Stressor identification

April 2020

Kettle River Watershed Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities and other aspects of streams and lakes

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Acronyms and term definitions

APM .... Aquatic Plant Management

AUID .... Assessment Unit (Identification Number) MPCA's pre-determined stream segments used as units for stream/river assessment – each has a unique number.

AWC .... MPCA's Altered Watercourse Project

CR .... County Road

CSAH .... County State Aid Highway

DO .... Dissolved Oxygen

DOC .... Dissolved Organic Carbon

DOW .... Division of Waters

DNR .... Minnesota Department of Natural Resources

DS .... Downstream

EPA .... United States Environmental Protection Agency

EPT .... Three important taxonomic orders of stream macroinvertebrates whose members are typically sensitive to stream degradation - **E**phemeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddisflies)

FIBI .... Fish-based lake Index of Biological Integrity; an index developed by the DNR that compares the types and numbers of fish observed in a lake to what is expected for a healthy lake (range from 0–100). More information can be found at the DNR Lake Index of Biological Integrity website

GIS .... Geographic Information System

HDS .... Human Disturbance Score – a measurement of human disturbance at and upstream of a biological monitoring site. The best score is 81 points.

HUC .... Hydrologic Unit Code (a multi-level coding system of the US Geological Survey, with levels corresponding to scales of geographic region size)

HSPF .... The hydrologic and water quality model **H**ydrologic **S**imulation **P**rogram **F**ortran.

IBI .... Index of Biological Integrity – a multi-metric index used to score the condition of a biological community.

Insectivorous species.. A species that predominantly eats insects

Intolerant species ...... A species whose presence or abundance decreases as human disturbance increases

KRW .... Kettle River Watershed

Littoral acres .... In this report, the acres of a lake that are 15 feet deep or less

ISTS .... Individual Sewage Treatment System

IWM .... MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling.

m .... The abbreviation for meter

MDA .... Minnesota Department of Agriculture

mg/L .... Milligrams per liter

µg/L .... Micrograms per liter (1 milligram = 1000 micrograms), equivalent to parts per billion (ppb)

Macrophyte .... Macro (= large), phyte (= plant). These are the large aquatic plants, such as *Elodea* and Coontail.

MDA .... Minnesota Department of Agriculture

MNDOT .... Minnesota Department of Transportation

MPCA .... Minnesota Pollution Control Agency

MSHA .... Minnesota Stream Habitat Assessment

M&A Report .... MPCA Monitoring and Assessment Report for the Mississippi River - Grand Rapids Watershed

MS4 .... Municipal Stormwater Plan, level 4

NLCD .... National Land Cover Database, a GIS layer

NPDES .... National Pollutant Discharge Elimination System

Natural background ... An amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors.

Nearshore survey ...... In this report, a fisheries survey conducted at evenly spaced, but random sites along the shoreline utilizing 1/8 inch mesh seines and backpack electrofishing to characterize primarily the nongame fish community of a lake

OP.................................. Orthophosphorus (a form of phosphorus that is soluble)

P .... Phosphorus

Palustrine wetland ..... A US Fish and Wildlife Service wetland classification which includes marshes, small ponds, wet meadows, fens, and bogs.

Periphyton .... Algae and diatoms that grow attached to hard substrates in streams.

SID .... Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.

Small benthic dwelling species .... A species that is small and predominantly lives in close proximity to the bottom

SNA .... Scientific and Natural Area; lands under special protection by DNR.

Sonde .... A deployable, continuous-recording water quality instrument that collects temperature, pH, DO, and conductivity data and stores the values which can be transferred to a computer for analysis

SSTS .... Subsurface Sewage Treatment Systems

StS .... Score the Shore

TALU .... Tiered Aquatic Life Uses, a framework of setting biological standards for different categories of streams.

Taxa .... Plural form - refers to types of organisms; singular is taxon. May refer to any level of the classification hierarchy (species, genus, family, order, etc.). In order to understand the usage, one needs to know the level of biological classification being spoken of. For MPCA fish analyses, taxa/taxon usually refers to the species level, whereas for macroinvertebrates, it usually refers to genus level.

TIV .... Tolerance Indicator Value

Tolerant species ………	A species whose presence or absence does not decrease, or may even increase, as human disturbance increases
TMDL ………………………	Total Maximum Daily Load
TSI ……………………………	Carlson Trophic State Index
TSS …………………………	Total Suspended Solids (i.e. all particulate material in the water column)
TSVS ………………………	Total Suspended Volatile Solids (i.e. organic particles)
TP ……………………………	Total Phosphorus (measurement of all forms of phosphorus combined)
US …………………………	Upstream
Vegetative dwelling species ……………………	A species that has a life cycle dependent upon vegetated habitats
Weight of evidence approach …………………	A method of using multiple sources or pieces of information to classify a waterbody as impaired
WRAPS ……………………	Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.
YOY ………………………	Young of Year fish (i.e., immatures hatched in current season)
10X …………………………	Ten times (chemistry samples collected on 10 dates)

Executive Summary for the Kettle River Watershed Stressor Identification Report

This report documents the efforts that were taken to identify the causes, and to some degree the source(s) of impairments to aquatic biological communities in the Kettle River Watershed (KRW). Information on the Stressor Identification (SID) process can be found on the United States Environmental Protection Agency's (EPA) website http://www.epa.gov/caddis/. Specific information on Minnesota's processes for SID in streams can be found on MPCA's webpage "Is Your Stream Stressed". The DNR also has a webpage "Stressors to Biological Communities in Minnesota's Lakes".

The KRW (Figure 1), located in the St. Croix River Basin, is situated within a mixed-landcover region of east central Minnesota, consisting of forests, large bog-type wetlands, and agricultural fields and pastures. Water resources are primarily streams/rivers and wetlands. Few lakes are found in this part of Minnesota, and those in the KRW are small in size, with the one exception of Sturgeon Lake. Agricultural land usage is generally not dense, but is more abundant than watersheds to the north. Agricultural lands are scattered quite evenly throughout the watershed, with the exceptions being the headwaters area, which has much peatland, and an area in the east-central part of the KRW, which has significant state-owned land (state forest, and Moose Lake and Banning State Parks) and tax-forfeit lands. The area west of the Kettle River has a somewhat more dense agricultural landscape than the area east of the Kettle River. Among the agricultural lands, that used for row crops is much less than that used for hay/pasture. Most of the cultivated land observed by the author was for corn production. There are several parcels of Native American Reservation lands in the KRW. Two parcels are located at the very northern boundary of the watershed, both of which are parts of the Fond du Lac Reservation. The Mille Lacs Band also has trust lands in the KRW. Also contributing to the relatively natural condition of parts of the watershed are the large peatlands, particularly along the north and northwest portions of the KRW. The KRW contains numerous public/protected lands (Figure 1). Two state parks are fully contained in the KRW (Banning and Moose Lake) and a third lies partly within the KRW (St. Croix). Parts or all of five state forests, 16 full or partial state wildlife management areas, and one Scientific and Natural Area also lie within the KRW.

The density of residential and urban land use is quite low in the KRW, with most being within the string of towns found in the I-35 corridor (part of Hinckley, Sandstone, Willow River, Sturgeon Lake, Moose Lake, and Barnum). Other cities and towns in the KRW include: Finlayson, Rutledge, Bruno, Kerrick, Denham, and Kettle River. None of the biologically-impaired AUIDs have a town near the channel, and so stressors related to developed lands (impervious surfaces, stormwater runoff, wastewater facility discharges, etc.) are not expected to be a significant issue here. The other somewhat dense, localized developments are the shoreline properties around several of the KRW's lakes. There are no wastewater treatment plant or permitted industrial effluent discharges associated with any of the biologically-impaired reaches.

Given these landscape/land use attributes, the primary anthropogenic stressors in the KRW are likely to be non-point types, and most likely from development and agricultural activities. Some ISTS failure may be present as well. One stressor that can occur anywhere roads are present is barriers to fish migration caused by the structures used to place a road over a stream. In particular, culverts are commonly found to be at least partial barriers to fish passage. All culverts in the KRW were assessed for fish passage by the Minnesota Department of natural resources (DNR) in 2016, and 78.9% were found to be problematic for passage to some degree, with 24.8% being significant or complete barriers.

Streams

Biological sampling previous to the Intensive Watershed Monitoring (IWM) had resulted in two river reaches being assessed as having impaired fish communities, these being the South Branch of the Grindstone River (AUID-516) and the Grindstone River (AUID-501). Recent sampling of fish in the Grindstone River (AUID-501) has found an excellent fish community, and this until-recently-listed impairment has a pending listing correction to be removed from the 303(d) list. Eight additional reaches from seven different streams were brought into the SID process (listed below and shown on Figure 1) because they were determined to have substandard biological communities via the 2016-2017 IWM and the subsequent 2018 Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. Three additional AUIDs having uncertainty about use class designation or insufficient data received some amount of SID work based on IWM findings. One of the AUIDs (North Branch Grindstone River, AUID-543) was determined to warrant a MPCA use class change from coldwater to warmwater, which removed the potential biological impairment. Larson Creek stays as a coldwater stream, with a natural background impairment classification. Heikkila Creek was finally assessed as insufficient data, due to the biological samples being potentially affected by an abnormally-large rainfall event. Additionally, Spring Creek was determined to be a natural background impairment due to beaver activity.

Stream impairment investigations

- Kettle River (AUID 07030003-511) - Fish
- South Branch Grindstone River (AUID 07030003-516) - Fish
- Cane Creek (AUID 07030003-525) - Macroinvertebrates
- Friesland Ditch (AUID 07030003-617) - Fish
- Skunk Creek (AUID 07030003-618) - Fish
- Hay Creek (AUID 07030003-619) - Fish
- Pine River (AUID 07030003-633) - Macroinvertebrates
- Pine River (AUID 07030003-634) - Macroinvertebrates

Other stream investigations

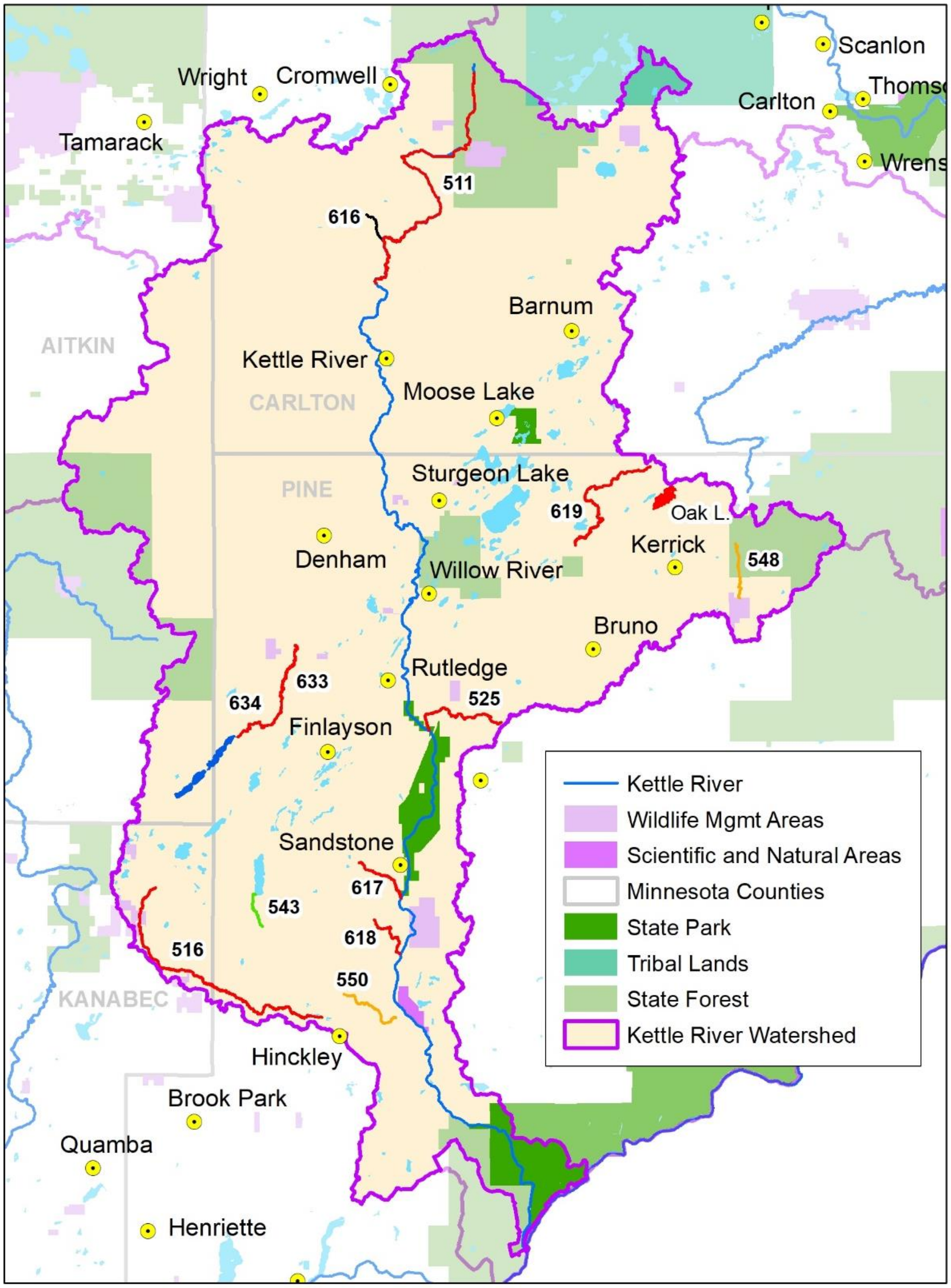
- North Branch Grindstone River (AUID 07030003-543)
- Larson Creek (AUID 07030003-548)
- Spring Creek (AUID 07030003-550)
- Heikkila Creek (AUID 07030003-616)

A number of stressors to the stream biological communities were found. These involved only non-point source pollution, infrastructure, or naturally-occurring circumstances. No point source pollution was associated with the biological impairments. Infrastructure stressors included culverts that were installed such that fish passage is difficult or not possible (AUIDs 525, 550, and 618). The Grindstone dam (a complete barrier to fish migration) is also a contributing stressor to the impairment of the fish community of South Branch Grindstone River. Also included in the infrastructure category are legacy ditching projects, which attempted to drain bog areas throughout much of the KRW in the early 1900's. While significant, these ditch systems are not as long or extensive as those to the north or west around the cities of Cromwell, McGregor, Aitkin, Palisade, Hill City, and Floodwood, for example. These ditches alter downstream hydrology, and appear to have caused channel damage in some locations, which has led to habitat loss (617 and 619). The ditches also likely contribute to low DO levels in streams due to the wetland-sourced water they convey to the streams (511 and 616). The natural stressors are low DO (633, 634), due to the extensive wetlands, and beaver dams (550 and 617), which also can block fish passage, preventing repopulation of streams in spring from downstream overwintering habitat.

Lakes

Of the fish communities sampled to evaluate biological health in 13 lakes within the KRW, only one lake, Oak Lake (DOW# 58-0048-00), was assessed as not supporting for aquatic life use based on the FIBI score that was below the impairment threshold established for similar lakes. No stressors are present at levels typically seen with lakes impaired based on the FIBI, making the stressor identification inconclusive. The primary candidate stressors possibly contributing to the condition of the lake's fish community, as measured with the FIBI, are physical habitat alteration resulting from increased riparian area development and aquatic plant management activity and eutrophication. Two additional lakes Big Pine Lake (DOW# 58-0138-00) and Pine Lake (DOW# 01-0001-00) were assessed as insufficient information and vulnerable to impairment based on the FIBI scores that were near the impairment thresholds established for similar lakes. The primary candidate stressors contributing to the vulnerable conditions in each of these lake's fish communities, as measured with the FIBI, are eutrophication resulting in increased nutrient loading and physical habitat alteration resulting from increased riparian area development or increased aquatic plant management activity.

Figure 1. Map of the KRW showing streams and lakes discussed in this report - reaches or lakes with biological impairments (in red), vulnerable lakes (dark blue), natural background impairments (orange), changed to meeting standards (green), not assessed (black). Numbers are stream AUIDs, listed in bulleted text above.



Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds, known as Major Watershed Restoration and Protection Strategy (WRAPS). The MPCA receives assistance from DNR and local governmental units to complete a WRAPS project. A WRAPS is in part comprised of several types of assessments. The MPCA conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2016 and 2017. The IWM assessed the aquatic biology and water chemistry of the Kettle River Watershed (KRW) streams and rivers (MPCA) and fish communities of KRW lakes (DNR). The second assessment, known as the Stressor Identification Assessment (SID), builds on the results of the IWM. The MPCA, along with its partner DNR, conducted the SID assessment during 2017 - 2018. MPCA performs SID for river and stream biological impairments, while DNR does SID for fish impairments in lakes. This document reports on the second step of a multi-part WRAPS for the KRW, and includes SID work for both streams and lakes.

It is important to recognize that this report is part of a series, and thus not a stand-alone document. Information pertinent to understanding this report can be found in the Kettle River Watershed Monitoring and Assessment (M&A) Report. That document should be read together with this Stressor ID Report and can be found from a link on the MPCA's Kettle River Watershed webpage.

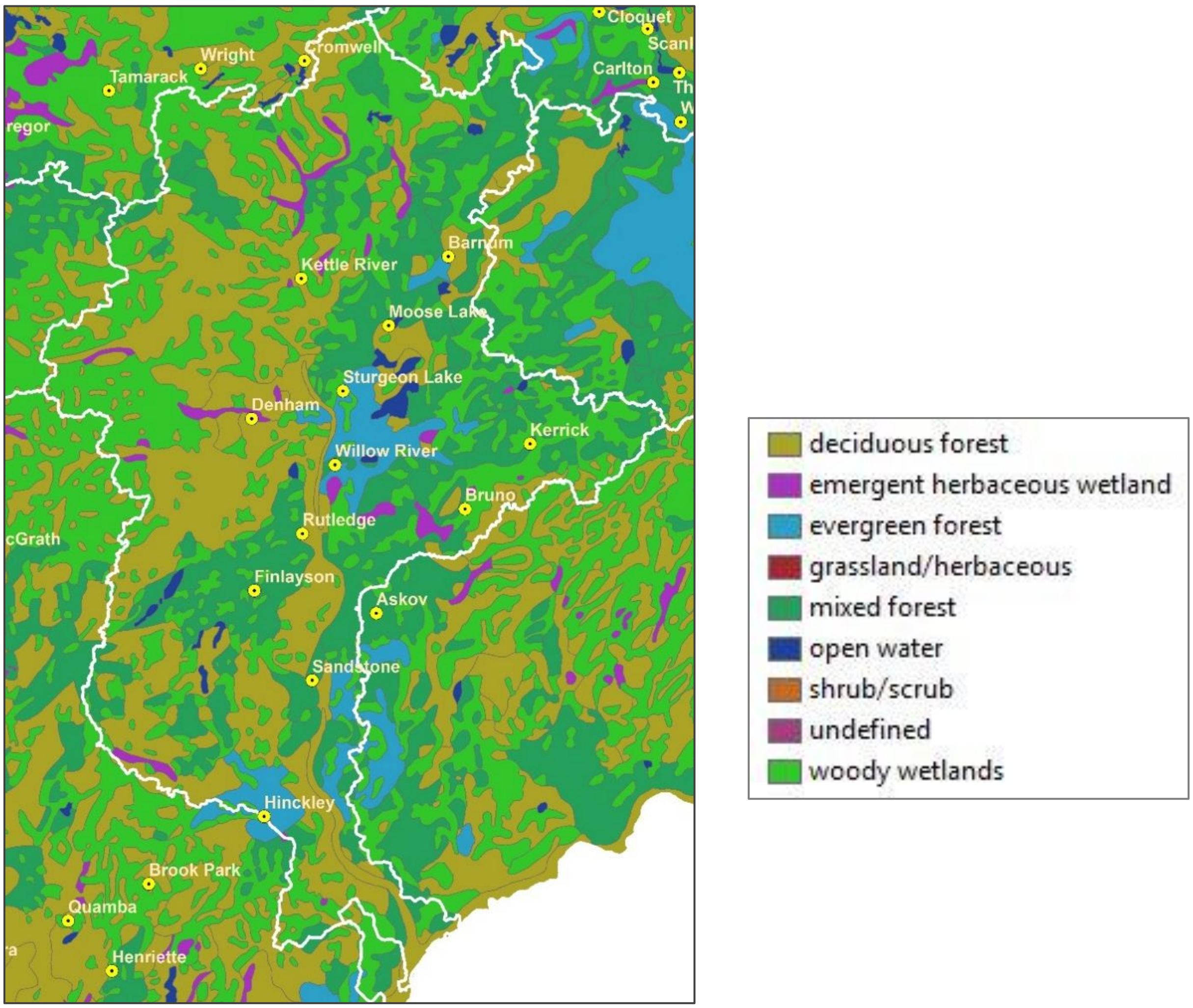
Landscape of the KRW

A detailed description of various geographical and geological features of the landscape of the KRW is documented in the Kettle River Watershed Monitoring and Assessment Report (MPCA, 2019a). Additionally, the web-based DNR Watershed Health Assessment Framework (WHAF) has a wealth of landscape data for each of the major watersheds of Minnesota, including a Watershed Context Report feature (DNR, 2018a). All of this information is useful and necessary for understanding the settings of the various KRW's subwatersheds, and how various landscape factors influence the hydrology within the KRW. The reader is encouraged to utilize these other resources. The following information is intended to provide a basic description of the KRW landscape.

The KRW is a varied watershed topographically. A large part of the northwestern area of the watershed is flat, and contains much wetland/peatland, and its streams are low gradient, soft bottomed, and darkly tannin-stained. Slow flow velocity can influence the dissolved oxygen levels in the streams both due to lower mixing of water that aids contact with the atmosphere, and because low gradient streams can take on wetland characteristics, having accumulations of organic particulate sediment, which reduces the amount of DO in the water column as bacteria consume oxygen as they work to decompose this organic material. The middle parts of the watershed are more topographically diverse, including the pocket of lakes near Moose Lake and Sturgeon Lake. Streams in this central part of the watershed have more gradient, swifter flows, and their beds are often lined with gravel, cobble, and boulders. This combination of features results in great habitat for aquatic organisms. The Kettle River itself is very diverse, as noted by author Tom Waters (1977). He highlighted differences of the various stretches of the river, from the low gradient, wetland-influenced headwaters, to swifter, rocky habitats, to large slow-flowing sections, and finally to the river gorge and raging waters in the final reaches of the river.

The original, pre-settlement landscape was almost exclusively forests, wetlands, and lakes (Figure 2). However, the original forest harvest at the turn of the century changed much of the forest from older growth to the younger forests that exist now, a large percentage of the originally-forested landscape

Figure 2. Original vegetation of the KRW and adjacent watersheds (Marschner, 1930). The white lines are the boundary of the KRW and adjacent watersheds.

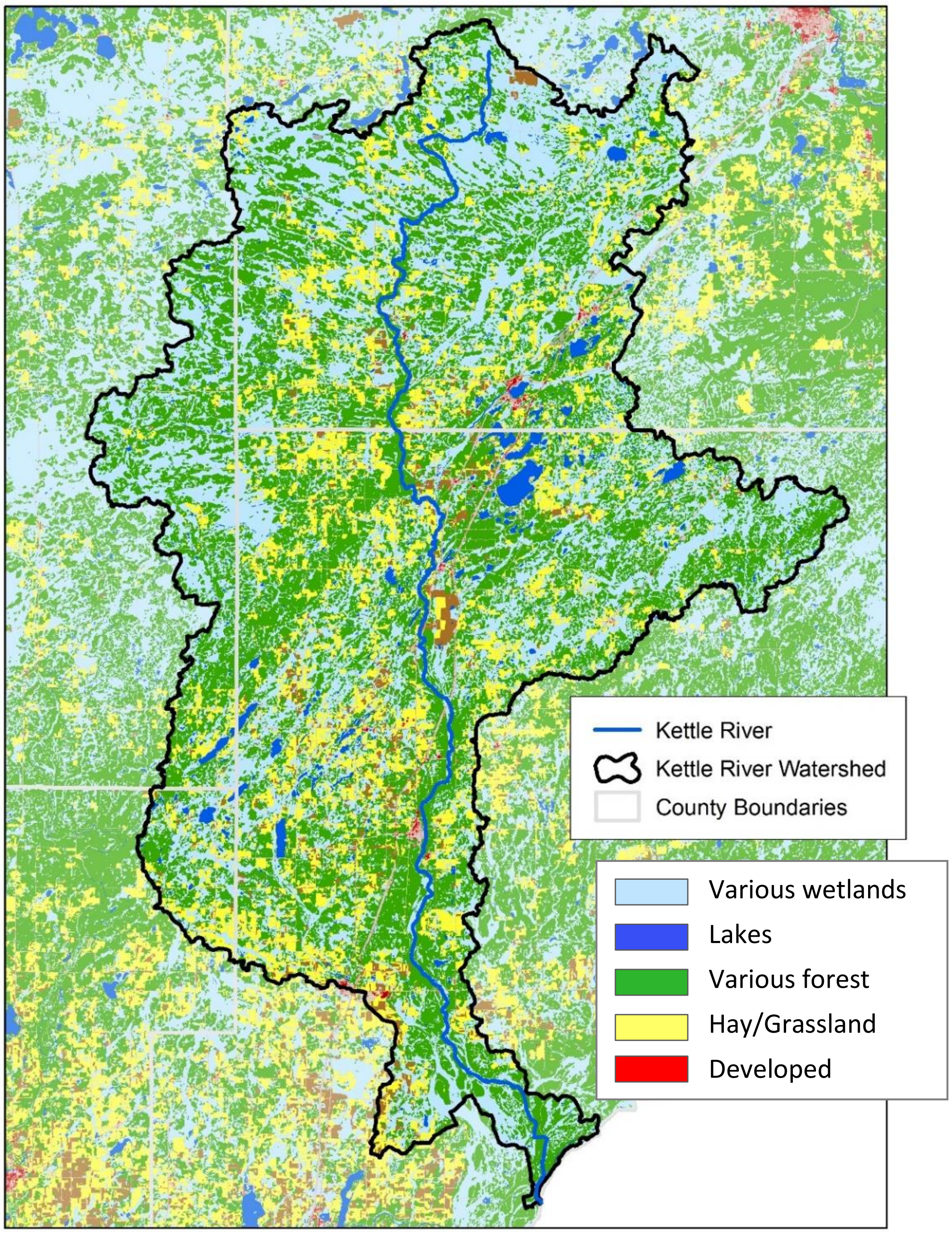


remains in a forested state. Wetlands, both emergent and forested, are abundant in the KRW, especially in the northern, northwestern, and far eastern (around Kerrick) portions. Lands utilized for agriculture are scattered throughout the KRW, and are predominantly hay/pasture, though a small amount of row crop agriculture is conducted (Figure 3). No particular region of the KRW has particularly dense agricultural lands. Feedlots of various sizes are also spread throughout the watershed (Figure 7). Percentages of various categories of land cover are presented in Table 1. Figure 3 shows the extent and locations of these cover types.

Table 1. Percentages of the various land cover types from 2011 NLCD GIS coverage (DNR, 2018a).

Land cover type	Percent of Land Area
Developed (all intensities grouped)	4.0
Cultivated Crops	2.1
Rangeland	14.1
Water, wetlands, and forest lands	2.7 + 38.4 + 38.8 = 79.9

Figure 3. KRW land use/cover as determined by the 2011 National Land Cover Dataset.



Determination of Candidate Stream Stressors

The process

A wide variety of human activities on the landscape can create stress on water resources and their biological communities, including; urban and residential development, industrial activities, agriculture, and forest harvest. An investigation is required in order to link the observed effects on an impaired biological community to the cause or causes, referred to as stressors. The EPA provides a long list of stressors that have potential to lead to disturbance of the ecological health of rivers and streams (see EPA's CADDIS website - http://www.epa.gov/caddis/). Many of the stressors are associated with unique human activities (e.g. specific types of manufacturing, etc.) and can be readily eliminated from consideration due to the absence of those activities in the watershed. The initial step in the evaluation of possible stressor candidates was to study several existing data sources that describe land usage and other human activities. These sources include: numerous GIS coverages, aerial photography, and the DNR Watershed Health Assessment Framework. Additionally, census records and various MPCA records, such as NPDES-permitted locations, added to preliminary hypotheses generation and the ruling out of some stressors or stressor sources.

In conjunction with the anthropological and geographical data, actual water quality, habitat, and biological data were analyzed to make further conclusions about the likelihood of certain stressors impacting the biological communities. Water chemistry and flow volume data has been collected within the KRW for many years. The determination of candidate stressors used both the historical data and data collected during the 2016-2017 IWM. Preliminary hypotheses were generated from all of these types of data, and the SID process (including further field investigations) sought to confirm or refute the preliminary hypotheses.

DNR Watershed Health Assessment Framework

DNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The WHAF includes an assessment of the nonpoint source pollution threat to water quality within the water quality component of watershed health, which shows non-point pollution, relative to other parts of the state, is not a widespread stressor in the KRW Figure 4. According to the Non-point Source Pollution Index, the KRW ranks as 16th best (least threat) out of the 80 watersheds in Minnesota. This equates to the 82nd percentile. A major urban source of non-point pollution is runoff from impervious surfaces. Due to the relatively low number and generally smaller sizes of the cities/towns in the KRW, this threat is low (Figure 5). The subwatersheds that have greater amounts of impervious surface are primarily those that Interstate 35 passes through, and the freeway probably contributes heavily to these lower scores. There are other localized situations, such as the immediate shoreline properties of lakes with significant development, where impervious surfaces may be an important water quality issue. The analysis scale of this map does not show those locations. Streams and rivers in the KRW generally do not have the degree of shoreline development as area lakes, and thus this near-shore threat is primarily related to lakes, and much less of an issue with rivers and streams. None of the stream impairments has a town located near the stream channel.

The Point Source Index (PSI) in the WHAF captures possible impact from point source and similar types of pollution sources, including pollutant contributions from animal husbandry, hazardous waste and superfund sites, wastewater treatment effluent, mining, and septic systems. Point source pollution is also not a significant source of stream stressors in the KRW, relative to many other Minnesota watersheds. The PSI score for the overall KRW was 93 out of 100, and 31st best of 80 watersheds. Subwatersheds that have relatively high septic system densities per the WHAF tool output are few, and primarily localized around some of KRW's lakes (Figure 6). The overall KRW "Water Quality" WHAF Component score was 64 out of 100, tied for 17 best of the state's 80 watersheds. The overall WHAF scorecard, which includes many more metrics, can be found on the WHAF webpage.

Figure 4. Scores and categorical ranking of the 80 Minnesota Major Watersheds for the DNR Non-point Source Pollution Index.

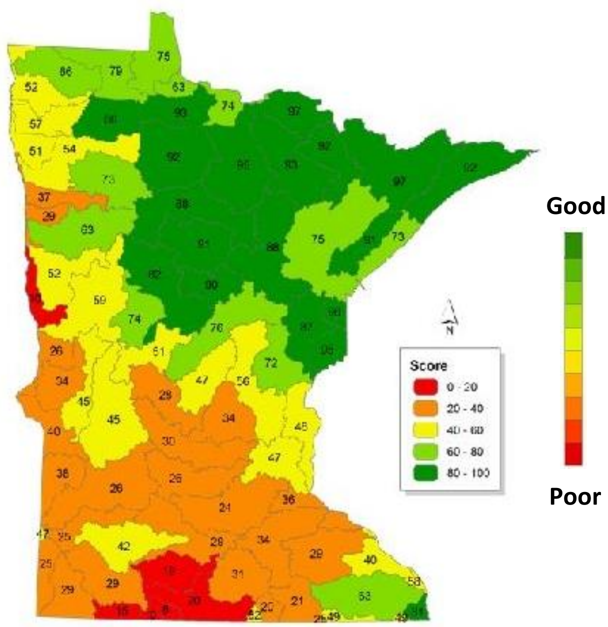


Figure 5. Catchment-scale impervious surface scores for the KRW and surrounding catchments.

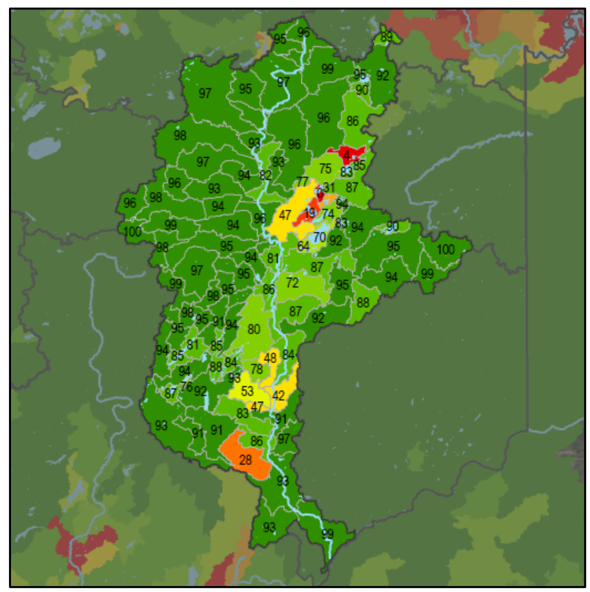


Figure 6. The WHAF Septic System metric within the Nonpoint Source Index for the KRW.

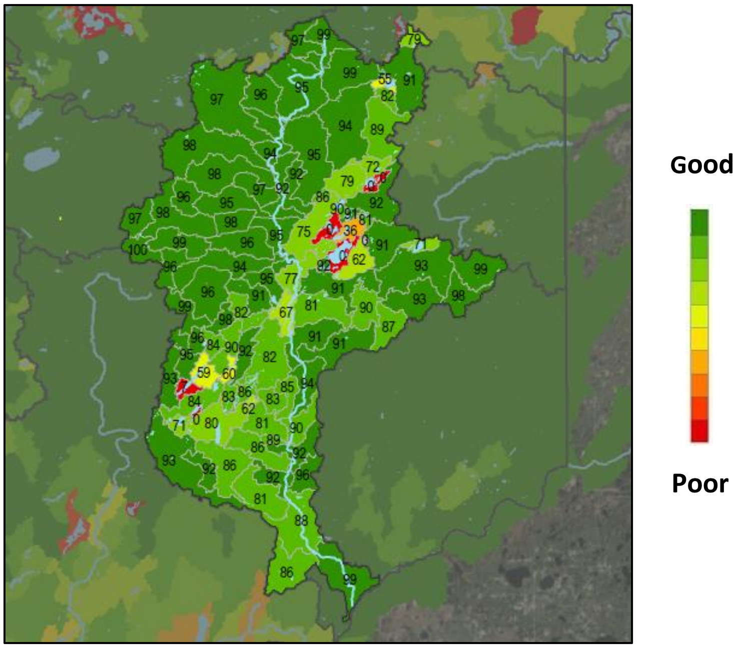


Table 2. Ranking of several attributes of the KRW relative to Minnesota's other 80 watersheds. A high rank number is a positive, while a low rank is a negative for water quality. Total possible is 80.

