Pine River Watershed Stressor Identification Report

This report describes the stressors to the biological community in the Pine River Watershed

Minnesota Pollution Control Agency

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Acronyms

AUID Assessment Unit Identification Determination

Basin HUC-8 watershed

BOD Biochemical Oxygen Demand

Ca Calcium

CCSI Channel Condition and Stability Index

CD County Ditch

Chl-a chlorophyll-a

CI Confidence Interval

CWLA Clean Water Legacy Act

DO – Dissolved Oxygen

EPA – U.S. Environmental Protection Agency

EPT ephemeroptera, plecoptera and trichoptera families

EQuIS Environmental Quality Information System

FIBI fish IBI

FS Full Support

HUC Hydrologic Unit Code

IBI Index of Biological Integrity

IF Insufficient Information

IWM Intensive Watershed Monitoring

MDNR Minnesota Department of Natural Resources

MIBI macroinvertebrate IBI

MPCA Minnesota Pollution Control Agency

MSHA Minnesota Stream Habitat Assessment

MTS Meets the Standard?

MWR meander width ratio

NA Not Assessed

Nitrate-N Nitrate Plus Nitrite Nitrogen

NHD National Hydrologic Dataset

NH_3 Ammonia

N nitrogen

NS Not Supporting

OP Orthophosphate

P Phosphorus

K Potassium

PRW Pine River Watershed

SID Stressor identification

SOE Strength of evidence

Subwatershed HUC-11 size subwatershed

SWCD Soil and Water Conservation District

TKN Total Kjeldahl Nitrogen

TMDL Total Maximum Daily Load

TP Total Phosphorous

TSS Total Suspended Solids

USGS United States Geological Survey

WRAPS Watershed Restoration and Protection Strategies

Executive summary

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

Stressor identification (SID) is a formal and rigorous process that identifies stressors causing biological impairment(s) of aquatic ecosystems, and provides a structure for organizing the scientific evidence supporting the conclusions (EPA, 2000). In simpler terms, it is the process of identifying the major factors causing harm to fish, macroinvertebrates, and other river and stream life. Stressor identification is a key component of the major Watershed Restoration and Protection Strategies (WRAPS) projects being carried out under Minnesota's Clean Water Legacy Act.

This report summarizes stressor identification work in the Pine River Watershed (PRW). The biologically impaired reaches, which are identified by their associated Assessment Unit Identification (AUID) number, are separated by aggregated Hydrologic Unit Code (HUC)-12 for this report. After examining many candidate causes for the biological impairments, the following stressors were identified for the biologically impaired streams in the PRW:

		Stressors					
Stream Name	**AUID #**	**Low Dissolved Oxygen**	**Flow Alteration**	**Increased Sediment**	**Elevated Nutrients**	**Lack of Physical Habitat**	**Physical Connectivity**
Wilson Creek	**07010105-529**		X		X	X	
South Fork Pine River	**07010105-531**			X		X	X
Arvig Creek	**07010105-509**	X				X	
Willow Creek	**07010105-631**					X	X

X – Stressor to biological community

Poor habitat quality is a common theme in the impaired AUID's throughout the PRW. Lack of physical habitat is a concern to the impaired biotic communities. The habitat tool used to evaluate this stressor is the Minnesota Stream Habitat Assessment (MSHA) score. This score was poor to fair at the impaired stream stations sampled in each impaired AUID. The South Fork Pine River has an elevated set of culverts located at 36th Avenue which is causing limited fish passage during the year along with deposition of fine sediment upstream of the road. Willow Creek also has a physical connectivity problem with the culverts located along Long Farm Road.

1. Introduction

1.1. Monitoring and assessment

Water quality and biological monitoring in the PRW has been active for three years. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2012 - -2013, 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 2012, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1.1.1).

Once a biological impairment(s) 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 result of the SID process is the identification of the stressor(s) for which the TMDL may be developed. For example, the SID process may help investigators diagnose 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.

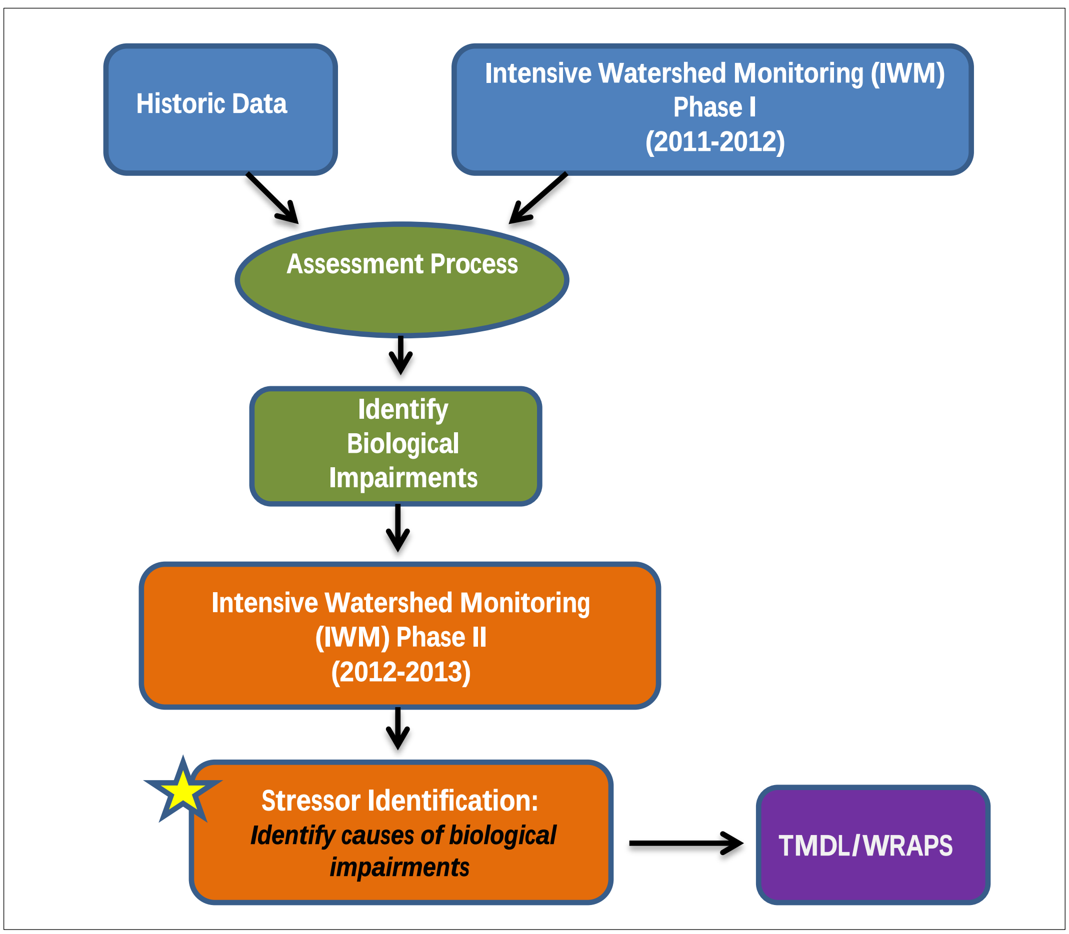


Figure 1.1.1: Process map of IWM, assessment, SID, and TMDL processes.

1.2. Stressor identification process

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

Stressor identification is a key component of the major WRAPS being carried out under Minnesota's Clean Water Legacy Act. Stressor identification 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 1.2.1. 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.

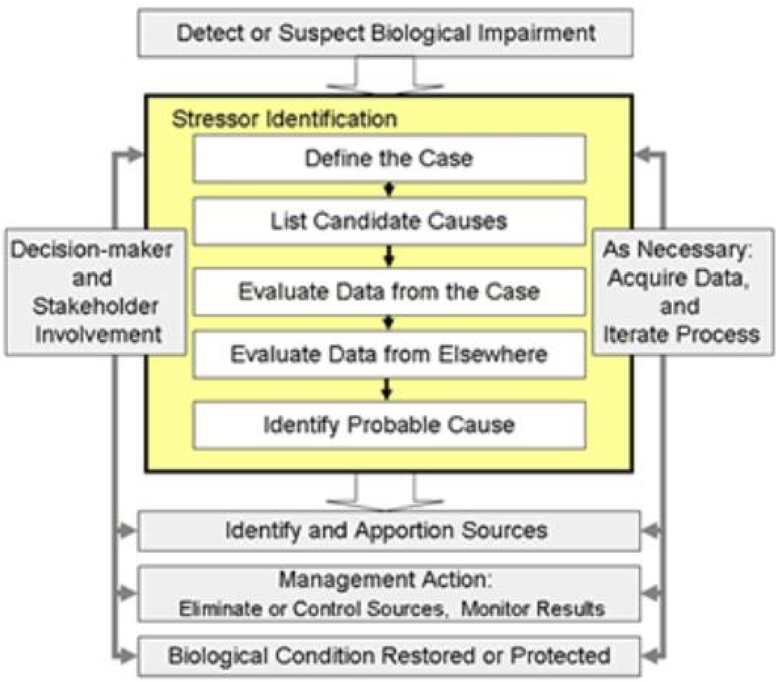


Figure 1.2.1: Conceptual model of SID process.

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(s). Additional detail on the various types of evidence and interpretation of findings can be found here: http://www.epa.gov/caddis/si_step_scores.html.

1.3. Common stream stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry, and stream biology. If one or more of the components are unbalanced, the stream ecosystem fails to function properly and is listed as an impaired water body. Table 1.3.1 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 1.3.1: 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 Assessment **Water Chemistry**	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 Low Dissolved Oxygen (DO) Concentrations Elevated levels of TSS Increased nutrients from human influence Widely variable DO levels during the daily cycle Increased algal and or periphyton growth in stream Increased nonpoint pollution from urban and agricultural practices Increased point source pollution from urban treatment facilities	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. There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream Biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

1.4. Report format

This report will be organized by AUID. Each AUID that has a biological impairment will be discussed in detail in Chapter 4 of this report. The candidate stressors that were considered during the SID process will be reviewed and discussed in Chapter 3 of this report.

2. Overview of Pine River Watershed

2.1 Background

From its source at Pine Mountain Lake in Cass County (approximately 0.5 miles west of Backus), the Pine River flows southeast to its confluence with the Mississippi River 10 miles north of Brainerd. Stony Creek and Unnamed Creek flow into Pine Mountain Lake to form the Pine River at the lake's outlet. The PRW begins in Cass County and flows into Crow Wing County covering 779 square miles and draining approximately 498,560 acres (Minnesota Stream Stats). The watershed has the Whitefish Chain of Lakes complex that runs through the center from west to east. The northern half of the watershed is predominately forest and wetland with scattered agricultural lands. The southwestern portion of the watershed is opposite, with predominately forests, agricultural lands and scattered wetlands, and small lakes (Figure 2.1.1).

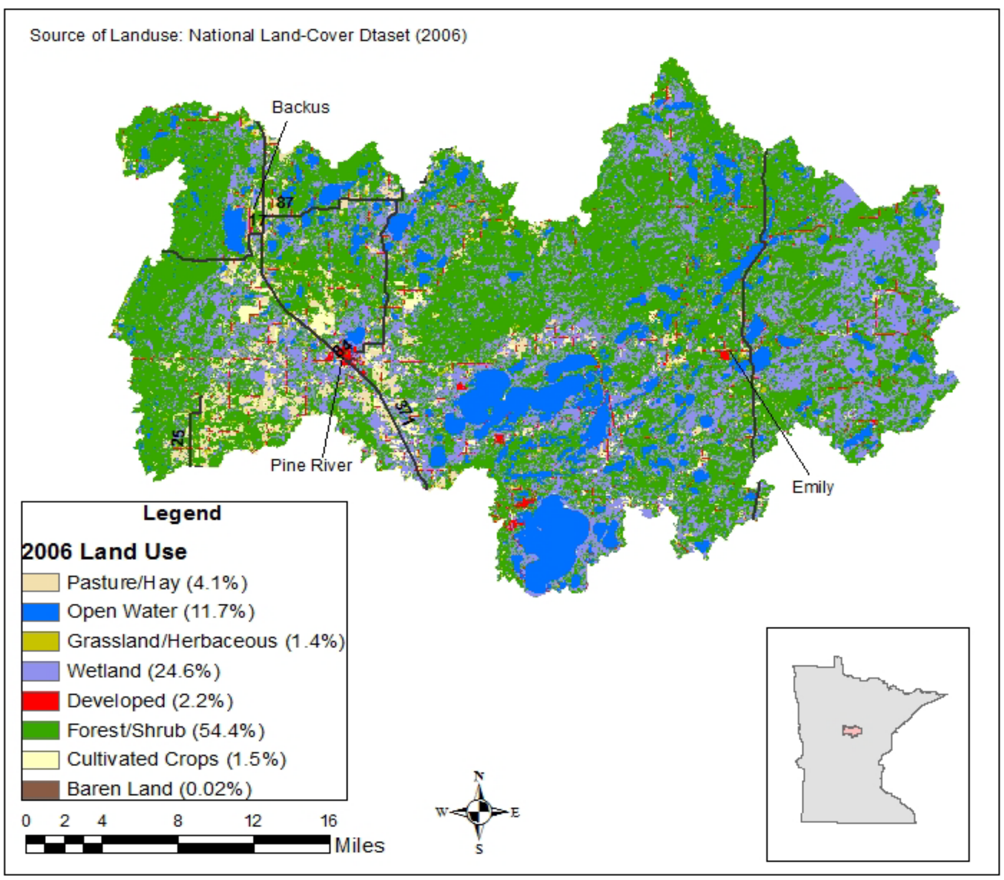


Figure 2.1.1: Land use in the Pine River Watershed.

2.1.1. Subwatersheds

Due to the sheer size of the watershed, it is difficult to evaluate potential stressors to aquatic life without further stratifying the Pine River drainage into smaller sections. Although there may be some consistent chemical and physical stressors found throughout the PRW, 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 PRW, the watershed was stratified into aggregated 12-digit Hydrologic Unit Code (HUC) units. Figure 2.1.2 below shows the watershed boundaries used in this report. The PRW has seven HUC-12 subwatershed units. Four stream AUIDs were impaired for biology in three different HUC-12 units. Two of the impaired HUC-12s have a significant amount of agricultural land use occurring in the subwatershed. This report will discuss the stream reach AUID that is impaired as part of the subwatershed that it resides in.

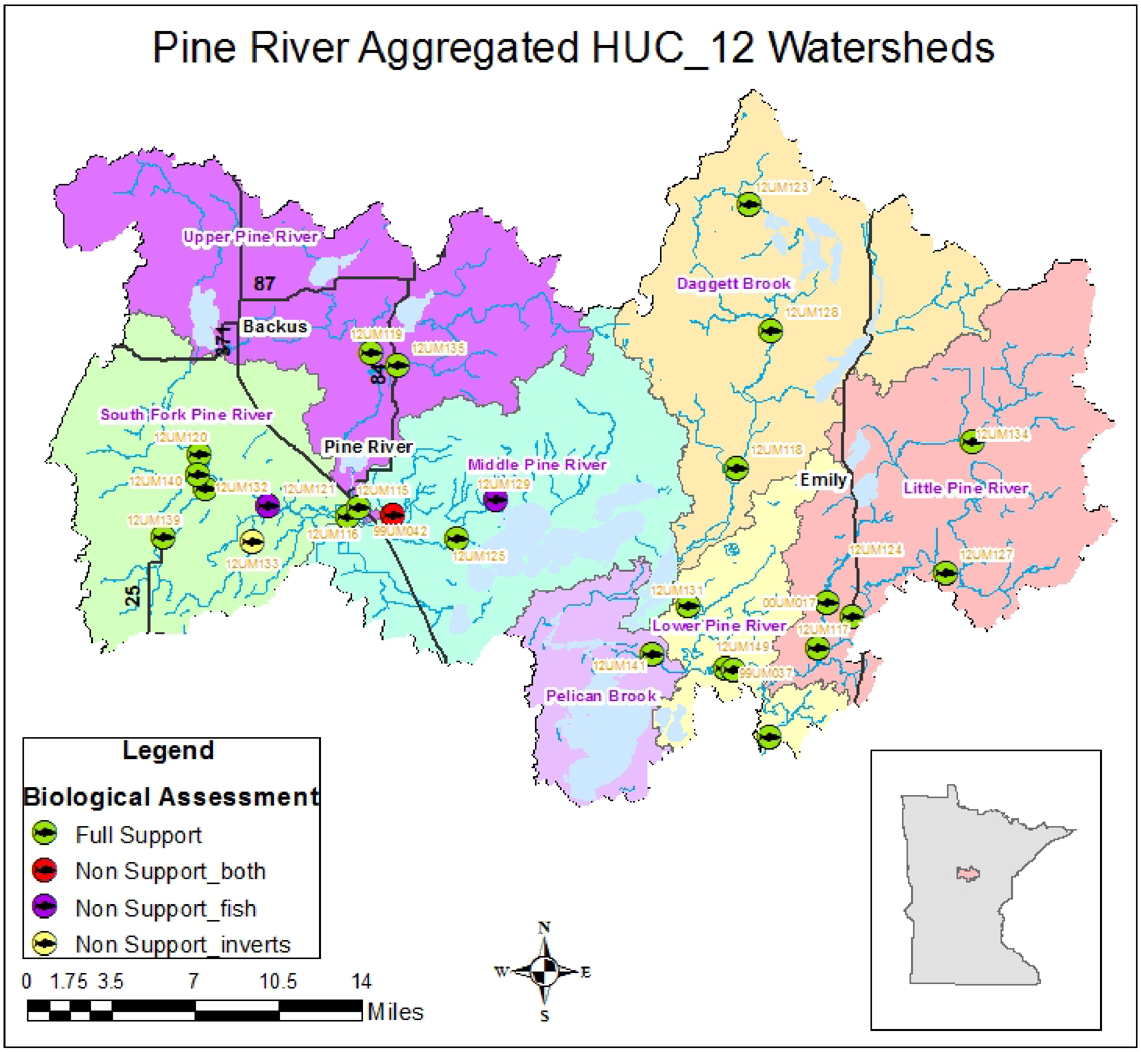


Figure 2.1.2: Aggregated HUC-12 watershed boundaries for use in segregating the watershed into manageable drainage areas for reporting.

2.1. Monitoring and assessment status

The PRW was assessed in 2014. For the full assessment report, access the Pine River monitoring and assessment report located here. The PRW has four AUIDs that are impaired for fish, macroinvertebrates, or both. The watershed was initially sampled in 2012 with follow up biological sampling occurring in 2013 and 2014 at select locations to verify initial results. Figure 2.2.1 shows the water quality stations, DO stations and biologically impaired sampling locations along with all biological sampling locations and select cities.

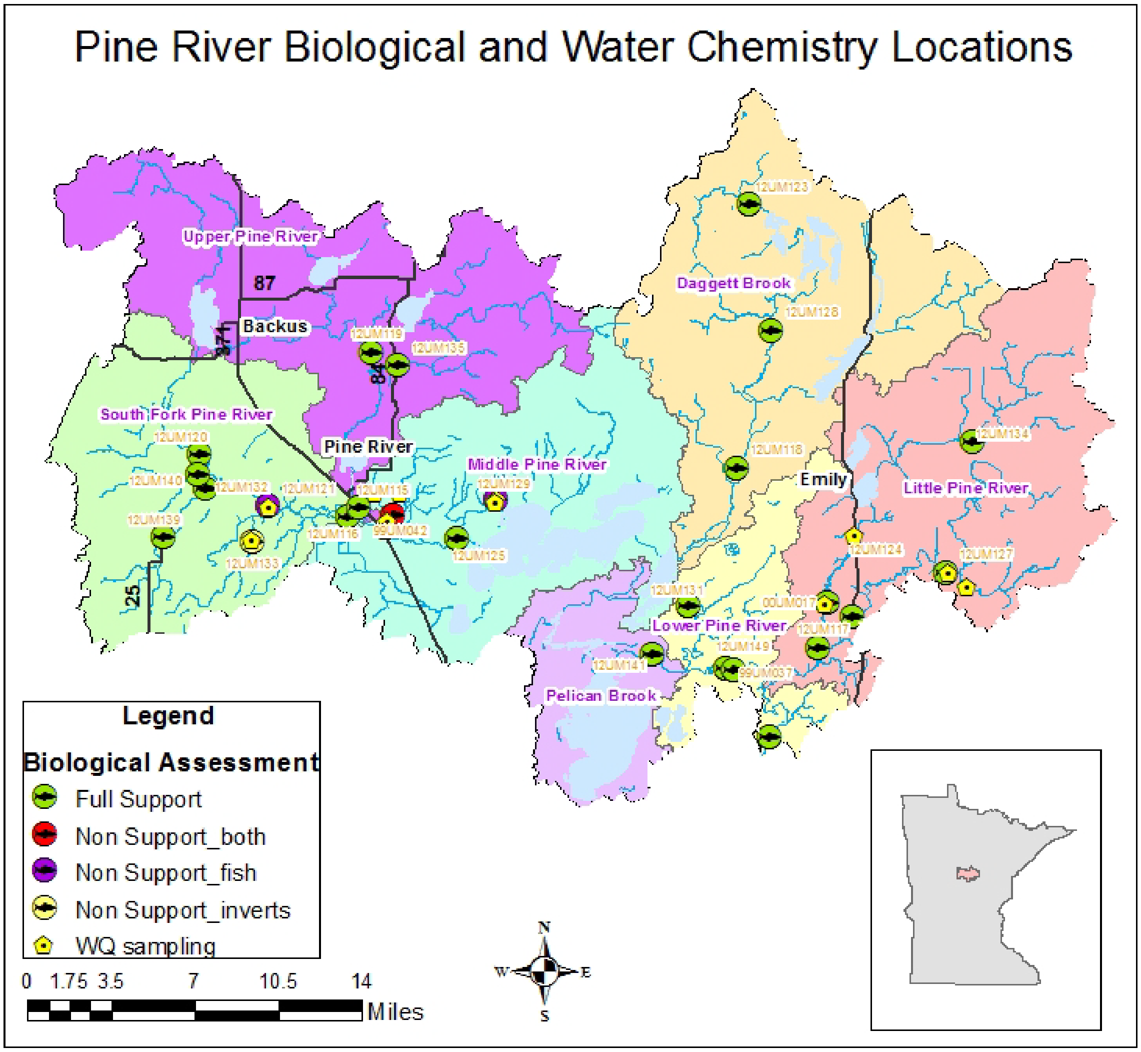


Figure 2.2.1: Map of monitoring stations and biologically impaired AUIDs along with HUC-12 used for later discussion in this report.

Water chemistry data used in the SID report comes from Environmental Quality Information System (EQuIS) sites. These sites can have data ranging from the 1990s through 2014. The locations on the above map were created and sampled in response to poor biological monitoring data or to answer questions about the water quality in a stream reach. This data was collected in 2013 and 2014. The data analyzed for this report is from 1999 through 2014. Nutrient concentrations and sediment concentration data is stored in EQuIS and can be accessed through the EQuIS website located here. This website also contains biological monitoring site information as well.

2.2. Summary of biological impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrate 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 a range of thresholds.

The fish and macroinvertebrates within each AUID were compared to a regionally developed threshold and confidence interval (CI) and utilized a weight of evidence approach. Within the PRW, four AUIDs are currently impaired for a lack of biological assemblage (Table 2.3.1).

Table 2.3.1: Biologically impaired AUIDs in the Pine River Watershed.

			Impairments	
Stream Name	AUID #	Reach Description	Biological	Water Quality
Wilson Creek	07010105-529	*T137 R30W S30, west line to Hoblin Cr*	Invert	NA
South Fork Pine River	07010105-531	*Bungo Cr to Hoblin Cr*	Fish	NA
Arvig Creek	07010105-509	*Rice Lk to Unnamed cr*	Fish/Invert	NA
Willow Creek	07010105-631	*Headwaters to Unnamed cr*	Fish	NA

Abbreviations for impairment status: NA= Not Assessed

The assessment process uses a weight of evidence approach when considering the status of the biological community. The water chemistry, biological IBI score for both fish and macroinvertebrates, along with the current land use and potential for pollutant transport are all reviewed when determining the status of the biological community. The IBI score is used as an indicator to the overall biological community health of the stream but it is often not the only factor used to base the decision on calling a site impaired. The fish and macroinvertebrate thresholds and confidence limits are shown by class for sites found in the PRW in Table 2.3.2 and Table 2.3.3. Each IBI is comprised of a fish or macroinvertebrate metric that is based on community structure and function and produces a metric score scaled 0 to 100 points. The number of metrics that make up an IBI will determine the metric score scale. For example, an IBI with eight metrics would have a scale from 0 - 12.5 and an IBI with 10 metrics would have a scale from 0 - 10.

Table 2.3.2: Fish classes with respective IBI thresholds and upper/lower confidence limits (CL) found in the Pine River 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
11	Northern Coldwater	37	47	37

Table 2.3.3: Macroinvertebrate classes with respective IBI thresholds and upper/ lower confidence limits (CL) found in the Pine River Watershed.

Class	Class Name	IBI Thresholds	Upper CL	Lower CL
3	Northern Forest Streams RR	50.3	62.9	37.7
4	Northern Forest Stream GP	52.4	66	38.8
5	Southern Streams RR	35.9	48.5	23.3
6	Southern Forest Streams GP	46.8	60.4	33.2
8	Northern Coldwater	26	38.4	13.6

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 (FIBI) scores are shown in Table 2.3.4.

The IBI scores are color coded by relationship to threshold and CI which is available in Table 2.3.5. Figure 2.2.1 shows the location of the impaired AUIDs within the PRW. The individual impaired AUIDs will be discussed in Chapter 4 of this report along with a more detailed analysis of the fish and macroinvertebrate metrics.

Overall the biological communities had passing IBI scores for both fish and macroinvertebrates during the 2012 sampling cycle in the PRW. Many of the passing IBI scores were well above the threshold and were near or above the upper CI.

Table 2.3.4: Fish and MIBI scores by biological station within AUID; key to color coding in Table 2.3.5.

AUID & Reach	Station	Year	Fish IBI Score*	Fish Class	Macroinvertebrate IBI Score*	Macroinvertebrate Class
07010105-529 Wilson Creek	12UM133	2012	62	6	40.75	4
07010105-531 South Fork Pine River	12UM121	2012 2013	42 –46	5	65.5	4
07010105-509 Arvig Creek	99UM042	2012 2013	0	6	21.21 - 32.93	3
07010105-631 Willow Creek	12UM129	2012 2013	20 - 30	6	60.16 - 62.7	4

Table 2.3.5: Key to color coded IBI scores. Example:

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

2.4. Hydrological Simulation Program - FORTRAN (HSPF) 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 and Non-Point Source models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient 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 land surfaces, runoff and constituent loading from impervious land surfaces, and 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. 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, the upland areas are separated into multiple land use categories.

An HSPF watershed model was run for the PRW to predict water quality condition throughout the watershed on an hourly basis from 1996-2009.

3. Possible stressors to biological communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found here (http://www.epa.gov/caddis/si_step2_stressorlist_popup.html). This comprehensive list serves two purposes. First, it can be a checklist for investigators to consider all possible options for impairment in the watershed of interest. Second, it can be used to identify potential stressors that can be eliminated from further evaluation. In some cases, the data may be inconclusive 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. Alternatively, there may be enough information to conclude that a candidate cause is not causing biological impairment and therefore can be eliminated. The inconclusive or eliminated causes will be discussed in more detail in the following section.

3.1. Eliminated causes

Initially, nine candidate causes were evaluated to address the biological impairments found in the four impaired AUIDs in the PRW. The following sections of the report will describe the reasoning behind either including the candidate causes for further analysis or placing the candidate causes into the inconclusive candidate portion of the report. At this point there are no eliminated candidate causes.

3.2. Inconclusive causes

Elevated stream temperature was deemed to be inconclusive as a stressor to aquatic life in the PRW. Warm water streams are not to exceed 30°C in any given day as a daily maximum temperature. Temperature data is readily available through much of the PRW. Most of the temperature data is instantaneous data and was collected sporadically over the course of 2002 through 2014. The temperature data that was reviewed showed no exceedances of the 30°C daily maximum, however; temperature data is limited and a more in depth collection of temperature data would be required to eliminate elevated temperature as a stressor.

Ammonia toxicity can be detrimental to aquatic life when the concentrations of un-ionized ammonia (NH_3) exceed 0.040 mg/L. There currently is limited data on either ionized (NH_4) or un-ionized ammonia

(NH_3). Arvig Creek has some unionized ammonia data that is close to the standard. Additional data collection would be required to adequately assess the impact that ammonia is having on the aquatic life in the PRW.

3.3. Summary of candidate causes in the Pine River Watershed

The initial list of candidate/potential causes was narrowed down after the initial data evaluation/data analysis resulting in seven candidate causes for final analysis in this report.

3.3.1. Candidate cause: Low dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species ((Davis, 1975); (Nebeker, 1991)). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If DO concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Many species of fish avoid areas where DO concentrations are below five mg/L (Raleigh, 1986). For more detailed information on DO go to the EPA Caddis webpage following this link (U.S.EPA, CADDIS:Sources, Stressors & Responses).

3.3.1.1. Water quality standards

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

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

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

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

The class 2A (coldwater) water quality standard for DO in Minnesota is 7 mg/L as a daily minimum.

3.3.1.2. Ecoregion information

There currently is no applicable ecoregion information for low DO.

3.3.1.3. Types of dissolved oxygen data

1. **Point measurements**

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

2. **Longitudinal (Synoptic)**

   A series of longitudinal synoptic DO surveys were conducted throughout the PRW in 2013. A synoptic monitoring approach gathers data across a large spatial scale and minimal temporal scale (as close to simultaneously as possible). In terms of DO, the objective was to sample a large number of sites from upstream to downstream under comparable ambient conditions. For the most part, the surveys took place in mid to late summer when low DO is most commonly observed. Dissolved oxygen readings were taken at pre-determined sites in the early morning in an attempt to capture the daily minimum DO reading.

3. **Diurnal (Continuous)**

   YSI sondes were deployed for 7-12 day intervals at sites located in the PRW in late summer to capture the diurnal fluctuations. This data revealed the magnitude and pattern of diurnal DO flux at each site. Sources and Causal Pathways Model for Low Dissolved Oxygen

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

3.3.1.5. Overview of dissolved oxygen trends in the Pine River Watershed

The PRW has multiple locations where DO data has been collected during the course of 2002 - 2014. The available DO data has been reviewed during the watershed assessment cycle in 2014. Currently there are no AUID's that are impaired for aquatic life based on DO data. The remaining AUID's in the watershed either did not have enough DO data to conduct an assessment or are showing full support based on the current DO data. Small individual AUID's that did not have sufficient DO data during assessment but had a low biological IBI have since been investigated with additional DO data being collected which will be presented in Chapter 4 of this report. Based on the available data low DO concentrations do not appear to be a watershed wide problem rather isolated to certain AUID's.

