Watershed health

June 2019

Mississippi River Brainerd Watershed Stressor Identification Report

A study of local stressors limiting the biotic communities in the Mississippi River Brainerd Watershed

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Contents

Figures

Tables

Key terms & abbreviations

CADDIS	Causal Analysis/Diagnosis Decision Information System
EPA	U.S. Environmental Protection Agency
IWM	intensive watershed monitoring
MPCA	Minnesota Pollution Control Agency
SID	stressor identification
SOE	strength of evidence
TMDL	total maximum daily load
WRAPS	Watershed Restoration and Protection Strategy
AUID	Assessment Unit Identification Number
TP	total phosphorus
NOx	Nitrate + Nitrite
TSS	total suspended sediment
BOD_5	Biological Oxygen Demand 5 day test
TKN	Total Kjeldahl Nitrogen
NH4	ammonia
DO	dissolved oxygen
SOD	soil oxygen demand
GLO	general land survey
PLSS	public land survey system
IBI	index of biotic integrity
MIBI	macroinvertebrate index of biotic integrity
FIBI	fish index of biotic integrity
HUC	hydrologic unit code
MR-B	Mississippi River Brainerd Watershed
CSAH	county state aid highway
MSHA	Minnesota stream habitat assessment
YSI	Yellow Springs Instrument

Executive summary

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

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

This report summarizes SID work in the Mississippi River-Brainerd Watershed.

The Mississippi River –Brainerd Watershed starts near the outlet of Big Sandy Lake on the Mississippi River and flows downstream to the City of Little Falls. The main tributaries that flow into the Mississippi River are the Rice River near Aitkin, the Nokasippi River near Fort Ripley and the Swan River near Little Falls. Land classification by land use in the Mississippi River-Brainerd Watershed show that 30% of land cover type is forest, 28% is wetland and 25% is crop and/or pasture, 6% is developed, 6% prairie/shrub and 6% is water. Seven stream assessment unit identification numbers (AUIDs) were identified to have a fish impairment based on fish IBI scores. Eight streams were identified as having a macroinvertebrate impairment based on macroinvertebrate IBI score. These fifteen impairments are distributed among thirteen AUIDs and have been analyzed and the corresponding stressors have been identified to address the lack of biological communities.

This report is organized by stream assessment unit identification number or AUID. Each stream reach has its own unique AUID. Candidate causes are evaluated and either eliminated or validated as stressors to the biology. Existing data for water quality was used where available or new data was collected in 2017-2018 to help understand the interactions of common stream pollutants and the link to stream biology.

After examining many candidate causes for the biological impairments, the following stressors were identified as probable causes of stress to aquatic life: low dissolved oxygen (DO) concentrations, excess nutrients, longitudinal connectivity, flow alteration, excess sediment, and lack of habitat. Low DO concentrations are found throughout the impaired stream AUIDs and many of the low DO concentrations are linked to watersheds that have a high percentage of wetland acres that export low DO water. Ditching is also prevalent in a number of the low DO reaches. Ditching has altered how water is delivered through the stream system by increasing peak flow or by diminishing low flow. Ditching is also playing a role in the lack of suitable habitat in certain AUIDs. Table ES-1 lists the stream name and AUID number along with the most probable stressor to the impaired biology.

Table ES-1. The Table lists the stream name along with most probable stressor to the impaired biology

		Identified Stressor					
Stream Name	AUID 07010104	Low DO	Elevated Nutrients	Longitudinal Connectivity	Flow Alteration Ditching	Lack of Habitat	Excess Sediment
Little Swan River	570	**X**			**X**		
Trib. to Mississippi River	684	**X**		**X**	**X**	**X**	
Buffalo Creek	610						**X**
Little Buffalo Creek	695				**X**		**X**
Trib. To Sand Creek (Modified Use)	679	**X**	**X**		**X**	**X**	
Sisabagamah Cr	659				**X**	**X**	**X**
Sisabagamah Cr	677	**X**		**X**			
Rabbit Creek	688	**X**		**X**			
Rice River	505	**X**					
Rice River	649	**X**			**X**		
Hay Creek	682	**X**			**X**	**X**	
Little Willow River Diversion Channel (Modified Use)	691	**X**			**X**	**X**	
Little Willow River* Old Channel	701						
Whiteley Creek**	589						

*Stressor ID concluded impairment not caused by pollutant and moved to Category 4C.

**Site was resampled and data was received late and not evaluated for Stressor ID this cycle.

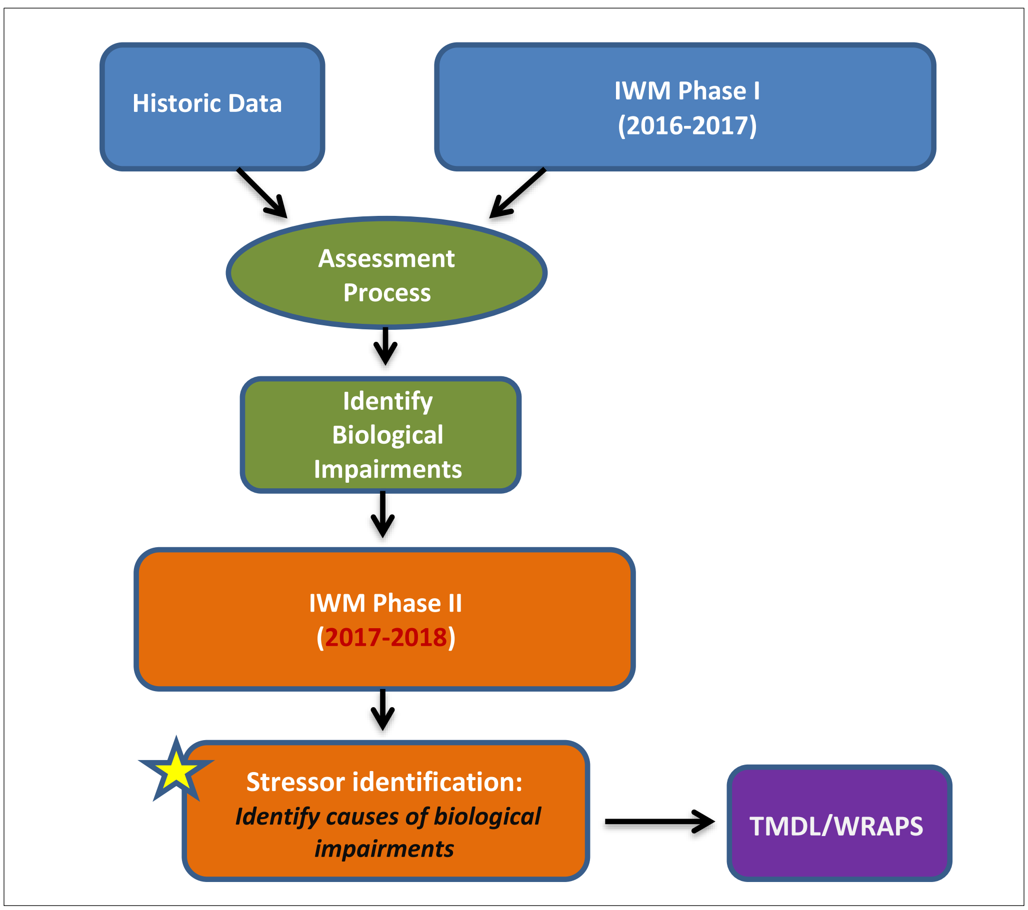
1. Introduction

1.1. Monitoring and assessment

Water quality and biological monitoring in the Mississippi River Brainerd have been ongoing for the past two years. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2016-2017, and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2016, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1.).

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

Figure 1: Process map of IWM, Assessment, SID and TMDL processes.

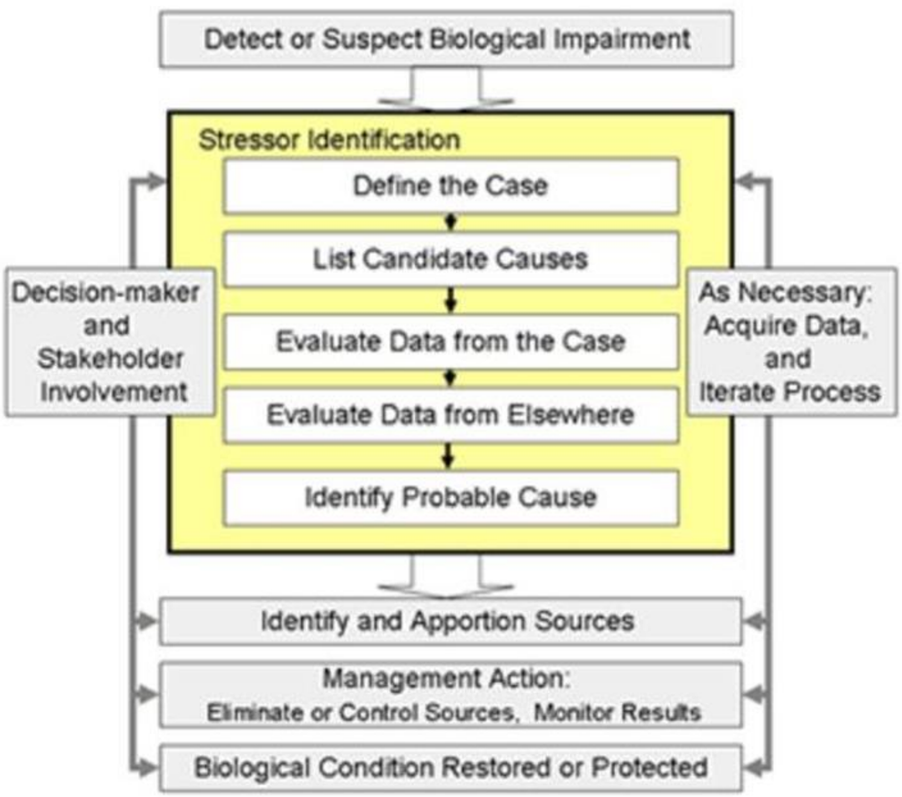


1.2. Stressor identification process

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

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

Figure 2: Conceptual model of SID process (Cormier et al. 2000).



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

Developed by the EPA, a standard scoring system is used to tabulate the results of the SOE analysis for the available evidence (Table A1). A narrative description of how the scores were obtained from the evidence should be discussed as well. The SOE table allows for organization of all of the evidence, provides a checklist to ensure each type has been carefully evaluated and offers transparency to the determination process.

The existence of multiple lines of evidence that support or weaken the case for a candidate cause generally increases confidence in the decision for a candidate cause. The scoring scale for evaluating each type of evidence in support of or against a stressor is shown in Table A2. Additionally, confidence in the results depends on the quantity and quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s) causing impairment. Additional detail on the various types of evidence and interpretation of findings can be found here: https://www.epa.gov/caddis-vol1/caddis-volume-1-stressor-identification-summary-tables-types-evidence

1.3. Common stream stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired water body. Table 1 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 1: Common streams stressors to biology (i.e., fish and macroinvertebrates).

Stream health	Stressor(s)	Link to biology
Stream connections	**Loss of connectivity** • Dams and culverts • Lack of wooded riparian cover • Lack of naturally connected habitats/ causing fragmented habitats	Fish and macroinvertebrates cannot freely move throughout system. Stream temperatures also become elevated due to lack of shade.
Hydrology	**Altered hydrology** **Loss of habitat due to channelization** **elevated levels of TSS** • Channelization • Peak discharge (flashy) • Transport of chemicals	Unstable flow regime within the stream can cause a lack of habitat, unstable stream banks, filling of pools and riffle habitat, and affect the fate and transport of chemicals.
Stream channel geomorphology	**Loss of habitat due to excess sediment** **elevated levels of TSS** • Loss of dimension/pattern/profile • Bank erosion from instability • Loss of riffles due to accumulation of fine sediment • Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.
Water chemistry	**Low dissolved oxygen concentrations** **elevated levels of nutrients** • Increased nutrients from human influence • Widely variable DO levels during the daily cycle • Increased algal and or periphyton growth in stream	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology

Stream health	Stressor(s)	Link to biology
	• Increased nonpoint pollution from urban and agricultural practices • Increased point source pollution from urban treatment facilities	tends to be dominated by a few tolerant species.
Stream biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

1.4. Report format

This SID Report follows a format to first summarize candidate causes of stress to the biological communities at the 8-digit hydrologic unit code (HUC) scale. Within the summary (Section 3), there is information about how the stressor relates broadly to the Mississippi River Brainerd Watershed, water quality standards and general effects on biology. Section 4 is organized by impaired AUID and discusses the available data and relationship to fish and macroinvertebrate metrics in more detail.

2. Overview of Mississippi River Brainerd Watershed

2.1. Background

The Mississippi River Brainerd (MR-B) Watershed covers 1,682 square miles (1,076,299 acres). There are five cities within the watershed with a population over 2100; they include Brainerd, Little Falls, Baxter, Crosby and Aitkin. The watershed is spread out over five counties with Aitkin and Crow Wing counties having the largest percentage of the watershed. Land use in the watershed is divided up by Forest (30%), wetland (28%), cropland (25%), Developed (6%), Prairie/shrub (6%) and water (6%). Figure 3 displays the major cities along with the locations of the biologically impaired streams in the watershed.

2.2. Subwatersheds

Due to the sheer size of the watershed and the presence of channelization and reservoirs, it is difficult to evaluate potential stressors to aquatic life without further stratifying the MR-B drainage into smaller sections. Although there may be some consistent chemical and physical stressors, found throughout the MR-B Watershed, some are likely acting locally, driven by landscape characteristics specific to a certain region of the watershed. For the purpose of addressing biological impairments in the MR-B, the watershed was stratified in the same 12-digit HUC units used in the MR-B Monitoring and Assessment Report. Figure 3 displays the aggregated 12 HUC subwatershed boundaries along with the biologically impaired stream AUIDs and location of larger cities within the watershed.

Land cover types in the MR-B watershed vary from southwest to northeast. The southwestern portion of the watershed has a higher amount of agricultural row crop and pasture/hay land cover while the northeastern portion of the watershed is dominated by forestland and wetland. Figure 4 displays the land cover types based on a 2011 National Land Cover Dataset.

Biological monitoring sites were distributed throughout the watershed Figure 5 displays the locations and ID numbers for the biological monitoring sites along with impairment status of selected AUIDs. Figure 6 displays the AUIDs that are impaired for biology and will be included in Section 4 of this report. Section 4 will break down the potential stressors to the biological communities impacted and also give potential strategies on what pollutants will need a TMDL.

Figure 3: Map of Mississippi River Watershed showing locations of cities within the watershed and impaired stream reaches for biology.

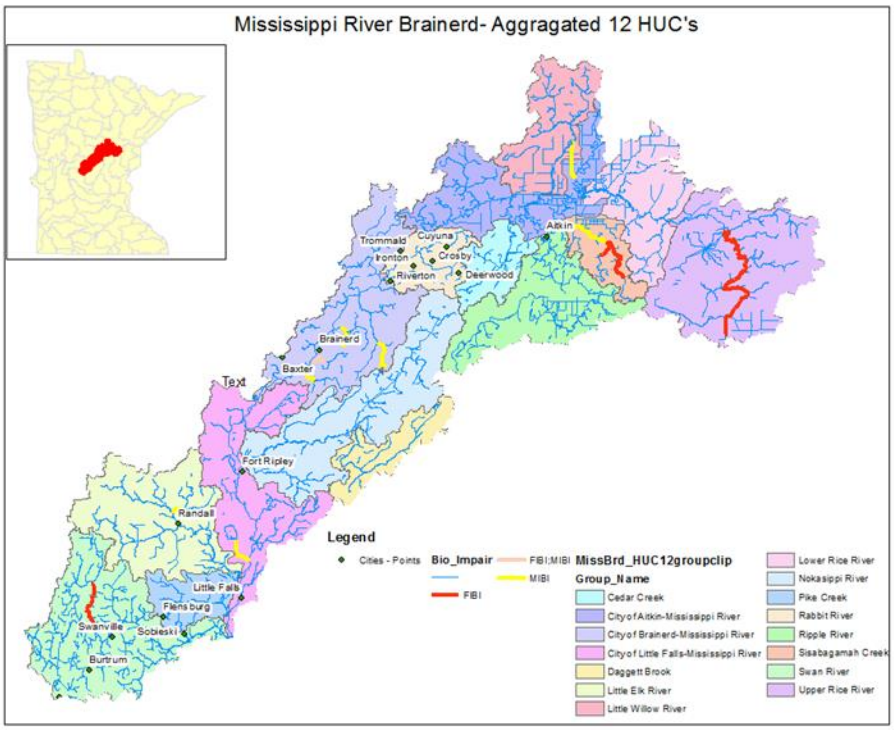


Figure 4: Map of land use cover types within the MR-B Watershed. Monitoring overview. Land use based on the 2011 NLCD land cover layer.

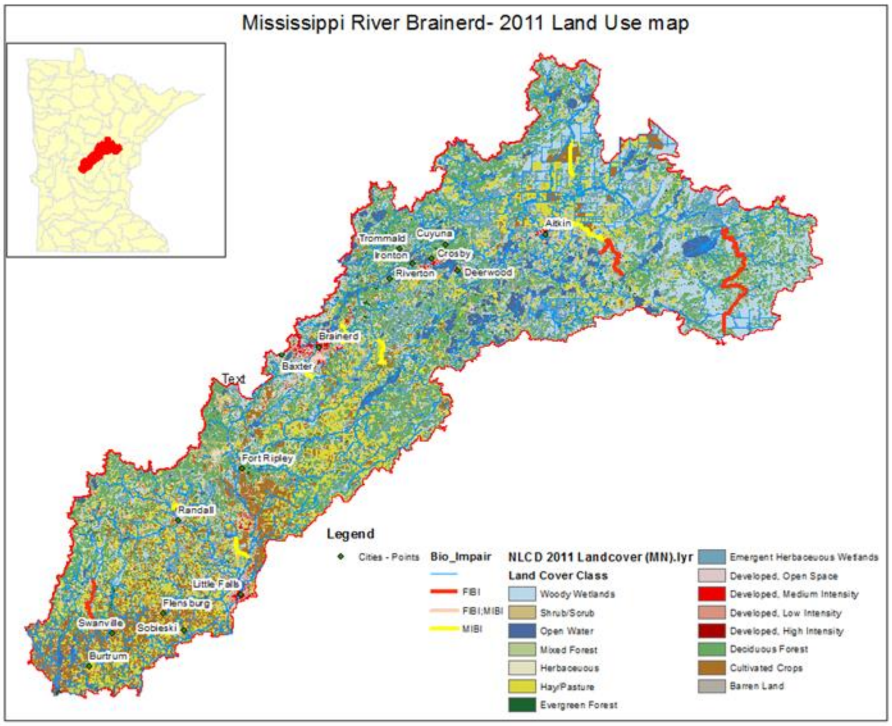


Figure 5: Map of monitoring stations in the MR-B Watershed.

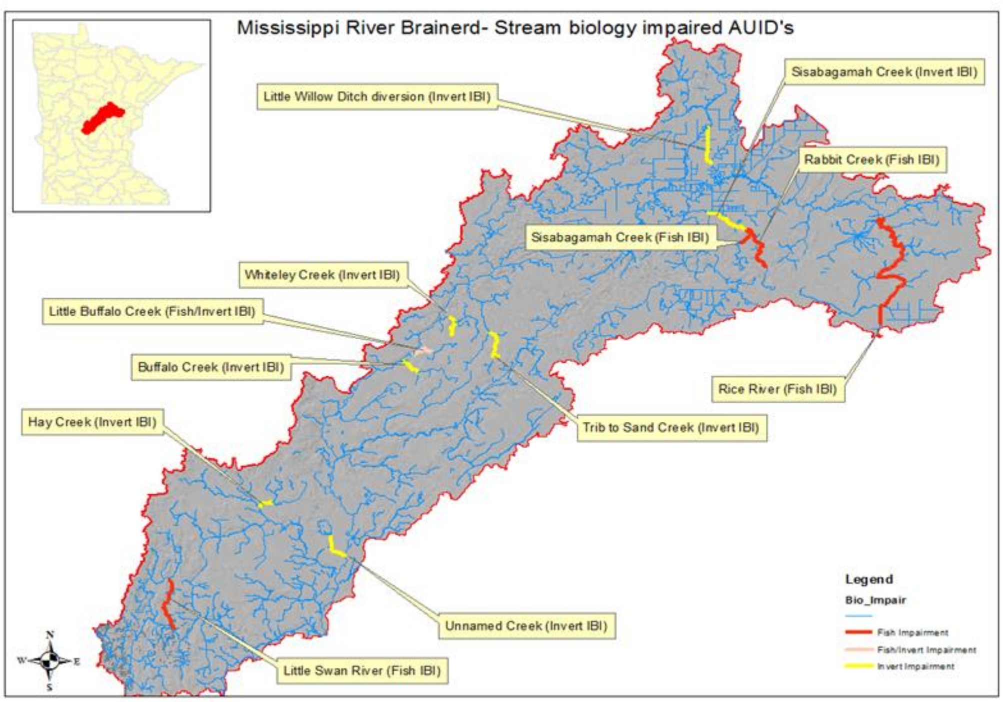
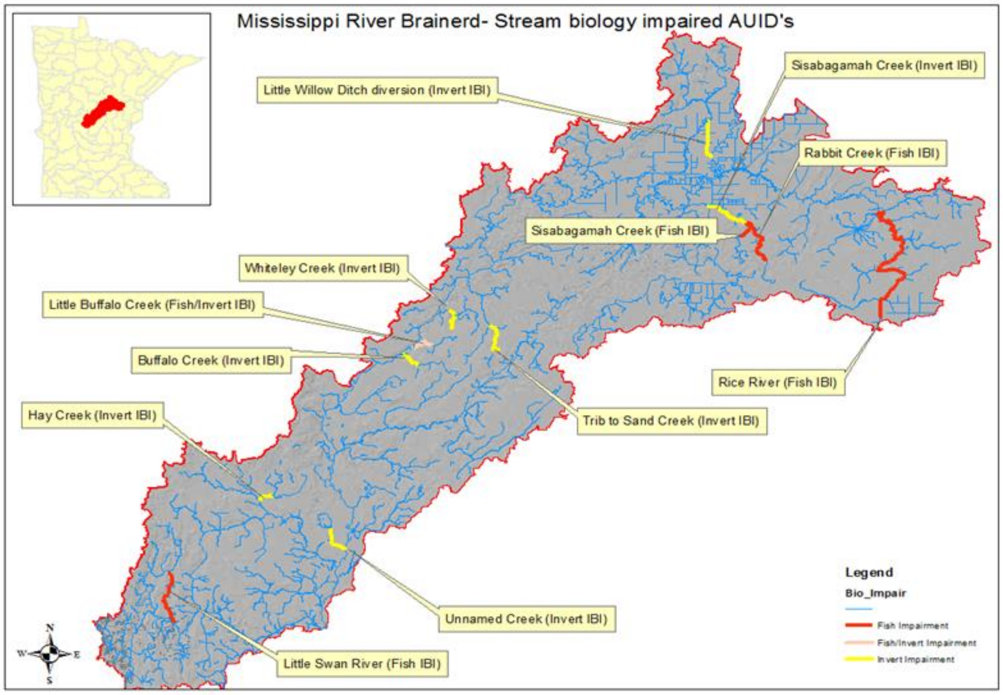


Figure 6: Map of impaired AUIDS in the MR-B Watershed.



2.3. Summary of biological impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrates communities and related habitat conditions at sites throughout a watershed. The resulting information is used to develop an IBI. The IBI scores can then be compared to range of thresholds.

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

In the **MR-B** Watershed, **twelve** AUIDs are currently impaired for a lack of biological assemblage (Table 2).

Table 2: Biologically impaired AUIDs in the MR-B Watershed.

			Impairments	
Stream name	**AUID #**	**Reach description**	**Biological**	**Water quality**
Rice River	07010104-505	Headwaters (Porcupine Lk 01-0066-00) to Section 5 Cr	Fishes Bioassessments	Dissolved Oxygen
Little Swan River	07010104-570	Spring Br to Swan R	Fishes bioassessments	Dissolved Oxygen
Buffalo Creek	07010104-610	Unnamed cr to Unnamed cr	Benthic macroinvertebrate bioassessments	
Rice River	07010104-649	Section 5 Cr to Wakefield Bk	Fishes bioassessments	Dissolved Oxygen, E.coli
Sisabagamah Creek	07010104-659	Unnamed cr to Mississippi R	Benthic macroinvertebrate bioassessments	
Sisabagamah Creek	07010104-677	Sisabagamah Lk to Rabbit Cr	Fishes bioassessments	Dissolved Oxygen
Trib. To Sand Creek (Modified Use)	07010104-679	Headwaters to Sand Cr (MU)	Benthic macroinvertebrate bioassessments	
Hay Creek	07010104-682	Unnamed cr to Little Elk R	Benthic macroinvertebrate bioassessments	
Trib. To Mississippi R.	07010104-684	Unnamed outlet to Mississippi R (MU)	Benthic macroinvertebrate bioassessments	Dissolved Oxygen
Rabbit Creek	07010104-688	Rabbit Lk to Sisabagamah Cr	Fishes bioassessments	
Buffalo Creek (Little Buffalo Creek)	07010104-695	Wright St to Mississippi R	Benthic macroinvertebrate bioassessments, Fishes bioassessments	E.coli
Little Willow River Diversion Channel (Modified Use)	07010104-691	Unnamed ditch to Flood Diversion Channel (4c)	Benthic macroinvertebrate bioassessments	

** Unnamed Creek -681 and Little Willow River -701, Stressor ID concluded impairment not caused by pollutant and moved to Category 4C.*

***Whiteley Creek -589, Site was resampled and data was received late and not evaluated for Stressor ID this cycle.*

Table 3 lists the fish stream class that all impaired stream reaches in the MR-B watershed are compared with. The assessment process is a weight of evidence approach that takes biological response into account along with water chemistry, physical, and exposure indicators when making decisions. The Monitoring and Assessment Report will give additional details on how each stream AUID was managed and the stream reaches were assessed.

Table 3: Fish classes with respective IBI thresholds and upper/lower confidence limits (CL) found in the MR-B Watershed.

Class	Class name	IBI thresholds	Upper CL	Lower CL
5	Northern Streams	50	59	41
6	Northern Headwaters	40	56	24
7	Low Gradient	40	50	30

Table 4 lists the macroinvertebrate stream class that all impaired stream reaches in the MR-B watershed were compared with.

Table 4: Macroinvertebrate classes with respective IBI thresholds and upper/lower confidence limits (CL) found in the MR-B Watershed.

Class	Class name	IBI thresholds	Upper CL	Lower CL
3	Northern Forest Streams RR	50.3	62.9	37.7
4	Northern Forest Streams GP	52.4	66	38.8
6	Southern Streams GP	46.3	60.4	33.2

The purpose of SID is to interpret the data collected during the biological monitoring and assessment process. Trends in the IBI scores can help to identify causal factors for biological impairments. The macroinvertebrate and fish IBI scores will be discussed in greater detail in section 4 of this report for the biologically impaired AUIDs. In general, the fish and macroinvertebrate IBI scores were above the threshold with the exception of the twelve AUIDs that are listed in Table 2. One common factor in AUIDs that failed for biology was generally low dissolved oxygen readings at various times of the summer.

Table 5: Fish and macroinvertebrate IBI scores by biological station within AUID. Key to color-coding in Table 6.

AUID & reach	Station	Year	Fish IBI score*	Fish class	Macroinvertebrate IBI score*	Macroinvertebrate class
701 (Little Willow Diversion)	17UM200	2017	**39**	7 (MU) (threshold 15)	**33.4**	4 (MU) (threshold 37)
676 (Sisabagamah)	16UM047	2016/17	**NA**		**37.9/42.0**	4
677 (Sisabagamah)	16UM046	2016	**31**	7	**61.3**	4
688 (Rabbit)	16UM032	2017	**34**	7	**59.2**	4
649 (Rice)	10EM088	2015	**39**	5	**43**	4
505 (Rice)	98NF143	2016	**31**	6	NA	
695 (Little Buffalo)	00UM015	2016	**16**	6	2017 (**24.2**)	3
610 (Buffalo)	16UM001	2016/17	**69**	6	**38.7**/**40.7**	3
679 (trib. to Sand)	16UM042	2016/17	**71**	7	**17.3/19.9**	4
682 (Hay)	16UM011	2016	**69**	7	**29.3**	6
570 (Little Swan)	16UM018	2016	**33/35**	6	**67.1**	6
684 (Trib. To Mississippi R.)	16UM056	2016	**24**	7	**14.4**	6

Table 6: Key to color-coded IBI scores.

≤ lower CL	**> lower CL & ≤ threshold**	**> threshold & ≤ upper CL**	**> upper CL**	**NA = Not available**

These AUIDs typically had large wetland areas upstream that were contributing to a decreased dissolved oxygen concentration during periods of higher precipitation in July and oxygen consumption. Table 5 displays the IBI scores for the AUIDs that will be discussed in detail in Section 4 of this report.

Most of the impaired AUIDs above were only impaired for one of the biological metrics evaluated. Two of the AUID were impaired for both fish and macroinvertebrate, (684) Trib. To Mississippi River and Little Buffalo Creek in downtown Brainerd. Little Buffalo Creek has cold water potential but is affected by storm water drainage. The storm water drainage causes elevated stream temperature and very flashy flows during heavy rain events.

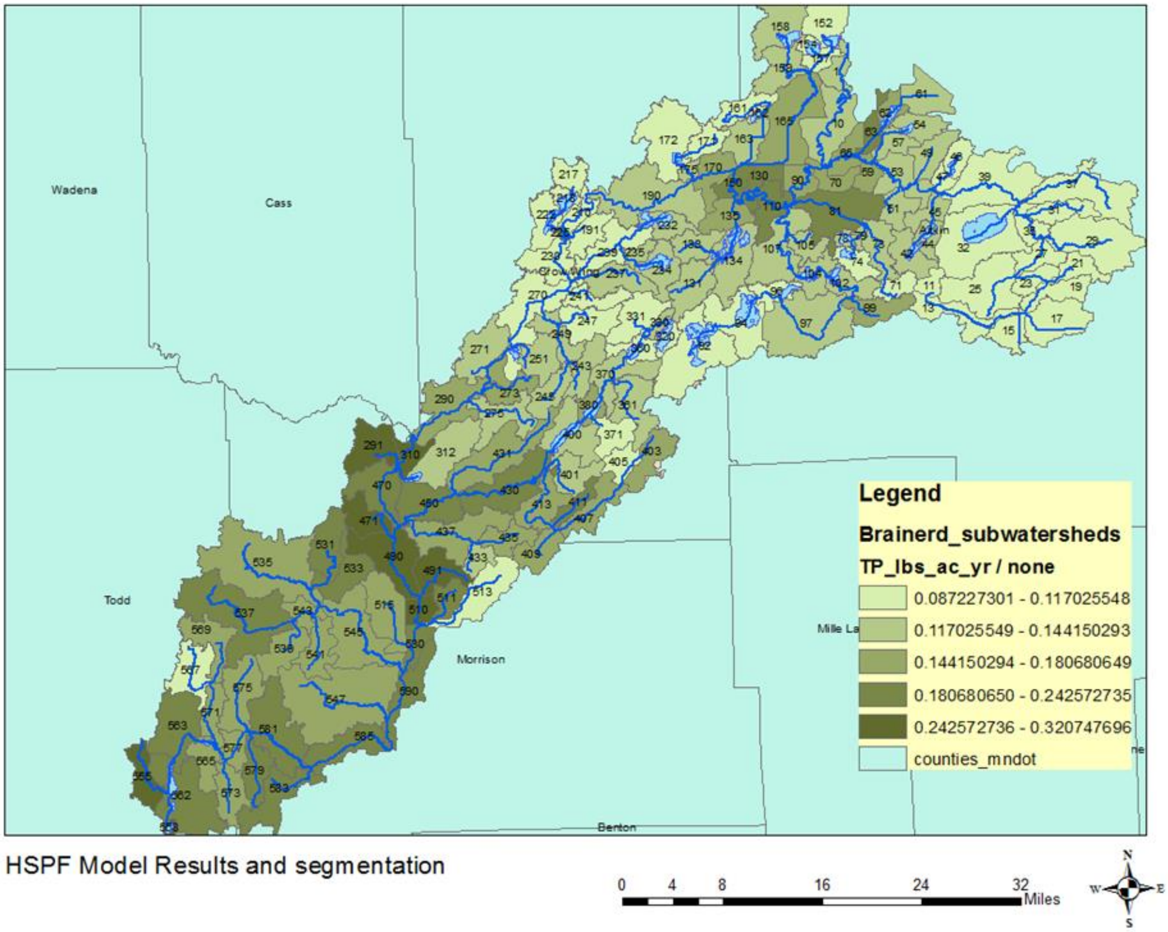
2.4. Hydrological Simulation Program – FORTRAN Model

The Hydrological Simulation Program – FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale Agricultural Runoff Model (ARM) and Non-Point Source (NPS) models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.

The HSPF watershed model contains components to address runoff and constituent loading from pervious and impervious land surfaces, flow of water, and transport/transformation of chemical constituents in stream reaches. Primary external forcing is provided by the specification of meteorological time series. The model operates on a lumped basis within subwatersheds (HUC12). Upland responses within a subwatershed are simulated on a per-acre basis and converted to net loads on linkage to stream reaches within each subwatershed and the upland areas are separated into multiple land use categories.

An HSPF watershed model was run for the MR-B Watershed to predict water quality condition throughout the watershed on an hourly basis from 1999-2015. Model information such as nutrient and sediment runoff per acre were evaluated to determine if they were potential stressors to the biological community. Minor watersheds with biological impairments used the model output to supplement water quality analyses. Refer to Figure 7 showing a map of the HSPF model numbered subwatersheds. Subwatersheds included in this study are Reach 81, 79, 73, 165, 273, 275, 243, 245, 249, 571, 569, 531 and 533. These reaches in the model correspond to the impaired AUIDs listed in Table 5.

Figure 7. HSPF modeled subwatersheds for the MR-B. Reach codes are used to label the subwatersheds and calculate loads for various parameters.



3. Possible stressors to biological communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found here (CADDIS Volume 2 | US EPA). This comprehensive list serves two purposes. First, it can serve as a checklist for investigators to consider all possible options for impairment in the watershed of interest. Second, it can be used to identify potential stressors that can be eliminated from further evaluation. In some cases, the data may be inconclusive and limit the ability to confidently determine if a stressor is causing impairment to aquatic life. It is imperative to document if a candidate cause was suspected, but there was not enough information to make a scientific determination of whether or not it is causing harm to aquatic life. In this case, management decisions can include modification of sampling plans and future evaluation of the inconclusive case. Alternatively, there may be enough information to conclude that a candidate cause is not causing biological impairment and therefore can be eliminated. The inconclusive or eliminated causes will be discussed in more detail in the following section.

3.1. Eliminated causes

Stream temperature was evaluated in all impaired AUIDs that had an adequate record of stream temperature. None of those streams were found to be thermally stressing to stream biology. The critical stress benchmark for stream temperature is 30 degrees Celsius (°C). There were no AUIDs with stream temperature data that approached the 30°C benchmark.

Nitrogen samples were also evaluated for AUIDs where nitrogen data was available. No stream AUIDs had elevated nitrogen data, so nitrogen was eliminated as a stressor in those streams. Although some streams did not have adequate nitrogen data to rule it out as a stressor initially, it was determined that there are other more likely stressors affecting the biology, which are discussed by AUID in the proceeding sections.

3.2. Inconclusive causes

Stream temperature data was limited in many of the impaired AUIDs. Streams that had under 10 records were determined to not have enough data. A lack of long temperature datasets covering a wide range of summer months left this stressor as inconclusive for some of the impaired reaches.

3.3. Summary of candidate causes in the Mississippi River Brainerd Watershed

Five candidate causes were selected as possible drivers of biological impairments in the MR-B Watershed. The initial list of candidate/potential causes was narrowed down after the initial data evaluation and analysis, resulting in the following five candidate causes for final analysis in this report: low DO, excess nutrients, lack of habitat, flow alteration, longitudinal connectivity, and total suspended solids (TSS) and/or bed sediment.

Background information specific to candidate causes/stressors in Minnesota can be found here. This information provides an overview of the pathway and effects of each candidate stressor considered in the biological stressor identification process, along with relevant data and water quality standards specific to Minnesota. The EPA has additional information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on its CADDIS website.

4. Evaluation of AUIDs

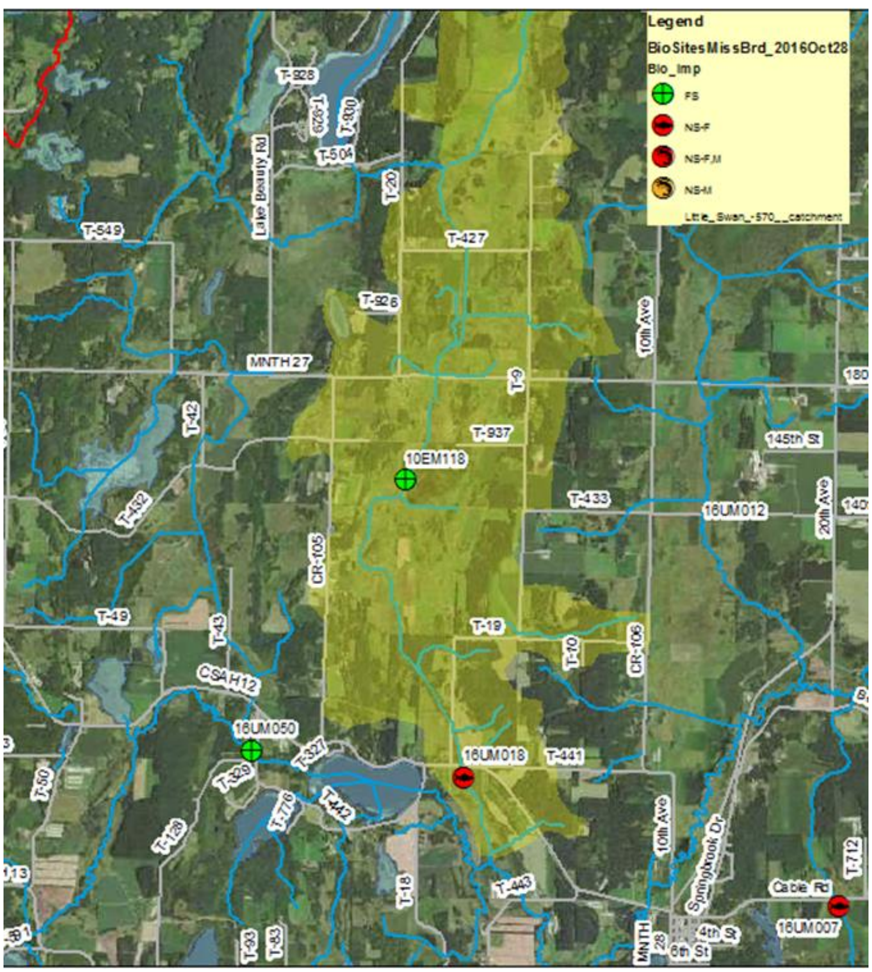
This section of the report will discuss the biological impairments along with the most probable causes of stress to the biological communities based on stream segment or AUID.