	Impervious Surface	Nonpoint Threat	Point Source	Storage Loss	Perennial Cover	Flow Variability	Ag. Chem. Use	Aquatic Connectivity
Rank	63	64	49(t)	66	65(t)	43(t)	67(t)	49

(t) = tied with other watersheds for these ranks.

Other MPCA Water Monitoring Programs

Aside from the IWM monitoring, MPCA has other programs that conduct various water monitoring efforts that can shed light on possible stressors. For example, MPCA's wastewater program compiles nutrient data routinely collected as part of a waste water permit requirement. Recent trend data for phosphorus originating from wastewater discharges is available for the major watersheds of MN. The MPCA has a load monitoring network, where numerous water quality parameters are frequently monitored, with sample sites near the pour point of each of Minnesota's 80 HUC8 scale watersheds. Phosphorus loads from each of Minnesota's 8HUC watersheds are found on MPCA's webpage: http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=c53c280bb959419e891aaebfc1da9bb4 . MPCA also provides water quality monitoring grants to local organizations, and this data, as well as all of the MPCA-collected data, is stored in the publically-available EQuIS database, at the following web page: http://www.pca.state.mn.us/index.php/data/environmental-data-access.html . Data from these other programs is included in the water chemistry discussions of individual AUIDs that follow later in the report, if applicable to the site.

Desktop review

Urbanization/Development/Population density

Census data provides a way to look at human-induced stress or pressure on the water resources of a region. Stressor sources that are related to population density include: wastewater effluent, impervious surface areas, and stormwater runoff, which all increase with population density. The KRW is relatively lightly populated. Localized exceptions are the areas around Sandstone (2,849), Moose Lake (2,751), Hinckley (1,800; about ½ of the town is within the KRW), and Barnum (613). All other towns have fewer than 450 persons. Population data presented here is from 2010 US Federal Census (MSDC, 2015). Many of these towns are located along or close to the Interstate 35 corridor.

Recent GIS-derived land use statistics showed that 4.05 % of the watershed area is categorized as Residential/Commercial (MPCA, 2019a). The KRW ranks 17th best of the state's 80 watersheds for the lack of impervious cover. The census and urbanization information suggests that most stressors related to population density are likely only active at highly-localized areas (e.g., lakeshore development acting on a particular lake), if at all. The Grindstone and Moose Horn Rivers are the most likely to be stressed by development due to the close proximity of adjacent cities. However, neither of those streams have biological impairments downstream of the cities near them.

One potential source of water resource stressors in rural areas is subsurface sewage treatment systems (SSTS), formerly known as individual sewage treatment systems (ISTS). Un-sewered areas can have old septic systems that are either failing or do not conform to current design standards. Most rural homes/cabins in the KRW are not connected to a municipal sewer system, and thus have individual treatment systems. Rural areas also have residences that discharge wastes directly to streams, though this is unlawful, and the numbers are declining. These systems can contribute significant levels of nutrients and other chemicals to water bodies. The dense locations of septic systems in the KRW are the lakeshores (Red/orange/yellow areas in Figure 6). These lakeshore areas are not associated with the impaired streams in the KRW. A relatively recent county-by-county SSTS assessment (MPCA, 2012) found that in shoreland areas of Carlton County, 14% of systems were failing, and another 4% were imminent threats to public health, while in Pine County, which reported by township, 5-28% were failing, and another 0-4% were imminent threats to public health. The township with 28% was an outlier in the dataset, as the next highest was 17%. These inspection reports were predominantly for cabins/homes around lakes, and many of these may have been corrected in the several years since the data was reported.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The KRW has relatively little manufacturing industry. There are no current industrial activities associated with any of the impairments in the KRW. However, one very notable legacy industrial situation is currently influencing Skunk Creek. In the early 2000s, investigations by MPCA and the Minnesota Department of Agriculture (MDA) identified the former Kettle River Creosote Plant in Sandstone as the source of creosote and tar discovered in and around Skunk Creek. This area is currently in the process of being cleaned up and assessed further by MDA (MDA, 2019), which has jurisdiction of pollution cleanup from this type of industry. Thus, industrial discharges are not considered to be a source of pollutants (stressors) causing known stream biological impairments in the KRW, except possibly for Skunk Creek.

Forestry

Forest harvest can create stress on water resources. Forest harvest has been and currently is a significant activity within the KRW and historic large-scale forest removal occurred in the watershed, which may have created legacy effects still being experienced. The significance and scale of this effect can be seen in the documentation of the Great Hinckley Fire of 1894, which burned forests and logging slash over more than 200,000 acres. Much information on this incident can be found on the internet. Nearly all of the non-wetland land area in the KRW was originally forested (Marchner, 1930). Stressors related to forest harvest are possibly occurring in the KRW. Tools to examine forest harvest impacts are fairly limited currently.

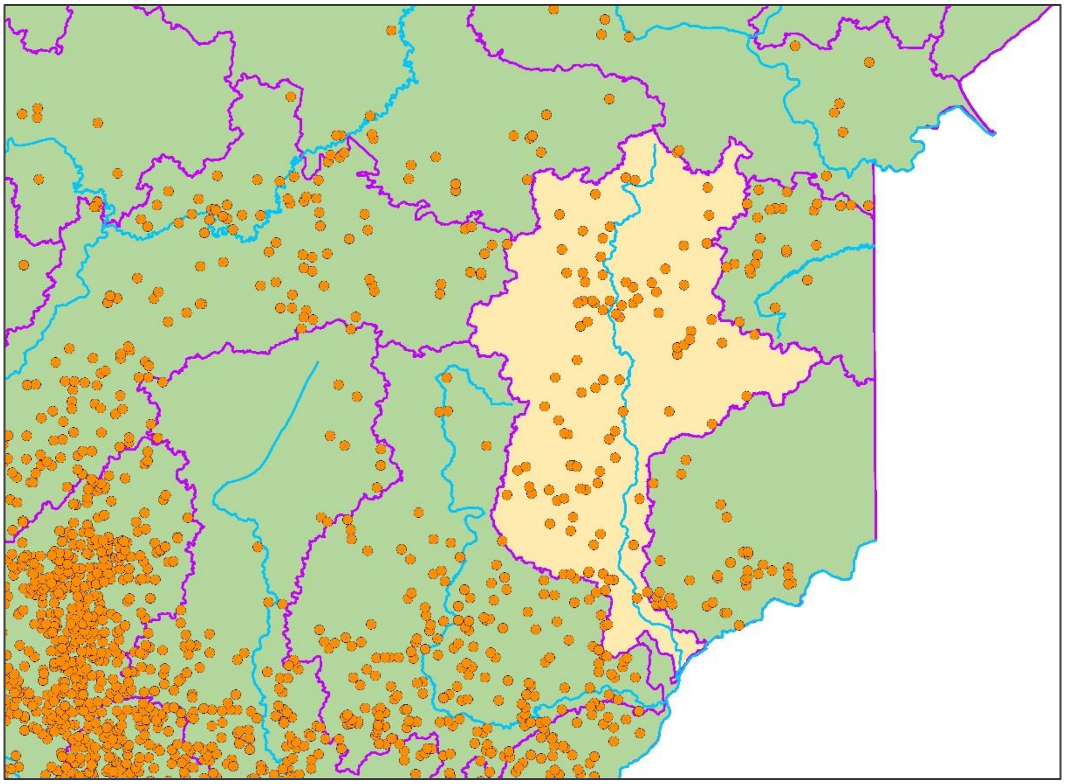
Agricultural activities

Row crop acreage is quite rare in the KRW. The review of the KRW's land use, shown previously (Table 1), indicates that only approximately 2.14% of the land cover is in cultivated crops. Animal agriculture is moderate, compared to watersheds to the south and west, versus those to the north (Figure 7). There are areas in the KRW that have no feedlots. It is reasonable to consider that animal agriculture might be a possible contributor to water quality problems, although its overall contribution would be expected to be much less than in more southern and western parts of Minnesota. A large quantity of professional research has associated landscape changes from natural to agricultural land uses with water quality degradation and/or negative affects to biological communities (e.g., Fitzpatrick et al., 2001; Houghton and Holzenthal 2010; Diana et al., 2006; Sharpley et al., 2003; Blann et al., 2011; Riseng et al., 2011). Well-documented agriculture-related stressors include nutrients, sediment, and altered hydrology.

Agricultural activity can result in elevated nutrients in the water resources located in or downstream from those areas (Sharpley et al., 2003; Riseng et al., 2011; MPCA, 2013a). With the substantially lesser degree of agriculture occurring in the KRW relative to some other MN regions, elevated nutrients from agriculture are not a systemic issue in the KRW, but could occur in localized areas.

Some alteration of hydrology has occurred simply by changing the vegetation from the original forest to open farmland or pasture. In addition, soil compaction from farm equipment or animal grazing can increase runoff. More sediment will move to streams from cultivated fields than from fields with perennial grasses. Since farmland acreage overall is relatively light in the KRW, and with much of that acreage being hay or pasture, erosion and alteration of hydrology due to agriculture are not a systemic issue in the KRW, though local hotspots may occur.

Figure 7. Registered feedlot locations ≥ 50 animal units (orange dots) in the KRW and adjacent watersheds. Purple lines are major watershed boundaries.



Pesticides

Given that the KRW is not an intensely agricultural watershed, it is reasonable to disregard pesticides as significant potential stressors to aquatic life. Pesticides as stressors were not given consideration in the few locations studied in this report due to the prevailing non-agricultural land use patterns at those locations. Pesticide testing is very expensive, and monitoring for pesticides is difficult as applications are spotty, and occur irregularly. More information on pesticide occurrence in Minnesota's environment continues to be gathered via Minnesota's statewide pesticide sampling program and results are available from the MDA at http://www.mda.state.mn.us/monitoring.

Summary of Candidate Stressor Review

Based on the review of human activity in the KRW in general, and then specifically the areas in close proximity to the locations with biological impairment or other issues, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the KRW, resulting in eight candidate causes moving forward for more detailed investigation.

Eliminated Causes

- Urban development/municipal stressors (altered hydrology, riparian degradation, high levels of impervious surfaces, residential chemical use, and specific conductance via effluent discharges). There are no urbanized areas associated with the impaired subwatersheds studied in this report.

- Pesticides - Impacts from pesticides are deemed unlikely due to small human population and little agricultural land use.
- Mining/Industrial stressors (i.e., toxic chemical, high conductivity discharges)

Inconclusive Causes

- Forest management stressors - historical/legacy effects are difficult to determine. The KRW was clear-cut in the early 1900s, and subsequent harvest of the regenerated forests has occurred at various times throughout the KRW. Impaired subwatersheds have had some recent forest harvest, though understanding and quantifying the effects of forest harvest, and threshold levels for stress to occur to streams is less well known compared to agriculture. There are current efforts underway or planned to better understand the effects of forest harvest impacts on streams at a landscape scale.

Candidate Causes

- Low Dissolved Oxygen
- Excess sediment (both suspended and deposited)
- Altered hydrology (non-urban sources)
- Altered geomorphology
- Habitat loss
- Connectivity loss
- Elevated phosphorus and nitrogen
- Elevated water temperature

Mechanisms of candidate stressors and applicable standards

A separate document has been developed by MPCA describing the various candidate stressors of aquatic biological communities, including where they are likely to occur, and their mechanism of harmful effect, and Minnesota's Standards for those stressors (MPCA, 2017). Many literature references are cited, which are additional sources of information. The document is titled "Stressors to Biological Communities in Minnesota's Rivers and Streams" and can be found on the web at: https://www.pca.state.mn.us/sites/default/files/wq-ws1-27.pdf. Additional information on Stressor Identification in Minnesota can be found on MPCA's website: https://www.pca.state.mn.us/water/your-stream-stressed. EPA (2017) has yet more information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on their CADDIS website at https://www.epa.gov/caddis.

Notes on analysis of biological data

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

Staff in MPCA's Standards, Biological Monitoring, and Stressor ID programs have worked to find metrics that link biological communities to stressors, and work continues toward this goal. Similarly, DNR has done this work for fish communities in Minnesota lakes and is developing the protocol for aquatic plants of lakes. Readers are directed to MPCA's "Is your stream stressed" webpage, and DNR's lake index of biological integrity webpage. National SID guidance is provided by EPA on their website http://www.epa.gov/caddis/, and the publication by Cormier et al. (2000).

Much work in this area was recently done to show the impact of nutrients (particularly phosphorus) on biological stream communities when Minnesota's River Nutrient Standards were developed (Heiskary et al., 2013). The Biological Monitoring Units of MPCA have worked to develop Tolerance Indicator Values for many water quality parameters and habitat features for species of fish, and genera of macroinvertebrates. This is a replication the well-known work of Hilsenhoff (1987; EPA, 2006) using Minnesota data. For each parameter, a relative score is given to each taxon regarding its sensitivity to that particular parameter by calculating the weighted average of a particular parameter's values collected during the biological sampling for all sampling visits in the MPCA biological monitoring database. Using those scores, a weighted average community score (a community index) can be calculated for each sample. Using logistical regression, the biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites to date. Such probabilities are only available for parameters that have developed standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

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

Notes on analysis of chemical data

Seasonal patterns of chemical parameters were sometimes analyzed to determine if these patterns could be linked with known landscape/climate-related effects (e.g., wetland soils becoming anoxic in mid-summer). Microsoft Excel 2010™ was used to draw polynomial regression lines and obtain R^2 values of the correlation fits of parameter concentrations and dates.

Notes on analysis of physical and hydrological data, and culvert assessment

Staff of the DNR provide assistance to the SID process by collecting physical data (e.g., Pfankuch (1975) assessments and Rosgen (1996) geomorphology studies) about the stream channel, and analyzing hydrological data. MPCA SID staff may also participate in the collection or analysis of this data. Summary information about these topics are included in this report. Detailed stream survey data (e.g., channel bed elevations, water slope, etc.) from these efforts is available from DNR Watershed Specialists in the Grand Rapids DNR office.

DNR has also recently developed a program to assess culvert crossings for the effect they have on stream channel stability and the fish community. These effects include blocking the passage of fish and harming the local stream channel by causing erosion. The complete Kettle River Watershed was assessed in 2016, and a report has been generated, “Kettle River Watershed: Stream Crossing Inventory and Prioritization Report” (DNR, 2019b).

Biologically impaired streams

The individual AUIDs assessed as impaired are discussed separately from this point on. The general format will be: 1) a review and discussion of the data and possible stressors that were available at the start of the SID process; 2) a discussion of any additional data that was collected during the SID process; and 3) a discussion of the conclusions for the AUID based on all of the data reviewed.

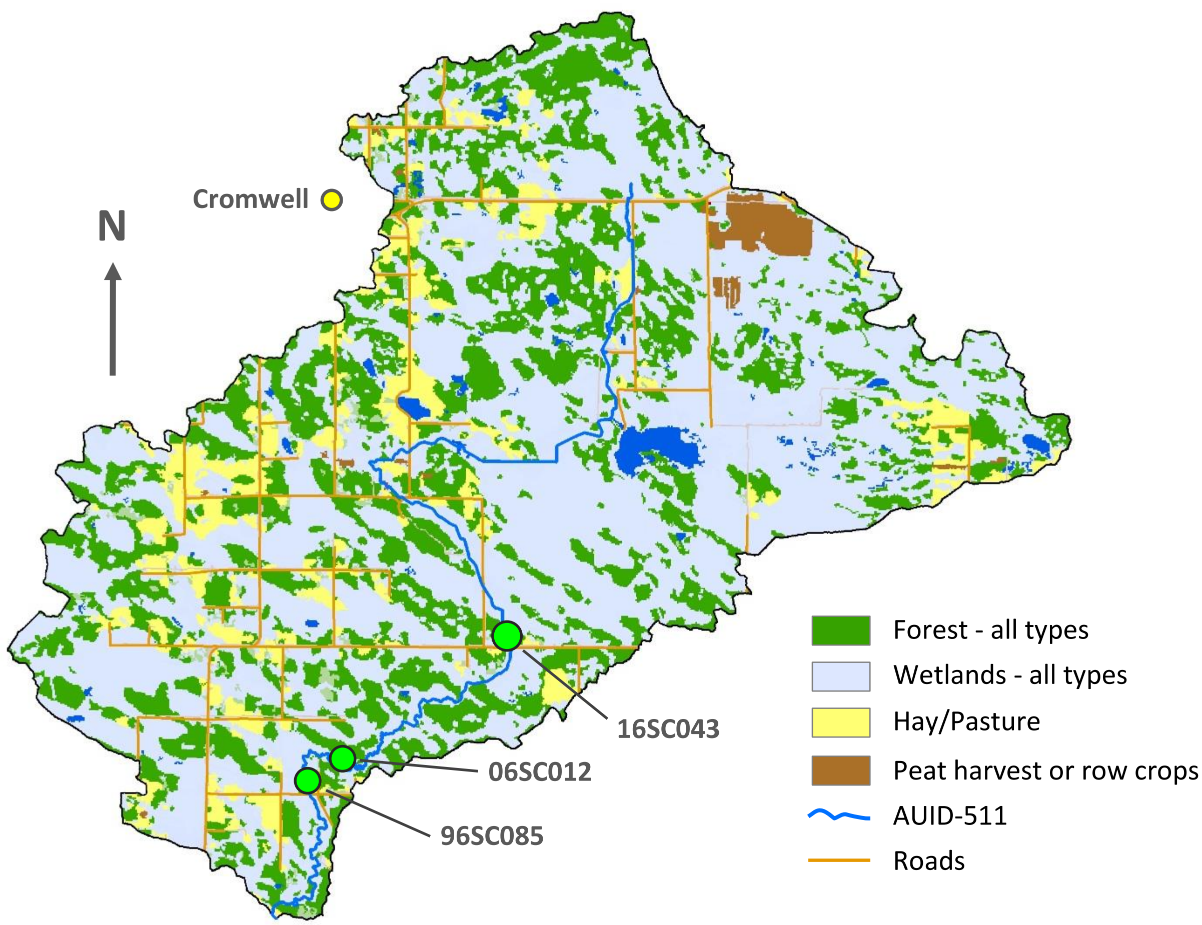
Kettle River (AUID 07030003-511)

Impairment: The river was assessed as having an impaired fish community at site 16SC043, located at the crossing of Mahtowa Road (CSAH-4), 6.5 miles south of Cromwell. The macroinvertebrate community met the passing threshold. Two other sites within this AUID, sampled in 1996 and 2006, had passing scores for the fish community, as did a small tributary that enters a ways upstream of 16SC043, just south of MN Highway 210 (16SC039).

Subwatershed characteristics

The subwatershed of AUID-511 (Figure 8), which is the headwaters of the Kettle River, is at the northern edge of the KRW. Much of the AUID is a low gradient channel. Site 16SC043 is a Fish Class 7 (Low Gradient) and Macroinvertebrate Class 4 (Northern Forest - Glide/Pool) stream. Other biological monitoring sites sampled during different projects on this AUID fall into other fish and macroinvertebrate stream classes, so there is habitat variation along the AUID. The subwatershed is completely rural, with no towns within its boundary. The city of Cromwell lies just outside of the subwatershed. State Highway 210 runs through the northern part of the subwatershed. The landscape is dominated by wetlands (primarily wet meadow type). A scattering of hayfields and pasture is the primary land cover change, though forest harvest is a temporary change that does occur as well. A large peat harvesting operation exists in the northeastern part of the subwatershed. Very little row crop agriculture occurs on this landscape. Few roads exist in the eastern half of the subwatershed, and only six road crossings occur on AUID-511. The Human Disturbance Score (HDS) at 16SC043 was 60.2 (at the 63rd percentile statewide). Site 06SC012 has not been scored.

Figure 8. Subwatershed of AUID-511 showing land use/land cover types. Note that tributaries are not shown. The yellow dot just outside the subwatershed is the location of Cromwell.



Data and analyses

Chemistry

Very little data has been collected from AUID-511 - no previous local government agency sampling has occurred on this reach. New data collected by MPCA is shown in Table 3. Two tributaries to AUID-511 were also IWM biological sites, and a small amount of chemistry data is available from them. Both sites were close to AUID-511, and so the measured chemistry at those two sites also informs the water quality found in AUID-511. One site is a headwater tributary to AUID-511 (an unnamed ditch, 16SC039) and the other is Heikkila Creek (16SC036), which enters AUID-511 just downstream of 96SC085, and thus does not contribute to the chemistry found in the three AUID-511 sites in Table 3.

Table 3. AUID-511 water quality measurements from MPCA historical visits and the IWM and SID monitoring of 2016-2018 (green rows), and tributaries AUID-615 (16SC039) and Heikkila Creek (16SC036) in the pink rows.

Site	Date	Time	Water Temp.	DO	DO % Sat.	Cond.	TP	Nitrate	Amm.	pH	Secchi Tube (cm)	TSS	TSVS
16SC043	8/2/16	10:35	23.2	4.45	55	100	--	--	--	6.92	43	--	--
16SC043	8/17/16	10:15	21.8	3.61	53	181	0.068	0.21	0.12	7.03	50	6.8	3.2
16SC043	9/5/17	14:58	15.5	6.52	68	90	0.042	< 0.05	< 0.05	--	74	6.8	--
16SC043	9/11/17	12:08	18.2	6.40	73	79	--	--	--	7.16	58	--	--
16SC043	8/3/18	12:30	18.5	6.82	72.7	137	--	--	--	--	--	--	--
16SC043	8/9/18	9:05	21.1	6.17	69.4	135	--	--	--	--	--	--	--
06SC012	8/2/06	12:40	26.4	4.80	--	332	0.066	< 0.05	< 0.05	7.09	--	18	--
96SC085	8/27/96	14:15	22.1	7.19	--	116	0.052	< 0.05	0.02	7.59	--	2.8	--
16SC039	8/2/16	12:04	19.7	5.57	64	218	--	--	--	7.29	54	--	--
16SC039	8/24/16	9:35	19.0	4.93	56	286	0.066	0.08	< 0.05	7.41	85	2.0	1.2
16SC036	8/2/16	9:39	20.2	0.85	10	185	--	--	--	6.68	30	--	--
16SC036	8/24/16	14:19	21.0	1.15	14	170	0.166	< 0.05	0.11	6.64	28	7.6	4.4

Nutrients - Phosphorus

Phosphorus values are quite typical of smaller streams draining landscapes with significant peatlands, such as those that occur in this subwatershed. Heikkila Creek is a significant source of phosphorus to the lower end of AUID-511.

Nutrients - Nitrate and ammonia

Nitrate values were extremely low, with three of five samples being below the lab detection limit. Ammonia values were also very low.

Dissolved Oxygen

The IWM monitoring at biological sampling visits found substandard DO levels several times, even when the sample time was well past the point of the daily low DO level. A synoptic sampling of DO was conducted on August 3, 2018 at five sites within the subwatershed draining to AUID-511 (Figure 9), including both upstream and downstream of the site of impairment (Table 4). Two of the five sites showed greater groundwater input by their lower temperatures and higher specific conductivities (Heikkila Cr. and the uppermost Kettle River site). Those were also the two sites with the lowest DO (especially Heikkila Cr.). The synoptic sampling was repeated on August 9, 2018, targeting earlier morning samples to better estimate daily low DO levels. The DO levels were indeed lower at all sites, though by a fairly small amount at most sites. The same pattern of relative levels was seen both days, and the two middle-AUID sites had the lowest DO levels, particularly the site at the Swede Lake Road crossing, which was just very slightly above the DO standard at the early-morning sample. That day's low probably occurred around 6:30 a.m., so the level was likely a bit below the standard earlier that morning. Both dates had sunny conditions.

It appears that the DO flux is relatively small as each site's change was quite minor from early morning to late morning/early afternoon, and with the DO saturation levels well below 100% in late morning/early afternoon, there does not appear to be eutrophication occurring. Additionally, most sites had little to no aquatic vegetation, and no filamentous or water column algae was observed at any site.

Observations of the stream channel characteristics at each site suggested that DO levels may be related to the nearby landscape features (much riparian wetland vs minimal riparian wetland) and the channel gradient at/near the measurement location. A channel elevation profile for AUID-511 was calculated in ArcMap using LiDAR to draw the stream channel shapefile and using 3D Analyst processing tools in ArcMap to derive the channel elevation at any point along the stream. These were plotted on a graph to show a visual depiction of channel gradient throughout AUID-511 (Figure 10, Table 5). Estimates of gradient were determined for various sections of similarity using the graph in Figure 10 (Table 14).

Figure 9. Subwatershed of AUID-511 with locations of DO sampling on August 3 and August 9, 2018 in and tributary to AUID-511 (the darker blue line). Locations and results of biological monitoring are also shown: Fish (F) and Macroinvertebrate (I) scores - green letter is passing, red letter is failing.

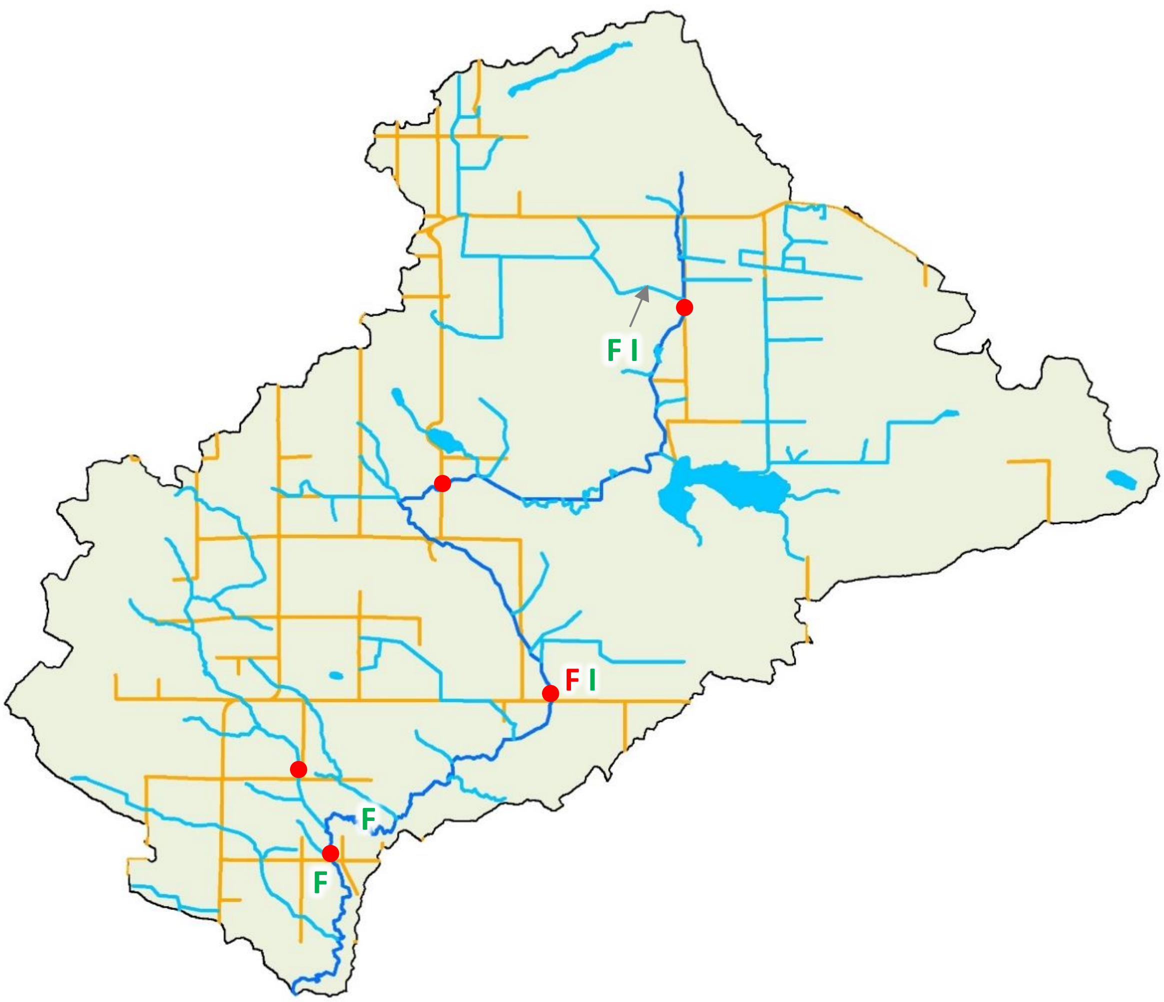


Table 4. DO, water temperature, and conductivity measurements from synoptic sampling on August 3, 2018 and August 9, 2018 in and tributary to AUID-511. Sites listed from south to north.

Date	Site	Time	DO	DO % Sat.	Water Temp.	Sp. Cond.
August 3	Kettle R. at CR-156	11:40	7.99	85.1	18.33	132
August 3	Heikkila Cr. at CR-129	12:00	1.70	17.7	17.10	166
August 3	Kettle R. at Mahtowa Rd	12:30	6.82	72.7	18.46	137
August 3	Kettle R. at Swede Lake Rd	12:50	6.75	75.0	20.49	128
August 3	Kettle R. at Kettle Lake Rd	13:15	6.26	62.8	15.48	213
August 9	Kettle R. at CR-156	9:30	7.37	82.1	20.68	132
August 9	Heikkila Cr. at CR-129	9:15	1.51	16.3	19.04	159
August 9	Kettle R. at Mahtowa Rd	9:05	6.17	69.4	21.11	135
August 9	Kettle R. at Swede Lake Rd	8:52	5.10	56.7	20.48	129
August 9	Kettle R. at Kettle Lake Rd	8:30	6.05	62.6	16.99	195

The headwater site along Kettle Lake Road is much colder than the other sites, has relatively high gradient, and has the highest conductivity. These combined factors suggest the somewhat lower DO found at this location is likely due to greater inputs of groundwater, which is generally quite low in DO. The higher gradient probably helps aerate the water by causing mixing of the water and greater atmospheric contact to increase water exposure to oxygen.

At lower flow volumes (e.g., August 9), the next two sites have relatively low DO. The gradient at these sites is quite low relative to the headwaters and downstream ends of the AUID (locations 6 and 9 in Figure 10). The sluggish flow, and organic content of the substrate leads to reduced atmospheric exposure, and greater bacterial consumption of oxygen due to decomposition.

The lower site has the best DO levels. It is in a section of river that has much greater gradient. The gradient has exposed hard substrate (gravel and cobble) and does not allow fine organic particles to settle out and accumulate (Photo 1). There are riffles present which are very helpful in providing aeration. These factors are able to overcome the very low-DO water that enters just upstream from Heikkila Creek.

Figure 10. Gradient graph of AUID-511, a distance of about 32,500 river meters (20.2 miles). The headwaters is at the left side of the graph. The vertical red lines delineate reaches of similar gradient and show where gradient changes occur. From about the 20,000-meter mark (12.4 mile), the river gradient generally is greater than all but the extreme headwaters at the left of the graph. Numbers correspond to locations in Table 5. The bold numbers were longitudinal DO measurement sites.

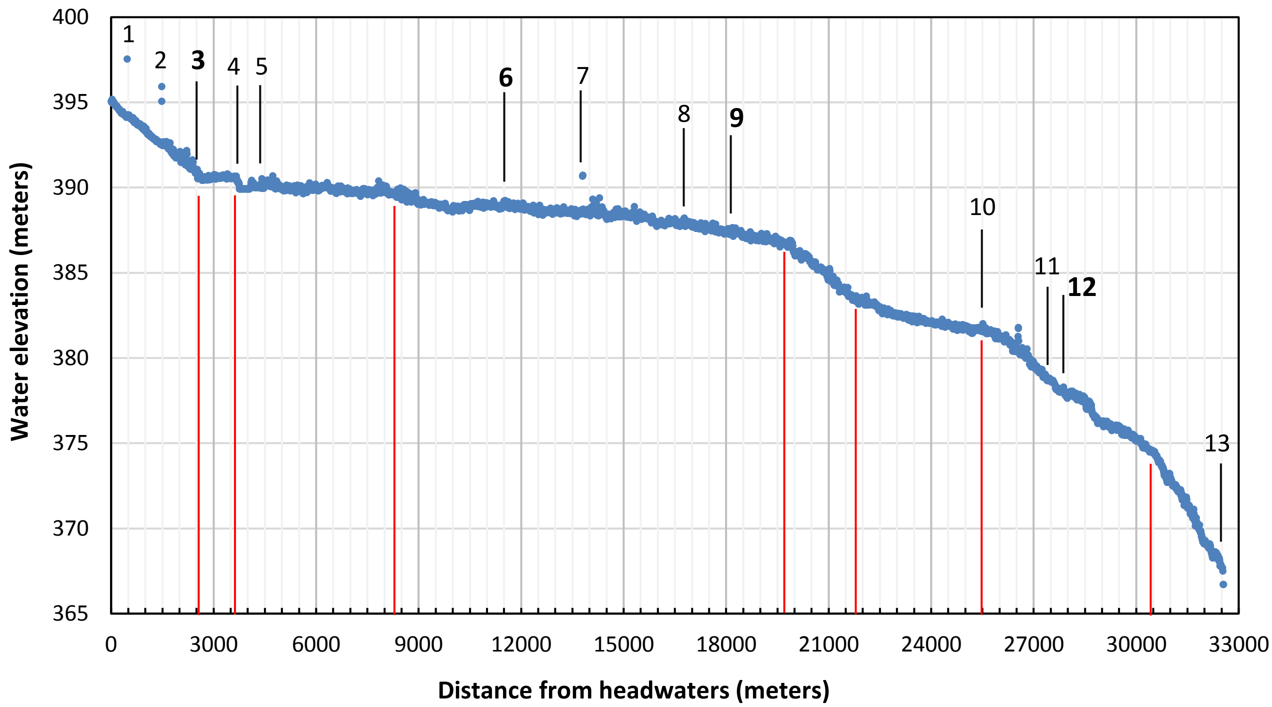


Table 5. Locations shown in Figure 10.

Number	Description of location
1	Minnesota Highway 210 crossing
2	Railroad tracks
3	Mouth of ditch containing site 16SC039, also site of Kettle Lake Road crossing DO measurement
4	Beaver dam
5	Township Road 112 crossing
6	Swede Lake Road crossing
7	Four Corners Road crossing
8	Four Corners Road East crossing and site 92SC020
9	Mahtowa Road crossing and site 16SC043
10	Site 06SC012
11	Site 96SC085
12	CR-156 crossing
13	End of AUID-511 and entry point of Kettle River West Branch

Table 6. Estimations of stream gradient within segments of similarity for AUID-511. The lower set of segments used a more general partitioning of like gradients.

Similarity segment	Distance (m)	Length (m)	Beginning elev. (m)	Ending elev. (m)	Drop (m)	Gradient (%)	Biological sites contained
1	0-2600	2600	394.8	390.5	4.3	0.1654	
2	2600-3650	850	390.5	390.5	0.0	0.0000	
3	3650-8300	4650	390.5	389.8	0.7	0.0151	
4	8300-19900	11600	389.8	386.8	3.0	0.0259	92SC020, 16SC043
5	19900-22400	2500	386.8	383.2	3.6	0.1440	
6	22400-26000	3600	383.2	381.4	1.8	0.0500	06SC012
7	26000-30500	4500	381.4	374.6	6.8	0.1511	96SC085
8	30500-32688	2188	374.6	366.8	7.8	0.3565	
1	0-2600	2600	394.8	390.5	4.3	0.1654	
2	2600-19900	17300	390.5	386.8	3.7	0.0214	92SC020, 16SC043
3	19900-26000	6100	386.8	381.4	5.4	0.0885	06SC012
4	26000-32550	6688	381.4	366.8	14.6	0.2229	96SC085

Transparency and suspended solids

TSS values were typically fairly low, except slightly above the northern MN standard at the 2006 visit at 06SC012. Transparency was fairly poor, most likely due to the high levels of tannins (tea-color staining) in the water from the area's wetlands.