3.3.2. Candidate cause: Flow alteration

Flow alteration is the change of the stream flow regime caused by anthropogenic sources. These sources can include channel alteration, water withdrawals, land cover alteration, agricultural tile drainage, and impoundment. To learn more about flow alteration go to the EPA CADDIS webpage here.

Across the conterminous United States, Carlisle et al. (Carlisle, Wolcock, & Meador, 2010) found that there is a strong correlation between diminished stream flow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to a decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space and when flows are reduced beyond normal baseflow, competition for resources increases. Pollutant concentrations can increase when flows are lower than normal, making it more difficult for populations to maintain a healthy diversity. Often tolerant organisms that can out compete others in such limiting situations will thrive. Low flows of prolonged duration lead to macroinvertebrate and fish communities comprised of generalist species or that have preference for standing water (EPA, CADDIS Volume 2 Sources, Stressors & Responses, 2012).

3.3.2.1 Water quality standards

There currently is no applicable standard for flow alteration.

3.3.2.2 Ecoregion information

There currently is no applicable ecoregion information for flow alteration.

3.3.2.3 Types of flow alteration data

Each 8-HUC has a minimum of four continuous recording stream gages located at various points within the watershed. The pour point of the 8-HUC has a permanent gage that will be collecting continuous stream stage data and corresponding discharge measurements for rating table calculations. Within the 8-HUC there is variability statewide as to the design and location of the representative 12-HUC scale stream gage locations. At a minimum there should be three smaller scale (12-HUC) stream gages that can be used to review flow conditions during the time of biological monitoring and post biological monitoring conditions. The data from the gages can be used for HSPF model calibration and can be extrapolated for smaller size streams with the 8-HUC. In some instances special short term gages can be installed to collect a 2 - 3 year record of stream discharge at smaller scale subwatersheds such as a 14-HUC level. This data would be available upon request and would need to be coordinated with the MPCA regional field staff or local partner for installation and operation. All relevant flow data shall be stored and calculated in the Hydstra database.

3.3.2.4 Sources and causal pathways model for flow alteration

The conceptual model for flow alteration can be found on the EPA webpage. The causes and potential sources for altered flow are modeled at EPA's CADDIS Flow Alteration webpage.

3.3.2.5. Overview of flow alteration trends in the pine watershed

The PRW has 9.7% of its stream miles altered. There are 590 stream miles in the PRW. Figure 3.3.1 below shows the PRW with green lines representing natural stream channels and red lines representing altered stream channels. Stream channelization is scattered throughout the watershed with many of the biologically impaired stream reaches located downstream of channelized stream reaches. The altered stream reaches can impact stream flow and alter the amount of available stream habitat.

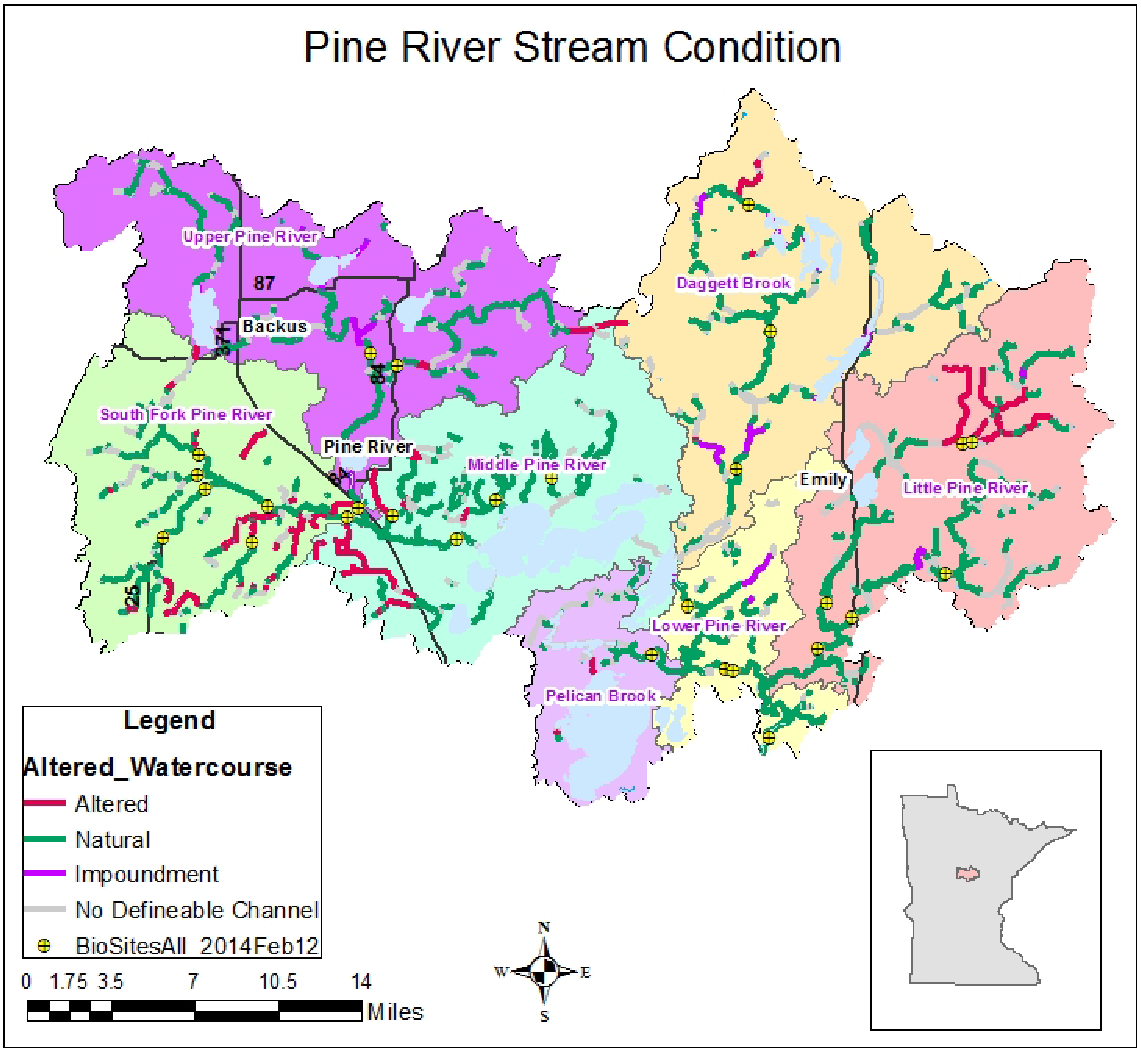


Figure 3.3.1: The Pine River Watershed and its altered stream channels.

3.3.3. Candidate cause: Increased sediment

Total Suspended Solids (TSS) and bedded sediment are related through several common watershed sources and processes, but each can affect aquatic biota in different ways. Due to the inter-related nature of these parameters, they are grouped together in this report for causal analysis purposes, but ultimately each of these candidate causes will be evaluated independently in terms of impact on fish and macroinvertebrate populations.

Whereas suspended solids and turbidity are potential stressors operating in the water column, bedded (= deposited) sediments impact the stream substrate. Excessive deposition of fine sediment can impair macroinvertebrate habitat quality and productivity ((Charles F. Rabeni, 2005)). To date, bedded sediment has not been extensively studied in the PRW, in part because there is no state or federal water quality standard for this parameter. Quantitative field measurement of bedded sediment (bedload) is very difficult. However, some data on substrate composition and embeddedness (the degree in which fine sediments surround coarse substrates on the surface of a stream bed) were collected. These data will be used to determine whether or not natural coarse substrate (a very important habitat type) is being covered or filled in by excess fine sediment.

To learn more about sediment effects on stream organisms go to the EPA CADDIS webpage here.

3.3.3.1 Water quality standards

The water quality standard for turbidity is 25 Nephelometric Turbidity Units for Class 2B waters. Total suspended solids and transparency tube/Secchi tube measurements can be used as surrogate standard. A regression of the TSS to turbidity indicates impairment at 15 mg/L for waters within the Northern Lakes and Forest Ecoregion.

A strong correlation exists between the measurements of TSS concentration and turbidity. In 2010, MPCA released draft TSS standards for public comment (MPCA, 2009). The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The draft TSS standard for the PRW has been set at 15 mg/L. For assessment, this concentration is not to be exceeded in more than 10% of samples within a 10-year data window.

For the purposes of SID, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. TSS results are available for the watershed from state-certified laboratories, and the existing data covers a much larger spatial and temporal scale in the watershed.

3.3.3.2 Ecoregion information

There currently is no applicable ecoregion information for increased sediment.

3.3.3.3 Types of sediment data

Total Suspended Solids (TSS) data is collected by collecting a stream water sample and having the sample filtered and weighed to determine the concentration of TSS in the sample. Bedded sediment is visually estimated by looking at the fine material surrounding rock or woody substrate within the stream channel. Bedded sediment is also analyzed by conducting pebble counts in stream reaches and analyzing the D50 particle size in both the stream reach and the representative riffle site.

3.3.3.4 Sources and causal pathways model for sediment

Rangeland and pasture are common landscape features throughout the PRW. Most of these areas are operated for cattle grazing. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase stream bank erosion and reduce substrate quality (Kauffman, 1984). In some areas, the riparian corridor along the Pine River tributaries has been cleared for pasture and heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect stream banks and provide shading. Exposures of these areas to weathering, trampling, and shear stress (water friction) from high flow events are increasing the quantity and severity of bank erosion.

The causes and potential sources for increases in sediment in the Pine River Watershed are modeled at EPA's CADDIS Sediments webpage.

3.3.3.5. Overview of sediment trends in the Pine Watershed

TSS data was collected throughout the PRW. The TSS results for the various aggregated 12-HUC s that were sampled in the PRW were often well below the proposed standard of 15 mg/L. Review of the EQuIS dataset revealed 4 of 681 TSS concentrations above the 15 mg/L standard.

Overall review of the TSS for the various watershed sites located throughout the PRW show that TSS is not a problem in the watershed.

3.3.4. Candidate cause: Increased bedded sediment

Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe & MacDonald, 1991). Aquatic macroinvertebrates are generally affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman & Ligon, 1988); (2) increase in drift (avoidance by movement with current) due to sediment deposition or substrate instability (Rosenberg & Wiens, 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Pekarsky, 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman, 1988) and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985); (Gray & Ward, 1982). Fish species that are simple lithophilic spawners require clean, coarse substrate for reproduction. These fish do not construct nests for depositing eggs, but rather broadcast them over the substrate. Eggs often find their way into interstitial spaces among gravel and other coarse particles in the stream bed. Increased sedimentation can reduce reproductive success for simple lithophilic spawning fish, as eggs become smothered by sediment and become oxygen deprived. The sediments primarily responsible for causing an embedded condition in Minnesota streams are sand and silt particles, which can be transported in the water column under higher flows, or as a bedload component. When stream velocities decrease, these sediments can "settle out" into a coarser bottom substrate area, thus causing an embedded condition.

To learn more about sediment effects on stream organisms go to the EPA CADDIS webpage here.

3.3.4.1 Water quality standards

There currently is no applicable standard for lack of habitat due to deposited and bedded sediment for biotic communities.

3.3.4.2 Ecoregion information

There currently is no applicable ecoregion information for increased sediment.

3.3.4.3 Types of sediment data

Bedded sediment is visually estimated by looking at the fine material surrounding rock or woody substrate within the stream channel. Bedded sediment is also analyzed by conducting pebble counts in stream reaches and analyzing the D^{50} particle size in both the stream reach and the representative riffle site.

3.3.4.4 Sources and causal pathways model for sediment

Rangeland and pasture are common landscape features throughout the PRW. Most of these areas are operated for cattle grazing, but several horse operations were noted during reconnaissance trips throughout the watershed. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase streambank erosion and reduce substrate quality (Kauffman, 1984). Unstable stream channels can often have the majority of their sediment load come from bank failure and channel bed sediment. Instability in stream pattern and profile can be caused by a lack of riparian vegetation along with altered hydrology. External sediment and channel sediment sources will need to be inventoried and addressed accordingly. The causes and potential sources for increases in sediment in the Pine River Watershed are modeled at EPA's CADDIS Sediments webpage.

3.3.4.5. Overview of increased bedded sediment trends in the Pine River Watershed

The amount of bedded sediment was only quantified at biological sampling locations that did not meet the expected IBI score. Review of watershed wide bedded sediment issues is limited to reviewing the percent of fish that are lithophilic spawners from the entire watershed. This review is difficult due to the fact that the fish communities that passed the IBI may or may not require a high percentage of simple lithophilic spawning fish. This depends on the stream fish class along with the species composition at the site. Watershed wide the average fish community was made up of 25% simple lithophilic spawners. This ranged from 0% to 72%. In Chapter 4 of this report we will discuss the potential of bedded stressors to the individual AUID's that did not meet their biological criteria standard.

3.3.5. Candidate cause: Elevated nutrients

Nutrients are elements that are essential for plant growth, including nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca). Nitrogen and P are often considered primary nutrients and are the major limiting nutrients in aquatic ecosystems. Nutrient concentrations are often linked to the trophic status of freshwater systems. Increased nutrients can cause excessive plant and algal growth, which can alter physical habitat, alter food chains, and create toxic conditions. Elevated nutrients have indirect effects on aquatic communities and direct impacts to aquatic communities from response variables such as DO flux, chlorophyll-a, and biochemical oxygen demand (BOD) (Heiskary, Bouchard, & Markus, 2013). Elevated nutrient sources can include urban stormwater runoff, agricultural runoff, animal waste management, fertilizer management, industrial and wastewater facility discharges. To learn more about elevated nutrients as stressor to aquatic life go to the EPA CADDIS webpage here.

3.3.5.1 Water quality standards

Streams classified as Class 1 waters of the state, designated for domestic consumption, in Minnesota have a nitrate-nitrogen water quality standard of 10 mg/L. At this time, none of the AUIDs in the PRW that are impaired for biota are classified as Class 1 streams. Minnesota currently does not have a nitrate standard for other waters of the state besides for Class 1. The MPCA has developed draft standards designed to protect aquatic life.

A stream nutrient criterion for Total Phosphorus (TP) is currently being developed by MPCA. The draft standard can be found in the Minnesota Nutrient Criteria Development for Rivers document published by MPCA in January 2013. This document can be found here. The TP nutrient criteria for rivers are divided into three regions for the state. Table 3.3.1 below lists the proposed river nutrient criteria by region. The current draft standard for P is a maximum stream concentration listed in table 3.3.1 with at least one response variable out of desired range BOD, DO flux, chlorophyll-a (Chl-a), and/or pH).

Table 3.3.1: Draft river eutrophication criteria ranges by River Nutrient Region for Minnesota

	Nutrient	Stressor		
Region	**TP µg/L**	**Chl-a µg/L**	**DO flux mg/L**	**BOD5 mg/L**
North	**≤50**	**≤7**	**≤3.0**	**≤1.5**
Central	**≤100**	**≤20**	**≤3.5**	**≤2.0**
South	**≤150**	**≤35**	**≤4.5**	**≤2.0**

3.3.5.2 Ecoregion information

McCollor and Heiskary (1993) compiled Nitrite (NO_2) – Nitrate (NO_3)data for minimally impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. The PRW falls within the Northern Lakes and Forest ecoregion, which has an ecoregion norm of 0.01 to 0.09 mg/L for NO_2+NO_3-N. The one sampling location that routinely was above the ecoregion norm was Arvig Creek at station S007-681. This site ranged from 0.14 to 1 mg/L.

3.3.5.3 Types of nutrient data

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

3.3.5.4 Sources and causal pathways model for elevated nutrients

Nitrate (NO_3) and nitrite (NO_2) forms of N are components of the natural N cycle in aquatic ecosystems. NO_2 anions are naturally present in soil and water, and are routinely converted to NO_3 by microorganisms as part of the nitrification and denitrification processes involved in the N cycle. Nitrogen cycling in the environment results in nitrogenous compounds such as ammonia denitrifying into the more stable and conservative nitrate ion (NO_3).

Given the amount of cultivated cropland in the watershed, it is feasible that fertilizer application is a prominent source of nitrate in surface water (Folmar, Samders, & Julin, 1979). Due to the limited nitrate-nitrite data this stressor cannot be fully assessed in the PRW. For a complete model of causes and potential causes of nitrates in the PRW, please see the EPA's CADDIS Nitrogen webpage.

Elevated phosphorus is closely tied to the DO fluxes that occur in streams. Increased phosphorus levels lead to increased algal and macrophyte growth which in turn leads to increased decomposition and respiration rates. Increased plant and algal growth causes increased oxygen production through photosynthesis during the day. The excess plant material eventually dies, and bacterial activity during decomposition strips oxygen from the water. This leads to low early morning DO readings in streams, and high readings in the afternoon. Streams dominated with submerged macrophytes experience the largest swings in DO and pH (Wilcox & Nagels, 2001). Phosphorus is delivered to streams by wastewater treatment facilities, urban stormwater, agricultural runoff, and direct discharges of sewage. Phosphorus bound to sediments in the river channel could be contributing to concentrations; however there is no data available. The causes and potential sources for excess phosphorus are modeled at EPA's CADDIS Phosphorus webpage.

3.3.5.5. Overview of elevated nutrient trends in the Pine River Watershed

Elevated nutrients alone will not cause a biological response by the fish and macroinvertebrate community. Often the response is seen with eutrophication which will increase the abundance and density of aquatic macrophytes in the stream system. This increase in eutrophication can often lead to increased DO fluctuations during the diurnal DO cycle. The PRW has a proposed in-stream TP concentration of 0.050 mg/L. TP data collected from the Pine River often show values above the proposed standard but the paired Chl-a concentrations are often below 7 µg/L. This data suggests that currently TP is not a concern to the biological community however; TP concentrations should be periodically sampled to quantify the eutrophication impacts to downstream water bodies.

Elevated NO_2+NO_3 concentrations do not appear to be significant problem in the overall water quality of the PRW. There are numerous water quality samples that have been collected throughout the watershed. Many of the streams have concentrations below 0.1mg/L for the majority of the sampling period. The Arvig Creek sites have some concentrations in the 0.2 to 2 mg/L range. These concentrations are generally seen during the mid-summer months and do not seem to persist for the entire summer. Elevated NO_2+NO_3 concentrations do not appear to be a watershed wide problem but rather isolated to a few tributaries.

3.3.6. Candidate cause: Lack of physical habitat

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. This section will focus on the physical habitat structure including geomorphic characteristics and vegetative features (Griffith, Rashleigh, & Schofield, 2010).

Physical habitat is often interrelated to other stressors (e.g., sediment, flow, DO) and will be addressed separately.

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on our landscape by way of resource extraction, agriculture, forestry, silviculture, urbanization, and industry. These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat; or reduced habitat quality, such as embedded gravel substrates. Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (Griffith, Rashleigh, & Schofield, 2010).

Degraded physical habitat is a leading cause of impairment in streams on 303(d) lists. According to the EPA CADDIS website, six attributes are the main features of physical habitat structure provided by a stream: *stream size and channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, vegetation cover and structure in the riparian zone, and channel-riparian interactions*. To learn more about physical habitat go to the EPA CADDIS webpage here.

3.3.6.1 Water quality standards

There are no state water quality standards for physical habitat.

3.3.6.2 Ecoregion information

There currently is no applicable ecoregion information for lack of physical habitat.

3.3.6.3 Types of physical habitat data

MPCA biological survey crews conduct a qualitative habitat assessment using the MSHA protocol for stream monitoring sites. The MSHA protocol can be found here. MSHA scores can be used to review habitat conditions at biological sampling locations and compare those conditions against similar size streams and a variety of IBI scores. The MPCA and Minnesota Department of Natural Resources (MDNR) partners are collecting stream channel dimension, pattern and profile data at select stream locations of various sizes and biological condition. This data can be used to compare channel departure from a reference condition. Habitat features can be analyzed to determine if a stream is lacking pool depth, pool spacing, adequate cross sectional area to convey discharge, and various other physical habitat features that are too numerous to list here. The applied river morphology method created by (Rosgen, 1996) is the accepted method for this data collection by the MPCA and MDNR.

3.3.6.4 Sources and causal pathways model for lack of physical habitat

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

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

Typically, physical habitat degradation results from reduced habitat availability (e.g., decreased snag habitat, decreased riffle habitat) or reduced habitat quality (e.g., increased fine sediment cover).

Decreases in habitat availability or habitat quality may contribute to decreased condition, altered behavior, increased mortality, or decreased reproductive success of aquatic organisms; ultimately, these effects may result in changes in population and community structure and ecosystem function. Narrative and conceptual model can be found on the EPA CADDIS webpage here.

3.3.6.5. Overview of lack of physical habitat trends in the Pine Watershed

Habitat quality differs throughout the PRW and is an essential tool when understanding and describing the biological communities. Habitat was measured using the Minnesota Stream Habitat Assessment (MSHA) during the fish sampling event. The MSHA is useful in describing the aspects of habitat needed to obtain an optimal community. It includes five subcategories: land use, riparian zone, substrate, cover, and channel morphology. In stream habitat data was also collected using Rosgen level 2 (Rosgen, 1996)stream assessments. These assessments consist of measuring the stream pattern, dimension, and profile at the biological sampling site. This data can lead to assessment of stream facets and can conclude if certain stream facets are missing or being degraded. Observations about riffle quality, pool quality and substrate composition can lead to a quantifiable measure of habitat features.

In the PRW, habitat scores were predominately good or fair throughout the watershed (Figure 3.3.2). Many of the poor habitat scores are channelized or have intensive agricultural land use. Habitat scores generally improved in the larger streams with slightly higher gradient or more forested landscapes.

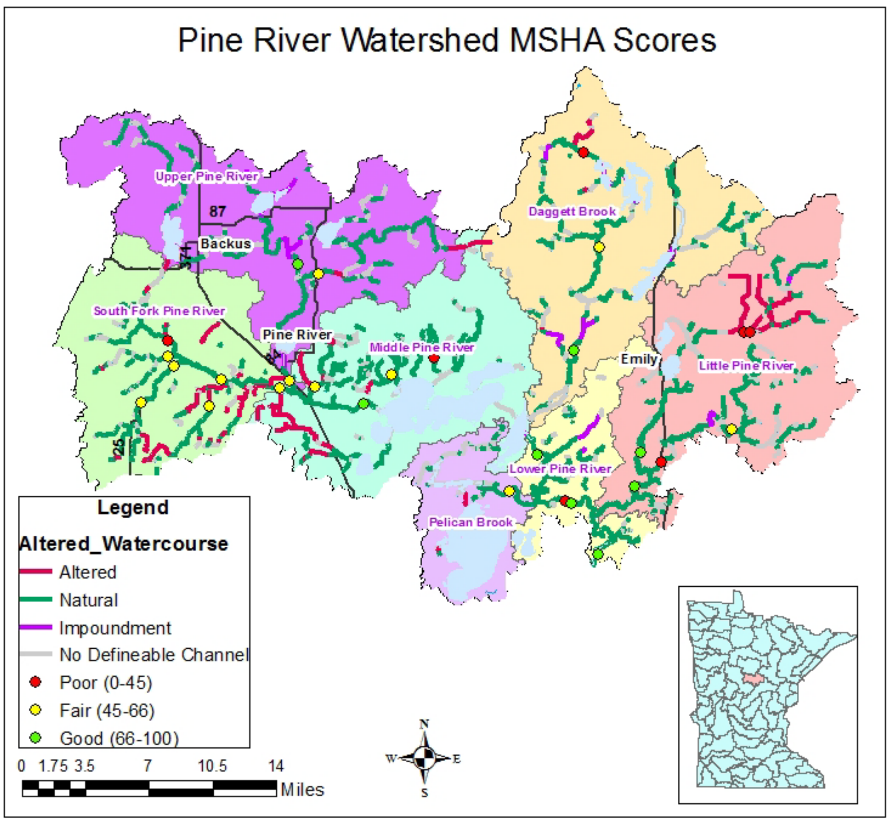


Figure 3.3.2: Average MSHA scores at biological sampling stations in the Pine River Watershed.

3.3.7 Candidate cause: Physical connectivity

Connectivity in river ecosystems refers to how waterbodies and waterways are linked to each other on the landscape and how matter, energy, and organisms move throughout the system ((Pringle, 2003)). Impoundment structures (dams) on river systems alter streamflow, water temperature regime, sediment transport processes and aquatic organism passage – each of which can cause changes in fish and macroinvertebrate assemblages ((Cummins M.J., 1979). Dams also have a history of blocking fish migrations and can greatly reduce or even extirpate local populations (Brooker, 1981) (Tiemann J.S., 2004). In Minnesota, there are more than 800 dams on streams and rivers for a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

Dams, both human-made and natural, can cause changes in flow, sediment, habitat, and chemical characteristics of a waterbody. They can alter the hydrologic (longitudinal) connectivity, which may obstruct the movement of migratory fish causing a change in the population and community structure. The stream environment is also altered by a dam to a predominately lentic surrounding (Mitchell SC., 2007). Longitudinal connectivity of flowing surface waters is of the utmost importance to fish species. Many fish species' life histories employ seasonal migrations for reproduction or overwintering. Physical barriers such as dams, waterfalls, perched culverts and other instream structures disrupt longitudinal connectivity and often impede seasonal fish migrations. Disrupted migration not only holds the capacity to alter reproduction of fish, it also impacts mussel species that utilize fish movement to disperse their offspring. Structures, such as dams, have been shown to reduce species richness of systems, while also increasing abundance of tolerant or undesirable species (Winston, 1991) (Santucci V.A., 2005).

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

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

3.3.7.1. Water quality standards

There is no applicable water quality standard for connectivity impacts.

3.3.7.3. Types of physical connectivity data

Geographic Information System layers with locations of dams and road culverts are a good source of potential connectivity issues within the watershed. Additionally, visual inspections of dams and road crossings showing the elevation difference between the upstream and downstream river stages.

3.3.7.4 Sources and causal pathways model for physical connectivity

The conceptual model for physical connectivity as a candidate stressor is found in Figure 3.3.3.

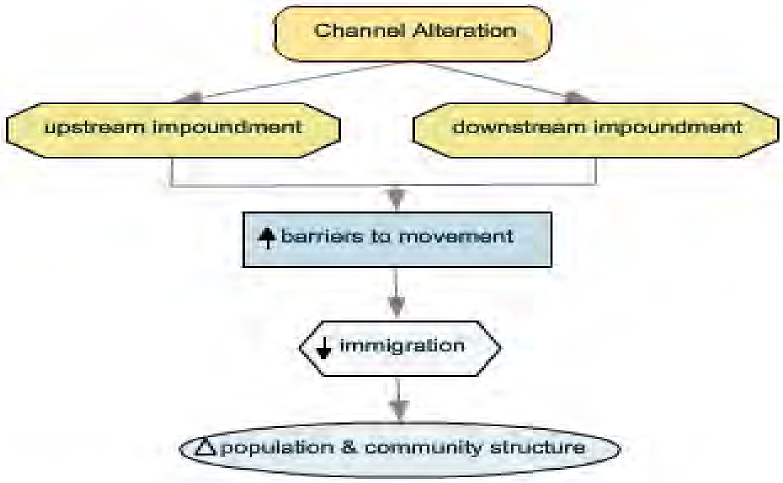
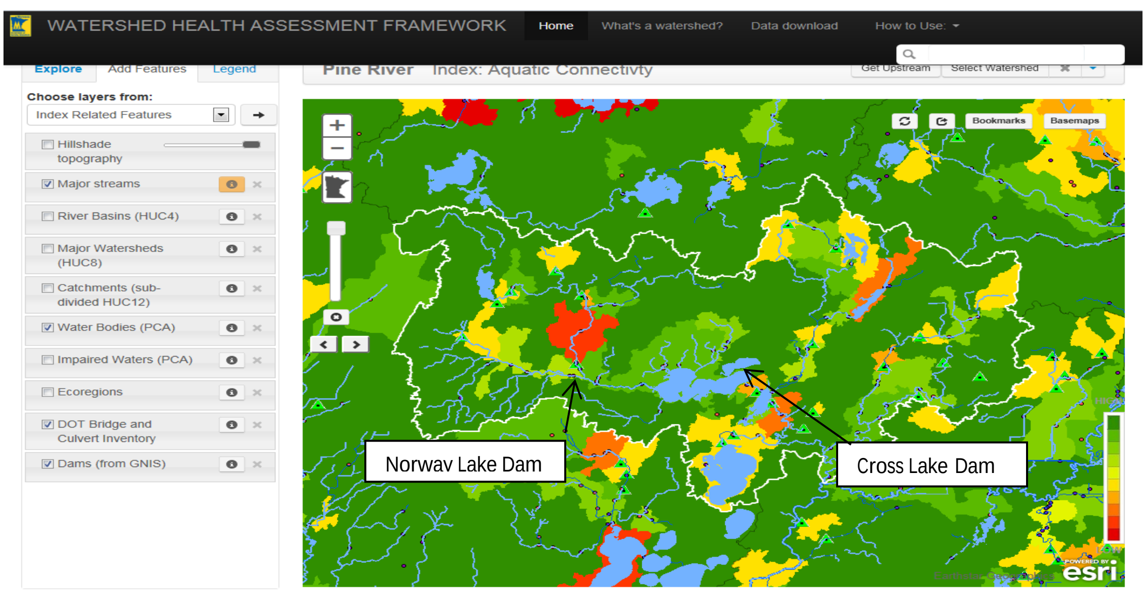


Figure 3.3.3: Conceptual Model for Connectivity.

3.3.7.5. Overview of physical connectivity in the Pine River Watershed

Aquatic connectivity was reviewed by using the MDNR Watershed Health Assessment Framework tool. This tool ranks catchment areas within the HUC-8 based on the location and abundance of dams and road culvert crossings. Dams place an immediate threat to fish migration due to the physical barrier present. Road culverts may or may not pose a fish migration issue depending on the position and elevation of the culvert. Overall the PRW does not appear to have an abundance of fish passage barriers. However, a watershed wide road crossing assessment has not been conducted for the PRW. The biological monitoring data collected in the PRW suggests that fish passage is not impeded in many of the sampled AUID's. The location of the dams on the Pine River at Norway Lake and Cross Lake may pose a threat to fish migration; however the upstream fish communities appeared diverse and healthy during the 2012 sampling events.



4. Evaluation of candidate causes

4.1. Arvig Creek (AUID-07010105-509)

4.1.1. Biological communities

The fish and aquatic macroinvertebrate community in Arvig Creek is impaired. Arvig Creek is located in the Middle Pine River aggregated HUC-12 (070101050401). The fish community at site 99UM042 was sampled in 1999 and in 2012. The 1999 FIBI score was above the general use (GU) threshold and above the upper CI. The FIBI score in 2012 was below the GU threshold and below the lower CI (Table 4.1.1). In 1999, 15 species of fish were sampled, while in 2012 only 3 species of fish were sampled. The loss of 12 fish species in this short time frame indicates that the stream is impacted by anthropogenic sources. All sensitive species were absent in the 2012 sample. The 2012 sample only collected 9 individual fish (3 species; central mudminnow, bluegill and northern pike). All 3 species are tolerant to low DO concentrations.