4.1. Little Swan River -570 (FIBI)

4.1.1. Biological communities

The reach of the Little Swan River that is AUID -570 is 6.21 miles long, and goes from Spring Brook downstream to the confluence with the Swan River. This subwatershed is part of the Swan River 12 HUC. There are two biological monitoring stations located on this AUID: 10EM118 and 16UM018 (Figure 8). The drainage area for this site is 26.17 sq. mi. The site is located on a channelized portion of the stream as well. Aerial photography reveals that the entire AUID is channelized and has been channelized since the 1939 aerial images were flown. A comparison of current stream conditions with those of the circa 1859 original Land Survey map show a misalignment of the old survey map's stream lines with the orange, straightened stream lines that represent current flow patterns of the Little Swan (Figure 11).

Figure 8: Little Swan River drainage area for AUID -570. The yellow highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM018 fails the aquatic life standard for Fish IBI score. Site 10EM118 meets the aquatic life standard for both fish and macroinvertebrate IBI scores.



Site 10EM118 was sampled for fish twice in 2010. This site is upstream of 16UM018 and had an average FIBI score of 39. Both samples were dominated by bigmouth shiner, central mudminnow and Johnny darter. The fish class 6-impairment threshold is 42. Macroinvertebrates were also sampled here in 2010 and were slightly above the class 6 threshold of 43, scoring a 44.3.

Site 16UM018 drains 30.13 sq. mi. and is located near the outlet of the Little Swan River. Two fish samples were collected at 16UM018 during 2016. The two samples averaged a 34 on the FIBI. This class 6 stream has a threshold of 42, and therefore does not meet the aquatic life standard for fish. The most common three fish species sampled were central mudminnow, Johnny darter, and white sucker. Central mudminnow are tolerant of many environmental stressors. They can survive in low DO water and breathe atmospheric oxygen. Macroinvertebrates were sampled at this site on August 17, 2016, and scored a 67 on the MIBI. They were well above the class 6 threshold of 43 and met the aquatic life standard.
The MSHA is the habitat evaluation score used by MPCA. There were three Minnesota Stream Habitat Assessment (MSHA) scores collected for site 16UM018. They averaged 47.3, which is on the lower end of fair, and near the “poor” category.

4.1.2. Data evaluation for each candidate cause

This section evaluates the five candidate causes of stress to aquatic life in AUID -570, which are: low DO, lack of habitat, flow alteration, longitudinal connectivity, and sediment.

Heavy rainfall occurred on July 9-11, 2016. This area received between 9-12 inches of rainfall during this time. Flows increased dramatically and dissolved oxygen concentrations dropped (Figure 9).

As the flow increased from a very low discharge, pre the July 9-11 rain event, it peaked at very high levels sometime on July 17, 2016. During this sudden and dramatic stream flow increase, the DO, Specific Conductance and pH values all dropped and became less variable throughout the daily cycle. Stream flow was measured at a location on the Swan River, near Sobieski on County State Aid Highway (CSAH) 238. DO concentrations from Little Swan River near 16UM018 were plotted against the Swan River discharge measurements (Figure 10). DO concentrations dropped significantly, as the stream reached flood flows for the event. This flow pattern would have been representative of the runoff in the Little Swan River as well. Though the peak discharge for Little Swan would be lower than that of Swan River, the sudden rise and general shape of the hydrographs are probably quite similar.

Figure 9: Continuous sonde water quality data collected on Little Swan River from June 22-July 18, 2016. On July 12, a large rain event occurred, dropping the in-stream DO levels. Note, "ODO" in the graph label represents DO.

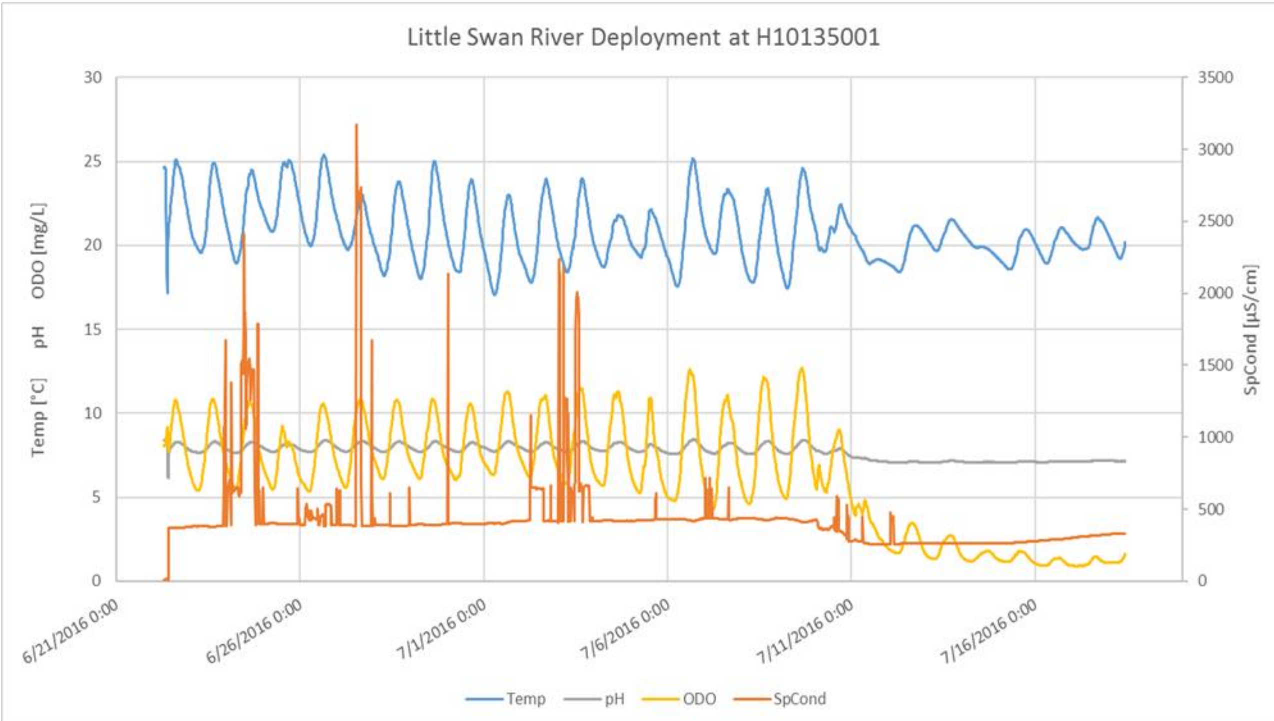
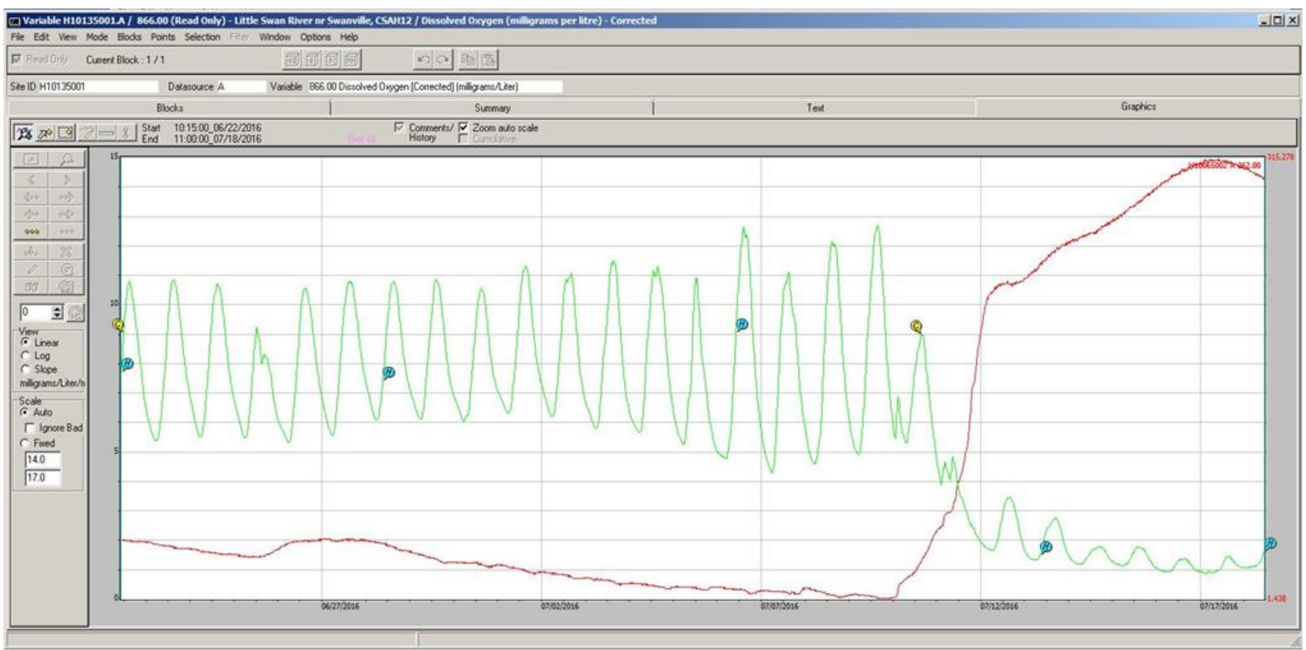


Figure 10: Stream flow (red line) from Swan River gage ([H10135001](H10135001)). DO concentrations from Little Swan at 16UM018 (green line) are plotted against discharge showing a strongly inverted relationship to flow. As flow increased, DO concentrations dropped significantly.



Roughly, 1.2 miles upstream from station 16UM018 there is a large, partially drained emergent wetland. This wetland is roughly 480 acres in size. Moving farther upstream near station 16UM019, there is another large emergent wetland that is partially drained. This wetland is approximately 550 acres in size. Both of these wetlands have the channelized Little Swan River running through the center. During periods of high flow, the wetlands have a floodplain connection to the river and water can spill out into the floodplain. This can trap nutrients and sediment but also can release nutrients back into the river. This may be one of the driving forces of low DO concentrations. The collected DO data from 2016 does show that low DO is a stressor to the biology during high flow events due to DO levels consistently below 5mg/L. The pictures below are from the 2016 sonde deployment period, and document the various flow and water clarity conditions during the deployment.

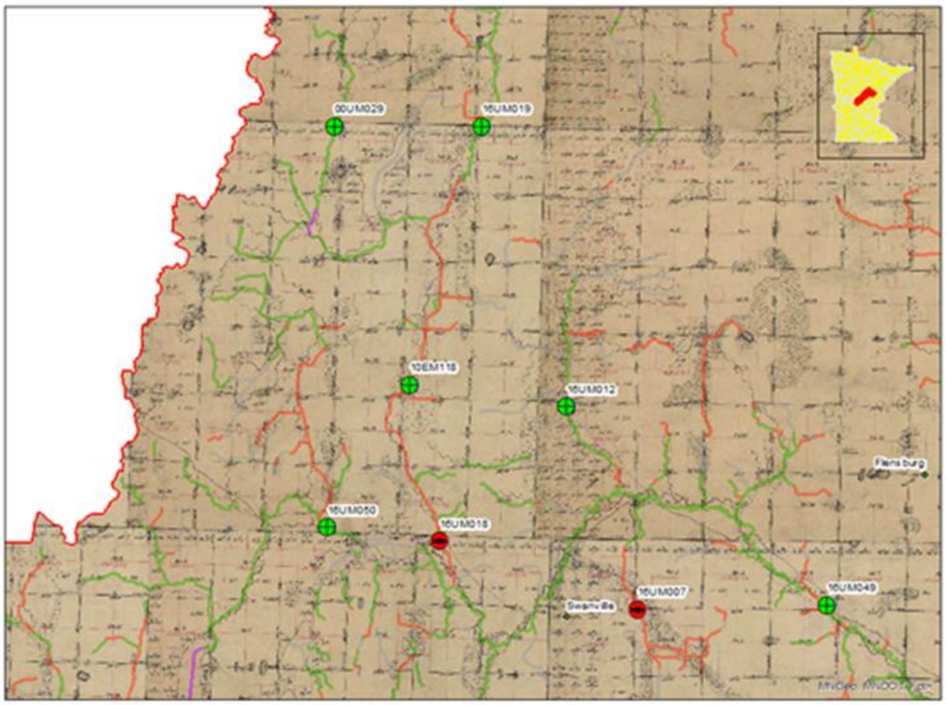

Little swan River sonde deployment on 6/23/2016


Little Swan 07/06/2016. pre rain event


Little Swan sonde retrieval 7/18/2016 higher flow

Figure 11: Map of Little Swan drainage area with the original Land Survey map, from circa 1859, as a background. The majority of drainage upstream of 16UM018 is channelized (orange is channelized; green is natural channel, from the MPCA's Altered Watercourse spatial data layer). Note the misalignment of the old survey map's streamlines with the orange, straightened streamlines that represent current flow patterns of the Little Swan.

Little Swan River (16UM018) General Land Survey map as background



No recent water chemistry data have been collected on the Little Swan River. In 2003, an extensive water quality dataset was collected from sampling site S002-377, on CSAH 12 (Table 7). Results from this sampling indicate that BOD can be elevated during the summer months. Biological Oxygen Demand (BOD) can help drive down the DO concentrations in streams and is often attributed to organic matter, such as animal waste, entering the stream. Upstream of this sampling location are some large pasture operations where livestock have free access to the stream. Anytime BOD is above 2.5 mg/L, the DO will generally be affected in a negative manner.

Table 7: Water quality data collected at site S002-377 on Little Swan River in 2003. All data collected between dates 6/16/2003 and 10/30/2003.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
NH4 [mg/L]	14	0.0786	0.19	0.05	0.0380
BOD_5[mg/L]	23	1.513	4.9	0.5	1.086
DO [mg/L]	27	6.52	11.02	1.29	2.76
TKN [mg/L]	26	1.101	1.91	0.72	0.330
pH	53	7.65	8.1	7.27	0.199
TP [mg/L]	12	0.039	0.082	0.028	0.013
Total suspended solids [mg/L]	22	6.89	34	1.2	9.16
Water Temperature [C°]	27	15.18	22.92	2.63	6.16

During the fish and macroinvertebrate sampling, a one-time water chemistry sample was collected (Table 8).

Table 8: Water chemistry results from the biological monitoring sampling events. Note that data from two different locations is displayed, and 16UM018 is co-located with site S002-377 from Table 7.

Date	Temp °C	DO mg/L	Sp. Cond. µS/cm	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
7/8/2010 10:25am 10EM118	20.8	5.04	390	7.8	0.07	0.14	0.101	6	2
6/23/2016 1:25pm 16UM018	22.7	9.66	307	8.07	0.1	0.201	0.067	3.2	3.2
8/4/2016 2:18pm 16UM018	24.35	7.82	402	7.62	0.1	0.212	0.117	3.6	2.2

Habitat was evaluated using MSHA scores. The average of the three site visits at 16UM018 revealed that the score was fair to poor (47). This may indicate that a lack of habitat is also stressing the fish community at site 16UM018. In the upstream biological samples at 10EM118, the fish and macroinvertebrates passed the IBI. Both of these upstream samples have very similar MSHA scores as the downstream site, 16UM018. The MSHA scores for the entire Little Swan River are fair or fair-poor. The channel has no depth or velocity variability throughout, and is almost all considered a "run" stream facet. The lack of depth variability and stream facet variability can be inhibiting the biological communities and should be considered a stressor to the biology in the stream.

4.1.3. Stressor pathway

Low DO does appear to be causing a reduced abundance of fish at the lower end of river system. The dropping in DO concentrations appears to be linked to the potential upstream wetland flushing events during periods of higher runoff. There is approximately 930 acres of partially drained wetlands upstream of the impacted reach. The drainage ditch runs through both of these upstream basins. Historically, these two basins were palustrine emergent vegetation wetlands that would be seasonally flooded. Once the ditch system was installed, the theory is that the fluctuating wet and dry cycle in the wetlands can export high chemical oxygen demand (COD) and/or have high soil oxygen demand (SOD), which will impact the downstream DO concentrations. Elevated nutrients do not appear to be driving the DO sags during higher flow periods. The nutrient data that is being analyzed is older data and a new data set of paired nutrient, BOD, and DO data should be collected if a DO TMDL is to be pursued.

Habitat limitations are also causing some stress to the biological communities. There is very little habitat variability in terms of riffles, pools, and runs in the system. Since the stream is completely channelized, the dominant stream feature is a run. This lack of variability can cause limitations in spawning habitat, rearing, flow refugia (areas for fish to escape high stream velocities), and feeding habitat for fish.

The stressor pathway in which low DO and lack of habitat are affecting the fish community in the Little Swan River may involve the historic ditching of the river, a type of flow alteration. As discussed already, draining wetlands can drop the DO levels in receiving streams. However, whether high flow events and wetland flushing had the same effect on Little Swan's DO levels before it was ditched is technically unknown. The physical impact of straightening the Little Swan would certainly have ruined valuable fish habitat. To what extent any of that habitat has reformed is also technically unknown, though it is known that ditching streams creates continuous "run" stream features, which is the Little Swan's main habitat issue. In sum, the low DO and lack of habitat stressors to the Little Swan River fish community are likely related to historic flow alterations, and any attempt to address these stressors should consider that stressor pathway.

4.1.4. AUID summary

Low DO during periods of high flow appear to be a main stressor to the biology, with lack of habitat also having an effect. The entire stream was channelized prior to 1939. Historical aerial imagery was used to evaluate the extent of historical ditching and the USDA 1939 aerial showed that the stream was channelized prior to that image. This suggests that the upstream emergent wetlands were partially drained even during the early 1930's. Since these wetlands are still functionally connected to the ditch during high water, it is very plausible that the wetlands are causing the DO sag when water can enter the basins. It is not clear the interaction of the ditch and the wetland but there is nearly 900 acres of partially drained wetlands upstream of site 16UM018.

4.2. Tributary to Mississippi River -684 (FIBI&MIBI)

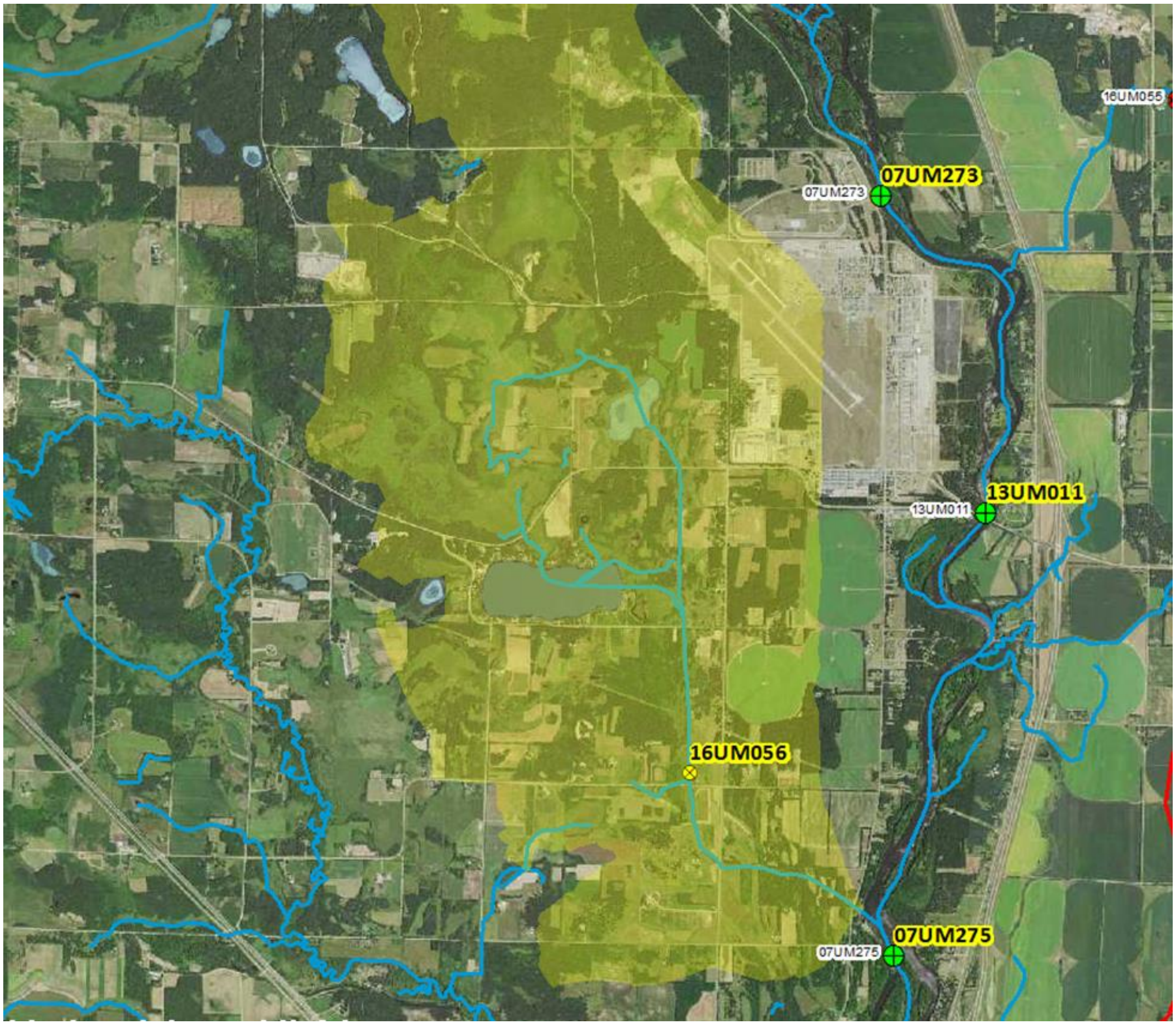
4.2.1. Biological communities

AUID -684 is a reach of the Trib. to the Mississippi River that is 2.77 miles long and goes from an unnamed outlet downstream to the confluence with the Mississippi River. This ditch is located in the City of Little Falls 12 HUC. There is one biological monitoring station, 16UM056, located on this AUID. Site 16UM056 drains 13.68 sq. mi and is located just upstream of the 200th St. Crossing.

Fish were collected on August 29, 2016 and scored a 24, which is below the IBI threshold of 42 for a Class 7 stream. The fish sample consisted of four species that are all tolerant to low DO conditions (central mudminnow, northern pike, brook stickleback and black bullhead).

Figure 12 shows the contributing drainage area for the Trib. To Mississippi River as it discharges to the Mississippi River at Grouse Road. The northeast portion of drainage area encompasses parts of Camp Ripley. There is a mixture of agricultural and forest lands in the subwatershed.

Figure 12: Trib. To Mississippi River drainage area for AUID -684. The yellow highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM056 fails the aquatic life standard for Fish and Macroinvertebrate IBI score.



Reviewing the macroinvertebrate community that was sampled can reveal community characteristics that are helpful in diagnosing potential stressors. MPCA has used this community based information to calculate conditional probability of macroinvertebrates passing the DO standard. If a sampled community has individuals that are tolerant to low DO, then the probability of passing the DO standard becomes lower.

Macroinvertebrates were sampled on August 24, 2016 and scored a 14.4, which is below the passing IBI threshold of 43. Based on the macroinvertebrate community sampled there is a 44% chance of passing Minnesota's water quality standard for DO. This suggests that the macroinvertebrate community is also dominated with low DO tolerant taxa. This class 6 stream fell way below a passing score even for a modified use stream.

The 2016 MSHA scored a 35.5, which indicates habitat is limiting. The channel morphology sub-category yielded a score of 3 out of a possible 35. There is no depth variability, sinuosity, or stream velocity variability within the sampling reach.

The current condition of the stream is ditched; however, the channel does not appear to have been maintained, as the banks were heavily vegetated and stable during biological sampling in 2016. However, in the winter of 2018, the entire channel was maintained between Hwy 115 and downstream of the sampling location. Below is photo documentation of the ditch maintenance that occurred on Unnamed Ditch in the winter of 2018. The photos are taken in a downstream direction. It can be noted that the channel width is narrower in the two upstream photos. Channel width and water depth are significantly different at the sampling location.

During sampling in 2016, the ditch had not been maintained very recently. Overall, it appears that not much has changed in the shape of the channel. The depth is slightly deeper and any accumulated fine sediment has been removed. By mid-summer in 2018, the channel was vegetated and appeared stable.

4.2.2. Data evaluation for each candidate cause

Water quality data from site S013-499, co-located with 16UM056, was collected in 2018 to understand the water chemistry in the stream (Table 9). Water chemistry data shows that nitrogen is not a stressor to the biology as all samples were below the detection limit. In addition, phosphorus concentrations are elevated but average below the state standard for the northern lakes and forest ecoregion. Elevated phosphorus can increase the macrophyte growth in the channel, which may increase the diurnal DO flux due to plant photosynthesis and respiration.

Table 9: 2018 water chemistry results for S013-499. This site is co-located with biological site 16UM056. Data were collected between 6/14/2018 and 8/29/2018.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.
NOx [mg/L]	4	<0.05	<0.05	<0.05
TP (mg/L)	4	0.047	0.146	0.031
Dissolved Oxygen [mg/L]	7	7.75	9.91	5.92
Temperature [°C]	7	19.38	24.3	12.75
Sp. Conductance [µS/cm]	7	226	325	183

During the 2016 fish and macroinvertebrate sampling, a one-time water chemistry sample was collected (Table 10). The difference observed in DO concentrations between the two biological sampling events is likely due to differences in the time of collection, as extreme temporal variability was also observed in diurnal DO flux during a 2017 sonde deployment (Figure 13).

Table 10: Water chemistry results from the two biological sampling dates at 16UM056.

Date	Temp °C	DO mg/L	Sp. Cond µmhos@25°C	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
8/29/2016 11:20am	18.62	3.15	220	7.21	0.1	0.02	0.035	2.8	2.6
8/24/2016 3:42pm	23.4	8.15	199.7	6.34	NA	NA	NA	NA	NA

Although low DO was not observed during the routine spot sampling that occurred in 2017, the biology that was sampled at this site was comprised of low DO tolerant communities. There is a 1 % chance of this AUID passing the DO standard based on the fish sampled. The macroinvertebrates also suggest that low DO is a main stressor. The sample had 0 intolerant taxa to low DO and 11 taxa that are tolerant to low DO. In addition, 81% of the relative abundance of the invertebrates were tolerant to low DO conditions. To investigate, a Yellow Springs Instrument (YSI) water quality sonde was deployed from June 28, 2017 through July 13, 2017 (Figure 13) to document the diurnal DO patterns.

Stream conditions went from very low flow during the first 9 days of deployment to slightly increased discharge during sonde retrieval. Using the Swan River stream gage as a surrogate for flow conditions at 16UM056, it is believed that this deployment may have been installed and operated at the lowest flow period for the year. Three site visits were made during the sonde deployment; photo 1 below documents the stream flow conditions during this time frame. The ditch had extensive submerged aquatic macrophyte growth. Daily DO dropped below 5 mg/L and showed highly variable diurnal fluctuation in the early part of the record. This diurnal fluctuation is caused by the macrophyte growth in the stream. Low DO is a stressor to the biology in the stream.

Figure 13: YSI sonde deployment at 16UM056 from June 27-July 12, 2017. Note that "ODO" in the graph represents DO.

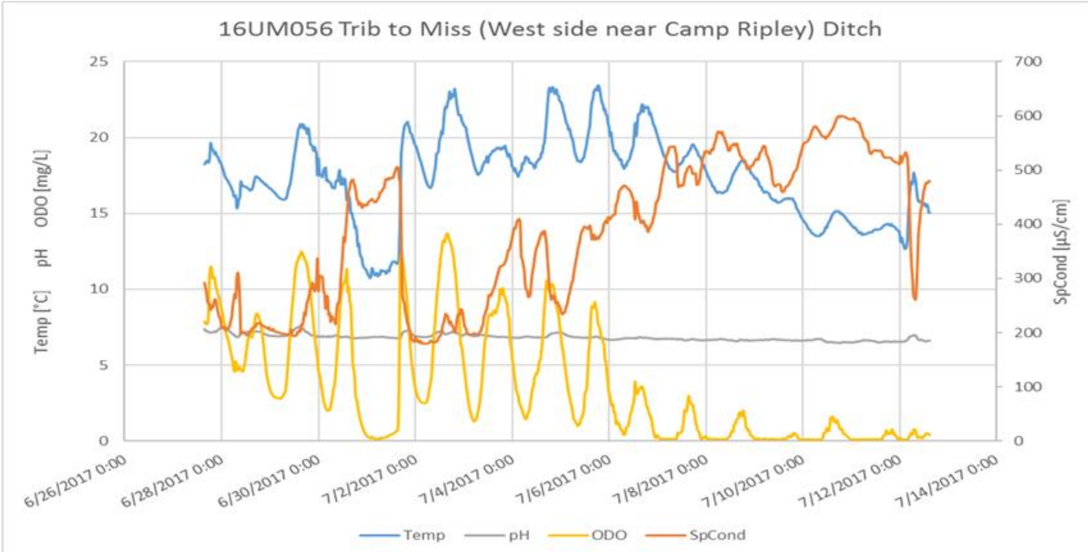


Photo 1: YSI sonde deployment conditions. Photo on left was taken on 6/27/2017 during the initial deployment. Stream flow was very low. Photo on the right was during sonde retrieval on 7/12/2017. Stream flow was also very low during this time. There was some rainfall that occurred during this period, which slightly increased stream discharge by July 12.

In addition to low DO, longitudinal connectivity appears to be a likely stressor. The road crossing located at Grouse Road has a three-foot drop (Photo 2) from the upstream to downstream side of the culvert, and the stream velocities are fast enough on the downstream side to partially impede fish migration during certain flow periods. Lack of longitudinal connectivity is a stressor to the fish community due to this road crossing. A highly variable flow regime has been documented in this ditch during field visits from 2016-2018. On September, 13, 2018 there was virtually no flowing water in the channel as seen in photo 3. This site inspection helps show that the stream can and often does get down to very low flow conditions. These annual drops in stream flow will have a negative effect on both fish and macroinvertebrate communities. The nature of the altered stream flow patterns due to channelization and a lack of upstream storage is causing stress to the stream biology.

Photo 2: Photos taken on 4/18/2017. Left photo: culvert inlet with drop. Right photo: high velocity stream flow on downstream side of crossing.

Photo 3: Photos taken on 9/13/2018. Stream flow is at 0 during this site visit. Photo on the left is viewing downstream of road crossing. Photo on the right is the upstream side of the road crossing.

4.2.3. Stressor pathway

Low DO is being caused by channelization along with the partial drainage of upstream wetlands. The low DO is then inhibiting the stream biology due to the occurrence of DO concentrations below 5 mg/L (which is happening for 40-50 % of the daily values). Lack of migratory fish is being caused by the Grouse Road stream crossing which inhibits fish passage at both the high and low flow stream discharge condition. A lack of water in the stream channel is also causing stress to the biology. Over the three years of study, it has been documented that stream discharge approaches 0 cfs. Biological organisms that require water have a hard time living in dry conditions.

4.2.4. AUID summary

Unnamed trib. to the Mississippi River is a channelized stream with a multitude of issues. It was sampled in August 2016, following a very dry spring with an extensive downpour occurring on July 11, 2016. This large event would have flooded the surrounding low-gradient landscape and caused very low DO conditions. The channel was later cleaned out through legal ditch maintenance during the winter of 2017-2018. This left the channel for the first few months of 2018 in a vulnerable state until the banks vegetated and stabilized.

The stream flow patterns are very dependent on precipitation. During periods of low rainfall, the stream discharge can approach 0 cfs. There is low DO documented during periods of high and low flow conditions. The DO can be near 0mg/L at times; both the fish and macroinvertebrate communities are stressed by low DO.

The channel has very little stream facet diversity. There are essentially no pools or riffles and the channel is one long run. Bank habitat can only be accessed during periods of higher flow as the channel is shallow and over-wide during most of the year. A lack of channel facet diversity is also a main stressor to the biology.

Nitrogen and temperature do not appear to stressing the biology in this ditch. Both of these parameters are below problematic levels as observed in 2017 and 2018. Low DO is a main stressor to the biology as it is documented to have near 0mg/L of DO during low flow conditions in 2017. A lack of habitat is also causing problems for the macroinvertebrate community, as the channel is over-wide, lacks any depth variability, and lacks consistent flow during dry periods. Longitudinal connectivity is also a concern for fish migration. There is a significant fish barrier located on Grouse Road that impedes fish movement during low and high flow periods. This road crossing causes a steep, one-foot water level drop during low flows, while at high flows the stream velocity is too swift.

4.3. Buffalo Creek -610 (MIBI)

4.3.1. Biological communities

AUID -610 is a reach of Buffalo Creek that is 2.83 miles long, and goes from Unnamed Creek downstream to Unnamed Creek. There is one biological monitoring station located on this AUID, 16UM001. Site 16UM001 drains 10.42 sq. mi. and is located just downstream of MNTH Business 371 (Figure 14). This stream is in the City of Brainerd 12 HUC.

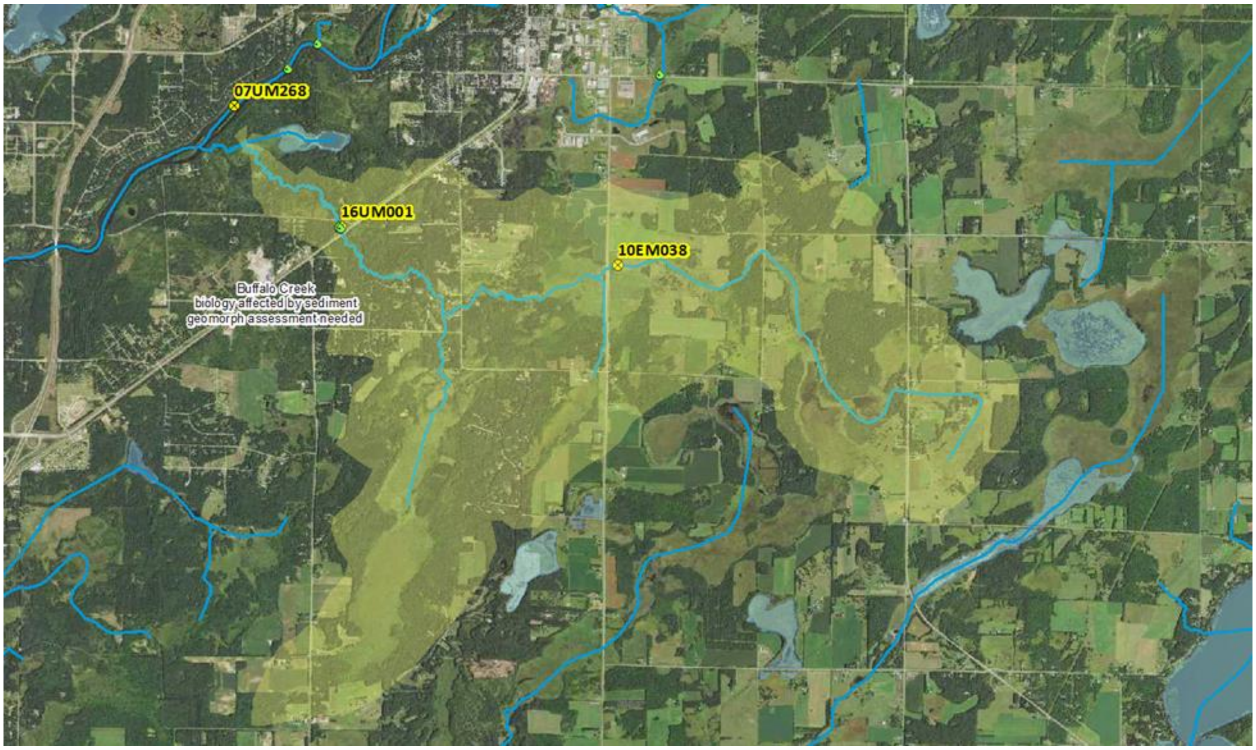
Two macroinvertebrate samples were collected. On August 24, 2016 the MIBI score was 38.7, and on July 31, 2017 the MIBI score was 40.66. This class 3 stream has an MIBI impairment threshold of 53; both samples are below the threshold and do not meet the state’s aquatic life standard. The samples were collected from riffle and wood habitats. Field notes indicate that banks showed instability, and some rocky substrate was embedded with fines.

The macroinvertebrate sample was composed of 63% tolerant taxa, and 26% are very tolerant. These taxa can survive in a variety of environmental conditions and are generally found in slightly lower abundance. The invert sample was dominated by net building caddisfly larvae, which are filter feeders. A fish sample was collected June 30, 2016 and scored a 69, which is well above the 42 threshold for a Class 6 fish stream.