Conductivity

Specific conductivity was very low and non-problematic.

Stressor signals from biology

Fish

The 2016 sampled fish community at 16SC043 was composed only of ubiquitous species, with central mudminnow being the dominant species. The 2017 community had several fewer species present, and was again dominated by central mudminnow. It did however have two less-common species which are more sensitive to habitat conditions, those being the brassy minnow and longnose dace. They were represented by two and one individual respectively. The sample from 06SC012 (2006), which is farther downstream in the AUID, was highly dominated by black bullhead. Likely, a school or two of young of year (YOY) were encountered. This site had many more species than upstream at 16SC043, including a number of positive or sensitive ones (smallmouth bass, golden redhorse, rock bass, shorthead redhorse, longnose dace, and burbot). The site farthest downstream on this AUID (96SC085) had an exceptional-level fish community (the only sample here is from 1996), and was dominated by the sensitive species longnose dace. A number of other sensitive species were collected, including; mottled sculpin, shorthead redhorse, logperch, burbot, slenderhead darter, stonecat, chestnut lamprey, and golden redhorse.

The Community TIV Index scores are shown in Table 7 and individual TIV metrics in Table 8. The fish samples show strong evidence of the influence of lower DO in the upper portions of the AUID. The DO Community Index scores were low at both visits to 16SC043, and the visit to 06SC012. The highest probability of the samples from those three visits coming from a DO standard-meeting reach was only 13%. The fish community at 16SC043 is highly unlikely to come from a site with standard-meeting DO, whereas the farthest downstream site, 96SC085, shows an extremely high likelihood of coming from a site with standard-meeting DO. The fish communities at the two more-upstream sites are also shown to be skewed toward low-DO tolerance in terms of the Tolerant vs Intolerant species numbers, and the percentage of Tolerant vs Intolerant individuals. Though the middle site, 06SC012, is skewed toward low-DO Tolerant species, there were a number of species present that signal good water quality, including smallmouth bass, golden redhorse, shorthead redhorse, longnose dace, and burbot. There is no evidence in the fish data of stress from TSS. The upper and lower sites' communities were highly likely to come from TSS standard-meeting waters. Though the middle site (06SC012) has a mediocre probability, this is due to the large number of YOY black bullheads (which form large schools and are not representative of the more-permanent community composition) that were captured, which confounds this TSS analysis for 06SC012. Black bullhead are at the 72nd percentile of 117 Minnesota fish species for high tolerance of TSS.

A DNR fish data set is available for this part of the Kettle River from sampling done in 1992. Sample method differences do not allow for assessment using the FIBI, but the taxa lists from those sites can be very informative. There were four sample sites in AUID-511 and one in the next downstream AUID-529, which is a very short stream reach. The DNR sample farthest downstream in AUID-511 was very near MPCA site 16SC043. This sample was dominated by yellow perch and central mudminnow, and included a total of six species, five of which are extremely ubiquitous and tolerant of lower DO concentrations. A single chestnut lamprey was the exception. The other three DNR sites higher up in AUID-511 had similar fish species. The DNR sample in AUID-529, approximately 2.1 miles downstream from the end of AUID-511, had a very different and robust fish community; 15 species were present, including sensitive or desirable species rock bass, golden redhorse, logperch, burbot, slenderhead darter, smallmouth bass, and walleye. Physical habitat differences play a role in the presence of these species, but this community also signals that DO concentrations are likely better. It is interesting to note that the uppermost DNR site in AUID-511 shows influence of groundwater inputs, as numerous finescale dace and pearl dace were collected there. These species are very sensitive, and often found in cool-to-coldwater habitats. Neither of these species were collected in any of the other DNR sites mentioned here.

Table 7. Fish Community DO and TSS Tolerance Index scores in AUID-511. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class (2018 versions). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards.

0	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16SC043	7	6.00	6.22/6.21	40	13.0	12.60	15.10/13.39	68	83.9
16SC043	7	5.59	6.22/6.21	14	6.6	12.76	15.10/13.39	63	83.4
06SC012	5	5.86#	6.99/7.11	3#	10.4#	22.35†	13.85/12.99	4	27.7#
96SC085	5	7.92	6.99/7.11	99	82.6	9.66	13.85/12.99	95	92.0

#This number is significantly reduced due to the catch of a school of YOY black bullheads.
†This number is significantly increased due to the catch of a school of YOY black bullheads.

Table 8. Metrics involving DO and TSS tolerance for the sampled fish communities at 16SC043, 06SC012, and 96SC085.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low DO	16SC043	0	0	5	3	0	68.0
Low DO	06SC012	1	0	7	4	0.6	80.1[#]
Low DO	96SC085	2	0	2	0	58.2	2.9
TSS	16SC043	0	0	0	0	0	0
TSS	06SC012	4	2	0	0	10.6	0
TSS	96SC085	5	3	0	0	66.3	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.
[#]This number is very inflated due to the catch of a school of YOY black bullheads.

Macroinvertebrates

The macroinvertebrate community passed the MIBI at all three sites that MPCA has sampled on AUID-511. The community found at 16SC043 on August 2, 2016 was dominated by *Simulium* (black flies), with caddisfly *Cheumatopsyche* and midge *Polypedilum* next most abundant, though their counts were much lower. The September 11, 2017 visit was dominated by mayfly family Leptopholebiidae, followed by *Simulium*, with all other taxa much less abundant than these two. The sample from 06SC012 was deemed un-assessable, due to the collection being done in a period of abnormally low flow. Thus, the sampled community may not be representative of normal conditions, though it did score above the passing threshold. At site 06SC012, the community was dominated by the midge *Endochironomus*, followed by the snail *Ferrissia*. This site had a distinct wetland-taxa signature, with a number of snail, Hemiptera, and beetle taxa, a few mosquito individuals, and many Coenagrionidae damselflies. The taxa list contained few taxa that require higher levels of DO. The taxa collected at the farthest-downstream site (96SC085) were drastically different than the other two sites, with a large number of sensitive taxa present, including some coldwater taxa.

The Community TIV Index scores are shown in Table 9 and individual TIV metrics in Tables 10 and 11. The DO TIV Index at 16SC043 from 2016 is not as helpful in the analysis due to the dominance of *Simulium*. The genus has a fairly high DO tolerance value, which is an artifact of their need for good flow velocity (due to their feeding method), which is commonly, but not always correlated with higher DO concentrations. Thus, they are likely artificially skewing the DO TIV Index scores to be higher (better) than they otherwise would be. The 2017 community does score quite a bit better than the class average. It is clear from the macroinvertebrate data that the DO conditions are greatly improved in the lowest parts of AUID-511 (compare the # Intolerant Taxa metric in Tables 10 and 11). Habitat is also much different at this lower site, with higher gradient (compare sites on the gradient profile - Figure 10), swifter flow, and the presence of rocky riffles. This habitat difference is an additional reason for the increased presence of low-DO Intolerant taxa. The macroinvertebrate community does not show significant negative effects from inadequate DO concentrations, though there is some evidence in the macroinvertebrate data that DO concentrations are lower in the upper parts of the AUID and good near the downstream end. This is somewhat masked by the dominance of *Simulium* in the 2016 sample at 16SC043, but evident in the comparison of the numbers of low-DO Intolerant taxa at 16SC043 versus 96SC085.

The TSS Index score differed significantly between 2016 and 2017 at site 16SC043, with the 2017 sample being much better. The probabilities of the samples coming from a TSS standard-meeting site are quite high, suggesting TSS is not a stressor. Conversely, the macroinvertebrate community is highly skewed toward TSS Tolerant taxa, both in terms of number of taxa, as well as percent of individuals. The three individual samples are inconsistent regarding their relationship to the average score for the class, with one being substantially worse, one slightly better, and one substantially better. It seems that this pattern may actually be associated with substrate type, as site 96SC085 was mostly rocky substrate and only 7.7% fine particulate sediment while the poor-scoring 16SC043 had predominantly sand and silt as substrate. The presence of many TSS Tolerant taxa may actually be due to the predominance of fine substrate material.

Table 9. Macroinvertebrate Community DO and TSS Tolerance Index scores at 16SC043 (class 4) and 96SC085 (class 3). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet those standards.

Site	Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16SC043	8/2/2016	7.33*	6.30/6.46	95*	76*	14.86	13.63/13.77	23	75.3
16SC043	9/11/2017	6.92	6.30/6.46	77	67	13.50	13.63/13.77	56	84.2
96SC085	8/28/1996	6.89	7.02/7.14	34	66	11.91	13.41/13.47	82	91.2

*These numbers are inflated due to the dominance of *Simulium* in the sample.

Table 10. Macroinvertebrate metrics related to DO, TSS, and conductivity for 16SC043 utilizing MPCA species tolerance values.

Parameter	Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	8/2/2016	4	1	3	0	3.5	2.2
DO	9/11/2017	7	2	3	0	5.9	4.9
TSS	8/2/2016	1	0	7	1	0.6	31.2
TSS	9/11/2017	0	2	15	3	0.7	23.0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Table 11. Macroinvertebrate metrics related to DO, TSS, and conductivity for 96SC085 utilizing MPCA species tolerance values.

Parameter	Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	8/28/1996	19	11	4	0	37.6	1.7
TSS	8/28/1996	13	6	10	4	15.9	14.2

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Overall biological data conclusions

Combining the signals from both fish and macroinvertebrates, these analyses provide evidence that the fish community is being stressed by inadequate DO levels in the upper 3/4^{ths} of the AUID, while TSS is not a stressor. There is little evidence that either low-DO or elevated TSS is stressing the macroinvertebrates. Site 16SC043 is near the downstream end of a long low gradient stretch of AUID-511 (Figure 10). Low gradient, wetland-fringed reaches are often found to have naturally low DO levels. That the higher measured DO levels and much better fish community is found a relatively short distance downstream, after gradient has increased, is further evidence that DO is low due to the channel morphology and riparian characteristics, and not due to a pollutant. The fish community TSS Index scores were fairly good (exceptionally good at 96SC085 - though the sample here was 24 years ago), well below their class averages. Taken together with the fish community analysis, the relatively good TSS samples, the low gradient, and the seeming substrate associations with macroinvertebrate TSS Index scores (rather than actual suspended material), TSS does not appear to be a stressor of the biology.

Temperature

Temperature measurements in Tables 3 and 4 showed none that would be problematic for the fish community. The 2006 measurement was somewhat high, but that date had a very low water level. During hot, sunny days, the stream may temporarily get near the point where temperature can be stressful for fish, due to the open exposure of the channel in ditched reaches and the dark coloration of the water. Warming of the water is a negative factor related to DO levels. Temperatures in the downstream section of the AUID are fairly close to being indicative of a coldwater stream. A temperature logger was deployed here in 2010, covering the last 5 days of July, and all of August (Table 12). Heikkila Creek delivers some cooler water a short distance upstream of 96SC085 (Table 4).

Table 12. Water temperature logger statistics from 96SC085 (just upstream of CR-156) from a deployment in summer 2010. In degrees Celsius.

July avg. temp.*	July avg. daily maximum*	August avg. temp.	August avg. daily maximum
20.61	21.67	21.12	22.59

*The July averages are only for the last five days of the month.

Habitat

Habitat changes greatly between the upper and lower parts of this AUID. The upstream sites are very low gradient, soft-bottomed, fine-sediment substrate channels, with few distinct channel features, while downstream, there is rocky substrate, more gradient that creates higher velocities (and variations in velocity), distinct channel features (e.g., riffles), and forested riparian conditions (Photo 1). Going another 4 miles downstream, within the next AUID, the fish community received a stellar score, far beyond the exceptional use stream category threshold.

MSHA scores quantify these habitat changes from upstream to downstream. Four assessments have been done over several years at 16SC043 (a ditched reach), and one at 06SC012 (a natural channel). The total and sub-component scores are shown in Tables 13 and 14. Total MSHA scores were averaged for the four visits to 16SC043, resulting in a score of 44, which is at the top end of the “Poor” category. The poorest-scoring sub-component scores from 16SC043 were “Channel Morphology” and “Substrate”. Larger substrates were highly embedded by fine sediment, smothering important habitat. Poor scores in these two categories are consistent with general findings of ditch habitat. The score at 06SC012 was

64.1, near the top end of the "Fair" category. The poorest-scoring sub-component scores from 06SC012 were "Cover" and "Channel Morphology". Substrate was predominantly sand and gravel, though some cobble was present. Embeddedness of cobble was 50-75%, which is fairly significant, suggesting excess fine sediment is present, though somewhat less than farther upstream. The poorest scoring features within "Channel Morphology" were "Channel Development" and a lack of variability in flow velocity.

Table 13. MSHA scoring for site 16SC043.

MSHA Component	Visit 1	Visit 2	Visit 3	Visit 4	Avg.	Maximum Poss. Score	Percent of Maximum
Land Use	4	5	4.5	5	4.63	5	92.5
Riparian	11	11	10.5	11	10.88	14	77.7
Substrate	7	19	8	8	10.50	28	37.5
Cover	11	12	9	5	9.25	18	51.4
Channel Morphology	3	12	8	12	8.75	35	25.0
Total MSHA Score	36	59	40	41	44	100	44.0 = "Poor"

Table 14. MSHA scoring for site 06SC012.

MSHA Component	Score	Maximum Poss. Score	Percent of Maximum
Land Use	5	5	100
Riparian	11	14	78.6
Substrate	18.1	28	64.6
Cover	9	18	50.0
Channel Morphology	21	35	60.0
Total MSHA Score	64.1	100	64.1 = "Fair"

Photo 1. Habitat differences along AUID-511. Photo A is at the site (16SC043) with an impaired fish community, while photo B is about 4 miles farther downstream (at CR-156, 96SC085), where the biological communities were excellent at a previous sampling (1996); the fish scored far above the exceptional use threshold and the macroinvertebrates also scored beyond their exceptional use threshold here.

Hydrology

There has been modification of the channel in parts of AUID-511. Some sections were straightened, and there is some trenching within some peatlands where there likely was not a channel originally present. However, the changes to the hydrology of the stream do not appear to be creating channel instability, as determined by observation at several points along the AUID.

Geomorphology

The upper parts of this AUID were channelized decades ago. The upstream site (16SC043) is on a channelized reach, and thus does not have natural geomorphological form, such as a sinuous pattern. The lower site (06SC012) is on a natural channel reach, and as a result, has much better habitat scores due to sinuosity and the features that sinuosity creates (depth and velocity variability, riffles and pools, etc.). No on-the-ground geomorphology studies were conducted on this AUID. The author viewed many crossings of this part of the river, and signs of channel instability were not evident.

Connectivity

There are no beaver dams on AUID-511 showing on recent aerial photography. There are only two road crossings with culverts. Both were assessed by DNR to be potentially occasional barriers, but both are well upstream of 16SC043. There are no culvert crossings below 16SC043. Downstream of this site, the river becomes too large to use culverts, and the road crossings are all bridges. Thus, there are no connectivity problems that would contribute to the impaired fish community at 16SC043.

Conclusions about stressors

Dissolved oxygen is a stressor in the upper two-thirds of AUID-511. This is the channel section that the gradient analysis showed to be quite flat. The direct DO measurements revealed below-standard levels, and the analysis of the fish community also clearly showed the community to be skewed toward fish that tolerate low DO conditions. The artificial drainage (ditches) throughout this subwatershed are very likely a negative influence on DO levels in the river.

There are no permitted pollutant dischargers active in this subwatershed. There is some potential for non-point nutrient pollution due to agricultural activity, but farmed acreage is quite moderate, and not of the more influential row crop type. The ditched condition of part of the AUID-511 channel is likely contributing to the substandard DO levels by being a wider channel than the original, allowing for more sunlight to reach the darkly stained waters of the river in this area (warmer water holds less oxygen). Other negative in-channel habitat conditions typical of ditches (i.e., fine sediment substrate, homogeneous velocity and reduced streambed contour) are found in the upper and middle portions of this AUID. In addition to being poor habitat, uniform stream channels create less-turbulent flows and reduce water interaction with the atmosphere (i.e., reduces aeration). Reduced habitat compounds the low DO as an additional stressor.

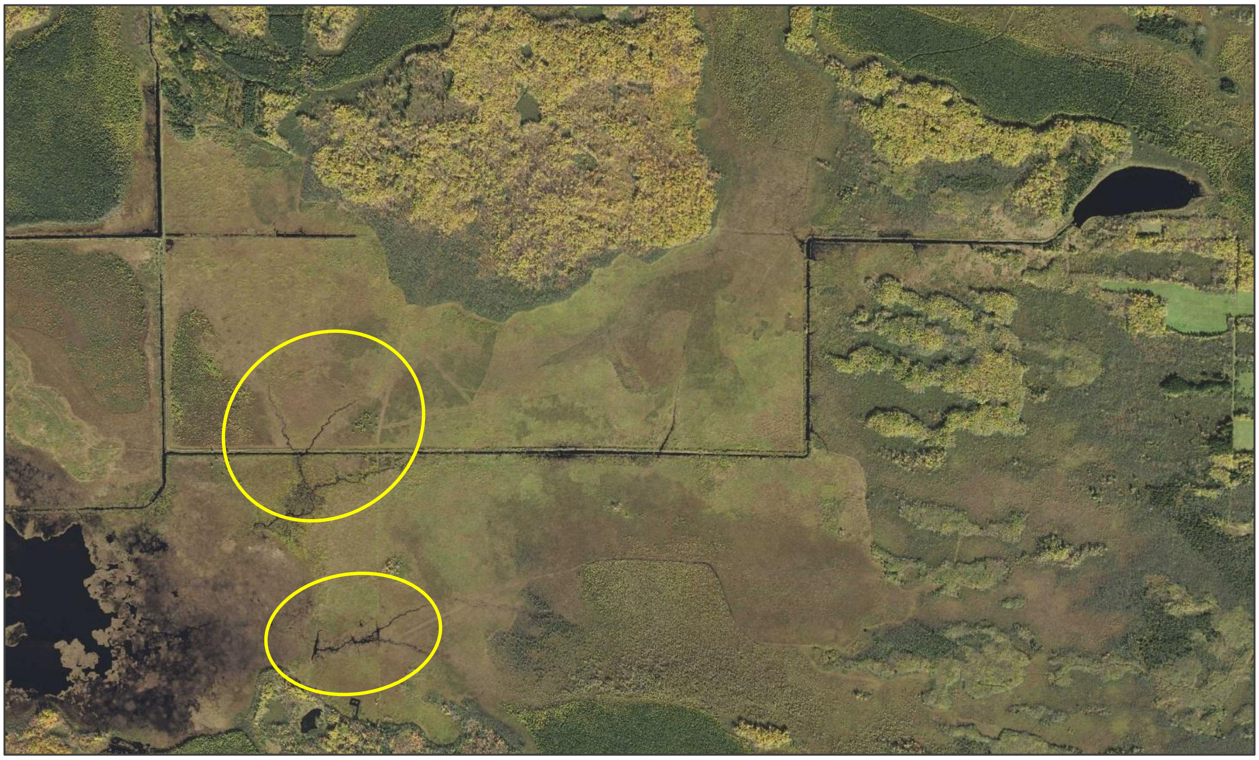
The downstream third of the subwatershed is a natural channel, and its features - more gradient, rocky substrate, and riffles - create a situation that enhances the exposure of the water to the atmosphere, and DO levels are significantly improved in this part of the AUID, which has received easily-passing biological scores in previous monitoring. This greater diversity of physical habitat also contributes to better biological communities in the lower reaches. Signs of physical channel instability were not present, and issues of altered hydrology are not of strong concern for bank erosion reasons, though the altered flow may contribute to periodic low flows due to reduced upstream storage. During these periods, DO levels may become especially problematic as stream flow becomes more stagnant. Ditching of peatlands also likely contributes to low-DO by routing anoxic peatland waters into the channel. Connectivity is good, and fish migration barriers to the majority of the AUID are absent.

Recommendations

There are some locations in this subwatershed where legacy ditches that appear to have to no landowner benefit could be plugged to restore a more natural hydrology, where water is more slowly released from the wetlands. There are also opportunities in this AUID for re-connecting flow into the original meandering channel, which would improve habitat in those areas where the channel was straightened. An easy reach to put back into its original channel is just downstream of Kettle Lake (Figure 11). Ditches within peatlands that are of little or no benefit could be plugged. One location would be the wetlands just east of Kettle Lake, particularly since some of this land is part of the Kettle Lake State Wildlife Management Area, and thus may be easier to conduct a restoration than where adjacent land is private (Figure 12). A discussion of similar restoration of ditched streams and ditch abandonment can be found in the SID report for the neighboring Mississippi River - Grand Rapids Watershed (MPCA, 2019b, pages 122-128). Hydrologists should be consulted to determine the effects of ditch plugging prior to taking action.

Figure 11. Example location where re-meandering could be accomplished to improve habitat and naturalize hydrology. This site is just west of Kettle Lake. The ditch spoil piles are still present and could be pushed back into the ditch to cause water to flow again in the original stream channel.

Figure 12. Example location where ditch filling could be accomplished to naturalize hydrology (improve storage). This peatland is just east of Kettle Lake, which can be seen at the far left. No stream channel existed in much of this wetland prior to ditching. The extent of the original, natural channels draining the wetland into Kettle Lake are circled in yellow.



South Branch Grindstone River (AUID 07030003-516)

Impairment: The river was assessed as impaired for not meeting fish community IBI thresholds at sites 16SC086, located at Old Velvet St, 7 miles northwest of Hinckley, and 96SC063, located at Southfork Road, 4 miles northwest of Hinckley. A third site, 16SC076, at Two Rivers Road, two miles west of Hinckley (farther downstream on the AUID) scored very well, suggesting only the more upstream reaches of the AUID are experiencing significant stress. Site 96SC063 is a "Long Term Biological Monitoring Site", and is sampled every two years. It has been sampled by MPCA three times. In 1996, it received a passing IBI score, and in both 2013 and 2015, the IBI scores failed. Two locations on this AUID were sampled for fish by DNR in mid-July of 2003. Both sites are quite close to the two failing MPCA sites. The DNR samples both receive passing IBI scores, though they were collected outside of the 10-year data period used in the current assessment. The macroinvertebrate community passed the MIBI at all sites.

Subwatershed characteristics

The South Branch Grindstone subwatershed is a mixed-use/mixed land-cover landscape, composed of significant wetland area, forest, hay and pastureland, row crops, and low-density residences (Figure 13). Sites 16SC086 and 96SC063 are both are Fish Class 7 (Low Gradient) and Macroinvertebrate Class 4 (Northern Forest - Glide/Pool) stream reaches. Site 16SC076 is a Fish Class 6 (Northern Headwaters) and

Macroinvertebrate Class 3 (Northern Forest - Riffle/Run) stream reach. There are no cities or towns located within the subwatershed, except a small piece of Hinckley right at the outlet. The HDS scores (81 is maximum score) for the three MPCA sites are 74.1 (16SC086), 72.3 (96SC063), and 68.8 (16SC076). All three sites' HDS scores are within the best 25% of all MPCA biological sample sites statewide.

Figure 13. South Branch Grindstone River subwatershed. Numbers are monitoring site locations to be discussed below in Table 15.

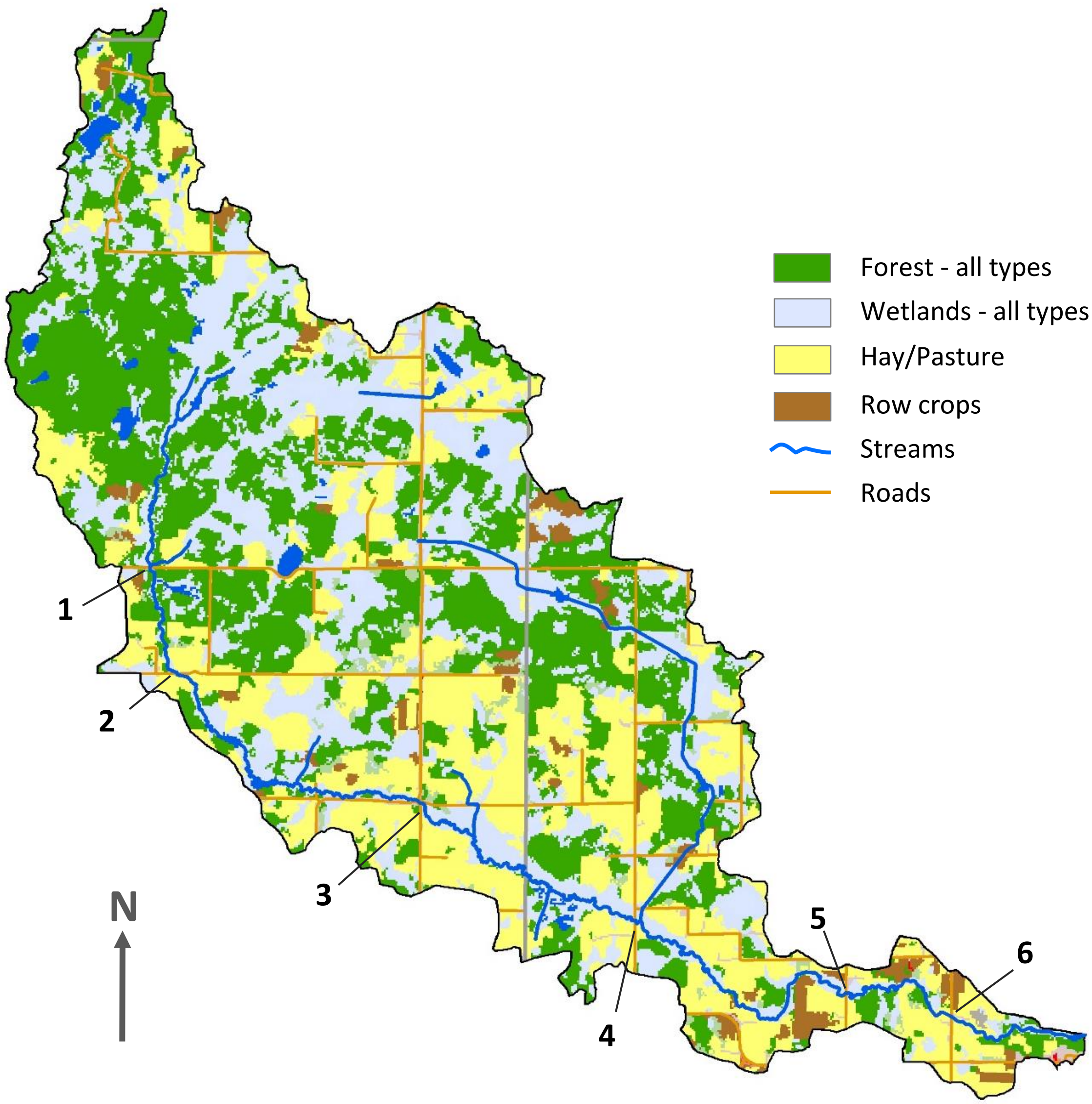


Table 15. Monitoring location designations corresponding to Figure 13 with site-specific IBI results.

Site	EQuIS #	Biological site #	Road Crossing	Macroinvertebrates	Fish
1	S005-544	NA	340th Avenue	--	--
2	S005-591	NA	330th Avenue	--	--
3	S005-541	16SC086	CSAH-20	Passing	Failing
4	S001-277	96SC063	Township 311	One exceptional, 2 passing, one exceptional (> 10 yr. old)	Two failing scores, one passing (> 10 yrs. old)
5	S001-279	NA	CSAH-17	--	--
6	S001-263	16SC076	Township 178	Passing	Passing

Data and analyses

Chemistry

There is a strong chemistry data set for AUID-516. The chemistry data that was collected at the biological sampling visits in 2016 and the biological sampling visits from 2013, 2015, and 2017 long-term monitoring visits are shown in Table 16. In addition, historical data exists for six sites spread along the nearly full extent of the AUID (Table 17). Longitudinal chemistry sampling was also conducted in the SID study in 2017-2019 (Tables 18 and 19).

Table 16. Chemistry measurements from IWM sampling at 16SC086, 96SC063, and 16SC076. Site 96SC063 is an MPCA "Long Term" biological monitoring site, and beginning in 2013 is sampled every two years.

Site	Date	Time	Temp	DO	DO % Sat.	pH	Cond.	T-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
16SC086	6/23/2016	12:08	20.1	5.85	67	7.2	142	> 100	0.075	< 0.05	< 0.05	3.2	2.0
16SC086	8/18/2016	15:38	22.5	4.87	59	6.9	106	96	--	--	--	--	--
96SC063	8/22/2013	7:45	17.4	6.92	75	7.4	269	> 100	0.032	< 0.05	< 0.05	2.4	2.0
96SC063	8/27/2013	10:17	23.0	7.11	86	7.8	356	> 100	--	--	--	--	--
96SC063	6/30/2015	7:36	17.9	5.95	65	7.2	--	74	0.096	< 0.05	< 0.05	3.2	1.2
96SC063	8/19/2015	8:47	16.5	6.08	65	7.1	159	> 100	0.074	< 0.05	< 0.05	2.4	2.0
96SC063	9/12/2017	12:34	17.2	9.38	103	7.5	171	> 100	0.056	< 0.05	< 0.05	1.2	--
96SC063	9/13/2017	10:39	16.8	8.42	91	7.4	159	> 100	0.056	< 0.05	< 0.05	2.0	--
16SC076	6/14/2016	12:41	19.2	9.36	106	8.1	196	98	0.067	< 0.05	< 0.05	3.2	1.2
16SC076	8/23/2016	16:14	23.2	6.14	93	7.5	134	83	--	--	--	--	--

Nutrients - Phosphorus

TP was generally higher than the northern region river standard, and in some cases, much higher. Based on the 2009 dataset, the highest average seasonal TP levels are in the middle portion of the AUID, where S005-541 and S001-277 are located. Among the four main 2009 sample sites, TP is highest at site S005-541 (highest average, maximum, and minimum concentrations), located at Velvet Street (Table

17). Site S001-279 had the highest TP measurement of all six sites, but only two samples were collected here, so it is not possible to determine how this site's TP generally compares to the other sites. The SID sampling from 2017-2019 showed a slightly different pattern for sites S005-541 and S001-277 (compare Tables 17 and 18). The relationships among the sites show more complex patterns when viewed along a seasonal continuum that trade off how the sites rank depending on the month of the year (Figure 14). At the far upstream end (S005-544), TP can be quite high in the middle of summer, but during fall and spring, this location has very low TP. This pattern fits a redox control (i.e., dependent on how much oxygen is present) of phosphorus in the headwaters area that makes sense given the large amount of wetlands adjacent to the channel in this part of the AUID. The TP levels become less predictable moving in the downstream direction (lower R^2 values; Figure 14, Table 20).

Table 17. Summary of historical (2009) TP data from multiple sites, listed from headwaters to downstream end of AUID. Values in mg/L. Bold, blue data is most comparable for longitudinal analysis due to same-date sampling.

Site	# Samples	Year(s)	Average	High	Low
S005-544	**11**	**2009**	**0.056**	**0.107**	**0.018**
S005-591	2	2009	0.073	0.106	0.039
S005-541	**11**	**2009**	**0.077**	**0.141**	**0.049**
S001-277	**11**	**2009**	**0.073**	**0.104**	**0.040**
S001-279	2	2009	0.109	0.157	0.060
S001-263	**12**	**2009**	**0.067**	**0.095**	**0.032**
S001-263	58	2007 - 2009	0.074	0.115	0.031

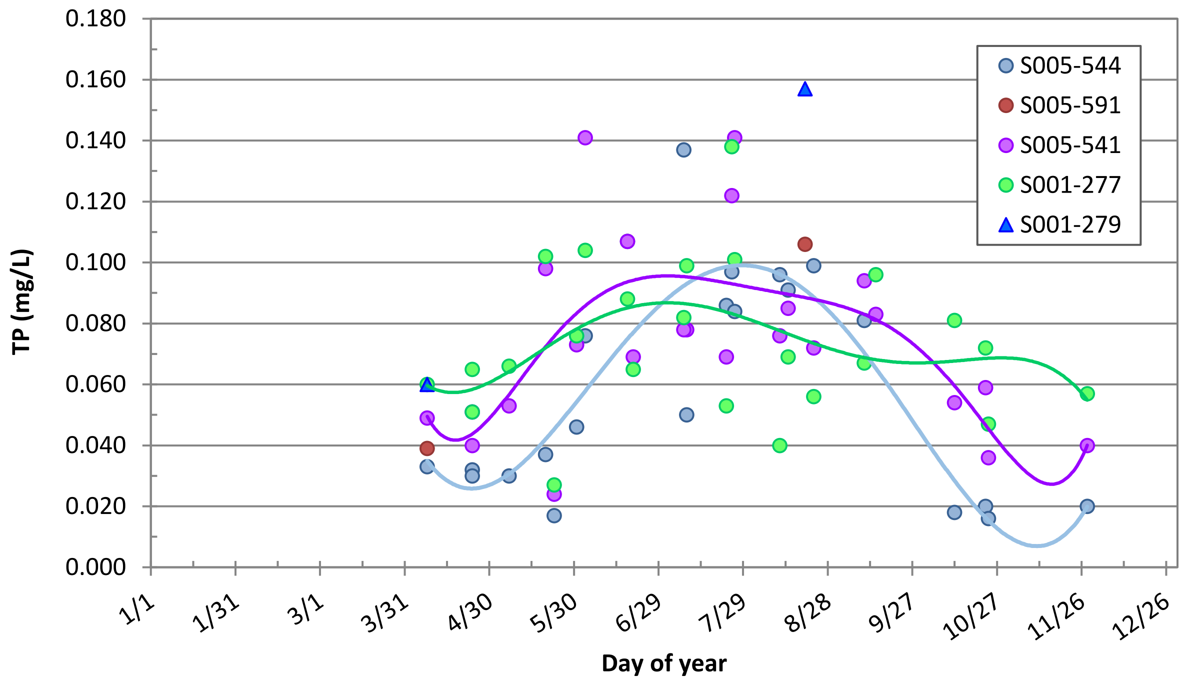
Table 18. Summary of 2017-2019 SID TP data from multiple sites, listed from headwaters to downstream end of AUID. Values in mg/L.

	TP				DOC				Total Iron (µg/L)			
Site	# Samp.	Ave.	High	Low	# Samp.	Ave.	High	Low	# Samp.	Ave.	High	Low
S005-544	11	0.062	0.137	0.016	10	14.5	22.5	4.6	9	2242.4	4010	233
S005-541	13	0.072	0.141	0.024	1	--	9.2	--	1	--	3290	--
S001-277	13	0.074	0.138	0.027	1	--	7.5	--	1	--	3950	--

Table 19. Same date longitudinal chemistry comparisons along AUID-516.