The macroinvertebrate IBI (MIBI) scores at site 99UM042 are below the threshold and lower CI for the 1999, 2012 and 2013 sampling events. The MIBI scores are 35.8, 21.2 and 32.9; respectively. The threshold and CI for this macroinvertebrate stream class is 53+ 13. All three sampling events are dominated by tolerant taxa (ranging from 65% to 90% of the sample), and the 1999 sample had one intolerant macroinvertebrate taxa present (Oxyethira, caddisfly). The 1999 sample was dominated by Caenis sp. (a tolerant mayfly) and the 2012 and 2013 sample is dominated by Hyallella sp. (a tolerant freshwater scud). The MIBI scores are being lowered based on five metric scores. These five metric scores are all well below the needed median score to pass the IBI (Figure 4.1.1). The low MIBI scores for each of these metrics indicates a low taxa richness and low predator richness in the respective macroinvertebrate sample. Low taxa richness could be an indicator of low DO and lack of suitable habitat which will be discussed later in this report.

Table 4.1.1: Class 6 Fish metric scores for the two sampling events in Arvig Creek. Biological site 99UM042 passes the Fish IBI in 1999 and fails the Fish IBI in 2012 and is impaired. Red lettering indicates values below the IBI mean values to pass the IBI score.

Site ID	Date	FishIBI	InsectCypPct	Minnows-TolPct	FishDELTPct	Insect-TolTxPct	PioneerTxPct	TolTxPct	DarterSculp	Hdw-Tol	Sensitive	SLithop	NumPerMeter-Tolerant
99UM042	28-Jul-99	61.13	0.048	4.065	0	6.220	6.624	7.999	10	6.667	7.5	4.677	7.336
99UM042	11-Jul-12	0.11	0	0	0	0	0	0	0	0	0	0	.011

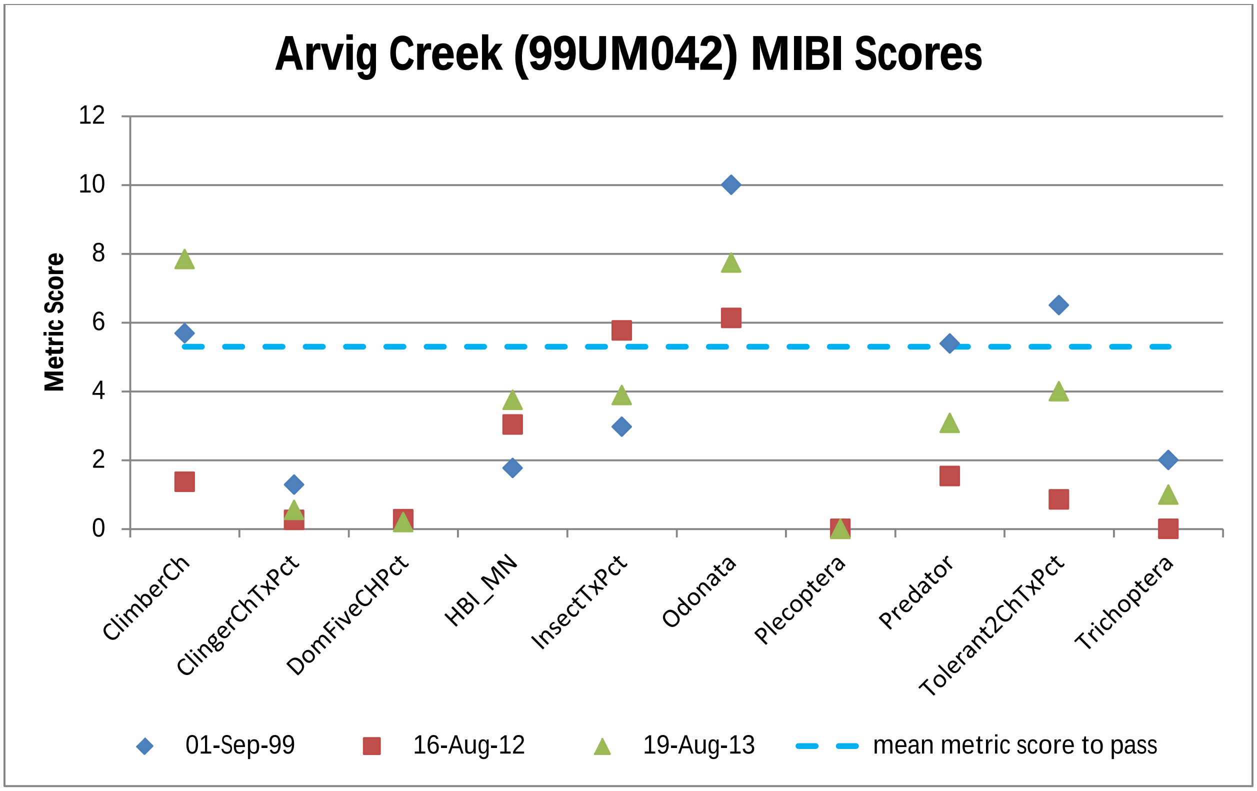


Figure 4.1.1: Macroinvertebrate individual IBI metric scores that are used to compute the overall MIBI score. Mean individual IBI would need to be 5.3 or greater to pass the MIBI. Most of the metric scores fall well below the 5.3 median score.

4.1.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen was collected at three locations in the impaired Arvig Creek AUID in 2013 and 2014 as well as one sampling location in the tributary to Arvig Creek. DO data was well below the Class 2B standard of 5 mg/L at all four sampling sites during late July through early September. Stream flow was very low to almost stagnant during some of the site visits during this time. Figure 4.1.3 shows the DO data collected at S007-681, S007-682 and S007-683 on Arvig Creek and Figure 4.1.2 shows the locations of the DO sampling sites.

Land use in the Arvig Creek subwatershed is primarily forest with a significant amount of agricultural land (either cropland or rangeland) located along the stream corridor (Figure 4.1.2). The upper headwaters area of impaired AUID 07010105-509 is a large forested wetland. Some of the wetland area has altered channel and is partially drained. North of County State Aid Highway (CSAH) 2, Arvig Creek flows through an extensive wetland complex. This wetland area appears to be naturally affecting the DO concentrations. As previously mentioned, during low flow Arvig Creek at site S007-683 is influenced by groundwater discharge which may help explain the decrease in DO further downstream. At sampling site S007-683 the DO concentrations are often below the 5 mg/L standard. Once the creek flows into Rice Lake which is just downstream, the stream should increase in DO concentrations because of photosynthesis from macrophytes and algal growth. During some of the sampling events it was evident at site S007-682 that DO concentrations were higher than the upstream location of S007-683. This was mainly evident during early to midsummer. As summer progressed and stream flow decreased there were periods of time when S007-682 DO was below the DO concentration of the upstream site S007-683. This may be a result of sediment oxygen demand and /or plant decomposition.

The low DO in this AUID is partially caused by the elevated nutrient concentrations in Arvig Creek. Total phosphorus (TP) can elevate algal growth in streams, but is also an indication of human disturbance in the watershed. TP concentrations in Arvig Creek just downstream of site 99UM042 ranged from 0.074 to 0.166 mg/L. The proposed state standard for streams in northern Minnesota is 0.05 mg/L. The TP concentrations are higher at site S007-681 which is downstream at the CR44 road crossing. Site S007-681 TP ranged from 0.052 to 0.226 mg/L. Elevated nutrients were highest during June and July but were not associated with elevated TSS concentrations. Total phosphorus in the system would need to be studied in greater detail to understand their interaction with the low DO concentrations. DO concentrations also are influenced by low oxygenated groundwater entering the creek. During periods of little precipitation, the groundwater base flow at site S007-683 is the dominate source of water which is also being reflected in the observed DO concentrations. Stream temperatures in August of 2014 ranged from 12.7°C to 15.9°C at S007-683 which is above Rice Lake. These temperatures were collected during very low flow. Temperatures in this range can only be attributed to groundwater influence as surficial water temperatures tend to be much higher during the hottest summer months. Total phosphorus concentrations were also lower during this low flow time period. Total phosphorus ranged from 0.092 to 0.102 mg/L in August 2014. During the summer of 2013 and 2014, a YSI sonde was deployed at site S007-681 which is downstream of 99UM042 for two 10 day periods. Figure 4.1.4 and 4.1.5 displays the daily DO flux (fluctuated between 2.0 and 5.0 mg/L per day) during the sampling periods along with daily minimum and maximum DO concentrations. Stream flow was greater during the summer of 2014 than in 2013. This led to slightly warmer stream temperatures in 2014 as well.

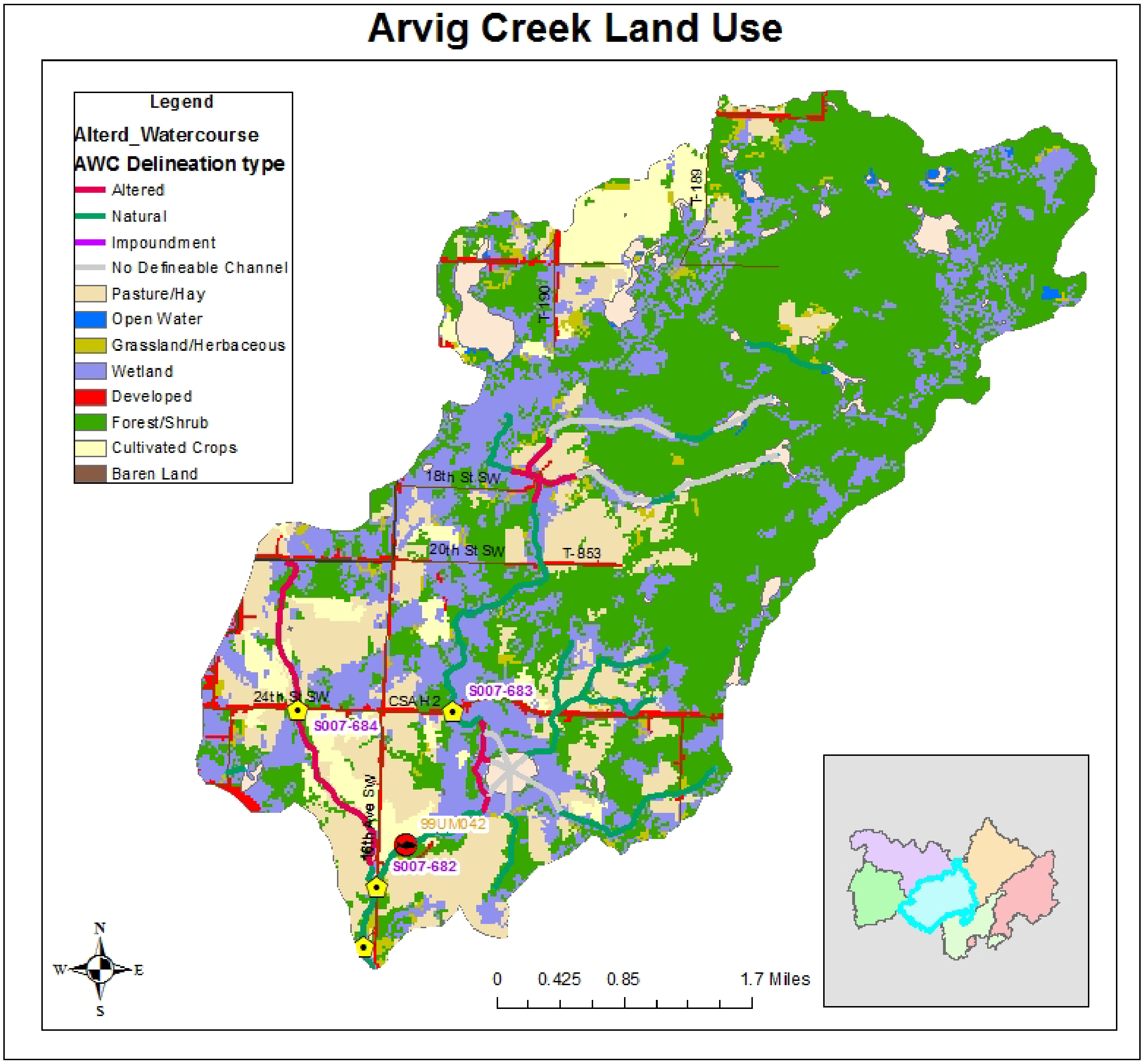


Figure 4.1.2: Land use in the Arvig Creek watershed. Green highlighted stream section is AUID 07010107-553 which is impaired for fish and macroinvertebrates.

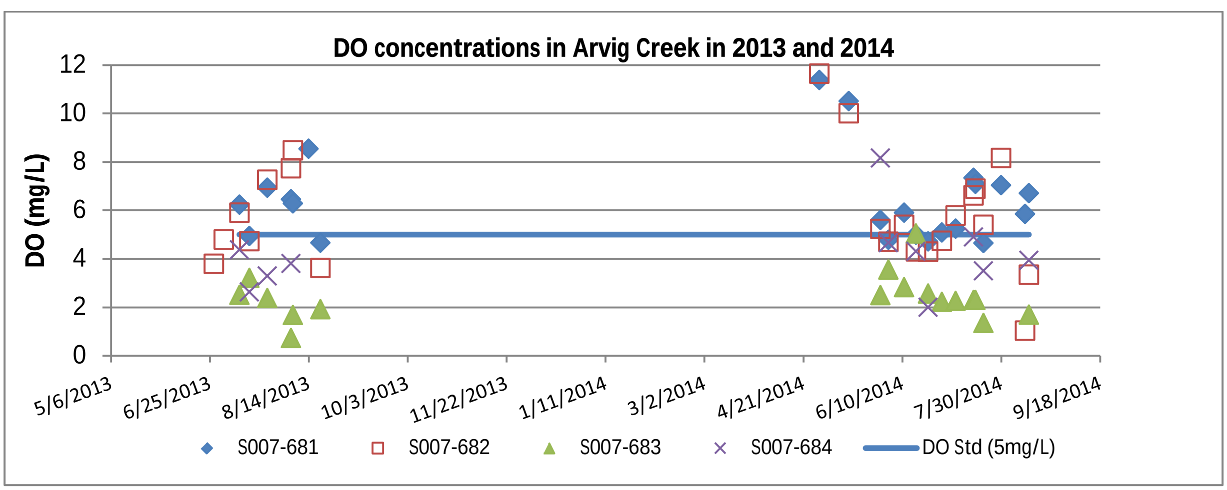


Figure 4.1.3: Early morning DO data collected at four EQuIS sites in Arvig Creek in 2013 and 2014.There are numerous DO readings well below the 5mg/L state standard.

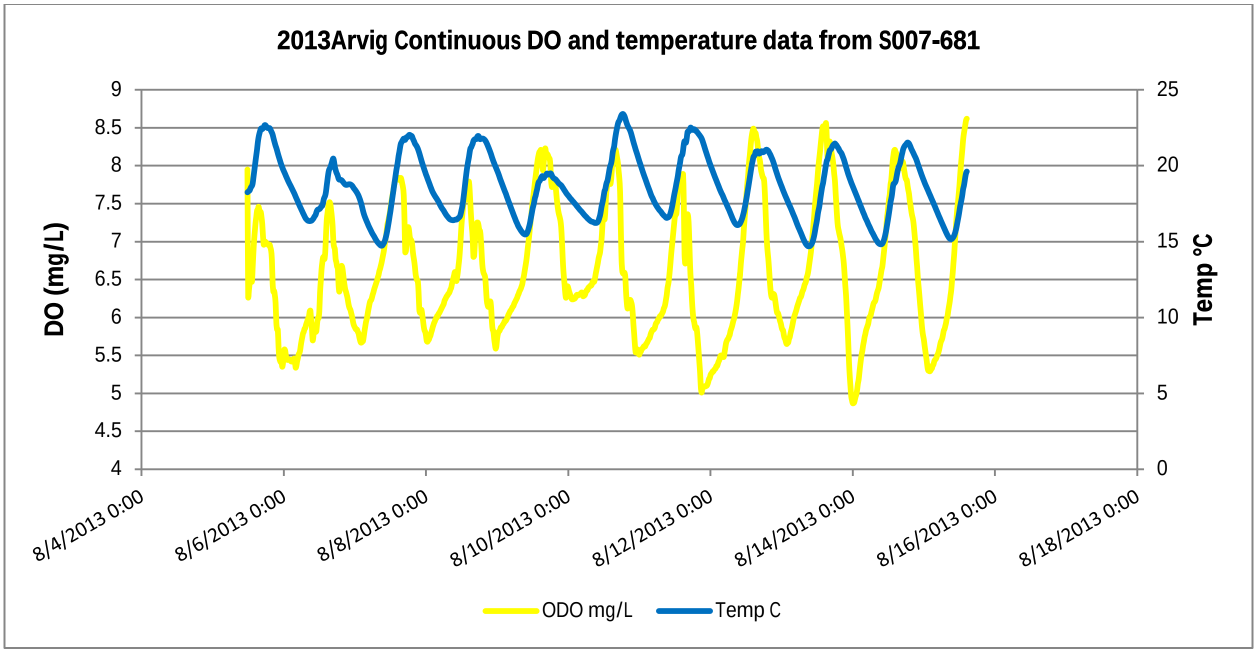


Figure 4.1.4: YSI continuous sonde data collected downstream of Biological Site 99UM042 in August, 2013. Dissolved oxygen levels are daily above the Class 2B five mg/L water quality standard.

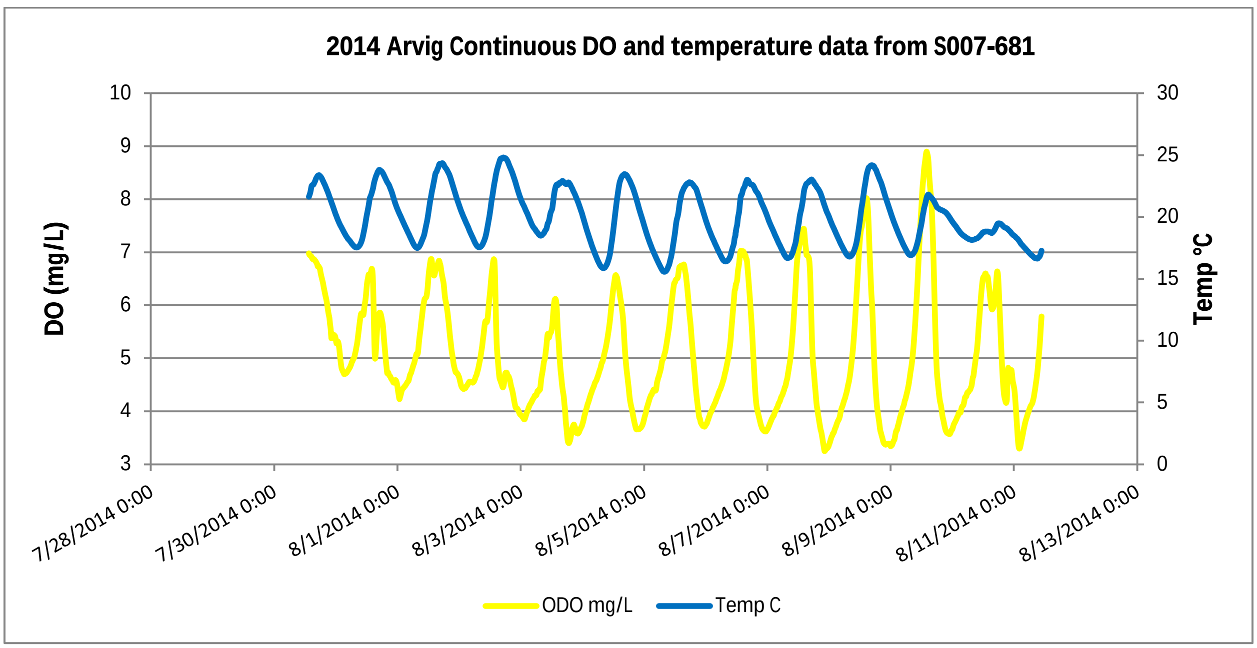


Figure 4.1.5: YSI continuous sonde data collected downstream of Biological Site 99UM042 in August, 2014. Dissolved oxygen levels are daily below the Class 2B five mg/L water quality standard.

Continuous DO data was also collected in August 2014 at site S007-682 which is just on the downstream end of biological sampling site 99UM042 (Figure 4.1.2). The sonde collected readings at 15 second intervals, instead of 15 minute intervals which reduced the life of the batteries and resulted in three days of diurnal data collection. During this three day collection however, the DO readings were almost continuously under 5 mg/L and approached 0 mg/L on a daily basis (Figure 4.1.6).

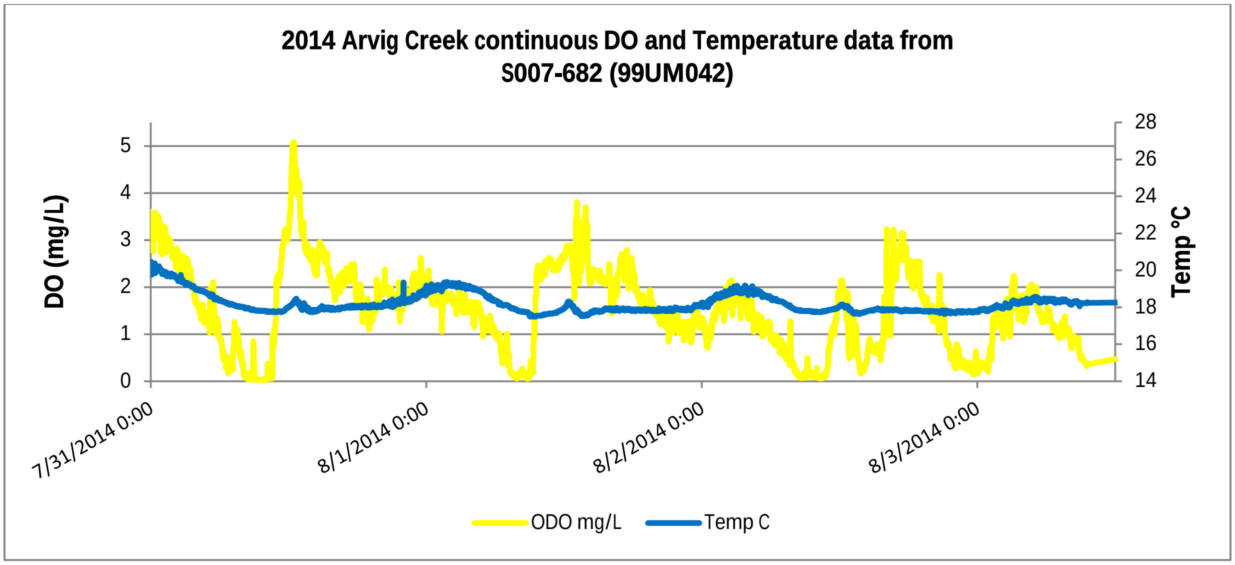


Figure 4.1.6: YSI continuous sonde data collected near Biological Site 99UM042 in August, 2014. Dissolved oxygen levels are continuously below the Class 2B five mg/L water quality standard.

The 2012 fish sampling event at 99UM042 showed that central mudminnow and northern pike were the dominant species found which are known to be tolerant to low DO readings. Figure 4.1.7 graphically displays the DO tolerance values for both 99UM042 fish sampling events. Low DO is a stressor to the fish and macroinvertebrate community at Arvig Creek (AUID 07010105-509). MPCA (Sandberg, 2013) compiled a fish community stressor Tolerance Indicator Value (TIV) Index to look at the probability of a sampled fish community to meet the designated water quality standard. Site 99UM042 in 1999 had an 18% chance of meeting the DO standard of 5 mg/L and in 2012 had a 7% chance of meeting the DO standard. This community TIV is also evidence that leads to low DO as a stressor to aquatic life.

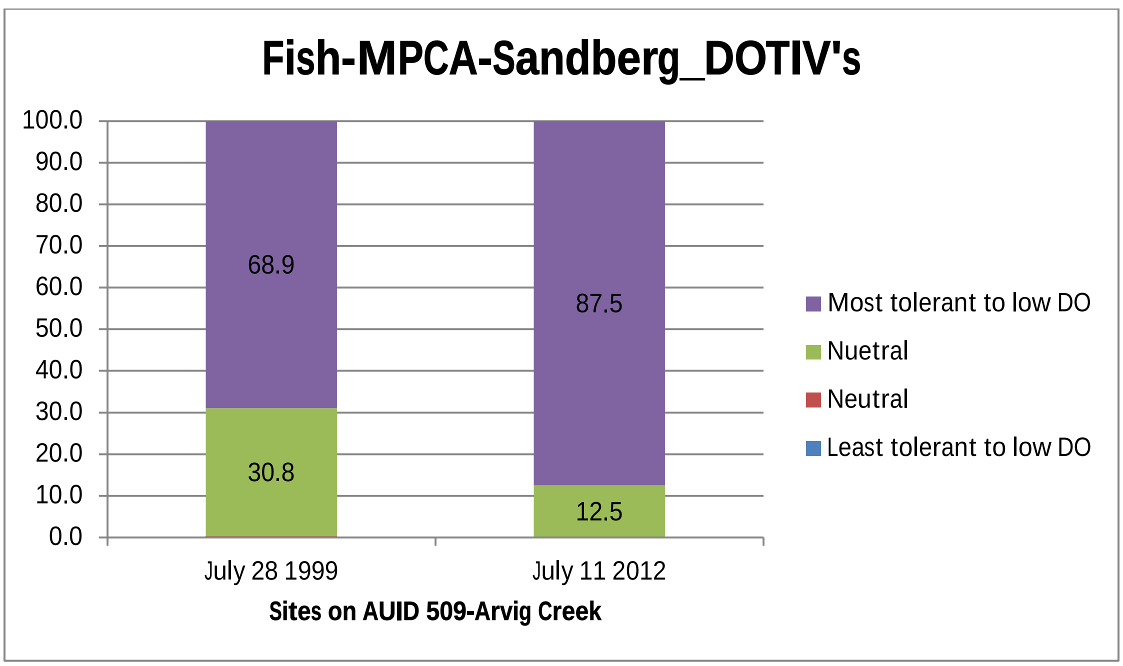


Figure 4.1.7: DO Tolerance values for fish at sampling site 99UM042 in Arvig Creek.

Macroinvertebrate community tolerance indicator values have also been calculated by MPCA. These community tolerance indicator values can be compared against all samples collected for a given stream type. Arvig Creek is in the northern stream riffle run (Class 3). The sampling location on Arvig Creek had low DO index scores for macroinvertebrates (Table 4.1.2). The HBI_MN score is a measure of organic pollution and was well above the class3 statewide average for passing MIBI scores. All macroinvertebrate metrics measured that are related to low DO concentrations are indicating that low DO is stressor to the macroinvertebrate community.

Table 4.1.2: Macroinvertebrate metrics that respond to low DO stress in the Arvig Creek

Station (Year sampled)	TaxaCountAllChir	EPTCh	HBI_MN	Low DO Index Score	Low DO Intolerant Taxa	Low DO Tolerant Taxa	Low DO Tolerant Pct
99UM042 (1999)	35	8	7.7	6.30	1	10	17.1
99UM042 (2012)	29	1	7.3	6.28	1	10	63.4
99UM042 (2013)	28	5	7.1	NA	NA	NA	NA
Statewide average for Northern Forest Stream RR that are meeting the MIBI Threshold (53)	53.8	19.6	5.8	7.05	11.49	4.9	9.80
Expected response to stress	↓	↓	↑	↓	↓	↑	↑

NA=data not currently in spreadsheet.

Based on the above data sets, low DO concentrations are a stressor to the biological communities in Arvig Creek.

Biotic response-fish and macroinvertebrates

Evidence of a potential causal relationship between low DO concentrations and the FIBI and MIBI impairment, associated with AUID509, and is provided by the following metric responses: 1) a decrease in fish abundance and 2) a decrease in sensitive fish taxa. These responses would lower the associated metric score. The 2012 fish sample had three species and nine individual fish collected. The 2012 and 2013 M-IBI impairment also shows a strong biotic response to low DO and is provided by the following measureable indicators 1) a low number of DO intolerant macroinvertebrates and 2) a high number of DO tolerant macroinvertebrates and 3) an elevated HBI_MN score. All three responses lead to the conclusion that low DO is causing stress on the aquatic life in Arvig Creek.

Lack of physical habitat

Habitat quality varies from good in 1999 to fair in 2012 on the biologically monitored site in Arvig Creek. The substrate changed from sand/ clay in 1999 to sand/ silt in 2012. The MSHA was the main tool used for evaluating this potential stressor. The scores from the two site visits have been converted to a proportion score based on the best possible score for each category and is presented in Figure 4.1.8. All categories scored lower in 2012 than in the 1999 sampling event. The main habitat value difference between the two site visits is the unstable channel morphology and the changing land use and loss of quality riparian vegetation. According to the MSHA score in 1999, site 99UM042 substrate showed no embeddedness and in 2012 substrate showed severe embeddedness.

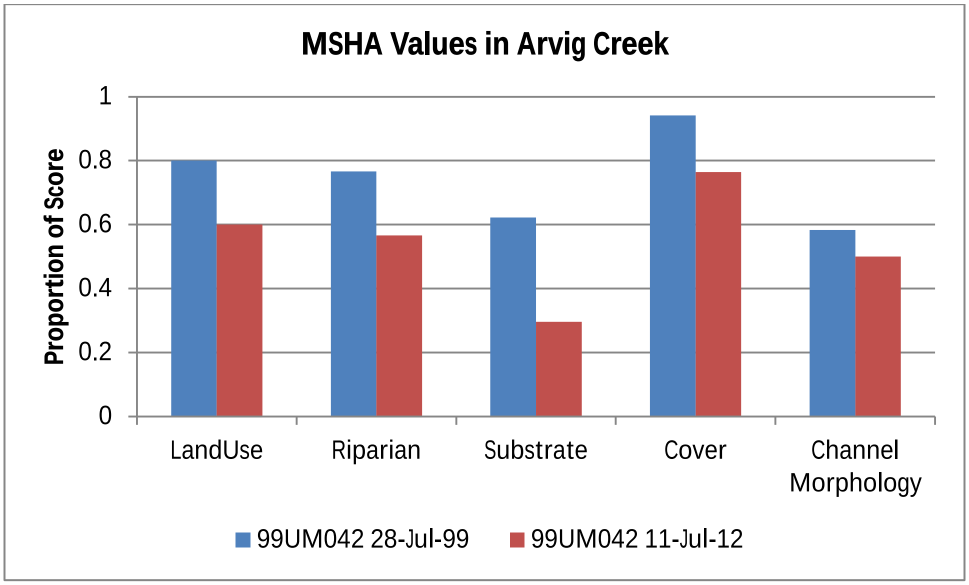


Figure 4.1.8: MSHA values for biological site (99UM042). MSHA data is from the 1999 and 2012 sampling event.