The MPCA has developed tools to look at the communities of fish and macroinvertebrates sampled and determine if low DO and TSS would be stressors based on the community metrics. Both the fish and macroinvertebrate communities suggest that low DO and TSS are not stressors to the biology. The macroinvertebrates had an 82% and 83 % chance of passing the state standard for each parameter.

The MSHA score was a 72.4 on June 30, 2016, which suggests the stream has excellent habitat. On August 24, 2016, the MSHA score was 64.35. Of note, both 2016 MSHAs recorded habitat abundance (AKA cover amount) as “sparse, 2-25%,” and the 2017 MSHA recorded it as “moderate, 25-50%.”

Figure 14: Buffalo Creek drainage area for AUID -610. The yellow highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM001 fails the aquatic life standard for Macroinvertebrate IBI score.



4.3.2. Data evaluation for each candidate cause

There is one Equis sampling location on Buffalo Creek: S003-787. This site has Secchi transparency data from 2005 and 2007. During this time, twenty-five readings were collected. One of those readings was below 40cm, which is the surrogate reading for TSS impairment in the Northern Lakes and Forest Ecoregion. This suggests that TSS is not a driving stressor to the macroinvertebrates.

Existing water chemistry data on AUID -610 was limited to one sample collected on June 30, 2016, during the fish-sampling visit (Table 12). In the summer of 2018, additional samples were collected at Equis site S013-463 (Table 11). Four samples were collected from May through August of 2018.

Table 11: Water quality sampling results from 2018. Samples collected May through August.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
NOx (mg/L)	4	0.108	0.19	0.06	0.057
TP(mg/L)	4	0.113	0.198	0.064	0.059
DO (mg/L)	4		12.3	7.47	
Temp (°C)	4		22.06	6.75	

Phosphorus has a standard of 0.05 mg/L in the Northern Lakes and Forest Ecoregion in Minnesota. The average concentration for phosphorus was nearly double the state standard in 2018. This elevated phosphorus could drive increased plant growth in the stream, which could cause a drop in DO concentrations during the nighttime hours. A sonde was deployed on the downstream side of Business 371 from July 10 through July 19, 2018. This deployment showed no evidence of DO concentrations falling below the 5 mg/L state standard (Figure 15). The elevated nutrient concentrations do not appear to be causing low DO issues; thus, neither phosphorus nor DO appear to be stressing the macroinvertebrate community.

The macroinvertebrate sample was dominated by taxa that are intolerant to low DO. The relative abundance for this group was 12.5% with 8 taxa, as opposed to 0.6% and 1 taxa that are tolerant to low DO conditions. DO data did show a dip following a small rain event on July 12, 2108, which experienced a 0.3-foot jump in stream stage. DO appears to recover within a two day time period as stream stage drops. Low DO is not a stressor to the biology at 16UM001.

Nitrogen can also be a cause of toxicity to the stream biology. Levels found in 2018 were well below expected levels that would cause stress to fish or macroinvertebrates. The macroinvertebrate sample had 2 taxa that are intolerant to nitrogen pollution, and 10 taxa that are tolerant to nitrogen pollution. The 10 taxa made up only 11% of the relative abundance of individuals in the sample. Nitrogen does not appear to be stressing the macroinvertebrates.

During the fish and macroinvertebrate sampling, a one-time water chemistry sample was collected. The results of this data collected can be found in Table 12 below. Results from the one-time sampling events have DO readings well above the 5 mg/L standard.

Table 12: Water chemistry results from the three biological site visits made at site 16UM001 on Buffalo Creek.

Date	Temp °C	DO mg/L	Sp. Cond µmhos@25°C	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
6/30/2016 8:27am	15.61	8.42	301	7.54	0.1	0.254	0.094	4.4	2.4
8/24/2016 10:54 am	19.3	7.35	233	7.18	NA	NA	NA	NA	NA
7/31/2017 1:40 pm	17.9	7.81	263	7.67	NA	NA	NA	NA	NA

A longitudinal survey was conducted of Buffalo Creek in May of 2018 (Figure 17). During this investigation, it was noted that the stream channel was experiencing frequent bank failure and large areas of fine sand deposition. This section of stream is deeply entrenched (Figure 16) and there is minimal access to a floodplain. This entrenchment is causing the stream banks to have excessive stress placed on them during periods of high flow. The sand dominated banks erode rapidly once bank vegetation is disturbed. The fine sand from the banks is migrating downstream, depositing into the channel. This fine sediment appears to be highly mobile during elevated flow events. The collected survey data was shared with DNR stream geomorphologists for further analysis. The following excerpt was provided by the DNR Grand Rapids office.

"To help describe stream geomorphology, PCA staff surveyed an 800' longitudinal profile and four channel cross sections downstream of Minnesota Hwy 371 BR in May of 2018. The bankfull elevation is typically collected in such a survey, but this reach contained few bankfull indicators due to the channel instability. Since most morphological descriptions depend on an accurate bankfull elevation, bankfull dimensions were derived from a regional curve for this assessment instead of field measurements. Based on its drainage area, the predicted cross-sectional area at bankfull classifies Buffalo Creek as a Gc stream type, an unstable stream type in a confined glacial till plain valley. G streams generally have low width to depth ratios, are entrenched, and have moderate sinuosity. A gully is a good way to think of G streams. The c in Gc denotes that the stream slope is less than 0.02, and no pebble count data is available to fully classify the stream based on dominant substrate type.

Buffalo Creek exhibits many characteristics of an unstable stream including meander cutoffs and accelerated bank erosion. (Figure 1) The channel evolution model suggests that Buffalo Creek was once a stable E or C channel that destabilized and down cut (Figure 2). Whereas a stable channel with floodplain access has a bank height ratio (top of bank height divided by bankfull height) of about 1, Buffalo Creek now has a bank height ratio of more than 2, signifying that the stream is deeply incised. Bankfull flows in deeply incised streams stay concentrated within the banks rather than spreading their energy out over a floodplain, increasing shear stress on the channel bottom and banks. The stream also has an entrenchment ratio of 1.29, meaning it is firmly entrenched. The entrenchment ratio is the floodprone width (channel width at a height of 2x the bankfull height from the thalweg) divided by the bankfull width and a stable E or C stream would have a ratio greater than 2.2. The degree of entrenchment at Buffalo Creek means that even small to medium floods are unable to access the historic floodplain that has now become an abandoned terrace. In addition, aerial imagery shows meander patterns associated with lateral instability such as truncated meanders, distorted meander loops, and meander cutoffs. These observations all indicate that Buffalo Creek is unstable and likely contributing excess fine sediment into the stream.

As streams progress through channel evolution after down cutting, they often widen out by eroding their banks before they can stabilize as an E or C stream type (Scenario 5 in Figure 2). The widening may already be happening at Buffalo Creek since the furthest downstream cross section is an F stream type, a much wider, shallower channel than the upstream cross sections. However, it could still take decades or longer to redevelop a floodplain at the lower base level, so impacts from instability will continue to be felt for a long time. The main effect of instability is often the introduction of excess fine sediments from accelerated bank erosion, which can fill in pools and smother larger substrates used for cover and reproduction by the stream biota. This appears to be part of the problem at Buffalo Creek. Survey data shows a fairly homogeneous channel bottom with reduced variation between pool and riffle depths. Most pools are less than two times the depth of riffles. A pebble count survey would help determine the predominance of fine particles in the stream channel. Furthermore, gathering reference data from a stable local stream of similar stream and valley type would provide a more detailed departure analysis from expected condition on Buffalo Creek. Lastly, factors that could have caused the initial destabilization include altered hydrology (54% of the stream length has been ditched), land use changes, a lowering of the downstream base level, or historic logging."

Drainage Area	Stream Slope	Cross-Sectional Area	Width/Depth	Sinuosity	Bank Height Ratio	Entrenchment Ratio
11.31	0.00312	27.8	7.78	1.53	2.2	1.29

Table 1. Stream morphological characteristics.

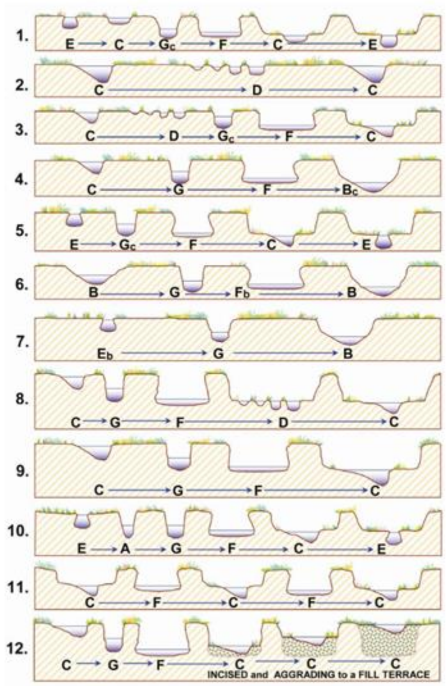


Figure 2. Some stream evolution scenarios documented in actual rivers (Rosgen, 2011).

Figure 15: Buffalo Creek continuous water quality data collected with 6920 YSI sonde from July 10-18, 2018.

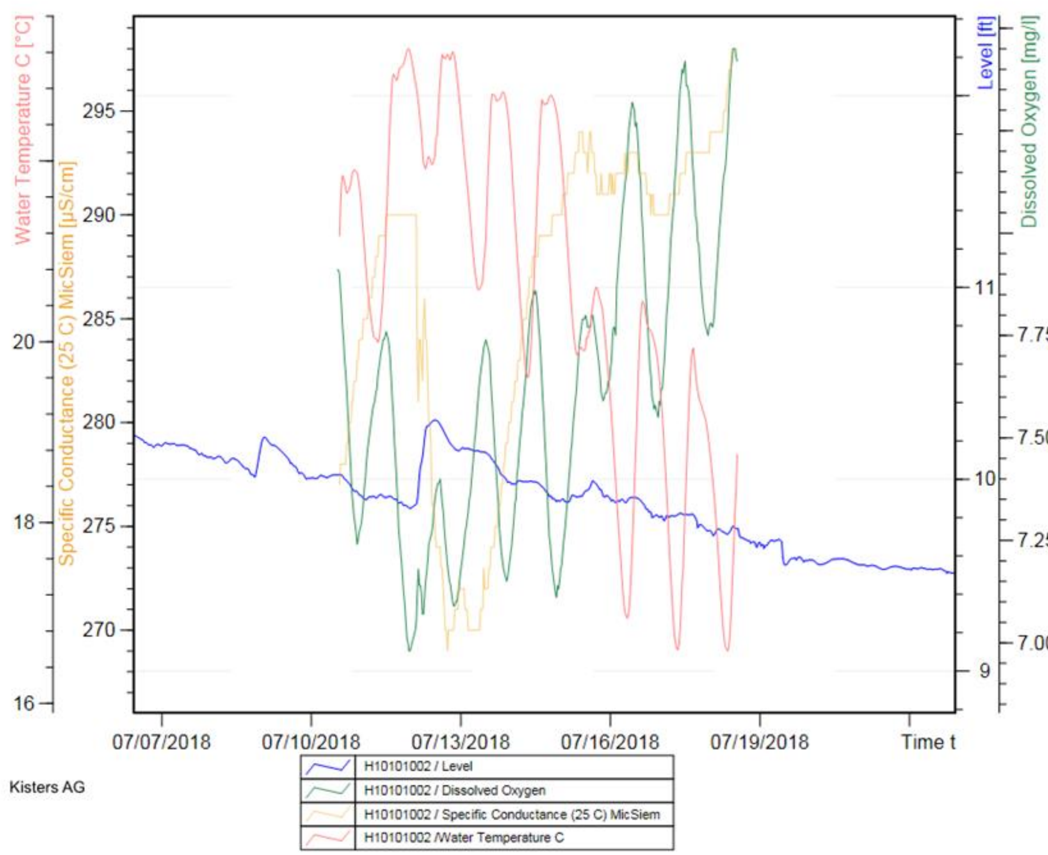
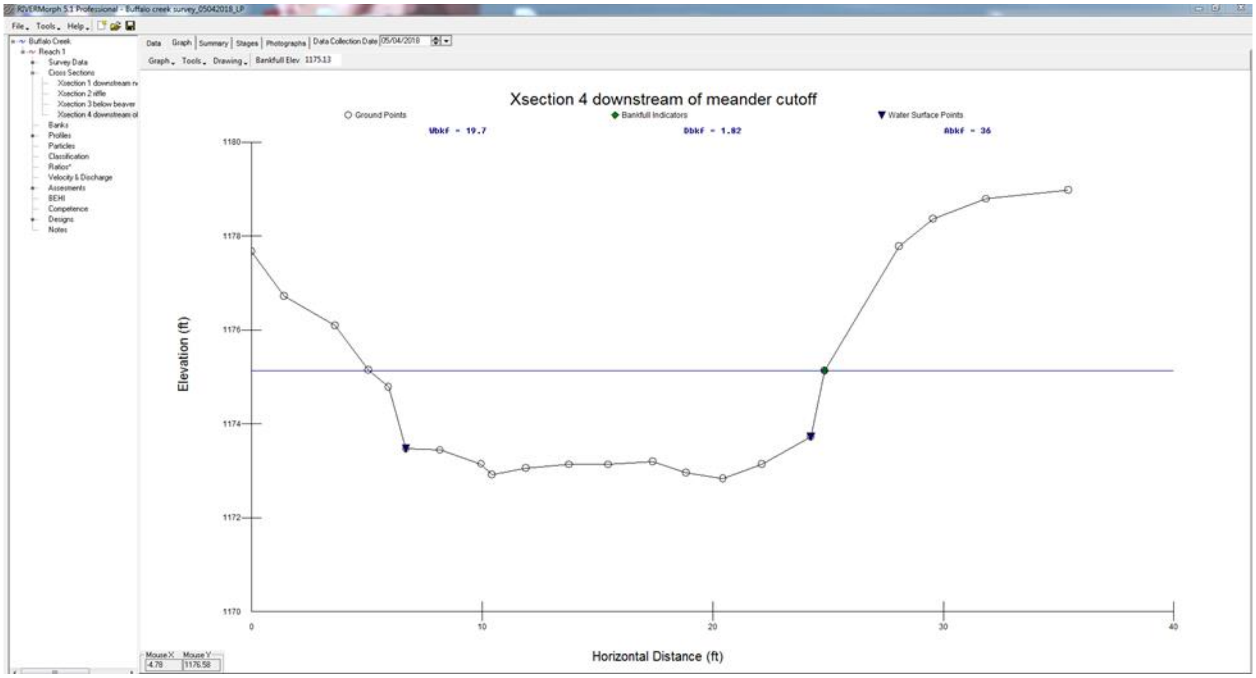


Figure 16: Buffalo Creek channel cross section showing the bankfull stage along with the deep incision of channel banks. Note that river left is over 2 times the height of the bankfull stage.



The mobile bed could be playing a role in the low macroinvertebrate scores. Effects of the mobile bed on the macroinvertebrates remains inconclusive. The evidence of channel instability does however; make it likely that channel instability is affecting the macroinvertebrate communities.

Reviewing the macroinvertebrate community that was sampled can reveal community characteristics that are helpful in diagnosing potential stressors. MPCA has used this community-based information to calculate conditional probability of macroinvertebrates passing the DO standard. If a sampled community has individuals that are tolerant to low DO, then the probability of passing the DO standard becomes lower.

Macroinvertebrate community index scores indicate that, based on 2 samples, collected in 2016 and 2017, there is a high probability that both macroinvertebrate samples would pass the standard for DO and TSS. The limited TSS data available does not suggest that TSS is a problem for the macroinvertebrate community. Generally, a lack of intolerant taxa can lead to a belief that there is a problem and it may be stressing the biology. Metrics collected for TSS tolerant versus intolerant taxa suggest a near even distribution. There were 4 intolerant taxa and 7 tolerant. TSS is inconclusive as a stressor.

Figure 17: Stream bottom longitudinal profile starting at the culvert under business 371 and going downstream. Water slope and bankfull elevations are also plotted in graph.

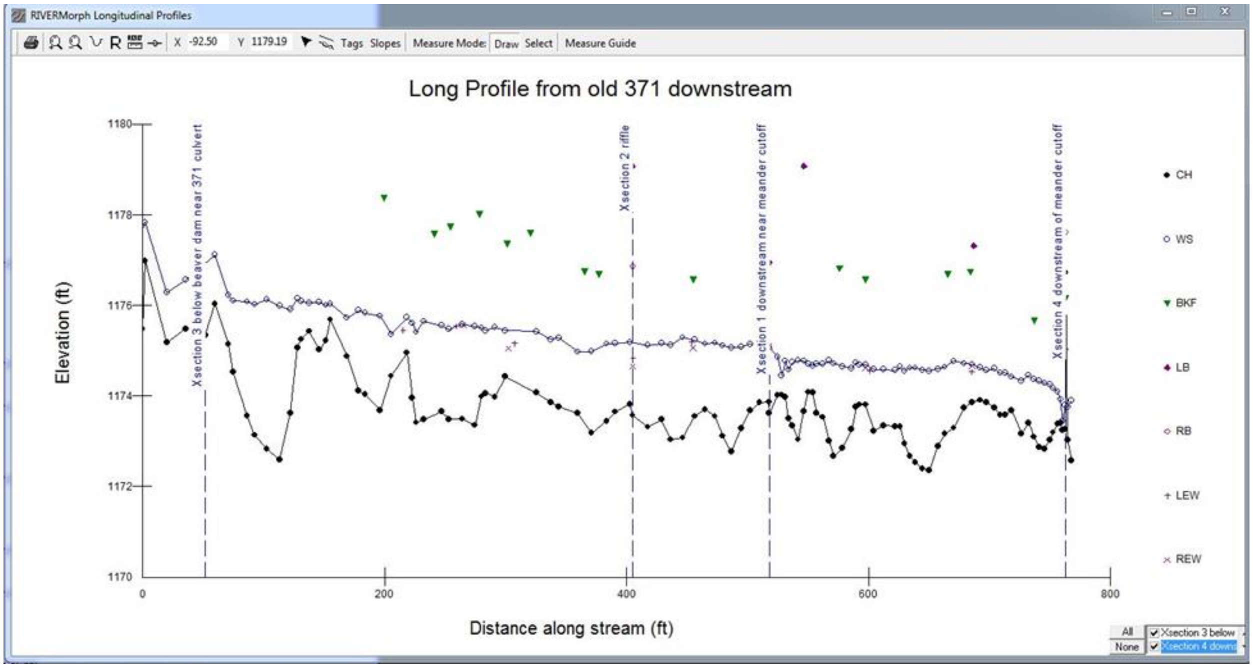
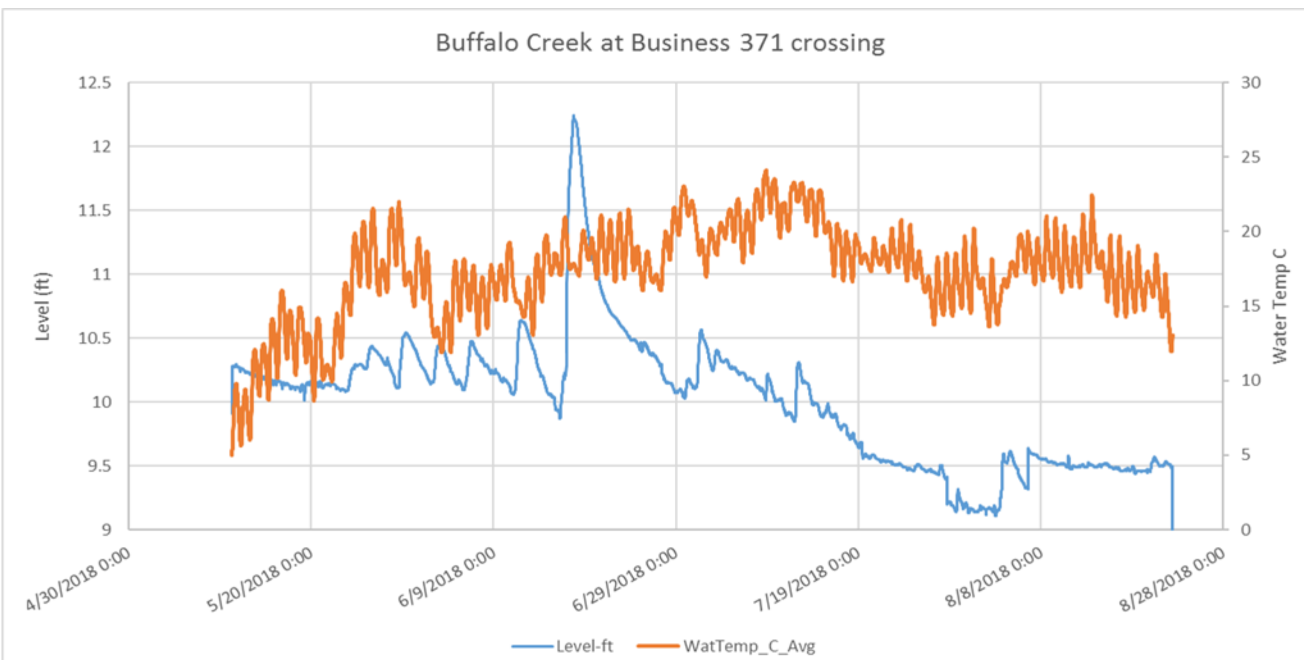


Figure 18: Stream stage on Buffalo Creek for 2018. Stage was collected just downstream of Business 371 culvert. Probe was dislodged on August 2, 2018. Probe remained in water, and temperature data appears good; however, stage is no longer accurate after 8/2/2018.



Probe was pulled out. Level is wrong after 8/2/2018. Water temp appears OK.

Stream stage was measured throughout 2018 to document the variability in water level. As noted in Figure 18, stream stage bounces rapidly following a significant rainfall. In mid-June, a significant rainfall of 2-3 inches occurred and the stream stage jumped by 2.4 feet. Another large rain event occurred in early August, however the water level sensor was dislodged during this time frame and the stage data was lost. This event was larger and more concentrated than the June event, so it is believed that the stream level jumped even higher. Stream stage appears to be highly influenced by rainfall and responds readily to rainfall events. Hydrologic alteration is also playing a role in the lack of macroinvertebrates in Buffalo creek. The stream shows signs of flashiness during large rain events as documented by the 2018 stream hydrograph. During periods of little precipitation baseflow conditions drop rapidly and very little flow is found in the creek. Flow alteration caused by upstream ditching and land use changes are stressing the macroinvertebrate community.

There are a number of beaver dams located near Hwy 371 and upstream. It is possible that during periods of low flow the beaver dams are holding back enough water that the stream is being depleted and lack of flow is playing a role in the low MIBI score.

Stream temperature was continuously collected during 2018 from May through August. Stream temperatures were all below 24°C. It seems that stream temperature is not stressing the stream biology.

4.3.3. Stressor pathway

Buffalo Creek data suggests that there are no conventional stressors that can be identified. DO and temperature data all suggest that they are not causing stress to the macroinvertebrates. Habitat data using the MSHA score appears to be adequate for biology and the fish data shows ample fish habitat. Nutrient levels are elevated, however there is no response observed, such as increased periphyton growth or daily drops in DO concentrations. TSS data collected does not show a response to increased taxa of TSS tolerant macroinvertebrates or fish.

Bank instability caused by channel incision is the only plausible stressor that could be identified in Buffalo Creek. Longitudinal survey of the channel downstream from the Business 371 culvert crossing, shows that the channel is deeply incised for the first 200 feet below this crossing. The perched culvert and position of the narrow valley is causing the stream to actively have bank failure and is supplying excessive fine bank material to the streambed. The fine bed material is mobilized in a downstream fashion as the stream readily responds to rainfall events, and may be dislodging macroinvertebrates. The size and position of this crossing should be evaluated to determine its effects on the downstream side of Business 371.

4.3.4. AUID summary

Many of the common stressors to stream biology have been eliminated in this reach, namely: low DO, TSS, nitrate pollution, and temperature. All data indicate that the biology is being affected by some other condition.

Bank instability was noted throughout the sampling reach. This is being caused by a lack of floodplain connectivity. The lack of floodplain access is containing the high flows within the channel and causing increased sheer stress, which in turn is causing banks to fail. Bed sediment mobility may be the biggest issue facing the macroinvertebrates in this reach. The sampling reach is located just downstream of Business 371 and the crossing may be undersized. The stream gradient in this particular stretch is higher than the upstream reach. The channel is incised and appears to have downcut into the valley. There is no access to a floodplain in the initial 500 feet of channel downstream of the road crossing. It is very plausible that the flow alteration, bank instability and road crossing are causing the greatest impact to the macroinvertebrate community.

4.4. Little Buffalo Creek -695 (FIBI&MIBI)

4.4.1. Biological communities

AUID -695 is Little Buffalo Creek, which is 5.62 miles long, and goes from the headwaters downstream to the confluence with the Mississippi River (Figure 19) and is part of the City of Brainerd 12 HUC. Little Buffalo Creek flows directly through the east side of the city of Brainerd, which has an extensive storm sewer network feeding the stream with storm water. This storm water has caused a flashy flow regime. Stream stage rises and falls very quickly as rainwater drains through the system. There is one biological monitoring station located on this AUID (00UM015). Site 00UM015 drains 5.41 sq. mi. and is located just downstream of South 6th St (Business 371).

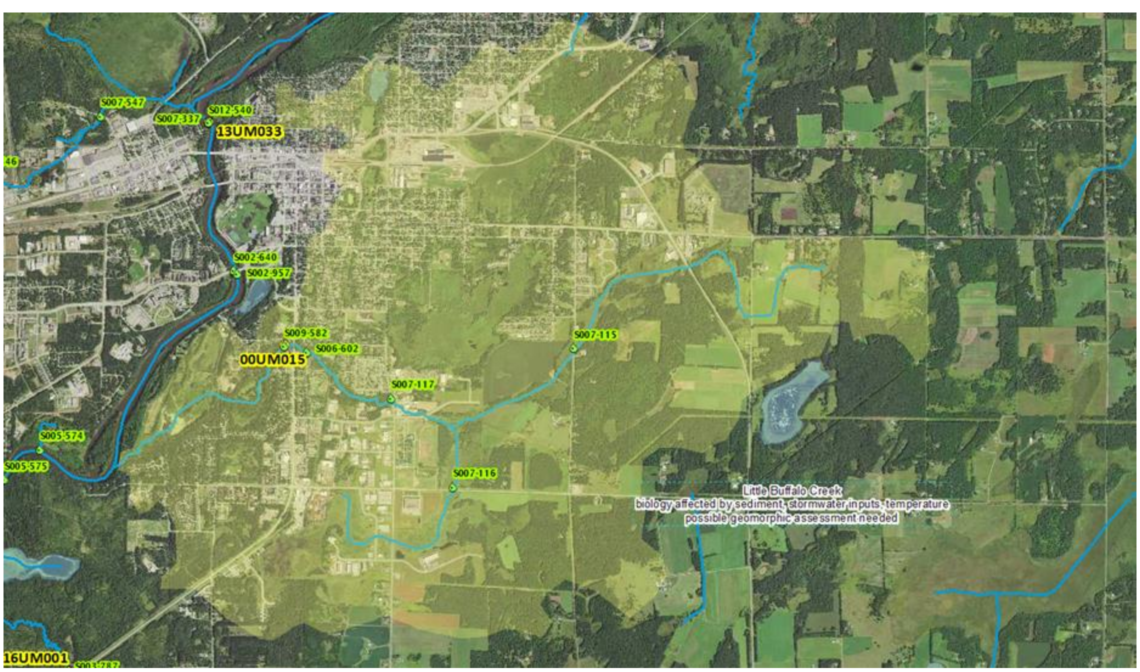
Two samples were collected for macroinvertebrates at 00UM015. Both samples were below the MIBI threshold of 53 for a "General Use" class 3 stream. On August 24, 2016 the MIBI score was 27.5 and on July 31, 2017 the MIBI score was 24.2. The MIBI scored very low for Trichoptera (1 out of 10) and very low for Clinger taxa (1 out 10). Clingers and Trichoptera would generally be found living in riffles with coarse substrates.

Inverts sampled suggest that the base flow conditions in this stream may be cold water, as many of the inverts sampled are cold water obligates, meaning they do not survive in warm water systems. An investigation will occur in 2018-2019 to determine if stormwater runoff is adversely affecting stream temperature and stream flow. Currently the stream is being evaluated as a warm water stream.

Fish were sampled on June 30, 2016 and scored a 16. The threshold for a class 6 stream is 42. Fish are well below the threshold. Six species were sampled (northern redbelly dace, white sucker, central mudminnow, brook stickle back, fathead minnow, and brassy minnow).

Stream habitat was evaluated twice during the 2016 and once during the 2017 sampling events. All three scores were considered fair poor. The scores were 56.9 and 57 in 2016 and 47.1 in 2017. The "channel morphology" section scores weighed down the total scores, as there is limited stream facet variability.

Figure 19: Little Buffalo Creek drainage area for AUID -610. The yellow highlighted drainage area is overlaid on the 2017 color aerial photo. Site 00UM015 fails the aquatic life standard for Macroinvertebrate IBI score.



4.4.2. Data evaluation for each candidate cause

Water quality data from Equis site S006-602 on the Little Buffalo Creek was collected in 2011-2012 (Table 13). Site S006-602 is located just upstream of the 7th St. crossing and consisted of the longest water chemistry record.

Table 13: water chemistry results from Little Buffalo Creek at equis site S006-602, located just upstream of the 7th St. Crossing. All data collected in 2011-2012, between the months of April and October.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
TKN(mg/L)	24	1.099	2.77	0.3	0.603
TP(mg/L)	24	0.129	0.715	0.05	0.135
TSS(mg/L)	32	4.78	19	0.05	5.288
NOx (mg/L)	21	0.24	0.45	0.057	0.103
DO (mg/L)	25	8.106	9.9	7.14	0.657
Temperature (°C)	25	14.69	25.87	6.49	3.596

A limited number of water chemistry samples were also collected upstream of S006-602, at site S007-117, which crosses at SE 13th St. just north of the Crow Wing County fairgrounds (Figure 20). This site collects storm water runoff from various industrial parking areas and the fairgrounds. Further upstream of S007-117, two additional locations were also sampled concurrently (Table 14). Site S007-116 is located upstream, at the CR117 crossing, and site S007-115 is located at the Oak Ridge Rd. SE crossing. These two sites represent two split reaches that combine to form Little Buffalo Creek, just east of the Crow Wing County fairgrounds.

Table 14: Sample results of upstream water chemistry sampling on Little Buffalo Creek. Sites are located on the far eastern side of the watershed near some industrial areas. Samples were collected in May and June of 2012.

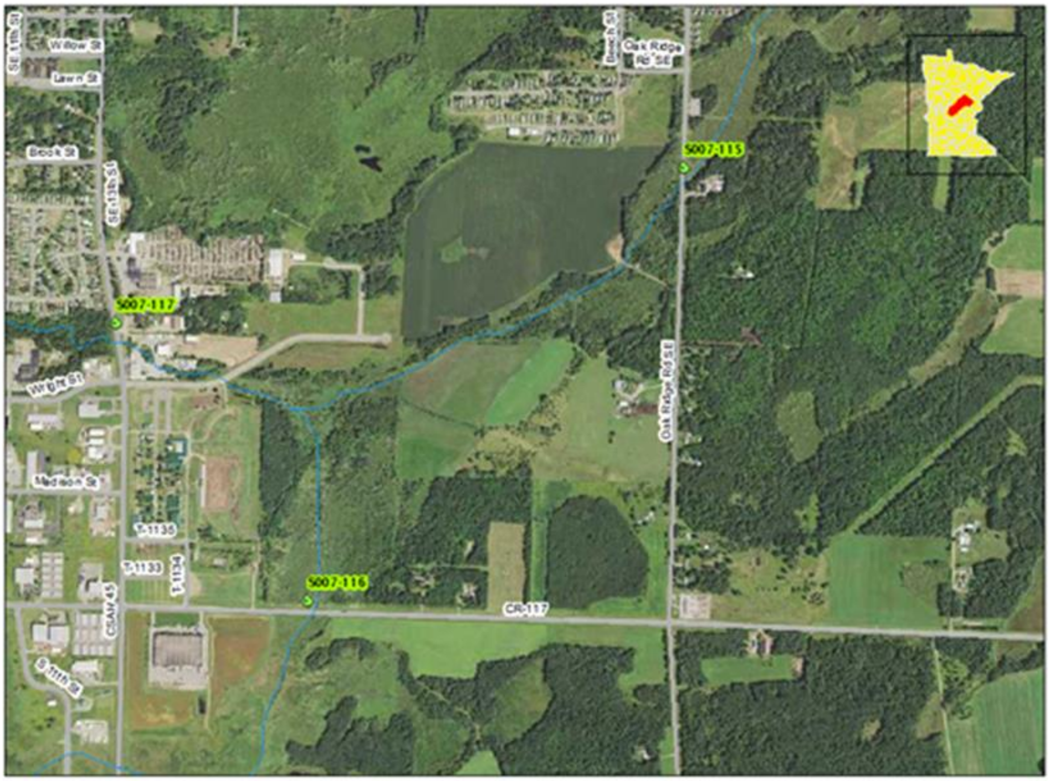
Site	Sample Count	TP Minimum	TP Maximum	TP Average	TSS Minimum	TSS Maximum	TSS Average
S007-115	3	0.111	0.332	0.187	6	12	9.3
S007-116	3	0.059	0.322	0.177	2	11	5.7
S007-117	3	0.112	0.233	0.176	23	46	34.7

All three of these sampling sites experienced elevated TP concentrations, as did the downstream sampling location on 7th St. in Brainerd. TSS concentrations appear to be highest at the S007-117 station, which is also influenced by storm water drainage. This site collects storm water from the north and northeast, and also from the south. This storm water flows through residential areas and industrial parking areas that have gravel and are storage areas for semi-trucks, tractors, and junk automobiles (Figure 20).

Macroinvertebrate samples collected in 2016 show that 2 taxa sampled are intolerant to TSS and 4 taxa are tolerant to TSS. In addition, the macroinvertebrate sample shows that site 00UM015 has a conditional probability of meeting the TSS standard 86-87% of the time. This probability is based on the macroinvertebrate community along with tolerance values for TSS that are assigned to macroinvertebrate taxa. This breakout of TSS taxa tolerance does not strongly suggest one way or the other that TSS is stressing the macroinvertebrate community. It certainly does not rule out the possibility and warrants further investigation. Stream bank instability is widespread throughout the stream downstream from south 7th street and is contributing to streambed embeddedness.

Figure 20: Sampling locations upstream of city of Brainerd on Little Buffalo Creek. Sites were sampled three times on simultaneous dates to determine impacts of various sections on water quality. Site S007-117 collects additional storm water from nearby industrial activities and street drainage. Direction of flow is northeast to southwest.

Little Buffalo Creek (00UM015) sampling location map for upstream sites



During the fish and macroinvertebrate sampling, a one-time water chemistry sample was collected (Table 15).

Table 15: Water chemistry collected during the fish and macroinvertebrate sampling events.

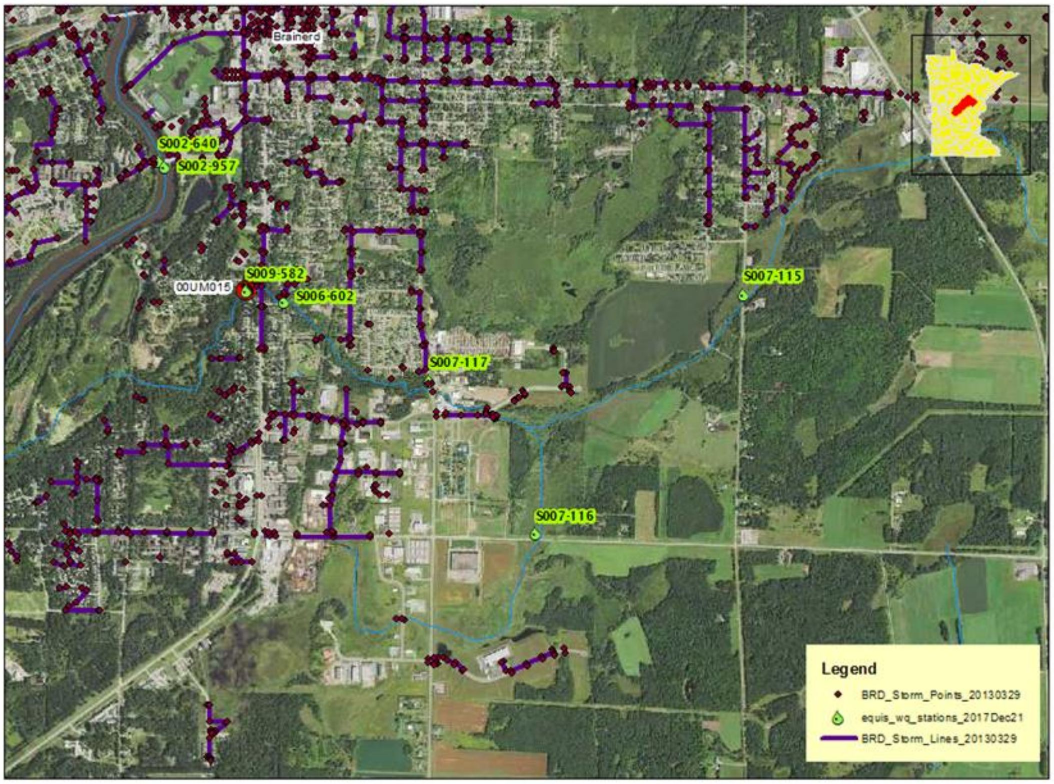
Date	Temp °C	DO mg/L	Sp. Cond µmhos@25°C	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
6/30/2016 1225pm	14.88	8.55	360	7.69	0.1	0.274	0.074	2.8	2.2
8/24/2016 931am	17.4	7.9	240	6.53	NA	NA	NA	NA	NA
7/31/2017 357pm	16.9	8.67	322	8.67	NA	NA	NA	NA	NA

Nitrogen samples were collected in 2012-2014 (Table 13) and again in 2016 (Table 15). The limited number of water samples analyzed for nitrogen show that, as compared to area streams, Little Buffalo Creek has some slightly elevated nitrogen levels. Even though sampled concentrations are below 0.5 mg/L, it is possible that nitrogen may be having an impact on the macroinvertebrates in the stream. A review of the invert metrics shows that 0 taxa were sampled that are intolerant to nitrogen pollution. Meanwhile 18 taxa were sampled that are considered tolerant to nitrogen. This is an increase of tolerant taxa from the previous invert sample, collected in 2000. During the 2000 sampling event, 3 taxa were intolerant and 11 were considered tolerant to nitrogen. Nitrogen does appear to possibly be stressing the invertebrate community.