Site	Date	TP	DOC	Total Iron (µg/L)	TSS	TSVS
S005-544	11/28/2017	0.020	10.4	--	--	--
S005-541	11/28/2017	0.040	9.2	--	--	--
S001-277	11/28/2017	0.057	7.5	--	--	--
S001-263	11/28/2017	--	--	--	--	--
S005-544	4/24/2019	0.030	8.8	--	1.2	2.0
S005-541	4/24/2019	0.040	--	--	2.4	1.6
S001-277	4/24/2019	0.051	--	--	3.2	2.0
S001-263	4/24/2019	--	--	--	--	--
S005-544	7/8/2019	0.137	22.3	4010	--	--
S005-541	7/8/2019	0.078	--	--	--	--
S001-277	7/8/2019	0.082	--	--	--	--
S001-263	7/8/2019	0.087	--	--	--	--
S005-544	7/26/2019	0.084	16.8	2680	--	--
S005-541	7/26/2019	0.141	--	3290	--	--
S001-277	7/26/2019	0.101	--	3950	--	--
S001-263	7/26/2019	--	--	--	--	--
S005-544	8/14/2019	0.091	18.5	3100	--	--
S005-541	8/14/2019	0.085	--	--	--	--
S001-277	8/14/2019	0.069	--	--	--	--
S001-263	8/14/2019	0.072	--	--	--	--

Figure 14. 2009 and 2017-2019 TP data for five sites along AUID-516. The sites as listed in the legend are in order from headwaters to near the Grindstone dam impoundment in Hinckley. The curved lines are polynomial regression lines for the three sites with large data sets. R2 values are: S005-544 = 0.7548, S005-541 = 0.4300, S001-277, 0.1568.



Phosphorus can come from a number of sources, both natural (wetland release from plant decomposition, rain, natural runoff) and from human activity (poorly functioning septic systems, soil erosion, farm animal waste, erosion of stream bank soil when hydrology has been altered). One way to determine if erosion/soil is involved is to check the correlation of TSS and TP, because phosphorus binds to soil particles. The historical data set from 2007 - 2009 sampling had numerous dates when both TSS and TP were sampled at several locations along AUID-516, covering most of the length of the river (Table 20). Correlations (i.e., R^2 values) were very low at two sites, low at a third, and high in the headwaters. This suggests that the phosphorus in the river is not primarily from upland soil erosion (e.g., from agricultural fields) nor from bank erosion, even though the headwater site is strongly correlated to TSS. Because the headwaters area is predominantly an undisturbed landscape, the stream has very little erosivity due to its low gradient here, and wetland abounds in this area, it is likely decayed organic particles, and not mineral soil, that are responsible for the strong correlation in the headwaters, and thus it is not likely human-activity-sourced phosphorus is responsible for much of the phosphorus in AUID-516.

Additionally, TSS is low even during high-flow periods along the whole AUID, so sediment-attached phosphorus does not seem to explain the phosphorus pattern longitudinally in the river. The longitudinal pattern is still somewhat a mystery, except for what is happening with TP concentrations in the headwaters area. An additional source could be failing septic systems, though these would need to be near the river or tributaries, and there are few residences that are close to the river, so this source appears to be unlikely. Due to the above discussions, it is not likely human-activity-sourced phosphorus is responsible for much of the phosphorus in AUID-516.

Table 20. Correlations of TSS and TP for sites along AUID-516. Sites listed from upstream to downstream.

Site	Sample year	Number of samples	R^2
S005-544	2009	11	0.9050
S005-541	2009	11	0.0629
S001-277	2009	11	0.3151
S001-263	2007 - 2009	42	0.0789

Nutrients - Nitrate and ammonia

Nitrate was extremely low, with all samples collected in recent years by MPCA staff being below the lab detection limit (Table 14) and thus also extremely low relative to levels that have a toxic effect. Ammonia was extremely low, with all samples collected by MPCA staff in multiple dates and years being below the lab detection limit. Unionized ammonia, a toxic form, would be well below the state standard based on the ammonia measurements. Nitrogen is not a stressor in this AUID.

Dissolved oxygen

A synoptic, longitudinal sampling of chemistry was done in 2009, including DO measurements, at sites S005-544, S005-541, and S001-277 (listed upstream to downstream). Additional DO synoptic sampling was done in 2017 and 2018. DO at the uppermost monitoring site (S005-544) is very poor in growing-season months (Figure 15). The DO readings at the upstream site were essentially always at levels that do not meet the standard. Measurements at two sites farther downstream in this AUID were much better. Comparing all sites, sampling showed DO improving continually in the downstream direction (Figure 16). Few measurements were taken before 9 a.m., and so daily minimums are not reflected in the dataset.

Figure 15. DO at monitoring visits during 2009 and 2018 at S005-544, S005-541, and S001-277. The curved lines are polynomial regression lines used to draw a non-biased pattern to the data, but is only moderately predictive of any day's DO, since the measurements were taken at various times of the day (DO has within-day fluctuations). None of the measurements was taken prior to 9:00 a.m., and therefore, none of these measurements likely represent that day's minimum DO concentration. The red line is the DO standard.

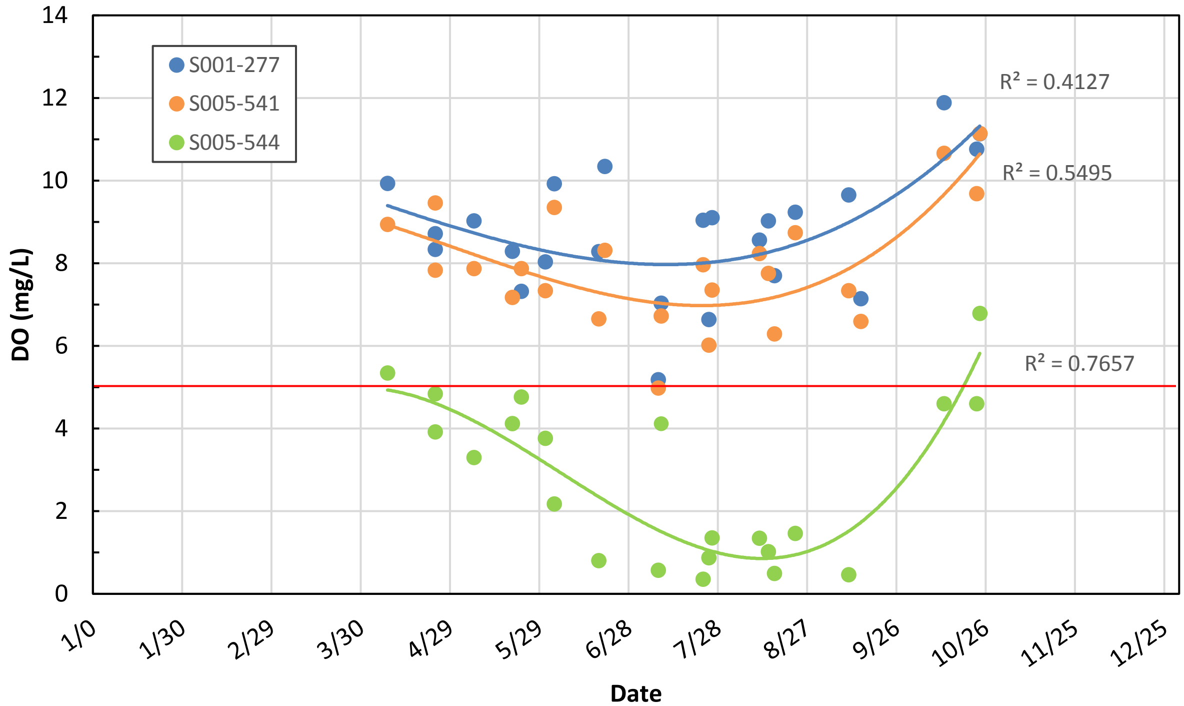
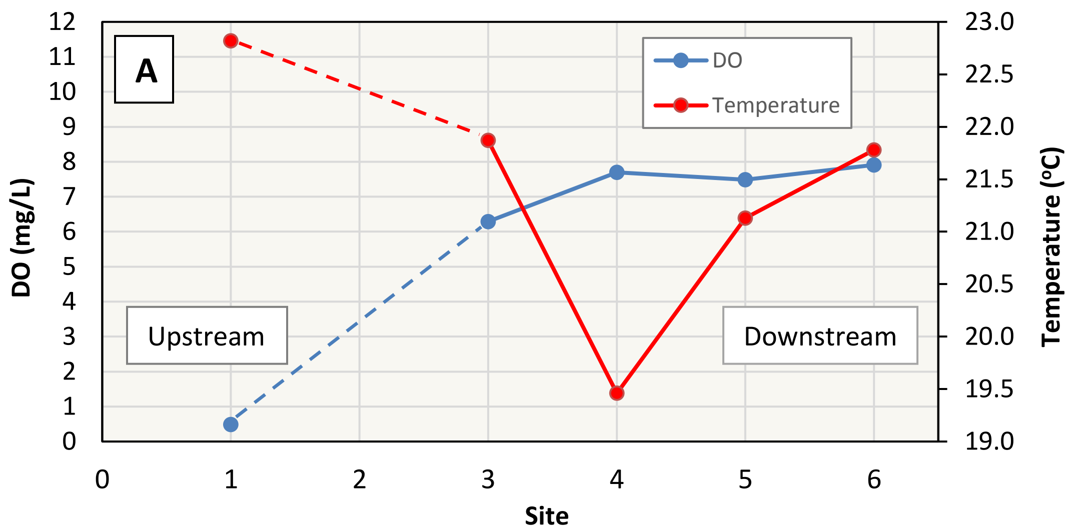


Figure 16. Single date longitudinal comparison of DO and water temperature at six sites along AUID-516. A = August 16, 2018; B = August 23, 2018. Sites get farther downstream moving from left to right in the graph. See Figure 13 for locations of the sites. Note that graph A does not have a measurement at site 2.



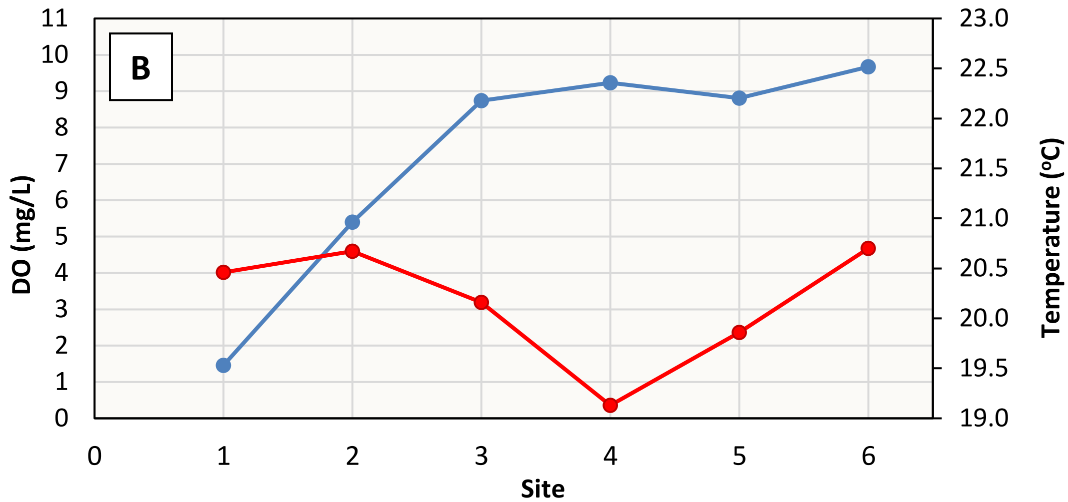


Figure 17. Elevation graph from headwaters at left, to the Grindstone impoundment at Hinckley. The noisy line beginning at the county line, near the center of the graph, is due to a slight offset in the GIS layers used to produce the graph. See Table 21 for more information about sites.

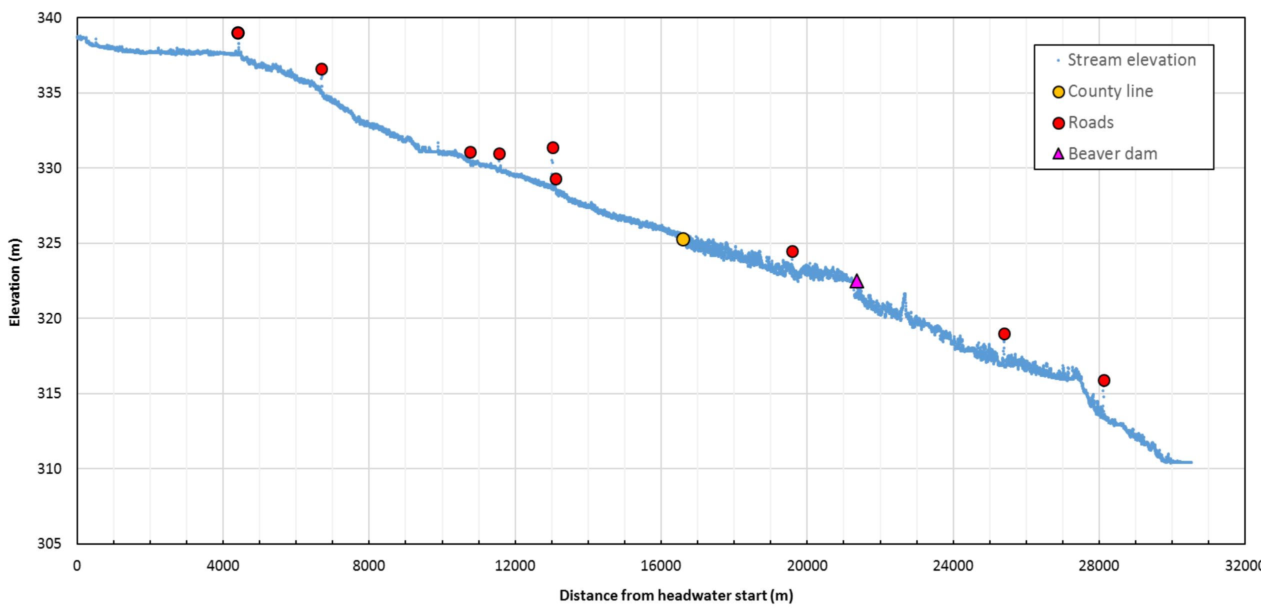


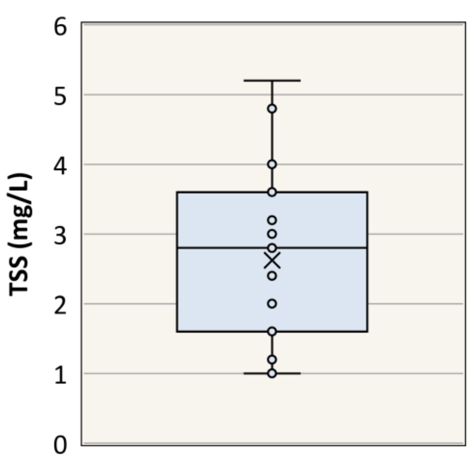
Table 21. Feature details for Figure 17. "Distance mark" means distance from the headwaters starting point.

Feature	Chemistry site	Site #	Distance mark (m)	Feature elevation (m)
County line	--		16594.1	325.3
Beaver dam	--		21365.5	322.5
Dam impoundment start	--		29940.8	310.5
Roads				
340th	S005-544	1	4426.1	338.3
330th	S005-591	2	6696.3	336.6
Private	--		10762.3	331.1
Private	--		11558.4	331
CSAH-20	S005-541	3	13016.4	331.4
Old bridge	--		13104.2	329.3
Twp-311	S001-277	4	19588.1	324.5
CSAH-17	S001-279	5	25386.7	319
Twp-178	S001-263	6	28114.4	315.9

Transparency and suspended solids

TSS was very low at all of the biological sampling visits, much below the state standard. TSVS (organic particles) ranged from 38 - 83% of the total particulate material. Secchi-tube readings were almost always exceptionally good. A significant number of TSS samples were collected in 2007-2009 at S001-263 (Two Rivers Road), near the downstream end of AUID-516 (Figure 17). All samples showed very low TSS concentrations, with a median value of about 2.8 mg/L, and a maximum value of 5.2 mg/L.

Figure 18. Box plot of 2007-2009 TSS samples (n = 43) at S001-263. The "X" mark is the average TSS value.



Conductivity

Conductivity is quite low and not at all problematic for the fish community. The longitudinal sampling that was conducted on August 16 and 23, 2018 showed a definite change between sites 2 and 4, with specific conductance being notably higher at site 4 (Figure 19). This confirms what the temperature pattern showed - that there are significant groundwater inputs starting somewhere between sites 2 and

3, and especially between sites 3 and 4. Springs can be seen on aerial photography (Figure 20). There is little change in conductivity downstream of site 4, probably meaning that there is not much groundwater entering the stream downstream of site 4.

Figure 19. Single date longitudinal comparison of specific conductance at 6 sites along AUID-516. A = August 16, 2018, B = August 23, 2018. Sites get farther downstream moving from left to right in the graph. See Table 21 for site location descriptions. Note that graph A does not have a measurement at site 2.

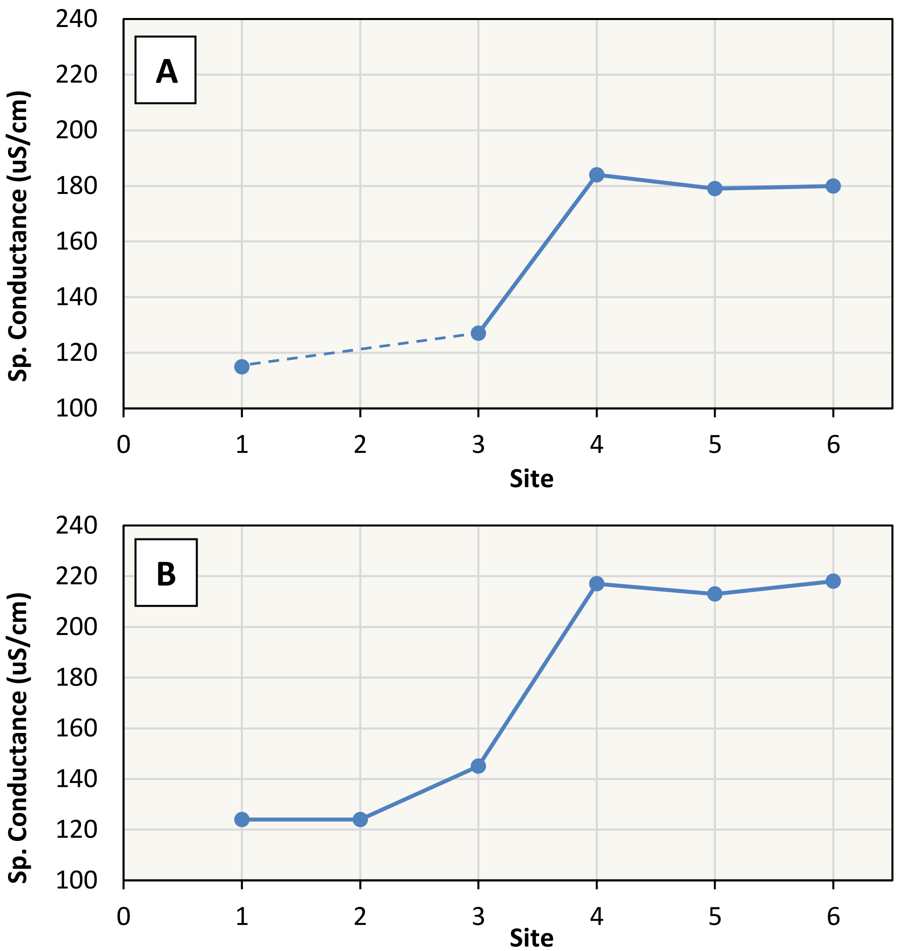
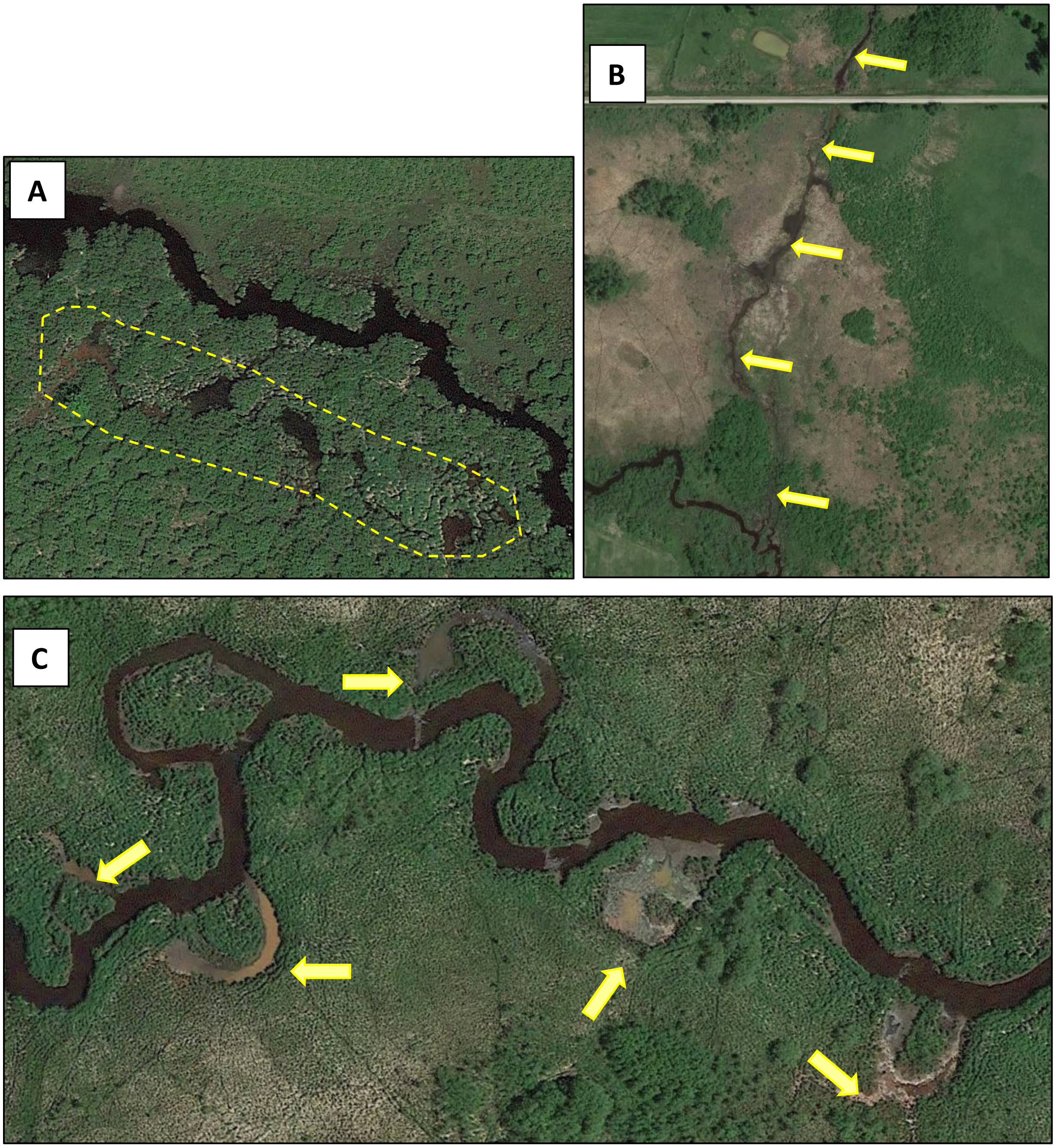


Figure 20. A) A set of springs along the channel near the Uniform St./320th intersection, B) A channel of spring water originating just north of 320th Avenue, near CR-20, C) Numerous springs along the channel upstream of Southfork Road - most showing substantial iron concentration from the groundwater.



Stressor signals from biology

Fish

An unusually small number of fish were captured in all of the fish sampling efforts at 96SC063 (the middle biological site). The upstream site (16SC086) had moderately greater numbers. Both of these sites had failing FIBI scores. The downstream site had better numbers of fish, more species, and a passing FIBI score. Six species present at the downstream site that were absent at the farthest upstream site were logperch, blacknose dace, common shiner, hornyhead chub, greater redhorse, and tadpole madtom. At the middle site, those absent were log perch, blacknose dace, and tadpole madtom (based on a composite of the three visits to 96SC063).

The DO and TSS metrics for the fish community were explored to add insight into possible stressors (Tables 22 and 23). The fish community DO TIV Index scores were very low upstream (at 16SC086) but show continual improvement moving in the downstream direction, based on sites 96SC063 and 16SC076 (Table 22). The TSS TIV Index scores were better than average at all three sites for the appropriate classes (Table 22). Based on the probabilities shown in Table 22, it appears the fish community is strongly influenced by low oxygen levels in the upper parts of the AUID and not significantly influenced by suspended sediment anywhere along the AUID. Additional fish metrics related to DO (Table 23) add to the evidence that the fish community is very skewed toward individuals that can live in low-DO waters at the upstream site (76.4%), and become much less so at the downstream site (5.4%).

Table 22. Fish Community Tolerance Index scores at 16SC086, 96SC063, and 16SC076 for DO and TSS. "Percentile" is the rank of the Index score within the fish Class 6 or 7 streams as appropriate (2018 version). "Prob." is the probability a community with this Index score would come from a Class 6 or 7 stream reach with TSS or DO that meets the standard. The values for site 96SC063-A are averages of two recent visits (2013 and 2015), while 96SC063-B is a historical sample from 1996.

Site and Class	DO TIV Index	Class avg./median	Percentile w/in class	Prob. as %	TSS TIV Index	Class avg./median	Percentile w/in class	Prob. as %
16SC086, 6	5.83	6.55/6.61	18	9.9	13.03	13.98/13.28	57	82.3
96SC063-A, 7	6.43	6.22/6.21	60.5	27.5	12.21	15.10/13.39	81	85.3
96SC063-B, 7	6.66	6.22/6.21	75	32.8	13.53	15.10/13.39	47	80.3
16SC076, 6	7.18	6.55/6.61	82	55.5	13.94	13.98/13.28	35	78.5

Table 23. Metrics involving DO tolerance for the sampled fish community at 16SC086, 96SC063, and 16SC076. The values for site 96SC063-A are averages of two recent visits (2013, 2015), and 96SC063-B is a historical sample from 1996.

Site	Stressor	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
16SC086	Low DO	0	0	3	2	0	76.4
96SC063-A	Low DO	0	0	1.5	1	0	42.5
96SC063-B	Low DO	0	0	3	2	0	30.1
16SC076	Low DO	0	0	3	2	0	5.4
16SC086	TSS	1	0	0	0	1.8	0
96SC063-A	TSS	0.5	0	0	0	4.2	0
96SC063-B	TSS	2	1	0	0	2.0	0
16SC076	TSS	2	1	0	0	7.3	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

In addition to water chemistry, there is potential that the Grindstone Dam at Hinckley is a stressor of the fish community in the South Branch of the Grindstone River. It separates the fish in AUID- 516 from migrating to refuge areas in the larger Kettle River downstream. This will be discussed in the "Connectivity" section below, using an analysis of the fish species present in various locations of the larger Grindstone River system.

Macroinvertebrates

The macroinvertebrate community passed the MIBI at all sites on the AUID. The upstream site, 16SC086 was dominated by *Simulium* (black flies), and next by the midge *Polypedilum* and caddisfly *Hydropsyche betteni*. At 96SC063, the middle site, the 2013 sample was moderately dominated by *Hyalella*, with caddisfly *Hydropsyche* and mayfly *Labiobaetis propinquus* next most abundant, while the 2015 sample was dominated by the tiny snail *Ferrissia*, followed by *Hyalella* and *Simulium*. The 2017 sample was about equally dominated by *Baetis brunneicolor*, *Simulium*, and an unidentified Hydropsychidae. The downstream site (16SC076) was dominated by *Simulium*, followed by mayfly *Baetis* and midge *Polypedilum*. The most abundant taxa were fairly similar among sites - *Simulium*, *Polypedilum*, and *Hydropsyche* were among the top three in abundance at two of the three sites. There were two stonefly taxa collected at 16SC076, *Acroneuria* and *Paragnetina media*. No stoneflies were collected at the two sites farther upstream.

The EPT taxa can be particularly useful in comparing stream habitat quality. A longitudinal comparison was made for AUID-516, using the three biological monitoring sites. Due to its being an "MPCA Long Term Biological Monitoring Site", 96SC063 has had numerous visits; the more recent ones were included in this analysis (2013, 2015, and 2017). For site 16SC076, two same-day samples were averaged. Results are given in Table 24 and show that water quality and habitat conditions improve from upstream to downstream. Natural factors, particularly effects due to gradient, likely play a significant role in this finding.

Table 24. Longitudinal EPT genus count for AUID-516. The site list is presented from upstream site to downstream. Numbers with decimals are averages of more than one sample.

Site	Ephemeroptera	Plecoptera	Trichoptera	Total EPT
16SC086	4	0	4	8
96SC063	6.0	0.0	6.3	12.3
16SC076	9.5	1.5	5.0	16.0

Table 25 shows DO and TSS Community Index data for 16SC086, 96SC063, and 16SC076. The macroinvertebrate community scores for DO, like for fish, show a trend of low-DO Tolerant taxa upstream and low-DO Intolerant taxa downstream. That trend is also shown in the metric scores of both the number of Intolerant taxa and the percentage of the individuals that are Intolerant (Table 26).

There is also an upstream to downstream pattern in the metric responses to TSS. The number of Tolerant taxa is similar at all three sites, but the number of taxa and percentage of individuals of Intolerant taxa increases moving in the downstream direction. There is not strong evidence to suggest that either DO or TSS are significantly influencing the macroinvertebrate community; both have relatively high probabilities that the communities would come from standard-meeting sites, even though within their stream class, the TSS Index scores are at very low percentiles. It could be argued that there is a signal that both low-DO and TSS are mildly influencing the community, as the percentage of Tolerant individuals is consistently higher than Intolerant individuals for both parameters, particularly TSS (Table 26), however, a large TSS dataset for this AUID shows no evidence of problematic TSS concentrations.

Table 25. Macroinvertebrate Community DO and TSS Tolerance Index scores at 16SC086, 96SC063, and 16SC076. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class (2018 version). "Prob." is the probability a community with this score would come from a stream reach with standard-meeting DO or TSS.

Site and class	Comm. DO Index score	Class avg./median	Percentile	Prob. as %	Comm. TSS Index score	Class avg./median	Percentile	Prob. as %
16SC086 - 4	7.01	6.30/6.46	82	69	15.33	13.63/13.77	15	71.5
96SC063† - 4	6.94	6.30/6.46	76.7	66.7	15.31	13.63/13.77	16.3	71.6
16SC076* - 3	7.16	7.02/7.14	51	72.5	14.93	13.41/13.47	17.5	74.7

†Average of three samples from different recent years, 2013, 2015, and 2017.
*Average of two same-day samples.

Table 26. Metrics involving species tolerance for the sampled macroinvertebrate community. Numbers for site 96SC063 are averages of the 2013, 2015, and 2017 samples.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	16SC086	3	1	4	1	2.8	10.5
DO	96SC063	3.0	1.0	4.3	1.0	7.5	14.1
DO	16SC076	9.5	4.5	5	1	16.4	16.7
TSS	16SC086	3	0	9	3	1.2	35.1
TSS	96SC063	4.3	0.7	11.0	3.0	4.1	31.0
TSS	16SC076	5.5	2	10	4.5	5.3	17.9

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Overall biological data conclusions

Combining the signals of influence related to DO and TSS for the fish and macroinvertebrates reveals that DO is likely a stressor to fish, and moderately for macroinvertebrates in the upper parts of the AUID. Evidence for influence of TSS is not existing for the fish community, while there appears to be some influence to the passing macroinvertebrate community, though this may be due to the sandy conditions within the AUID.

Temperature

Water temperature data does not show temperature levels that would be problematic for fish, though the samples from biological visits contained no July or early August measurements which would reveal how warm the stream gets during the seasonally-peak air temperatures that typically occur in that period. Some of the longitudinal monitoring done for SID were during this warm, mid-summer period (Table 27). These measurements show quite consistent temperatures longitudinally, as well as temperatures that should not be stressful to warmwater fish species. Two other longitudinal measurement efforts in August 2018 showed site S001-277 being the coldest location measured along AUID-516, suggesting this area receives more groundwater input or has greater shading (Figure 16). The discussion about conductivity above adds evidence that the reason is groundwater input. Periods when there has recently been precipitation (enough for some runoff) will likely result in more similar temperatures along the stream length. There is an impoundment in the upstream part of the AUID that appears to be caused by a private road crossing (Figure 21). This area likely increases water temperature due to sun exposure, having a negative effect on downstream DO levels to an unknown degree.

Table 27. July afternoon temperatures (Celsius) at several locations on the South Branch Grindstone River, 2018-2019.

Date	Time	S005-544	S005-541	S001-277	S001-263
7/9/2018	14:10 - 15:15	26.6	27.0	26.4	--
7/25/2018	14:30 - 15:20	21.8	21.5	21.5	--
7/8/2019	12:45 - 13:55	23.3	23.8	22.8	22.5
7/26/2019	13:40 - 15:00	22.6	24.2	24.3	24.3

Figure 21. Impoundment caused by a private road crossing. Arrow points to the road.

Habitat

MSHA scores from three biological sample sites on AUID-516 are presented in Table 28. The 1996 visit to 96SC063 was not included in the averages for the 2013 - 2017 visits, since it is separated in time by about 20 years from the recent visits. The total score for 1996 was moderately lower (62.7 = "Fair") than the average of the recent visits. Habitat scores follow the pattern of improving as the gradient goes from low in the upper parts of the AUID to higher in the middle and lower reaches of the AUID. The three sub-component scores that pulled down site 16SC086 were less-natural surrounding land use, lack of larger hard substrates, and less-distinct channel features (a more homogeneous habitat).

Table 28. MSHA scoring for sites 16SC086, 96SC063, and 16SC076. Average scores were calculated for the multiple visits to each site.

Site	MSHA Component	Average Score	Maximum Poss. Score	Percent of Maximum
16SC086	Land Use	2.75	5	55.0
	Riparian	10.25	14	73.2
	Substrate	16.15	28	57.7
	Cover	12.00	18	66.7
	Channel Morphology	15.50	35	44.3
	Total MSHA Score	56.7	100	56.7 = "Fair"
96SC063	Land Use	3.5	5	70.0
	Riparian	10.3	14	73.2
	Substrate	19.7	28	70.4
	Cover	15.0	18	83.3
	Channel Morphology	21.3	35	60.7
	Total MSHA Score	69.7	100	69.7 = "Good"
16SC076	Land Use	3.8	5	75.0
	Riparian	10.0	14	71.4
	Substrate	17.7	28	63.2
	Cover	13	18	72.2
	Channel Morphology	25.5	35	72.9
	Total MSHA Score	69.7	100	69.7 = "Good"

Connectivity

There are three public road crossings downstream of the two sites with impaired fish communities, at Township-178, CSAH-17, and Township-311. The DNR culvert assessment team assigned all three as level 3, meaning "Partial or seasonal barriers". However, one of these is just downstream of the site that passed the FIBI very well, so these partial barriers may not be having a strong effect on the fish community. There were no beaver dams evident in the aerial photos between the passing site downstream, and the next-upstream non-passing site, but there is recent beaver damming between the two non-passing sites, where the small tributary enters from the north, soon after crossing 320th Ave. Impedances of fish migration, both human created and beaver dams, within the AUID do not appear to be a major influence on the fish community, though may have some effect. The private road mentioned in the above section (Figure 21) may be a barrier to fish movement in the upper part of the AUID, above any of the fish sampling sites. Another site with a private foot bridge/recreation area has a possible structure in the stream (visible on aerial photography) that could also be a barrier (Figure 22). It may be a natural riffle, or maybe has been artificially augmented into a little rock dam structure - there has been shoreline rip-rapping there. It is located between sites 96SC063 and 16SC076.