The section of Arvig Creek downstream of the biological sampling site is heavily pastured. The pastured areas have no riparian vegetation and many of the stream banks are exposed and actively eroding. Photographs of the stream just downstream of 99UM042 were taken in June and July of 2013 (Figure 4.1.9). These photos show the various bank erosion and lack of riparian cover along the stream in general. Above site 99UM042 the channel is also lacking in riparian vegetation. Aerial photograph review shows that this stream section between Rice Lake and 99UM042 is over widened and pastured. Figure 4.1.10 shows the current conditions of the stream channel and the riparian vegetation found along the stream corridor. The aerial photograph is from 2013. There appears to be a stream crossing located just upstream of sampling location 99UM042. This stream crossing is almost 10 times wider than the upstream and downstream channel width.

Stream channel that are classified as an E or C channel type are highly susceptible to over widening and becoming shallow if the riparian vegetation is disturbed. The w/d ratio at surveyed cross section 3 is 23.37. An E channel type w/d ratio would be less than 12 and a C stream type would be greater than 12. The surveyed cross section w/d ratio is within the range of C channel w/d ratios published by Rosgen. The mean particle size of 5.34 mm (small gravel in the riffle) places this channel in the C4 stream type. This data was collected near the 99UM042 sampling location which is in the non-pastured area of Arvig Creek. Using ARCGIS to estimate w/d ratios both above and below sampling location 99UM042 it appears that the w/d ratios range from 29 to 42. The larger w/d ratios can help with understanding that as the channel increases in w/d ratio it also is becoming shallower and wider. This appears to be happening in Arvig Creek. The lack of riparian vegetation and possible changes in hydrology due to land use changes is allowing the channel to become wider and shallower which in turn is causing degraded habitat for fish and macroinvertebrates.

Photo 1 (06/27/2013) Photo 2 (06/27/2013)

Photo 3 (07/10/3013) Photo 4 (07/10/2013)

Figure 4.1.9: Photos of active pasturing occurring along Arvig Creek in 2013. Photos 2 and 3 are located at the downstream end of 99UM042. Photos 1 and 4 are located just downstream on the road crossing on CR44. At this location Tributary to Arvig Creek joins in with Arvig creek. Tributary to Arvig flows south from CR 1 near the Pine River airport and flows through various pastures before joining Arvig Creek.

Multiple visits at the lone biological station (99UM042) in the upstream portion of Arvig Creek (07010105-509) produced an average MSHA score of 50 (fair). Factors bringing down the score are the surrounding land use, areas of bank erosion (causing increased fine sediment), moderate embeddedness, and poor channel stability.

Biologically, in 1999 the fish community had fifteen taxa sampled with a high number of individuals. However, the number of fish sampled in 2012 was represented by three taxa and nine individual fish. Also the highly tolerant fish species brook stickleback/central mudminnow is 23.6 % of the sample on July 28, 1999 and 66.7 % of the sample on July 11, 2012. Due to the highly tolerant fish species and lack of simple lithophilic taxa at site 99UM042, along with 92% and 89% of the macroinvertebrate sample from the 2012 and 2013 macroinvertebrate sampling are tolerant , and the poor habitat score, lack of physical habitat is a stressor to the biological community in Arvig Creek. This is also demonstrated by reviewing the two macroinvertebrate metrics ClimberCh and ClingerChTxPct. A review of Class 3 sites in the PRW that passed the MIBI the respective metric scores are 5.07 and 5.78. In Arvig Creek the three samples collected averaged 4.97 and 0.70; both metric scores are below the mean of 5.3 needed to pass the MIBI. The lack of clinger taxa solidifies that there is very little gravel substrate in Arvig Creek. Both fish and macroinvertebrate metrics are related to habitat features that are typical in riffle run streams. At station 99UM042 the percentages of habitat specific metrics are generally below the mean Class 3 percentages, except the percentages of climber and legless are slightly elevated. Figure 4.1.11 displays the mean percent for all Class 3 stream sites statewide versus the 99UM042 percentages for the habitat related metric.

Based on the available data and metric analysis, lack of habitat is a stressor to the biology in Arvig Creek.

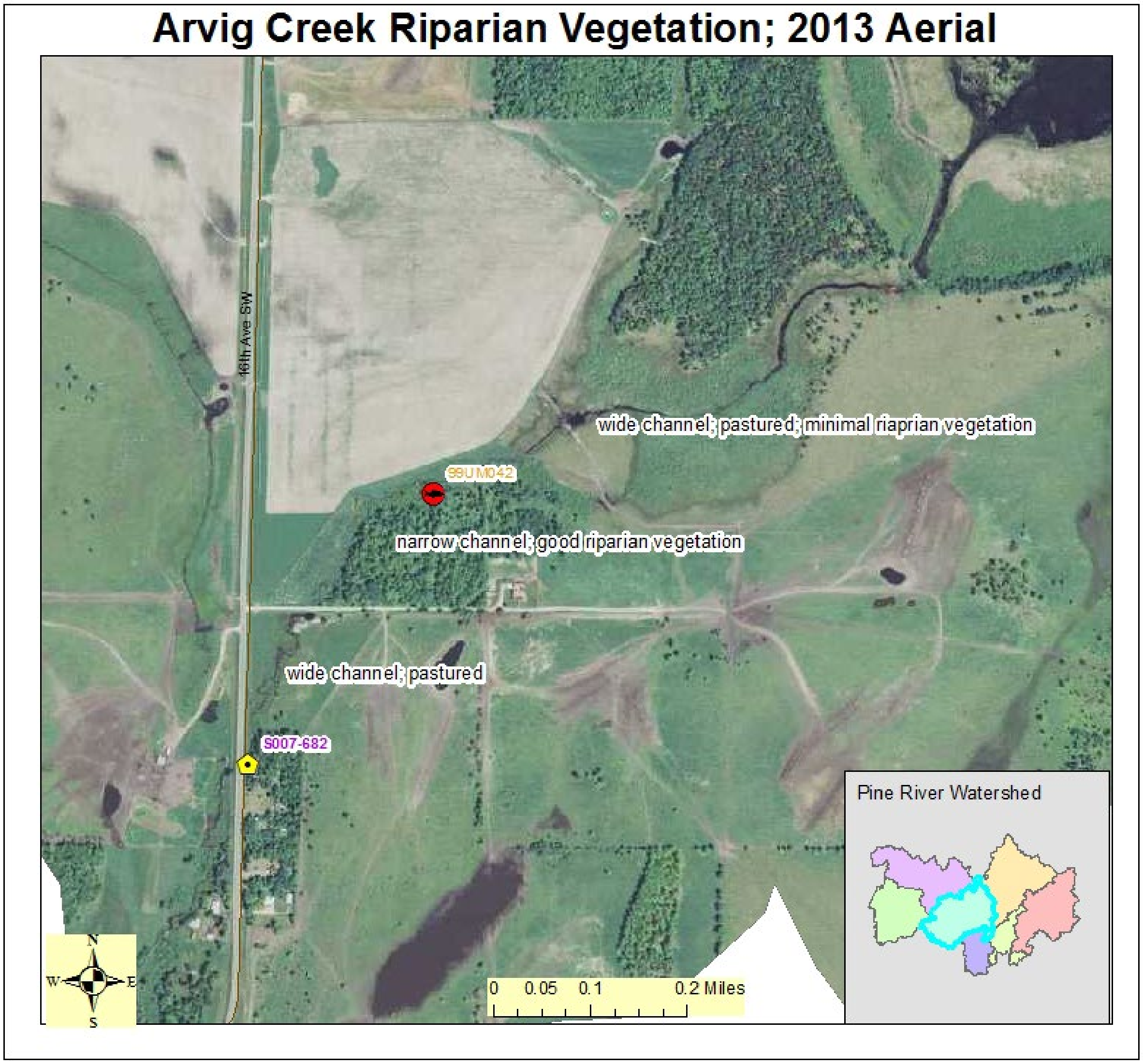


Figure 4.1.10: Habitat and stream condition at 99UM042 and upstream and downstream of the site. Lack of riparian vegetation is affecting the stream channel width and sediment supply to the stream.

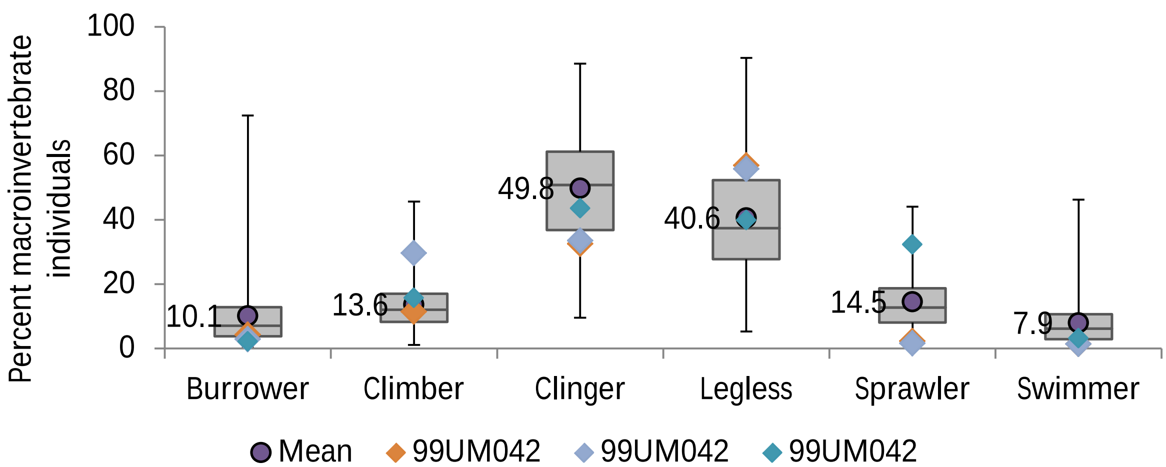


Figure 4.1.11: Class 3 macroinvertebrate percent of individuals in each habitat related metric. The station 99UM042 data is displayed versus mean percentage for each metric.

The downstream section of Arvig Creek is not suitable for fish year round. The hydrology of the system indicates flashy flows during rainfall events followed by very low water levels during dry periods. The land use practices and lack of riparian vegetation are causing channel instability throughout the AUID. Stream connectivity may also be a problem in Arvig Creek. The over widened channel becomes very shallow during periods of low to no flow which may impede fish from freely moving throughout the stream corridor. The multiple stream crossings may also be impacting fish movement throughout the stream. Further investigation of the stream crossings would need to be conducted to determine fish passage potential.

Channel stability

On September 27, 2013, a stream channel survey was conducted by MDNR to assess the stability of the reach using methods developed by Dave Rosgen (Rosgen, 1996). Stream channel dimension, pattern and profile were inventoried to determine stream type, slope, substrate composition, and available habitat features. Table 4.1.3 shows the stream classification along with mean particle size of the substrate for sampling site 99UM042.

Table 4.1.3: Pool and riffle cross section measurements used for stream classification in Arvig Creek.

XS-Feature	Bankfull width (ft)	Floodprone width (ft)	Entrenchment Ratio	W/D Ratio	Bankfull Area(ft^2)	Classification	Particle D^{50} (mm)
XS1-riffle	16.67	299	17.93	17.19	16.22	C4	11.53
XS2-pool	31.01	259	8.35	40.8	23.43	C - D	
XS3-riffle	20.8	200	9.61	23.37	18.55	C4	5.34

Stream habitat features can be analyzed by viewing the channel profile survey. Features such as pool depths and spacing along with riffle depths and spacing can be analyzed to determine if habitat features are missing in the study reach. The reach has all main stream features, riffles, runs, pools and glides. The pool to pool spacing is short averaging a pool every 58 feet in stream length. The riffles and pools are also very short in length. Riffles are averaging 3.2 feet in length and pools are averaging 8.3 feet in length. The pools are also very shallow. The average pool is around 1.4 to 1.5 times the depth of the riffles. This may indicate that the stream does not have enough power to keep the pools clean of fine sediment. Figure 4.1.12 displays the longitudinal profile which covers 808 feet of stream length. This figure depicts the stream bankfull elevation in green and the channel bottom in black. Stream substrate particle size can also be used to determine if habitat features are being buried with fine substrate particles. The D^{50} particle size in the two riffles that were surveyed is 11.53 and 5.34 mm. This particle size shows that the riffles are still small gravel but being covered with fine sand. Four percent of the particles in the riffle were silt, 38% of the particles were sand and 46% of the particles were gravel. The gravel was as large as 64 mm indicating that the stream has potential for gravel substrate riffles; however, the gravel is being smothered by the introduction of fine particles from bank erosion that is occurring throughout this reach. The pool is also being filled by fine particles. 14.8% of the pool pebble count was silt, 61.4% was sand and 23.8% was gravel or cobble. The pool pebble count had two cobble size particles ranging from 90 - 180 mm in size.

Cattle access to the stream in various locations along with a change in land use is causing an increase in bedded sediment and a general lack of stream features. The pools are becoming shallower and the spacing of the pools is short. Pool depth versus riffle depth is shallow and there is a general lack of quality stream substrate. Figure 4.1.13 shows a photo of the stream a day after a rain event. The tributary draining into Arvig Creek has cattle standing in the channel during this increased runoff event. The cattle are dislodging fine sediment and the fines are being delivered downstream and settling out. During this event sampling site S007-682 (Arvig on CR44) had a stube reading of 91 cm. At the tributary confluence the stube reading was 11cm. At the downstream location S007-861 the stube was 70 cm. This helps us understand the impacts that the cattle access is having on the substrate in Arvig. The turbid water is settling out some of the sediment somewhere between the confluence of the tributary and the downstream sampling location. It also helps us understand the impacts of sediment transport in the stream because of free cattle access to the stream.

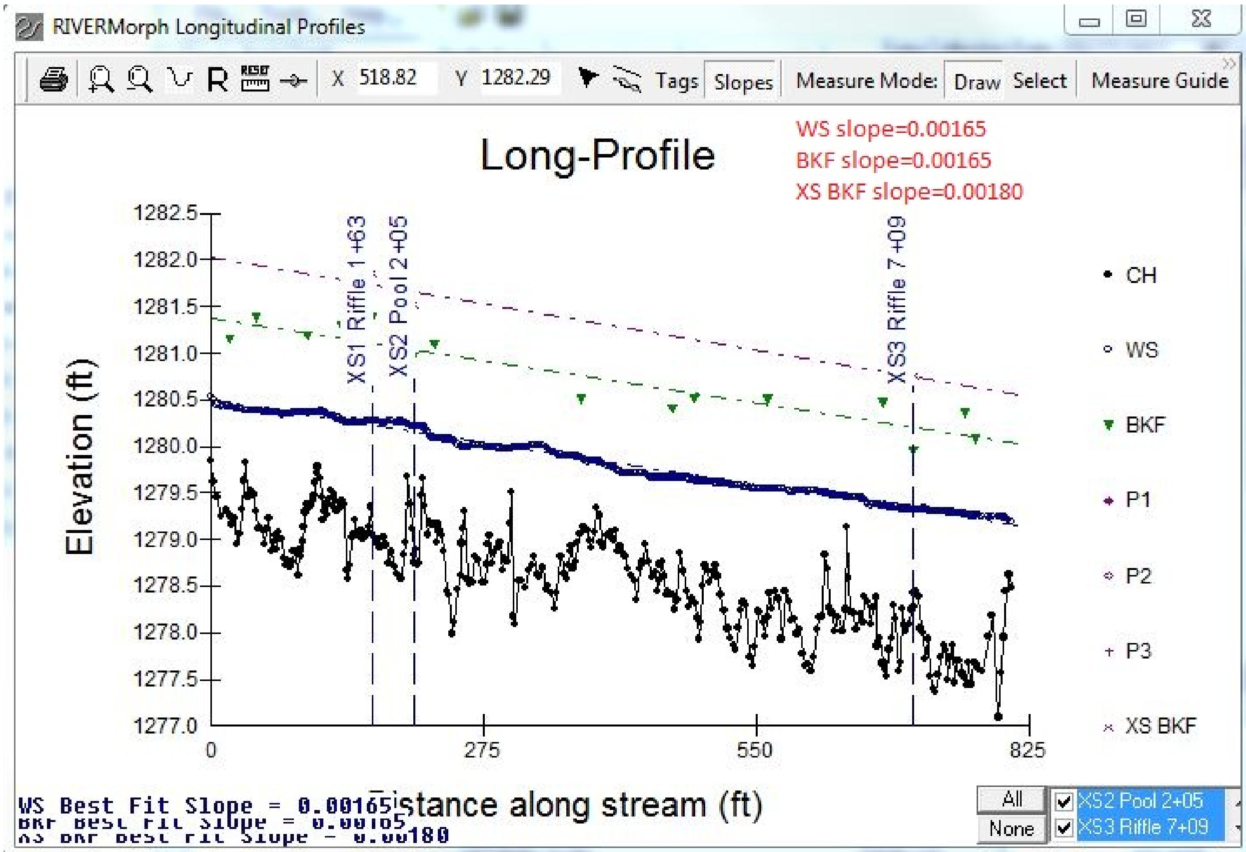


Figure 4.1.12: Longitudinal profile of Arvig Creek at site 99UM042.

Stream turbidity being caused by upstream cattle standing in stream. Flows are elevated because of summer rainfall. Photo taken on July 17, 2014. Stube reading in tributary is 11 cm. Stube reading in Arvig Creek upstream is 91 cm.

On July 17, 2014, these cattle were standing in tributary to Arvig Creek which is causing highly turbid water to be washed downstream into Arvig Creek. This turbid water is allowing suspension of fine sediment which will settle out downstream and cause a degradation of stream substrate.

Figure 4.1.13: Photos of the pastured areas along CR44 in Arvig Creek. Both sides of the road have a fair amount of cattle pasturing activity that is causing bank instability and suspension of fine sediment.

Animal access to the stream is causing an increase in fine sediment deposition (due to channel instability) and an alteration in habitat conditions in Arvig Creek. Lack of habitat (channel instability included) is a major driver to the impaired biological community in Arvig Creek.

Biotic response-fish and macroinvertebrates

Evidence of a potential causal relationship between lack of physical habitat and the FIBI and MIBI impairment, associated with AUID 509, is provided by the following individual metric responses: 1) decrease in benthic insectivore fish species (none present), 2) a decrease in simple lithophilic spawning fish species (none present) 3) decrease in darter, sculpin and round bodied suckers (none present) and 4) an increase in tolerant fish species (three fish species sampled and all are tolerant species). The present fish community that was sampled in 2012 is very different than the community that was sampled in 1999. This indicates also that some change in habitat occurred during this 13 year time span. The MIBI response variables that show a causal relationship between lack of physical habitat and the MIBI impairment are 1) increase in tolerant macroinvertebrates 2) decrease in clinger taxa and 3) a decrease in climber taxa present in the sample. The lack of biological diversity at site 99UM042 and the change in the community structure between 199 and 2012 support the lack of physical habitat stressor.

4.1.3. AUID summary

Arvig Creek lies in the central portion of the PRW. The streams in the subwatershed are a mixture of natural channel and altered stream channel. Land use is a mixture of forest and row crop agriculture along with three registered feedlots that operate multiple animal pasturing units. These pasturing units can pose stream channel bank stability problems when animals are given access to the stream corridor. Stream banks can experience accelerated erosion rates due to loss of riparian vegetation from grazing and stream bank failure caused by hoof shear and animal crossings. A large percentage of the land along CR44 is actively pastured and cattle are given access to the stream. The elevated nutrients can cause fluctuation in DO concentrations. Samples collected in 2013 and 2014 did show elevated nutrient concentrations along with DO concentrations that are well below the state Class 2B DO standard of 5 mg/L. Analysis of macroinvertebrate metrics show that HBI_MN metric values are elevated and total taxa and mayfly, stonefly and caddisfly (EPT) taxa metric values are lower than expected mean Class 3 metrics on MIBI passing sites which can indicate low DO stress. Fish community tolerance indicator values support that the fish community is stressed by low DO conditions.

The amount of riparian pasture land is causing some in stream habitat problems in this AUID. The cattle being pastured in the riparian corridor are causing bank erosion by trampling on banks and grazing down the riparian vegetation that is required to hold the banks together. The channel instability is causing sediment to entering the stream which is causing a general lack in habitat. This can be seen by reviewing the macroinvertebrate metrics burrower and clinger. Both metrics are habitat related and score lower than MIBI passing Class 3 sites.

Stream DO concentrations are often below the state Class 2B DO standard of 5 mg/L. This is being driven by the upstream wetland areas and elevated nutrient concentrations causing increased primary productivity. During the dry summer of 2013, the base flow was dominated by shallow groundwater which is also low in DO. The driving factors behind the lack of fish and macroinvertebrates in Arvig Creek are lack of physical habitat, and low DO.

4.1.3.1. Stressor pathway discussion

Most of the observed stressors in Arvig Creek are indirectly tied to the disturbed landscape adjacent to the creek. The lack of riparian vegetation in the majority of the downstream section near CR44 is directly impacting the fish and macroinvertebrate community. The impacts are seen with elevated nutrients when compared to adjacent watersheds, lack of physical habitat, filling of pools and riffles with fine sediment, and low DO concentrations (either from increased decomposition or during low flow periods with an influx of low oxygenated groundwater). During periods of lower flow the channel has been enlarged enough over time to not sufficiently carry the sediment through the system. Altered hydrology may also be driving some of the channel instability problems. Increases in agricultural land use may be affecting the duration and magnitude of runoff entering Arvig Creek. Runoff appears to be flowing through the system at an accelerated rate and low flow conditions return shortly after rainfall stops. There appears to be prolonged periods of low flow during the summer months which appear low enough to prevent the fish community from establishing resident populations. During 1999, the fish community appeared to be a resident community.

4.1.3.2. Weight of evidence (See Appendix A)

4.1.3.3. Stressor conclusions

The main stressors that are affecting the biological community in Arvig Creek are lack of physical habitat, increased bedded sediment (channel instability), and low DO. During the summer of 2013 and 2014 instantaneous and continuous YSI sonde data was collected to determine if DO was a cause of stress to the biotic community. During both summer sampling periods DO was often below the state Class 2B water quality standard of 5 mg/L. DO concentrations appear to be driven by elevated nutrient concentrations, low DO concentration groundwater and a lack of aeration potential within the stream. Bedded sediment is also a problem in Arvig Creek. The stream banks are eroding because of a lack of riparian vegetation, high spring flow conditions along with animal access along the banks. The animal pasture areas are causing bank erosion due to animal grazing activity and hoof stress along the top of the banks. Excessive fine sediment is entering the stream and filling the pools causing a general lack of physical habitat. The pool quality is diminished in Arvig Creek. Riffle quality in the study area is also diminished. There is very little quality habitat for clinging macroinvertebrates and simple lithophilic spawning fish.

4.2. Willow Creek (AUID-07010105-631)

4.2.1. Biological communities

One site (12UM129) was located on Willow Creek and sampled in 2012 and 2013. Both fish samples were below the threshold for general use and are impaired while both macroinvertebrate samples are above the general use threshold and meet standards. Willow Creek flows into Upper Whitefish Lake from the northwest and is located in the Middle Pine River aggregated HUC-12 subwatershed. This stream has a low mean FIBI score of 25, which is below the FIBI threshold of 40 for Northern Headwater streams (fish Class 6). The neighboring stream Arvig Creek (99UM042) had a FIBI score of 0. These are the only Northern Headwater streams that were sampled for fish in the Middle Pine River aggregated HUC-12. Neighboring site Dabil Creek (12UM140) is located to the west of Willow Creek in the South Fork Pine River aggregated HUC-12. This site has the highest scoring FIBI for Northern Headwater streams in the PRW. Dabil Creek scored a 74. Table 4.2.1 lists the FIBI scores for individual metrics and compares the differences between the three sites. Median passing score for each FIBI metric would need to be at 4.0 or above to pass the FIBI. Scores below 4.0 are labeled red in Table 4.2.1 and indicate a potential problem with the fish community.

Comparison of the three sites shows that there is a lack of darter sculpin species at site 12UM129, along with a general lack of headwater species and sensitive fish species sampled. In 2012, the overall fish community at site 12UM129 was made up of 10 fish species and 56 individual fish, and in 2013 was made up of 6 fish species and 92 individual fish. The majority of the sampled fish were central mudminnow and creek chub in 2012, and white sucker and central mudminnow in 2013. The majority of the white suckers in 2013 were young of the year fish, indicating some reproduction is occurring in Willow Creek. White sucker are a migratory species during spawning season and would most likely use a small stream like Willow as a spawning ground. The adult white suckers would leave the stream after spawning. Central mudminnow are tolerant to low DO conditions and poor habitat quality in general, while creek chub and white sucker are not tolerant to low DO or poor habitat conditions. Regarding the fish assemblages, the main difference between Willow and Dabil Creek (12UM140) is the presence of 5 sensitive fish species in Dabil Creek. The fish community was dominated by pearl dace (which is a fish species sensitive to human disturbance) and creek chub instead of central mudminnow and creek chub.

Table 4.2.1: Comparison of two FIBI scores and the metric scores for the highest and lowest scoring fish sites in the Middle Pine River and South Fork Pine River HUC-12.

Site ID	Date	FishIBI	DarterSculp	Hdw-Tol	InsectCypPct	Insect-TolTxPct	Minnows-TolPct	NumPerMeter-Tolerant	PioneerTxPct	Sensitive	SLithop	TolTxPct	FishDELTPct
12UM129 Willow	20-Aug-12	30	0	0	0	6.9	0.35	0.44	10	0	2.33	10	0
12UM129 Willow	09-Jul-13	20	0	0	0	0	0.21	0.15	7.75	0	4.68	7.50	0
99UM042 Arvig	11-Jul-12	0	0	0	0	0	0.110	0	0	0	0	0	0
12UM140 Dabil	12-Jun-12	74	10	10	10	7.18	7.03	2.86	8.18	10	7.02	6.92	0

Downstream of 12UM129 the stream flows through a pasture before draining to Whitefish Lake. The pasture area is actively eroding and depositing sediment in the stream and the stream is over widened and shallow. The sand dominated substrate in the downstream portion of the stream is causing some filling of the pools and a general lack of quality stream habitat. The upstream portion of this AUID also flows through wetland that is impounded by beaver dams. The unnamed branch that flows in from the west also has some agricultural land use that may be delivering increased nutrients to the system. The stream discharges during the two years of study are often very low during the summer months (often below 1.5 cfs). During periods of heavy rainfall and snowmelt the stream discharge will increase but appears to flush through in a relatively short period of time. The perennial flow is enough to support a year round fish community but may be affecting which fish species will permanently live in the stream. The boundary conditions are such that site 12UM129 may not have the potential for a much better fish community.

4.2.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen data was collected at one location on AUID 07010105-631 to better understand and characterize the DO concentrations throughout the summer of 2013 and 2014. The DO sampling site was located just upstream of biological monitoring site 12UM129 as shown by Figure 4.2.1. DO data was collected between June 27, 2013, and August 13, 2014. All DO data was collected between 0815 and 1300. Four of the 20 DO samples collected were pre 9 a.m. Data from S007-685 were rarely below the

Class 2B 5 mg/L standard for DO. DO data was also collected in 2014 at the downstream AUID (07010105-632) at sampling site "2nd Site". DO data at this site was also above the 5 mg/L DO standard during all sampling events. Low DO does not appear to be a stressor to the biological community. Figure 4.2.2 displays the DO data from the 2013 and 2014 sampling dates.

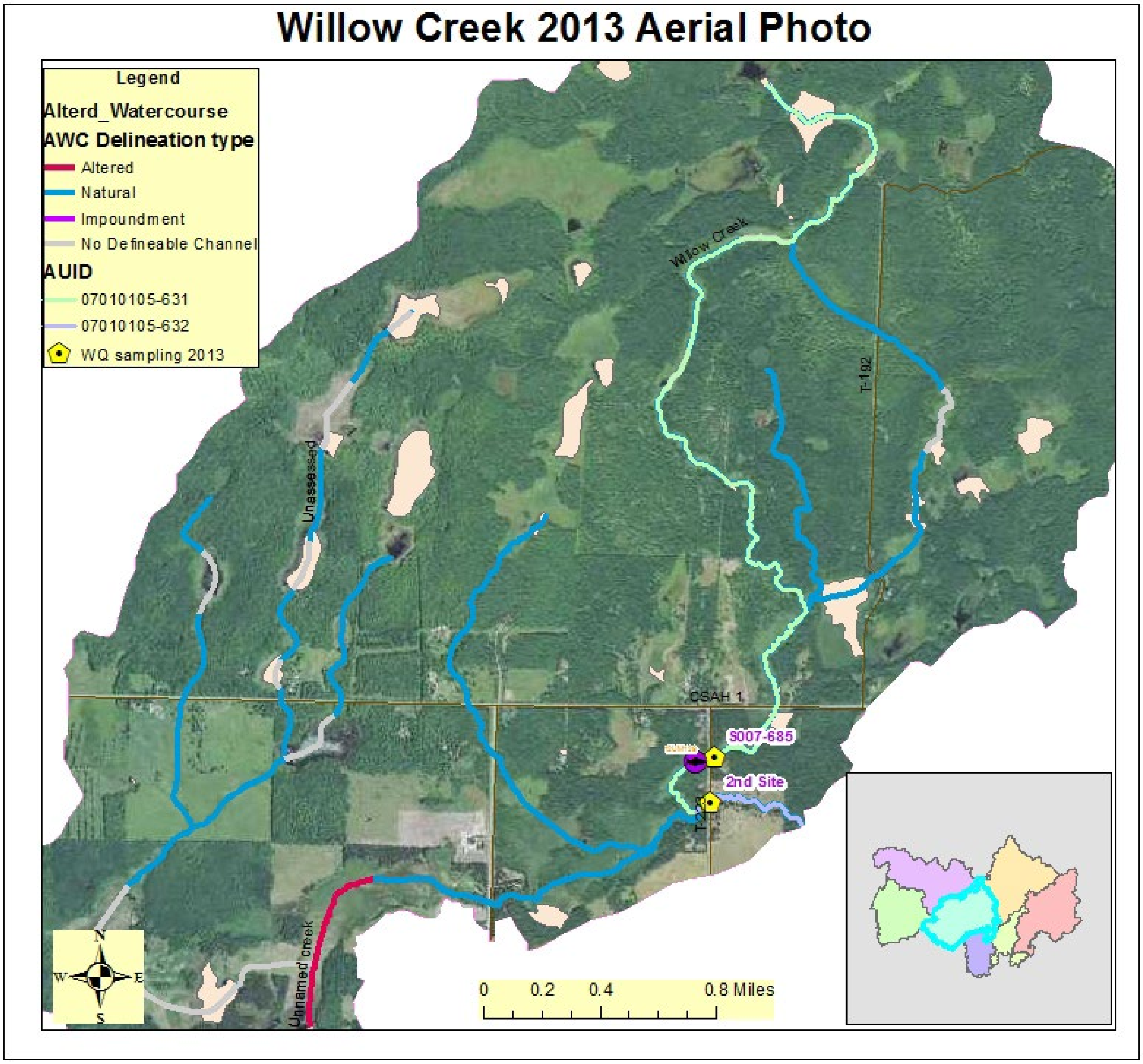


Figure 4.2.1: Sampling locations on Willow Creek, Site S007-685 is on the impaired AUID while 2nd Site is just downstream of the impaired AUID. Map also shows current channel condition.