Little Buffalo Creek has an abundance of stormwater discharge points along its path (Figure 21). The stream is still considered a cold water resource. Temperature loggers were installed in 2018 at seven locations to determine the effects of storm water runoff on the temperature of the stream.

Figure 21: Storm drain network in Little Buffalo Creek's watershed, represented by purple lines and red dots. During periods of rainfall, a significant portion of stream flow is from the storm drain network.

Little Buffalo Creek (00UM015) sampling location map with storm drain locations



Stream temperature was elevated following storm events (Figure 23). Stream temperature increased rapidly following the July 12 and August 4, 2018 rain events. As storm water flows into the stream, a larger percentage of stream flow is made of the surface overland flow, which is warmer than the groundwater. Conversely, during periods of no rainfall, most of the stream flow is made of the cooler groundwater. The temperatures observed in Little Buffalo Creek are not high enough to be a stressor of warm-water aquatic species, but could be a stressor to cold-water species. Review of the stream temperature data at Business Highway 371 crossing show that stream temperature does not exceed the warm water threshold of 30°C (Figure 22). Stream temperature is not a stressor to the warm water fish and macroinvertebrate communities.

Figure 22: Daily maximum stream temperature collected with HOBO temperature logger at Business Highway 371 in downtown Brainerd. Daily maximum show that the stream does not exceed maximum temperatures for warm water fish species.

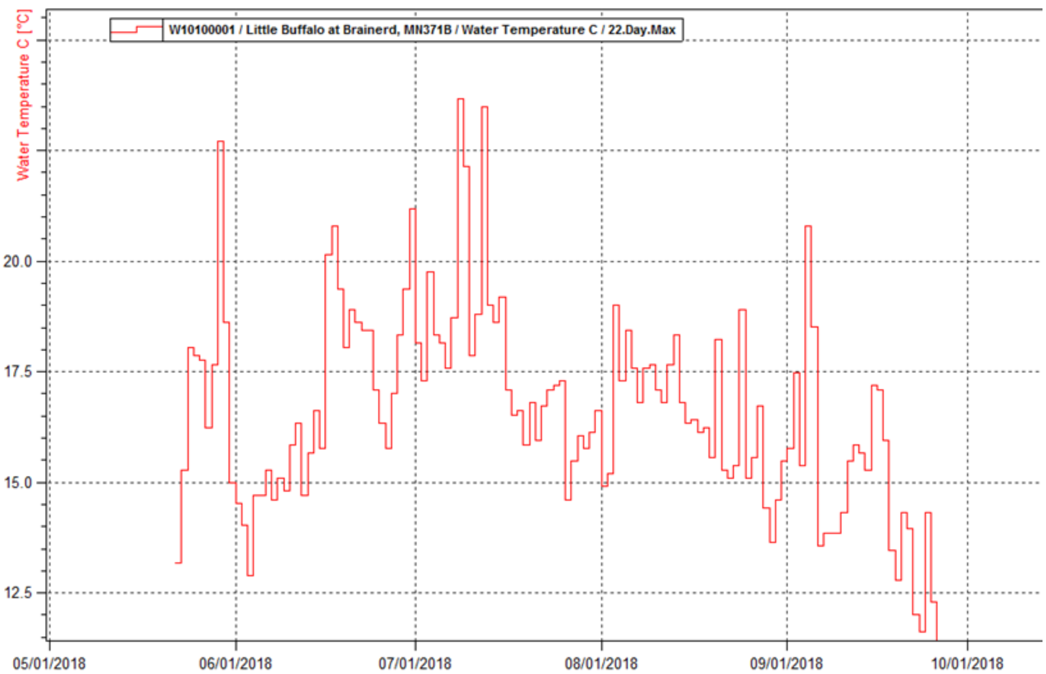


Figure 23 shows the drop in specific conductance in Little Buffalo Creek following a significant rain event. Groundwater generally has higher specific conductance than surface water due to the minerals that are attached as the water flows through the soil profile. Rainwater is generally much lower in specific conductance because of less contact with soil. Urban rainwater will even be lower because of the impervious nature of the drainage area. Rainfall falling on pavement and rooftops will runoff quickly and have very little chance of increasing its specific conductance. This process was captured during the sonde deployment in July of 2018, and shows the change in the stream's water chemistry due to surficial runoff.

Continuous DO data was collected during the week of July 10 through the 18, 2018. DO readings ranged from 6.55 mg/L to 8.07 mg/L and averaged 7.39 mg/L during this period. Placed against the warm water standard for class 2B waters, which is 5mg/L, there is adequate DO in Little Buffalo Creek, and low DO is not a source of stress to the biology. In 2011 and 2012, 25 DO readings were also collected at this site on South 7th St. All 25 DO readings were above 7 mg/L and do not indicate that low DO would be a stressor to the biology. Based on the fish community sampled at site 00UM015 the fish do show a tolerance to low DO conditions. The 2016 sample was dominated by fathead minnow, white sucker, central mudminnow, northern redbelly dace, brook stickleback, and a couple of brassy minnow. All of these species are low DO tolerant and generally tolerant to most stressors. The macroinvertebrate sample showed the opposite of the fish. The majority of taxa sampled are considered intolerant to low DO. Nine taxa are intolerant and 3 taxa are tolerant to low DO in the 2016 sample. Low DO does not appear to be stressing the biology. DO concentrations do show a slight decline when stream stage increased after a precipitation event. Figure 23 below documents the stream stage conditions along with the water quality parameters measured.

Figure 23: Continuous water quality data collected with YSI 6920 multi-parameter sonde over 8.5-day period on Little Buffalo Creek at South 7th St crossing. Stream stage was also collected and is the blue line on the graph.

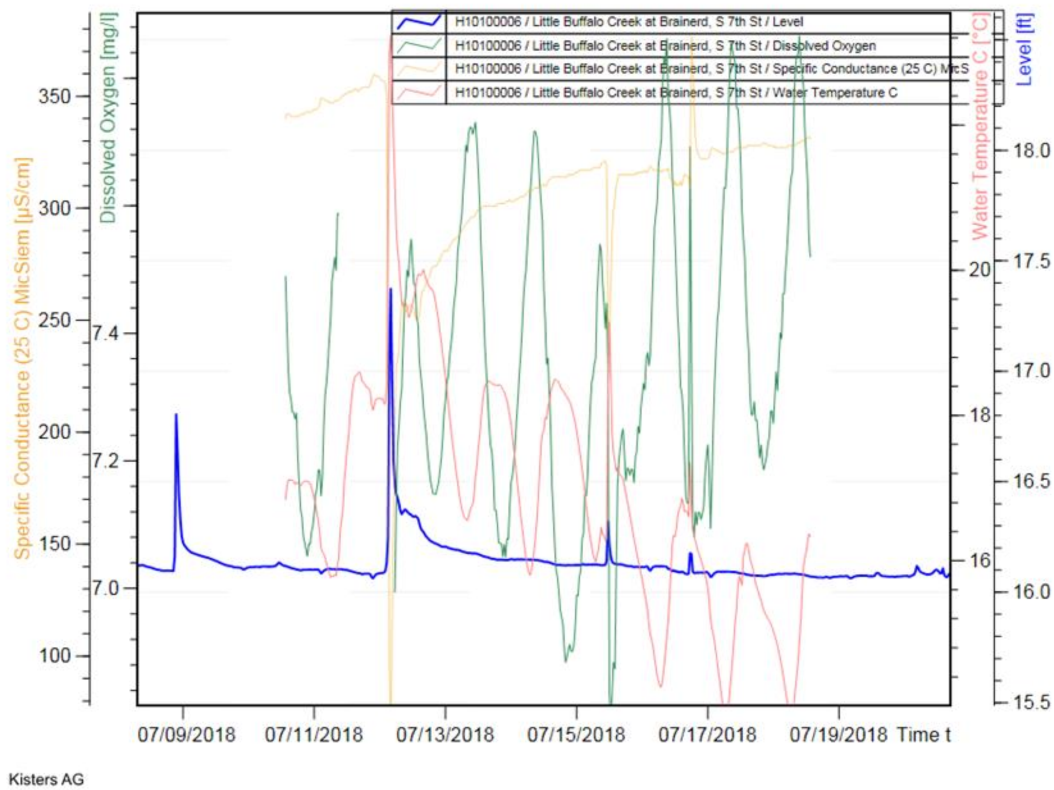
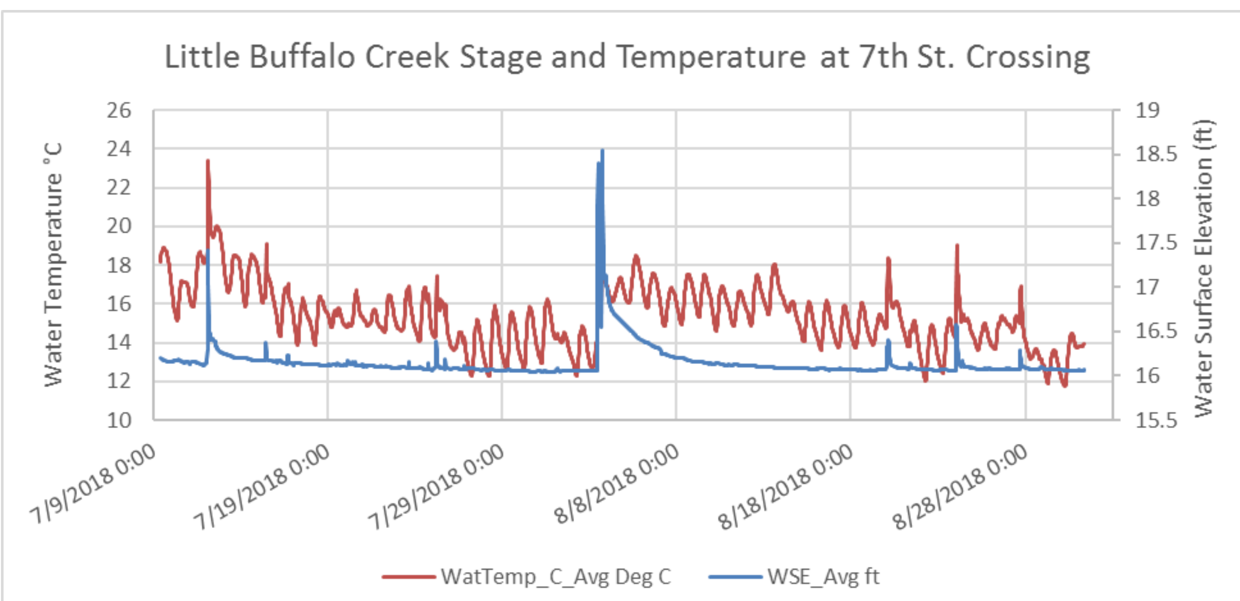


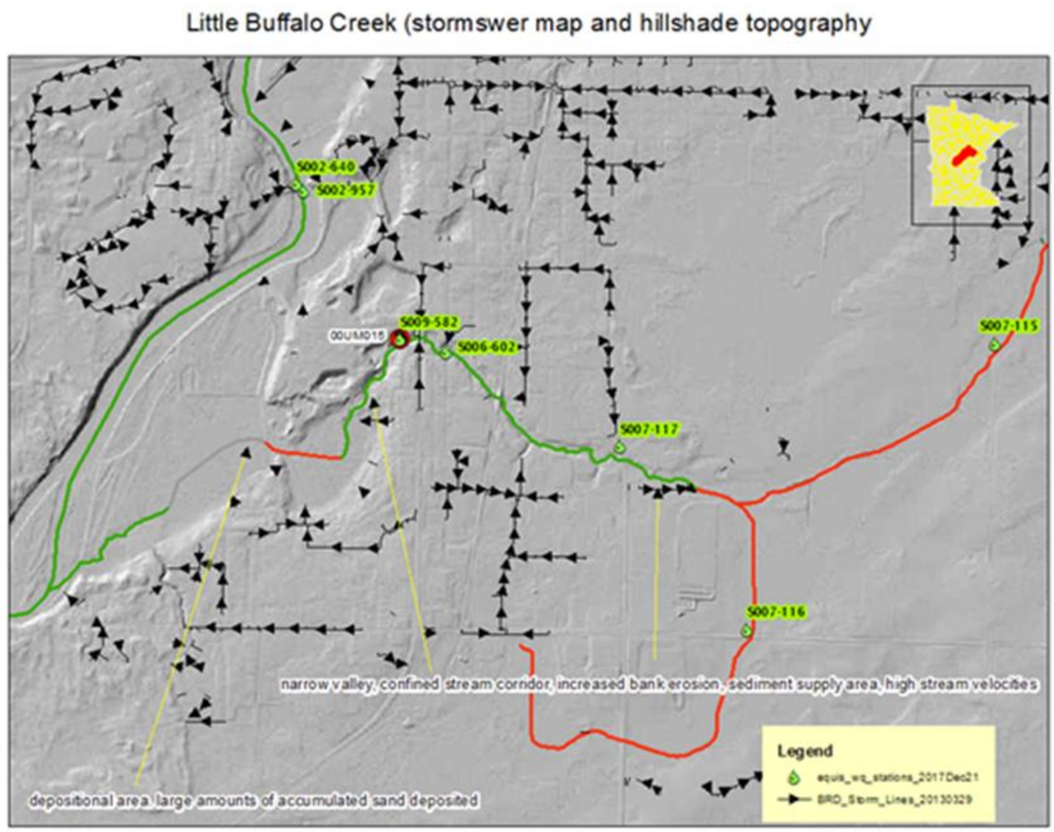
Figure 24: Stage data and water temperature data collected at Little Buffalo Creek at South 7th St. crossing. Data shown is from July through August 2018. Note the stream stage from 8/3 through 8/7/2018: it takes 3.5 days for the stream to return to near baseflow from a four-inch rain event.



Longitudinal connectivity can be considered a stressor in Little Buffalo Creek. The farthest downstream section of stream is very flat with a low slope and low stream power. This is a depositional area for sediment and the channel is wide, shallow, and filled with mobile sand. During periods of lower flow, the water is less than 3 inches deep. Minnow species may be able to migrate, but fish larger than 2 inches would not be able to pass through the channel during low flow. During higher flow periods following a storm event, the water is turbid and the bed sediment is in a constant state of flux.

The sand in this area is being supplied from bank failure upstream (between S007-117 and S009-582), where the channel is laterally confined, stream slope is higher, and stream power is higher. The addition of storm water from the storm sewer network has changed the stream bank stability and caused areas of massive bank failure (Photo 4).The TSS data collected in 2011 and 2012 is inconclusive as a stressor. However, the number of bank failures and major supply of sediment from bank instability suggests that the stream has a highly mobile bed, which may be a major contributor to the poor biology. Altered flow patterns and sediment supply are a stressor to the system's biology.

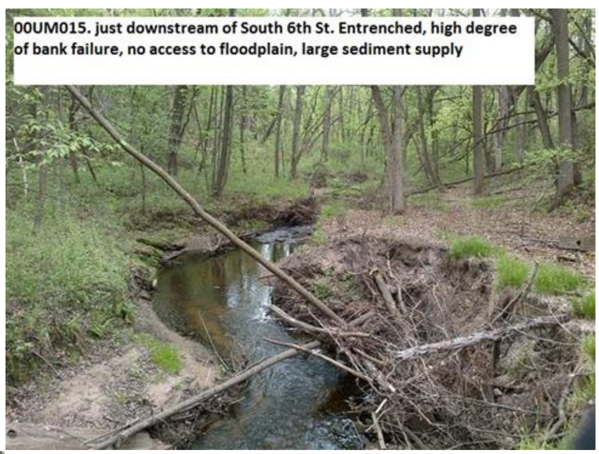
Figure 25: Topographic hill shade map of Little Buffalo Creek. This map displays the various stream reach conditions from a slope and lateral connectivity perspective. Stream is laterally confined in the middle section, which is promoting severe bank erosion and large volumes of sediment transport downstream to the lower gradient depositional zone.

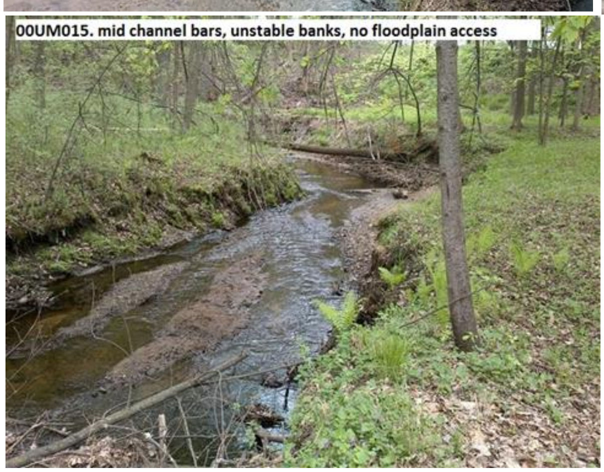


Review of 1939 aerial imagery confirms that this section of Little Buffalo has been altered for an extended period of time. Figure 26 shows the 1939 aerial image and has highlighted the area of Little Buffalo Creek that was straightened upstream of South 7th St. This area has been exporting sediment to the downstream portion for at least the last 80 years.

Figure 26: 1939 aerial image of Little Buffalo Creek in Brainerd, Minnesota. Note the yellow highlighted section where stream channel was straightened.

Photo 4: Photographs documenting various stream conditions along Little Buffalo Creek. Areas above the depositional zone are actively eroding, while the deposition zone is constantly being supplied with new sand being exported downstream.





4.4.3. Stressor pathway

Storm sewer drains affect the rate and quantity of water that is flowing through Little Buffalo Creek. The extensive network of storm sewers is delivering storm water runoff, which is carrying elevated phosphorus levels, increased temperature, and other pollutants. However, the chemical and thermal pollution of storm water does not appear to be the driving stressor in this case. More importantly, the flow alteration caused by excess storm water runoff is stressing the biology through a few different pathways.

Phosphorus concentrations during the 2011-12 sampling period showed that the phosphorus concentrations are 3 times above the area's phosphorus standard of 0.05 mg/L. The stream's response to elevated phosphorus would be increased algal growth and therefore a greater diurnal DO flux. This response has not been documented, as the diurnal DO flux is below 2.5 mg/L/day, which is considered an acceptable level for non-eutrophic streams. Additionally, the stream temperatures observed in Little Buffalo Creek are not limiting to a warm water fish community ("Class 2B").

Rapid increase in stream flow caused by storm water runoff may be the biggest factor affecting the fish and macroinvertebrate communities in Little Buffalo Creek. For example, almost instantaneous stream stage rise of 2.5 feet was documented on August 3, 2018, following an intense 3-4 inch rainfall event. With this rapid rise in water levels and stream velocity, the fish and macroinvertebrates may not be able to find refuge; they could be washed downstream or experience injury or death. This rapid change in stage is also causing significant bank failures along the length of the stream. As banks fail, sediment is being transported downstream and in-stream habitat is degraded. Ultimately, the fine sands are accumulating in the bottom section where the stream gradient is low; this is creating an impediment to fish passage at some flows.

4.4.4. AUID summary

The rapid change in stage during storm events appears to be the largest stressor. This stream has an extensive storm drain network that is causing extreme changes in water level during rain events. A rapid drop in specific conductance during rain events verifies that the majority of stream flow during rain events is storm water runoff. Habitat does not appear to be limiting at the sampling location, according to MSHA scores, though habitat has clearly been degraded over time and will continue to degrade as noted by the frequency of stream bank failure and amount of material being introduced from erosion. The biological sampling reach is in a section of stream that has high gradient and flows through a wooded riparian, moving toward the Mississippi River.

Down near the Mississippi River, the stream gradient flattens and the channel becomes very shallow and wide with a dominant substrate of sand. This bottom section during low flow periods can become prohibitive of upstream migration of fish larger than two inches because of a lack of water depth. Excessive bank failure upstream and transport of sand downstream to the lower section are causing stress to the biological communities.

Nitrogen may be stressing the macroinvertebrate community. Not enough is known about the current nitrogen levels in the stream and further sampling would be justified to better understand the role elevated nitrogen is having on the biology.

Low DO, elevated nutrients, and stream temperature do not appear to be stressors in Little Buffalo Creek, which is currently considered a warm water stream (FIBI class 6, Northern Headwater Streams; MIBI class 3, Northern Forest Streams).

4.5. Trib. To Sand Creek -679 (MIBI) (Modified Use)

4.5.1. Biological communities

The reach of Trib. to Sand Creek is 3.78 miles long, is located in the City of Brainerd 12 HUC, and goes from the headwaters downstream to the confluence with Sand Creek (680) (Figure 27). There is one biological monitoring station located on this AUID (16UM042). Site 16UM042 drains 3.18 sq. mi. and is located just upstream of CR 159.

Biological monitoring was conducted for fish on June 23, 2016. This sampling event collected 11 fish species and scored a 78 on the fish IBI. The threshold for a class 6 stream is 42. The fish pass the IBI and are doing well. The three dominant fish species were blacknose shiner, brassy minnow and northern redbelly dace. All three species had greater than 50 individuals sampled.

The macroinvertebrates were sampled on August 30, 2016 and scored well below the 51 threshold with a 17.3. The 2016 macroinvertebrate sample showed 84.6% of the organisms were tolerant. There were no intolerant taxa sampled in 2016. This score indicates that the macroinvertebrate community is not meeting its designated use. Macroinvertebrates were again sampled on September 13, 2017 and scored a 19.88. This score is also below the Class 4 modified use threshold of 37.

During both 2016 sampling events, an MSHA score was computed to analyze stream habitat features. Both scores were poor with a 32 and a 29 being reported. During both MSHA evaluations, channel morphology and substrate scores were very low. There is very little habitat available at this station due to a lack of stream facet diversity, no sinuosity, and a lack of quality substrate. The sampling reach is run-dominated with clay and silt as the main substrate. The channel also flows through some active cattle farms. Both farms use the stream corridor as pasture and both sites allow free access to cattle.

The section of stream within the sampling site was cleaned out in the winter of 2017 and any habitat that was available has been temporarily altered. A portion was repaired between Highway 18 and CR 159. Ditch repair records were recorded with Crow Wing County. Photo5 below shows the condition of the channel pre-repair and post-repair. Prior to the ditch repair, the channel was overwide and shallow, with an abundance of grasses and sedges growing in the channel. The substrate was sand and silt dominated, and the channel lacked any pools or riffles. Post-cleanout, all of the vegetation in the channel is now gone and the sand and silt was removed and placed on the spoil piles.

Figure 27: Tributary to Sand Creek drainage area for AUID -679. The yellow highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM042 fails the aquatic life standard for Macroinvertebrate IBI score.

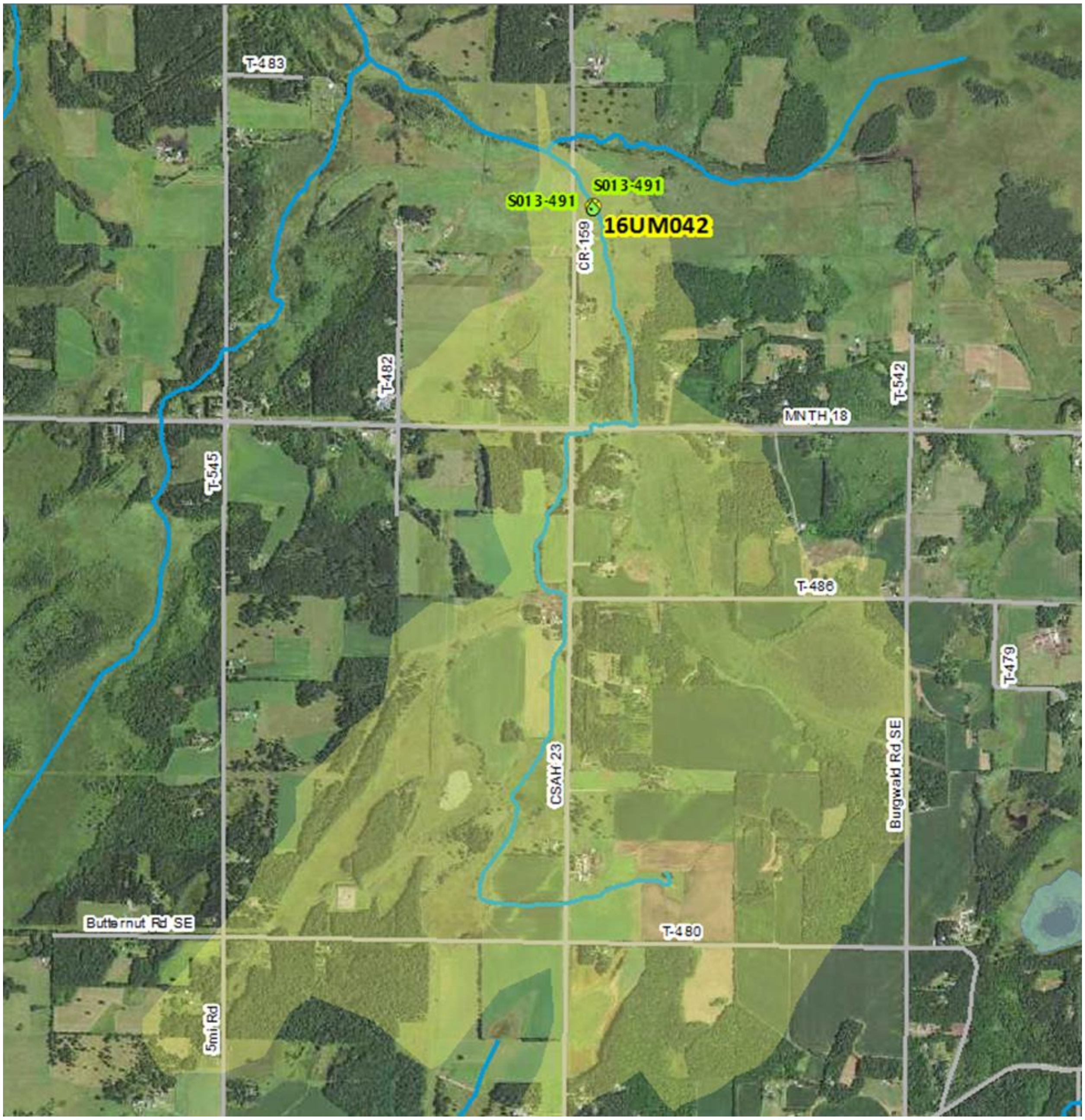


Photo 5: Pre and post ditch maintenance photos of sampling location 16UM042 on tributary to Sand Creek.

4.5.2. Data evaluation for each candidate cause

Water quality data from Equis site S013-491 on Sand Creek at CR 159 is presented below in Table 16. Seven samples were collected in 2017 to characterize nutrient levels in the AUID. Water sampling shows that the stream has very high TP concentrations. TP averaged 0.297 mg/L during 2017 and was as high as 0.443 mg/L. The state eutrophication standard calls for TP to be at or below 0.05 mg/L for this ecoregion of the state. High TP can drive algal productivity, which in turn can cause low DO concentrations during respiration of algal in the nighttime hours. Nitrate levels were generally low and are not indicative of nitrogen as a stressor.

Table 16: Results of water quality sampling at site S013-491 on Trib. To Sand Creek.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
TP (mg/L)	7	0.297	0.443	0.188	
NOx (mg/L)	7		0.41	<0.05	
Temperature	8	16.42	19.1	12.83	2.35
Dissolved Oxygen	8	6.687	9.62	4.07	

Based on the macroinvertebrate community at site 16UM042, there is a 9.5% chance of passing the DO standard. In addition to the community probability metric, there is a metric for macroinvertebrates to assess tolerance to low DO. At 16UM042 there were 0 taxa sampled that are intolerant to low DO and 8 taxa sampled that are tolerant. This indicates that the community has evolved to survive in low DO conditions. Based on this information, low DO appears to be a stressor to the macroinvertebrates.

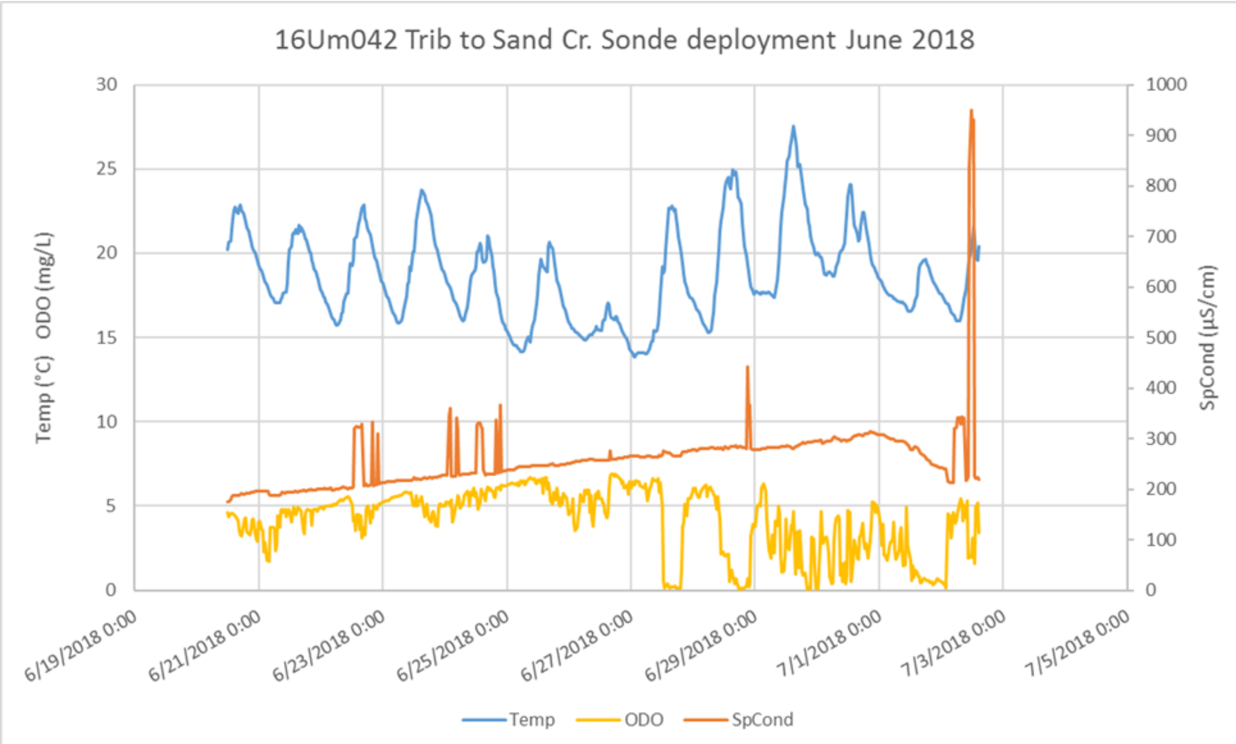
During the fish and macroinvertebrate sampling, water chemistry parameters were collected for stream temperature, DO, Specific Conductance, pH, ammonia, nitrogen, phosphorus, total suspended sediment and total suspended volatile sediment (TSVS). TSVS is a measure of the amount of inorganic material found in the sample. It is burned off the sample at a very high temperature, leaving only the inorganic material behind. Table 17 below shows the results of these one-time water chemistry samples.

Table 17: Water chemistry results from the biological monitoring events in 2016.

Date	Temp °C	DO mg/L	Sp. Cond µmhos@ 25°C	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
6/23/16 12:50pm	19.57	5.78	275	7.09	0.444	0.109	0.418	11.2	4.8
8/30/2016 6:55pm	18.42	5.14	239	6.79	NA	NA	NA	NA	NA

A YSI 6920 continuous logging sonde was deployed on the upstream side of the culvert on CR 159 at 12:00 (CST) on June 20, 2018. This sonde collected continuous data at 30-minute intervals until 14:30 (CST) on July 2, 2018. During retrieval of the equipment, field notes indicated a strong manure odor in the stream along with heavy amounts of suspended material in the stream. Stream flow appeared to be fairly consistent during the deployment period and the sonde was installed in ample flow. Photo 6 was taken on July 2, 2018 during sonde retrieval. During the deployment (Figure 28), 581 readings were collected for DO. Of those readings, 58% were below the 5 mg/L DO standard, and 25% were below 3 mg/L. Low DO is stressing the macroinvertebrates.

Figure 28: Continuous sonde data collected at 30-minute intervals on Trib. To Sand Creek in June 2018. DO probe may have been partially covered during deployment from June 29 through July 2, 2018.



The elevated phosphorus levels in the stream may be causing some increased algal productivity, however it is more likely that the high BOD rate coming from the two cattle operations located upstream are causing the drop in DO readings in the evening hours.

Photo 6: The photo was above taken on July 2, 2018 on the upstream side of CR159. The sonde was located on the upstream edge of the culvert at the road crossing.

Elevated phosphorus, and possibly suspended sediment, concentrations are being imported from a cattle operation located approximately 1.5 miles upstream of 16UM042. The area upstream is devoid of all vegetation and the channel is trampled to the point of a lack of stream channel. This area was visited many times during 2017 and 2018 to document any changes to the site's management. The photos below show the condition of the cattle yard in spring of 2017 and again spring of 2018. The channel at this location is very shallow and over widened. Cattle have direct access to the stream.

Nutrient concentrations are high at the downstream sampling location partially because of the land management practices observed at the two cattle operations along this reach. Below is a photo taken on May 23, 2018, just downstream of this cattle operation, showing the sheen on the surface of the stream which is believed to be organic byproducts from direct manure infusion in the stream. There was also evidence of detrital looking material in the stream, which appeared to be cattle manure clumps. During this photo, the smell of manure was extremely strong. The macroinvertebrates sampled also were highly tolerant to elevated phosphorus. Eight taxa were considered tolerant to phosphorus.

Low DO levels and elevated nutrients are stressing the biological communities, as well as lack of habitat. Ditch maintenance that occurred in the winter of 2017/18 is having an immediate impact on the biology. The disturbance caused by the cleanout process would have removed any overhanging vegetation and left the banks and spoil piles temporarily exposed. The chance of sediment shifting around during high flows and having banks erode back into the channel were high during this time. By late summer in 2018, the banks were revegetated and erosion potential was minimized.

4.5.3. Stressor pathway

The section of stream from CR159 upstream to the headwaters on Highway 23 (south of Highway 18) has three active pastures located along its corridor. All three pastures have cattle that allow free access to the stream corridor.

However, based on site visits, the pasture located on the west side of CR 23, approximately 0.5 miles south of the intersection of Highway 18, appears to be the largest single contributor of nutrients and bacteria. This particular farm has enough cattle to have eliminated all vegetation and entirely eroded the stream channel. There is no stream bank or confined area for the stream to stay contained in on this property. All of the manure will drain directly into the stream during rain events, as there is no vegetation throughout the growing season at this site. Review of aerial photography suggests that this site became overgrazed starting in 2011. Pre-2011 aerials show some vegetation along stream corridor, reviewing the 2013 aerial and newer shows no vegetation and the stream channel is disappearing (photo below is from June 2015).

Sediment and manure flowing downstream is causing excessive nutrients in the stream and is impacting the DO concentrations. Low DO was evident during the June 2018 sonde deployment; DO was low enough to prohibit a healthy macroinvertebrate community. Also, grab sample data from 2017 suggests that low DO conditions persist at various times throughout the year. The stream also lacks habitat diversity. There are no pools or riffles in the sampling reach. Substrate composition is dominated by sand and clay. The only habitat available is the remaining overhanging vegetation in areas where cattle have not grazed.

4.5.4. AUID summary

This AUID is a maintained section of County Ditch 26. Historically, there was no connection of this area to Sand Creek via a stream channel. During the ditching process, this area was drained to the north and water was transported into Sand Creek. The ditching process has added some stream miles to the system; however, these are poor quality stream miles that hold little value to aquatic macroinvertebrates. Elevated nutrients and low DO are causing stress to the macroinvertebrates along with poor habitat. Direct runoff from three cattle pastures located upstream are impacting the nutrient and DO concentrations. The macroinvertebrate sample verified that the majority of the taxa are tolerant or very tolerant to these three stressors, with a very low number of taxa that are intolerant.

4.6. Sisabagamah Creek -659 (MIBI)

4.6.1. Biological communities

The reach of the Sisabagamah Creek is 2.12 miles long and goes from Unnamed Creek downstream to the confluence with the Mississippi River. There are two biological monitoring stations located on this AUID (16UM047 and 16UM171).

Site 16UM047 drains 30.13 sq. mi. and is located just downstream of CR54 and upstream of the Aitkin regional airport (Figure 29). This reach has been significantly modified. The reach is channelized through the airport and that channelization carries upstream to CR54 crossing. Review of historical General Land Office maps (produced as the original survey of Minnesota) reveals that a large drainage area was noncontributing to this lower section of Sisabagamah Creek. This area was later drained through the public ditch system installed in the early 20th century.

The new drainage network added approximately 9.5 sq. mi. of additional drainage area to the stream. This is, on average, an additional 912 ac-ft. /yr. of runoff going through the stream system. This conversion of a noncontributing to a contributing drainage area has increased the streams flow throughout the year and caused more bank erosion and sediment transport. Figure 30 below shows the historical survey map along with the ditches; it highlights the additional drainage area added to Sisabagamah Creek just upstream of 16UM047.

