin Average				**22**	**10**	**18**										
Class 5 Basin Average				**43**	**18**	**39**										
Class 6 Basin Average				**57**	**25**	**58**										

4.12 Appendix B – Macroinvertebrate data

Relative abundance (%) of individuals per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics											
				BurrowerPct	ChironomidaeChPct	ChironominiPct	Collector-filtererPct	DomFiveCHPct	HBI_MN	LeglessPct	LongLivedPct	SprawlerPct	SwimmerPct	TrichwoHydroPct	VeryTolerant2Pct
518	14RD216	8/04/14	7	0.3	6.4	25.0	73.7	88.5	6.5	10.3	1.3	5.8	9.9	0.0	5.1
	14RD216	8/17/15	7	3.0	24.1	48.1	21.3	44.2	6.5	29.6	9.5	5.5	27.7	4.0	19.2
	14RD218	8/06/14	6	6.5	5.6	16.7	71.0	90.0	6.6	15.0	0.0	11.8	3.4	0.6	8.4
652	14RD255	7/29/14	5	0.9	7.8	48.0	87.5	92.8	6.4	9.4	0.0	2.2	5.0	0.0	5.0
	14RD255	8/05/15	5	6.6	50.0	43.8	37.8	65.6	7.3	56.6	0.0	8.8	2.5	0.9	38.4
527	14RD231	7/30/14	5	2.1	40.7	29.3	35.2	64.2	7.5	51.1	2.4	19.6	5.5	2.8	49.8
	14RD235	7/30/14	6	14.2	80.5	38.5	34.7	57.6	7.2	85.8	1.9	13.9	2.5	0.3	44.6
	15EM098	8/5/15	5	22.3	35.5	61.8	9.4	49.4	6.5	55.5	22.3	9.4	2.6	6.5	40.6
646	05RD046	8/24/05	7	9.4	21.5	56.3	4.2	60.1	7.1	23	16	24.8	5.7	3.6	21.5
	05RD046	8/6/15	7	6.1	15.1	36.2	2.6	74.7	6	62.2	0.3	2.6	9.9	18.9	15.7
Class 6 Basin Average				**7**	**23**	**55**	**15**	**59**	**7**	**30**	**6**	**16**	**20**	**8**	**42**
Class 5 Basin Average				**11**	**31**	**38**	**16**	**59**	**7**	**50**	**5**	**19**	**10**	**5**	**46**
Class 7 Basin Average				**13**	**27**	**44**	**9**	**70**	**8**	**57**	**4**	**17**	**11**	**2**	**54**

Taxa richness (#) per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	Metrics										
				ClimberCh	ClingerCh	Intolerant2lessCh	IntolerantCh	Odonata	Plecoptera	POET	Predator	PredatorCh	TaxaCountAllChir	Trichoptera
518	14RD216	8/04/14	7	21.7	39.1	0.0	0.0	1.0	0.0	3.0	3.0	4.0	23.0	1.0
	14RD216	8/17/15	7	16.2	43.2	1.0	1.0	1.0	0.0	11.0	4.0	6.0	37.0	7.0
	14RD218	8/06/14	6	22.2	22.2	0.0	0.0	0.0	0.0	3.0	2.0	5.0	18.0	1.0
652	14RD255	7/29/14	5	13.6	31.8	1.0	1.0	0.0	1.0	3.0	3.0	4.0	22.0	1.0
	14RD255	8/05/15	5	19.4	27.8	0.0	0.0	2.0	0.0	8.0	3.0	8.0	36.0	2.0
527	14RD231	30-Jul-14	5	7.0	15.0	3.0	3.0	0.0	0.0	13.0	1.0	2.0	33.0	6.0
	14RD235	30-Jul-14	6	6.0	13.0	2.0	2.0	1.0	0.0	7.0	5.0	9.0	44.0	4.0
	15EM098	05-Aug-15	5	5.0	18.0	9.0	1.0	2.0	1.0	13.0	13.0	18.0	51.0	7.0
646	05RD046	24-Aug-05	7	5.0	19.0	4	6	1	1	12	11	16	47	4
	50RD046	06-Aug-15	7	8.0	8.0	1	0	1	0	5	4	6	27	3
Class 6 Basin Average				6	13	5	4	1	1	12	7	9	36	5
Class 5 Basin Average				7	13	4	3	1	0	10	7	10	40	4
Class 7 Basin Average				8	7	2	1	2	0	6	7	10	32	2