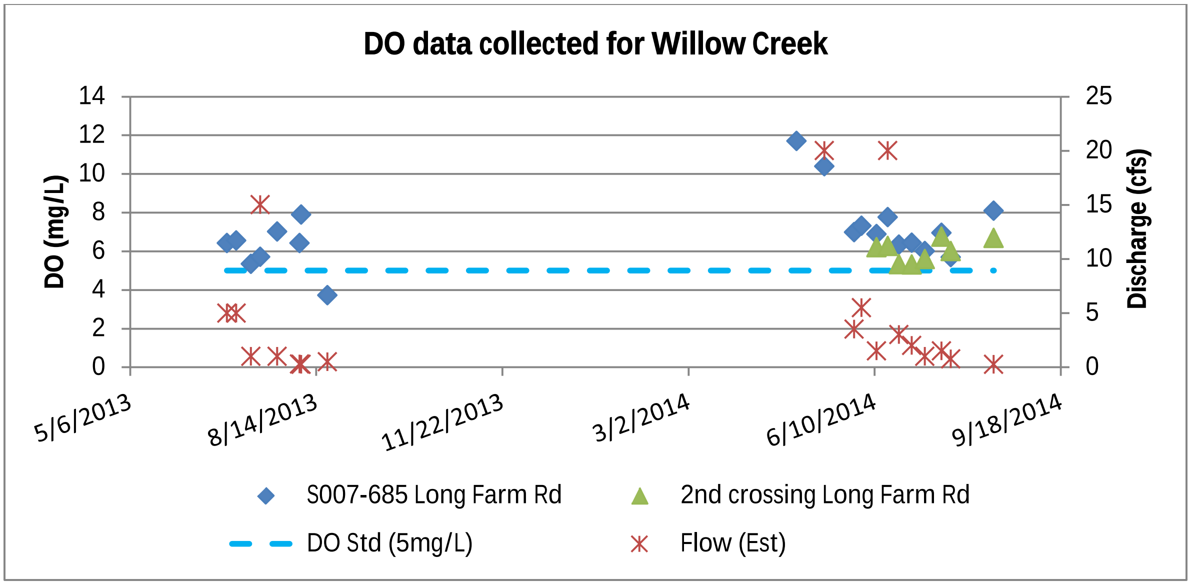


Figure 4.2.2: 2013 Dissolved oxygen sampling results from AUID 07010107-554

The fish community at site 12UM129 is dominated by species that require moderate DO concentrations (71% and 65%). The MPCA (Sandberg, 2013)created a tolerance value (TV) for each fish species commonly sampled in Minnesota. The TV is assigned to the fish species and is divided into quartiles of even distribution. The lowest quartile is assigned a tolerance value and if the fish community has greater than 50% of its sample in this quartile the community is dominated by fish species that thrive in low DO conditions. The top quartile is assigned an intolerant value and indicates fish species that require high DO concentrations. The fish community at 12UM129 is dominated by creek chub, white sucker and central mudminnow. Creek chub and white sucker are not tolerant to low DO concentrations and central mudminnow can live in all types of conditions and habitat, indicating that low DO is not a problem in the sampled fish community. Site 12UM129 fish community falls in quartile 2 and 3 which are intolerant to low DO. Review of the DO data and the fish community data suggest that low DO is not a stressor in this AUID. Figure 4.2.3 shows the fish community tolerance to DO based on the individual fish tolerance metrics developed by MPCA (Sandberg). Review of community tolerance probability shows that the Willow Creek site has a 31% chance of meeting the DO standard. When comparing to Dabil Creek (a site that scored much higher on the FIBI) there is a 34% chance of meeting the DO standard based on the sampled fish community. While neighboring Arvig Creek fish community showed an 18% chance of passing the DO standard. The data suggests that low DO is not a driving factor in the overall low FIBI score. However, low DO cannot be completely ruled out as a stressor at this time. Additional data will be collected in 2015. A continuous sonde will be deployed at the 2nd Site location for a two week interval to quantify the daily DO flux.

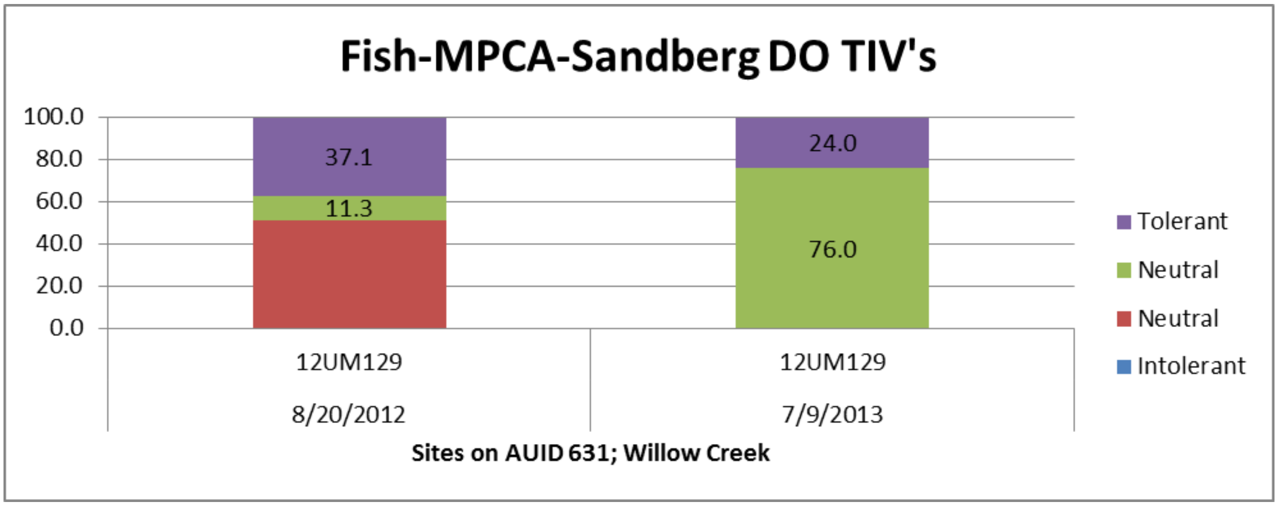


Figure 4.2.3: Fish community tolerance indicator values for Willow Creek.

Biotic response-fish

Evidence of the potential causal relationship of low DO to the fish community is inconclusive at this time. The biological metrics suggest that low DO could be a contributing factor to the impaired fish community. The number of sensitive fish taxa is zero in both neighboring Arvig Creek and Willow Creek, while the number of long lived fish taxa (>3 years) during both the 2012 and 2013 sampling event in Willow Creek is 1 taxa. The total number of fish sampled at Willow was nine times greater than the total number of fish sampled at neighboring Arvig Creek.

Elevated nutrients

Nutrient data was collected seven times between July 10, 2013, and August 13, 2014. Grab samples were collected and analyzed for TP, Nitrate-Nitrite NO_2+NO_3, Ammonia (NH_3), and Total Kjeldahl Nitrogen (TKN). The TP concentrations were all below 0.125 mg/L and the summer averaged 0.07 mg/L. This is above the proposed TP standard of 0.050 mg/L for northern streams. The early spring 2014 samples were below 0.05 mg/L during spring rains. NO_2+NO_3 data averaged 0.05 and peaked at 0.10 mg/L. Ammonia data also was very low. Elevated nutrients do not seem to be a stressor to the aquatic biological community and eutrophication does not appear to be driving the DO concentrations. The stream channel is not showing signs of elevated peryphyton growth or submerged aquatic macrophyte growth. The channel is quite narrow and incised in most of the stream corridor which limits the amount of sunlight that can penetrate the open water and promote plant growth.

Lack of physical habitat

The maximum MSHA score that a site can achieve is 100. Habitat quality based on the MSHA score was fair (62) at site 12UM129. Neighboring Arvig Creek (99UM042) scored a 50 which is also fair. The MSHA was the main tool used for evaluating this potential stressor and the comparative results for the two sites habitat scores can be seen in Figure 4.2.4. Habitat scores were divided by the maximum score to obtain the proportion on each score to the total. Arvig Creek had a high FIBI along with an MSHA score of 69 (good) in 1999. In comparison the substrate score was seventeen at 99UM042 in 1999 and eight in 2012. This indicates that the substrate is less coarse and changed in the thirteen year period. The substrate MSHA score at 12UM129 was nine. The substrate present during the sampling event was sand dominated pools and riffles and runs that were dominated by sand and silt. Approximately 60% of the sampled reach was run and 20% pool and riffle. This indicates fine sediments and a lack of coarse substrate at the 12UM129 sampling location. No coarse substrate was observed during the 2012 or 2013 sampling events.

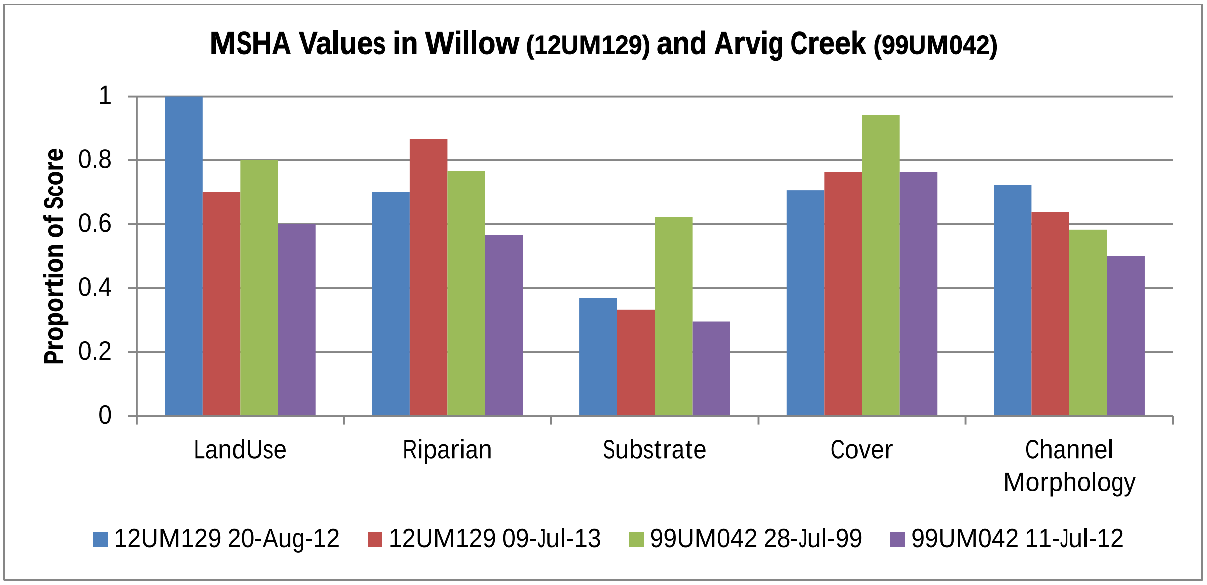


Figure 4.2.4: MSHA subcategory values at biologically impaired Site 12UM129 and biologically unimpaired Site 99UM042 during the 1999 sample. In 2012 site 99UM042 scored a zero on FIBI.

Biologically, 12UM129 had low numbers of lithophilic spawning fish (1.82% in 2012, and 54% in 2013), nearly no benthic insectivores, or darter/sculpin/round bodied suckers. These fish metrics tend to decrease when habitat becomes degraded. Due to the fair MSHA score as well as the fish metrics scoring poorly, the lack of habitat is a stressor to the impaired fish community in Willow Creek. Figure 4.2.5 below shows the condition of the site at the upstream section of the biological monitoring site. This site has been recently altered due to culvert cleaning with the associated upstream and downstream channel. The twin culverts are placed at an elevation that is partially filling the southern culvert with sediment. The bankfull cross sectional area in the culverts is nearly twice the bankfull stream cross sectional area, so the culverts are actively filling to reduce the bankfull area. The culverts are definitely oversized and cleaning them is promoting the refilling process and general stream instability.

Figure 4.2.5: Photos of the road crossing above biological Site 12UM129. Photo on the left shows sediment delta downstream of road crossing. Photo on the right is looking at the same sediment delta after a summer of vegetation growth. Channel appears to have been cleaned out with a backhoe in the recent past and is now starting to recover and narrow back down. Sinuosity is being formed again in this section of channel.

Stream channel assessment (stability and bed sediment analysis)

The MDNR and MPCA conducted a stream classification survey at two locations in Willow Creek in 2013 and 2014 to help understand the stability of the stream channel. The two locations were located just downstream of the Long Farm Road crossings. Stream channel surveys are conducted to answer some basic channel stability questions. Is the stream currently stable or is it in a state of flux? What type of stream channel and in what evolutionary stage of channel development are we currently seeing? The two surveys were conducted as a means of understanding the current conditions at site 12UM129 and at the downstream location "2nd Site" after another tributary enters Willow Creek and essentially doubles the drainage area. Both sites are showing signs of channel bank erosion and the survey data can help us understand the nature of the bank erosion and potential corrective actions.

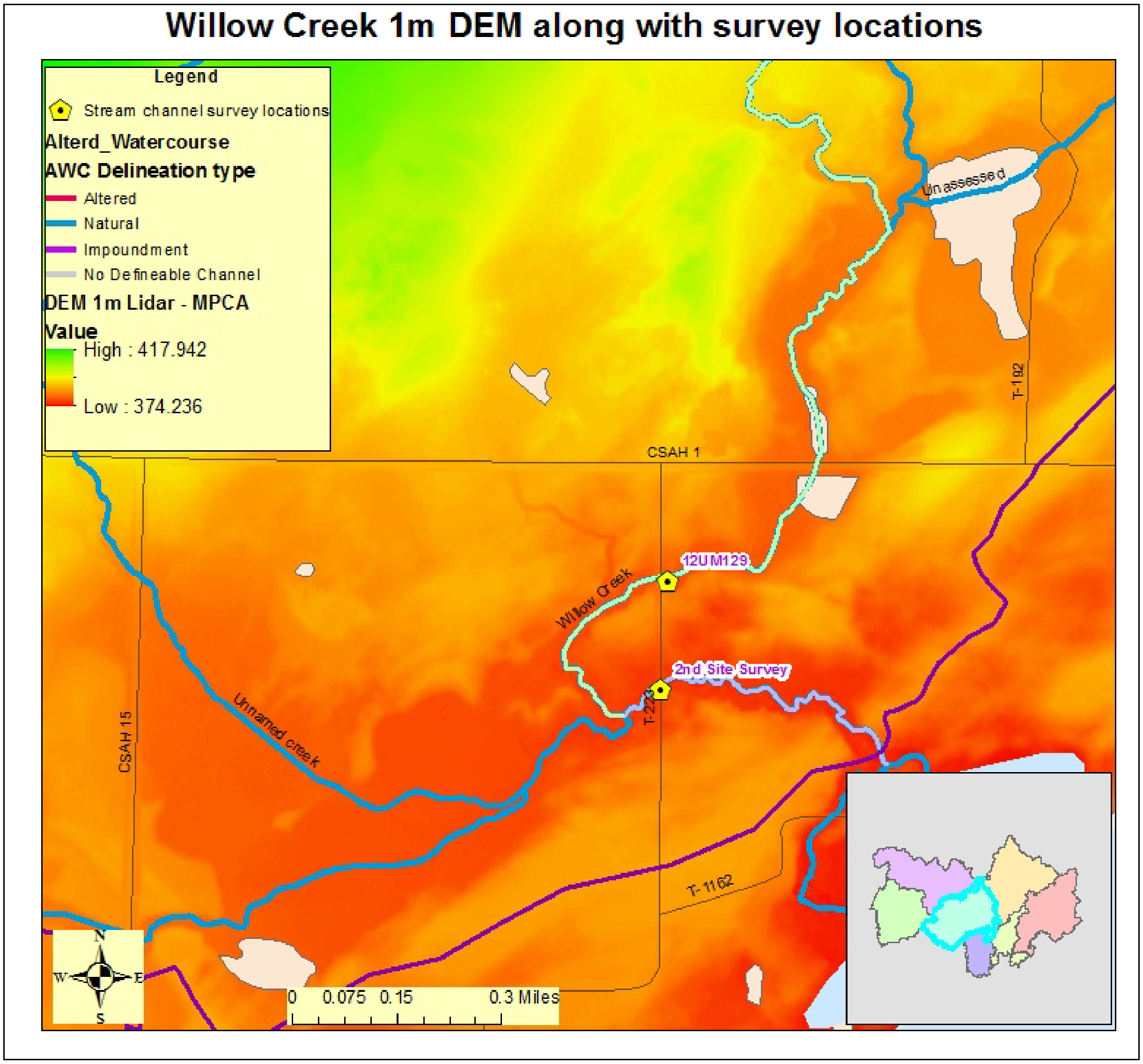


Figure 4.2.6: Location of the surveyed reaches on Willow Creek. These two locations are used for classification and channel stability calculations.

Data collected during the two survey events included channel dimension, pattern and profile data to assess the current condition of the channel. The two locations surveyed are referred to as site 12UM129 and 2nd Site survey as indicated in Figure 4.2.6. The upstream site was surveyed by a MDNR crew and the downstream site was surveyed by a MPCA crew. Table 4.2.2 displays the information for each surveyed reach so comparisons of the two sites can be made. A representative channel cross section at a riffle was surveyed in each reach so an overall shape and area calculations could be performed.

Table 4.2.2: Survey data collected from the two stream reaches on Willow Creek.

Site	Classification	Drainage Area(mi^2)	Average water surface slope(ft/ft)	Average Bkf slope (ft/ft)	Low Bank Height slope	Sinuosity	Bankfull width(ft)	Cross-section area (ft^2)	Width/Depth ratio	Entrenchment ratio	Riffle pebble count (D50 mm)
12UM129	**E5**	**5.4**	**0.0022**	**0.0026**	**0.00019**	**1.31**	**7.9**	**11.73**	**5.34**	**31.01**	**0.38**
2nd Site (XS2)	**E5**	**11.2**	**0.00085**	**0.00082**	**0.00046**	**1.53**	**11.53**	**16.99**	**7.84**	**3.19**	**0.14**
2nd Site (XS4)	**F5**	**11.2**	**0.00085**	**0.00082**	**0.00046**	**1.53**	**18.02**	**21.79**	**14.89**	**1.15**	**0.14**

Pebble counts are collected at the surveyed riffle cross sections to be used in velocity and discharge calculations. Typically 100 pebbles are counted across the stream cross section in an effort to understand the resistance of the bed material, and come up with a roughness coefficient to be used in the discharge calculations. Drainage area is plotted against a regional curve to find the approximate discharge for the size watershed being studied. If the channel is incised (cut down) the drainage area becomes important in trying to find the appropriate discharge cross sectional area for the channel. When incision occurs, the channel contains the typical bankfull flow (1.5 year event); this will often cause bank failure and sediment movement in the channel because the channel can no longer reach its flood plain during the bankfull flow event. Once the channel is disconnected from the floodplain it becomes unstable and will cause bank failure until a new floodplain is formed and new channel equilibrium is reached.

Depositional patterns also can help us understand the stability of a stream channel. The depositional patterns include point bars and side bars. Channel blockages consisted of small twigs and limbs with other floatable, easily moved material. A Pfankuch assessment was not performed by the MDNR on Willow Creek at 12UM129. MPCA did perform a Pfankuch assessment at the 2nd Site reach. Results from the Pfankuch assessment showed the channel was in poor condition with a rating of 131. The sediment supply was high and the channel appears to be aggrading. The meander width ratio (MWR) is below the lower limit of the range for E stream types. The typical range for E stream types is 20 – 40, with an average value of 24.6 (Rosgen, 1996, 2006). The survey reach MWR of 1.58 indicates that the stream is laterally contained or confined. Streams that are confined are often associated with channel enlargement, lateral accretion, high bank erosion rates, and sediment transport problems (Rosgen 2006).

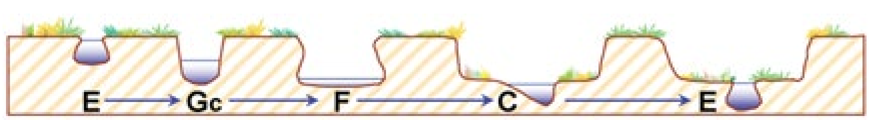


Figure 4.2.7: Channel succession scenario of Willow Creek (adapted from Rosgen, 2001a, 2006, 2007; USEPA, 2006).

Willow Creek is in the process of channel succession. Channel succession occurs when the stream evolves from a stable channel type, through unstable types, and finally back to a stable channel type. Willow Creek was previously an "E" stream channel that was connected to the floodplain at the banks. It is now an "E" channel that has incised and is in between the first two stages of the succession above (Figure 4.2.7). The channel has not yet incised enough to the point where the flood prone elevation is contained within the banks, which would officially make it a "Gc" stream type (gully). Since this initial phase of the succession is in a stable form, the succession isn't usually initiated until events such as large scale land use alterations, improperly set/sized culverts, floods, etc. occur. The initial transition of Willow Creek from an "E" stream type through this succession could have occurred from various factors. The most probable would include a large flood event or improperly sized culverts. Culvert width should be equal to the bankfull width of the channel. The culverts themselves measure around 20 feet in total at the upstream Long Farm Road crossing and around 24 feet in total at the 2nd Long Farm Road crossing. The bankfull width is around 9 feet and 15 feet at the two surveyed reaches. This indicates that the culvert is roughly double as wide as it should be for the stream type passing through it. This is possibly one of the reasons that the southern barrel of the culvert looks to be partially plugged (Figure 4.2.5).

This succession shift is highly unstable (Rosgen, 2001a, 2006, 2007; USEPA, 2006). This indicates that as the channel evolves through this succession sequence, it will contribute sediment as it erodes and carves its way into a new "E" type stream channel. After succession, the channel should establish an "E" stream type at a lower bankfull elevation with a new floodplain. The old bank heights would become the terraces surrounding the new floodplain in this scenario.

Channel stability can also be affected by the degree of channel incision. The degree of channel incision can be looked at by observing the bank-height ratio. The bank-height ratio is the bank height divided by the max bankfull depth. Streams that reach their bank and spill into their floodplain at bankfull flows will have a bank-height ratio of one, indicating a stable degree of channel incision. The cross-sections and corresponding bank-height ratios for Willow Creek indicate various degrees of channel incision (Table 4.2.3). Although the incision levels vary by cross-section, the overall trend is observed in the longitudinal profile (Figure 4.2.8 and 4.2.9). It can be observed that as the bankfull elevations continue on a 0.00263 slope while the low bank height slope stays relatively flat at a slope of 0.00019. This "wedge" of incision indicates that the channel becomes more incised near the downstream end of the reach. The degree of incision information enhances the high instability conclusion of Willow Creek based on the channel succession shift.

Table 4.2.3: Bank-height ratios of cross sections at both survey locations in Willow Creek.

Bank-height ratios of cross-sections on Willow Creek (AUID-07010105-631) & (AUID-07010105-632)				
Cross-section	**Max Bankfull Depth (ft)**	**Low Bank Height (ft)**	**Bank-Height Ratio**	**Degree of Channel Incision**
XS1 – Pool	**3.47**	**4.16**	**1.20**	**Slightly Incised**
XSQ1 – Riffle	**2.42**	**3.50**	**1.45**	**Moderately Incised**
XSQ2 – Riffle	**2.65**	**3.00**	**1.13**	**Stable/Slightly Incised**
XS2 – Riffle	**2.69**	**4.34**	**1.61**	**Deeply Incised**
2nd Site Survey				
XS2 – Riffle	**1.73**	**2.48**	**1.43**	**Moderately Incised**
XS4 – Riffle	**1.41**	**3.41**	**2.42**	**Deeply Incised**

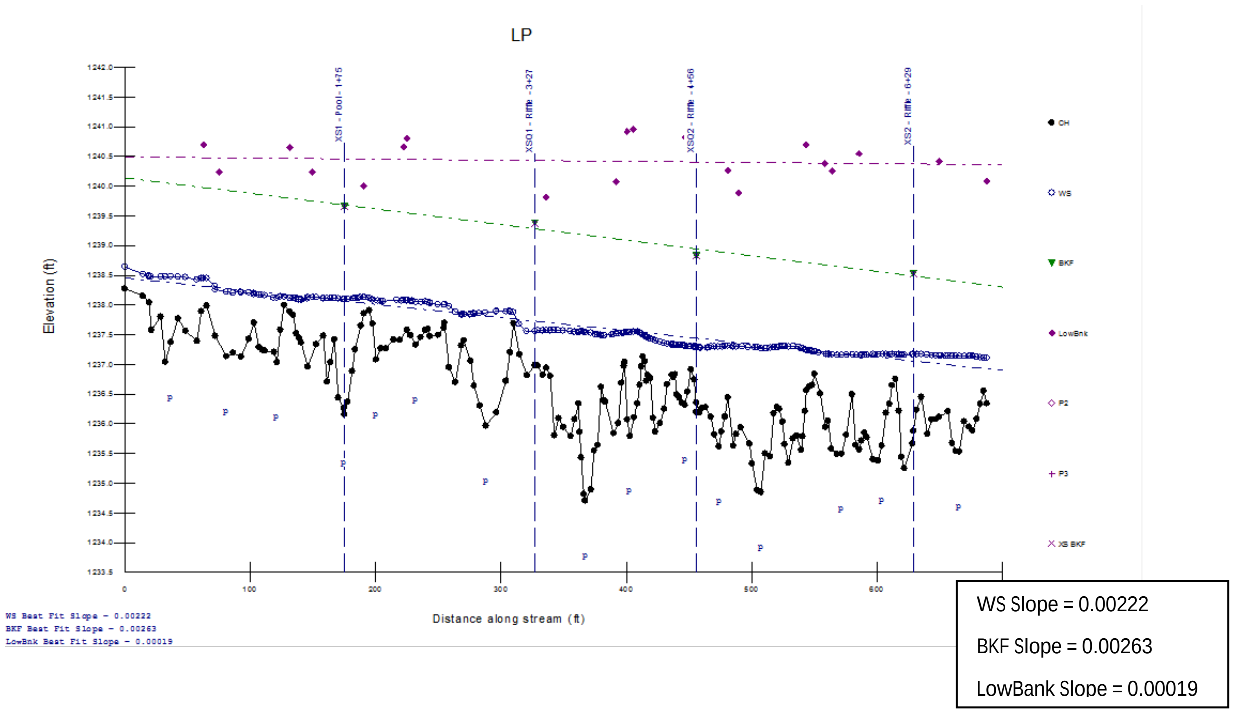


Figure 4.2.8: Longitudinal profile at 12UM129. Survey by MDNR in 2013.

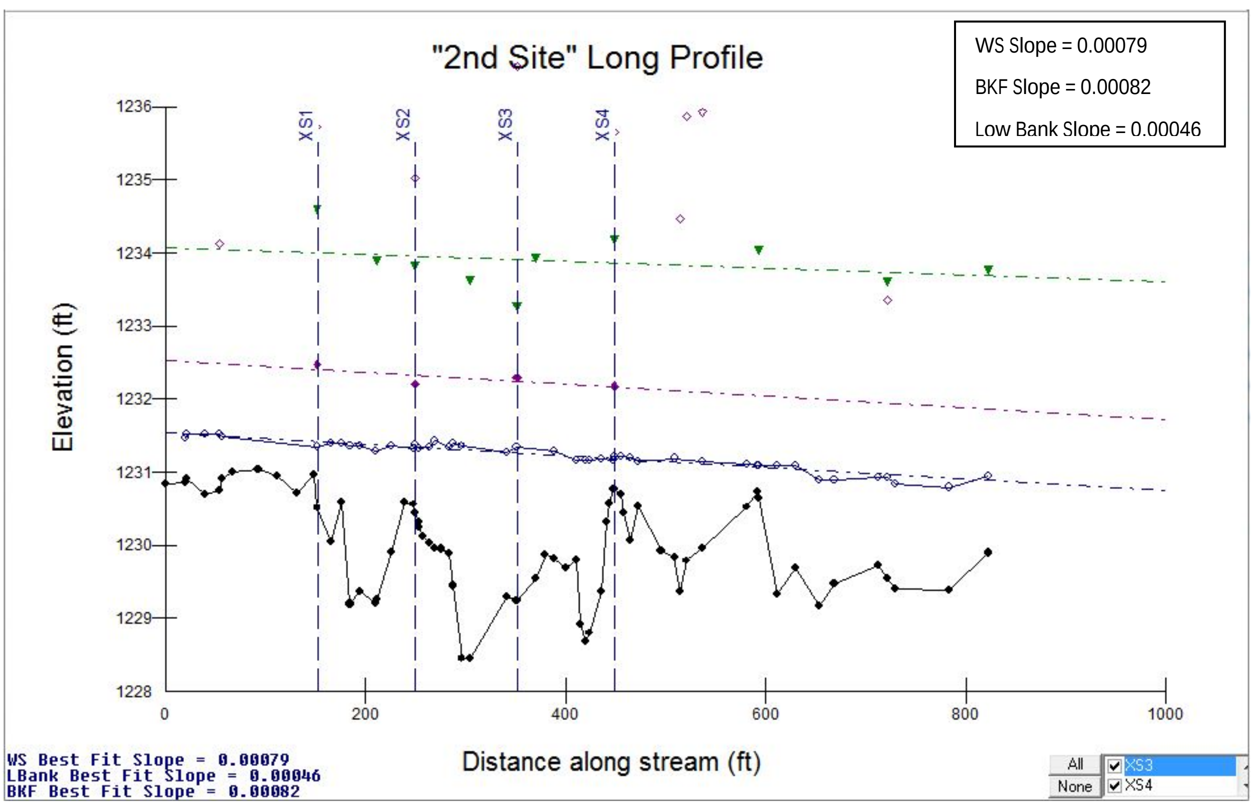


Figure 4.2.9: Longitudinal profile for Willow Creek downstream of Long Farm Road at "2nd Site" in pastured area. Survey by MPCA in 2014.

Aerial photography review and observations from the road indicated that channel instability was a problem at the “2nd Site” stream reach. On July 1, 2014, the MPCA conducted a bank erosion hazard index (BEHI) survey of Willow Creek downstream of Long Farm Road. The stream was accessed from the road and the survey was conducted by walking down the center of the stream channel and documenting the bank erosion length, height and position along the stream corridor. Data was then summarized using the Rivermorph program (Rosgen, 1996) to calculate stream water slope, cross sectional area, and the potential for sediment supply to the stream from the study reach. Water surface slope within this reach was relatively flat at 0.00079 ft. /ft. and the bankfull slope is also flat at 0.00082 ft. /ft. The section of stream classifies as an E5 to F5. This is a sand dominated channel with a low slope. The channel is slightly entrenched and has diminished access to the floodplain. The sand substrates along with sand dominated banks are unstable do to a lack of riparian vegetation. E channel types are susceptible to erosion when the riparian vegetation is altered which causes bank erosion and increased sediment supply to the stream.