Figure 22. Possible stream modification that may be a barrier. This site is located about 0.35 miles upstream of CSAH-17.

As mentioned above, there is a definite fish migration barrier just downstream of the end of AUID-516, that being the Grindstone Dam located in Hinckley. The impoundment behind the dam had flooded the confluence of the North and South Branches of the Grindstone River, such that they are separated by a sizeable lentic environment. Therefore, both branches of the river are separated from the main stem of the Grindstone River, which begins below the dam.

The known habits of various fish species were used to assess whether the dam has resulted in an extirpation of some species above the dam, a sign that the dam has altered the fish community in AUID-516. Some statistics of note:

Grindstone River (beginning at the Grindstone Dam, down to the Kettle River)

- Avg. # species/sample below the dam = 21.7
- Total # species collected = 34
- Migratory species (bold species found only below Grindstone Dam) = **walleye**, Iowa darter, **blackside darter**, **slenderhead darter**, **central stoneroller**, golden redhorse, greater redhorse, silver redhorse, and shorthead redhorse.

South Branch Grindstone River (AUID-516)

- Avg. # species/sample above the reservoir = 9.6
- Total # species collected = 16
- Of species considered "migratory", there were eight species found downstream of the dam, and only one species (greater redhorse) found upstream of the dam in AUID-516.

North Branch Grindstone River (AUID-544)

- Avg. # species/sample above the reservoir = 16.3
- Total # species collected = 34
- Of the nine migratory species downstream of the dam in the Grindstone River, there were five species found above the dam in AUID-544 (4 redhorse species and Iowa darter).

Grindstone Lake (directly connected to the North Branch Grindstone River)

- Of the nine migratory species downstream of the dam in the Grindstone River, there were five in Grindstone Lake (four redhorse species and Iowa darter).
- Walleye is the migratory species not found in Grindstone Lake, nor either branch above the dam.

Migratory fish species that are found below the Grindstone Dam are almost completely missing in the South Branch Grindstone River. North Branch Grindstone River has more migratory species because some use Grindstone Lake as a refuge. Walleye are found nowhere above the dam. The reduced presence of migratory species found above the dam strongly suggests that the dam is a fish stressor for South Branch Grindstone River.

Hydrology

Due to the land cover change of original forest to hay fields that have occurred at moderate levels in this subwatershed, hydrology has been somewhat altered from the original flow regime, but there are no signs that the alteration has created significant channel instability issues. Stream banks are in relatively healthy condition, and there does not appear to be excess deposition of eroded fine particle sediments.

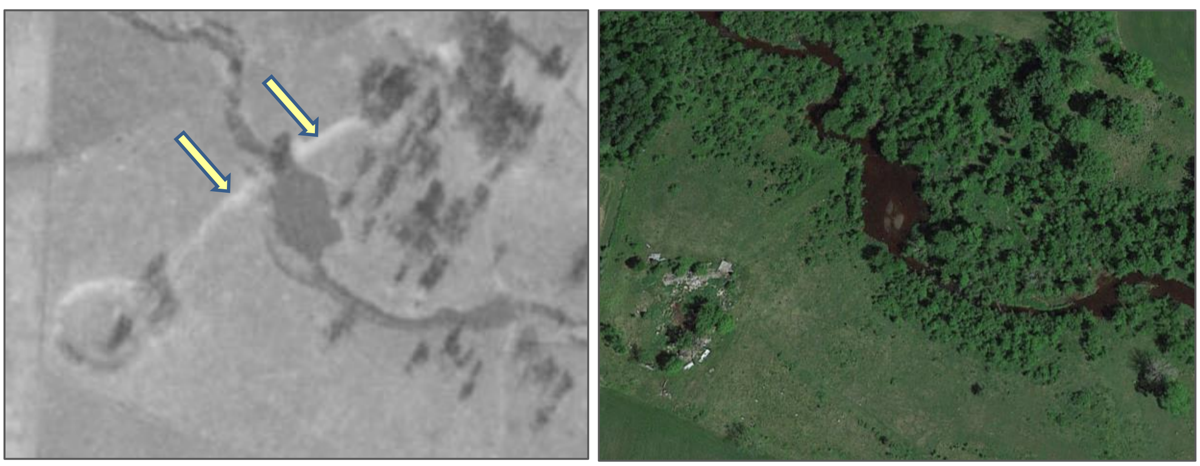
Geomorphology

Observations of the stream at multiple locations did not find obvious signs of channel instability due to altered hydrology in the subwatershed. The natural rock substrate found in the river helps provide some resilience to the channel, which current land cover change has not overwhelmed. Channel problems occur at local areas of the stream caused by factors unrelated to altered hydrology (Photo 2, and Figure 23). Some of these have their origins decades ago (Figure 24). Areas of local erosion and physical channel change are mostly from livestock trampling, and are consistent with findings of typical damage from livestock (widening of channel, increase in fine sediment, reduced depth of channel; (Kauffman and Krueger, 1984). When banks are not protected by vegetation, erosion and habitat degradation is inevitable (Waters, 1995). Allowing a natural buffer to grow along the creek will also reduce nutrient input to the stream from adjacent pasture area (Osborne and Kovacik, 1993). If deep-rooted grasses, or woody vegetation as originally found here, were allowed to re-colonize the banks, erosion would be reduced.

Photo 2. Example of local, over-widened areas. A. Upstream side of culverts on CSAH-17 (Fox Road) B. Downstream side of culverts on CSAH-17 (Fox Rd.). The yellow bars show the natural stream channel width. A heavily used cattle crossing exists here, and along with the current design of the culverts, factor into the creation of this large pool.

Figure 23. Aerial view of the pools shown in Photo 2. The yellow bar corresponds to the location of the width measurement shown in Photo 2(B). Arrow shows flow direction.

Figure 24. 1939 aerial photo of an eroded pool, still present in 2017. A road crossing existed at the head of the pool, which eliminated the floodplain there, and focused high flows, increasing the erosive force of the water. Arrows point to road, which is visible as a raised grade on recent LiDAR imagery.



Channel morphology is being tracked by surveyed measurements at the long-term biological monitoring site 96SC063, where measurements were collected by DNR staff in the fall of 2018. The DNR provided the following summary regarding the 2018 study:

Rosgen measurements

Most indicators suggest that the South Branch Grindstone River is in stable condition. The channel is not incised nor entrenched so bankfull and higher flows access the floodplain. This allows floods to spread out over a wide area rather than concentrating energy within the channel where it can cause excess bank erosion or channel down-cutting. Furthermore, bank erosion is low because the banks and floodplain are densely vegetated with grasses and clumps of willow and alder. Aerial imagery does show signs of isolated instability such as channel migration and meander cutoffs, but the instability does not appear to be systemic.

DNR specialists surveyed a 600’ reach of the South Branch Grindstone River west of Southfork Road in June 2018. The reach classifies as a second order, E4/5 stream in an unconfined glacial till plain valley. An E4/5 stream is relatively narrow and deep with gravel and sand as the dominant substrates. The reach pebble count consists of 10% silt/clay, 38% sand, 35% gravel, 14% cobble, and 3% boulder. The prevalence of silt/clay and sand could be negatively affecting fish habitat since the small particles easily become mobile at higher flows and provide fewer microhabitats than larger substrates. In addition, the fine particles may have filled in some pools. Maximum pool depth in several lateral scour pools is not as deep as expected with max pool depth to mean riffle depth values of 1.6-2.1 rather than the expected 2.0-4.0. The stream also lacked much woody debris for habitat, however it did contain several large boulders, undercut banks, and pockets of large cobble that provide habitat niches for biota. Overall, geomorphology may be affecting habitat but does not seem to be the main stressor to biology in this stream.

Pfankuch assessment

The Pfankuch score for the South Branch Grindstone River was 75, a good (stable) score for an E4/5 stream. Of the fifteen total parameters, twelve rated as good or excellent. Nevertheless, the cutoff between good and fair (moderately unstable) is 76, so only one more point from any parameter would have changed the condition rating to fair. The upper banks scored very well due to the dense vegetation and the low landform slopes adjacent to the channel. Lower bank scores were mostly good, but the bank rock content parameter scored poorly due to the lack of large particles. Two of the six channel bottom parameters rated as fair, though the rest were good or excellent. The lack of particle consolidation and the minor scouring and deposition in the channel bottom were the biggest impacts to the overall score.

Conclusions about stressors

A combination of inadequate DO levels and the barrier of the Grindstone Dam and reservoir is the primary stressor in the South Branch Grindstone River (AUID-516). The river changes in character along its pathway. In the headwaters, it is a low-gradient, wetland-influenced stream and gradually changes to a moderate-gradient, solid-bottomed (sand/gravel/cobble) stream in its middle and lower reaches. There are low-DO conditions in the headwaters, with substantial improvement of DO in the middle and lower reaches where the DO levels achieve the standard. Part of the improved DO is likely due to coldwater inputs of groundwater in the middle portions of the AUID, where springs could be seen in aerial photography, and documented with specific conductivity and temperature measurements made longitudinally along the AUID.

No evidence was found to suggest that eutrophication is the cause of the reduced DO levels. There are few macrophytes in the stream, and no suspended or filamentous algae growths were seen anywhere along the river by the author over many visits. There is a slight sign of sediment/TSS influence in the macroinvertebrate data, but not from the fish data, nor from a large number of TSS samples. Secchi tube readings also show no sign of problematic TSS concentrations. There is some beaver activity along this reach, both upstream and downstream of biological sites, but dams are relatively few, and in some years appear to be absent (per aerial photography review). As there are numerous residences and farms along the reach, it may be that beavers are largely controlled by citizen trapping to prevent development of reservoirs/high water. Therefore, barriers due to beaver dams are probably not responsible for failing biological scores. There are some culverts that look to be possible barriers on private driveways in the upper area of the reach, above the biological sites. There is also a large impoundment that appears to be human-created, though again, it is above the upper-most biological site, and thus neither of these situations is a migration barrier responsible for poor IBI scores. However, the impoundment likely contributes to warming the water and lowering DO concentrations downstream for a distance. A third possible barrier on private land should be checked out. The overall condition of the stream channel appears very stable - only very local geomorphological issues exist and are caused by activities near the stream channel (cattle accessing the river), rather than systematic hydrological alteration.

Recommendations

Removal of the dam just below this AUID, in Hinckley, has been discussed within the local community, and would also very likely improve the fish community in the river upstream of the dam, as it would create continuous riverine conditions, allow for fish migration from below the dam (including from the excellent fish community in the Kettle River) up into the South Branch Grindstone River, and increase gradient in parts of this river system, including the low end of AUID-516. Additional recommendations to improve the biological communities in South Branch Grindstone River are to exclude cattle from the stream at several locations, remove impoundments, narrow the channel where poor culverts or cattle trampling have created wide pools, replace culverts that are at an incorrect elevation or are improperly sized with those that will better allow fish passage, and planting/encouraging woody vegetation along riparian areas where natural vegetation has been removed. These projects will result in cooler stream temperatures and better DO concentrations, and allow fish to access more habitat. This river has strong potential to have exceptional biological communities, and in the downstream reaches in the Grindstone River, it still has those.

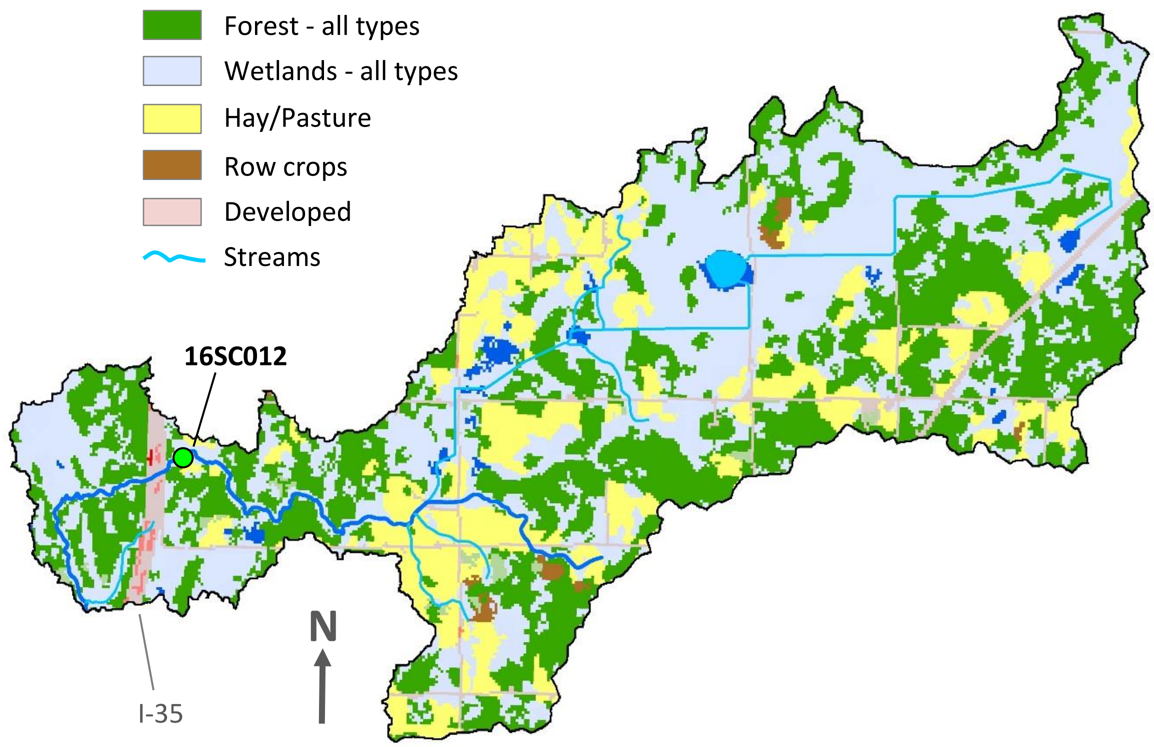
Cane Creek (AUID 07030003-525)

Impairment: The creek was assessed as impaired for not meeting the macroinvertebrate community IBI threshold at site 16SC012, located just upstream of Cane Creek Road, 2.5 miles southeast of Rutledge. The fish community scored slightly above the passing FIBI threshold.

Subwatershed characteristics

The AUID drains a relatively natural subwatershed. Site 16SC012 is a Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 3 (Northern Forest - Riffle/Run) stream reach. There is much wetland acreage, and the headwater wetland areas have been trenched for drainage (Figure 25). There is a fairly even mix of hayfield and forest acreages. Very little row crop agriculture exists in the subwatershed. The HDS was 67.91 (of 81 max., at the 74th percentile statewide). This AUID flows directly into the Kettle River.

Figure 25. Subwatershed of Cane Creek. The darker blue line is AUID-525.



Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 29). Field measurements were also collected at a SID visit on August 16, 2018. At that visit, flow volume was very low, estimated to be about 0.50 - 0.75 cfs.

Table 29. Chemistry measurements collected at the biological sampling visits and during SID from 16SC012. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Ammon.	TSS	TSVS	S-tube (cm)
8/16/2016	8:30	19.3	7.64	86	7.19	81.8	--	--	--	--	--	50
8/31/2016	10:12	16.5	8.24	86	7.29	92.1	0.071	0.06	< 0.05	2.4	1.6	77
8/16/2018	12:25	19.1	7.86	85.0	--	112	--	--	--	--	--	--

Dissolved oxygen

The three instantaneous DO measurements were above the standard, and at a healthy level for the time of day measured. The measurements do not represent the minimum temperatures for those days however. The field measurements are remarkably similar at all three visits.

Nutrients - Phosphorus

The TP level from the lone sample was somewhat high, but not unusual for small streams with significant wetland influence, which is the case for this AUID.

Nutrients - Nitrogen and ammonia

Both the nitrate and ammonia samples were in very low concentration, at or below the lab's detection limit for both parameters.

Transparency and suspended solids

The two Secchi-tube readings were mediocre. However, the one measurement of TSS was very low. The photos taken by the biological monitoring crew show quite tea-stained water. This dark watercolor may be the cause of the somewhat low Secchi-tube readings, and not particulates in the water.

Stressor signals from biology

Fish

The sample at 16SC012 produced nine species, and was dominated by creek chub. Most of the species collected are ubiquitous ones, with the two exceptions being northern redbelly dace and pearl dace, the latter being a "sensitive" species. These two species were each represented by only one individual.

Metrics pertaining to DO and TSS are shown in Tables 30 and 31. According to statistics in both tables, there is a slight signal that DO levels may be a bit problematic, with the relative numbers of tolerant to intolerant species present, though there is still a fairly good probability that this community comes from a DO standard-meeting site. The TSS TIV Index was poorer than average for this class, but has strong probability that the community would come from a TSS standard-meeting site. There were no TSS Tolerant taxa present.

Table 30. Fish Community DO and TSS Tolerance Index scores at 16SC012. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 6 (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Aug. 2016	7.02	6.58/6.65	71	69.7	14.30	13.96/13.27	28	85.5

Table 31. Fish metrics related to DO and TSS for 16SC012 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low DO	0	0	4	3	0	18.7
TSS	1	0	0	0	1.3	0

*Includes # Low-DO Very Intolerant Taxa as part of the count.

Macroinvertebrates

The macroinvertebrate community was dominated by *Simulium* (black flies), and secondarily by the midge *Polypedilum*. Tolerance Index, TIV metric scores, and statistics are shown in Tables 32 and 33. There are many more low-DO Intolerant species present than Tolerant ones, including four taxa that are Very Intolerant. Additionally, the probability that the sampled community would come from a site with healthy DO levels is quite good. Regarding TSS metrics, there were more TSS Intolerant taxa than Tolerant, but there was a larger percentage of Tolerant individuals, by a substantial amount. However, this community has a relatively high probability of coming from a site with TSS standard-meeting water quality.

Table 32. Macroinvertebrate Community DO and TSS Tolerance Index scores at 16SC012. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 3 (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Aug. 16, 2016	7.47	7.01/7.14	81	78	14.95	13.42/13.47	17	75

Table 33. Macroinvertebrate metrics related to DO for 16SC012 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	10	4	2	0	6.7	2.9
TSS	7	2	5	0	2.5	31.5

*Includes # Very Intolerant or # Very Tolerant Taxa as part of the count.

Overall biological data conclusions

Though the fish community showed a very moderate signal of the influence of inadequate DO levels, the macroinvertebrate community does not. There is also little evidence that TSS is stressing the macroinvertebrate community, and the fish metrics confirm that elevated TSS is likely not a stressor. Neither low DO nor TSS appear to be stressing the biological communities.

Habitat

The biological sampling crews conducted the MSHA protocol on two different dates. Total scores were 74.45 and 87.75, for an average of 81.1. These scores are both well above the score threshold that begins the "Good" category (> 66). An average of each of the five MSHA subcomponents was calculated. The subcomponent score averages were used to calculate a percentage of that subcomponent's possible score. These percentages were: Land Use = 100%, Riparian = 96.4%, Substrate = 73.6%, Cover = 75% and Channel Morphology = 78.6%. None of the subcategory scores suggests a particular aspect of stream health is lacking. Substrate got the lowest score, but a small margin, due to the relative abundance of sand substrate. Habitat is not a stressor.

Connectivity

Connectivity impediments due to road crossing infrastructure are not a stressor for macroinvertebrates. It is however noteworthy that though the fish community passed the FIBI, there are connectivity issues that are likely limiting the fish community. DNR staff observations noted one “complete” barrier (under I-35, just downstream of site 16SC012; Photo 3) one “significant” barrier (at Township-909, upstream of 16SC012) one “partial or seasonal barrier” (at a private property, upstream of 16SC012).

Photo 3. Cement drop structure at top of culvert that runs under I-35, a complete barrier to fish migration moving up from downstream.

Hydrology

Though the hydrology of the subwatershed of AUID-525 has been somewhat altered with conversion of originally-forested land to hay fields and a moderate amount of wetland ditching in the headwaters, the hydrological pattern of the stream has not been altered to the extent of causing channel instability. Numerous beaver dams provide some landscape storage of runoff. When visited in mid-August 2018, there was an extremely small amount of flow. This reach may go dry or become stagnant pools in some years. Such situations would cause stress to the macroinvertebrate community. If these conditions occur during most years, the long term macroinvertebrate community would be continually in a stressed condition.

Geomorphology

Observations made by the author on a 2018 visit found no significant signs of channel instability, and thus no geomorphology work was conducted on this AUID.

Conclusions about stressors

All of the water chemistry parameters measured are at healthy levels, and the habitat assessment scores were excellent. There may be an intermittency issue that is limiting the macroinvertebrate community. The author visited the stream on 8/16/2018 and found very low flow conditions. In the upstream area that has been straightened (along CSAH-33), water was present, but not flowing. Downstream, at the biological monitoring site (16SC012), there was very little flow, estimated to be about 0.75 cfs. This observation was made during a non-drought period, so it is likely that this stream can go dry during drought years. Occasional drying periods can alter the macroinvertebrate community that exists in a given stream reach. Given the good quality water found here, and the very good habitat, occasional low flow volumes is the best explanation of the sub-standard macroinvertebrate community found in this stream. There must be some deeper refuge areas where fish can maintain themselves during droughts, because it is not possible for them to recolonize this stream reach due to the impassable cement drop-structure at the I-35 crossing. There are numerous beaver impoundments between CSAH-33 and I-35 that may be refuge areas for fish during dry times, though these do not appear sufficient to support sensitive species well.

Recommendations

It is unclear as to how to change management of this AUID to improve the macroinvertebrate community. The majority of the subwatershed's land cover is natural. There is some evidence that this stream does not maintain persistent enough flow to produce a community that would achieve a passing MIBI score. However, the fish community passed the FIBI, there is an absolute barrier (the cement drop structure at I-35) just downstream of the sample site. This structure dates to 1962 per construction permit review by DNR. Interstate 35 was built at this time, and this drop structure has something to do with the freeway/creek intersection. Designs could not be found at the DNR, but the permit noted alterations to the channel at the freeway. It was likely built as part of the channel reconfiguration to provide grade control to prevent upstream erosion. Thus, it likely would be difficult and costly to replace with a fish-passable structure. Given the relatively small size of the creek (i.e., somewhat limited fish habitat, particularly for game fish/recreational fishing), this is probably a low priority compared to other potential projects in the KRW that would be of more ecological benefit.

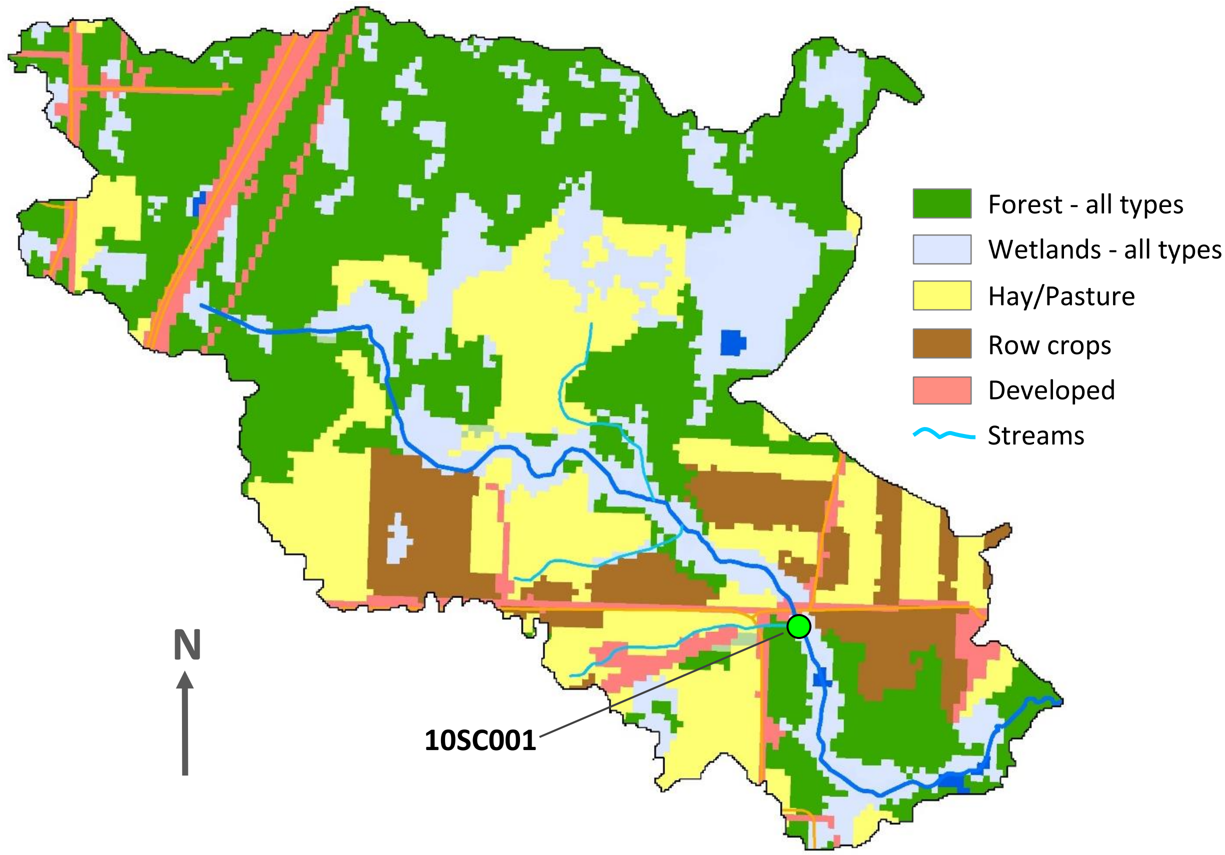
Spring Creek (AUID 07030003-550)

Impairment: Spring Creek was assessed as having an impaired coldwater fish community at site 10SC001, just downstream of Old Government Road, 2.5 miles East of Hinckley. Macroinvertebrates marginally passed the MIBI. After further review including the SID work, this impairment is being considered for impairment category 4D (Natural Background) due to beaver activity.

Subwatershed characteristics

The AUID (and the creek itself) begins immediately east of I-35. Site 10SC001 is a Fish Class 11 (Northern Coldwater) and Macroinvertebrate Class 8 (Northern Coldwater) stream reach. The landscape is an even mix of forest and hayfields, with the hayfields more prominent in the upper half of the subwatershed, and forests more prominent in the lower half (Figure 26). The riparian corridor is natural vegetation throughout its length, but in some places, the distance from the channel to non-natural area is fairly narrow (~ 75 - 200 feet). The majority of the channel however is > 200 feet from non-natural land cover, and often much greater than that distance. The HDS score was 69.49 (at the 76th percentile statewide).

Figure 26. Subwatershed of Spring Creek, AUID-550. The darker blue line is AUID-550.



Data and analyses

Chemistry

This site was sampled as an MPCA coldwater biocriteria development site in 2010, and then again in the IWM of 2016, resulting in four sets of chemistry data from biological sampling visits that are shown in (Table 34). In addition, local government staff sampled the creek in 2008 - 2010 (Table 35).

Table 34. Chemistry measurements collected at MPCA biocriteria, IWM, and SID visits from 10SC001. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
June 29, 2010	9:50	14.4	8.43	--	7.62	1627	0.073	0.15	< 0.05	1.2	< 1	--
Aug. 16, 2010	18:28	18.3	6.88	--	--	736	--	--	--	--	--	--
Aug. 18, 2016	10:45	17.8	7.31	82	7.24	166	--	--	--	--	--	> 100
Aug. 25, 2016	12:24	16.8	7.74	83	8.00	208	0.115	0.16	0.06	8.8	2.8	> 100
Aug. 16, 2018	9:10	15.55	8.38	84.0	--	260	--	--	--	--	--	--
July 26, 2019	13:15	17.62	8.26	86.6	--	245	--	--	--	--	--	--

Table 35. Chemistry results collected in 2008-2010 at S004-895 (10SC001). Values in mg/L.

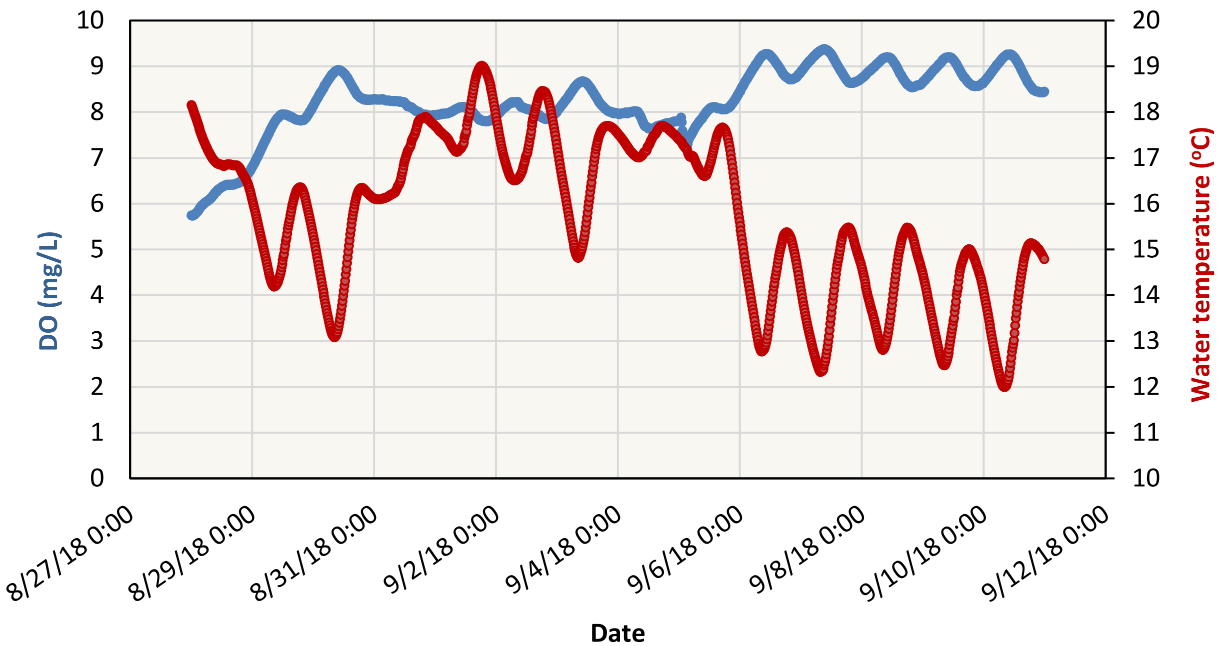
Parameter	Year(s)	# samples	Average	High	Low
DO	2009 - 2010 (July - August)	6	6.95	8.01	5.19
TP	2008 - 2010	22	0.055	0.157	0.025
Nitrate	2008 - 2010	23	0.147	0.52	< 0.02
Sp. conductance	2009 - 2010	10	155.7	259	65
TSS	2008 - 2010	20	5.4	44	< 1
Chloride	2008 - 2010	22	8.79	15.0	1.8
Water Temp (°C)	2008 - 2010 (June - August)	7	16.84	18.8	13.1

Dissolved oxygen

Dissolved oxygen may not meet the coldwater standard. One of the four measurements was just below the standard, but at a time of day when DO should be near its peak. The two 2016 measurements were a bit above the standard, but were probably below it in the early mornings of those dates. Data from six July or August 2009 - 2010 measurements in Table 35 were generally right around 7 mg/L, and averaged slightly less than 7 mg/L, even though they were all taken after 11:15 a.m. Taking into account the time of day of measurement, most of all of these dates probably were below the 7 mg/L coldwater standard in the early hours of the morning on those dates.

A sonde was deployed in 2018 (August 28 - Sept. 10; Figure 27). Almost all DO measurements were above 7 mg/L, though time of season needs to be considered in the interpretation of this data. Stream temperatures have cooled by this time of year from their seasonal highs in late July/early August, so DO was very likely higher during the deployment period than it would have been a month earlier. It is noteworthy that DO in Spring Creek is highly dependent on stream temperature. These are inversely related, and they clearly show this relationship in the graph. The lowest DO levels are at 10 p.m. - 12 a.m. In streams where DO levels are more driven by algal presence (photosynthesis), DO minimums occur at about sunrise. Additionally, the DO daily peaks are at about 12 p.m. - 1 p.m., and streams with algal production typically peak in late afternoon, when sunlight begins to be less direct in the stream.

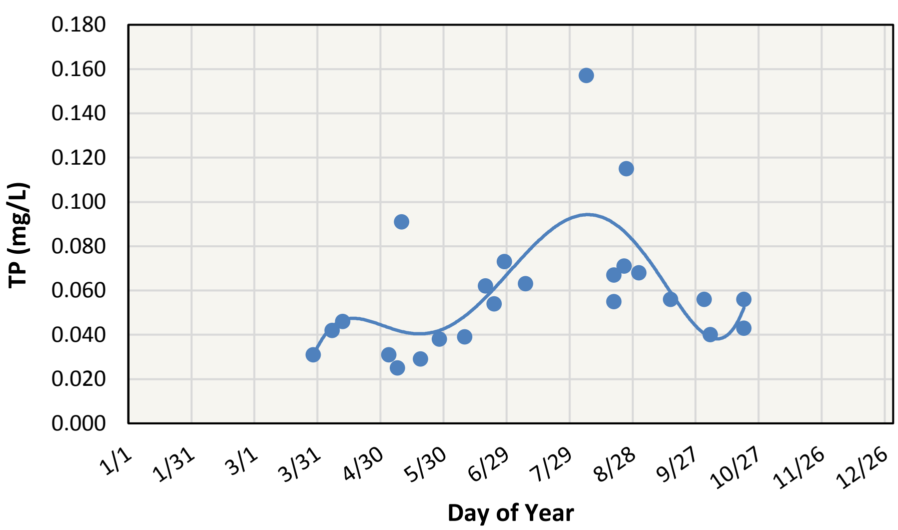
Figure 27. DO and water temperature at 10SC001 in late summer, 2018.



Nutrients - Phosphorus

TP concentrations are high at times (Figure 28). There is a seasonal pattern of TP peaking in mid-summer, which is common in small, groundwater-fed streams with peatlands in their riparian areas. This distinct pattern suggests TP is natural (coming from riparian peat soils when they become anoxic in mid-summer).

Figure 28. All available TP data, 2008-2016 at 10SC001. The curved line is a polynomial regression line with R2 = 0.4591, approximating the normal TP seasonal pattern.



Nutrients - Nitrate and ammonia

Both nitrate and ammonia concentrations were very low (and very consistently so) in the two samples taken, six years apart. Forms of nitrogen are not a stressor.