Macroinvertebrates were sampled twice at 16UM047, and both samples were well below the MIBI threshold of 51 for a class 4 stream. On August 22, 2016, a macroinvertebrate sample was collected following the heavy rains of July 11, 2016. This sample scored a 37.9 on the MIBI. A second sample was collected on August 14, 2017 and scored a 42 on the MIBI. During sampling, it was noted that wood was fairly rotten and the site experienced heavy sediment embeddedness. The two dominant macroinvertebrates sampled in 2017 were two net spinning caddisfly larvae. They are both generalists and are tolerant to a wide range of environmental stressors. The site scored low due to a low abundance of POET taxa, predator taxa and overall taxa count.

The two MSHA scores for this site were a 36.5 and a 37. This indicates that habitat for macroinvertebrates was poor during sampling and maybe should have been classified as modified use based on the historical ditching and poor habitat features at the site. The macroinvertebrate samples were collected downstream of the CR54 bridge. The ditch that flows into Sisabagamah Creek was recently cleaned sometime in winter/spring of 2017. There was no seeding or erosion control placed along the banks during a site visit on March 31, 2017 (Photo 7). A high flow event or a heavy rainfall would have washed a bunch of sediment into the ditch and dumped it into Sisabagamah Creek just a half mile upstream of the sampling location.

Figure 29: Sisabagamah Creek drainage area for AUID -659. The green highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM047 fails the aquatic life standard for Macroinvertebrate IBI score.

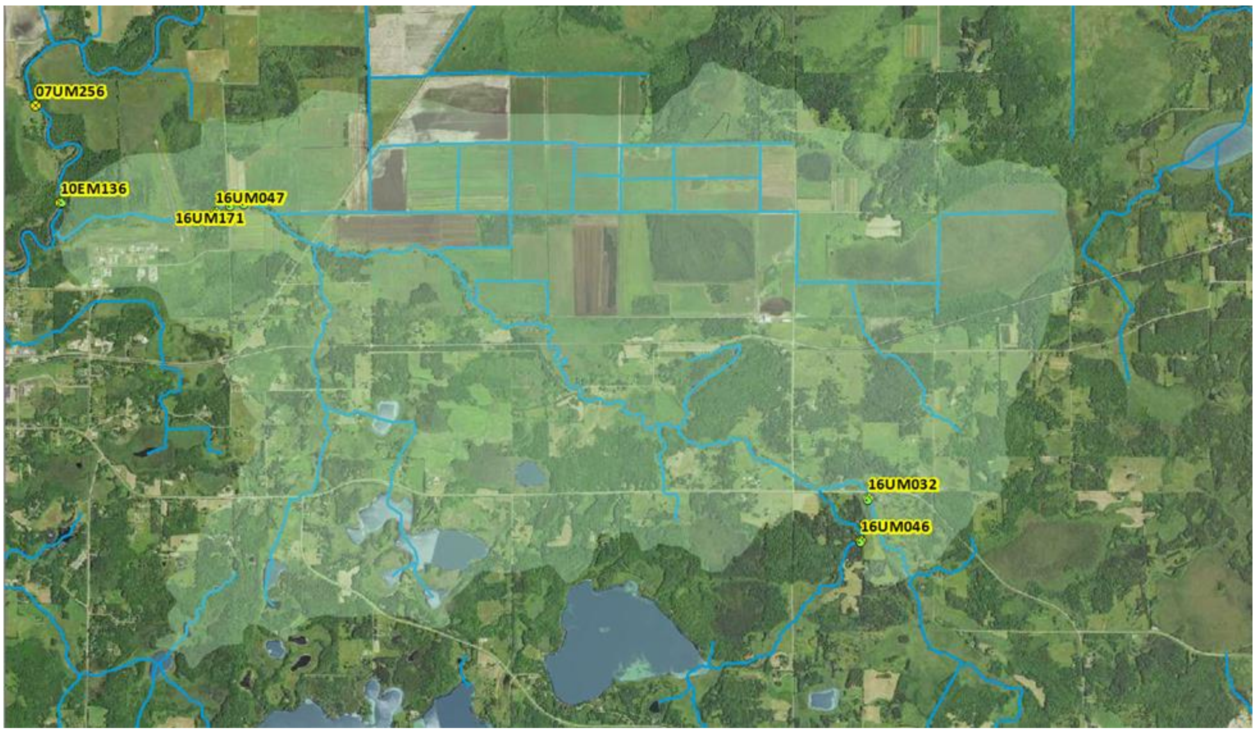


Figure 30: Minnesota GLO map created from MN GEO webpage. Showing the addition of ~9.5 square miles of drainage area from historically noncontributing areas.

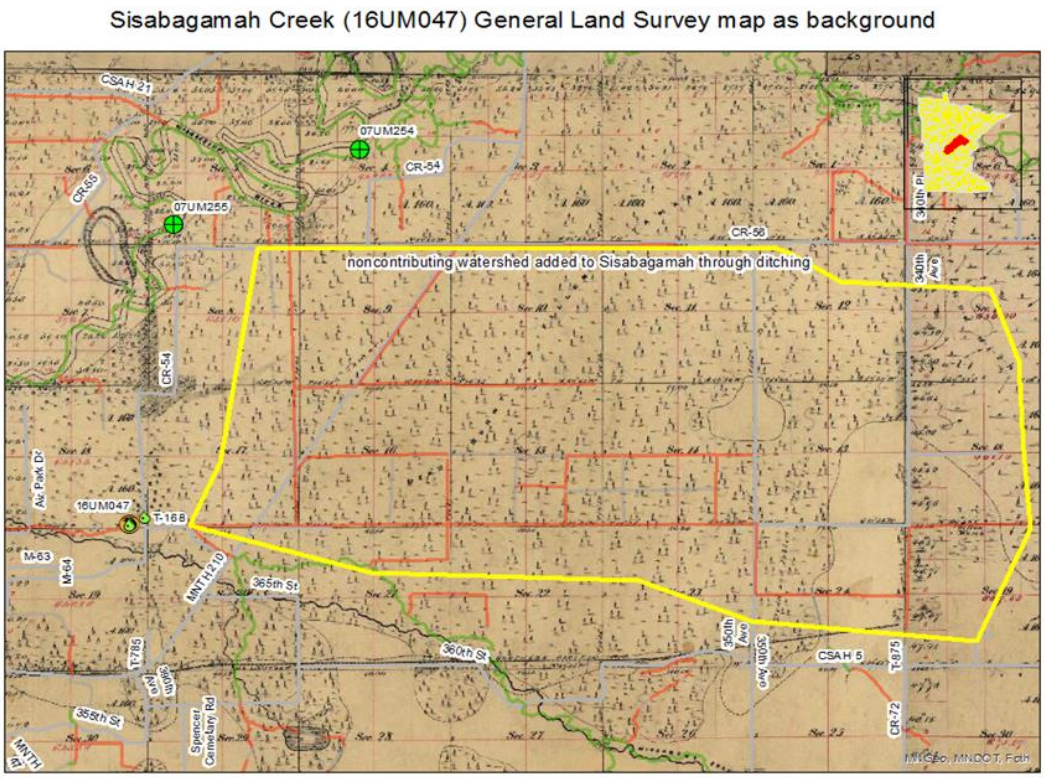


Photo 7: Maintenance of private ditch entering Sisabagamah Creek just upstream of Highway 169. Note spoil piles and no erosion control measures at site.

The sampling location for macroinvertebrates is downstream of CR54. Photo 9 below was taken on 3/31/2017 looking downstream at the sampling location. We can see from the photo that the stream channel is over widened and the substrate is dominated by sand. This sand substrate has been filling pools and creating an embeddedness issue throughout this lower reach. As stream banks erode, trees are falling into the channel creating logjams and depositing more sand and fine sediment in the channel.

Photo 8: High flow event from 6/18/2018 on the left and the receding flow from 6/21/2018 on the right. Both photos show milky looking water with suspended sediment being transported downstream.

Photo 9: Low flow period on Sisabagamah Creek. Showing sand substrate and wide stream channel.

Data evaluation for each candidate cause

Water quality data was collected from Equis site S008-826 on Sisabagamah Creek at CR54 in 2016-2017. Table 18 shows 2016 data collected as part of the MPCA's Intensive Watershed Monitoring sampling program. This information was collected during the first year of the IWM sampling program. Data shows that Sisabagamah Creek has elevated nutrients and elevated TSS concentrations.

TSS concentrations averaged 6.72 mg/L during this sampling event, which is low. However, there is field evidence indicating that TSS can be very high following high flow events. The coarser substrate in the channel is highly embedded with fine sediment, as is the in-channel wood features. This fine sediment is dislodged from stream banks during high flows and then is deposited as stream flow recedes.

Phosphorus levels are also high when compared to other streams in the northern-forested portion of Minnesota. The TP standard is 50 µg/L and this reach of stream averaged 92 µg/L during 2016. Phosphorus is often tied to sediment particles and generally, when TSS is elevated there is also elevated phosphorus. Elevated TP concentrations become a problem when aquatic plant growth in the stream affects the DO concentrations. There is no observed plant growth in the stream. The macroinvertebrate sample at 16UM047 has 3 taxa intolerant to phosphorus pollution and 4 taxa tolerant. Elevated stream flow and unstable stream banks are the underlying cause of a poor macroinvertebrate community. The macroinvertebrate sample has 8 TSS tolerant taxa sampled along with only 1 TSS intolerant taxa. This suggests that TSS has affected the macroinvertebrates and TSS concentrations may be driving what taxa are present in the stream. Even though sample concentrations are relatively low in 2016, the macroinvertebrates are showing stress based on TSS. This low TSS concentration can be explained by not sampling storm flows when the majority of the TSS would be delivered to the stream. Photo evidence (Photo 8) of site visits during high flow events also support a very turbid stream at times. The evidence suggests that TSS is a stressor.

Table 18: Water chemistry summary for Sisabagamah Creek at site 16UM047. Data was collected in 2016 as part of water sampling for the Mississippi River Brainerd IWM process.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
Temp-(°C)	13	18.38	23.7	10.6	3.93
Chl-a (µg/L)	8	1.94	5.78	1	1.607
DO (mg/L)	13	5.95	8.73	3.12	1.93
NH4 (mg/L)	11	0.085	0.213	0.04	0.0497
TKN (mg/L)	11	1.29	2.56	0.805	0.500
NOx (mg/L)	11	0.248	0.676	0.052	0.202
TP (mg/L)	11	0.092	0.187	0.028	0.042
TSS (mg/L)	11	6.72	16	2	4.02

In the summer of 2017, an YSI sonde was deployed to collect continuous data for a 14-day period. During this deployment, measurements of DO, water temperature, specific conductance, and pH were recorded (Figure 31). The DO never fell below the state standard of 5mg/L during the deployment. Water temperature fluctuated, but never reached higher than 26 °C. Both the DO and the temperature would not be considered stressors to macroinvertebrates during this deployment.

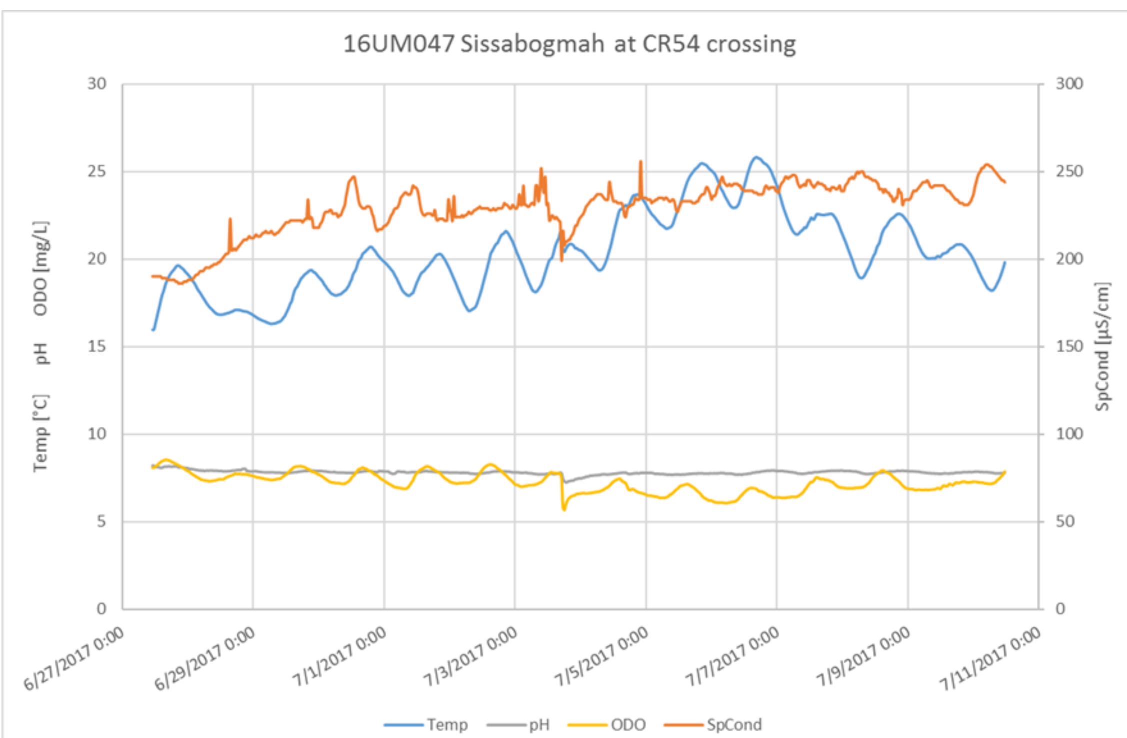
Values of pH ranged from 7.26 to 8.22, which is well within the standard for warm water (Class 2B) streams. Specific conductance was also well within regionally expected values. Neither pH nor specific conductance would be considered stressors to aquatic life.

During the 2017 deployment, there were no significant rain events, so stream flow was normal and well within its banks. In 2016, a heavy 12-inch rainfall occurred on July 11, which elevated the stream to flood stage. Following this large abnormal event, the DO concentrations in the stream were typically below 5mg/L. As seen in the upstream reaches of Sisabagamah Creek, DO can be lowered significantly following large rainfall events with flood stage flows. The 2016 macroinvertebrate sample did show that low DO is not a stressor. The sample had 4 taxa that are intolerant to low DO and 2 taxa that are considered tolerant.

Increased drainage within this area has caused an elevated level of fine sediment to be transported. The process of adding drainage ditches in areas that traditionally did not have direct contribution to the watershed has increased the volume of water entering the stream channel, and also has increased the amount of sediment available to the channel. This is evidenced by stream bank failure located upstream of CR54, stretching to the Highway 169 bridge crossing. During 2017, the county ditch located just north of Sisabagamah Creek was cleaned. During this process, there was no erosion control installed, and even after months, the spoil piles and ditch banks were not vegetated. Not having vegetation growing along the ditch banks promotes erosion along the ditch; this erosion causes plumes of fine sediment to enter the creek (Photo 7).

As the creek becomes filled with sediment, it changes the slope of the channel, which in turn can cause higher stream levels during 2 year and larger flow events. More frequent higher stages, in turn, increase streambank erosion, which then causes even more sediment to enter the stream. Once too much sediment is in the stream channel, all of the pools and riffles are covered by fine sediment, and habitat is significantly degraded. This lack of habitat is probably the main stressor to the macroinvertebrates, however it is being caused by the additional drainage area created through the ditching network.

Figure 31: Continuous data collected using a YSI 6920 multi parameter sonde from June 27, 2016 through July 10, 2016. Data collected at 30-minute intervals, deployed on downstream side of CR54 road crossing in center of channel.



Photographs at the CR54 road crossing show the impacts of sediment export at various times of the year with differing flow regimes. At low flow conditions in spring of 2017, there was very little sediment in the water. This coincided with little snow melt and before any spring rains occurred. On June 21, 2018, the stream was very turbid following a significant (2-4 inch) rainfall. Much of this fine sediment is being introduced to the stream from the ditch network just north of the U.S. Highway 169 crossing. Sampling on the same date at 16UM046, which is upstream of U.S. Highway 169, showed that there was no turbidity and the Secchi tube reading was 100 cm, which is the maximum.

The MSHA score at site 16UM047 was also very low (36-37). This places habitat in the poor category for this station. Review of the subcategories for the MSHA reveal that the site had no coarse substrate and was dominated by sand and clay. There were no pools or riffles identified during the time of macroinvertebrate sampling. Stream habitat diversity was limited to runs and woody debris. A high percentage of the woody debris was old and embedded with sand. The above photos also show how wide the stream channel is at this location and indicates bank erosion. Since this reach is dominated by a run, there is very little stream velocity difference, which also can limit the species of macroinvertebrates that would inhabit this type of habitat. A lack of habitat diversity is limiting the diversity of macroinvertebrates found at this location.

4.1.1. Stressor pathway

Stream habitat is limiting within this area of Sisabagamah Creek. The lack of habitat features is evidenced by sand dominated runs and no coarse substrate or deep pools. The woody debris that is located in this section of stream is limited to old, large embedded trees that have fallen into the stream. Stream flow alteration has occurred in the past by the addition of 9.5 sq. mi. of drainage area being added to the stream via a ditch network that is located northeast of the Highway 169 crossing. This additional stream flow has impacted the channel shape by causing bank erosion and widening the stream channel. This action in turn has allowed the channel slope to flatten by the process of depositing fine sand on the bed. In addition, historical straightening of the channel downstream to the Mississippi River has caused the channel slope to change, allowing for more deposition and inefficient transport of the sediment load entering the stream. Elevated nutrients along with higher TSS levels are also signs of increased sediment moving through the stream.

4.1.2. AUID summary

This AUID has been significantly altered in terms of the dimension, pattern and profile of the stream. There has been a significant amount of additional drainage area added, approximately 9.5 sq. mi., through the CD 24 ditch network. This additional flow, along with stream straightening in the past have changed how the stream can carry its sediment load and affected its ability to be a self-cleaning system.

The additional flow carries fine sediment. The stream bank erosion in both the ditch network and the stream corridor are adding sufficient amounts of sand and fine sediment that are filling pools and covering any coarse substrate that was available. The macroinvertebrates have two habitat cover types available: woody debris and undercut banks due to bank erosion. There are no rooted macrophytes found in the stream.

Stream turbidity can very high during large rain events. Nutrient levels are elevated along with TSS concentrations during high flow events. Evidence of channel instability is present by the number of unstable stream banks and the amount of fine sediment deposited in the channel. A lack of habitat is the main stressor, being caused by flow alteration and the amount of sediment coming into the stream from stream bank instability and no vegetated ditch banks. TSS is also a stressor to the macroinvertebrates. Low DO is not a stressor.

4.7. Sisabagamah Creek -677 (FIBI)

4.7.1. Biological communities

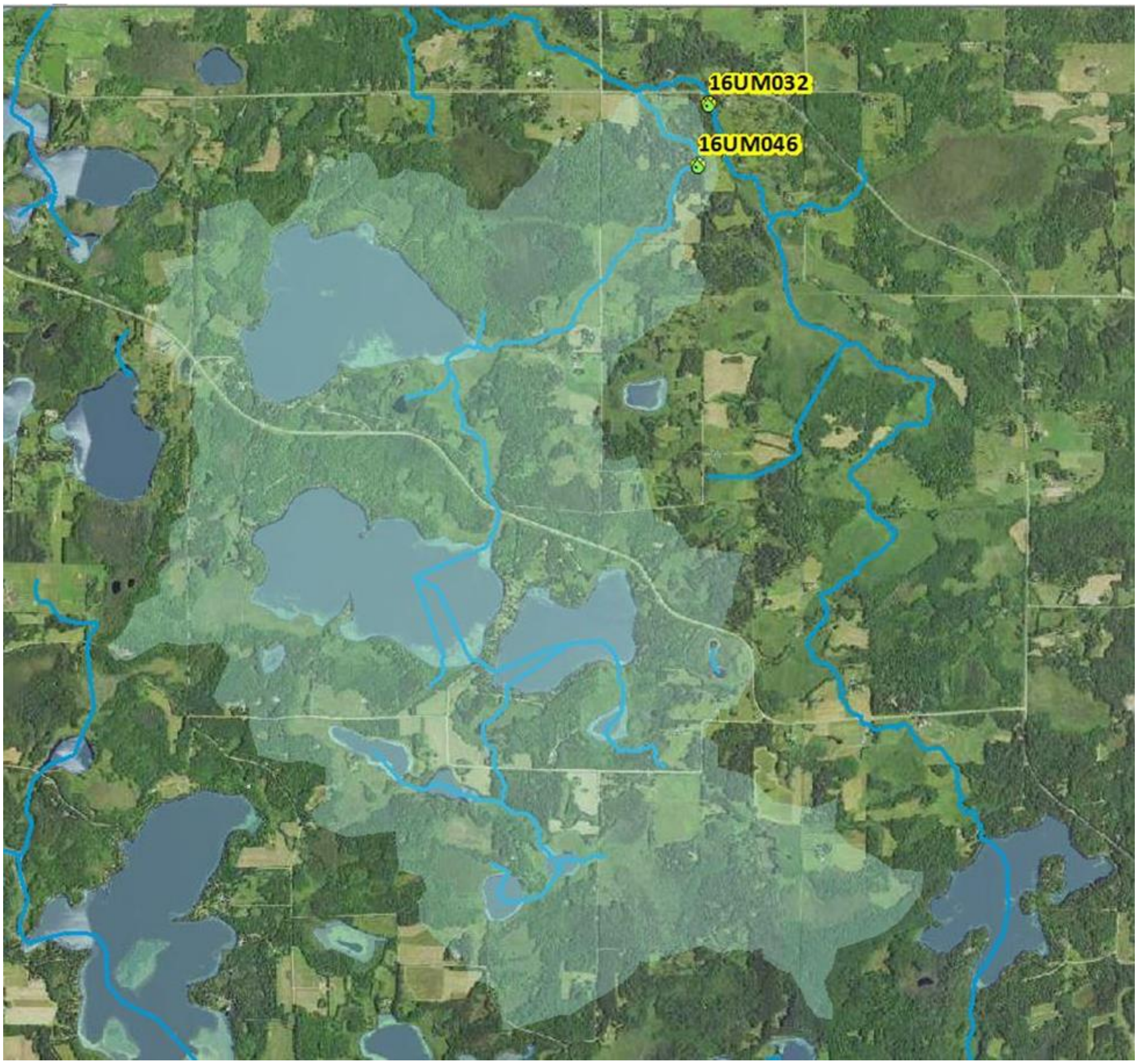
The reach of the Sisabagamah Creek is 2.13 miles long and goes from Sisabagamah Lake downstream to the confluence with Rabbit Creek (Figure 32). There is one biological monitoring station located on this AUID (16UM046). Site 16UM046 drains 9.54 sq. mi. and is located near the outlet of the AUID, just upstream of MNTH47 and 345th Place. This stream is located in the Sisabagamah Creek 12 HUC.

Macroinvertebrates were sampled in 2016 after the major July rain event. This sample was not assessable due to the effects of the flood. Macroinvertebrates were again sampled on August 14, 2017 and this sample passed the MIBI with a score of 61.28.

Fish were sampled on June 23, 2016 before the flood of July 11, 2016. This Class 7 stream scored a 31 on the FIBI and the threshold is 42. Only four fish species were sampled (central mudminnow, white sucker, bluegill and northern pike). Central mudminnow dominated the sample with 75 individuals.

The MSHA was recorded three times at the site. On June 23, 2016, the MSHA score was 61.75, on August 30, 2016 a 43 (following the July 11, 2016 flood event) and a 64 on August 14, 2017. The MSHA scores indicate that habitat is not limiting the biology at this site.

Figure 32: Sisabagamah Creek drainage area for AUID -677. The green highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM046 fails the aquatic life standard for Fish IBI score.



4.7.2. Data evaluation for each candidate cause

A probability index of passing the DO and TSS standard are computed based on the fish community sampled. This index uses the species and abundance of fish to calculate the chances of meeting the water quality standard. Based on the fish sampled at 16UM046 there is a 5% chance of the site meeting the DO standard and an 85% chance of meeting the TSS standard.

The 2017 macroinvertebrate community showed a different result for low DO conditions. In 2016, following the July 11 flood, the macroinvertebrate community showed a 30% chance of passing the DO standard, however in 2017 when no major flooding events occurred the macroinvertebrate community showed a 61% chance of passing the DO standard. This suggests that low DO may not be solely driving the fish impairment.

Lack of connectivity in the stream channel is also playing a role. There are multiple documented beaver dams downstream of the site that are inhibiting fish migration. The MSHA was a 61.75 on June 23, 2016, a 43 on August 30, 2016 (following the July 11, 2016 flood event), and a 64 on August 14, 2017. The MSHA scores indicate that habitat is not limiting at this site.

Water quality data from Equis site S013-493 on Sisabagamah Creek near site 16UM046 was collected in 2017 (Table 19). This data was used to determine the level of nutrients in the stream and determine if excessive nutrients are driving the low DO conditions. The TP concentrations were below the 0.05mg/L northern lakes and forest ecoregion phosphorus standard during the summer months; with the exception of a 0.102 mg/L TP reading on 6/15/2017. Site visits revealed clear water with plant growth in the stream but very little evidence of periphyton or algal growth observed. Nutrients do not appear to be driving the low DO readings at this site and can be eliminated as a stressor. During the 2017 sampling season, minimal concentrations of nitrogen were found. Nitrogen can also be eliminated as a stressor to the biology.

Table 19: Water quality data collected during 2017 at Sisabagamah Creek (S013-492).

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
TP (mg/L)	8	0.03	0.102	0.012	0.03
NOx (mg/L)	8	<0.05	<0.05	<0.05	NA
Temperature	8	15.237	17.87	13.25	
DO (mg/L)	8	6.319	8.07	4.4	
Sp. Cond. (µS/cm)	8	123	236	76	

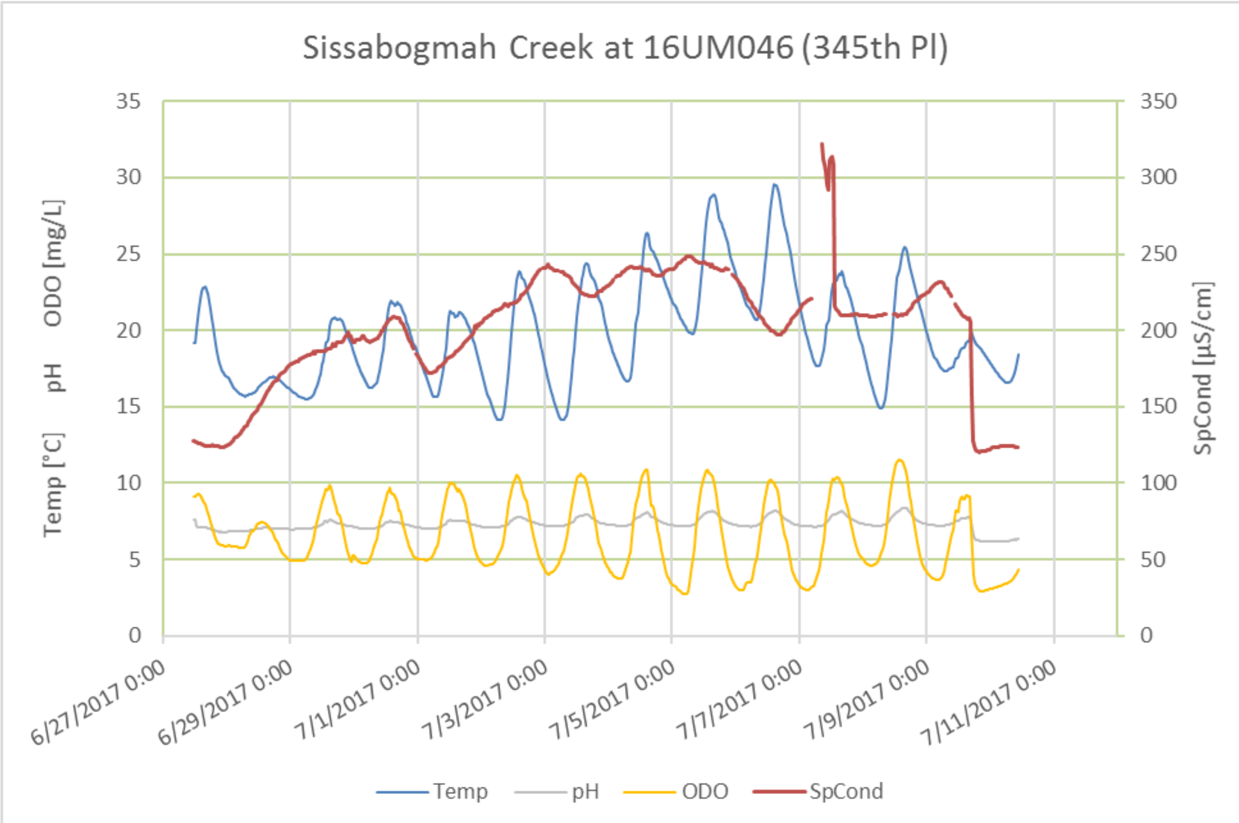
During the fish and macroinvertebrate, sampling a one-time water chemistry sample was collected. The results of this data collected can be found below in Table 20.

Table 20: Water chemistry results from the biological monitoring events.

Date	Temp °C	DO mg/L	Sp. Cond µmhos@25°C	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
6/23/2016 8:42 am	17.3	4.87	118		0.1	0.02	0.05	3.6	3.2
8/14/2017 3:25 pm	19.6	8.19	139	7.38					

In 2017, a continuous recording sonde was placed in Sisabagamah Creek near site 16UM046. The results from this thirteen-day deployment are shown in Figure 33. The results show that DO does drop below 5 mg/L during the deployment. This data set also shows that temperature can approach the 30°C mark, which is considered stressful to aquatic organisms. This sonde deployment was collected during very low flow conditions.

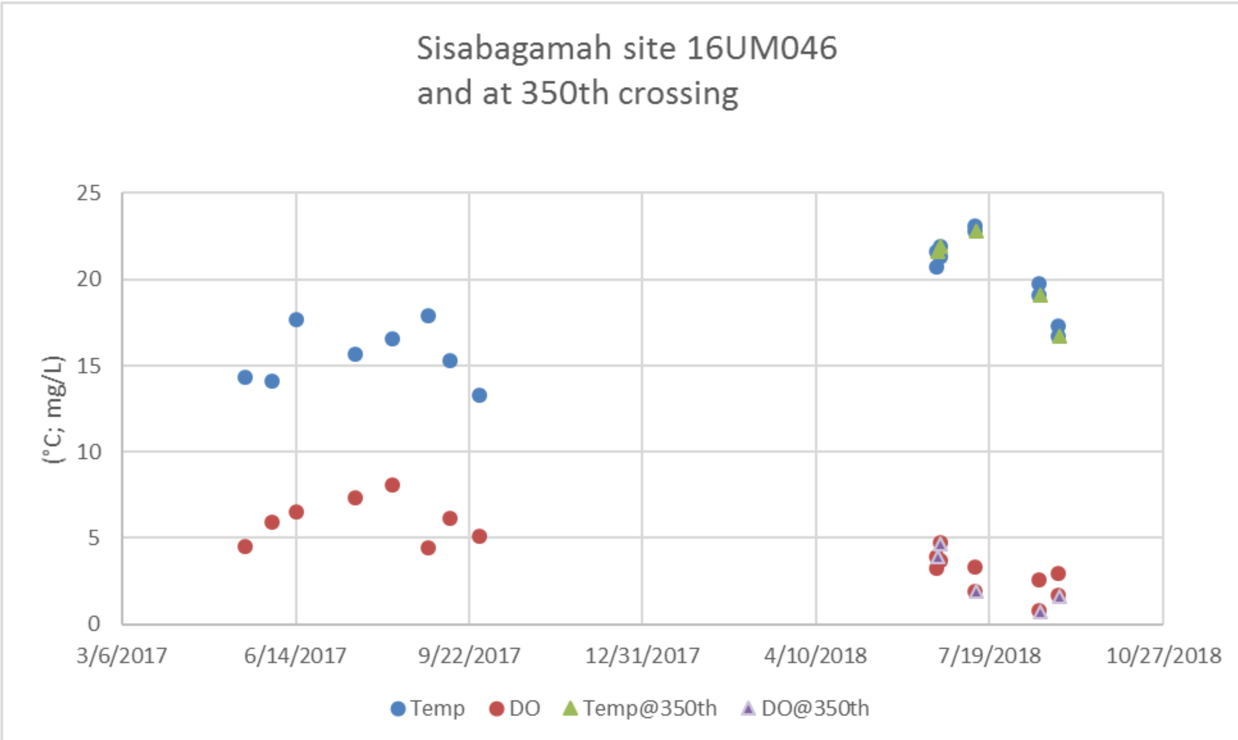
Figure 33: Continuous sonde data collected at 16UM046 from June 28 through July 10, 2017.



Additional water chemistry data was collected during 2018 to show the impact of the upstream wetland on site 16UM046. Following a significant rain event within the subwatershed additional sonde data was collected. A heavy rain event occurred on 6/17/2018 and dumped 2-4 inches of rain. This rain event filled the wetland basins and subsequent stream discharge increased dramatically. On June 19, 2018, sonde readings were collected at 16UM046 and the upstream road crossing at 350th Ave. Both locations had low DO concentrations of 3.9 and 3.23 mg/L. There is no recovery of DO concentrations in this reach due to the low gradient nature of the channel and the proximity of the surrounding upstream wetlands. On June 21, 2018, an additional sonde reading was collected at the two locations again with a 3.64 and 4.67 mg/L DO concentrations. Again, on July 11, 2018 a paired set of sonde readings were collected. This time during very low flow event when the wetland flushing had nearly ceased. The results at this sampling was 1.91 and 3.28 mg/L.

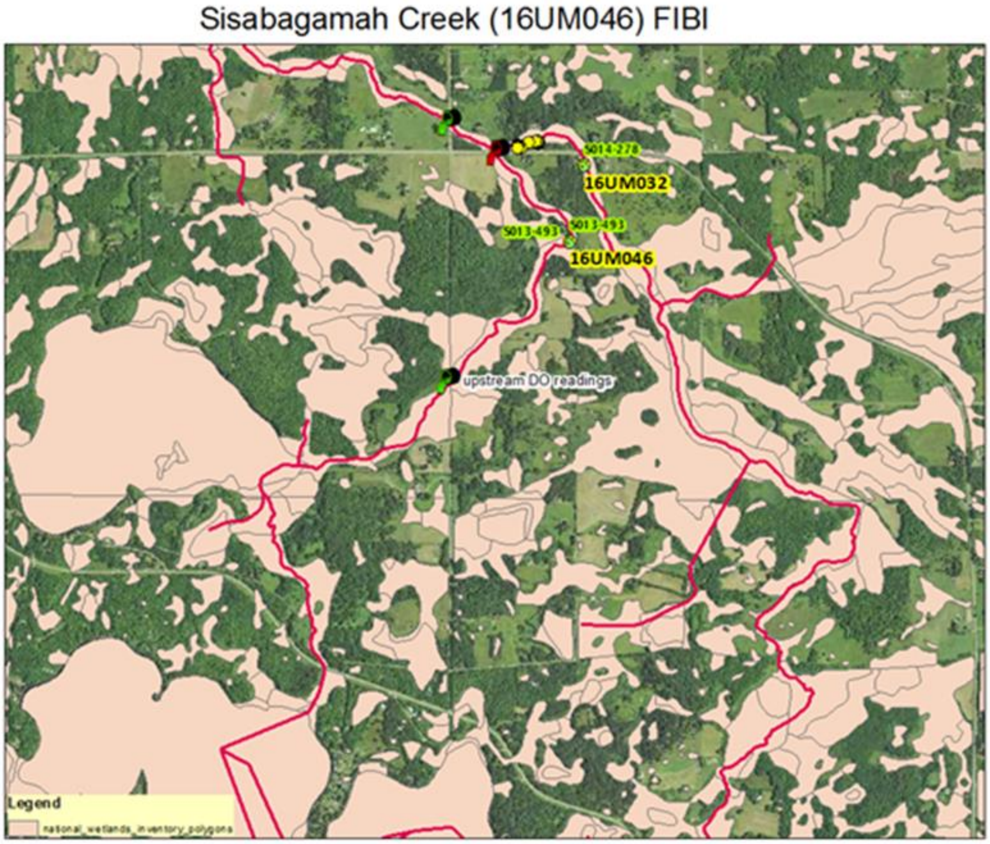
The large wetland just downstream of Sisabagamah Lake is causing a drop in DO concentrations and the stream does not have the ability to recharge DO by the time it travels downstream to site 16UM046. This is a naturally occurring situation as there is very little human activity within this area. The graph below (Figure 34) displays the 2017 and 2018 spot sampling results for DO and water temperature. In 2017, precipitation did not come in the form of large rain events as in June of 2018. The stream stage did not fluctuate in 2017 nearly as much as it did in 2018 and the DO concentrations did not experience the variability seen in 2018.

Figure 34: Spot DO and temperature readings at 16UM046 in 2017 and 2018. Also in 2018, an upstream site at 350th St was also collected to determine the contribution of low DO to the downstream stream segment.



The map below (Figure 35) shows the two DO sampling locations along with the wetland areas shown in tan. A large portion of the upstream corridor is wetland in nature. This section of stream also flows through some large shallow lake basins. During the five-paired 2018 sampling events, the DO was below 5 mg/L at both sites.

Figure 35: Sisabagamah Creek drainage area upstream of Highway 47 crossing. Tan areas represent wetland areas and open water.



The photos below document the conditions during the various DO sampling events in 2018. DO concentrations were below the 5 mg/L standard during all sampling visits in the summer of 2018. The top photos (Photo 10) were taken on 6/19/2018 following a significant 2-4 inch rain event that increased stream flow dramatically. The theory with the low DO this year is that the wetland riparian fringe flooded and as water receded the SOD and/or BOD that was washed into the stream corridor was stripping the DO from the stream. Limited reaeration occurs in this reach as the gradient is very flat and there are no riffles. During the August 28, 2018 site visits, (Photo 11) stream flow was once again very low in this section of Sisabagamah creek. Stream flow at S013-493 was 0.5 cfs on this date and stream flow at the 350^{th} street crossing was 0.2 cfs. The DO concentrations were recorded as 2.9 and 1.63 mg/L respectively at the two locations.