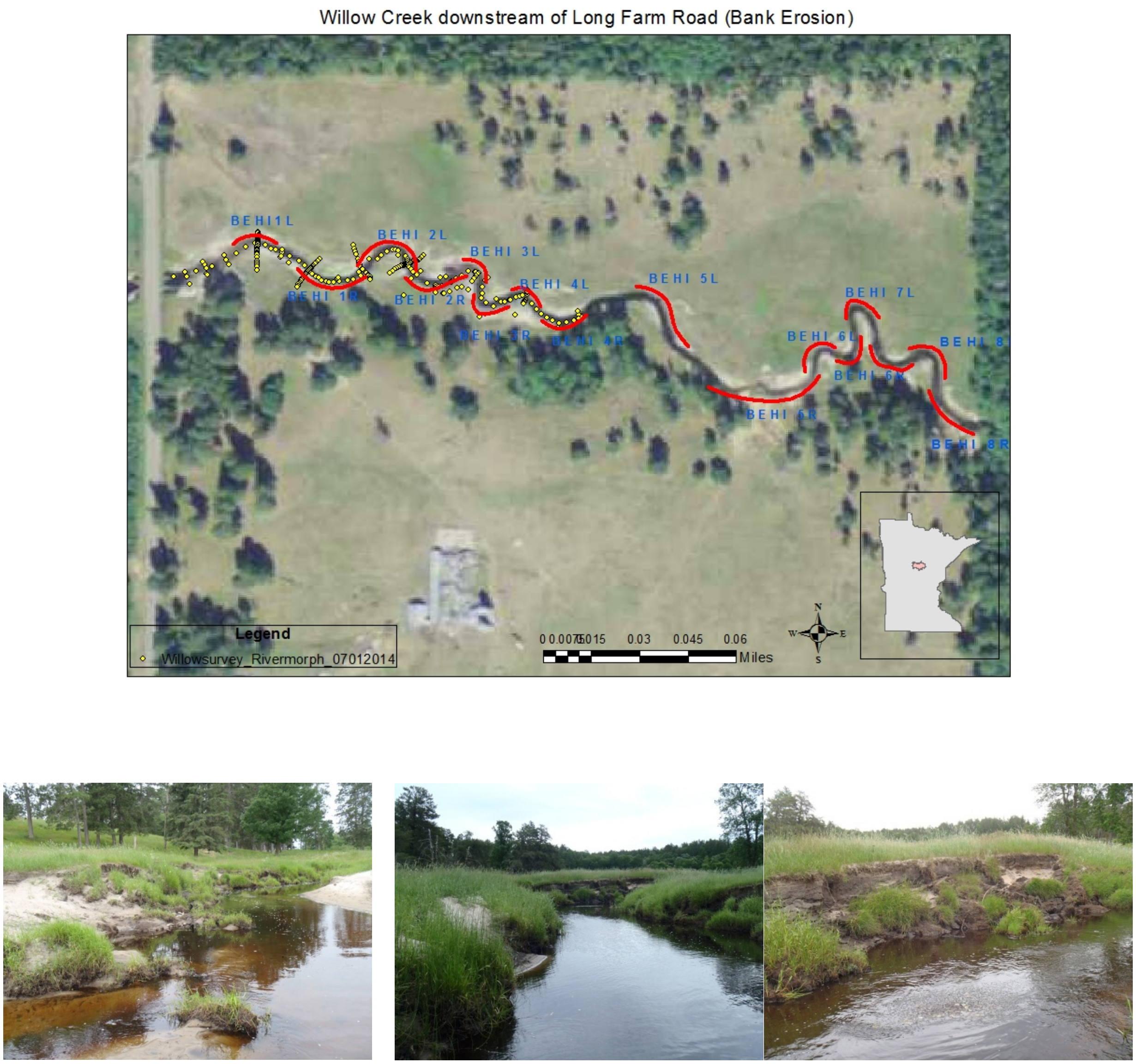


Figure 4.2.10: Map of BEHI stations located on Willow Creek downstream of Long Farm Road in pasture area. Photos are of representative bank erosion areas found within the study reach.

Bank erosion hazard index (BEHI) calculations for Willow Creek downstream of Long Farm Road 2nd Crossing are listed in the table below. Figure 4.2.10 illustrates the locations that are mapped in Table 4.2.4, and also includes three photographs providing illustrations of bank erosion potential along the surveyed reach. The annual sediment supply entering the stream from this reach is estimated at 380 tons/year. Not all of this sediment is leaving the reach. Some sediment is being deposited on the channel floodplain areas and some is being deposited on the channel bed. At bankfull discharge (1.5 year event) the stream discharge is contained within the channel and accelerating the bank erosion. The larger, less common flood events still have access to small floodplain areas along the reach which can be seen in Figure 4.2.10 as white areas along the stream corridor. This white signature on the aerial photograph is deposited sand along the floodplain.

Table 4.2.4: Bank Erosion Hazard Index (BEHI) values for Willow Creek at "2nd Site".

Stream:		**Willow Creek, Reach - Reach 1**			Location:			
Graph Used:			Total Stream Length (ft):		**1818**		Date:	**7/1/2014**
Observers:		**cgj**		Valley Type:			Stream Type:	**C 4c-**
(1)		**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Station (ft)		**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft³/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1.	**BEHI 1R**	**High**	**Very High**	**1.573**	**55.0**	**3.0**	**259.55**	**0.22720**
2.	**BEHI 1L**	**High**	**Very High**	**1.573**	**116.0**	**2.5**	**456.17**	**0.18930**
3.	**BEHI 2R**	**High**	**High**	**1.094**	**104.0**	**2.0**	**227.55**	**0.10530**
4.	**BEHI 2L**	**High**	**Moderate**	**0.761**	**80.0**	**2.0**	**121.76**	**0.07330**
5.	**BEHI 3R**	**Very High**	**High**	**1.094**	**206.0**	**1.5**	**338.05**	**0.07900**
6.	**BEHI 3L**	**Very High**	**Very High**	**1.573**	**206.0**	**5.0**	**1620.19**	**0.37870**
7.	**BEHI 4R**	**High**	**Very High**	**1.573**	**55.0**	**3.0**	**259.55**	**0.22720**
8.	**BEHI 4L**	**High**	**Moderate**	**0.761**	**142.0**	**2.0**	**216.12**	**0.07330**
9.	**BEHI 5R**	**High**	**Moderate**	**0.761**	**213.0**	**5.0**	**810.46**	**0.18320**
10.	**BEHI 5L**	**Extreme**	**High**	**1.828**	**150.0**	**5.0**	**1371.00**	**0.44000**
11.	**BEHI 6R**	**High**	**High**	**1.094**	**63.0**	**2.8**	**192.98**	**0.14750**
12.	**BEHI 6L**	**High**	**Moderate**	**0.761**	**81.0**	**4.0**	**246.56**	**0.14660**
13.	**BEHI 7R**	**High**	**Moderate**	**0.761**	**91.0**	**3.5**	**242.38**	**0.12820**
14.	**BEHI 7L**	**High**	**Moderate**	**0.761**	**82.0**	**2.5**	**156.01**	**0.09160**
15.	**BEHI 8L**	**Very High**	**High**	**1.094**	**235.0**	**3.8**	**976.94**	**0.20020**
16.	**BEHI 8R**	**High**	**High**	**1.094**	**110.0**	**3.3**	**397.12**	**0.17380**

Sum erosion subtotals in Column (7) for each BEHI/NBS combination	Total Erosion (ft^3/yr)	7892.39	
Convert erosion in ft^3/yr to yds^3/yr {divide Total Erosion (ft^3/yr) by 27}	Total Erosion (yds^3/yr)	292.31	
Convert erosion in yds^3/yr to tons/yr {multiply Total Erosion (yds^3/yr) by 1.3}	Total Erosion (tons/yr)	380.00	
Calculate erosion per unit length of channel {divide Total Erosion (tons/yr) by total length of stream (ft) surveyed}	Unit Erosion Rate (tons/yr/ft)	0.2090	

This reach of Willow Creek (07010105-632) is just downstream of the impaired AUID (07010105-631). Willow Creek AUID 07010105-632 was not sampled for biology because it is too close to Whitefish Lake. The amount of sediment entering the stream from this reach is possibly impacting the migratory nature of stream fish and is having a negative impact on the fish community that is found upstream. The substrate is dominated by fine sand and the channel becomes very shallow during periods of low flow. Connectivity to the upstream reaches is impacted by this reach.

Biotic response-fish

Evidence of a potential causal relationship between a lack of instream habitat and the FIBI impairment, associated with AUID 631, is provided by the following individual metric responses: 1) a decrease in the relative abundance of taxa that are benthic insectivores, excluding tolerant species (BenInsect-TolTxPct) and 2) an increase in the relative abundance of taxa that are detritivorous (DetNWQTxPct); each of these responses would lower the associated metric score. Benthic insectivores require quality benthic habitat (e.g., clean, coarse substrate) for feeding and reproduction purposes, while detritivorous species utilize decomposing organic matter (i.e., detritus) as a food resource and, therefore, are less dependent upon the quality of instream habitat. The fish sample was also dominated by tolerant taxa (78% in 2012 and 96% in 2013) Tolerant taxa percentage within the community will increase when habitat quality decreases.

Lack of longitudinal connectivity

The downstream section of Willow Creek is shallow and wide. During periods of low flow the stream channel lacks the amount of water needed to support fish movement. This can be seen in the photographs in Figure 4.2.10. The cross section of the channel is wide and during low flow periods there is very little water in the channel. This will disconnect the lower portion of the stream from the upstream portion of the stream. Sampling in 2012 for fish was conducted after a significant rainfall event that caused major flooding in June2012. Following this event there were zero migratory fish species sampled. As a follow up to the 2012 sample, MPCA collected a 2013 fish sample to verify the 2012 conditions. In 2013, migratory fish increased to 54% of the sample. All of these fish collected were YOY white sucker, which indicates those white suckers are using this stream as a spawning area. However during the sampling no adult fish were captured and no other migratory species were sampled. This may indicate that during spring runoff there may be adequate flow and fish passage to partially repopulate the stream but the stream may become impassable during the late summer as flows diminish. A stream gage will be installed in 2015 to document flow conditions within Willow Creek.

4.2.3. AUID summary

Willow Creek (AUID 07010105-631) lies in the west-central portion of the Middle Pine River aggregated HUC-12. The land use surrounding this impaired AUID is predominately forest with a mixture of rangeland and wetland. The majority of the riparian corridor along this AUID is low laying shrub wetland plant dominated landscape. Some of the area in the adjoining AUIDs is pastured. Multiple beaver dams in the headwaters area of the AUID may be impacting the stream flow pattern and altering the hydrology. There are no permitted feedlots located in this subwatershed. There are a couple of large pasturing operations within the watershed boundary. The channel incision appears to be affecting bank stability within the reach. The instability is causing an excessive amount of bank erosion which is limiting the amount of physical habitat for fish. The lack of habitat appears to be the main stressor on the fish community.

4.2.3.1. Stressor pathway discussion

Connectivity and channel instability due to incision appear to be main stressors to the fish community in AUID 07010105-631. It is believed that the pastured area downstream of Long Farm Road (07010105-632) along with the stream channel instability partially caused by the culverts along Long Farm Road (07010105-631) are supplying excessive amounts of fine sediment to the stream which are partially filling pools and smothering any gravel substrate. This is impacting the fish community through loss of habitat. The channel is actively widening and filling. This is causing a loss of stream power and the ability for the stream to clean out the fine substrate. The channel is incised downstream of Long Farm Road. There is minimal floodplain access at the bankfull discharge level. This is causing channel instability. Bank failure is causing sediment to enter the stream from the banks. As the channel fills, the substrate particle size is reduced in size. Figure 4.2.11 below show the bank erosion process occurring along this section of Willow Creek.

Figure 4.2.11: Photos of bank instability located downstream of Long Farm road near "2nd Site" sampling location.

The two culverts along Long Farm Road are also potentially part of the problem. Both sets of culverts are wider than the bankfull stream channel and are playing a role in the channel instability. Further analysis and data collection would be required to determine possible culvert alterations. The stream channel currently is in an unstable phase of channel evolution which will cause further erosion and sediment supply until channel equilibrium is achieved.

Using the Shields curve to calculate entrainment, the section of Willow Creek below the second Long Farm Road crossing can retain particles up to 5.5 mm in size. The entrenchment and incision of the stream is forcing a high volume of water through a small cross sectional area during peak flows and causing the movement of both bed sediment and sediment from the failing banks. When conducting the pebble count at cross section 1 only fifteen particles larger than 5.7 mm were counted. The largest particle was 16 mm in this riffle cross section. Using the Rosgen Colorado data set to estimate entrainment; particles up to 23.9 mm are mobile. Most of the stream bed is mobile during bankfull flow and it appears that the stream bed is in a state of constant flux. During high flow the mobile bed may be impacting fish movement because of increased turbidity and bank sediment contribution. When flows decrease the stream does not appear to have adequate depth to sustain a resident fish population.

4.2.3.2. Weight of evidence

(See Appendix A)

4.2.3.3. Stressor conclusions

Willow Creek (07010105-631) is biologically impaired for fish. The stream flows through areas of wetland and forest. Downstream of the sampling site the channel again flows through a riparian pasture before discharging into Whitefish Lake. The DO data that was collected during 2013 and 2014 shows infrequent periods during the summer when DO concentrations are below the class 2B water quality standard for DO. Additional DO data will be collected in 2015 to characterize the daily flux during the summer months. Nutrient concentrations are above the northern streams TP recommendations based on the water chemistry samples collected in 2013 and 2014. Nitrate-Nitrite concentrations are low and comparable to the typical Northern Lakes and Forests ecoregion mean concentrations. Throughout both the survey locations there is a significant amount of bank erosion due to a lack of riparian vegetation and channel incision before entering Whitefish Lake. The entire surveyed section of Willow Creek is incised and showing signs of instability. Further investigation will need to be conducted to address the channel instability before restoration can occur. The downstream portion of this area was not monitored for biology in 2012; however, it is believed that this lack of riparian vegetation and bank erosion is causing a longitudinal connectivity issue and a general lack of habitat in this lower portion of Willow Creek.

Lack of physical habitat is also a concern in the upstream portion of the stream. The use of the MSHA score to compare to a neighboring stream with high biological scores can help reveal which habitat features may be lacking in Willow Creek. The substrate scores are lower at site 12UM129 compared to other adjoining Northern Headwaters fish class stations that have FIBI scores meeting or exceeding the general use threshold. This suggests that lack of coarse substrate along with channel instability is contributing to the impaired fish community at site 12UM129.

4.3. Wilson Creek (AUID-07010105-529)

4.3.1. Biological communities

The macroinvertebrate community in Wilson Creek is impaired. One biological sampling site (12UM133) is located in this AUID. Biological sampling site 12UM133 is in the Class 4 (Northern Forest Streams Glide/Pool Habitats) MIBI class. Table 4.3.1 below lists the M-IBI metrics for the Northern Forest Streams class (Macroinvertebrate Class 4) sampling locations. The fish communities were above their respective threshold during the 2012 sampling.

The mean metric score required to pass the M-IBI is 5.2 per metric, meaning if the score is above that mean value the individual metric passes. Scores that are below that mean value bring the overall score down and are causing the low M-IBI score. Table 4.3.1 has the metric values highlighted in bold red that are below the mean value. This table also is comparing another Class 4 stream site in the PRW that is above the M-IBI (12UM129; Willow Creek). Seven of the 10 metrics used to calculate the MIBI score are below the mean value of 5.2 for site 12UM133. There is a general lack of predator taxa, a lack of non hydropsychid trichoptera individuals, and a low taxa richness of POET (stoneflies, dragonflies, mayflies and caddisflies). A qualitative multi-habitat sample was collected from available habitat within the reach; this consisted of snag/woody debris habitats at 12UM133. This indicates that there is a general lack of macroinvertebrate habitat in this reach. Macroinvertebrates could be sampled from many different habitat types, such as, aquatic macrophytes, riffle rock, undercut banks-overhanging vegetation and snags/woody debris. Sampling one habitat type suggests there may be a lack of habitat diversity. A channel survey of this reach in 2014 confirmed that there was a general lack of habitat diversity. The woody debris located in the stream is marginal as a majority of the wood is small willow twigs that appear to be mobile during high flow periods. Undercut banks and overhanging vegetation habitats are present throughout this reach, however during the macroinvertebrate sampling index (August - September) water levels were not suitable to allow for the sampling of this habitat type.

Table 4.3.1: MIBI metrics used to compute IBI scores for Northern Forest Streams (Macroinvertebrate Class 4). Sites are listed in order going upstream.

Site ID	Date	MIBI Score	ClingerCh	Collector filtererPct	DomFiveChPct	HBI_MN	Intolerant2Ch	POET	PredatorCh	TaxaCountAllChir	TrichopteraChTxPct	TrichwoHydroPct
12UM133	**14-Aug-12**	**40.7**	**7.33**	**7.97**	**4.02**	**3.33**	**0**	**3.57**	**2.86**	**4.73**	**5.22**	**2.0**
12UM129	**20-Aug-12**	**60.2**	**6.67**	**7.61**	**8.99**	**6.81**	**0**	**5.71**	**8.57**	**9.41**	**4.77**	**1.9**
12UM129	**19-Aug-13**	**62.7**	**6**	**8.11**	**7.87**	**6.13**	**5.0**	**5**	**6.43**	**6.78**	**7.24**	**3.7**

4.3.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen data was collected at one location in this AUID. The data was collected from EQuIS stations S007-845. Figure 4.3.1 below displays the results from the 2014 DO data collection. The instantaneous DO data that was collected in 2014 was always above the 5 mg/L DO standard. An YSI sonde was placed in Wilson Creek for a sixteen day period to document the diurnal fluctuation of DO and stream temperature. During this time period there were short periods of DO falling below the 5mg/L standard. Figure 4.3.2 displays the continuous sonde data. The daily DO flux observed during the sampling period ranged from 2.5 to 4.5 mg/L. Figure 4.3.5 displays the DO sampling locations. With the current data DO does not appear to be a significant stressor to the biological community in the AUID. The macroinvertebrate DO index value is 6.95 at biological site 12UM133. This value indicates that there is a 20% probability that the macroinvertebrate community is affected by low DO concentrations. There are more DO intolerant macroinvertebrate taxa than there are DO tolerant taxa in the sample and zero DO very tolerant taxa.

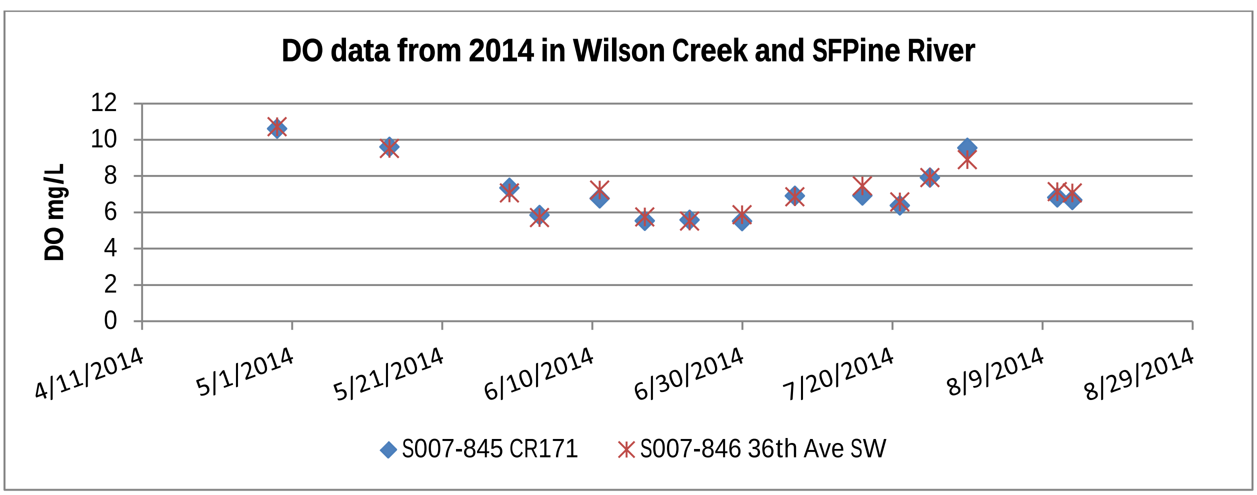


Figure 4.3.1: Synoptic DO data from AUID 07010105-529 at CR176 road crossing. All DO readings were above 5 mg/L.

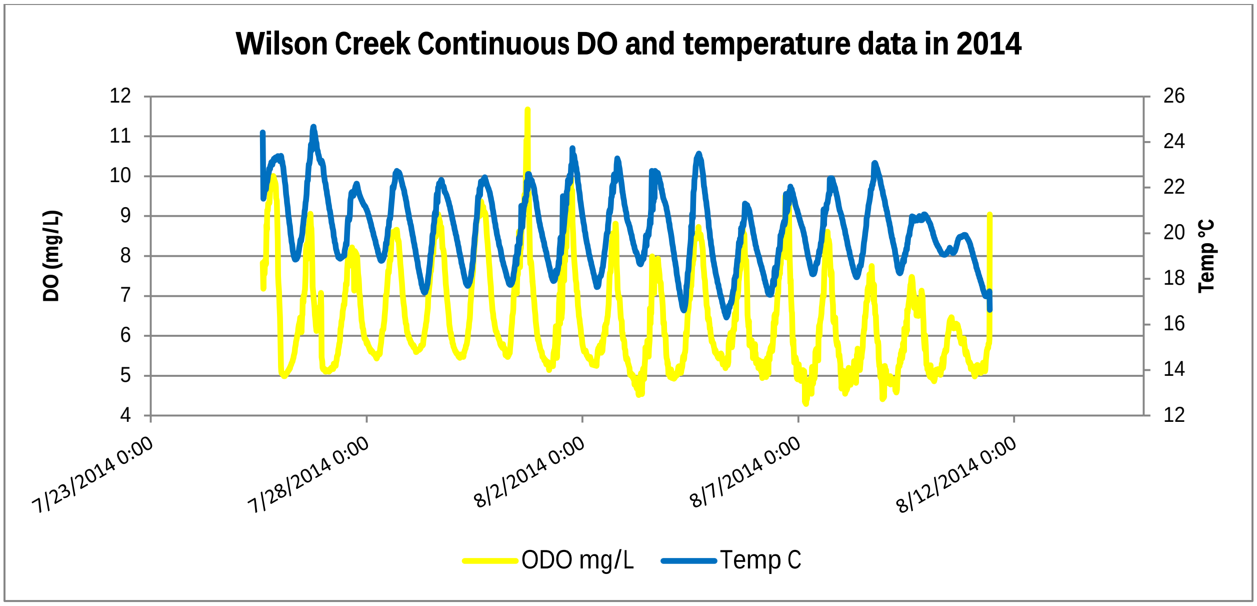


Figure 4.3.2: Continuous DO and stream temperature data from Wilson Creek just upstream of CR171. There are short periods of DO falling below the 5 mg/L standard. Daily DO flux ranges from 2.5 to 4 mg/L per day.

Macroinvertebrate community tolerance indicator values have also been calculated by MPCA. These community tolerance indicator values can be compared against all samples collected for a given stream type. Wilson Creek is in the northern stream glide pool (Class 4). The sampling location on Wilson Creek had higher than average Low DO index scores for macroinvertebrates (Table 4.3.2). The HBI_MN score is a measure of organic pollution and was well above the Class 4 statewide average for passing MIBI scores.

Table 4.3.2: Macroinvertebrate metrics that respond to low DO stress in the Wilson Creek

Station (Year sampled)	TaxaCountAllChir	EPTCh	HBI_MN	Low DO Index Score	Low DO Intolerant Taxa	Low DO Tolerant Pct
12UM133	35	7	7.86	6.95	4	1.3
Statewide average for Northern Forest Stream GP that are meeting the MIBI Threshold (53)	47.3	12.4	6.45	6.62	3.9	22.9
Expected response to stress	↓	↓	↑	↓	↓	↑

Based on the above data sets, low DO concentrations is not a stressor to the macroinvertebrate biological community in Wilson Creek. The elevated HBI_MN score does however suggest that organic enrichment is occurring at the site and low DO could become a problem.

Elevated nutrients

Wilson Creek has one EQuIS station (S007-845) that has a limited amount of water chemistry data from the 2014 season. Water quality data was collected and analyzed for TP, TKN, NO_2NO_3, and NH_3. Samples were collected from April 29, 2014, (snowmelt) through August 13, 2014. The nutrient concentrations were mostly above the Ecoregion TP standard of 0.050 mg/L but less than 0.100 mg/L. The minimum TP sampled was 0.04 mg/L on 8/13/2014 and the maximum TP sampled was 0.12 mg/L on 6/30/2014. The average TP sample concentration was 0.083 mg/L for the 2014 monitoring season. During snowmelt and the end of June TP concentrations were slightly elevated (Figure 4.3.3).The daily DO flux as seen in figure 4.3.2 is around 4mg/L per day. This suggests that nutrient enrichment is causing an increase in primary production. Eutrophication caused by elevated TP concentrations does appear to be an issue in Wilson Creek. Nitrite-nitrate (NO_2NO_3) concentrations are low in Wilson Creek (minimum of <0.05, maximum of 0.12, average of <0.05). Ammonia concentrations are slightly elevated but below levels of concern.

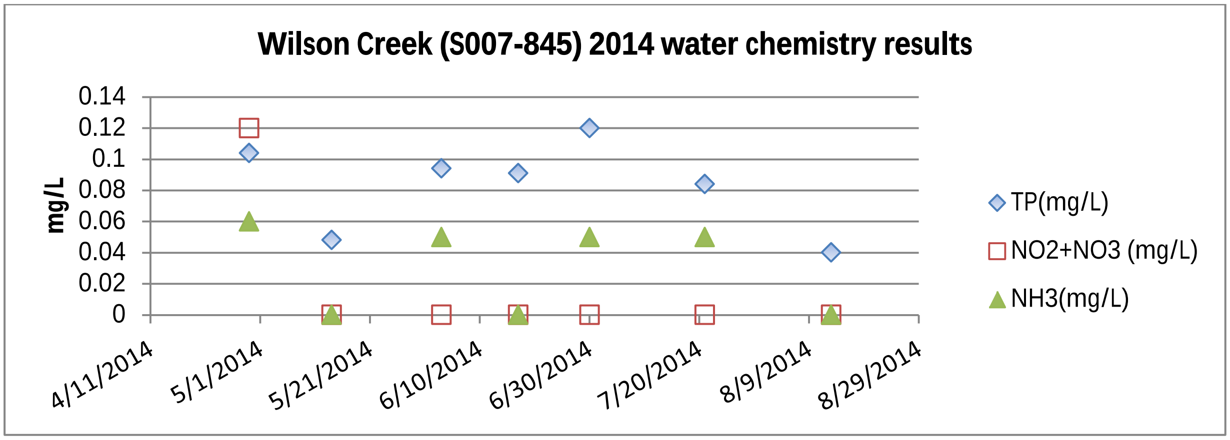


Figure 4.3.3: Nutrient concentrations at water quality sampling locations along the Wilson Creek. Data was collected in 2014.

Biotic response-macroinvertebrates

Evidence of a potential causal relationship between elevated Phosphorus and the MIBI impairment, associated with AUID 529, is provided by the following individual metric responses: 1) an increase in the HBI_MN score, 2) an increase in the percent of taxa that are tolerant (72%) and 3) a decrease in Tanytarsini taxa. Wilson Creek has the lowest Tanytarsini taxa percentage when compared to streams that have passing M-IBI scores in the same stream class. Elevated nutrients are not the main stressor to the macroinvertebrate community but are having an impact on the community through altered primary production in the stream system.

Lack of physical habitat

Habitat quality in Wilson Creek is fair to good. The MSHA was the main tool used for evaluating this potential stressor and the results of the habitat scores can be seen in Figure 4.3.4 below.

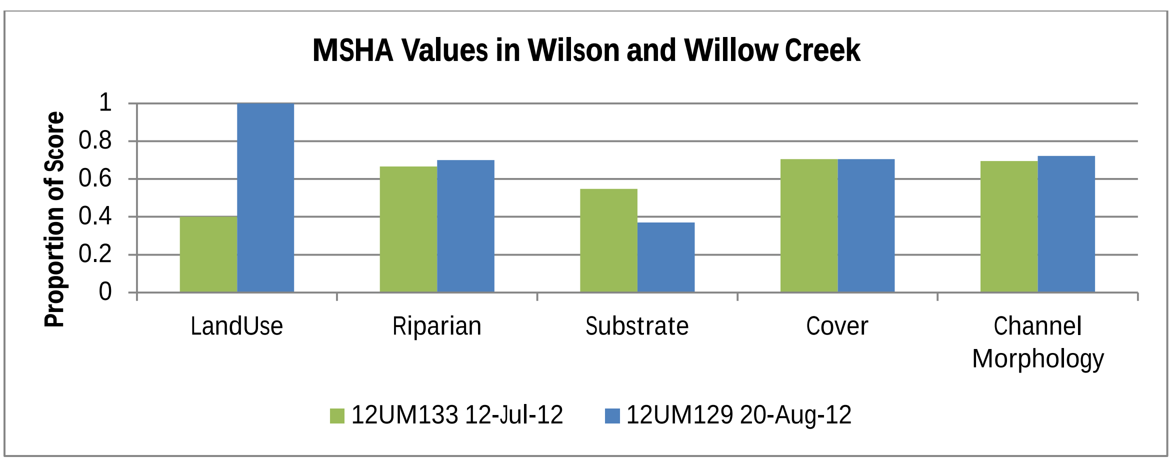


Figure 4.3.4: MSHA values at biologically impaired site on Wilson Creek and on Willow Creek. Both sites are Class 4 for macroinvertebrates. Wilson Creek failed the MIBI while Willow Creek passed the MIBI.

Wilson Creek (12UM133) scored a 63.8 on the MSHA while Willow Creek (12UM129) scored a 63.5 during the 2012 sampling events. Wilson Creek scores low in the land use section because the reach flows through an active cattle pasture that is lacking in riparian vegetation and has limited bank erosion occurring. The macroinvertebrate sample was collected from one habitat type (snag/woody debris). This limited habitat will affect the types and abundance of macroinvertebrates at the site. Due to the limited habitat that was sampled for macroinvertebrates it is believed that lack of habitat diversity is a stressor to the macroinvertebrate community in Wilson Creek. Figure 4.3.5 below shows the general condition of the stream. The far left picture shows the typical snag/woody debris habitat. The right picture shows the sand substrate.

Figure 4.3.5: Wilson Creek 09/24/2014 pictures looking upstream from CR171. Lower section of reach near X-SEC4 of longitudinal profile.

The macroinvertebrate metrics associated with habitat can be found in Figure 4.3.6. Site 12UM133 is compared against the Class 4 mean metric value. Three of the metric values for 12UM133 are below the mean value for Class 4 streams. The metrics sprawler percent and swimmer percent are near 0 for site 12UM133. This indicates that a habitat feature is missing in Wilson Creek and the associated macroinvertebrates that are associated with that habitat type are also missing from the stream.