Conductivity

The conductivity measurements from 2010 are extremely high for this area. No high conductivity readings occurred among the 10 measurements taken in 2008 - 2010 by Pine County SWCD staff. Other MPCA measurements after 2010 have been in the range expected. The 2010 MPCA measurements may not have been accurate.

Chloride

A number of chloride samples were collected in 2008-2010. Given that the headwaters of this creek likely receives runoff from I-35, it is prudent to look at whether levels are problematic. The samples showed concentrations far below the state aquatic life standard, though it is not clear whether any were collected during snowmelt, the time of year when the concentrations would likely be highest. The earliest samples were April 8 and April 13, which may have been after snowmelt, though residual road salt still may be present along the roadway at those dates.

Transparency and suspended solids

Secchi-tube readings were very good. The 2010 TSS concentration was extremely low, while the 2016 sample was a bit above the coldwater standard. The concentrations were also typically very low in the 2008-2010 samples. The average of slightly over 5 mg/L is exaggerated due to one extremely high sample, taken in early May. Four of the 20 samples were over the standard.

Stressor signals from biology

Fish

Nine species were collected in the 2010 sample. The community was dominated by brook stickleback, with pearl dace and central mudminnow next most abundant. Three species in the sample are considered “sensitive” species, those being pearl dace, northern redbelly dace, and Iowa darter. The 2016 sample had 12 species, and was dominated by creek chub, with pearl dace and northern redbelly dace also being relatively abundant. Again, three sensitive species were present, the same species as in 2010. The only species in either sample that are somewhat oriented to cooler waters was pearl dace. None of the typical coldwater species were present (e.g., trout, sculpin, longnose dace, and burbot).

Metrics pertaining to DO and TSS are shown in Tables 36 and 37. The TIV Index metrics for both DO and TSS varied between the two samples. The community metric scores were far below average for DO, and also quite a bit poorer than average for TSS. The probability of the fish community coming from a site that meets the DO standard was very low, while a bit better than even for TSS. There were no low-DO Intolerant species captured in either sample, while there were six and seven low-DO Tolerant species collected in 2010 and 2016 samples respectively. The percentage of low-DO Tolerant individuals was very high in 2010. Though low-DO Tolerant individuals were somewhat fewer in 2016, they were still dominant versus low-DO Intolerant species, of which there were none. These metrics suggest DO levels can be problematic. The TSS-related metrics showed the community to be essentially uninfluenced by TSS in 2010, and moderately skewed toward TSS-intolerance in the 2016 sample. DO appears to be a stressor to the fish community, while TSS does not.

Table 36. Fish Community DO and TSS Tolerance Index scores at 10SC001. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 11 (2018 version). "Prob." is the probability a community with this score would come from a class 11 stream reach with DO or TSS that meet the standards.

Year	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2010	5.99	7.61/7.55	3	2.1	13.01	10.84/11.25	22	56.0
2016	6.74	7.61/7.55	13	19.1	14.0	10.84/11.25	7	54.4

Table 37. Fish metrics related to DO and TSS for 10SC001 utilizing MPCA species tolerance assignments.

Parameter	Year	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	2010	0	0	6	4	0	86.7
Low-DO	2016	0	0	7	4	0	41.8
TSS	2010	2	1	0	0	3.7	0
TSS	2016	1	0	0	0	14.3	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Macroinvertebrates

Three samples have been collected, in 2009, 2010, and 2016. The 2009 community was moderately dominated by the aquatic fly *Dixa*, with the next most abundant taxa being the midges *Parametriocnemus* and *Paramerina*. The top four most abundant taxa were all aquatic flies (the fourth being *Dixella*), which is unusual with the sampling method applied by MPCA. The 2016 sample differed quite dramatically from the 2009 sample. This recent sample was dominated by the coldwater caddisfly *Lepidostoma*, followed by *Simulium* and the mite Acari. A number of cool to coldwater taxa were collected, including caddisflies *Lepidostoma*, *Lype diversa*, Uenoidae, *Glossosoma*, *Hydatophylax*, *Protoptila*, *Ptilostomis*, *Goera*, and *Neophylax*, the cranefly *Tipula*, the riffle beetle *Optioservus*, the mayfly *Baetis brunneicolor*, and midges *Brillia* and *Heterotrissocladius*. The presence of *Goera* is especially noteworthy, as it has been collected by MPCA in only ten other non-North Shore streams in Minnesota, and only in two other St. Croix Basin streams.

The macroinvertebrate community shows somewhat mixed signals as to an influence of low DO conditions (Tables 38 and 39). Two of the three DO TIV Index scores were somewhat lower than the class average, with the third being slightly above. However, both the number of taxa and the percentage of individuals are highly skewed toward low-DO Intolerant taxa. It is highly unlikely that there would be this many low-DO Very Intolerant taxa present if DO was at problematic levels for fish.

Table 38. The 2009, 2010, and 2016 Macroinvertebrate Community DO Index statistics at 10SC001. For DO, a higher index score is better. "Percentile" is the rank of the index score within class 8 streams (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO that meets the standard, based on class 8 and 9 streams.

Year	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %
2009	8	7.03	7.33/7.46	27	80
2010	8	7.40	7.33/7.46	45	83
2016	8	6.83	7.33/7.46	20	78

Table 39. Macroinvertebrate metrics related to Low-DO at 15UM044 utilizing MPCA species tolerance assignments.

Year	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
2009	7	5	7	2	33.1	12.3
2010	11	5	8	4	39.7	7.1
2016	14	8	3	0	28.7	3.8

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Overall biological data conclusions

DO signals are somewhat conflicting between the fish and macroinvertebrate communities. This may be because other factors, including low DO in other places in the AUID (e.g., in beaver impoundments) have stressed coldwater fish species (particularly the trout) to the point of becoming extinct from the stream. Warmer water temperatures due to beaver activity have a correlating effect on coldwater species as low-DO, so it may actually be the warmer waters due to impoundments that are the root cause of the fish showing an effect from inadequate DO levels.

Temperature

The temperatures measured at the IWM visits were quite cold, though no visits were in the period of typically warmest temperatures (late July). Temperatures measured by Pine County staff in 2009/2010 were also always below 19^{o}C (Table 35). A temperature logger was deployed in 2010 and again in 2016 (Table 40). No periods of brook trout lethal temperatures occurred, nor were there any periods were water temperatures were too cold for brook trout growth. Suitable brook trout temperatures were found 90% or more of the time. It is important to note that the accessible location where these temperature measurements were taken was upstream of where most of the beaver activity is, and where water temperatures are being warmed due to that activity.

Table 40. Summary statistics for continuous temperature measurements at 10SC001 in 2010 and 2016. The four columns at the right are percentages of the time during June-August that water temperatures were in the lethal, stressful, growth (healthy), and no growth (too cold) ranges for brook trout.

Year	Summer Ave.	June Avg.	July Avg.	August Avg.	Lethal %	Stress %	Growth %	No Growth %
2010	17.31	15.62	17.86	18.40	0	9.02	90.98	0
2016	15.50	15.26	15.62	16.51	0	1.24	98.76	0

Habitat

The biological sampling crews conducted the MSHA protocol on three different dates. Total and subcomponent scores are shown in Table 41. The first score, in 2010, was in the range considered "Good", while the two scores from 2016 were near the bottom of the scoring range of the "Fair" category. It is not known why the scores are quite different between the 2010 and 2016 visits. Substrate and Fish Cover both show a decline, which could be related to the extreme rain event in July 2016.

The "Riparian" and "Land Use" MSHA components scored the best, while the instream subcomponents scored poorer, particularly "Substrate" and to a lesser extent "Channel Morphology". There was little substrate size diversity, as sand and silt were the predominant substrates, with a small area of gravel. Review of the metrics that make up the subcomponent scores showed some evidence that the pools were shallower, and the overall channel features (riffles, pools, and runs) were less defined (i.e., the channel was more homogeneous).

It should be noted that there is much beaver activity in the subwatershed, and their impoundments affect habitat, potentially reducing gradient and warming the water. There are several dams just downstream of the sample reach. The channel becomes braided in this area as well, with flow diverted into numerous small channels.

Table 41. MSHA scoring for site 10SC001.

MSHA Component	Visit 1	Visit 2	Visit 3	Avg.	Maximum Poss. Score	Percent of Maximum
Land Use	4	2.5	2.5	3.0	5	60.0
Riparian	13.5	10.5	12	12.0	14	85.7
Substrate	16.1	11.6	8.35	12.0	28	42.9
Cover	13.5	10	6	9.8	18	54.4
Channel Morphology	22	14	18	18.0	35	51.4
Total MSHA Score	69.1	48.6	46.85	54.9	100	54.9 = "Fair"

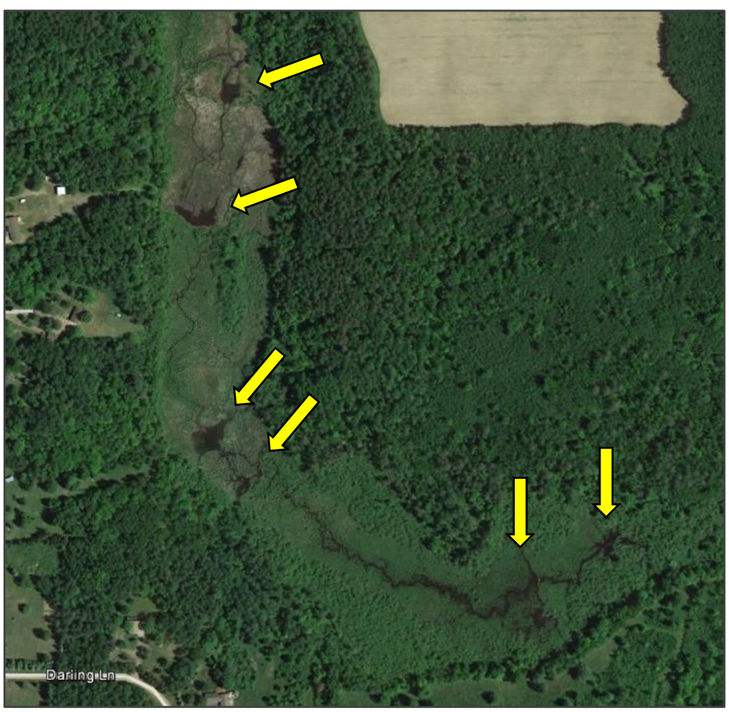
Connectivity

The infrastructure of the road crossing just upstream of 10SC001 (Old Government Road) is a significant barrier to fish passage (Photo 4). This may be cutting off important upstream areas fish need for refuge (such as localized cold water at spring inputs). There are a few field-road crossings with culverts that are quite new, installed in about 2014. It is not known whether these interfere with fish passage.

Additionally, there is significant beaver activity in the reach just downstream of 10SC001 (Figure 29). Beaver dams warm water temperatures and reduce gradient, which slows flow velocity and causes deposition of particulate material on the streambed, smothering important habitat features for both trout and macroinvertebrates. These dams are also barriers to fish that would migrate up from the Grindstone River (likely important overwintering habitat) in springtime. There have also been beaver dams upstream of the sample site, near the area with the new field-road crossings. Those appear to be gone currently.

Photo 4. Perched culverts (downstream side) at Old Government Road on Spring Creek, just upstream of biological monitoring site 10SC001. Both culverts are several inches above the August 16, 2018 water level.

Figure 29. Beaver activity a short distance downstream of 10SC001 is evident in this 2017 aerial photo. Arrows point to dams, which warm water temperatures and reduce gradient, the latter of which causes deposition of particulate material on the streambed, smothering important habitat features for both trout and macroinvertebrates.



Hydrology

The hydrology of this subwatershed is somewhat altered from its original condition, as parts of it have been cleared for pasture or hay fields. Additionally, a relatively new airport runway was constructed (about 2004) near the stream, and its runoff, via a vegetated swale, flows into the creek just downstream of the biological site. There have been some forest cuts within the last five years or so, some of which appear to have been re-planted as pine plantation. The hydrology from these acres will be different than it was for a number of years until the pines become more mature.

Geomorphology

The channel looks quite stable. The banks are fairly well armored by the root systems of the abundant alder bushes that grow along the creek. No geomorphology work was conducted on this creek due to a lack of obvious signs of instability.

Conclusions about stressors

Analysis of fish TIV metrics suggested that DO levels are problematic for a coldwater fish community to exist in this AUID. However, the macroinvertebrate community contradicts the signal of a strong low-DO influence on the fish community. The macroinvertebrate community is skewed toward low DO Intolerant taxa and individuals. DO levels do sometimes drop below the coldwater DO standard, but all measurements were above the general DO standard. Daily minimum temperatures, however, have not been collected. Sonde data showed DO to be strongly related to water temperature, and not to algal photosynthesis/respiration.

Poor longitudinal connectivity is the likely the primary stressor of the fish community in this AUID. There is a human-caused barrier to migration at Old Government Road, a perched culvert, which blocks access to seasonally-important habitat upstream. There are also several private field road crossings upstream of Old Government Road that could have culverts that are also problematic for fish passage. There are numerous beaver dams downstream of the 10SC001 site that likely block connectivity to downstream overwintering areas and contribute to the fish impairment. The beaver impoundments also likely warm up the water in the lower part of the AUID where the stream is larger and could potentially have more trout habitat (e.g., deeper water, more gradient near the Kettle River). The cleared, open area of the new airport/runway has a swale that drains to the creek, and may increase water temperatures in the creek during summer rainstorms. Poor connectivity may explain the fish community composition of species that can withstand lower DO levels, as there may be times when the water warms beyond coldwater species abilities to withstand (meaning lower DO levels in the water and higher DO requirements for fish due to increased metabolism at higher temperatures), and barriers prevent them from being able to move to temporary temperature refuge locations such as spring inputs.

Recommendations

Barriers likely need to be fixed/removed to allow this stream to meet the fish community passing IBI threshold. Barriers are both human-caused (perched culverts), and nature-caused (beaver). There are two culverts at the crossing of Old Government Road. One culvert is set higher, which is a good management practice, but the one set lower is still at too high an elevation. So, the situation could be fixed by only correcting the one culvert. Management of this stream as a coldwater fishing resource probably would require the removal of beaver to allow trout to migrate as needed up and down Spring

Creek. The upstream private culverts should be assessed and if undersized or perched, local government staff could work with landowners on fixes for those locations.

Runoff from the airport area could be monitored to determine how often and how much water it contributes to stream flow in rain events. This runoff water will be relatively warm in summer, and could increase stream temperatures for a period of time in Spring Creek. If runoff regularly occurs during sizeable rain events, it would likely be of some benefit to construct a small infiltration basin on the swale that carries the runoff from the airport runway and surrounding open area to prevent warm surface runoff from entering the creek. Additionally, since DO in Spring Creek is highly related to water temperature, shading of the stream channel is important, and should be increased where possible to keep the stream water colder, and thus having better DO levels.

The stream will need a more thorough habitat assessment and oversight by the DNR if it is to be productively managed as a trout fishery.

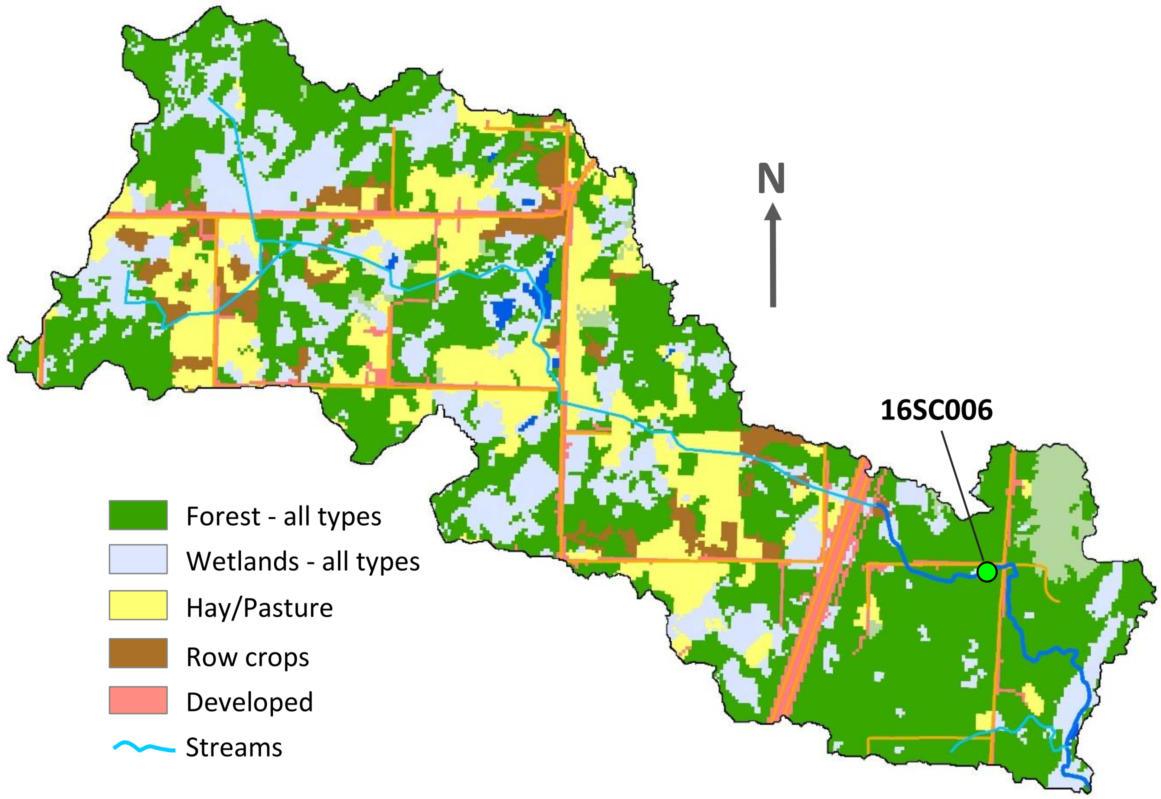
Friesland Ditch (AUID 07030003-617)

Impairment: AUID-617 was assessed as having both impaired fish and macroinvertebrate communities at 16SC006, just upstream of Old Government Road, two miles south of Sandstone.

Subwatershed characteristics

The subwatershed area draining to site 16SC006 is 9.2 mi^2, which is quite small for a perennial stream, unless it is getting significant groundwater input. Site 16SC006 is a Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Stream - Glide/Pool) stream reach. The upper two-thirds of the length of the AUID is a straightened channel of very small width, and flows through a relatively evenly mixed forest/hayfield/wetland landscape, with a small amount of row crop agriculture (Figure 30). The lower third of the AUID is a natural channel and flows through well-forested landscape. A local resident said the stream usually goes dry in the summer. The HDS score was 59.93 (at the 63rd percentile statewide).

Figure 30. The subwatershed of the Friesland Ditch, AUID-617. The darker blue line is the extent of AUID-617.



Data and analyses

Chemistry

This site only had IWM 1X chemistry monitoring (Table 42). A minor amount of additional monitoring was done in the 2018 SID work.

Table 42. Chemistry measurements collected at 2016 IWM visits and a 2018 SID visit to 16SC006. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	T-tube (cm)	DOC
Aug. 17, 2016	15:42	23.8	7.16	88	6.8	53.8	--	--	--	--	--	56	--
Aug. 25, 2016	9:20	18.7	8.28	92	6.8	48.6	0.340	0.11	0.09	6.0	2.8	60	--
July 25, 2018	13:25	20.11	8.02	88	--	45	--	--	--	--	--	--	26.7

Dissolved oxygen

The three instantaneous DO measurements were at very healthy levels. Though no pre-9am samples were collected, the August 25 measurement is just after 9 a.m., and was at a very good level. DO %-saturation measurements were also at healthy levels.

Nutrients - Phosphorus

The lone TP sample was at a very high concentration, substantially above the regional river nutrient standard. The water in this AUID is darkly stained (tea-colored), a sign of significant water contribution from wetlands, which can contain significant phosphorus due to plant material breakdown. Whole-season sampling in many other small, north-central Minnesota streams has shown TP peaks in late July. Reviewing land use of the subwatershed did not find other obvious human activity sources for phosphorus.

Nutrients - Nitrate and ammonia

Both the nitrate and ammonia concentrations were very low, and not at all problematic.

Transparency and suspended solids

Secchi-tube readings were fairly low at both visits. At one visit, a TSS sample was collected, which was quite low (well below the north region standard), and was composed of a bit more than half being mineral material, with the remainder being organic particulate material. The sampling photos showed strongly tea-stained water, which probably is largely responsible for the low Secchi-tube visibility, given that TSS was low.

Conductivity

The conductivity of the Friesland ditch is extremely low, and suggests that the stream receives little groundwater input.

Dissolved organic carbon

A DOC sample was collected on July 25, 2018 and measured 26.7 mg/L. This is a fairly high concentration, signifying that there is significant connectivity to upstream wetlands.

Stressor signals from biology

Fish

There were six species in the sample, five of which are ubiquitous, and one being a sensitive species (pearl dace). Relatively few total fish (33) were collected in the sample. The most abundant species was brook stickleback. Others present were central mudminnow, largemouth bass, creek chub, and fathead minnow.

Metrics pertaining to DO and TSS are shown in Tables 43 and 44. The DO TIV Index score was well below the class average and the probability metric shows extreme unlikeliness that this community could be found in a reach meeting the DO standard. There were no low-DO Intolerant species captured, while the sample contained five low-DO Tolerant taxa, and the percentage of low-DO Tolerant individuals was extremely high. This could well be a result of the frequent summer intermittency of the stream as told by a local resident. The TSS TIV Index was better than average for this stream class. The TSS-related metrics showed the community was not skewed toward either TSS Intolerant or TSS Tolerant species, as no taxa from either category was collected.

Table 43. Fish Community DO and TSS Tolerance Index scores at 16SC006. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 6 (2018 version). "Prob." is the probability a community with this score would come from a class 6 stream reach with DO or TSS that meet the standards.

Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
6	5.77	6.55/6.61	16	9.0	13.13	13.98/13.27	54	81.2

Table 44. Fish metrics related to DO and TSS for 16SC006 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	5	3	0	97.0
TSS	0	0	0	0	0	0

*Includes # Very Intolerant or # Tolerant taxa as part of the count.

Macroinvertebrates

The sampled macroinvertebrate community was dominated by the insect order Diptera (the flies). Four of the top five most abundant taxa were midges, with the other being the black fly (gnat) *Simulium*. There were zero EPT taxa present, which is very abnormal for a stream community. A high percentage of the taxa here were midges, many of which live in fine sediments. There was only one individual representing a long-lived taxon, a dragonfly that can be found in stagnant waters. This community could be explained by the stream being generally intermittent, going dry in parts of most summers.

Tables 45 and 46 show DO- and TSS-related metric scores for the macroinvertebrate community at site 16SC006. The DO TIV Index appears better than it should be; an artifact of the high number of *Simulium*. The genus has a fairly high DO tolerance value - an artifact of their need for good flow velocity (due to their feeding method), which is commonly, but not always correlated with higher DO concentrations. Thus, they are likely artificially skewing the DO TIV Index scores to be higher (better) than they ought to be. The number of low-DO Intolerant versus Tolerant taxa is moderately skewed toward Tolerant, while the percentage of individuals is more strongly skewed toward Tolerant. The probability that this community would be found at a site with standard-meeting DO levels is a bit more likely than not (again due to *Simulium*, and thus a suspect number). Regarding TSS, the Tolerant versus Intolerant taxa are skewed toward Tolerant, however, there were very small percentages of both Tolerant and Intolerant individuals. The probability that this community would come from a site with standard-meeting TSS is high. TSS does not appear to be a major stressor.

Table 45. Macroinvertebrate Community DO and TSS Tolerance Index scores at 16SC006. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within class 4 streams (2018 version). "Prob." is the probability a community with this score would come from a class 4 stream reach with DO or TSS that meet the standards.

DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
6.74	6.30/6.49	67	62	13.6	13.63/13.77	52	83.5

Table 46. Macroinvertebrate metrics related to Low-DO and TSS for 16SC006 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low DO	2	1	4	2	1.6	28.3
TSS	1	0	5	1	0.3	2.2

*Includes # Very Intolerant or # Tolerant taxa as part of the count.

Overall biological data conclusions

The analysis of the biological data suggests that low-DO could be a stressor. Occasional low DO issues may be related to noted intermittency patterns in the creek. Additionally, fish may not be able to recolonize the reach following low water levels and/or low DO levels from larger, refuge waters downstream, due to migration barriers (discussed below), resulting in a tolerant resident fish population that can withstand the occasional low water/low DO.

Habitat

The biological sampling crews conducted the MSHA protocol on two different dates. Total scores were 53.3 and 62.9, with an average of 58.1. These scores are both in the range of the “Fair” category, as is the average score. An average of each of the five MSHA subcomponents was calculated, and were used to calculate a percentage of that subcomponent’s possible score. These percentages were: Land Use = 100%, Riparian = 73.2%, Substrate = 51.3%, Cover = 61.1%, and Channel Morphology = 50.0%. In general, this suggests that it is “instream” features that are missing, as opposed to positive, adjacent terrestrial features. In particular, this analysis suggests that “Substrate” and “Channel Morphology” are the aspects that are least sufficient among the habitat components. Sand was the prominent substrate, with some gravel, and a small amount of cobble. The embeddedness of hard substrates was rated as “Moderate” at one visit, and “Severe” at the other visit. Among the “Channel Morphology” component, the individual scores that limited the component score were “Moderate Stability”, somewhat shallow pool depth, and poorly defined riffle/run/pool features. It is likely that fine sediment from the somewhat unstable banks has partially filled pools. Degraded habitat is probably a stressor in this AUID, though the connectivity issue discussed next, and the intermittency reported by a local resident reduces the degree of certainty about habitat problems.

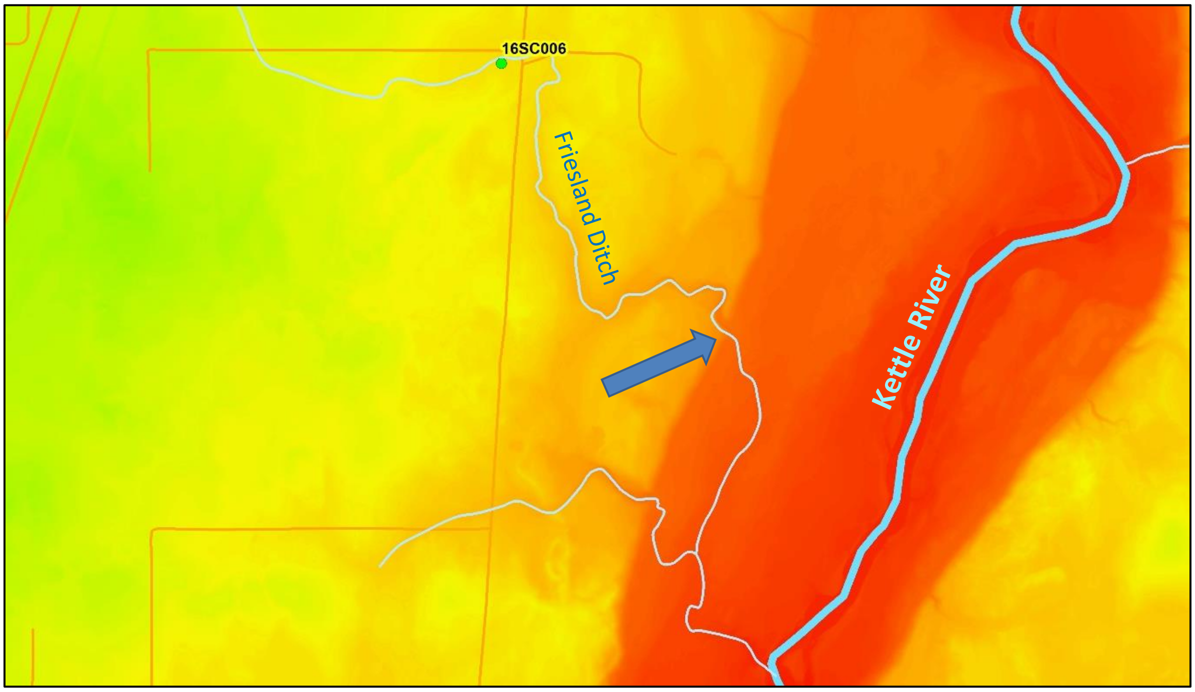
Connectivity

There are three road crossings downstream of 16SC006, between the site and the mouth of the AUID at the Kettle River (at Old Government Road, Township-1329, and a private drive). None of these culverts were assessed in the 2016 Kettle River Culvert Assessment performed by DNR. The author visited the first two sites on July 25, 2018 and concluded that neither set of culverts were barriers on that date (i.e., not perched, flow was sufficient and of passable velocity). The culverts on Old Government Road are relatively small, and may cause a seasonal barrier in spring/early summer when flows are higher. A scour pool was found below these culverts. Township-1329 has 4 culverts, the largest appearing to be very new. Three have passable flow, while one (on the inside bend) was silted in. The private drive culverts were not visited. Near the Kettle River, the stream is colonized by beavers, including a set of dams, which likely are significant barriers for fish to recolonize the stream in spring (Figure 31).

Figure 31. Set of dams near the floodplain of the Kettle River. The stream enters this beaver complex as marked with the blue line at the top and bottom of the photo.

Based on a topography, it appears that there may be a natural barrier to fish migration a short ways upstream of the beaver dams, which is the steep valley wall at the edge of the historical Kettle River floodplain (Figure 32).

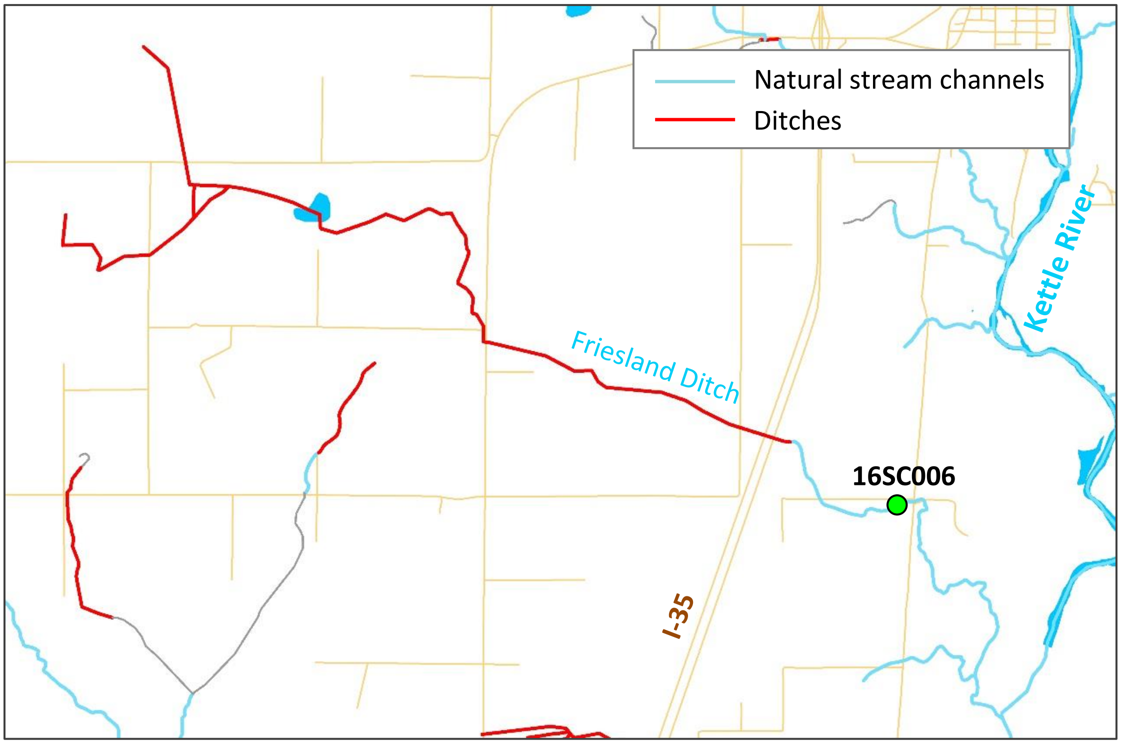
Figure 32. Topography of the landscape near the mouth of Friesland ditch. Elevations move from high to low in transition from green to yellow to orange to red. The broad orange band is the historical Kettle River floodplain. At the edge of the floodplain is a steep transition to the surrounding upland area (abrupt color transition from orange to yellow). This transitional area of high gradient (arrow) may be a natural barrier to fish migration.



Hydrology

The hydrology of the subwatershed area that flows to 16SC006 has been altered by ditches dug decades ago through both uplands and wetlands (Figure 33). This likely extended the channel system farther upstream than its original extent, meaning runoff from those land areas more efficiently enters the creek, resulting in higher peak flow volumes than this stream channel was formed to handle. Water storage has also been reduced by the ditching, likely resulting in reduced flow during dry periods.

Figure 33. Friesland ditch, showing ditched and natural sections.



Geomorphology

Signs are evident that the channel has and is experiencing instability due to altered hydrology and that damage to the physical channel has occurred (incision and overwidening). Photos taken during the biological monitoring visits show the channel having relatively high, raw vertical banks (Photo 5), and there appears to be significant movement of sand on the streambed (wavy dunes).

Photo 5. The AUID-617 channel within the biological sampling reach. The stream is in its natural channel here (i.e., not ditched). The channel shows signs of instability; raw banks, apparent incision, overwidening, and excessive bedded fine sediment.

DNR Watershed Specialists conducted Rosgen classification protocols and Pfankuch assessment at 16SC006 in October 2018. DNR staff provided a summary of the study:

Rosgen measurements

Friesland Ditch exhibits signs of instability but its adjustment to altered hydrology has been tempered by good bank vegetation and coarse channel substrates. Close to 70% of the stream length has been ditched, likely affecting the hydrologic regime and instigating channel evolution. The stream has incised and widened, but this has not caused excessive bank erosion. There are some pattern issues and areas of excess sand deposition, but there still appears to be good aquatic habitat available.

DNR specialists surveyed 600' of Friesland Ditch west of Old Government Road in October of 2018. The stream is an E4/5 stream type, meaning it is relatively deep and narrow with substrate dominated by gravels and sand. Though the stream is ditched through a majority of its watershed, it returns to a more natural, meandering channel upstream of the survey site. Its valley is confined upstream but opens into an unconfined glacial till plain valley through the surveyed reach. The reach pebble count showed 6% silt, 29% sand, 49% gravel, and 16% cobble.

The stream has a wide floodplain, but bankfull indicators and regional curves indicate that the stream has incised and abandoned that floodplain at bankfull flows. Bank height ratios, the ratio of the lowest bank height to the bankfull height, average between 1.25-1.72, meaning the channel is slightly too deeply incised. It is only slightly entrenched so small to medium floods are still able to access the floodplain. The large substrates should help to minimize further incision, but the stream will remain moderately unstable until it finds a new equilibrium. Fish habitat still appears to be adequate despite the instability. Woody material, deep pools, undercut banks, and channel and substrate variability are all providing habitat niches for biota. Several pools have filled with sediment but others are maintaining very good depths. The ratio of maximum pool depth to mean riffle depth ranges from 1.6 to 2.9, while the expected range is 2-4.