Photo 10: Sisabagamah Creek flow conditions during the June 19, 2018 water quality sampling events. Flow was high (40 cfs).

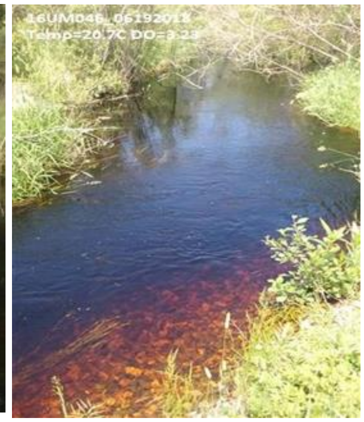


Photo 11: Sisabagamah creek flow conditions during the August 28, 2018 water quality-sampling event. Flow was 0.5 cfs.

Low DO is a partial cause of the low biological diversity found in the stream. In 2016 following a major flow event in July, a low MIBI score was observed. When sampled in 2017 there were no significant flow events in this reach and the DO appeared to be above the 5 mg/L standard all summer. This scenario was met with a passing MIBI score that showed very few low DO tolerant taxa. Again in 2018 the stream experienced low DO conditions following a significant rainfall (2-4" in 24 hours). This condition dropped the DO in the stream and probably impacted the biological communities. Low DO is a stressor to the biology, however it is directly related to the stream flow and having riparian wetlands experience some type of flooding during the summer months. The contributing watershed is undisturbed in this area and a TMDL for low DO is not needed. It is believed that the low DO is being caused by the flushing of upstream and adjacent wetlands.

Longitudinal connectivity is an issue for fish in this reach. There are numerous documented beaver dams located downstream of the site (Photo 12, 13). The abundance and condition of the beaver dams would make fish passage difficult and under normal flow, conditions would inhibit the migration of fish into the reach. This condition was documented in 2016-2018. The dams are persistent and do not appear to be going away any time soon. The map below shows the location of the beaver dams (Photo 12). The beaver dams are large enough and frequent enough to cause both migratory fish blocks during higher flows and during low flows. The number of beaver dams is locally affecting the fish sampled at this site in 2016 and is considered a stressor. It is also possible that the abundance of dams is exacerbating the low DO and high temperature problems.

Photo 12: Location of documented beaver dams found on this AUID of Sisabagamah Creek. Google earth was used to display locations on the October 1, 2015 aerial image.

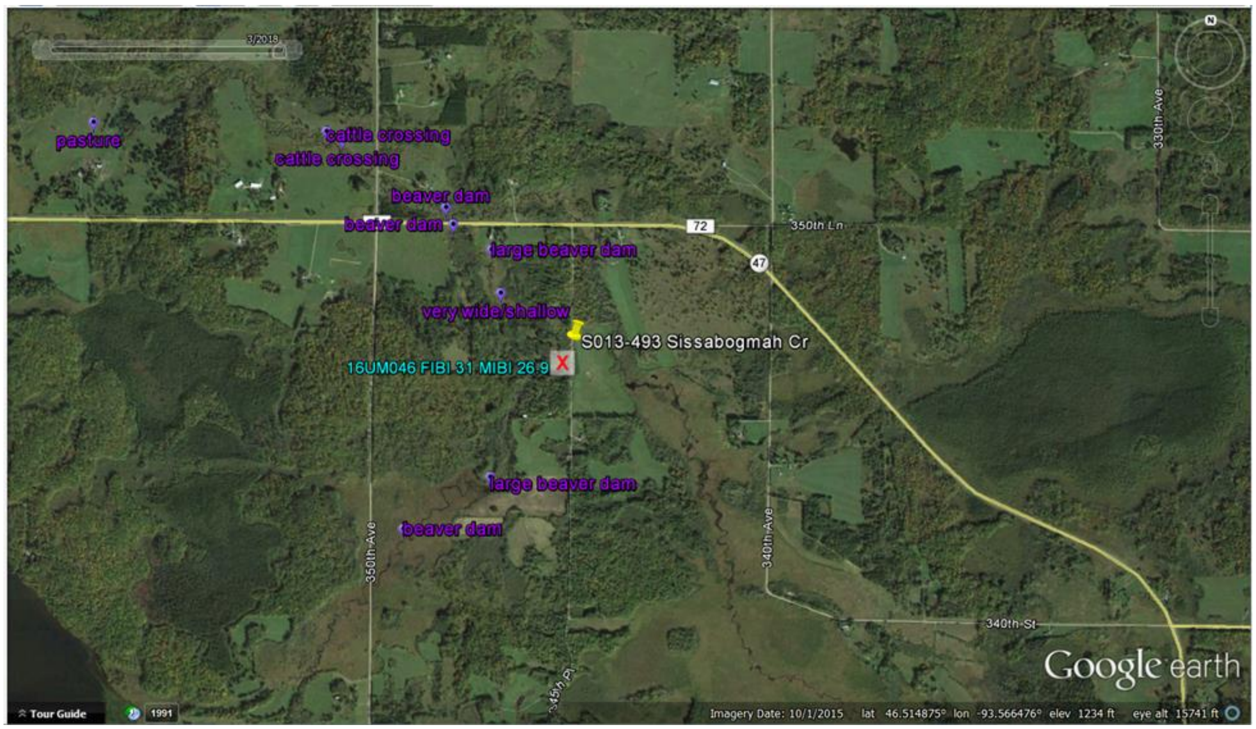


Photo 13: Beaver dams located on upstream side of Highway 47 road crossing. July 10, 2017.

Photo 14: Beaver dams located on Sisabagamah Creek just downstream of the confluence of Rabbit Creek and Sisabagamah creek on the downstream side of Highway 47.

4.7.3. Stressor pathway

As discussed above, low DO is having an effect on the biological communities. The low DO appears to be caused by the flushing of upstream wetland riparian areas. In 2018, following a 2-4" in 24 hour rain event, the stream stage rose quickly and accessed the wetland riparian corridor. This caused a significant drop in stream DO concentrations followed by a prolonged period of low DO. The upstream corridor is natural and relatively undisturbed. There are very few residences located in this area and very few roads, as seen in above aerial photographs (Photo 6). The abundance of beaver dams located downstream of the site is causing a lack of longitudinal connectivity. This is perhaps the greatest driver in the low fish IBI score, as fish would find it difficult to migrate upstream and populate this area of stream.

4.7.4. AUID summary

In summary, lack of longitudinal connectivity appears to be a main stressor for fish in this AUID. The sheer number and duration of documentation of the beaver dams suggests that they will be there for an extended period of time. Low DO is also a stressor, impacting both the fish and macroinvertebrates, depending on water levels. The DO is low following large precipitation events as documented in 2016 and again in 2018. It does not appear that low DO is caused by excess nutrients as the nutrient levels are below state standards. The low DO appears to be caused by wetland flushing during the summer storm periods.

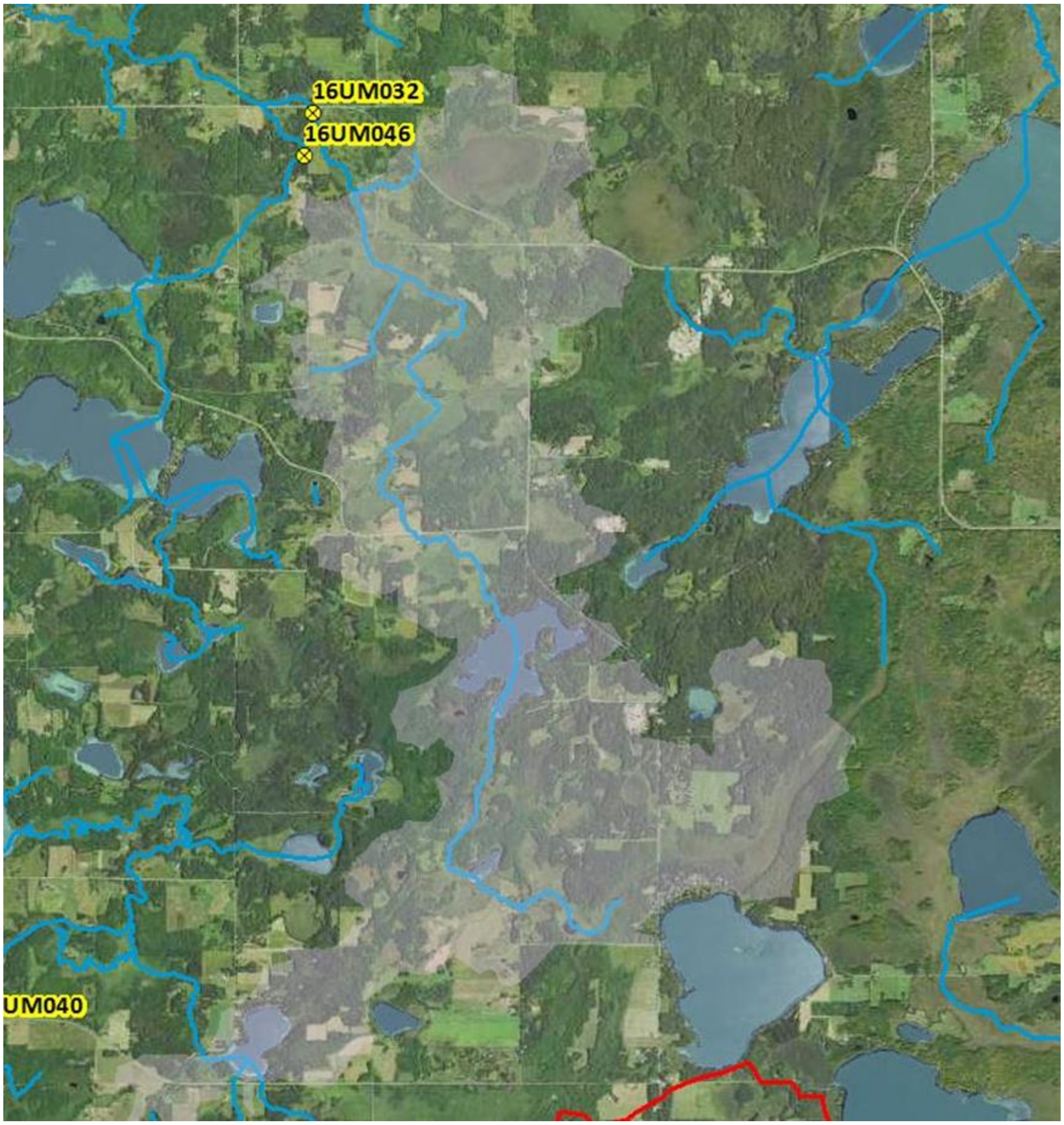
4.8. Rabbit Creek -688 (FIBI)

4.8.1. Biological communities

The reach of Rabbit Creek is 6.04 miles long and goes from Rabbit Lake downstream to the confluence with Sisabagamah Creek. There is one biological monitoring station located on this AUID (16UM032). Site 16UM032 drains 14.04 sq. mi. and is located near the outlet of the AUID just upstream of MNTH47 (Figure 36).

Macroinvertebrates were sampled on August 9, 2017 and this sample passed the MIBI with a score of 59.2 (threshold of 51). Fish were sampled on July 11, 2017. This Class 7 stream scored a 34 on the FIBI and the threshold is 42. Only six fish species were sampled (central mudminnow, creek chub, golden shiner, tadpole madtom, white sucker, and yellow perch). Central mudminnow dominated the sample with 128 individuals. The MSHA averaged 60.5 in 2017. This places the habitat in the "good" category and suggests that habitat is not limiting.

Figure 36: Rabbit Creek drainage area for AUID -688. The blue highlighted drainage area is overlaid on the 2017 color aerial photo. Site 16UM032 fails the aquatic life standard for Fish IBI score.



4.8.2. Data evaluation for each candidate cause

During field visits in 2017 and 2018 it was documented that a large beaver dam was located just downstream of the private driveway crossing downstream of Hwy 47. This beaver dam posed a 1.5-foot drop during a survey conducted on April 27, 2018. Photo 13 shows the condition of the beaver dam during this elevation survey.

Photo 15: Large beaver dam located approximately 400 feet downstream of private driveway on Rabbit Creek. This beaver dam is backing up water and has the potential to block fish passage. Location is also downstream of site 16UM032.

Water quality data from Equis site S014-278 on Rabbit Creek near site 16UM032 was collected in 2018. Water samples were collected four times during the summer of 2018 and the results are displayed in Table 21. The nutrient concentrations during the four sampling events indicate that eutrophication is not a driving factor of the low DO observed in the stream. Sonde readings were collected eight times in 2018 and revealed that in the summer of 2018 the DO levels were nearly all below the 5 mg/L state standard for class 2B streams. The relatively low specific conductance readings indicate a high degree of surface water, suggesting that the stream water source is mainly coming from Rabbit Lake upstream.

Table 21: Water chemistry results from 2018 sampling at Highway 47 crossing of Rabbit Creek, at site S014-278. Samples were collected from May through August

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
TP (mg/L)	4	0.048	0.083	0.025	0.027
NOx (mg/L)	4	<0.05	<0.05	<0.05	NA
Temperature (°C)	8	19.59	22.9	14.25	
DO (mg/L)	8	3.52	5.31	0.32	
Specific conductance(µS/cm)	8	131	162	111	

During the fish and macroinvertebrate sampling a one-time water chemistry sample was collected (Table 22).

Table 22: Water chemistry data collected in 2017 during biological sampling visits.

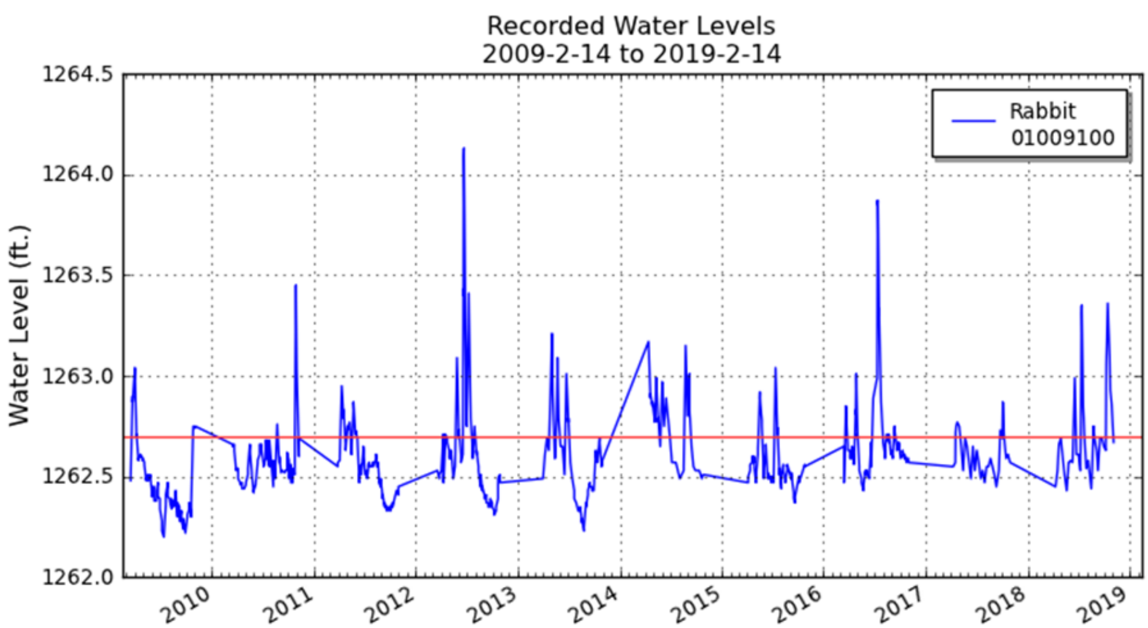
Date	Temp °C	DO mg/L	Sp. Cond µmhos@25°C	pH	NH4 mg/L	Nitrogen mg/L	Phosphorus mg/L	TSS mg/L	TSVS mg/L
7/11/2017	21.4	7.33	135	7.25	0.1	0.02	0.021	1	<1
8/9/2017	19.7	5.69	139	7.01					

Overall, the available water chemistry data collected does not indicate any anomalies that would be causing stress to the fish community. The DO was low in 2018 during sampling, however, many of the samples were collected after a significant rainfall event, which elevated stream flow and flushed out riparian wetlands.

4.8.3. Stressor pathway

The stream reach in 2018 appears to have been heavily influenced by upstream wetland conditions, particularly the drainage coming out of Rabbit Lake (01009100). Rabbit Lake is a deep lake with 77 acres of littoral area. May and June water quality sampling events showed very low TP and NOx concentrations at the Hwy 47 crossing. This supports that the watershed at this point in the season is not exporting high nutrient concentrations and the low DO is naturally occurring due to BOD and SOD within the wetland complex downstream of Rabbit Lake. Water level data recorded at the outlet of Rabbit Lake shows that 2016 and 2018 are above the Ordinary High Water (OHW) level of 1262.7 ft. at various times during the summer (Figure 37). Water quality data for Rabbit Lake is limited to secchi transparency readings. The lake does meet the recreation standard based on secchi transparency readings. There are no indications of low DO conditions for Rabbit Lake as there are no documented winterkills from the DNR Lake survey information and the lake supports a healthy fish community.

Figure 37: Water levels at Rabbit Lake outlet. Data is from 2009 through 2018. The red line is the OHW. Data shows that 2017 water levels were relatively low compared to 2016 and 2018 water years.



Of note, the fish community in Rabbit Creek seems to be more stressed than the macroinvertebrates. The fish IBI scored 7.7 points below the threshold of impairment, while the macroinvertebrates scored 8.2 points above the threshold. It is believed that the downstream beaver dam is causing the greatest impact on the fish community. However, during periods of heavy rainfall, the DO concentrations will drop below the 5 mg/L level and will also affect the biological diversity of both fish and macroinvertebrates. This low DO is caused by naturally occurring wetland complexes located upstream of the sampling area.

Photo 16: Rabbit Creek site visit photos. Photo on the left is upstream side Hwy 47 on June 19, 2018, the photo on the right is upstream side Hwy 47 on April 27, 2018. Both are high flow events.

Flow gage data from nearby Dean Brook shows that the stream jumped by 2 feet in stage between 16:30 on June 16, 2018 and 17:30 on June 17, 2018 (Figure 38). With this increase in stream stage there is a high probability that the upstream wetland areas also had a significant flushing event. The stream stage was high during various site visits in 2018 as documented in Photo 14. The high stream stage events can explain the low DO observed during the following sampling period and helps us understand the cause and effect of the low biodiversity within the channel during the year. There is no gage located on Rabbit Creek but Dean Brook is located within 10 miles as the crow flies and similar rainfall occurs in both subwatersheds.

Figure 38: Continuous stream stage (ft.) data collected at Dean Brook in 2018. Dean Brook is located 10 miles west of Rabbit Creek. Similar stream response is expected between the two sites.

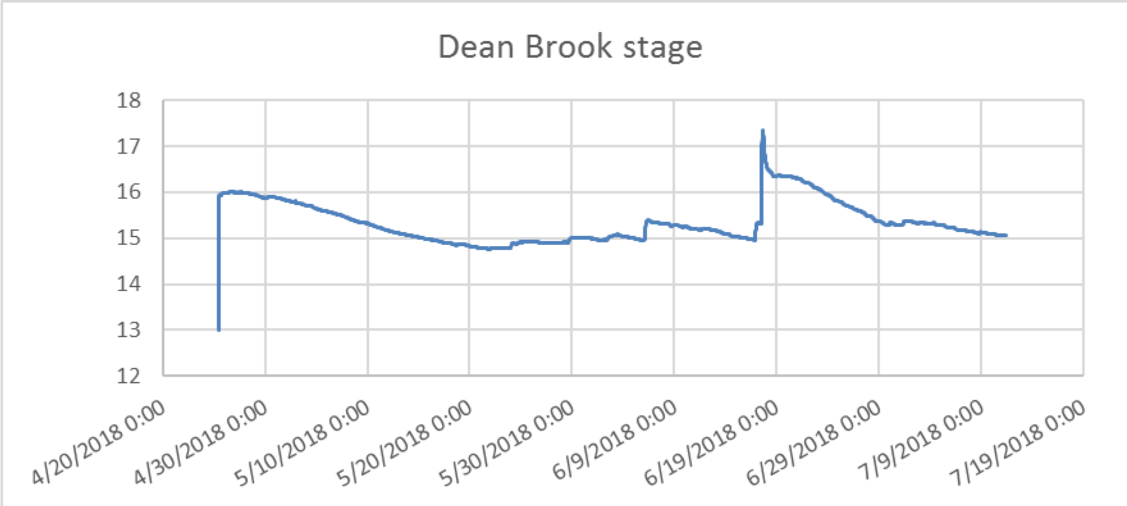
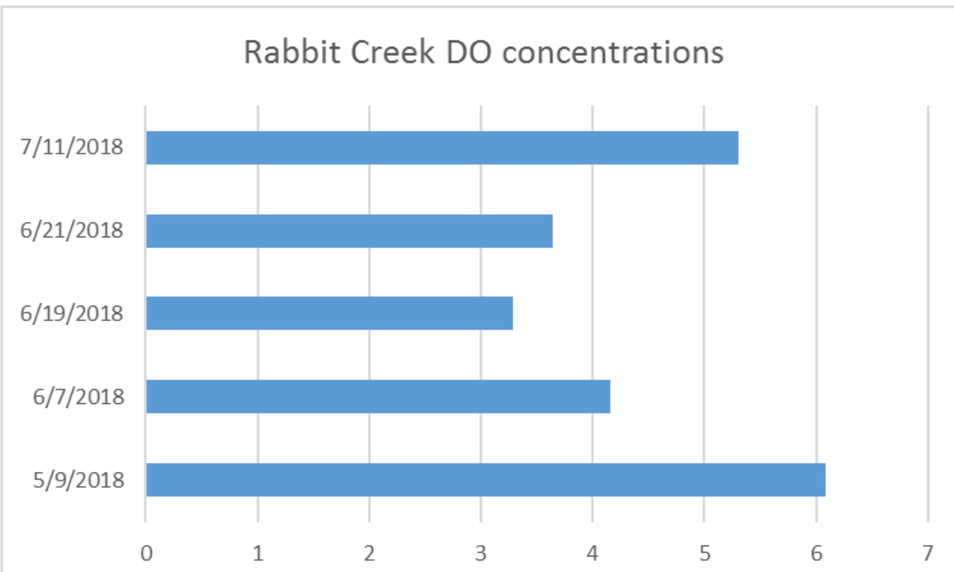
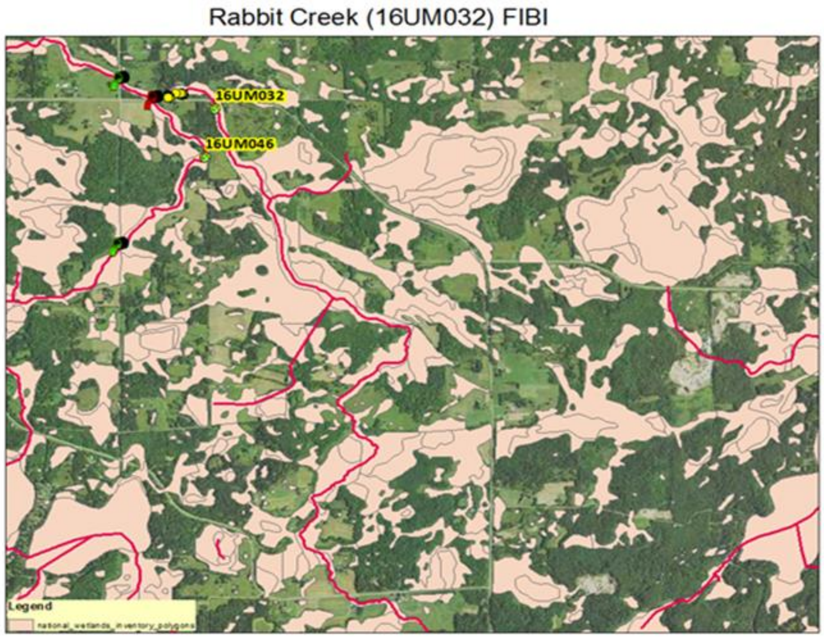


Figure 39: Instantaneous DO (mg/L) data collected at Rabbit Creek on Highway 47.



The DO data at Rabbit Creek suggests that DO concentrations dip after precipitation events occur and flow increases. The June samples were all collected following some type of rain event and the corresponding DO was below the 5 mg/L standard (Figure 39). With the low nutrient concentrations observed, it is very likely that the low DO is being caused by the wetland conditions that are prevailing upstream. Wetlands naturally have water chemistry that exhibits greater oxygen demands than lotic waters due to greater biological, chemical, and/or sediment interactions with the DO in the water column. There is no indication that eutrophication is driving the low DO concentrations. Rather the low DO is being driven by wetland flushing and elevated BOD and /or SOD concentrations stripping DO out of the water as it leaves the large wetland complex (Figure 40).

Figure 40: Rabbit Creek drainage area upstream of site 16UM032. Areas in tan are wetland complexes. A large percentage of the drainage area is wetland and may be reducing the DO concentrations in the Rabbit Creek system during high flow events.

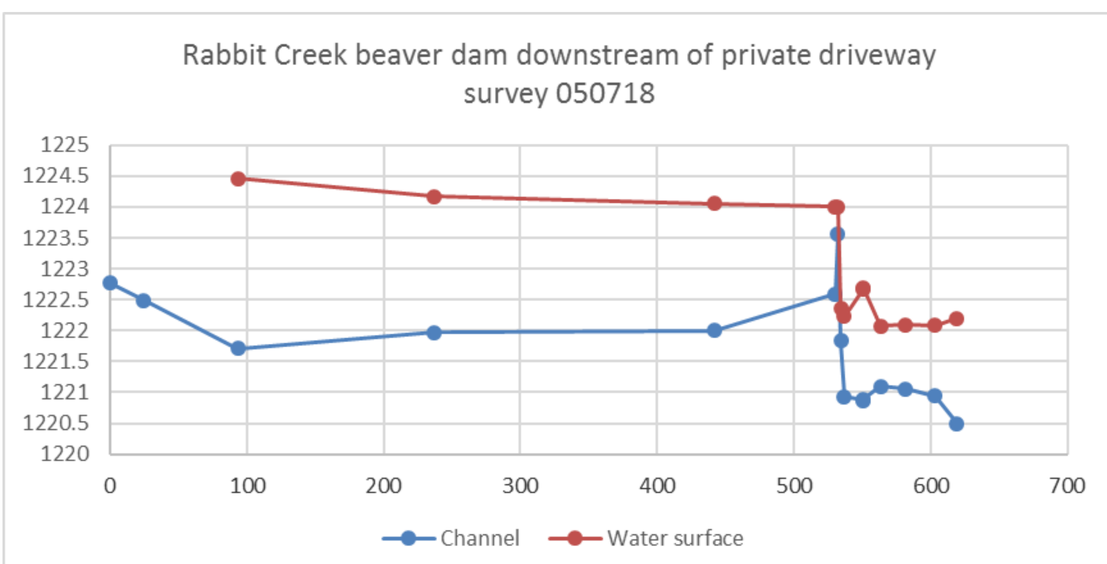


As the map above indicates, there is a large wetland component within the drainage network. There are very few residences or human activities upstream of the sampling location. The main driver of the water chemistry is the vast wetland upstream.

Connectivity barriers

A fish barrier has been identified on the downstream side of Hwy 47. This large beaver dam was holding back 1.6-1.7 ft. of water during a May 7, 2018 survey. Figure 41 below shows the extent of the beaver dam and the relative distance from the private driveway northwest of Hwy 47 crossing.

Figure 41: Longitudinal stream elevation survey from the private driveway north of Hwy 47. Survey goes downstream for 625 feet past a major beaver dam on channel.



4.8.4. AUID summary

The Rabbit Creek fish community is affected mainly by a lack of longitudinal connectivity due to a series of downstream beaver dams. The beaver dams can be as high as 1.5 feet of elevation difference making it nearly impassable for small fish species to migrate through. A lack of DO is also stressing the fish community. The upstream drainage area is largely wetland and during periods of higher flow, the wetlands flush. This causes a drop in DO concentrations in the stream that can persist for extended periods as observed in 2018. The amount of human activity in the upstream portion of the watershed is minimal and it appears that the low DO is naturally occurring.

4.9. Rice River -505 (FIBI)

4.9.1. Biological communities

The reach of the Rice River is 13.27 miles long and goes from its headwaters (Porcupine Lake 01-0066-00) downstream to the confluence with Section Five Creek. There are two biological monitoring stations located on this AUID (16UM036 and 98NF143).

Site 98NF143 drains 39.88 sq. mi. and is located just upstream of 300th Lane. This AUID drains a large wetland complex. This wetland complex is partially ditched and also has multiple ditched networks feeding the Rice River. Fish were sampled on June 13, 2016 and scored a 31. This class 6 stream has a threshold of 42 for the FIBI. The fish sample was dominated by central mudminnow, which is very tolerant to low DO conditions. Macroinvertebrates were collected on August 29, 2016. During this sampling event, the stream flow was high due to the July heavy rainfall. The sample's MIBI was below the threshold, but was deemed not reportable due to high flow conditions. More biological sampling was attempted in 2017 but was hindered by a newly built beaver dam in the sampling reach. The MSHA scored varied between a 53 and 62.25 in 2016. This places the habitat in the fair category.

Station 16UM036 is downstream of 98NF143 and has an 81.82 sq. mi. drainage area. The site is located on CSAH 4, just west of MNTH65. This station is near the downstream end of the AUID and has Equis site S005-402 collocated at the road crossing. Station 16UM036 was sampled for fish on August 22, 2016, but was determined non-reportable due to the flood conditions encountered from the July 11-12, 2016 9" rainfall. The fish sample was dominated by central mudminnow and black bullhead, which are both tolerant to low DO conditions. For the remainder of 2016, stream flow stayed very high and was considered outside base flow-high. Macroinvertebrates were sampled on August 29, 2016 and were also non-reportable due to outside base flow high conditions. The MSHA score varied between 48.5 and 49 for this site-placing habitat in the poor category.

4.9.2. Data evaluation for each candidate cause

Water quality data from Equis site S005-402 on the Rice River at CSAH 4 (just downstream of 16UM036) were collected in 2010 and 2011. Stream transparency and temperature was collected from 2008-2014. Table 23 presents the results from the sampling events. The water chemistry data shows that the AUID has elevated phosphorus concentrations. The average phosphorus concentration was 0.085 mg/L, which is above the 0.050 mg/L state standard for the Northern Lakes and Forest ecoregion. Elevated phosphorus can lead to increased plant growth, which can elevate the daily DO flux in the stream and cause low DO conditions. The stream does experience low DO concentrations but there appears to be very little DO flux as observed in the 2017 continuous data record collected at 98NF143 (Figure 42). Accelerated plant growth is inhibited by the tannic stain of the water as the stream flows out of large upstream wetland complexes. Phosphorus is elevated but not resulting in eutrophication problems.

Table 23: Water chemistry results from May through September 2008-2014, sampling of S005-402 on Rice River.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
Dissolved Oxygen	25	3.914	7.79	0.63	1.782
Nitrate-nitrite	24	0.0567	0.2	0.1	0.033
Kjeldahl nitrogen	24	2.108	2.9	1.1	0.494
Phosphorus	25	0.085	0.161	0.024	0.037
Temperature	102	17.749	27.8	3.33	5.68
Total suspended solids	24	5.667	14	2	2.869
Stream transparency tube	140	42.9	96	16	44% exceed standard of 40cm

DO data shows that the DO concentrations are often below the 5 mg/L standard during the summer months. During the spot readings collected in 2010 and 2011, the majority of the June through August DO readings were below the 5 mg/L standard. A sonde was deployed at 98NF143 for 10 days from July 12-July22, 2017. Figure 42 below shows the results of this deployment. The DO during most of the deployment was barely above 5 mg/L, with some minor periods dropping just below 5 mg/L. Upstream of site 98NF143, land cover is dominated by wetland conditions. This can explain the elevated phosphorus concentrations along with the low DO concentrations. The macroinvertebrates sampled have 7 taxa that are tolerant to low DO and 1 taxa that is intolerant. The fish community sampled suggests a high degree of tolerance to low DO conditions. Low DO may be the largest factor stressing the fish community.

The Altered Watercourse layer and the original GLO map layer shows that the wetlands in the drainage area of 98NF143 were ditched. This area contributed 17.4 sq. mi. of additional drainage to the Rice River that previously contributed water to the Rice River via wetland discharge and subsurface flow (Figure 42). The ditching created channels that are wide enough to be seen as open water from aerial imagery, which suggests they may have been wide enough to have been sketched onto the General Land Survey maps if they existed at the time. A review of the maps shows that area was previously only wetland with no historical stream features mapped during the 1861 or 1871 surveys. The consequences of the wetland ditching are that previously lesser-contributing areas are now contributing more flow to AUID 505, which can have adverse effects on nutrient and sediment export. Ditching can accelerate the rate at which water moves through the wetlands. Non-drained wetlands would capture rainwater and either have subsurface flow or direct discharge when the wetland basin was full of water. Both scenarios would retain water on the landscape for a longer period of time, thus reducing the amount of nutrient and sediment export. Ditching will move water off the landscape at a faster rate as water no longer has to percolate to subsurface flow and is directly flowing out the ditch channel, increasing the potential for nutrient and sediment transport. The ditching does not appear to have changed the landscape from wetland dominated because the nature of the wetland area cannot be sufficiently drained to convert land use (Figure 43). The ditching has probably changed how nutrients are cycled within the wetland and how the nutrients are being exported downstream.

Figure 42: Original GLO map as a background with the altered watercourse layer showing ditching in the Rice River watershed upstream from station 98NF143. The yellow highlighted area represents 17.4 sq. mi. of additional drainage that is moving water into the stream faster than historical natural drainage.

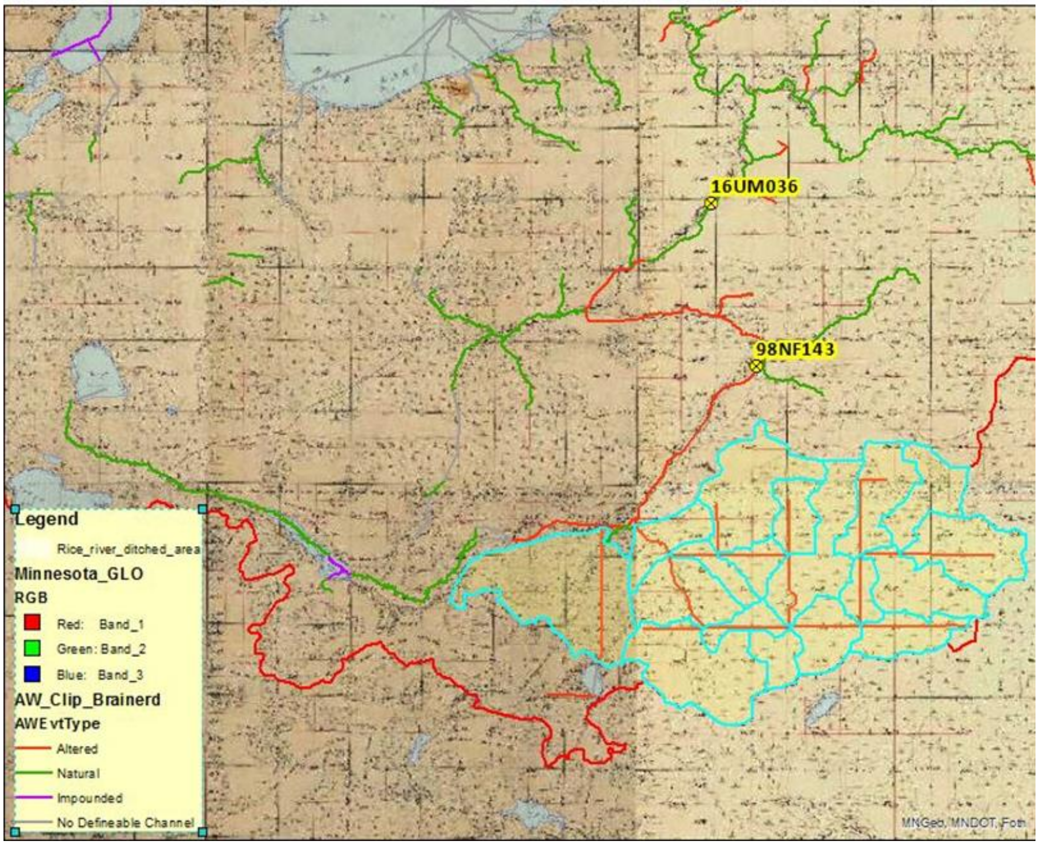


Figure 43: Aerial image of drainage network upstream from site 98NF143. Land use is still wetland. Drainage was ineffective to convert land to alternative land use.