Relative abundance (%) of taxa per selected M-IBI metric

AUID Suffix	Station	Visit Date	Class	BurrowerChTxPct	ChironomidaeChTxPct	ChironominiChTxPct	ClingerChTxPct	InsectTxPct	LeglessChTxPct	LongLivedChTxPct	SprawlerChTxPct	SwimmerChTxPct	Tolerant2ChTxPct	TrichopteraChTxPct
518	14RD216	8/04/14	7	0.0	39.1	4.3	39.1	73.9	56.5	13.0	17.4	8.7	73.9	4.3
	14RD216	8/17/15	7	8.1	29.7	5.4	43.2	81.1	43.2	10.8	18.9	8.1	73.0	18.9
	14RD218	8/06/14	6	5.6	27.8	5.6	22.2	61.1	50.0	5.6	33.3	11.1	83.3	5.6
652	14RD255	7/29/14	5	9.1	45.5	13.6	31.8	86.4	68.2	0.0	22.7	18.2	68.2	4.5
	14RD255	8/05/14	5	13.9	52.8	19.4	27.8	88.9	66.7	2.8	25.0	5.6	77.8	5.6
527	14RD231	30-Jul-14	5	3.0	21.2	3.0	45.5	81.8	33.3	9.1	12.1	15.2	75.8	18.2
	14RD235	30-Jul-14	6	20.5	52.3	20.5	29.5	81.8	65.9	6.8	27.3	6.8	79.5	9.1
	15EM098	05-Aug-15	5	17.6	35.3	13.7	35.3	90.2	51.0	7.8	19.6	9.8	60.8	13.7
646	05RD046	24-Aug-05	7	14.9	36.2	21.3	40.4	89.4	42.6	14.9	19.1	10.6	74.5	8.5
	05RD046	06-Aug-15	7	18.5	40.7	11.1	29.6	77.8	66.7	3.7	7.4	3.7	63	11.1
Class 6 Basin Average				**5**	**28**	**11**	**34**	**88**	**40**	**11**	**19**	**15**	**73**	**14**
Class 5 Basin Average				**14**	**35**	**12**	**31**	**82**	**52**	**9**	**22**	**9**	**77**	**9**
Class 7 Basin Average				**14**	**32**	**11**	**22**	**78**	**53**	**8**	**20**	**13**	**84**	**4**

Macroinvertebrate TIVs and tolerance-related data

AUID Suffix	Station	Visit Date	Class	Data												
				Mean TSS TIV (mg/L)	TSS Tolerant Individuals (%)	TSS Intolerant Taxa Richness (#)	Mean DO TIV (mg/L)	DO Tolerant Individuals (%)	DO Intolerant Taxa							
518	14RD216	8/04/2014	7	4	11.4	2	7	5.5	1							
	14RD216	8/17/2015	7													
	14RD218	8/06/2014	6	4	4.1	2	7	10.2	0							
652	14RD255	7/29/2014	5	4	3.8	1	7	0.9	4							
	14RD255	8/05/2015	5													
	05RD078	8/24/2005	6	6.	27.6	4	6	15.9	6							
527	14RD231	30-Jul-14	5													
	14RD235	30-Jul-14	6													
	15EM098	05-Aug-15	5													
Class 6 Basin Average				**15**	**26**	**2**	**6**	**19**	**3.7**							
Class 5 Basin Average				**11**	**21**	**3**	**6**	**17**	**6**							
Class 7 Basin Average				**22**	**28**	**2**	**6**	**34**	**2**							

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