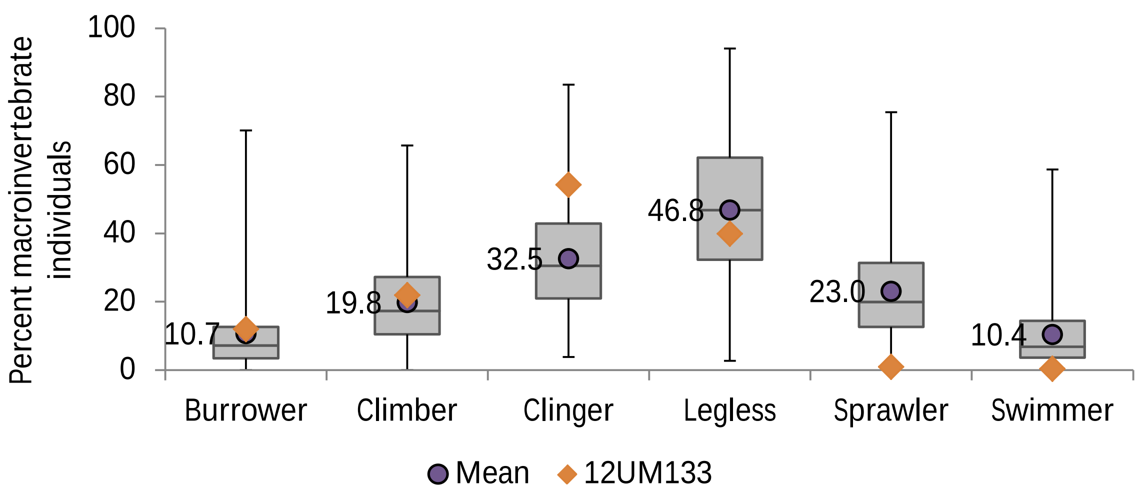


Figure 4.3.6: Macroinvertebrate habitat metrics with box plot showing range of values from natural channel Northern Forest Stream GP stations with MIBI greater than 46.8 (threshold), mean of those stations, and metric values from station 12UM133.

Physical habitat is a limiting factor in the macroinvertebrate community found in Wilson Creek. The macroinvertebrate habitat is limited to one main habitat type.

Increased bedded sediment/ stream channel instability

Channel dimension and profile survey work was conducted just upstream of CR171 on Wilson Creek in 2014. Site 12UM133 was surveyed using the method developed by Rosgen (Rosgen, 1996). Stream channel dimensions along with channel profile and substrate composition were collected at the sampling location. Table 4.3.3 below shows the characteristics of the channel survey inventory. The over widened channel cross section at X-SEC2 is at the tail of a pool and allowing the deposition of fine particles. The stream cannot generate enough stream power to move the sediment out of the pool through the system.

Table 4.3.3: Stream channel statistics for the Wilson Creek Rosgen channel inventory sites.

Site ID	Drainage Area (mi^2)	BKF Width (W_{bkf})	Width of Flood-Prone Area (W_{fpa})	Entrenchment Ratio (W_{fpa}/W_{bkf})	Width to depth ratio	Mean pool Depth to Mean Riffle Depth (d_{bkfp}/d_{bkf})	Reach Particle Size (D_{50}) mm	Classification	Ratio of Incision	Cross-sectional area (ft^2)
Riffle X-SEC3	8.47	6.62	100	15.106	6.37	1.4 to 1.7	0.25	E	1.05	6.86
Pool X-SEC2	8.47	10.16	315	31.00	8.83	1.4 to 1.7	0.12	E	1.17	11.65
Shallow Pool X-SEC1	8.47	11.22	340	28.007	10.0			E	1.65	12.59
Riffle X-SEC4	8.47	9.62	218	22.661	9.82		0.25	E	1.58	9.43

Based on Pfankuch stability rating the surveyed reach had a stability rating of fair (96). The riparian vegetation was intact except at the two main areas where the cattle are accessing the stream for crossing or watering. The amount of bank erosion was minimal. The stream banks have low amounts of bank rock. Bank rock can help stabilize the bank and prevent mass wasting and supply the stream with coarse substrate. Channel incision is a measure of how easily the stream can reach its floodplain. Incision was calculated for the four measured cross sections. Channel incision is a 1.0 when the bankfull water elevation is at the top of the stream banks and can easily expand out into the floodplain. This helps dissipate stream energy and maintains a stable stream bank. As we approach a number of 1.5 or greater the stream is incised and has lost the floodplain connection during bankfull (1.5 year) events. The channel incision is localized to the lower 250 feet of the surveyed channel near the road which results in minimal bank erosion and low sediment supply. Figure 4.3.7 displays the surveyed profile of Wilson Creek. Survey section is just upstream of CR171.

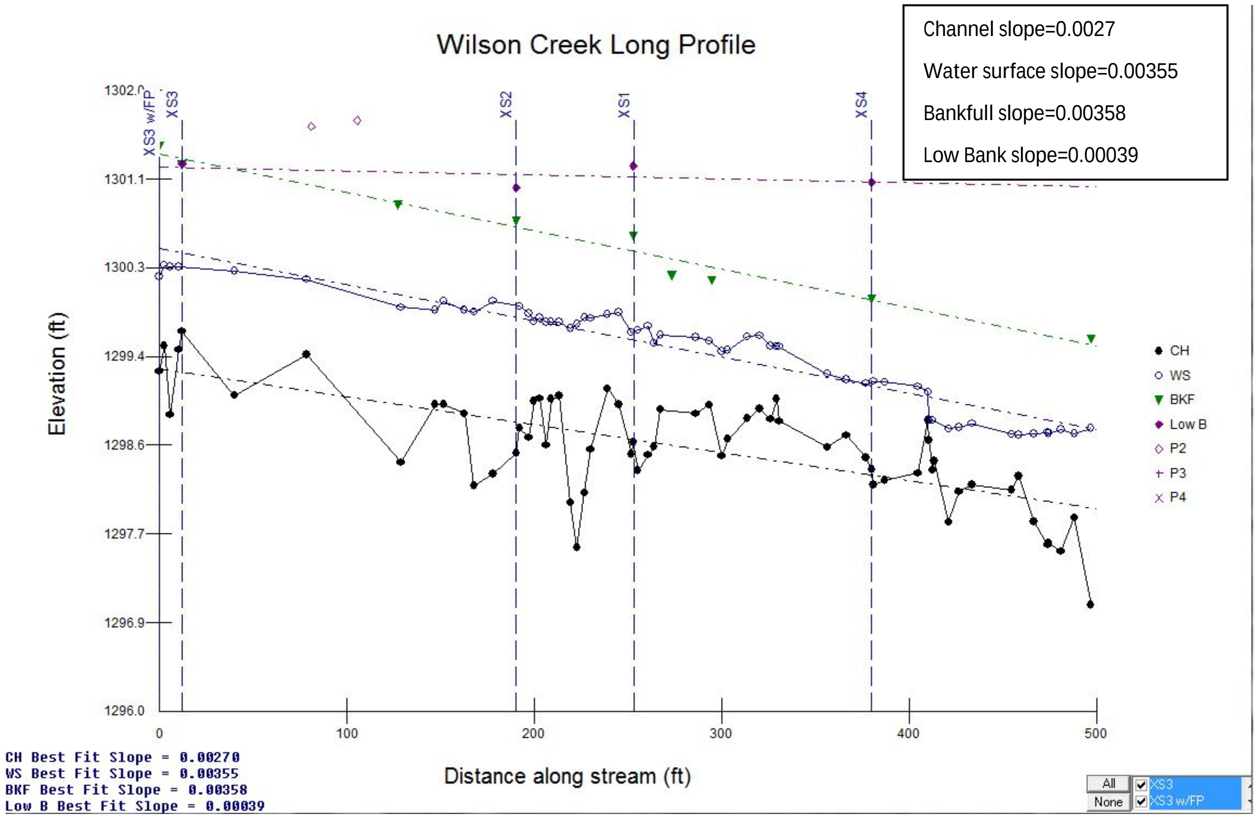


Figure 4.3.7: Wilson Creek survey channel profile. Stream channel becomes incised in the lower 250 feet of survey. This also is the area where cattle have appeared to congregate.

Channel incision will lead to bank instability. As the bankfull discharge stays contained within the channel there is more shear stress applied to the banks. The channel has also widened in the downstream section where the stream is incised. There are areas of bank erosion in the incised area of the creek, and it appears the channel does not have well defined pools in this lower portion. Photo 1 below shows some areas of exposed sediment along the banks. This is partially caused by the cattle having access to the channel along with the localized instability from the channel being incised. Photo 2 below shows the relative height of the stream banks in relation to the bankfull stream discharge elevation.

Photo 1: Looking downstream at Cross section 4 from the survey. Both banks are high compared to bankfull elevation.

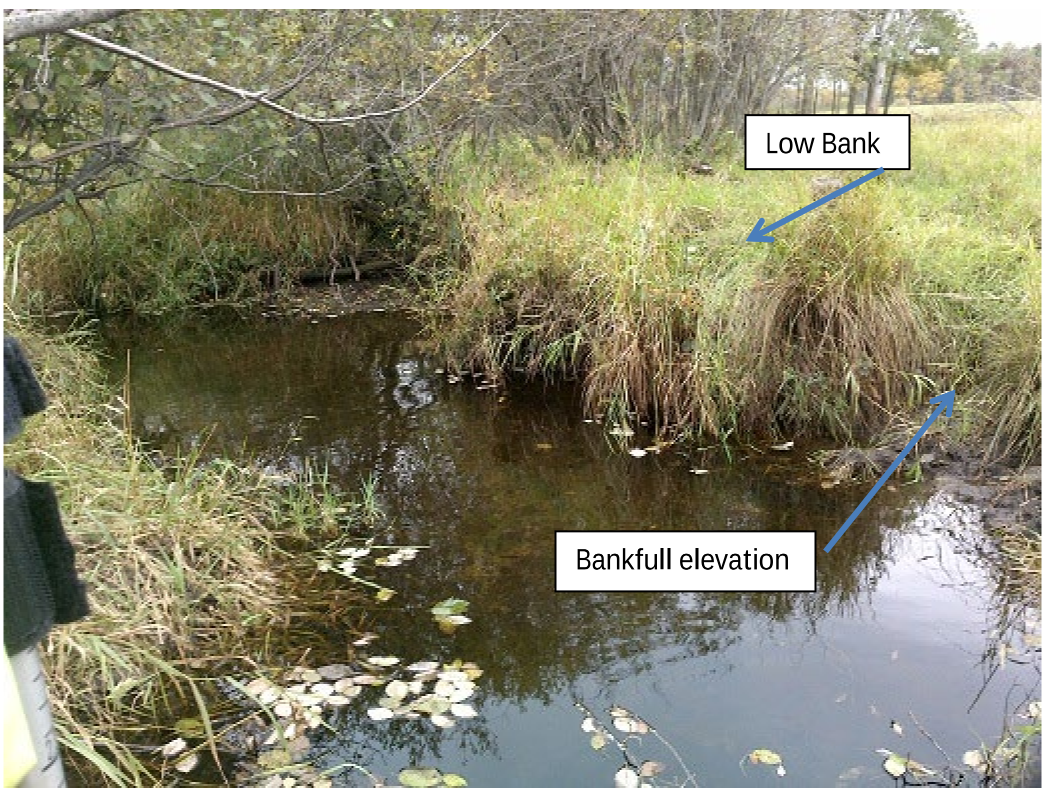


Photo 2: Taken looking downstream from cross section 1. Banks are high in respect to bankfull discharge.

Review of the cross section surveys shows how the channel changes at approximately station 250+00 on the profile. Stations upstream of this point have low banks in relation to the bankfull height, and the stream can access its floodplain at bankfull discharge. The vegetation along this portion of the reach also changes. The willows found in the downstream section become sparse and the majority of the riparian vegetation becomes reed canary grass with some sedges mixed in. Photo 3 shows the riparian vegetation along the stream along with a typical view of the stream. This upstream portion is narrower and has slightly larger substrate size. There is small gravel located in this area of the stream.

Fine sediment deposition was evident in the downstream section of the surveyed reach. The stream bottom was 83% sand and silt/clay. What little gravel was in the channel was embedded by fine sediment. There is enough evidence to show that increased bedded sediment (lack of physical habitat) is a stressor to the macroinvertebrate communities in this AUID.

Photo 3: Cross section 3 of stream. Riparian vegetation has a change from willow to reed canary grass in this section of the reach

Altered stream flow

Wilson Creek flows through a large wetland complex in the headwaters. The stream proceeds to flow north under CSAH 26 where the culvert is perched and causes an effective barrier to any fish migration upstream of this point. Throughout the headwaters region extending throughout the length of Wilson Creek there are numerous beaver dams (Figure 4.3.9) that can hold back water and cause a change in the stream flow regime. During periods of low water there may be times that the stream is nearly dry which will have an impact on the available wetted surfaces for macroinvertebrate colonization. The macroinvertebrate community shows some characteristics of a flow stressed community. The percent of long lived macroinvertebrates is 0.65% of the sample and the relative percent of climber species is nearly double the percent of similar class streams with passing MIBI scores. Various headwater streams and small tributary streams to Wilson Creek have been altered. This can change the delivery of surface runoff by allowing the runoff to enter the streams at a faster rate than under natural conditions. This can also lead to stream bank failure due to higher peak discharges and more frequent peak stream discharges. The channelization that is present in the southern portion of the watershed appears to be designed to drain some wetland areas and allow for pasturing and/ or haying of meadow grasses. There appears to be a relationship between the altered stream flow and the lack of macroinvertebrates at this site.

4.3.3. AUID summary

Wilson Creek lies in the southwestern portion of the PRW. Land use in the impaired portion of Wilson Creek is predominately a mixture of forest, agricultural cropland and rangeland, with 1 registered feedlot located in the subwatershed (Figure 4.3.5). Most of the agricultural land use is located in the downstream section near sampling location 12UM133. There are a small number of unregistered cattle operations also located in the downstream section of Wilson Creek near the sampling location. These operations are utilizing some of the riparian corridor as pasture areas. The pastures can pose a potential for animal waste to enter the stream either directly as cattle stand in the stream or indirectly as runoff occurs during precipitation events.

Photo to the left was taken on September 24, 2014. The cattle had just been placed in the pasture at the survey location. Previous field inspections showed no cattle at the site and the meadow was hayed in 2014 to recover some feed value for winter livestock. Around 10 cows were pastured for around one month in 2014. Various sections of stream channel in the headwaters area have been altered. The altered watercourse layer used to identify stream channels that have been channelized in the past is also shown on the map in Figure 4.3.8. Various headwater streams and small tributary streams to Wilson Creek have been altered. This can change the delivery of surface runoff by allowing the runoff to enter the streams at a faster rate than under natural conditions. This can also lead to stream bank failure due to higher peak discharges and more frequent peak stream discharges. The channelization that is present in the southern portion of the watershed appears to be designed to drain some wetland areas and allow for pasturing and/ or haying of meadow grasses.

The quality of woody habitat is a direct result of the channel flowing through wetland riparian. This wetland corridor is dominated by willows and sedges, and is wet enough to prevent any substantial tree growth from occurring. Just upstream of the sampling location there is an active pasture that lacks any woody riparian vegetation. There are also numerous beaver dams upstream of the sampling site. The beaver dams may be impacting the stream flow in Wilson Creek.

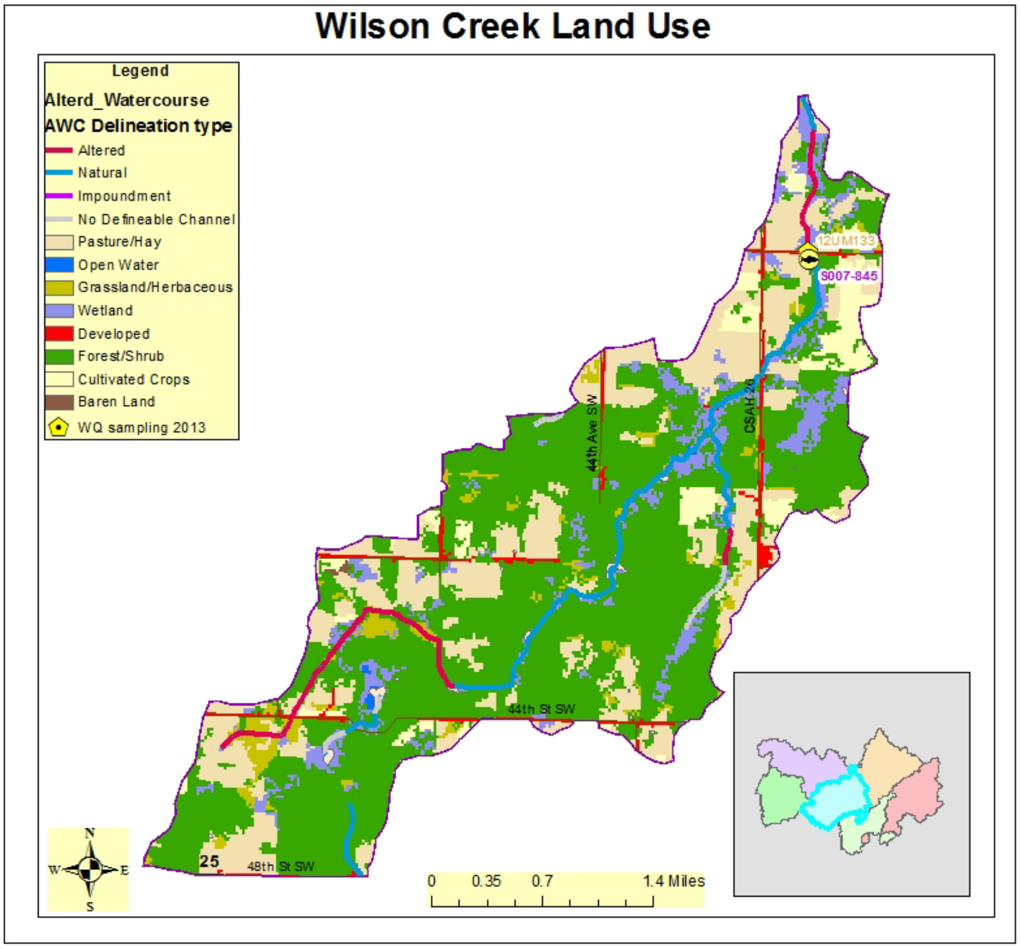


Figure 4.3.8: Wilson Creek sampling locations along with stream channel condition. Land use is also depicted.

Figure 4.3.9 shows the 2013 aerial photo with wetland and highlighted features. The wetland classification of the riparian corridor is Type 3 shallow marsh with some Type 6 shrub swamp interspersed.

Figure 4.3.9: 2013 aerial imagery of sampling location 12UM133 along with NWI circular 39 wetland type and desktop review points of interest.

4.3.3.1. Stressor pathway discussion

The lack of habitat in the stream appears to be a result of the wetland characteristic of the riparian corridor. The increase in fine sediment causing a lack of coarse substrate is probably coming from bank erosion in the pastured section upstream of the sampling location. As seen in Figure 4.3.8, the property just east of CSAH 26 has an active pasture with a significant amount of bare ground that may be contributing significant amounts of fine sediment to the stream during runoff events.

4.3.3.2. Stressor conclusions

Wilson Creek (AUID 07010105-529) is impaired for macroinvertebrates. The MIBI score during the 2012 sampling was 40.7, which is 11 points below the threshold of 52 for the Class 4 macroinvertebrate stream class. Dissolved oxygen and nutrients concentrations were evaluated in 2014, and determined to be within ecoregion norms or above existing water quality standards. The lack of habitat variability at this reach was determined to be the driving factor in the low MIBI scores. Only snag-wood was sampled in 2012. A field survey was conducted in 2014 to determine the stream profile conditions along with substrate composition. It was determined that the section of stream surveyed lacked deep pools and riffles, and the substrate was made up of fine sand with very little habitat complexity and/ or diversity. The stream channel also was incised in the lower half of the survey reach, causing further channel instability. The riparian corridor is made up of sedge/willow wetlands and the E channel type is slightly over widened and shallow during the dryer summer months. The woody debris that is located in the channel appears to be mobile and may not allow for colonization by many macroinvertebrate species.

Exposed sediment caused by overgrazing in upstream pastures is allowing fine sediment to be transported to the stream which is depositing in the downstream sampled area. The particle size in the reach was 0.12 to 0.25 mm. Any coarse substrate that was available is covered with fines. The macroinvertebrate sample was dominated by midges (Chironomini 63%) and five taxa made up 90% of the sample. The sample was also dominated by tolerant taxa (72%). In conclusion, lack of habitat diversity appears to be the main stressor at this location.

Additional sampling for macroinvertebrates will occur in 2015 to understand the nature and extent of the macroinvertebrate impairment. Site 12UM133 will be sampled again along with a new location upstream of CR26. Flow gaging will take place as well in 2015 to better understand the hydrology of the creek.

4.4. South Fork Pine River (AUID-07010105-531)

4.4.1. Biological communities

The fish community in South Fork Pine River (07010105-531) is impaired. The FIBI scored 2 points below the general use threshold at the one sampling location (12UM121). The fish community was dominated by central mudminnow, white sucker and johnny darter. The upstream fish sampling site (12UM120) and the downstream fish sampling site (12UM116) both scored above the general use threshold for FIBI. Sampling site 12UM120 scored 15 points above the threshold and site 12UM116 scored 18 points above the threshold. This indicated that there is something happening at site 12UM121 that is changing the fish community. At sampling location 12UM116, which is downstream of 12UM121 there were 11 fish species sampled with zero central mudminnow. At sampling location 12UM120 there were 18 fish species sampled, and the sample was dominated by creek chub and white sucker. The macroinvertebrate community at this same site scored 14 points above the general use threshold. Table 4.4.1 below shows the comparison in FIBI scores between site 12UM121 and 12UM116 (both Class 5 northern streams).

Table 4.4.1: Class 5 (northern streams fish class) FIBI scores for the South Fork Pine River. Site 12UM121 is located in the biologically impaired AUID (07010105-531) while site 12UM116 is located downstream in AUID (07010105-533). Red highlighted values in table are below the mean score of 5 required to pass the FIBI.

Site ID	Date	Fish IBI	DarterSculpSucTxPct	DetNWQPct	DomTwoPct	FishDELTPct	General	Insect-TolTxPct	IntolerantPct	MA>3-TolPct	SensitiveTxPct	SLithopPct	SSpnTxPct	Vtol
12UM121	24-Jul-12	46	5.68	5.30	9.21	0	6.22	2.27	0.13	2.82	4.83	3.04	2.19	5.45
12UM116	18-Jun-12	65	5.86	6.44	5.45	0	9.09	7.46	0	9.09	7.51	2.17	2.82	9.09

4.4.2. Data analysis/evaluation for each candidate cause

Dissolved oxygen

Dissolved oxygen data was collected at one location in this AUID. The data was collected from EQuIS station S007-846. Figure 4.4.1 below displays the results from the 2014 DO data collection. The instantaneous DO data that was collected in 2014 was always above the 5 mg/L DO standard. A YSI sonde was placed in the South Fork Pine River at station S007-846 for a 16 day period to document the diurnal fluctuation of DO and stream temperature. Figure 4.4.2 displays the continuous sonde data. Figure 4.3.7 displays the DO sampling locations. With the current data, DO does not appear to be a significant stressor to the biological community in the AUID. Low DO does not appear to be limiting the fish and macroinvertebrate community in this AUID. The MPCA (Sandberg, 2013) compiled a fish community stressor Tolerance Indicator Value (TIV) Index to look at the probability of a sampled fish community to meet the designated water quality standard. Site 12UM121 in 2012 had a 28% chance of meeting the DO standard of 5 mg/L, and in 2013 had a 33% chance of meeting the DO standard. This community TIV shows that the fish community is somewhat tolerant to low DO. The fish metric MA>3% is lower at site 12UM121 than it is at site 12UM116 which is downstream. However another fish metric that can help explain if low DO is a problem is the percent of sensitive fish at a sampling location. The percent of sensitive fish are nearly identical at site 12Um121 and site 12AUM116. The fish community is not conclusive in eliminating low DO as a stressor; however the 2014 data does not suggest that low DO is a problem in this AUID.

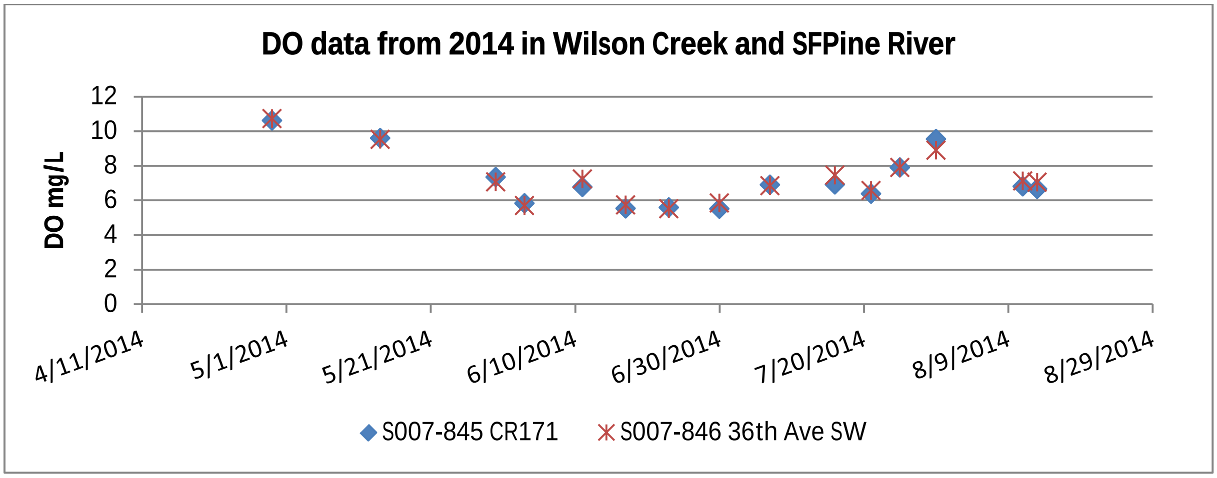


Figure 4.4.1: Synoptic DO data from AUID 07010105-529 at CR176 road crossing. All DO readings were above 5 mg/L.

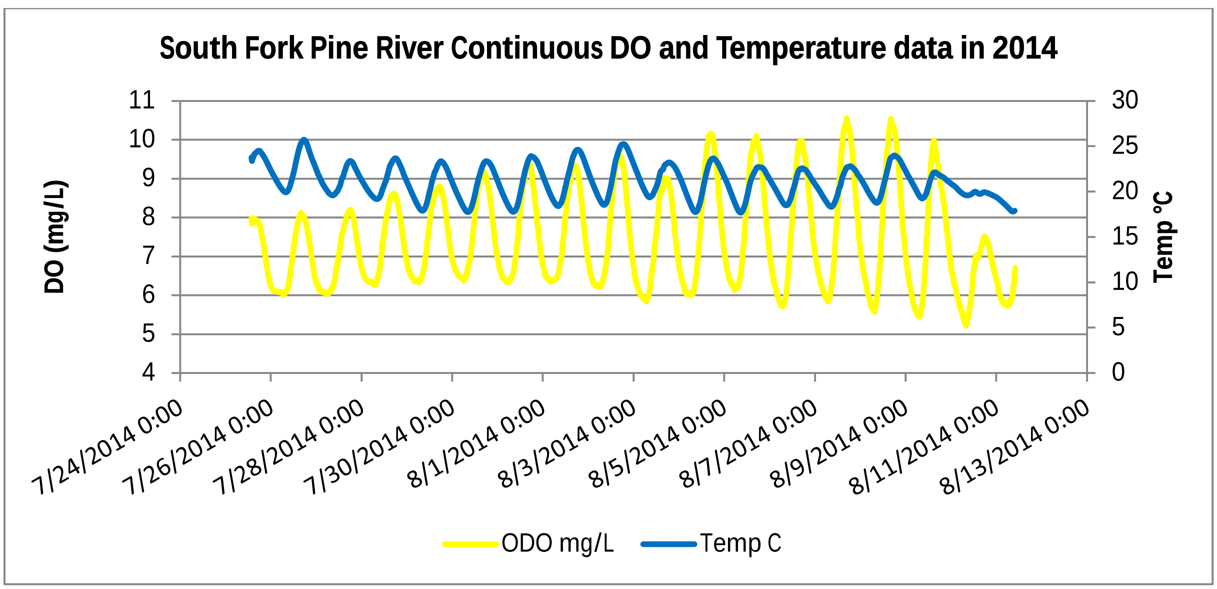


Figure 4.4.2: Continuous DO and stream temperature data from Wilson Creek just upstream of CR171. There are short periods of DO falling below the 5 mg/L standard. Daily DO flux ranges from 2.5 to 4 mg/L per day.

MPCA has also created a stressor tolerance index for macroinvertebrates. Splitting the community DO index value into the different stream classes for macroinvertebrates in Minnesota is one way to identify if the macroinvertebrate community is showing signs of DO tolerance. Site 12UM121 scored a 7.24 on the DO Index Value. This value is then compared to the rest of the Class 4 streams in the state to determine the relative placement of the score. Table 4.4.2 below shows the statistics for all Class 4 stream macroinvertebrate community DO index values. The value of 7.24 ranks Site 12UM121 in the upper 70th percentile which indicates that the macroinvertebrate community is intolerant to low DO readings. There are more DO intolerant macroinvertebrate taxa than there are DO tolerant taxa in the sample, and 0 DO very tolerant taxa at site 12UM121. Looking at the DO data along with the fish and macroinvertebrate community data tells us that low DO is not a stressor to the biological communities at site 12UM121.

Table 4.4.2: Class 4 macroinvertebrate DO Index Value ranked for all Class 4 sites in Minnesota. The lower the value the more tolerant to low DO levels in the stream.

	DO Index Value
N of Cases	252
Minimum	5.85
Maximum	7.70
Interquartile Range	0.62
Arithmetic Mean	6.98
Standard Deviation	0.41
Method = CLEVELAND	
1.00%	6.00
5.00%	6.22
10.00%	6.40
20.00%	6.69
25.00%	6.69
30.00%	6.76
40.00%	6.90
50.00%	7.05
60.00%	7.15
70.00%	7.25
75.00%	7.31
80.00%	7.38
90.00%	7.46
95.00%	7.49
99.00%	7.65

Elevated nutrients

AUID 07010105-531 has one EQuIS station (S007-846) that has a limited amount of water chemistry data from the 2014 season. Water quality data was collected and analyzed for TP, TKN, NO2NO3, and NH3. Samples were collected from April 29, 2014, (snowmelt) through August 13, 2014. The nutrient concentrations were mostly below the ecoregion TP standard of 0.050 mg/L. The 2014 TP samples had a concentration minimum of 0.021 mg/L, maximum of 0.096 mg/L and average of 0.051 mg/L. During the end of June and late July, TP concentrations were slightly elevated (Figure 4.4.3). Certain biological metrics can help in understanding if eutrophication is a cause of stress to the fish community. Biological metrics such as sensitive percent, darter percent, and tolerant percent can all help explain if the fish community is impacted by elevated nutrients. The sensitive percent for 12UM121 averaged 18%, the darter percent averaged 19%, and the tolerant percent averaged 47%. When comparing site 12UM121 against site 12UM116 (which is downstream and passes the FIBI) the sensitive percent is 4% lower at site 12UM121 and the tolerant percent is 30 percentage points higher at 12UM121. The tolerant percent is even higher at the upstream sampling site 12UM120 which passed the FIBI. The tolerant percent averaged 60% at site 12UM120. Macroinvertebrate data also suggests that eutrophication is not a driving factor in the south Fork Pine River. A response to eutrophication would be an increase in peryphyton growth which would show as an increase in the scraper macroinvertebrate community. The relative abundance of scrapers at site 12UM121 was 7%. The macroinvertebrate community was also diverse and the dominant two taxa accounted for 37% of the relative abundance. Eutrophication caused by elevated TP concentrations does not appear to be an issue in the South Fork Pine River. Nitrite-nitrate (NO_2NO_3) concentrations are low in the South Fork Pine River as well. Ammonia concentrations are slightly elevated in mid-summer but below levels of concern. Eutrophication does not appear to be an issue in this AUID.