Pfankuch assessment

The Pfankuch score for Friesland Ditch is 78, a fair (moderately unstable) score for an E4/5 stream. Ten of fifteen parameters score as good or excellent. The upper banks score excellent due to the low landform slopes and good vegetative protection. Lower bank parameters have the only two poor scores and are negatively influenced by the channel incision and the amount of fines within the banks. The worst channel bottom scores are fair, due to the lack of particle consolidation and the amount of scour and deposition throughout the reach.

Conclusions about stressors

This appears to be a sometimes-intermittent stream, and the biology reflects that, with tolerant fish species forming the community, and numerous wetland-oriented macroinvertebrate taxa that can make it through stagnant times or “dry” times. The channel is unstable, and excess sand makes the substrate unstable as well for biological habitat. The upstream ditching likely has reduced water storage in the headwaters, which makes intermittency more likely downstream. In July 2018, there was found to be good flow in the stream. Beavers have created dams near the Kettle River that are likely barriers to fish that would migrate up from the Kettle River. DO seems to be fine when there is flow, as was the case in the July 25, 2018 visit. The main stressor is the upstream ditching and the changes it has caused to the hydrology of the stream.

Recommendations

There is probably little that can feasibly be done to fix conditions in Friesland Ditch. The upstream ditches could be either plugged in areas where there was not a channel originally and landowners would not be affected (e.g., the headwaters area upstream of CSAH 27), or the channel be re-meandered back into it original more sinuous channel. This would help with water storage, making the flow more stable farther downstream, though a hydrological assessment would be beneficial to determine how much restoration would be needed to make beneficial change. The stream is not a recreational fishery, and thus probably does not rank as a high priority given the cost that ditch abandonment and/or re-meandering the channel would require. A more thorough assessment of fish habitat along more of the reach would be suggested to assess the benefits of a project.

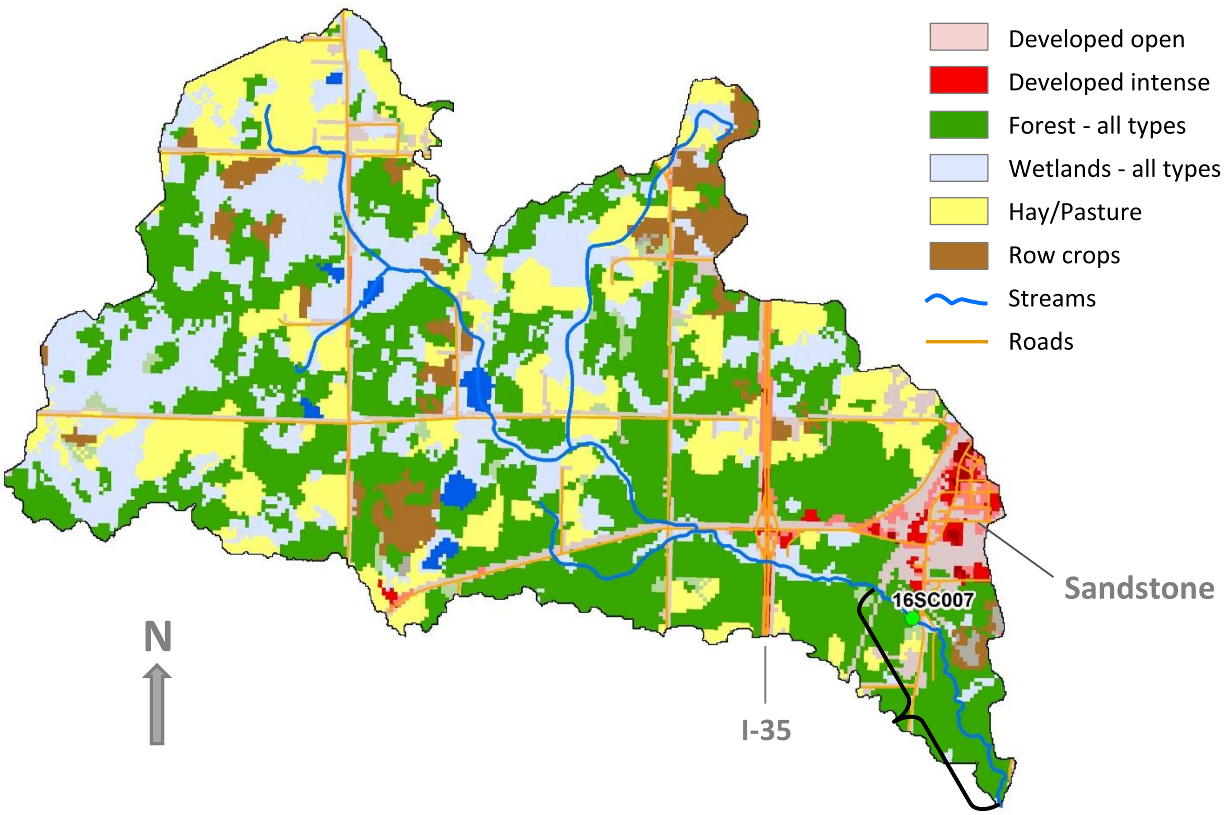
Skunk Creek (AUID 07030003-618)

Impairment: The creek was assessed as impaired for not meeting the fish community coldwater IBI threshold at site 16SC007 located just upstream of CR-129, six miles north of Kettle River. The macroinvertebrate community scored above the passing MIBI coldwater threshold.

Subwatershed characteristics

Site 16SC007 is a Fish Class 11 (Northern Coldwater) and Macroinvertebrate Class 8 (Northern Coldwater) stream reach. The landscape of the subwatershed that drains to 16SC007 is mix of peatlands, forest, and hay/pasture (Figure 34). Almost all of the immediate riparian corridor of the creek is wet meadow. The HDS score was 63.7 (at the 69th percentile statewide). A moderate-sized pond was dug in the channel just west of the freeway exit ramp sometime after the 1965 aerial photos were taken. Of importance to the current management of Skunk Creek is a historic industrial plant that has left legacy pollution near and in the creek. The Kettle River Company creosote plant in Sandstone leaked tar material into the ground at the plant site, and waste tar was also dumped along and into the creek near the plant. The location is now a state-funded contamination remediation site, being worked on by the Minnesota Department of Agriculture (the product is classified as a wood pesticide). Information about the history and clean-up process can be found on the MDA website.

Figure 34. Subwatershed of AUID-618 showing land use/land cover types, the Skunk Creek system, and the biological sample location (16SC007). The toxic contamination area of the creek is the span that is shown with the black bracket.



Data and analyses

Chemistry

The only chemistry data entering the SID work was the parameters collected at the IWM biological sampling visits (Table 47).

Table 47. Chemistry measurements collected at the biological sampling visits at 16SC007, values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	T-tube (cm)
July 26, 2016*	14:28	23.3	5.54	84	6.73	83.5	0.123	0.17	0.07	6.0	2.8	66
Aug. 17, 2016	8:09	16.7	6.97	84	6.97	106	--	--	--	--	--	78
Aug. 31, 2016	17:07	18.2	8.02	88	6.77	117.2	0.058	0.34	< 0.05	2	1.6	> 100
Sept. 12, 2017	8:58	12.0	8.52	82	6.94	127.1	0.046	0.51	< 0.05	3.2	--	--
Sept. 12, 2017	7:53	11.8	8.51	81	6.86	100.5	--	--	--	--	--	> 100

*The stream was above the flow level considered normal for fish sampling; chemistry should be evaluated with high water in mind (warmer water, lower DO, and higher TSS than normal).

Dissolved oxygen

All instantaneous DO measurements were above the warmwater standard, but not the coldwater standard, including a pre-9 a.m. August measurement. Without more early morning (pre-9 a.m.) samples, which reveal the daily minimum DO concentrations, these data cannot determine that the stream is meeting the DO standard. They do however show that there are good DO levels during the day. Samples taken in mid-afternoon during summer did not show high DO readings that occur with eutrophication. DO %-saturation measurements also did not signal eutrophication (all were < 100%).

Nutrients - Phosphorus

TP levels were typical small, north central Minnesota streams, except for the July 26, 2016 higher-flow sample. The somewhat more “stirred-up” condition of the creek, and likely flushing of wetlands that would be occurring with high water, are likely the reason for the elevated TP on this date. The tea-colored water is additional evidence of wetland influence.

Nutrients - Nitrogen and ammonia

Both the nitrate and ammonia samples were consistently in very low concentration, with ammonia typically below the lab’s detection limit.

Transparency and suspended solids

The TSS levels sampled are very low. Even at the higher water encountered on July 26, 2016, the TSS was quite low. The sampling crew that day noted that the water was quite tea-stained, which contributed to the moderately low Secchi-tube reading on that date. The other Secchi tube readings were quite good.

Stressor signals from biology

Fish

In each of the two assessable fish samples, few species were caught, as well as only a small number of individuals. In August 2016, four species were caught, with three being highly ubiquitous, and a lone pearl dace being the only sensitive species. In September 2017, only two species and nine fish were caught - both highly tolerant; brook stickleback and central mudminnow.

Metrics pertaining to DO and TSS for the 2016 sample are shown in Tables 48 and 49. The 2017 sample had too few fish to make the metrics meaningful. The fish community is completely skewed to low-DO

Tolerant species. There is no suggestion in these metrics that TSS levels are stressing the fish community.

Table 48. Fish Community DO and TSS Tolerance Index scores at 16SC007. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 11 (2018 version). "Prob." is the probability a community with this score would come from a class 11 stream reach with standard-meeting DO or TSS.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
August 2016	5.73	7.61/7.55	1	0.4	16.3	10.84/11.25	1	50.7
September 2017	5.48	7.61/7.55	1	0.4	13.3	10.84/11.25	14	55.5

Table 49. Fish metrics related to DO for 16SC007 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	4	3	0	100
TSS	0	0	0	0	0	0

*Includes # Very Intolerant or Very Tolerant Taxa as part of the count.

Macroinvertebrates

The macroinvertebrate community was assessed as meeting the standard. Samples were collected in two years, and the samples differed somewhat significantly between the two years. In both samples, the black fly *Simulium* was dominant, though less so in 2017. A significant number of sensitive and cold or coolwater taxa were collected, including good numbers of caddisflies *Lepidostoma*, *Glossosoma*, and *Protoptila*, and mayfly *Ephemerella*. Other notable species with fewer individuals were riffle beetle *Optioservus*, small fly *Hemerodromia*, cranefly *Tipula*, caddisfly *Lype diversa*, and stoneflies *Taeniopteryx*, *Paragnetina media*, and *Acroneuria*.

Macroinvertebrate metrics were evaluated to see if there might be some signal in the community to confirm that low DO is a stressor (Tables 50 and 51). For both DO and TSS parameters, the sampled community is more likely than not to come from a site that passes those water quality standards, especially for DO. The metrics assessing low-DO effects show the community are very skewed toward low-DO Intolerant taxa and individual abundance, with no low-DO Tolerant taxa present in the sample. The 2017 sample did have three low-DO Tolerant taxa present, but there were also an additional five low-DO Intolerant taxa present, and the % Intolerant individuals was much higher in the 2017 sample. The DO TIV Index scored above its class average for both samples, while fish scored far below its class average. The TSS metrics show a skewing toward TSS Intolerant taxa, but really no skewing toward either TSS Tolerant or Intolerant individuals. There is no evidence in the macroinvertebrate community that DO levels are problematic, which strongly contradicts the fish analysis, and there is weak evidence of the possible influence of TSS.

Table 50. Macroinvertebrate Community DO and TSS Tolerance Index scores for 16SC007. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 8 (2018 version). "Prob." is the probability a community with this score would come from a class 8 stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/17/2016	7.71	7.33/7.46	69	86	13.59	12.23/12.25	22	52
9/12/2017	7.54	7.33/7.46	57	84	11.76	12.23/12.25	60	59

Table 51. Macroinvertebrate metrics related to DO for 16SC007 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO (2016)	12	8	0	0	19.4	0
Low-DO (2017)	17	10	3	2	30.6	1.0
TSS (2016)	9	3	5	1	5.2	13.8
TSS (2017)	8	4	8	3	18.2	12.4

*Includes # Very Intolerant or Very Tolerant Taxa as part of the count.

Overall biological data conclusions

With the uncertainty of the impact of the legacy toxic materials on the fish community, it is difficult to determine if there are other chemical stressors to the fish community. The macroinvertebrates did not show a stress response regarding DO or TSS.

Temperature

Temperature measurements were in the range considered to be found in a coldwater stream, though these measurements were taken in late summer, a time when some cooling naturally has happened in all streams.

Habitat

The biological sampling crews conducted the MSHA protocol on five different dates. Total scores were 70.5, 87.9, 74.8, 69.5, and 75.8. The average of 75.7 fall well into the "Good" category of habitat. An average of each of the five MSHA sub-components was also calculated. The sub-component score averages were then used to calculate a percentage of that sub-component's possible score (Table 52). The only sub-component score that was somewhat mediocre was "Substrate". It would have rated higher had boulder-sized substrate or somewhat greater amounts of cobble been present. As a positive, very little silt was observed, and the consensus was that embeddedness was light (at 25-50%). Habitat in this location is very adequate to support a healthy fish community.

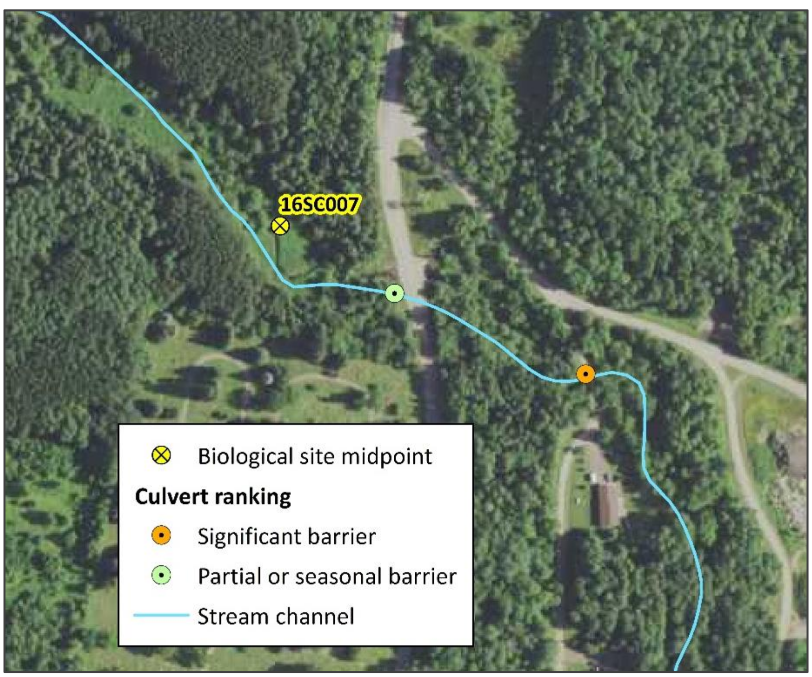
Table 52. Averaged sub-component scores for MSHA at 16SC007.

MSHA Component	Avg. Score	Maximum Poss. Score	Percent of Maximum
Land Use	4.7	5	94.0
Riparian	12.0	14	85.7
Substrate	18.8	28	67.1
Cover	14.2	18	78.9
Channel Morphology	26.0	35	74.3
Total MSHA Score	75.7	100	75.7 = "Good"

Connectivity

The DNR culvert assessment found two locations just downstream of the biological site that are problematic for fish passage (Figure 35). In small streams (such as Skunk Creek), overwintering conditions can be inhospitable, and fish move downstream to larger waters in the winter and travel back up into the smaller streams to repopulate them in spring. The DNR assessments suggest this seasonal migration is substantially blocked for returning fish by the infrastructure at these two road crossings. Beaver dams can also be problematic for fish passage, but via aerial photo interpretation, there are no signs of beaver activity between 16SC007 and the confluence of AUID-618 at the Kettle River.

Figure 35. Skunk Creek, location of biological sampling site 16SC007, and road crossings with infrastructure barriers to fish passage.



Hydrology

The hydrological patterns of flow in Skunk Creek have changed relative to pre-settlement times, due to alterations of the landscape, especially land clearing and creation of impervious surfaces. Numerous roads cross through the watershed, most notably Interstate-35 and CSAH-61. A moderate-sized pond was dug in the channel just west of the freeway exit ramp sometime after the 1965 aerial photos were taken. A new ditched channel was constructed upstream of the pond in the road ditch of CSAH-61, again sometime after 1965. The habitat information suggests that any negative consequences of alterations to hydrology are minimal in Skunk Creek.

Geomorphology

Geomorphology assessment was not done here, due to the status of this stream as being an active industrial legacy contaminant site due to leaching and waste dumping done by the former Kettle River Company Creosote plant in Sandstone. Photos taken during biological sampling were reviewed and there were no signs of channel instability. The channel looked very healthy physically.

Conclusions about stressors

The culverts downstream of the sample site are a main stressor, and may well explain the very contradictory evidence from the fish and macroinvertebrate communities as to adequate DO levels in the stream. Sensitive species may not be able to survive the long term conditions above the culverts, and cannot recolonize the site from downstream areas. The toxic legacy pollution from industrial dumping decades ago potentially has some effect on the stream’s fish, though the degree is not known. Toxins have been found in the water column, and tar chunks have been found along the banks in parts of the creek. This pollution is now actively being addressed and cleaned up, though it will likely take a number of years until this remediation/restoration project is complete.

Recommendations

Aside from the cleanup of toxic waste in the stream, the downstream culvert needs to be re-installed with correct elevation and sizing to allow for fish passage. The stream has very good habitat, and this should allow fish to recolonize the stream each spring from overwintering habitat farther downstream, including the Kettle River itself. DNR is not actively managing the stream for trout until the pollution problem is resolved.

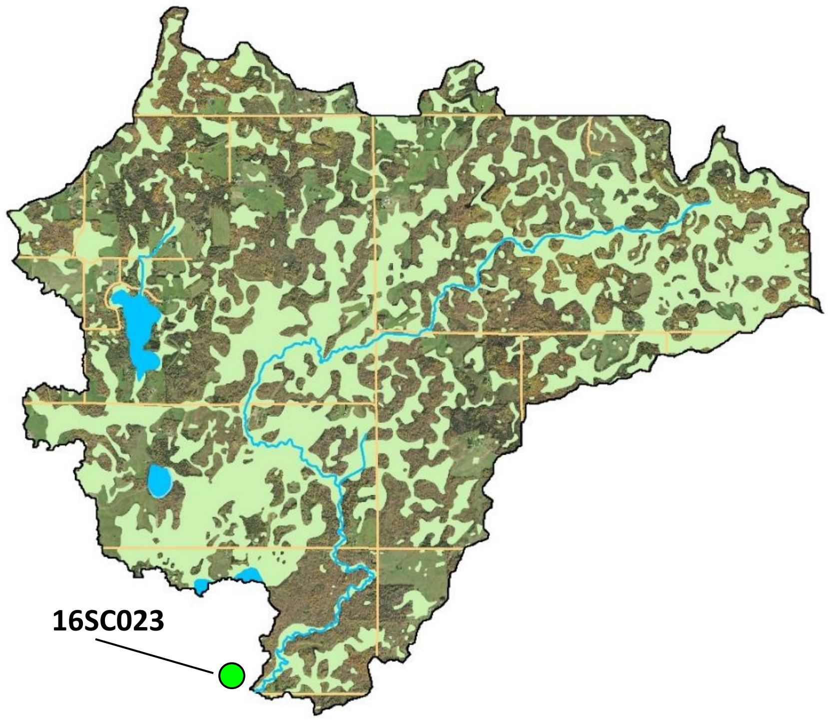
Hay Creek (AUID 07030003-619)

Impairment: The creek was assessed as having an impaired fish community at 16SC023, just upstream of CSAH-46, four miles northwest of Kerrick. The macroinvertebrate community met the MIBI passing threshold.

Subwatershed characteristics

Hay Creek is a tributary of the Willow River. Site 16SC023 is a Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 3 (Northern Forest Streams - Riffle/Run) stream reach. The subwatershed of Hay Creek is a somewhat even mix of forest, hayfield/pasture, and wetland (Figure 36). The wetlands are interconnected in a lacy pattern, and significantly associated with the creek. Most of the creek’s riparian corridor is wetland. In comparing the NLCD cultivated area designations, it appears, by aerial photo review, that only one of these small patches (~ 25 acres) is actually used for a cultivated crop, and this location is at the extreme northeast edge of the subwatershed. There are no towns in the subwatershed. Most of the riparian corridor of the stream channel is wetland. The HDS score was 75.85 (at the 86th percentile statewide).

Figure 36. The subwatershed for sample site 16SC023 on Hay Creek outlined in black. Green patches are wetlands from the National Wetlands Inventory map.



Data and analyses

Chemistry

The only chemistry data that exists in this AUID is that collected at the IWM fish and macroinvertebrate sampling visits (Table 53) and SID investigations.

Table 53. Results from the 2016 - 2017 IWM chemistry monitoring at 16SC023. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)	DOC
Aug. 4, 2016	10:49	22.3	6.01	73	7.0	78	--	--	--	--	--	24	--
Aug. 24, 2016	17:29	22.5	6.48	79	7.7	69	0.092	0.06	0.07	12	3.6	36	--
Sept. 5, 2017	18:07	14.6	8.01	81	5.8*	59	0.068	< 0.05	< 0.05	7.2	--	55	--
Sept. 11, 2017	14:52	19.3	7.29	82	7.0	54	--	--	--	--	--	47	--
July 17, 2018	11:40	20.6	6.72	74.8	--	53	0.106	--	--	--	--	--	38.4

*Field crew questioned this reading.

Dissolved oxygen

The five instantaneous DO measurements were at healthy levels, though no pre-9 a.m. samples were collected. Without early morning measurements, it is not possible to determine that the DO meets the standard. DO %-saturation measurements were at healthy levels that suggest eutrophication is not an issue in this AUID. The high DOC darkening the water also makes it difficult for algae to obtain sufficient sunlight to grow.

Nutrients - Phosphorus

TP concentrations are fairly high. The DOC analysis suggests there is a lot of wetland contribution to the stream flow.

Nutrients - Nitrate and ammonia

Both nitrate and ammonia concentrations were very low (very near or below the lab detection limit) in the two sets of samples.

Conductivity

All five conductivity readings were very low.

Transparency and suspended solids

Neither of the two TSS samples exceeded the standard, however, Secchi tube readings were quite poor. The poor Secchi tube measurements are likely attributable to the darkly-stained water noted by the sampling crew and DOC sample. This results in loss of visual depth that is not due to suspended particles.

Dissolved Organic Carbon (DOC)

A sample of DOC was collected on July 17, 2018. The water was strongly tea-colored and the concentration was 38.4 mg/L, which is quite high, signaling strong wetland influence.

Stressor signals from biology

Fish

Very few fish were caught in either of the two sample efforts; only 17 and six. The 2016 sample had five species, with johnny darter the most abundant. Others were burbot, mottled sculpin, northern pike, and white sucker. The 2017 sample had just three species; burbot, johnny darter (again the most abundant), and white sucker.

With so few fish captured, calculation of metrics is not very helpful. It should be noted however, that the majority of individuals captured were sensitive or neutral (i.e., not tolerant) species, especially burbot and mottled sculpin, both of which are cool-to-coldwater species. No signature of a particular stressor shows up with these two small catches.

Macroinvertebrates

The macroinvertebrate samples were both very near the passing threshold, with one (2016) just under and one (2017) just over. The 2017 sample was given more weight in assessment due to the extreme rainfall event that occurred in summer 2016, which may have temporarily impacted the macroinvertebrate community. Both samples were moderately dominated by the black fly *Simulium*. There were a number of sensitive taxa collected between the two samples, including some that are more indicative of coldwater streams: *Optioservus*, *Lype diversa*, *Hemerodromia*, *Baetis brunneicolor*, *Helicopsyche borealis*, *Nyctiophylax*, *Hexatoma*, *Tipula*, *Limnophila*, *Dicranota*, *Boyeria vinosa*, *Capniidae*, and Uenoidae.

Tolerance-related metrics are shown in Table 54. The community was highly skewed toward being intolerant of low DO levels, while it was quite balanced between taxa that are Intolerant and Tolerant to elevated TSS.

Table 54. Tolerance metrics from 2017 visit for DO and TSS at 16SC023.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low DO	9	5	1	0	16.9	0.3
TSS	6	1	5	1	6.6	11.2

Overall biological data conclusions

There is no evidence to support that either parameter is negatively influencing the macroinvertebrate community, nor the fish community.

Temperature

The temperatures measured at the five biological sampling and SID visits (which included a mid-July sunny day and an early August measurement) were at non-stressful levels. In fact, temperatures were fairly cool. High water temperature is not a stressor in this AUID. The macroinvertebrate and fish communities suggests this is a cool-water stream and temperature measurements confirm this. Cool-water streams are considered warmwater streams within the current MPCA stream classification protocol.

Habitat

MSHA scores were calculated from four visits to this AUID in 2016 and 2017. The total and sub-component scores are shown in Table 55. Total MSHA scores were averaged for the four visits to 16SC023, resulting in a score of 63.8, which is near the top end of the scoring range for the “Fair” category. The poorest-scoring sub-component scores from 16SC023 were “Channel Morphology” and “Substrate”. Sand was the most prominent substrate, with some gravel and cobble present. All scorers rated embeddedness of coarse substrate as “Light”. The poorest scoring features within “Channel Morphology” were “Depth Variability” and “Channel Stability”, both of which can be caused by altered hydrology that leads to excess bank erosion and bed sedimentation.

Table 55. MSHA scoring for the four different visits to site 16SC023 in 2016 and 2017.

MSHA Component	8/4/16	8/24/16	9/5/17	9/11/17	Avg. score	Maximum Poss. Score	Percent of Maximum
Land Use	5	5	5	5	5	5	100
Riparian	12	10	12.5	11.5	11.5	14	82.1
Substrate	18.75	13.6	19.6	15.15	16.8	28	59.9
Cover	13	10	12	11	11.5	18	63.9
Channel Morphology	19	20	18	19	19	35	54.3
Total MSHA Score	67.8	58.6	67.1	61.7	63.8	100	63.8 = “Fair”

Connectivity

Five roads cross AUID-619. Four of these crossings are upstream of the biological sampling site, with one at the downstream end of the biological reach. DNR observers rated the crossing in the biological reach as a partial/seasonal barrier, while the four upstream crossings rated as alternating significant and partial/seasonal barriers moving in the upstream direction. This many crossings with some barrier effect could be contributing to the impaired fish community in AUID-619, though the effect should be less at 16SC023 since there is just one crossing between it and the Willow River, and that crossing is only a partial barrier. The upper half of the AUID also has significant beaver activity with numerous dams, which add to the difficulty of fish movement in the upstream areas.

Hydrology

There has not been any anthropogenic drainage enhancement in this subwatershed. The hydrologic regime of the stream has been somewhat altered from historical condition due to the creation of open pastures and hayfields. This landcover change may have been enough to cause some channel instability. The stream has quite sandy bank material, which is more sensitive to flow disturbance due to its low cohesiveness.

Geomorphology

Review of photos taken during biological sampling indicate that some incision and overwidening has/is occurring. There are raw, eroding banks. DNR Watershed Specialists conducted Rosgen classification protocols and Pfankuch assessment at 16SC006 in October 2018.

Rosgen measurements

Hay Creek has channel stability issues evidenced by incision and bank erosion, but the cause is unclear. Land cover within the watershed is still mostly forest and wetland with only 15% pasture/hay, and there is minimal upstream ditching. The channel could be adjusting to hydrologic changes instigated by historic logging and fires or a more recent disturbance such as a large flood, but additional investigation is needed to form any conclusions. Regardless of the cause, fish habitat is being impacted by the instability and lack of stable channel substrate.

DNR specialists surveyed 850’ of Hay Creek just upstream of Deerfield Rd/Hwy 46 in October of 2018. The E4/5 stream, a relatively narrow and deep channel with primarily gravel and sand substrates, flows through an unconfined – glacial till plain valley. A riffle pebble count shows 2% silt, 39% sand, 58% gravel, and 1% cobble. The gravels are mostly 2-8mm in size, so there are few large particles that can provide channel stability and habitat niches for biota. There is also some pool filling by fine particles, but several pools are maintaining expected depths of two or more times the mean riffle depth.

Few bankfull indicators exist below the abandoned floodplain so the bankfull elevation and stream type is based off regional curves. Using the expected cross-sectional area, the channel is moderately to deeply incised with bank-height ratios (BHR) values ranging from 1.41 – 1.85 (BHR is the ratio of the lowest bank height to the bankfull height). The incision has created stretches of accelerated bank erosion and deposition, but the stream is not yet entrenched so small to medium floods still access the floodplain. However, if Hay Creek down cuts much further, even medium floods would lose access to the floodplain, which could exacerbate the instability.

Pfankuch assessment

The Pfankuch score for this reach is 101, a poor (unstable) score for an E4/5 stream. Eleven of the fifteen parameters score as fair or poor. The upper banks (above bankfull) have the best ratings thanks to the low landform slopes adjacent to the channel and good vegetation protection. Most of the lower bank parameters have fair scores due to the lack of large particles in the channel banks, the amount of bank cutting, and the deposition of sand. Channel bottom scores are mainly fair or poor, and have the largest negative influence on the overall score. The worst scores are from a lack of consolidated particles, the amount of channel flux, and the lack of aquatic vegetation.

Conclusions about stressors

The current primary stressor is channel instability, and the subsequent habitat problems caused by such instability. DNR geomorphology survey work found significant incision and channel widening, and increased fine particulate streambed substrate. The MSHA work found that much of the substrate was sand. At some point in time, channel instability was initiated by altered hydrology (excess flow). The cause of the alteration of hydrology is not clear, as the subwatershed’s land cover is currently quite natural. The initial cause of the channel instability may have been the widespread clearcutting of the original old growth white pine forest in the late 1800’s and early 1900’s, which would have radically changed the vegetative cover on the landscape, and led to more precipitation runoff that when it was forested. Streams can recover from such disturbance, though it can take many decades once the landscape has naturalized again.

Connectivity problems are likely a moderate stressor due to problematic culverts, mostly upstream of the biological sample site, but one downstream as well. Water chemistry parameters do not appear to be stressors. DOC was high, and there may be a connection between poorer fish communities in small streams with darkly-stained water - this has also been found in other northern Minnesota locations, but the link is not definitive at this point.

Recommendations

In-stream work to stop incision, and even raise the grade of the streambed would be helpful. Stream restoration specialists should be consulted. Culvert replacement with size and elevation that promote good fish passage would also likely benefit the fish community. Current culverts may be providing grade control in this incised stream, so care should be taken to provide other grade control measures if culverts need to be lowered in elevation for fish passage.

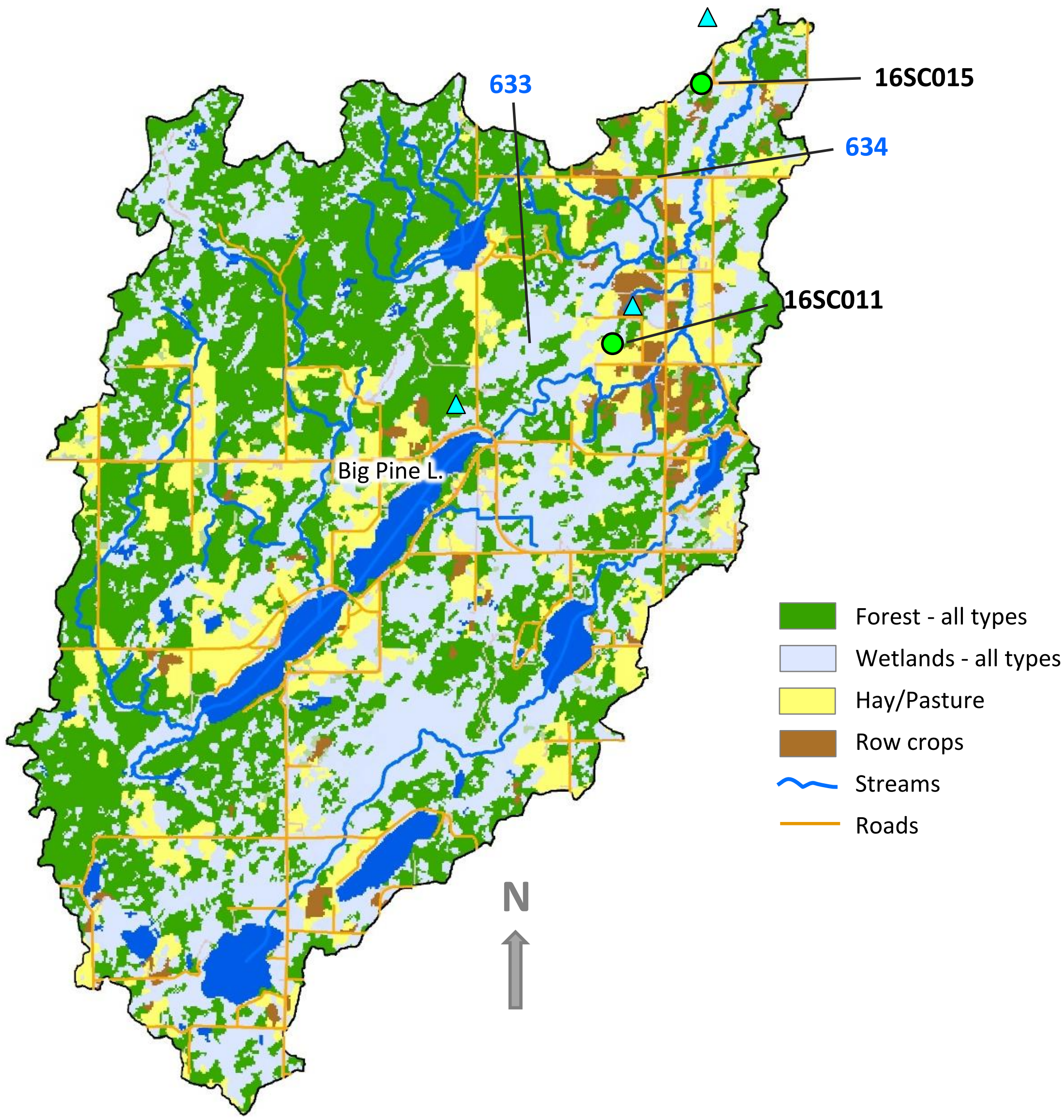
Pine River (AUID 07030003-633 and 634)

Impairment: Two consecutive AUIDs of the Pine River will be discussed together. AUID-633 is from the outlet of Big Pine Lake to the entrance of the Little Pine River, while AUID-634 is immediately downstream, from the confluence of the Little Pine River down to the entrance of Bremen Creek. The Pine River was assessed as having an impaired macroinvertebrate community at two sites - 16SC011, upstream of Dahlstein Road, three miles northwest of Finlayson (in AUID-633), and 16SC015, downstream of CR-150, four miles west of Rutledge (in AUID-634). The fish community met the FIBI passing threshold in both AUIDs; at 16SC011, the fish community surpassed the Exceptional Use threshold.