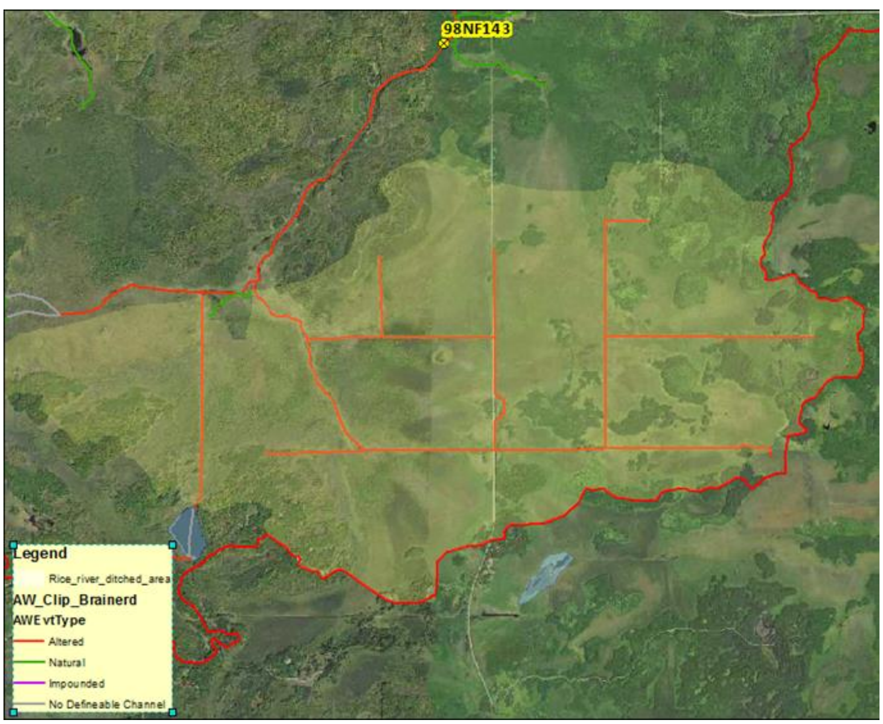
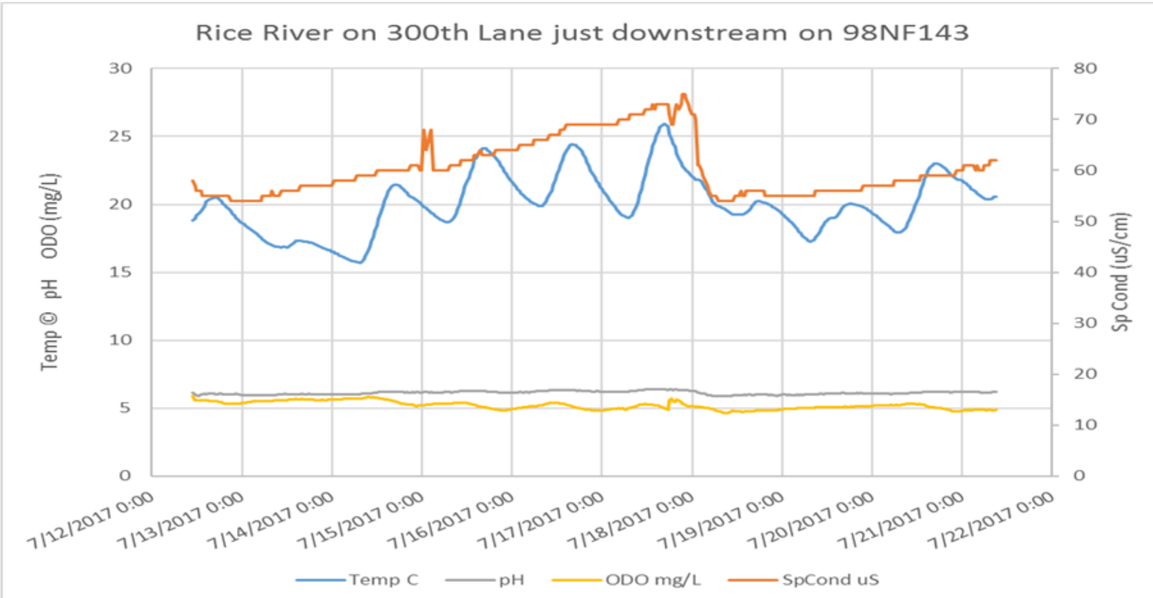


Figure 44: YSI 6920 sonde deployment results for July 2017 on Rice River near 98NF143.



Nitrogen data was collected in 2010 and 2011 (Table 23). The concentrations observed were low and do not appear to be high enough to affect the biological community. The available data indicate that nitrogen is not a stressor.

TSS concentrations were below the 15 mg/L state standard for TSS. However, there were also 140 stream transparency tube (Secchi tube) readings, which is a surrogate parameter for TSS. Of the transparency tube readings, 44 percent were below 40cms, the surrogate standard for a TSS impairment, indicating that transparency may be an issue for biology. The average transparency tube reading for the data set was 42.9 cm, which is slightly above the standard.

Fish communities can be analyzed to determine the probability of passing the current TSS standard. MPCA biologist have developed a model that predicts if a known water quality standard would be met by analyzing the biology sampled at the site. Based on this analysis a prediction can be made for the probability of meeting the TSS standard of 15 mg/L or 40cm (secchi tube). The three fish community index scores on AUID 505 indicate that TSS and fine sediment are not stressing the fish community. This analysis showed that the probability of attaining the TSS standard would be 82 to 89 percent based on the fish communities sampled. Based on this information along with the relatively low TSS concentrations observed in 2010-2011, TSS is not considered a stressor to the biology.

4.1.3. Stressor pathway

Stressors to the fish community were analyzed by looking at available data. Of the potential stressors reviewed, only low DO was identified as a likely stressor. The fish community sampled had a low probability (5-12%) of meeting the DO standard and the fish sampled were very tolerant to low DO conditions. This section of stream also showed elevated phosphorus concentrations, which could promote plant and algal growth in the stream. This can lead to respiration at night, which can lead to a drop in DO concentrations. However, continuous DO data collection revealed that the stream is not experiencing a high daily flux in DO. DO is at or near the 5 mg/L standard during the entire sonde deployment which shows that DO does not fluctuate greatly throughout the period sampled. It is suspected that the dark, tannic acid staining of the water is inhibiting primary productivity in the channel. This coloration may also affect transparency tube measurements.

TSS and stream transparency tube readings suggested some periods of elevated stream turbidity. There does not appear to be a direct correlation to the low fish diversity and stream turbidity. The fish community sampled showed an 80 % chance of passing the 15mg/L TSS standard using the conditional probability model developed by MPCA biologist John Sandburg.

4.9.4. AUID summary

DO concentrations that are constantly hovering around the 5 mg/L state standard appear to be the largest stressor to the fish community in this AUID. Large wetland complexes are located upstream of the sampling locations and low DO readings are persistent throughout the upstream and downstream AUIDs. The majority of this area is undeveloped and there is very little anthropogenic activity. It appears that the low DO is naturally occurring as the stream is low gradient, flows through large wetland complexes and is mainly large blocks of undisturbed forestland. Even though the biology is not meeting standards, it does not appear that a successful TMDL could be written with meaningful load reductions that could improve the current DO conditions.

4.10. Rice River -649 (F&MIBI)

4.10.1 Biological communities

The reach of the Rice River is 7.8 miles long and goes from Section 5 downstream to the confluence with Wakefield Brook. There is one biological monitoring station located on this AUID (10EM088). Site 10EM088 drains 121.07 sq. mi. and is located just upstream of the outlet of Big Rice Lake. This fish class 5 stream scored a 39 on 7/23/2015 for fish, which is below the 47 threshold. Eleven species of fish were sampled but the three most dominant species are low DO tolerant (black bullhead, central mudminnow and white sucker). Black bullhead dominated the sample. Macroinvertebrates were sampled in 2011 and again in 2015. The August 18, 2011 MIBI score was a 56.9 and the August 10, 2015 score was a 43. This macroinvertebrate class 4 stream has a threshold of 51. The latter score is below the threshold, but 5 points above the lower confidence interval.

4.10.2. Data evaluation for each candidate cause

Equis site S006-243 is located on this AUID on 363rd Lane, which is downstream of the outlet of Big Rice Lake. Water quality data was collected at S006-243 from 2010 through 2014. DO concentrations varied throughout the sampling period and often were below or near the 5 mg/L DO state standard. Table 24 below displays the number of samples per parameter along with the minimum, maximum and average concentration for that parameter.

Table 24: Water quality results from S006-243 on the Rice River.

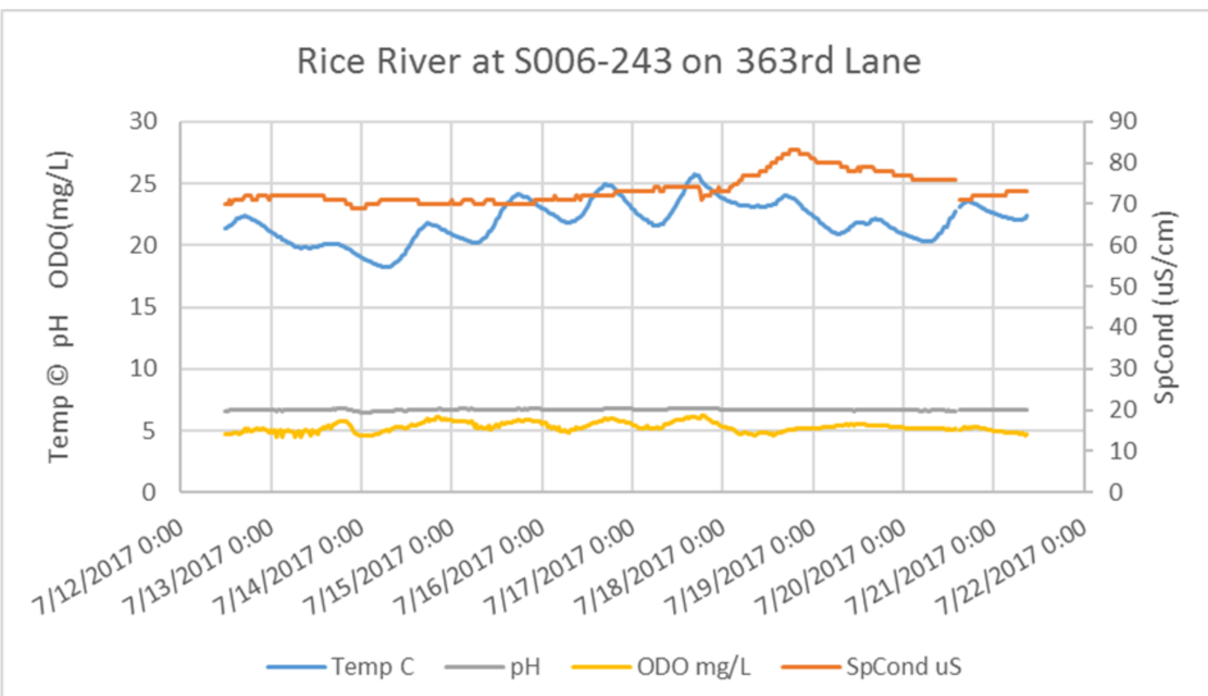
Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
DO (mg/L)	26	5.82	9.8	2.725	1.65
NOx (mg/L)	24	0.049	0.1	0.01	0.013
TKN (mg/L)	24	1.92	2.8	1.1	0.482
TP (mg/L)	24	0.087	0.164	0.029	0.036
Temperature	80	18.00	26.7	4.44	5.15
TSS (mg/L)	24	4.875	10	2	2.17
Stream Transparency	117	44.9	86	18	

Low DO concentrations have been repeatedly observed in this reach of the Rice River. During the two sampling events for macroinvertebrates, it was observed that both samples had high numbers of taxa that are tolerant to low DO conditions (2011-12, 2015-8). Meanwhile both samples had only 1 taxa that were considered intolerant of low DO. The fish community sampled at 10EM088 also suggest that low DO is a cause of stress. The probability of the fish community that was sampled is 3% for passing the 5 mg/L DO standard. DO conditions are not extremely low, as seen by the 2017 mid-summer continuous DO record (Figure 45). The diurnal DO flux was low (<1.5 mg/L/day) which indicates that eutrophication from elevated phosphorus is not a driving factor. This reach is upstream of Rice Lake and is generally flowing through and out of a large wetland complex. There is very little human activity within this subwatershed and the low DO appears to be natural. Low DO is stressing the macroinvertebrates and fish but there is very little management changes that can affect the low DO concentrations.

Nitrogen samples were also collected during the 2010-2014 time period. The results from this sampling showed very low concentrations of nitrogen. The macroinvertebrate samples also showed that nitrogen was not having a negative effect on the community. Both macroinvertebrate samples had a similar number of nitrogen intolerant taxa and nitrogen tolerant taxa. With the macroinvertebrate sample being evenly distributed with both tolerant and intolerant taxa for nitrogen, we can say that nitrogen is not a stressor to the macroinvertebrates.

Elevated phosphorus concentrations can come from wetland drainage. Generally, when phosphorus is elevated the response will be increased plant or algal growth in the stream. This in turn will cause DO to flux in the diurnal cycle and drop below levels safe for aquatic life. The elevated phosphorus does not appear to be having this effect on this reach of the Rice River. Plant and algae growth within the river may be inhibited by the tannic stain of the water, which is reducing light penetration. The macroinvertebrate sample was dominated by phosphorus tolerant taxa but also had a small representation of phosphorus intolerant taxa. There is not enough evidence to suggest that elevated phosphorus is causing stress to the biological community.

Figure 45: Sonde deployment for 9 days in July of 2017 at 363rd St. crossing on the Rice River.



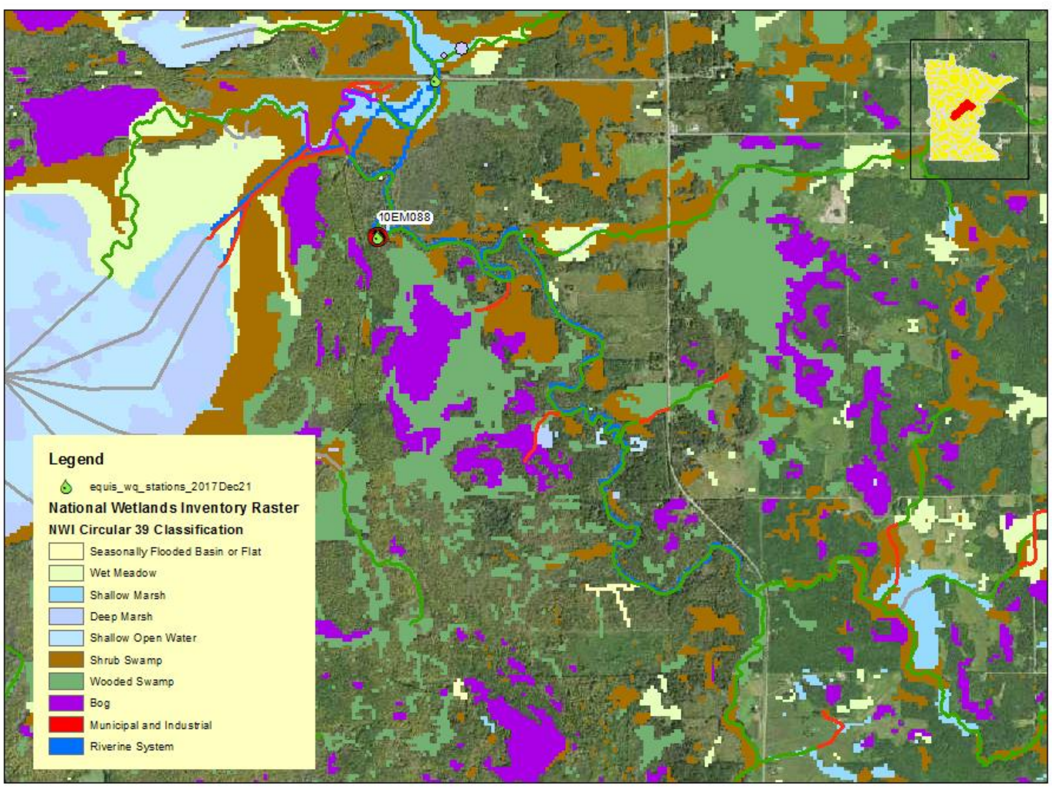
TSS can be measured directly and also by using stream transparency (<40 cm) as a surrogate parameter. TSS and transparency tube data suggest that TSS may be a problem in this reach of the Rice River. However, the water is bog (tannic) stained in this river, which may be giving a false low reading with the transparency tube. Macroinvertebrates that are tolerant to TSS make up a significant number of the taxa observed at 10EM088. In 2015, there were 17 TSS tolerant taxa observed and 1 TSS intolerant taxa. The TIV for TSS, based on the fish community sampled, suggests that there is a 42 percent chance of passing the TSS standard. This alone does not justify listing TSS as a stressor, however it does suggest that additional data should be collected to better characterize the TSS distribution in this reach. Since TSS is usually tied to higher flow regimes, it is recommended that some storm related TSS samples be collected to better understand the fate and transport of TSS in this reach.

4.10.2. Stressor pathway

The upper reaches of the Rice River (AUID 505) drain into this AUID. The upstream reaches have a high degree of partially drained wetland areas along with a high percentage of wetland soils that have a tendency to export elevated phosphorus concentrations. Immediately upstream of site 10EM088 there are also numerous shrub swamp and bog wetland areas as seen in Figure 46.

Figure 46. Rice River AUID 649 along with the immediate land use in the upstream drainage area. This area is primarily owned by the USFWS and is part of the Rice Lake NWR system. There is very little human influence in this portion of the drainage area.

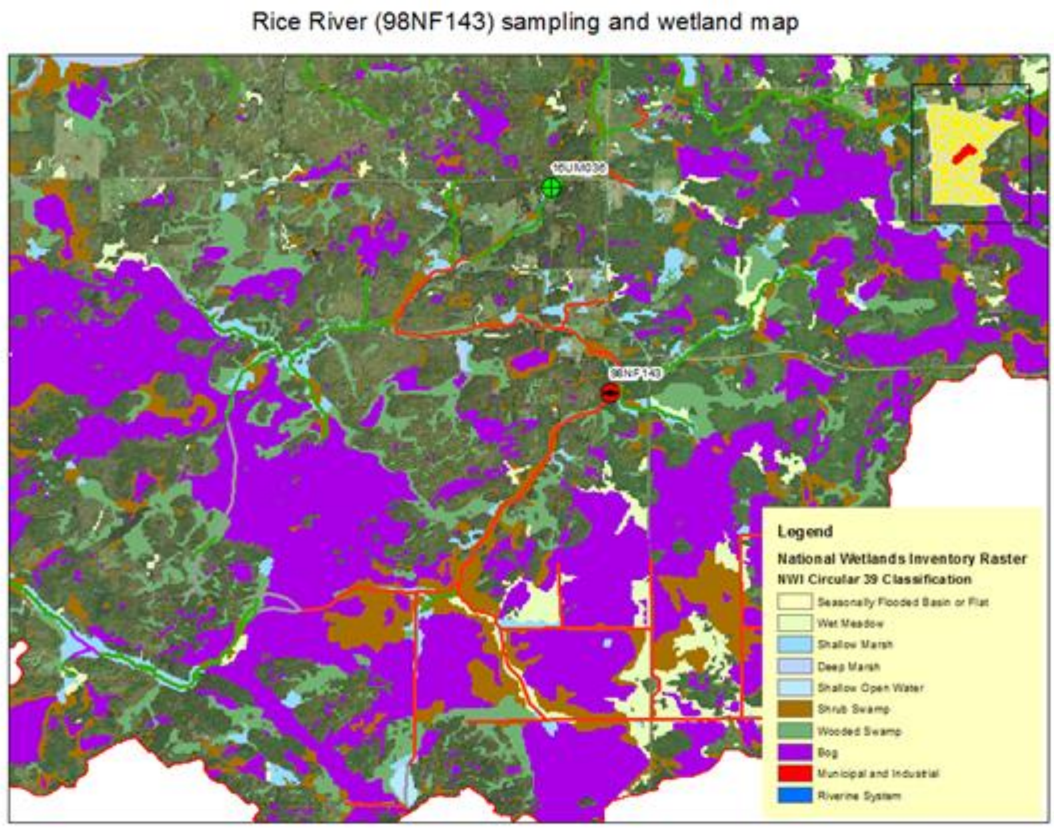
Rice River (10EM088) sampling location map



Low concentrations of DO are often found in this AUID along with the upstream AUID (505) There is very little disturbance, aside from the wetland ditching, in this part of the Rice River watershed and the low DO appears to be caused by the position of the river with respect to the vast wetland acres in the drainage network. Low DO is causing the biological communities to have lower than anticipated IBI scores; however, there does not appear to be any anthropogenic causes in the subwatershed for low DO. It is believed that low DO is naturally occurring.

Figure 47 below shows the large wetland component of the upstream AUID 505 drainage network. A significant portion of this upstream network is ditched and is partially draining bog wetland areas. The Rice River in this area is also very flat with a low slope and minimal riffles to re-aerate the stream water. With the low gradient and low DO water, there is very little room for the river to re-aerate through agitation or instream plant growth due to the bog stain of the river water.

Figure 47: Rice River AUID 505 drainage area with wetland areas highlighted. The ditching network is partially draining vast areas of bog, which is exporting low DO water.



4.10.3. AUID summary

Nitrogen and phosphorus do not appear to be stressors to the biological community. TSS may be a stressor but limited data is not strong enough to say yes for sure. Low DO is impacting the biological community in this reach and is considered the primary stressor to biology. The low DO may be a naturally occurring scenario, though possibly exacerbated by wetland ditching, as the majority of the upstream drainage area has very little human development and drains an extensive wetland area that is in a very natural state.

4.11. Hay Creek -682 (MIBI)

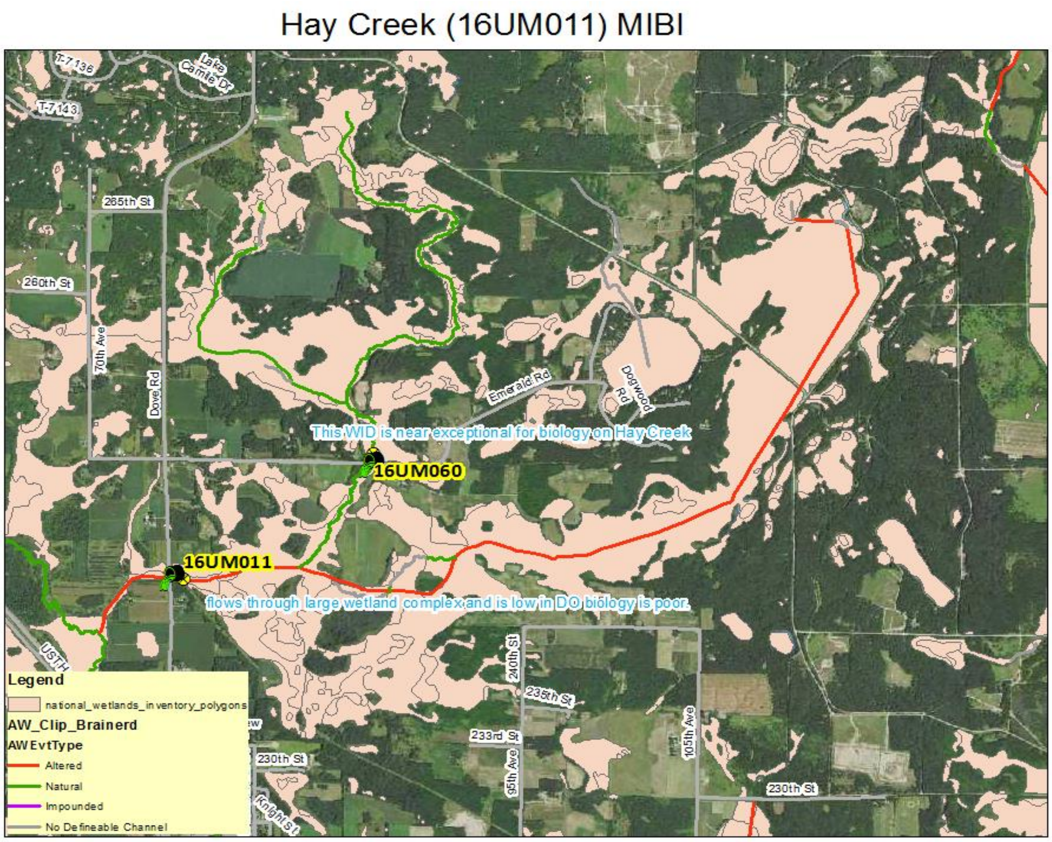
4.11.1. Biological communities

The reach of Hay Creek is 1.36 miles long and goes from Unnamed Creek (AUID 683) downstream to the confluence with Little Elk River. There is one biological monitoring station located on this AUID (16UM011). AUID 683 drains into this section of Hay Creek and has biological monitoring station 16UM060.

Site 16UM011 drains 22.1 sq. mi and is located near the outlet of the AUID, just upstream of Dove Road, north of USTH10. Macroinvertebrates were sampled on August 10, 2016, after the major July rain event of 2016. This sample was labeled assessable and notes indicate iron floc floating downstream during sampling, which is indicative of low DO concentrations. DO during this event was 2.17 mg/L. Fish were sampled on June 29, 2016 and scored a 69, which is well above the 42 threshold. During fish, sampling the DO was also reported as 3.44 mg/L. This sampling location is downstream of a large wetland complex that also has a tributary drainage ditch entering from the east. Figure 48 displays the positioning of the sampling location in relation to the wetland complex and the tributary ditch that enters from the East.

Upstream of this site is station 16UM060 which scored near exceptional for both fish and macroinvertebrates during the 2016 sampling events. The combined MSHA was a 53 in 2016. This places the habitat in the "fair" category and suggests that habitat may be limiting.

Figure 48: Hay creek drainage area showing the large wetland drainage component entering from the east and the north. Site 16UM011 has low DO concentrations during both high and low flow events, which is limiting the biology at the site.



The fish community sampled had 12 species present. Many are low DO tolerant species, commonly found in wetland or low gradient systems. The invert sample was dominated by scuds, leeches, aquatic earthworms, and tolerant mayflies. The following excerpt comes from the assessment discussion,

"The macroinvertebrate index of biological integrity (M-IBI) score is well below the lower confidence interval for southern forest streams in the glide-pool class. The biological condition gradient (BCG) model corroborates this result as this macroinvertebrate community straddles tier 5 and 4; indicating stressful conditions. Dissolved oxygen measurements made at the fish, invert and spot checks were all well below the 5 mg/L warm water standard. The macroinvertebrate community is likely stressed by the low dissolved oxygen conditions. At the time of the macroinvertebrate sample, the stream was covered with iron floc, further suggesting that the low dissolved oxygen causes the bound iron to precipitate. A local landowner stopped at the time of benthic macroinvertebrate sampling and indicated that the stream turns this 'color' every August".

Fish are highly mobile and can pass through this AUID during acceptable flow periods and populate upstream areas that are more favorable to aquatic life. The macroinvertebrates that are not as mobile must be able to persist in this reach or become eliminated if conditions are not favorable. The conditional probability index for macroinvertebrates suggests that site 16UM011 has a 9.5% chance of passing the DO standard of 5 mg/L. This is based on the taxa found during sampling.

4.11.2. Data evaluation for each candidate cause

Water quality samples were collected in 2018 at two sites along Hay Creek and unnamed Creek. Site S013-472 is located at Dove Road near station 16UM011, and on a separate AUID (683), site S013-501 is located on Emerald road near station 16UM060 (see Figure 48). Site 16UM060 had nearly exceptional biology for both fish and macroinvertebrates. Water quality samples were collected from May through August 2018 and results are presented in Table 25. Nutrient levels do not appear to be high enough to be causing eutrophication. Nitrogen is not a stressor to the biology as all samples collected were below the laboratory detection limit.

Table 25: Hay Creek water quality results from 2018 sampling. Site S013-472 is located near biological site 16UM011 near Dove Road. Site S013-501 is located near biological site 16UM060 at Emerald Road.

Parameter	EQuIS site	Sample Count	Average Conc.	Max Conc.	Min Conc.
TP (mg/L)	S013-472	4	0.078	0.155	0.044
TP (mg/L)	S013-501	4	0.092	0.142	0.056
NOx (mg/L)	S013-472	4	<0.05	<0.05	<0.05
NOx (mg/L)	S013-501	4	<0.05	<0.05	<0.05
Temperature (°C)	S013-472	9	17.77	23.57	9.8
Temperature (°C)	S013-501	9	15.775	21.36	7.09
DO (mg/L)	S013-472	9	5.04	7.8	2.27
DO (mg/L)	S013-501	9	6.31	8.21	4.92

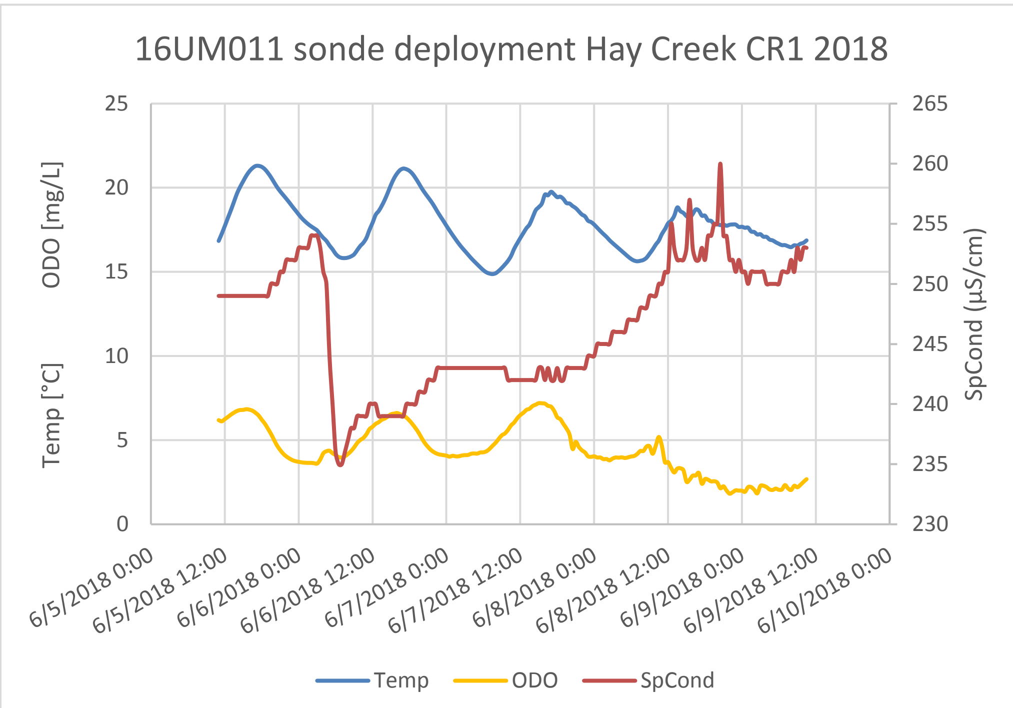
During the fish and macroinvertebrate, sampling a one-time water chemistry sample was collected. The results of this data collected can be found in Table 26 below.

Table 26: Water quality analysis results for one time grab samples collected during the fish and macroinvertebrate sampling.

Site	Date	Temp °C	DO mg/L	Sp. Cond µS/cm	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
16UM011	6/29/2016	17.7	3.44	361	7	0.1	0.02	0.05	2	1.6
16UM011	8/10/2016	22.64	2.17	346	7.21					
16UM060	6/21/2016	18.4	7.21	353	7.36	0.1	0.035	0.078	4.4	2.4
16UM060	8/10/2016	20.8	4.57	355	7.2					

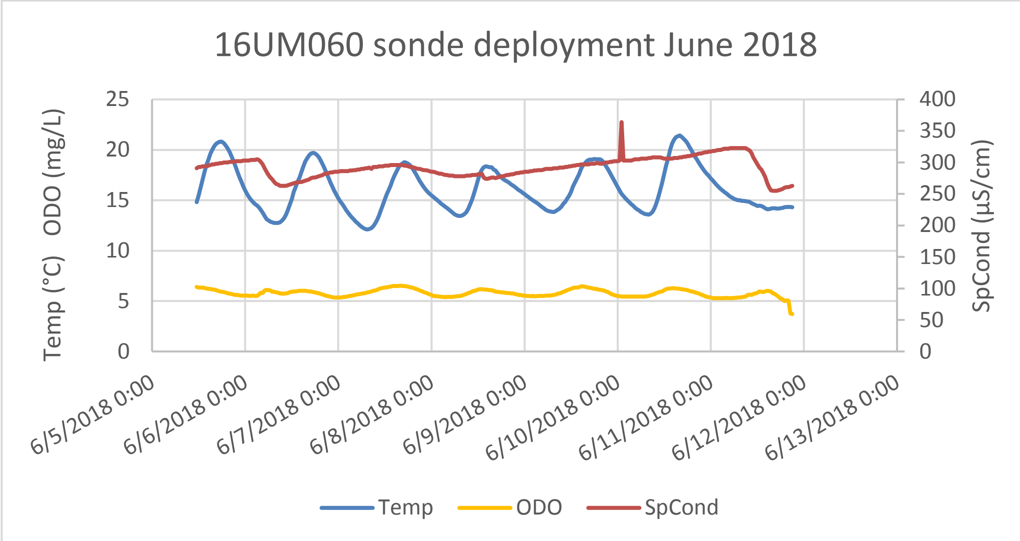
Continuous water quality data was collected from June 5, 2018 through June 9, 2018 at site 16UM011 on Hay creek (Figure 49). The sonde was deployed for a longer period but became buried in sediment and was not reading properly after June 9, 2018. The data clearly shows that DO fluctuates during the day and often dips below the 5 mg/L standard after dark. This is also seen in the spot readings collected during the summer in Hay Creek. DO is often limiting and it appears to be limiting during periods of higher flow (when the wetland is flushing and also during periods of extreme low flow conditions as seen in August of 2018. Low DO does appear to be a significant stressor to the biology in the lower portion of Hay Creek. The low DO appears to be directly related to the large drainage area that is contributing to Hay creek from the drainage ditch that enters from the east. This drainage ditch was built in the early 20th century and has added a significant amount of partially drained wetland acres to the drainage network. Unless the drainage ditch and its partially drained wetlands are addressed, a TMDL for low DO in Hay Creek would seem unnecessary.

Figure 49: YSI 6920 continuous sonde data collected in Hay Creek at 16UM011 near Dove Road.



Farther upstream, at site 16UM060, a sonde was also deployed during the same time period (Figure 36). This deployment showed minimal periods of DO falling below the 5 mg/L DO standard and may be an explanation for why this site has an improved biological structure. The diurnal DO fluctuation is lower at this upstream site. There is also less aquatic plant growth.

Figure 50: YSI 6920 continuous sonde data collected in Hay Creek at 16UM060 on Emerald Road.



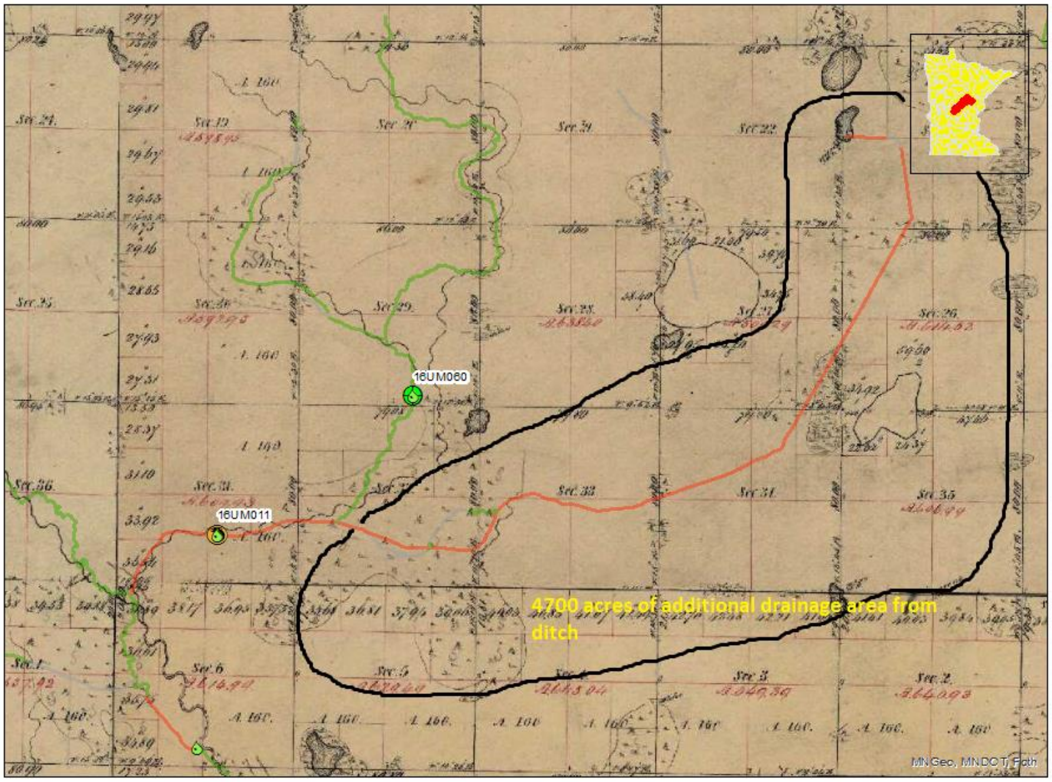
4.1.4. Stressor pathway

The section of Hay creek that is impaired for macroinvertebrates flows through a large wetland complex. This complex has been partially drained and also has a ditch flowing through it from the east, which, during periods of higher flow, carries anoxic water through the system. This ditch network has also added additional drainage area to Hay Creek. Reviewing the original GLO maps, which were created in 1859, shows that there was not a drainage way entering Hay Creek to the east of the confluence with AUID 683. Further investigation shows that this ditch drains approximately an additional 4700 acres of land that otherwise did not directly drain to Hay Creek (Figure 51).

The low DO appears to be persistent during high flow following summer thunderstorms and also during periods of very low flow in August. The sediment oxygen demand is believed to be high in this wetland complex. Further upstream in Hay Creek, the low DO does not appear to be problematic at Emerald Road, which also has a high biological score and very diverse biological community. Water flowing into and through the wetland complex is being stripped by SOD, and decomposition of plant material in the wetland (=BOD). The lower reach of Hay Creek (AUID 682) will probably always be low in DO and is acting as a travel corridor for fish to migrate to the more favorable AUID upstream.

Figure 51: Hay Creek along with additional direct drainage area added with eastern ditch.

Hay Creek (16UM011) General Land Survey map as background



The following picture was taken on May 24, 2018 at the site on Dove Road, 16UM011/S013-472. This photo is looking upstream and shows the condition of the wetland riparian area along the reach.