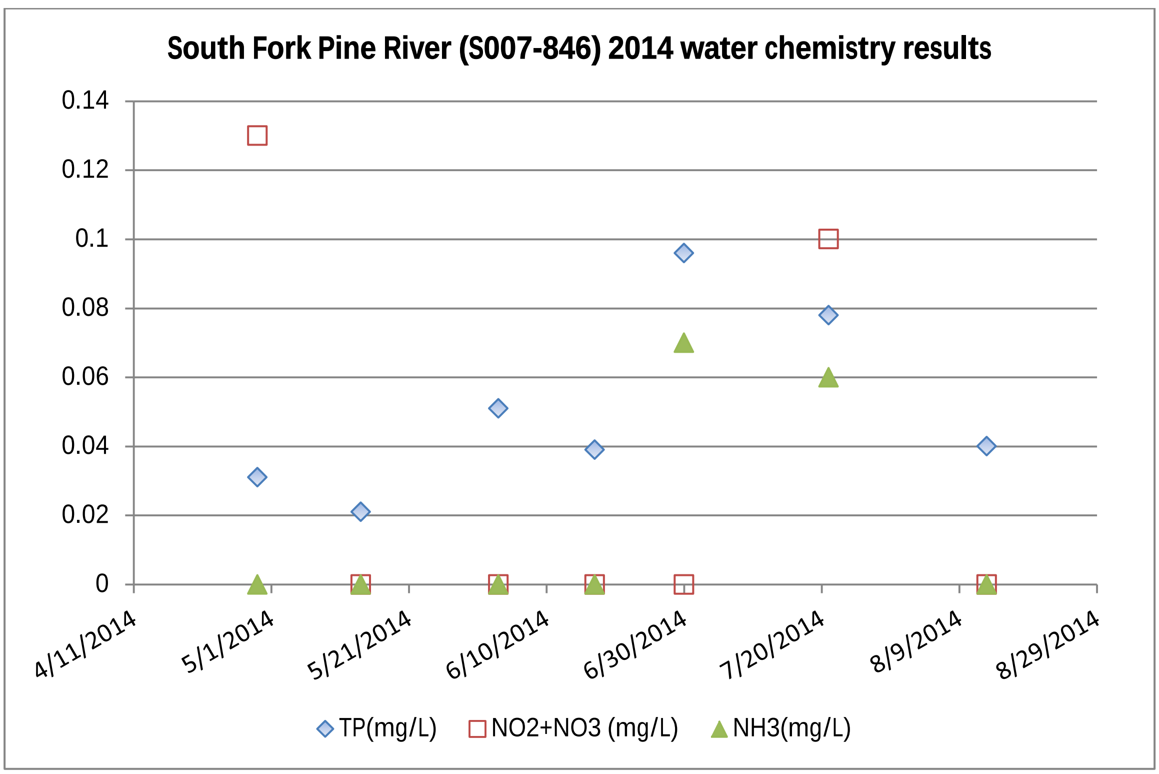


Figure 4.4.3: Nutrient concentrations at water quality sampling locations along the South Fork Pine River (S007-846). Data was collected in 2014.

Biotic response-fish and macroinvertebrates

There is not a clear relationship between eutrophication and the biological communities at AUID 531. The macroinvertebrate community would be dominated by a small number of taxa and the relative abundance of scrapers should be higher than the observed relative abundance. Scrapers feed on peryphyton and during field visits there was not an abundance of peryphyton growth in the stream. Increased peryphyton would be a direct response to elevated nutrient concentrations. The fish community would show a reduction in sensitive fish taxa and darter taxa, and an increase in tolerant taxa. Sensitive fish taxa are lower at 12UM121 than at the downstream passing FIBI site 12UM116, and the tolerant taxa relative abundance is nearly 30% higher at site 12UM121. However the relative abundance of tolerant taxa at site 12UM120 (which passes the FIBI and is upstream) is even higher in tolerant fish taxa relative abundance. The biological data does not suggest that eutrophication is currently acting as a stressor to the community.

Lack of physical habitat

The South Fork Pine River has three biological monitoring stations. The upstream site 12UM120 scored an average of 68 on FIBI, with an average MSHA score of 45 for two visits. Site 12UM121 (which is in the middle of the three sites and is impaired for fish) averaged a 44 on FIBI and 58 on MSHA, while site 12UM116 which is the farthest downstream biological site scored a 65 on FIBI and a 57 on MSHA. Something is causing the drop in FIBI score between the three sites. It is believed that the downstream culverts are adversely affecting the stream reach upstream of 36th Avenue at site 12UM121. The culverts appear to be slightly undersized and perched (Figure 4.4.5). This is causing fine sediment particles time to settle out in the stream reach and alter the natural particle distribution. The coarse substrate is being covered with sand and silts which is limiting the substrate variability and limiting the species of fish found in this reach. Figure 4.4.5 shows the condition of the triple culverts on 36th Avenue along with channel conditions.

Habitat quality in South Fork Pine is fair as indicated by the scores of 57 and 59. The MSHA was the main tool used for evaluating this potential stressor and the results of the habitat scores can be seen in Figure 4.4.4 below. Site 12UM121 scores low in the substrate and channel morphology categories. The substrate scores low because the entire reach is dominated by sand and silt. Upon walking the reach in September 2014 and conducting pebble counts, the reach and the riffles are sand dominated. This substrate diminishes the available habitat for simple lithophilic spawning fish. The two fish sampling events showed 23% of the sample was simple lithophilic spawners in 2012 and 16% simple lithophilic spawners in 2013. Site 12UM120 averages 45% simple lithophilic spawners while site 12UM116 has 17% simple lithophils. The fish metrics that scored poorly at site 12UM121 are simple lithophilic percent, the serial spawning taxa percent, fish that mature at age >=3 years, the number of insectivore fish species minus the tolerant insectivore fish species. These four IBI metrics accounted for the low FIBI score. Three of the four metrics are directly related to reproduction and a case can be made that a lack of suitable spawning habitat is causing the low numbers of fish taxa in these categories.

The MSHA data is not giving us enough difference between sites to distinguish if habitat is the driving factor in the lower FIBI at 12UM121. Because of the scoring and similarities in scores, it is impossible to tease out if aspects of the habitat are causing the fish impairment. It is believed that the consistent lower scoring substrate score is different enough from the two passing sites to be causing a change in fish community on a local scale.

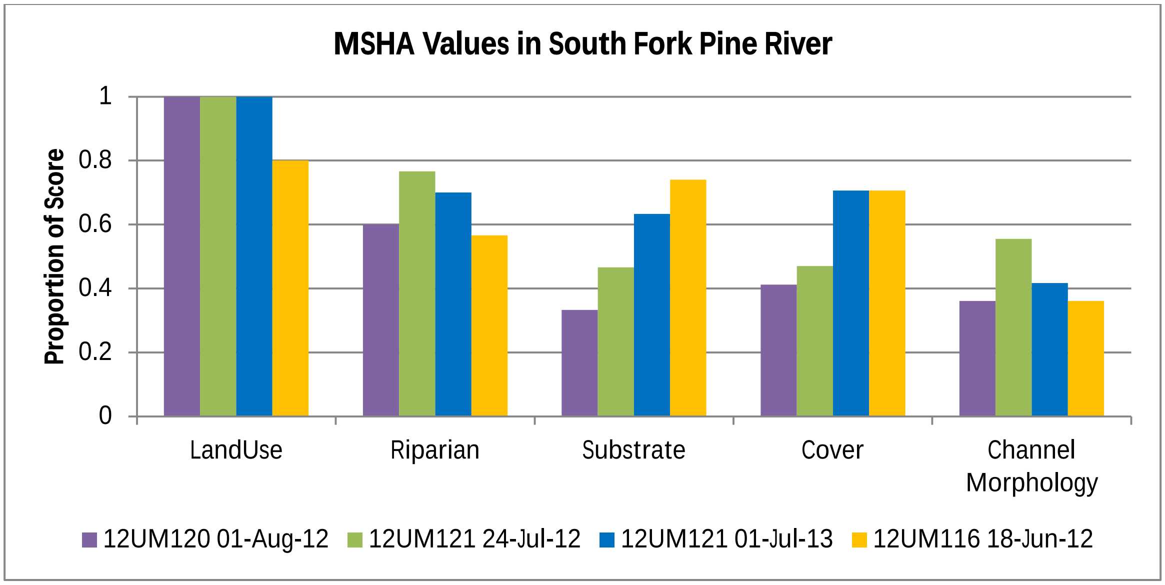


Figure 4.4.4: MSHA values at biologically sampled sites on South Fork Pine River. All sites are Class 6 for fish. Site 12UM121 failed the FIBI while sites 12UM120 and 12UM116 passed the FIBI.

Another data set was collected to help understand the differences between the three sites. In 2014 the MPCA partnering with the MDNR collected some additional data at sites 12UM120, 12UM121 and 12UM116 to determine if habitat or lack of is driving the low FIBI score at 12UM121. Pfankuch stability rating was conducted at the three biological sites. Site 12UM120 which is farthest upstream scored a 91 which is a fair rating for a C5 stream type. This site is controlled by a culvert under 48th Avenue which may be impacting the stream at this location as well. There is a large scour pool located just downstream of the culverts which is caused by water being forced out of the culverts during high flow. Moving downstream the South Fork Pine has bridges crossing the channel until we reach sampling site 12UM121 where three arch culverts are installed. These culverts appear undersized based on the large scour pool downstream and the downstream channel appears at least 25% wider downstream of the culverts. The Pfankuch stability rating at this site was also fair for a C5 stream type. Moving downstream to site 12UM116 the Pfankuch rating was good for a C4 stream type. This downstream section has gravel and cobble dominated substrate which is much coarser than the two upstream locations which are sand. The difference in Pfankuch stability rating between site 12UM121 and site 12UM116 leads to the conclusion that the culverts are locally causing problems for the 12UM121 stream reach. There is greater channel aggradation and sediment deposition at the 12UM121 site than downstream. The debris jam potential is also greater in the 12UM121 reach along with a higher chance of bank instability (there is very little rock content in the 12UM121 banks, exposed banks are sand dominated and easily eroded). In conclusion lack of physical habitat is considered a stressor to the fish community at site 12UM121.


June 17, 2014, photos of 36th Avenue crossing. Left photo is upstream side. Right photo is downstream side. Note velocity differences from two sides of culvert. Upstream slope is flat. Downstream has greater slope with higher velocity.


September 25, 2014, photos of deposition near site 12UM121 along with typical channel condition along reach.

Figure 4.4.5: Photos of South Fork Pine River during high flow period in June 2014 and low flow period in September, 2014. During high flows the culverts may be backing up water allowing fine particles to settle on the upstream side.

Increased sediment

The water quality standard for TSS is 15 mg/L in the PRW. Excess sediment is a commonly recognized stressor in many biologically impaired streams because it can reduce habitat, cause direct physical harm, as well as reduce visibility and increase oxygen demand.

South Fork Pine River had limited TSS samples collected in 2014 at EQuIS site S007-846. The TSS samples were all below the 15 mg/L standard in 2014 (ranged from 1.2 to 4.8 mg/L) however; the dataset is small and is limited to only 2014 data. Biological metric data will be used to determine if TSS is considered a stressor to the fish community.

During the field survey conducted in September 2014 it was documented that there was a small amount of bank erosion occurring in the study area. This bank erosion is active on outside bends of the river. The significance of this bank erosion is difficult to link directly to the lack of fish at the study site. It is believed that the bank erosion is having an impact on the fish community. When the individual fish are analyzed based on tolerance metrics developed by Carlisle (Carlisle, Wolcock, & Meador, 2010) and analyzed to determine tolerance to excessive sediment, the individual fish species show 44 - 50% of the sample is tolerant to excess sediment. Figure 4.4.6 below shows the individual fish species when ranked against sediment tolerance values developed by Carlisle in 2010. Quartile 1 and 2 would be the fish species most tolerant to elevated sediment. Some fish taxa metrics that can help identify TSS as a stressor are increased benthic insectivores and a decrease in long lived fish species. The relative abundance of benthic insectivores is highest at site 12UM121 (15 - 20% higher than both the upstream and downstream sites) and the relative abundance of long lived fish at both site 12UM121 and 12UM120 is 40% lower than at site 12UM116.

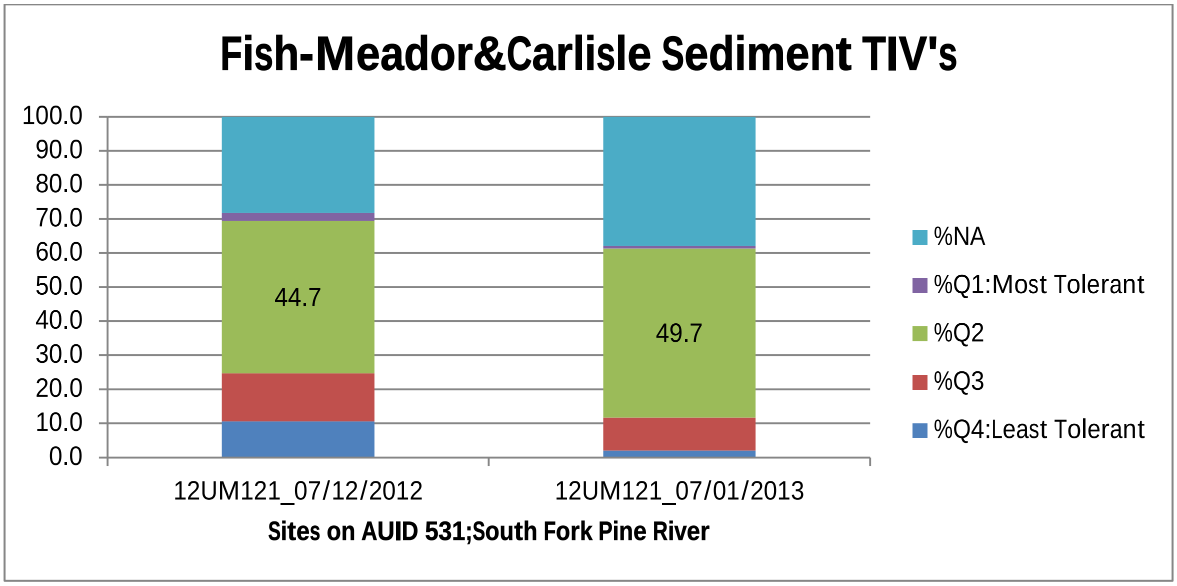


Figure 4.4.6: Tolerance to increased sediment based on TVs developed by Carlisle (2010). Fish genera are given a TV and ranked according to quartiles.

On September 25, 2014, a crew from MDNR and MPCA went to the site to survey the stream reach above 36th Avenue to document the stream profile and cross sectional area. This data was collected in an attempt to better understand the geomorphology of the reach and help understand the interactions of the culverts. The channel survey revealed a very flat water surface slope (0.0004 ft. /ft.) and a very flat bankfull discharge slope (0.00045 ft. /ft.). There was evidence of deposition along the channel in the form of point bars, lateral bars, and some transverse bars. The material being deposited was medium sand as seen in Figure 4.4.5. The particle size in the channel was 0.26 mm for the reach and 0.1 mm in riffle cross section 2. Fines could be seen throughout the entire reach and areas of bank erosion were also occurring. This reach has a history of moving around within the valley walls and new channels being formed and abandoned periodically according to the aerial photography available for review. Historically there is some evidence of ditching and deforestation. It is possible that the historical land alterations have caused instability within this reach and the instability has been further enhanced by the placement of the undersized culverts at 36th Avenue. Increased fine sediment in the stream channel does appear to be impacting the fish community at this site.

Physical connectivity

The culverts on 36th Avenue appear to be causing a localized slope issue in the channel and possibly a fish barrier issue during periods of high flow. Spring snow melt events can elevate the stream high enough to cause flooding of 36th Avenue. This occurred in April of 2014 and according to local residents it is an annual occurrence. The culverts also pose fish passage issues during heavy rain events as can be seen in Figure 4.4.5 above.

The slope of the channel is flat above the culverts at 36th Avenue and this appears to be causing excessive fine sediment deposition and loss of stream features. The substrate in the upstream portion of the AUID is also dominated by fine sand. The culvert at 36th Avenue is acting as a fish barrier during periods of moderate to high flow. This may be limiting the migratory patterns of some of the smaller minnow species which are present downstream of 12UM121. The cross sectional area of the channel upstream of 36th Avenue at a typical riffle is around 55 ft^2 while the 3 - 6 foot culverts at 36th Avenue have a cross sectional area of approximately 84 ft^2. The upstream bottom elevation of the culverts is also 0.5 foot higher than the stream bottom. Estimated velocity at bankfull discharge is 3.2 to 4.6 ft./sec. This velocity would prohibit most minnow size fish from migrating through the culverts at bankfull discharge. The percent of migratory fish at site 12UM121 averages 13%, while the migratory fish percent at both the upstream and downstream sites are closer to 20% of the sample. Using migratory fish as a surrogate for connectivity suggests that the culverts at 36th Avenue are acting as a partial fish barrier and should be considered a stressor to the localized fish community at site 12UM121.

4.4.3. AUID summary

AUID 07010105-531 lies in the southwestern portion of the PRW in the South Fork Pine aggregated 12-HUC. The land use surrounding this AUID is predominately forest with a mixture of pasture and agricultural row crop. Figure 4.4.7 shows the land use along with the position of the AUID in relation to the overall watershed boundary. There are sections of altered stream channel located in tributaries to the South Fork Pine River. These sections may be altering the delivery of flow and possibly changing the hydrology of the receiving stream. More study would need to be conducted to determine if altered hydrology is affecting the South Fork Pine River. The South Fork Pine River has multiple road crossings. Most of the road crossings are bridges with would have no impact on fish migration. However there are two crossings that have culverts. One of these crossings is at 36th Avenue which is just downstream of biological site 12UM121. The other is at 48th Avenue which is just downstream of biological site 12UM120. The culverts at 12UM121 appear to be changing the slope of the channel on the upstream side and may also be preventing fish from passing during periods of high flow. Stream slope and velocities increase on the downstream side of the 36th Avenue culverts.

Registered feedlots and riparian pasturing operations can have an impact on water quality. Direct drainage of nutrient rich soil and manure runoff can increase the phosphorus and nitrogen concentrations in the stream. This can increase plant productivity in the stream and have an effect on the daily DO concentrations. The riparian corridor was reviewed using ArcMap with the 2013 aerial image to determine if there was riparian encroachment from pasturing operations or row crop production. There were 0 pasturing operations and only a few small hayfields located adjacent to the South Fork Pine River. There are 0 registered feedlots located in the South Fork PRW. The riparian corridor is predominately shrub swamp and is mostly intact.

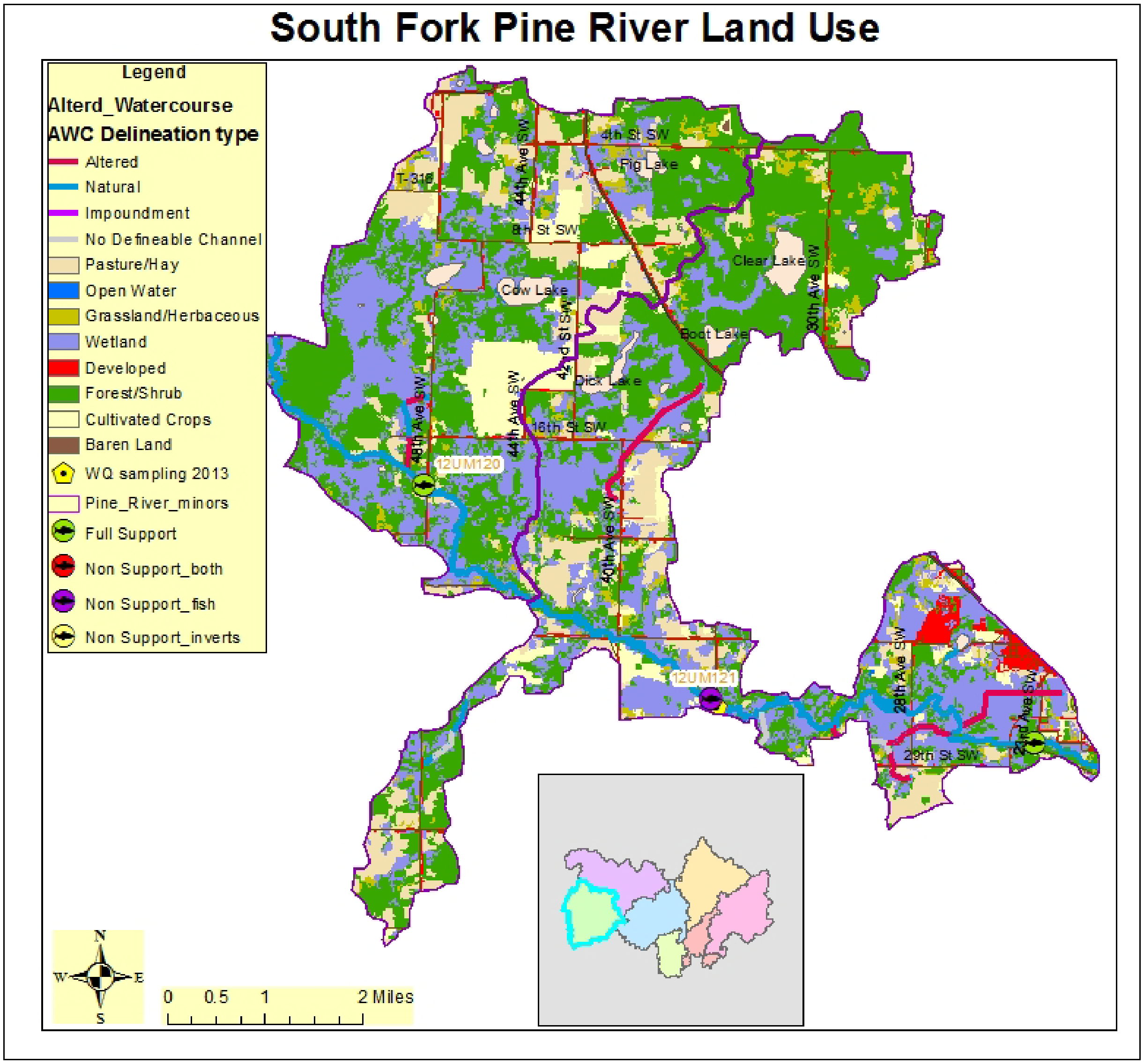


Figure 4.4.7: Land use within the boundaries of the South Fork Pine River upstream from the city of Pine River.

4.4.3.1. Stressor pathway discussion

The stream channel slope in the study reach was flat in the stream section surveyed. The bankfull discharge is estimated to have 3.2 to 4.6 ft./sec velocities which may cause significant amounts of bank failure during bankfull discharge events. The bankfull event will occur on average every 1.5 years. So this event is common and can occur during snowmelt or heavy summer thunderstorms. The increased sediment is causing a lack of habitat.

4.4.3.2. Stressor conclusions

Dissolved oxygen concentrations along with nutrient concentrations appear to not be affecting the biological community in the South Fork Pine River. Data collected in 2014 shows that at least during the monitoring season the concentrations of DO were above the standard and nutrient concentrations were only slightly elevated when compared to the river nutrient standards. Fish habitat seems to be one of the driving factors in the lower FIBI score. The slope of the channel is flat above the culverts at 36th Avenue and this appears to be causing excessive fine sediment deposition and loss of stream features. The substrate in the upstream portion of the AUID is also dominated by fine sand. The culvert at 36th Avenue is acting as a fish barrier during periods of moderate to high flow. This may be limiting the migratory patterns of some of the smaller minnow species which are present downstream of 12UM121. The cross sectional area of the channel upstream of 36th Avenue at a typical riffle is around 55 ft^2 while the 3 - 6 foot culverts at 36th Avenue have a cross sectional area of approximately 84 ft^2. The upstream bottom elevation of the culverts is also 0.5 foot higher than the stream bottom. Estimated velocity at bankfull discharge is 3.2 to 4.6 ft./sec. This velocity would prohibit most minnow size fish from migrating through the culverts at bankfull discharge.

5. Conclusions

Poor habitat quality is a common theme in the impaired AUIDs throughout the PRW. Lack of physical habitat is a concern to the impaired biotic communities. The habitat tool used to evaluate this stressor is the MSHA score. This score was poor to fair at the impaired stream stations sampled in each impaired AUID. Rosgen Level 2 survey work was also conducted at the impaired reaches to document channel pattern and profile along with stream facet conditions. The South Fork Pine River has an elevated set of culverts located at 36th Avenue which is causing limited fish passage during the year along with deposition of fine sediment upstream of the road. Table 5.1 below lists the stressor(s) to the biotic community by stream AUID. Each AUID has multiple stressors affecting the biology.

Table 5.1: Summary of probable stressors in the Pine River Watershed.

		Stressors					
Stream Name	**AUID #**	**Low Dissolved Oxygen**	**Flow Alteration**	**Increased Sediment**	**Elevated Nutrients**	**Lack of Physical Habitat**	**Physical Connectivity**
Wilson Creek	**07010105-529**		**X**		**X**	**X**	
South Fork Pine	**07010105-531**			**X**		**X**	**X**
Arvig Creek	**07010105-509**	**X**			**X**	**X**	
Willow Creek	**07010105-631**					**X**	**X**

X Stressor to biological community

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7. Appendix

7.0 Appendix A

Figure 7.0.1: Scoring of candidate causes for Wilson Creek.

	Wilson Creek (AUID 07010105-529)		
	Scores of candidate causes		
Types of evidence	Lack of physical habitat	Flow alteration	Elevated nutrients
Spatial/temporal co-occurrence	+++	++	+
Temporal sequence	++	0	0
Field evidence of stressor-response Causal pathway	+++	++	+
Evidence of exposure, biological mechanism	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE
Verified or tested predictions	+++	++	++
Symptoms	+	0	0
	Evidence using data from other systems		
Mechanically plausible cause	+	+	+
Stressor-response in other lab studies	NE	NE	NE
Stressor-response in other field studies	++	+	+
Manipulation experiments at other sites	NE	NE	NE
Analogous stressors	NE	+	+
	Multiple lines of evidence		
Consistency of evidence	+++	++	+
Explanatory power of evidence	+++	+	+

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	but other possible factors
++	Strongly supports	but potential confounding factors
+	Some support	but association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	somewhat weakens support	but association does not necessarily reject as a cause
--	strongly weakens	but exposure or mechanism possibly missed
---	Convincingly weakens	but other possible factors
NE	No evidence available	

Figure 7.0.2: Scoring of candidate causes for South Fork Pine River.

	South Fork Pine River (AUID 07010105-531)		
	Scores of candidate causes		
Types of evidence	Physical connectivity	Lack of physical habitat	Increased sediment
Spatial/temporal co-occurrence	+	++	++
Temporal sequence	+	+	+
Field evidence of stressor-response Causal pathway	0	++	+
Evidence of exposure, biological mechanism	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE
Verified or tested predictions	+	+	++
Symptoms	+	++	+
	Evidence using data from other systems		
Mechanically plausible cause	0	+	++
Stressor-response in other lab studies	NE	NE	NE
Stressor-response in other field studies	+	+	++
Manipulation experiments at other sites	NE	NE	NE
Analogous stressors	NE	NE	NE
	Multiple lines of evidence		
Consistency of evidence	+	++	+
Explanatory power of evidence	+	++	+

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	but other possible factors
++	Strongly supports	but potential confounding factors
+	Some support	but association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	Somewhat weakens support	but association does not necessarily reject as a cause
--	Strongly weakens	but exposure or mechanism possibly missed
---	Convincingly weakens	but other possible factors
NE	No evidence available	

Figure 7.0.3: Scoring of candidate causes for Arvig Creek.

	Arvig Creek (AUID 07010105-509)		
	Scores of candidate causes		
Types of evidence	Low DO concentration	Elevated nutrients	Lack of physical habitat
Spatial/temporal co-occurrence	++	++	++
Temporal sequence	+	+	+
Field evidence of stressor-response Causal pathway	+	+	0
Evidence of exposure, biological mechanism	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE
Verified or tested predictions	++	++	+
Symptoms	+	0	0
	Evidence using data from other systems		
Mechanically plausible cause	+	++	+
Stressor-response in other lab studies	NE	+	NE
Stressor-response in other field studies	+	+	0
Manipulation experiments at other sites	NE	NE	NE
Analogous stressors	+	+	NE
	Multiple lines of evidence		
Consistency of evidence	++	++	++
Explanatory power of evidence	++	++	+

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	but other possible factors
++	Strongly supports	but potential confounding factors
+	Some support	but association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	Somewhat weakens support	but association does not necessarily reject as a cause
--	strongly weakens	but exposure or mechanism possibly missed
---	Convincingly weakens	but other possible factors
NE	No evidence available	

Figure 7.0.4: Scoring of candidate causes for Willow Creek.

	Willow Creek (AUID 07010105-631)	
	Scores of candidate causes	
Types of evidence	Lack of physical habitat	Physical connectivity
Spatial/temporal co-occurrence	++	+
Temporal sequence	+	+
Field evidence of stressor-response Causal pathway	++	++
Evidence of exposure, biological mechanism	NE	NE
Field experiments/ manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	+	0
Symptoms	++	+
	Evidence using data from other systems	
Mechanically plausible cause	+	+
Stressor-response in other lab studies	NE	NE
Stressor-response in other field studies	+	+
Manipulation experiments at other sites	NE	NE
Analogous stressors	NE	NE
	Multiple lines of evidence	
Consistency of evidence	+	+
Explanatory power of evidence	++	+

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	but other possible factors
++	Strongly supports	but potential confounding factors
+	Some support	but association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	Somewhat weakens support	but association does not necessarily reject as a cause
--	Strongly weakens	but exposure or mechanism possibly missed
---	Convincingly weakens	but other possible factors
NE	No evidence available	