Field visits during data collection throughout 2018 verify that low DO is probably the main stressor in AUID 682. Nutrient levels are elevated but do not appear to be the driving force behind the low DO conditions. Daily DO flux for the short deployment was around 3 mg/L but the deployment only lasted for 3 days so the record is short and it is not clear if eutrophication is a main driver of the low DO. The upstream AUID, which does not have the same wetland influence in the riparian, has a DO flux of around 1mg/L. This site has very similar water chemistry concentrations but does not respond like the downstream site that has a higher percentage of wetland acres draining through it. There is a substantial amount of submerged plant growth in the stream as can be seen in the pictures below. In addition, the pictures show some low DO ground water input, evidenced by the iron precipitate in the photo.

June 5, 2018 photo

June 20, 2018 photo

Same location on Hay Creek as top two photos taken on August 29, 2018. Water levels were below baseflow on this day.

4.1.5. AUID summary

In summary, the two AUIDs on Hay creek and Unnamed Creek exhibited very different biological samples. The lower section (AUID 682) had a strong fish sample and passed the FIBI but had a weak macroinvertebrate score and failed the MIBI. The upstream AUID passed both IBIs, and scored almost exceptional in both categories. The main difference between the two stream reaches is the amount of partially drained wetland that the stream flows through. The larger percentage of drained wetland in the downstream reach is causing the DO to drop below the state standard of 5 mg/L almost daily and is having an impact on the macroinvertebrate community.

Fish are mobile and can pass through this reach to travel to the upstream AUID that is more favorable with DO conditions. The upstream reach has similar nutrient levels as the downstream reach but the response to DO is not correlated to nutrients alone. It appears that either high SOD or BOD are driving the low DO conditions in the downstream reach. There is a large drainage ditch that also enters the downstream reach from the east. This is draining a significant portion of wetland acres and is contributing to the loss of DO holding capacity in AUID 682. Water temperatures are 2°C warmer near Dove Road and the DO concentrations during the paired sampling events are 1.3 mg/L lower. The lack of shade and low gradient nature of this AUID make conditions less than favorable for macroinvertebrates. A TMDL is not warranted for this AUID at this time, as the nature of the drainage system is not likely to change any time soon. Low DO is occurring due to the drainage network and the wetland soils.

4.2. Little Willow River Diversion Channel -691 (MIBI) Modified Use

4.2.1. Biological communities

The reach of the Little Willow River Diversion Channel is 3.96 miles long and goes from Little Willow Ditch old channel downstream to the Mississippi River. This reach is extremely straight and serves as a water supply for the neighboring wild rice paddies. The water in this system is used to flood the rice paddies in early summer and the ditch is used to move water back out of the paddies during harvest time. There is a biological monitoring station located on this AUID (17UM200).

Site 17UM200 drains 55.49 sq. mi. and is located off of 430th St about 1.2 miles upstream from the outlet on Great River Road. Macroinvertebrates were sampled on August 24, 2017 and this sample failed the MIBI with a score of 33.4. This AUID was placed on the modified use standard, for which the MIBI threshold is 37. The macroinvertebrate sample was dominated by a midge (genus *Polypedilum*) and snails (genus *Ferrissia*). Both taxa are generally tolerant to a variety of environmental conditions. Fish were sampled on July 27, 2017. This class 6 stream scored a 39 on the FIBI and the threshold is 23. Only five fish species were sampled (central mudminnow, tadpole madtom, yellow perch, black bullhead, and burbot). Central mudminnow dominated the sample with 36 individuals. The MSHA was a 39 and 45 in 2017. This places the habitat in the "poor" category and suggests that habitat is limiting.

4.2.2. Data evaluation for each candidate cause

Water quality data from Equis site S014-220 on Little Willow Diversion Channel downstream of site 17UM200 on Great River Road was collected in 2017-2018 from May through September. The results can be found in Table 27. The phosphorus readings were all below 0.071 mg/L except for the July 12, 2018 concentration of 0.138 mg/L. The TP state standard is 0.05 mg/L in the Northern Forest Ecoregion for stream. Elevated nutrients do not seem to be driving the low DO issues observed in this AUID. Wetland drainage of both agricultural wetlands and natural wetlands are having an impact on the DO concentrations. SOD and BOD are probably the two main driving factors on low DO. Heavy localized rainfall occurred in mid-June of 2018. Water samples were collected on June 19th and 21st to document the effects on the DO concentrations during the elevated flow event. The DO concentrations were at 2.71 and 2.72 at 10:00 and 11:00 on both sampling dates. This low DO was being driven by the flushing of upstream wetlands.

Table 27: Water quality results for Little Willow ditch at 430th Avenue. Data was collected in the summers of 2017 and 2018.

Parameter	Sample Count	Average Conc.	Max Conc.	Min Conc.	Std. Deviation
TP (mg/L)	10	0.068	0.138	0.043	0.028
NOx (mg/L)	10	<0.05	0.08	<0.05	NA
Temperature (°C)	14	18.65	22.87	10.85	
DO (mg/L)	14	6.00	9.24	2.71	

During the fish and macroinvertebrate, sampling a one-time water chemistry sample was collected. The results of this data collected can be found in Table 28 below.

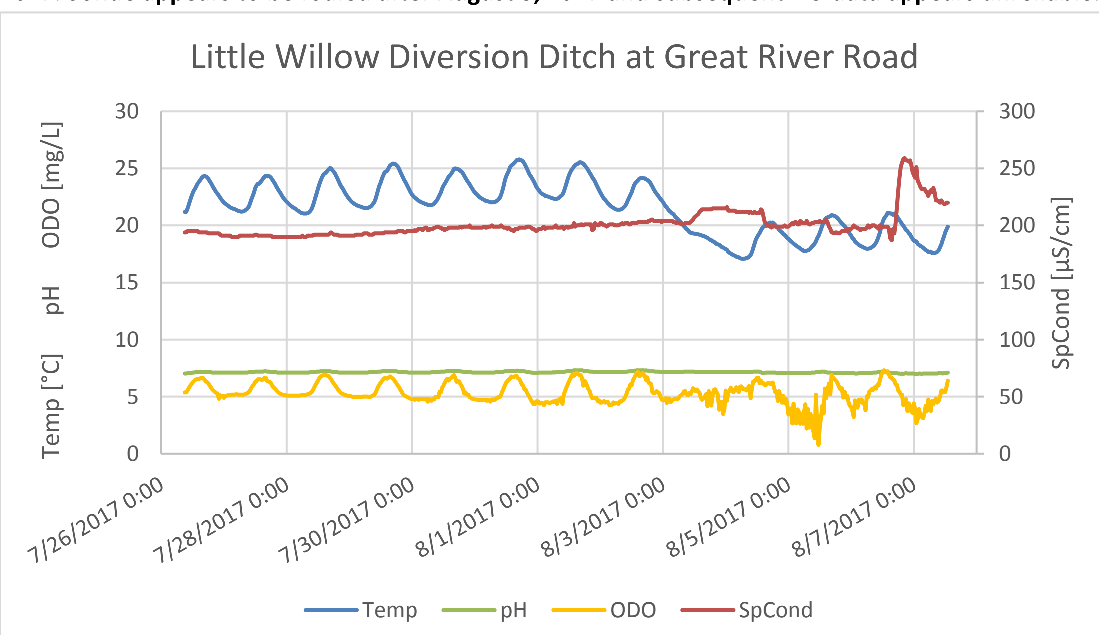
Table 28: Results of one time water chemistry data collected during the fish and macroinvertebrate sampling.

Date	Temp °C	DO mg/L	Sp. Cond µS/cm	pH	NH4 mg/L	NOx mg/L	TP mg/L	TSS mg/L	TSVS mg/L
7/27/2017	23.5	4.41	183	7.19	0.1	0.02	0.06	2	Na
8/24/2017	17.8	4.98	140	7.12	Na	Na	Na	Na	Na

An YSI sonde was deployed at the Great River Road crossing from July 26, 2017 through August 7, 2017. The daily DO flux during this time period ranged from 1.5 to 1.9 mg/L (Figure 52). This indicates that algal, plant growth is not driving the daily DO flux, and eutrophication is not problematic at this site.

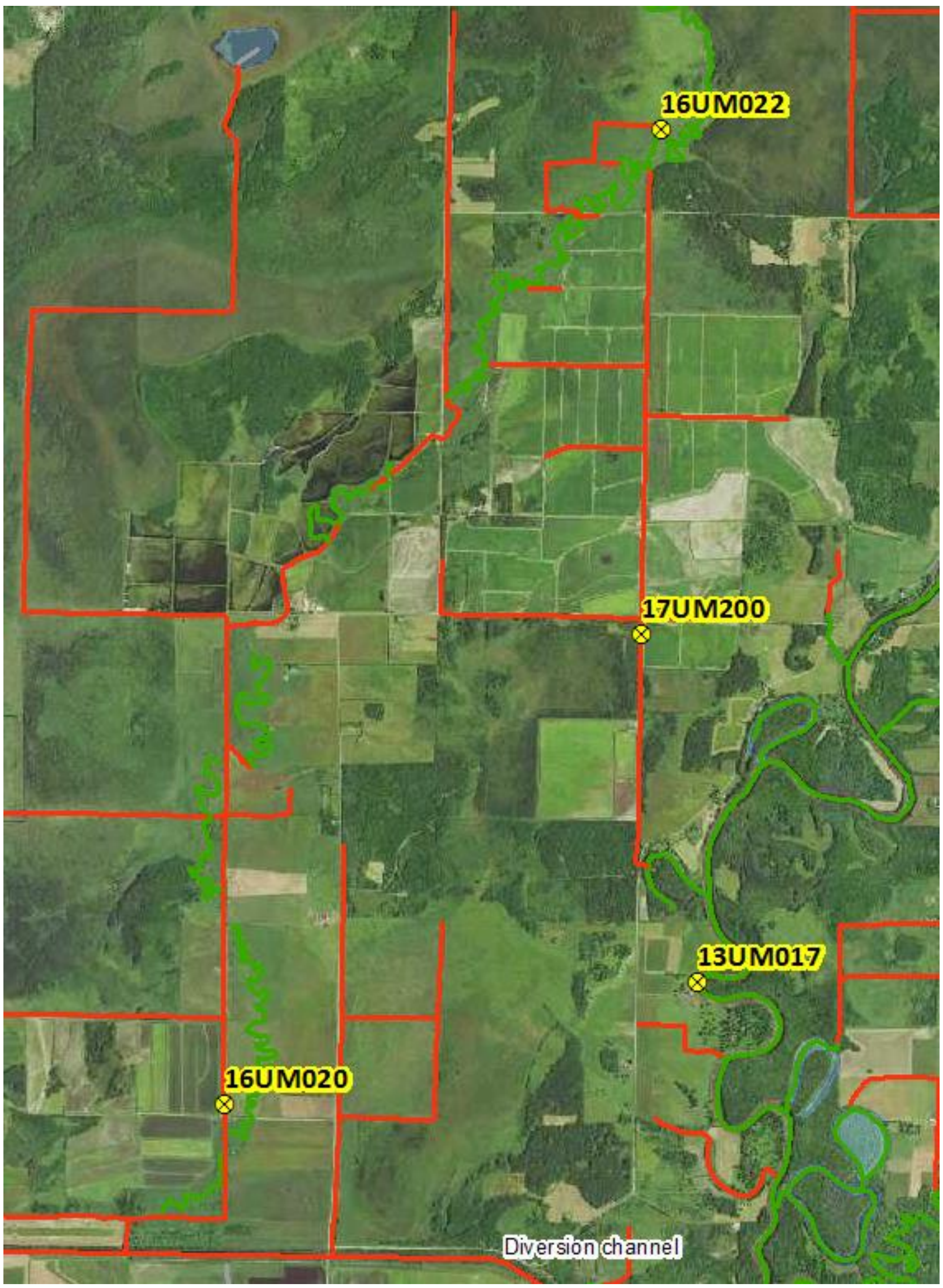
Hydrologic alteration is also playing a role in the low DO concentrations observed. Highly fluctuating water level in the ditch is caused by water withdrawal from pumping stations to fill the rice paddies, and excess water runoff during periods of intense rainfall in the summer following thunderstorms. Conversations with the landowner revealed that during early stages of rice production the pumps in the ditch can draw the water level down in the ditch to nearly nothing. According to the operator, pumping activity depends on how dry the season has been and how much water is needed to fill the rice paddies in a given year. If water levels in the ditch are rapidly lowered, then the macroinvertebrates that live along the banks will be left without any water and would disappear. This could help explain why the macroinvertebrates are not doing that well. Poor quality habitat along with the potential of lower the water levels would have an impact on the macroinvertebrates.

Figure 52: Continuous sonde data collected on Little Willow Diversion Ditch from July 26, 2017 through August 7, 2017. Sonde appears to be fouled after August 3, 2017 and subsequent DO data appears unreliable.



Stream discharge data was collected during the summer of 2017 to understand the stream flow distribution between the Little Willow Diversion Ditch and the old Little Willow River channel that flows to the west of the diversion ditch (Figure 53 and Figure 55). During the summer of 2017, a large percentage of stream flow discharged through the diversion channel at Great River Road and directly entered the Mississippi River through AUID 691. This section of channel, that is AUID 691, was developed and designed to supply water to the rice paddy farming operation that encompasses a large area immediately adjacent to the ditch network. This ditch is designed with water control structures and pumping stations located throughout the system to allow filling of the rice paddies and also dewatering of the rice paddies when harvest time is near.

Figure 53: Little Willow river drainage network. Site 16UM020 is located on AUID 700, which is partially the old Little Willow River channel. Site 17UM200 is on AUID 691, which is the diversion ditch that supplies water to the wild rice paddies along the Eastern portion of the ag network.



A conversation with the local rice farmer revealed a maximum potential amount of water withdrawal out of the ditch system to be approximately 22,000 gallons per minute (gpm) if all pumps were operated at the same time. This rarely happens, as not all paddies are utilized in a given season and are rotated between soybeans, wild rice, and fallow. It is possible that during summers of low precipitation the ditch water levels can be greatly lowered during the pumping cycle to fill the rice paddies with water. This rapid water level drop could impact the macroinvertebrates, as the water level would be dropped down, away from the overhanging vegetation, leaving macroinvertebrates possibly stranded out of water.

Figure 54 below shows the 2018 planting strategy for the agricultural fields located upstream of 17UM200. The areas outlined in blue represent wild rice paddies and areas in green are planted in soybeans. The fields east of CR1 (Osprey Ave) represent fields that would be supplied with water and drainage from AUID 691. This area has a total field acreage of 1448.7 acres. In 2018, wild rice was planted in 659.5 acres, soybeans in 704.8 acres and 84.4 acres were left unplanted according to the area farmer. That equals 45.5% of available acres are planted in wild rice, and 48.6% are planted in soybeans.

Figure 54: 2018 map of the planting strategy for the farm fields near the Little Willow Diversion Ditch. This ditch is the water supply for flooding the wild rice paddies and draining any excess water off the wild rice paddies.

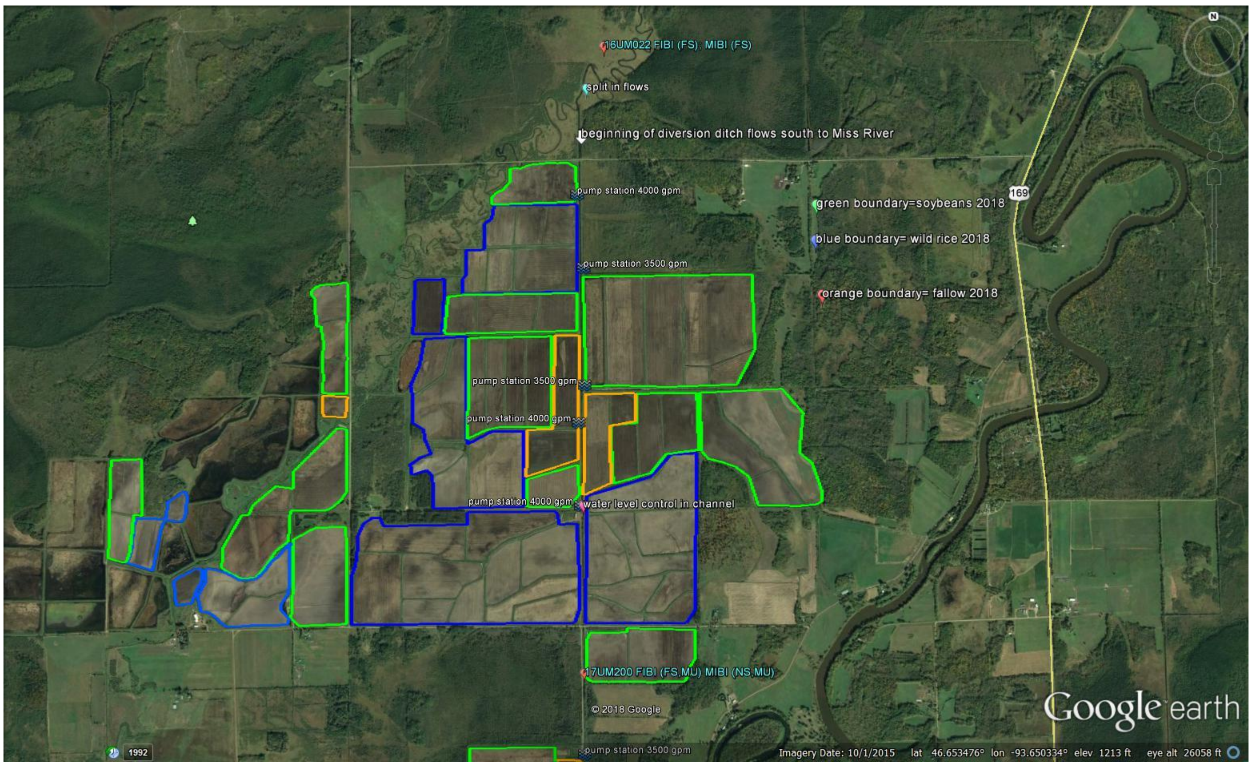
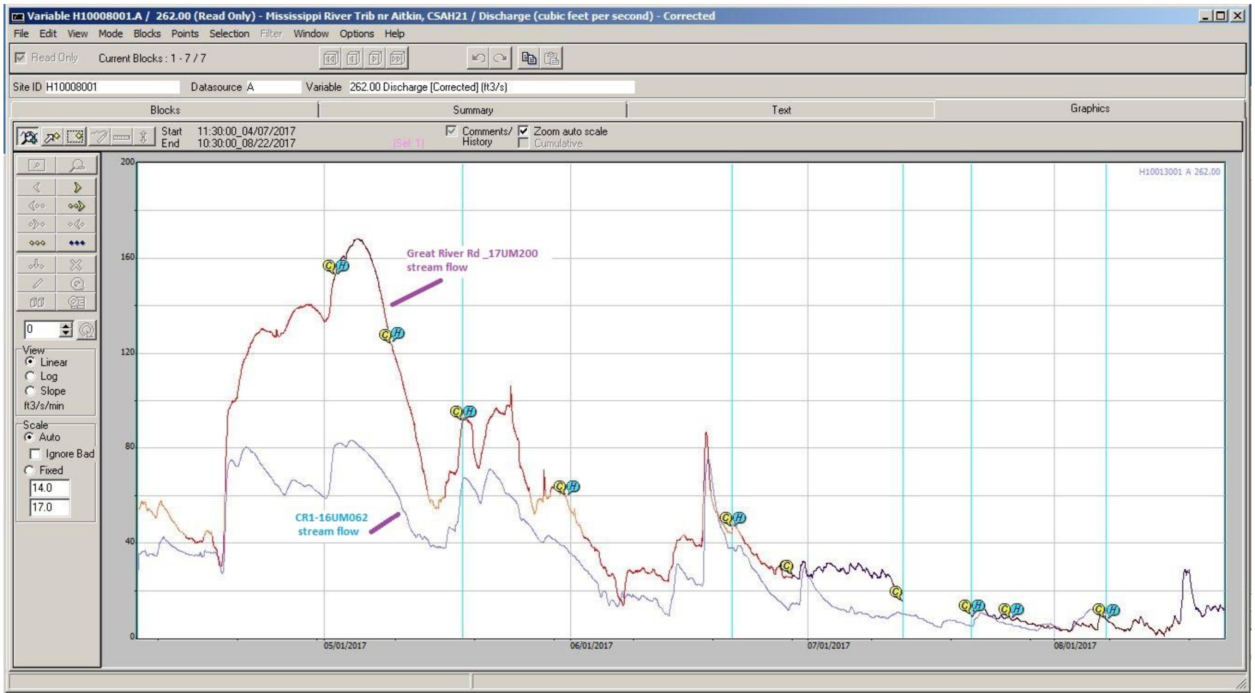
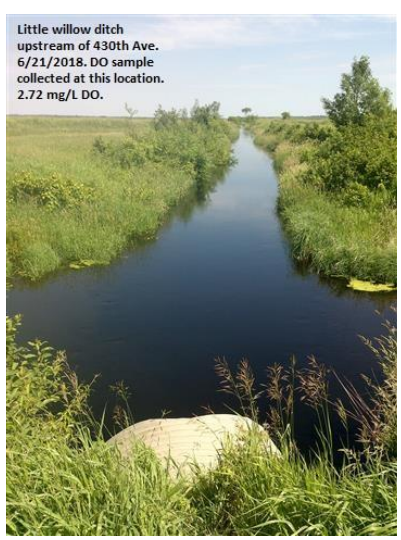


Figure 55: Stream discharge for the summer of 2017 at two locations along the Little Willow River system. The site at Great River Road (17UM200) is located on the diversion ditch that splits of off Little Willow River just upstream of 450th Ave. The site at 16UM062 is located on the old Little Willow River channel just upstream of the Mississippi River bypass channel west of CR1.



Lack of habitat is also a problem in this AUID. This entire AUID is channelized and has the sole purpose of supplying water to the neighboring wild rice paddies. Sampling was conducted downstream of 430th Avenue and this crossing is influenced by an undersized culvert. Water has very high velocity as it leaves the culvert and causing a redistribution of sediment locally. At the sampling site further downstream, the culvert is no longer influencing the substrate, however the substrate in the sampling reach is sand and clay with some minor silt, and detritus along the edges. There are no pools, no channel depth variability, and no rock or gravel riffles. The only available habitat for macroinvertebrates was very small woody debris in the form of twigs (mobile during high flows) undercut banks, overhanging vegetation, and submerged macrophytes. If the water levels drop substantially during the pumping season much of the overhanging vegetation and undercut bank habitat would become dry and not available for macroinvertebrates to utilize.



The photograph displayed here shows the high stream flow and turbulent stream velocity exiting the culvert at 430th Ave along with the upstream side of culvert where DO readings were collected.

4.2.3. Stressor pathway

Low DO concentrations are having an impact on the macroinvertebrate community. The low DO appears to be driven by the physical nature of the landscape that the ditch drains through. The areas immediately upstream of AUID 691 are wetland and the majority of the agricultural land immediately adjacent to the ditch is also wetland soils and sufficiently drained. There is little evidence suggesting that eutrophication is driving the low DO, as TP concentrations average 0.068 mg/L during sampling conducted in 2017-2018. This is slightly elevated but the expanse of peat soils that are in this area would be naturally high in phosphorus. The seasonal availability of the in-stream habitat is also a major stressor to the macroinvertebrates at this site. The water in the ditch is utilized to fill the wild rice paddies during the summer months and this pumping action can leave the channel with very little water during dry summer months, according to the landowner. This can be evidenced by the potential pumping rates of the upstream pumps, as a potential for 22,000 gpm of water can be withdrawn from the channel if all pumps are actively in full operation.

4.2.4. AUID summary

The main stressors for the macroinvertebrates in this AUID are lack of habitat, potential of dewatering during pumping operations and low DO caused by high water periods when the upstream wetlands are flushing. The portion of ditch that is located from 450th Ave downstream to 430th Ave is surrounded by wild rice paddies that are dependent upon the water supply within the ditch network to supply water to the paddies. During dry springs with little snowpack and little spring precipitation, it is possible that the ditch water levels can be drawn down dramatically during the process of pumping water to fill the wild rice paddies. There are numerous pumping stations located along the ditch network between these two streets.

Upstream of the 450th Ave lies the Little Willow River, which at this point is flowing through a very large wetland network that, during high flows, can export low DO water due to SOD and BOD in the wetland system. As the Little Willow River gets diverted into the ditch that makes up this AUID, the channel becomes deeply incised and there is no active flood plain or any way to relieve sheer stress along the channel. During high flows the water velocity can become inhibiting to macroinvertebrates especially downstream of 430th Avenue, as velocities exiting that culvert can be well over 4 ft. /second during high flows, which is very fast and would wash any macroinvertebrates downstream.

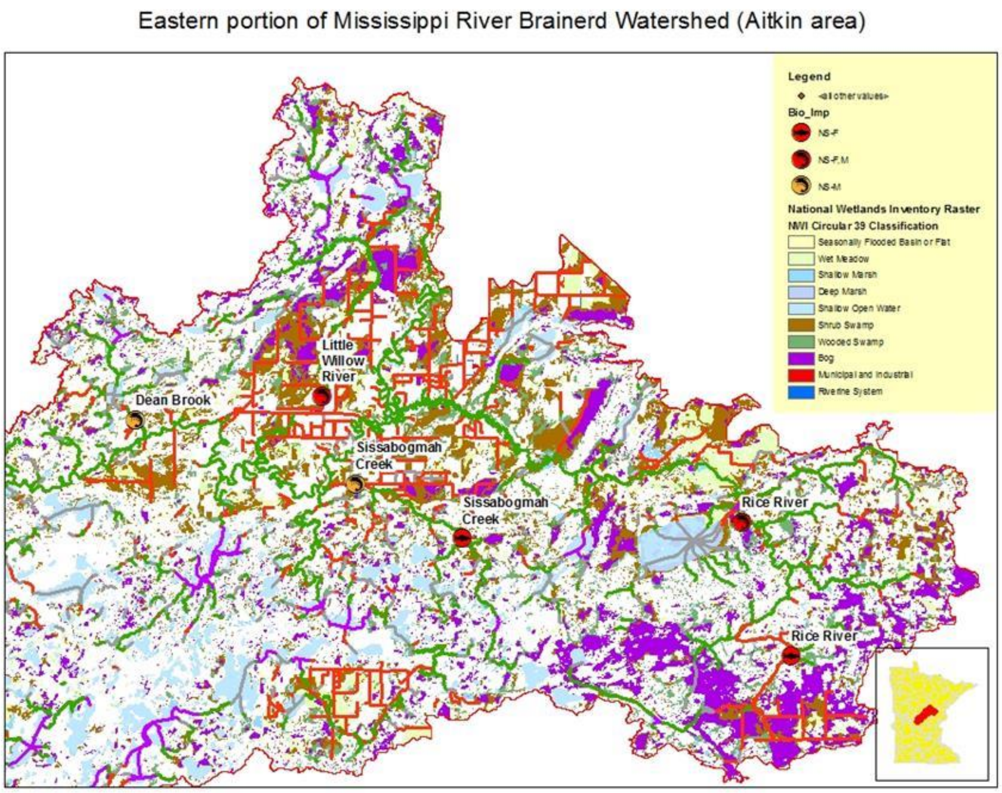
This section of channel also has very limited habitat variability, with no pools, riffles, or sinuosity. Macroinvertebrate habitat is limited to overhanging vegetation, undercut banks, submerged macrophytes, and small woody twigs from riparian shrubs. At this point in time, it seems like writing a TMDL for this AUID would not be warranted. The nature of the poor habitat conditions, low DO from drainage, and possibility of dewatering during pumping activity are causing the stress to the biology. These items are not easily separated out and dividing up load allocations would be difficult if not impossible. Land management activities could be pursued with the landowner to see if a change in the pumping schedule would be possible as this may alleviate the low water conditions during dry periods of pumping. Otherwise, it seems evident that the nature of the low DO water is being driven by drainage, which is the sole purpose of the ditch network.

5. Conclusion

5.1. Summary of probable stressors

Low DO was a common stressor found during the stressor identification monitoring activities in this watershed. Often the low DO are believed to be caused by natural sources from wetland drainage, low gradient stream systems, and the contribution of low DO concentrations in groundwater. Figure 56-58 shows the MRB watershed along with the MDNR's National Wetlands Inventory spatial data layer as a background.

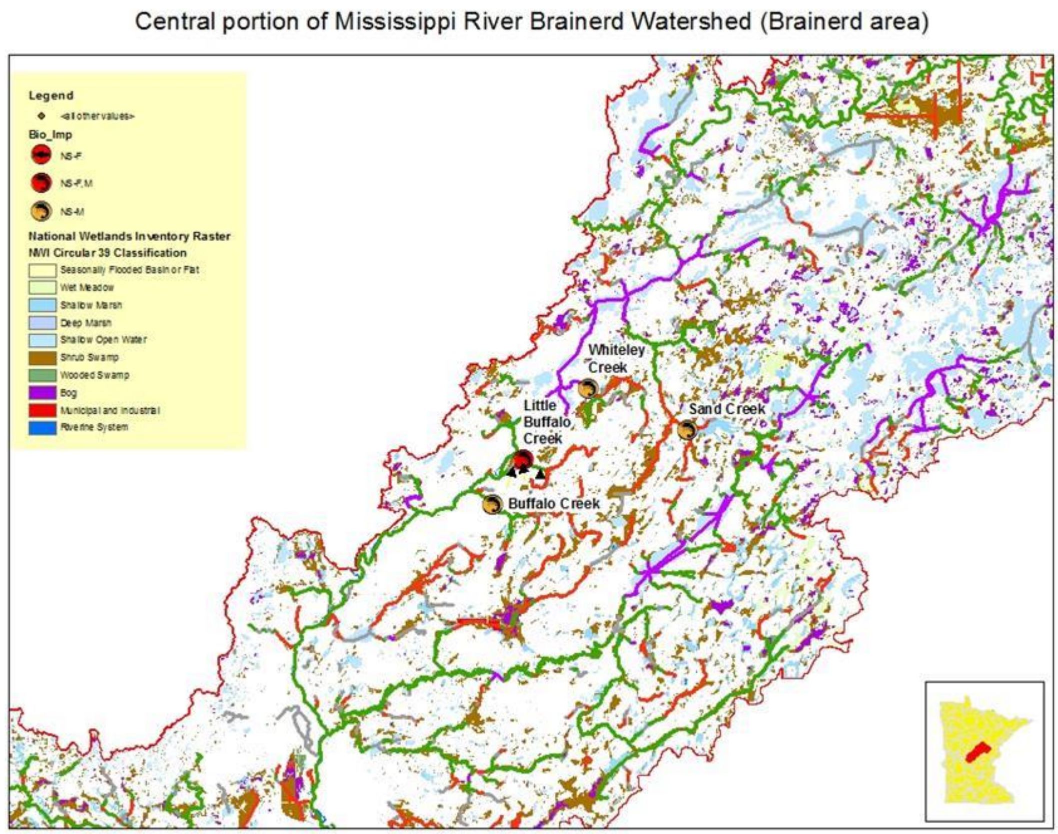
Figure 56: Eastern portion of the MRB watershed. This map has the NWI wetland layer as the background highlighting the large amount of wetland area present in this portion of the watershed.



The eastern portion of the MRB watershed has a large percentage of its original wetland acres. Some of these wetlands have been partially drained over time but are still functioning and contributing low DO concentration water during periods of higher flow. In addition, the extensive ditching network in this area has increased the contributing drainage area to many area streams, causing an increase in water volume, which in turn has caused many stream banks to erode and widen over time. This process has contributed to filling of pools and a general loss of habitat features, reducing the potential for fish and macroinvertebrate populations to thrive.

The red lines in the series of figures shows the channelized portions of stream from the MPCA's Altered Watercourse spatial data layer. Drainage networks will cause an increase in annual water volume in streams as water storage is reduced because of the dewatering effects of drainage. This is a watershed wide issue but is more evident in the eastern portion of the watershed near Aitkin. Longitudinal connectivity is also a stressor in this area, as the number of beaver dams is higher than other portions of the watershed. Many streams in the Aitkin area have a multitude of beaver dams located in the stream corridors.

Figure 57: Central portion of the MRB watershed showing the amount of wetland acres.



The Central portion (Figure 57) of the watershed has many of the same drainage and low DO issues as the eastern portion. The one added stressor in this area that was identified was storm water runoff in the Little Buffalo Creek subwatershed. Little Buffalo Creek is a cold water resource that is now acting more like a warm water system due to the extensive storm water network that drains to it from the city of Brainerd. This biology in this stream is currently being held to MPCA's warm water aquatic life use standards. Temperature monitoring was conducted in 2018 at various locations and it was identified that during rainfall events the temperature of the creek increased rapidly. In addition, the additional storm water runoff is causing stream bank instability due to the rapid increase in discharge following a rain event. Buffalo Creek is also experiencing bank instability due to an increase in stream flow due to drainage and channel incision. Low DO is also evident in this central section of the watershed but not as widespread as in the other areas of the watershed. Low DO in this region is tied to elevated nutrient concentrations and altered stream flow due to extensive pasturing in the Sand Creek subwatershed.

The southwestern portion of the watershed is quite different than the central and eastern portion. This southwestern area (Figure 58) is a mixture of agricultural land and small-forested areas. In this area there are longitudinal connectivity issues preventing fish passage that have been documented and these streams have been placed in the 4c impaired waters category. Low DO is also evident in this area, but is largely tied to wetland areas and ditching that has increased the amount of partially drained wetland acres that are contributing low DO water during periods of elevated flow. Habitat available is also diminished in the impaired watersheds due to past ditching and present maintenance of the ditch networks. Hay Creek, Little Swan River and Trib. to Mississippi River all have low DO concentrations that can be connected to drainage network changes due to ditching and potential increases in contributing drainage area.

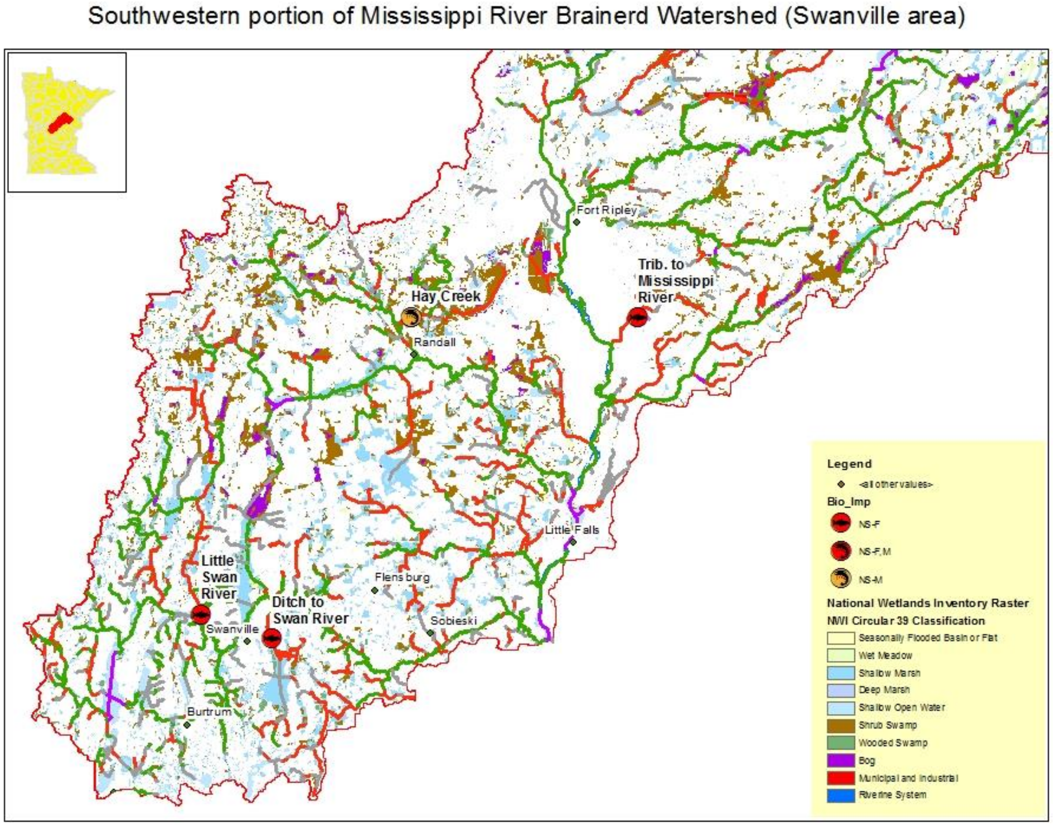


Figure 58: Southwestern portion of the MRB watershed near Swanville. NWI map as background highlighted the wetland areas.

Table 29 summarizes the impaired streams along with the identified stressors for each AUID. Streams are organized from upstream to downstream from the Aitkin area downstream to Swanville area.

Table 29. Summary of probable stressors in the MRB Watershed.

			Stressors					
Stream name	**AUID**	**Biological impairment**	**Low DO**	**High nutrients**	**Longitudinal connectivity**	**Flow alteration/ditching**	**Lack of habitat**	**Excess Sediment**
Rice River	505	Fish	●			●		
Rice River	649	Fish and macroinvertebrates	●			●		
Rabbit Creek	688	Fish	●		●			
Sisabagamah Cr.	677	Fish	●		●			
Sisabagamah Cr.	659	Macroinvertebrates				●	●	●
Little Willow Diversion Channel	691	Macroinvertebrates (modified use)	●			●	●	
Trib. To Sand Cr.	679	Macroinvertebrates (modified use)	●	●		●	●	
Little Buffalo Creek	695	Fish and macroinvertebrates				●	x	●
Buffalo Creek	610	Macroinvertebrates					x	●
Hay Creek	682	Macroinvertebrates	●			●	●	
Trib. To Mississippi R	684	Fish and macroinvertebrates	●		●	●	●	

Little Swan River	570	Fish	●			●		

● = probable stressor; X = inconclusive stressor

6. References

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