Subwatershed characteristics

The upper AUID-633 begins as the outflow of Big Pine Lake, while the lower AUID-634 includes both the flow of AUID-633 and the flow of Little Pine River, and ends at the confluence of Bremen Creek (Figure 37). Site 16SC011 is a Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool) stream reach. Site 16SC015 is a Fish Class 5 (Northern Streams) and Macroinvertebrate Class 3 (Northern Forest Streams - Riffle/Run) stream reach. The contributing landscape is a mix of forest, wetland, and small farms, mostly raising livestock and hay, though some row crop agriculture does exist. The riparian corridor is in natural vegetation throughout most of its length. However, there are locations where the vegetation has been altered or removed right up to the stream bank. There is significant lake influence on the Pine River, as Pine and Big Pine Lakes contribute flow directly to the Pine River, while Upper Pine and Little Pine Lakes contribute flow to the Pine via the Little Pine River. The HDS scores were 72.2 (16SC011, at the 81st percentile statewide), and 72.8 (16SC015, at the 82nd percentile statewide).

Figure 37. Subwatershed of AUID-633, and 634 showing land use/land cover types. The outlet of AUID-634 is at the top right of the map. The blue triangles signify the boundaries of the two AUIDs.



Data and analyses

Chemistry

Within these two AUIDs, chemistry data was collected at the two biological sites (Table 56) and a much more comprehensive collection at site S009-064 in AUID-634, between the two biological sites (at CSAH-39) in 2016 and 2017 (Table 57).

Table 56. Chemistry data collected at biological sampling visits to 16SC011 and 16SC015. Values in mg/L.

Site	Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
16SC011	Aug. 16, 2016	14:15	27.5	10.3	138	8.51	135	--	--	--	--	--	99
16SC011	Aug. 22, 2016	13:48	23.5	7.49	92	7.51	141	0.035	0.07	< 0.05	2.4	2.0	> 100
16SC015	Aug. 15, 2016	17:17	23.6	6.67	82	7.28	124	--	--	--	--	--	> 100
16SC015	Aug. 17, 2016	18:02	26.1	6.79	88	7.62	128	0.047	0.08	0.07	3.6	2.0	> 100

Table 57. Chemistry data collected at sample site S009-064 (CSAH-39) on AUID-634 in 2016 and 2017 (May - September). Sample times ranged from 8:24 - 14:30, but most were late morning. Values in mg/L.

Parameter	# samples	Average	High	Low
Total Phosphorus	28	0.045	0.078	0.027
Orthophosphorus	27	0.015	0.028	0.005
DO	29	7.43	10.07	1.31
Temperature (May - September)	29	18.30	25.09	10.1
Temperature (June 15 - August 31)	17	20.21	25.09	16.17
Secchi Tube transparency* (cm)	32	> 98.3	> 100	68

*This data also contains a few spring and fall measurements.

Dissolved oxygen

The instantaneous DO measurements taken at biological monitoring visits were generally at very healthy levels, though no pre-9 a.m. samples were collected so it cannot be confirmed that the daily minimums were not below the DO standard. The August 16, 2016 measurement at 16SC011 is somewhat high, signaling possible influence of excess plants/algae. This is further confirmed by the supersaturated DO level, which was well above 100%. The DO level at an intermediate site, S009-064 (CSAH-39), which is not a biological monitoring site, occasionally has shown low DO (Table 58 and 59).

Further investigation of DO was conducted in the SID effort in 2018 and 2019. On July 17, 2018, a synoptic sampling was done in mid-morning at six locations spread throughout the subwatershed downstream of Big Pine Lake (Figure 38). Water had been and was still high in the rivers of this area. DO concentrations were very low along the whole length of AUID-623 (Table 59). Tributary Little Pine Creek had a much better DO level, though still slightly below the standard. Tributary Rhine Creek was several degrees colder than the Pine River, but its DO concentration was very similar to the Pine's. The colder temperature and low DO suggests groundwater input into Rhine Creek. Some orange floc was observed which provides more evidence of groundwater seepage into Rhine Creek.

A second synoptic DO measuring effort was conducted on August 3, 2018, in order to provide insight into how water levels may influence DO concentrations. It had been relatively dry since the first synoptic effort, and stream levels had receded significantly. The times of visit to each site were quite close on the two dates, so time of day sampled should not be a significant factor in the differences seen between dates. At the second visits, DO concentrations and % saturations were significantly higher, and water temperatures were a few degrees cooler. At baseflow conditions, it appears that Rhine Creek may be a coldwater stream. At this second visit, all sites had DO concentrations that met the standard, though these were collected a short while past the 9 a.m. cutoff used in the MPCA protocol for considering approximate daily minimum concentration. DO concentrations were lowest near Big Pine Lake, and continually increased in the downstream direction among four sites on the Pine River (the farther from the lake, the better the DO concentration).

A third repeat of the synoptic sites was conducted on August 14, 2019, this time in mid-afternoon, rather than mid-morning. Flow was similar to the second synoptic visit. The DO in the Pine River sites was quite a bit higher than at visit 2, and likely is mainly attributable to the heavy vegetation growing in the channel - by mid-afternoon, these plants had been photosynthesizing (releasing oxygen) for many hours. The Little Pine River is much smaller and more shaded, and has less aquatic vegetation. DO was much less increased from visit two, probably due to the lesser amount of photosynthesis in the stream. DO in the Pine River was always lowest in the low gradient, wetland-fringed area upstream of site 1.

Riparian wetlands are likely playing a significant effect in the DO regime. During high water periods, these wetlands are draining water to the stream. Since wetlands are areas of significant plant decay, they often have low DO levels. When they are contributing significant water to the stream, the DO levels in the stream decrease. This likely explains why the DO is better at lower water levels (see Photo 6). From a combination of the flow patterns and DO concentrations from 2016 (Figure 39) and 2018 (Table 59 - site 5), a hypothesis might be that DO becomes temporarily low a few days after a mid-summer, large precipitation event.

Table 58. DO data from the earliest morning readings in the 2016-2017 dataset at site S009-064 (CSAH-39) shown in Table 57. The flow gage was located farther downstream on the Pine River.

Date	Time	DO	Gage (cfs)
June 27, 2016	9:05	5.79	588.9
July 21, 2016	9:15	1.31*	316.9
August 2, 2016	8:40	5.1	115.0
August 11, 2016	9:30	5.56	119.4
August 18, 2016	8:24	5.79	76.9

* Several days after the historic rain event on July 12, 2016.

Figure 38. Synoptic site locations for monitoring water temperature, DO, and DO % saturation on July 17 and August 3, 2018. Arrows show flow directions.

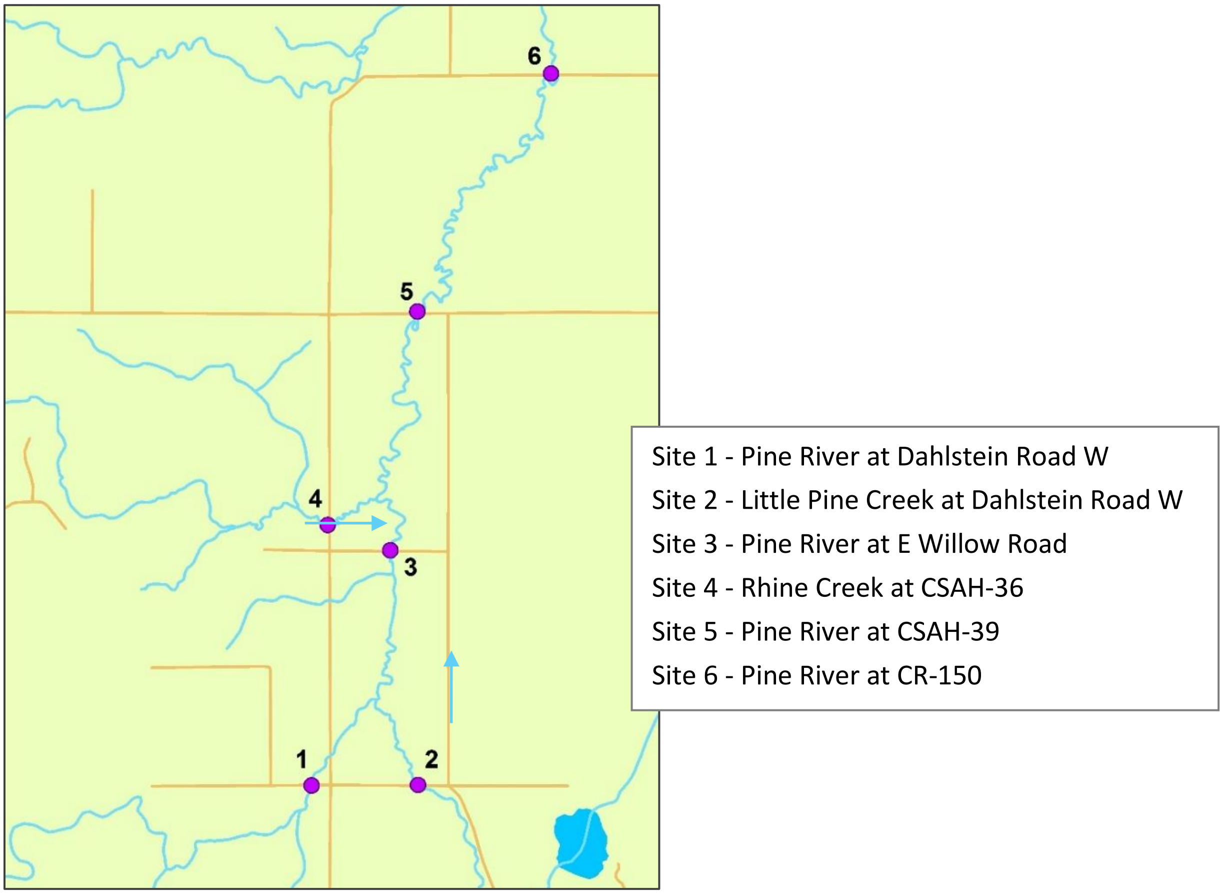


Figure 39. Pine River flow gage record for summer 2016. Red dots are flow at the dates presented in Table 58 to show context of relative water levels and recent flow patterns.

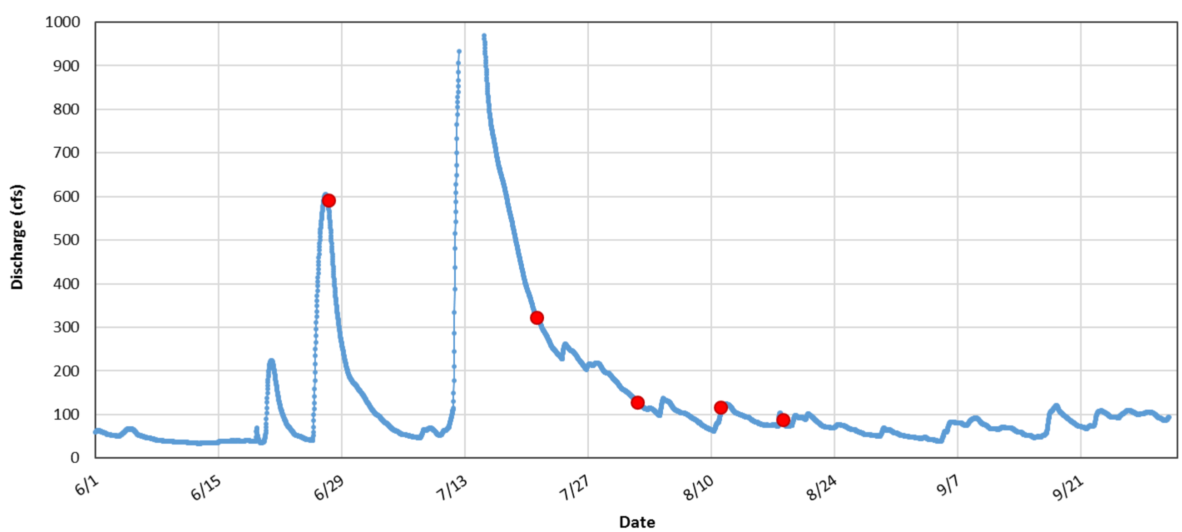


Table 59. Pine River system synoptic water temperature, DO, and DO % saturation on July 17 and August 3, 2018, and August 14, 2019. The flow volumes are average daily flow from the temporary Pine River gage farther downstream.

Parameter	Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Gage (cfs)
Time	July 17	9:40	9:53	10:05	10:16	10:27	10:40	421*
Water Temp. (°C)	July 17	23.17	--	23.08	20.72	22.51	22.16	
DO concentration (mg/L)	July 17	1.48	4.85	2.59	2.62	2.66	2.52	
DO % Saturation	July 17	17.3	57.5	30.1	29.2	30.8	28.9	
Time	August 3	10:05	9:55	10:20	10:30	10:40	10:50	136
Water Temp. (°C)	August 3	19.97	20.88	19.86	15.10	19.76	19.78	
DO concentration (mg/L)	August 3	5.41	6.88	6.02	5.49	6.58	7.09	
DO % Saturation	August 3	59.5	77.1	66.0	54.6	72.1	77.6	
Time	Aug. 14	15:40	15:50	16:05	NA	16:30	16:50	NA
Water Temp. (°C)	Aug. 14	23.94	23.41	22.92	NA	23.31	23.14	
DO concentration (mg/L)	Aug. 14	8.53	7.62	9.54	NA	10.13	9.29	
DO % Saturation	Aug. 14	101.4	89.5	111.2	NA	118.8	108.8	

*This visit was 4 days after a significant rainfall event.

Photo 6. This riparian wetland area (likely an oxbow) is contributing very little water to the river when flows are low. This wetland has been observed to be very connected to the stream at higher flow volumes. The yellow line is the edge of the stream channel and the arrow shows flow direction.

Nutrients - Phosphorus

Both of the TP samples were at relatively healthy levels, though at a more heavily monitored site between the two biological sites, the average TP concentration is fairly close to the northern eutrophication standard (Table 61). The levels as measured should not be a significant problem or cause eutrophication, particularly since nitrate concentrations are extremely low. In 2016, fairly abundant filamentous algae were present (Photo 7). During SID work in 2018 and 2019, very little filamentous algae was observed during multiple visits to various locations on the two AUIDs discussed here. At the lower two sites visited for longitudinal monitoring (5 and 6 on Figure 38), on August 14, 2019, it appeared there was a thin layer of periphyton (algae or diatoms) growing on the sand substrate of the riverbed.

Photo 7. August 16, 2016 photo of algal growth taken at the biological site 16SC011.

Nutrients - Nitrate and ammonia

Both the nitrate and ammonia concentrations were very low, and not at all problematic.

Transparency and suspended solids

Secchi-tube readings were excellent at all four biological sampling visits. The two TSS samples were also extremely good. The larger 2016 - 2017 dataset contained 32 Secchi Tube measurements, which were nearly always greater than 100cm visibility (Table 57). The one notably lower reading was a sizeable rain event sample: the Kettle River gage showed a hydrograph peak on this same day, having a flow that was approximately 7 times greater than the flow volume in the river just before the rain event.

Stressor signals from biology

Fish

At 16SC011, the fish community far exceeds the passing FIBI threshold, and is into the "Exceptional Use" range. Noteworthy species were hornyhead chub, tadpole madtom, rock bass, longnose dace, and shorthead redhorse. A number of ubiquitous species were also present, making a total of 17 species. At 16SC015, the community was not as strong, and received a much lower, though passing score. The same notable species were present, with the addition of burbot; the big difference being many fewer hornyhead chub. Again, there were 17 species, though the composition of the community was slightly different.

Though the fish communities passed at the two sites in this AUID, metrics pertaining to DO and TSS were examined to see if there still may be any signals that inform the macroinvertebrate impairment (Tables 60 and 61). The Community TIV Index metrics for both DO and TSS varied a relatively small amount between the two sites, with the upstream site (16SC011) having the better DO and TSS Index scores, which aligns with the better FIBI at the upstream site. The community scores at 16SC011 were better than average for class 6 streams for DO and TSS, while at 16SC015, the DO Index score was right at average, and TSS slightly better than average. The probability of the fish community coming from a site that meets the DO standard was about 50% for both sites, while for TSS, it was about 80% at both sites.

There was only one low-DO Intolerant species captured at each site, while there were seven and six low-DO Tolerant species collected at the upstream and downstream sites respectively. The percentage of low-DO Tolerant individuals versus Intolerant ones was quite a bit higher at both sites. The TSS metrics were skewed toward Intolerant species. Therefore, though a passing fish community was found in the AUID, there is some evidence that low DO levels are influencing the fish community, while evidence is lacking that TSS is a concern.

Table 60. Fish Community DO and TSS Tolerance Index scores at 16SC011 and 16SC015 (2018 version). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards.

Site	Stream class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16SC011	6	7.11	6.55/6.61	78	52.6	13.03	13.98/13.28	57	82.3
16SC015	5	7.04	6.99/7.11	44	49.2	13.60	13.85/12.99	37	80.0

Table 61. Fish metrics related to DO and TSS for 16SC011 and 16SC015 utilizing MPCA species tolerance assignments.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	16SC011	1	0	7	4	0.2	10.3
Low-DO	16SC015	1	0	6	4	2.1	12.4
TSS	16SC011	2	1	0	0	0.6	0
TSS	16SC015	3	2	0	0	4.3	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Macroinvertebrates

At site 16SC011, the sampled macroinvertebrate community was moderately dominated by four taxa, listed here in order of abundance; three midges - *Tanytarsus*, *Polypedilum*, and *Endochironomus,* followed by the amphipod *Hyalella azteca*. There were few EPT, just three mayfly taxa (all from Family Baeitidae), *Iswaeon*, *Acerpenna*, *Labiobaetis propinquis*, and two caddisfly taxa (both from Family Hydroptilidae), *Hydroptila*, and *Oxyethira*. A number of taxa that are ambivalent about DO were found, including snails *Gyraulus*, *Physella*, and Hydrobiidae, the fingernail clam Pisidiidae, Hemipteran *Microvelia*, and beetle *Haliplus*, the fly Dixidae, the damselfly Coenagrionidae, and a mosquito larva Culicidae. At site 16SC015, there were seven taxa that were relatively more abundant that the others, listed in order of abundance midge *Polypedilum*, amphipod *Hyalella azteca*, black fly *Simulium*, midges *Tanytarsus* and *Paratanytarsus*, snail Hydrobiidae, and midge *Rheotanytarsus*. Again, there were very few EPT taxa for a stream this size, with only five mayfly, two caddisfly, and zero stonefly taxa.

Metrics pertaining to DO and TSS are shown in Tables 62 and 63. The same day replicate sample at 16SC011 is substantially different than the other sample, and it is being largely disregarded in the following analysis. At 16SC011, the DO TIV Index score is slightly less than the class average and at a relatively low percentile. Farther downstream at 16SC015, the DO TIV Index score is well below the class average and is at a very low percentile. The community is heavily skewed toward low-DO Tolerant taxa, both in terms of the taxa present, and the percentage of individuals that are low-DO Tolerant. There were zero low-DO Intolerant taxa present at 16SC011, and one taxon at 16SC015. The skewedness toward a low-DO Tolerant community was much stronger at the upstream site (16SC011). This is consistent with lower measured DO in the upper part of this two-AUID reach, after the water comes through the low gradient wetland near Big Pine Lake.

The TSS TIV Index score is higher (meaning poorer in the case of TSS) than the class average values for the class designation appropriate to each site, and more so at 16SC011. However, the probabilities are high that these samples would come from a TSS standard-meeting site. This is because this low-gradient class as a whole has low TSS.

Table 62. Macroinvertebrate Community DO and TSS Index statistics at 16SC011 and 16SC015. For DO, a higher index score is better. "Percentile" is the rank of the index score within the appropriate stream class (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO that meets the standard, based on all stream classes combined.

Site	Stream class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16SC011	4	6.18	6.30/6.49	34	53.5	14.13	13.63/13.77	39	80.5
16SC011 replicate	4	5.16	6.30/6.49	9	32.0	10.36	13.63/13.77	95	95.2
16SC015	3	6.42	7.02/7.14	13	58.8	13.57	13.41/13.47	47	84.0

Table 63. Macroinvertebrate metrics related to DO and TSS for 16SC011 and 16SC015 utilizing MPCA species tolerance assignments.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	16SC011	0	0	12	5	0	29.9
Low-DO	16SC015	1	1	2	0	1.2	19.4
TSS	16SC011	4	1	9	5	8.68	31.5
TSS	16SC015	4	1	6	3	5.76	22.7

Overall biological data conclusions

With the wetland-oriented macroinvertebrate taxa present, the poor DO TIV Index scores, the high number of low-DO Tolerant taxa, and the more-abundant Tolerant individuals, there is reason to conclude that low DO is a stressor to the macroinvertebrate community, with the fish community showing evidence of a low-DO effect was well. Evidence for TSS being a stressor is lacking.

Temperature

The temperatures measured at two of the biological sampling visits were somewhat high (August 15 and 16). This may be a result of the water in this AUID being the immediate outflow of a lake (Big Pine). Water temperature was collected in the two longitudinal sampling efforts in 2018 that were described in the dissolved oxygen section above (Figure 36, Table 59). In two of the three longitudinal sampling efforts, the warmest temperature was found at the site closest to the lake outlet. The two sampled tributaries add cooler water to the Pine River (Rhine Creek and Little Pine River), which helps the water hold more oxygen. From the dataset that exists, there is no evidence that water temperature is elevated or atypical, nor that measured levels are stressful to aquatic life.

Habitat

The biological sampling crews conducted the MSHA protocol at 16SC011 and 16SC015 twice each in 2016. The habitat scored well into the "Good" category at 16SC015, and in the "Fair" category at 16SC011. The rank of the MSHA scores is the reverse of the FIBI scores, as 16SC015 scored much better than 16SC011 for the MSHA. In other words, the site with the lesser quality habitat had a much better fish community.

Total and component scores are presented in Table 64. An average of each of the five MSHA subcomponents was calculated, and were used to calculate a percentage of that subcomponent's possible score. The "Land Use" and "Channel Morphology" MSHA components were most responsible for the mediocre score at 16SC011. The area immediately adjacent to 16SC011 and nearby has a greater density of cleared/farmed lands than the majority of the full length of the Pine River. Site 16SC015 has a much greater undisturbed/forested riparian area, and there is much less local agriculture at 16SC015. This explains the relatively low land use scores at 16SC011. Channel morphology has not been altered with respect to straightening or moving the original river channel. Among the "Channel Morphology" component, the primary reason for the low score was due to an overall lack of channel feature diversity (defined riffles and pools), and relatively uniform depths. In addition, sinuosity scored low, but as mentioned, this is the natural sinuosity of the river.

Regarding specific habitat features for macroinvertebrates, important stable habitats were present (cobble/gravel and wood), but macrophytes were nearly absent. A significant amount of attached algae were noted, which may be due to combination of the presence of stable materials to attach to, relatively open canopy for sun exposure, and clear water that allows good sun penetration.

Table 64. MSHA scoring for the two visits each to sites 16SC011 and 16SC015 in 2016.

Site	MSHA Component	8/15/16	8/16/16	8/17/16	8/22/16	Avg. score	Maximum Poss. Score	Percent of Maximum
16SC011	Land Use	--	0	--	2.5	1.25	5	25.0
	Riparian	--	13	--	13	13	14	92.9
	Substrate	--	19	--	16	17.5	28	62.5
	Cover	--	11	--	14	12.5	18	69.4
	Channel Morphol.	--	16	--	16	16	35	45.7
	Total MSHA	--	59	--	61.5	60.25	100	60.25 = "Fair"
16SC015	Land Use	5	--	2.5	--	3.75	5	75.0
	Riparian	11	--	12	--	11.5	14	82.1
	Substrate	22.25	--	19.15	--	20.7	28	73.9
	Cover	15	--	16	--	15.5	18	86.1
	Channel Morphol.	26	--	26	--	26	35	74.3
	Total MSHA	79.25	--	75.65	--	77.45	100	77.5 = "Good"

Connectivity

In-stream barriers are a problem for fish but not macroinvertebrates, and since the fish passed the FIBI, it is not a high priority to search for migration barriers. Even so, the 2015 aerial photos were reviewed from the Kettle River all the way upstream to Big Pine Lake. One beaver dam was found, a short ways downstream from the confluence of the Little Pine River, in AUID-634. It does not create a significant widening of the channel upstream, and so it may be breached, and thus passable for fish.

All road crossings between the Kettle River, upstream beyond CSAH-39, are bridges, and bridge crossings are almost always passable for fish. There are no migration barriers between the Kettle River and AUID-634. The first culvert crossing occurs near the upstream end of AUID-634, at East Willow Road, and then there are two other culvert crossings upstream. The DNR's culvert report rated all three sets of culverts as category 3, meaning they are generally passable, but may not always be for all species. Connectivity for fish is good from the dam outlet at Big Pine Lake all the way to the Kettle River.

Hydrology

There is a small lake outlet dam on Big Pine Lake that potentially changes the flow regime in AUIDs 633 and 634, though it is unclear how much it alters flow in the river, and whether this contributes to the low-DO levels. If there is an effect, it would likely be stronger in AUID-633, since a significant amount of water enters the upstream end of AUID-634 from the Little Pine River. The Little Pine River also has better DO levels than AUID-633 has, so it likely also improves the DO in AUID-634 that way as well.

Geomorphology

The author saw no signs of channel instability at any of the crossings visited during the longitudinal chemistry sampling. As a result, no geomorphological surveying was conducted on this reach and altered hydrology was eliminated as a stressor.

Conclusions about stressors

Both biological communities show evidence that low-DO is a stressor. Direct DO measurements also show that there are periods when DO levels drop well below the standard, sometimes substantially. The fish community did pass the FIBI, but fish are mobile, and able to move downstream during periods when DO in AUIDs-633 and 634 is low. Macroinvertebrates are much more stationary, and unable to escape these low-DO periods and have to endure them, if they can. This may well explain why the fish pass the FIBI while the macroinvertebrates did not pass the MIBI.

Factors causing the sometimes low-DO conditions may be largely natural. The first section of stream channel below Big Pine Lake is very low gradient, and flows through a wide, wetland corridor. Macrophyte (aquatic plant) growth in the channel here is quite extensive and can be seen on aerial photography. The wide, wetland-fringed channel allows abundant sunlight into the stream to enhance macrophyte growth. These macrophytes are likely responsible for much of the low morning DO in the river from their overnight respiration (use of oxygen). Organic matter decomposition in this slow section of stream also likely contributes to dropping the DO levels. Nearing site 16SC011, there is significant amount of agriculture and some residences along the river. Measured nutrient concentrations in the river do not suggest that runoff from these areas is causing problematic nutrient additions to the river. The great majority of the length of AUID-633 + 634 has a good, naturally-vegetated buffer, with much of it being excellent, forested buffer. Water from the Little Pine River contributes to Exceptional communities of both fish and macroinvertebrates, so this input (right at the break point of AUID 633 and 634) probably improves some characteristics of water quality in the Pine River.

Sampling in both 2016 and 2018 found that water levels may be a significant factor in the DO concentrations in the river. DO levels along the length of the combined AUIDs were much lower when water levels were quite high, and were much improved when sampled again 2 weeks later, when water levels in the river had dropped substantially. The low DO periods appear to occur a few days following large, mid-summer rain events. Flooding of riparian wetlands and greater contribution from other wetlands in the landscape likely are responsible for this drop in DO during high flows.

Recommendations

There is no obvious recommendation as to how to improve stream conditions for macroinvertebrates in the two impaired AUID's, as no human activities seem to be responsible for the low DO that exists at times in the river. The Pine Lakes do have a nutrient impairment, and steps taken to fix that situation may cause a modest improvement in the DO levels of the stream by the reduction of phosphorus concentrations. However, a lesser TP level creates impairment for lakes than for rivers, and the Pine Lakes' TP levels are lower than those that create eutrophic conditions in rivers, so it is debatable as to the effect the lakes have of the Pine River.

Other stream investigations

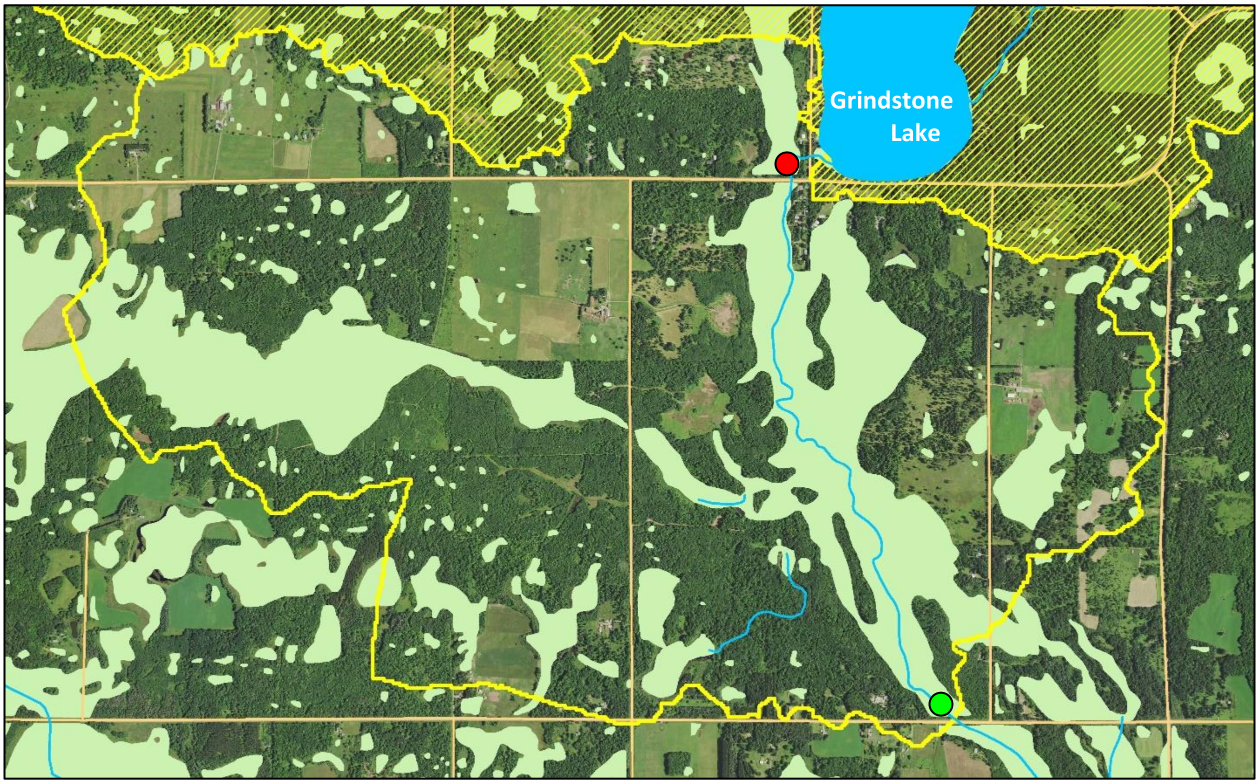
North Branch Grindstone River (AUID 07030003-543)

Impairment: The creek was initially assessed as impaired for not meeting the coldwater fish community IBI threshold at site 16SC081, located just upstream of CSAH-26 (Friesland Road), 4 mi. northwest of Hinckley. After collection of more water temperature data via the SID work, the stream was determined to be in need of a use class change from MPCA perspective, to a warmwater stream, as water temperatures did not remain low enough during summer to support coldwater fish and macroinvertebrate communities, and it was not deemed to be in this condition due to anthropogenic disturbance. MPCA re-assessed the stream with the appropriate warmwater fish and macroinvertebrate IBIs, and the stream achieved passing scores, showing non-impaired conditions for these communities.

Subwatershed characteristics

The stream begins as the outflow of Grindstone Lake, where there is a dam. In the past, streamflow has been augmented with groundwater inputs via a DNR well pump. This pump has not been run for many years by DNR. The riparian corridor of the stream is very natural except near the lake, where there are some residences along the stream. The corridor is mostly wetland (Figure 40). The HDS score was 62.59 (at the 67th percentile statewide).

Figure 40. The non-hatched, yellow-bounded area is the subwatershed contributing runoff to biological monitoring site 16SC081 that adds flow to the Grindstone Lake outflow. The yellow-hatched area also contributes to the North Branch Grindstone River, but enters the lake first. Wetland area is shown in light green. The red dot is the location of the upstream temperature logger and the green dot is the location of the downstream temperature logger (at site 16SC081).



Data and analyses

Chemistry

The chemistry data collected at IWM biological sampling visits from 16SC081 is shown in Table 65. All of the parameters are at healthy levels except that temperature is at stressful level for coldwater fish and macroinvertebrates.

Table 65. Chemistry measurements from 2016 IWM sampling at 16SC081. Values in mg/L.

Date	Time	Temp	DO	DO %Sat.	pH	Cond.	T-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
August 17	15:08	25.8	8.18	106	7.5	122	> 100	0.028	< 0.05	< 0.05	5.2	2.8
August 18	16:45	24.9	7.81	99	7.5	125	> 100	--	--	--	--	--

A robust data set was collected during 2008 and 2009 by the Pine County SWCD office (Table 66).

Table 66. Chemistry data summary at S004-892 (16SC081) in 2008-2009. Values in mg/L.

Parameter	Year(s)	# samples	Average	High	Low
DO	2008	11	9.4	12.0	7.1
TP	2008 - 2009	22	0.020	0.055	0.011
Nitrate	2008 - 2009	20	< 0.034	0.20	< 0.01
Chl-a	2009	3	2	3	< 1
TSS	2008 - 2009	20	1.8	5	1
Water Temp*	2008	10	17.9	23.0	13.9

*Late May - late Sept., samples collected primarily at 10:00 - 11:30 a.m.

Dissolved oxygen

DO levels met the coldwater standard at all visits during 2008, 2009, and the IWM sample visits. However, none of the measurements was early in the morning, so none of the data points represents the day's minimum concentration. A measurement of 7.14 mg/L on August 12, 2008 probably was below the coldwater standard early that morning. The measurement of 7.81 mg/L in late afternoon of August 18, 2016 was also probably below the coldwater standard that morning. No measurements were below the warmwater standard.

Nutrients - Phosphorus

TP levels were very low and non-problematic.

Nutrients - Nitrate and ammonia

Concentrations from both datasets were extremely low.

Chl-a

Concentrations from 2009 were extremely low.

Transparency and suspended solids

TSS concentrations are very low and easily meet the standard.

Stressor signals from biology

Fish

A total of 18 species were captured, which is excellent for a class 6 stream. This sample was moderately dominated by blacknose dace, johnny darter, and common shiner, in that order. A number of lake-associated species were collected, including bluegill, pumpkinseed sunfish, yellow perch, and largemouth bass, probably due to the relatively close upstream source of the streamflow, Grindstone Lake. Four sensitive species were collected, including hornyhead chub, rock bass, smallmouth bass, and greater redhorse. No coldwater species were collected (i.e., trout, sculpin, burbot, and longnose dace).

Metrics related to DO and TSS are shown in Tables 67 (as a coldwater stream), 68 (as a warmwater stream), and 69 (not specific as to class). The poor or mediocre probabilities for both DO and TSS for classification as coldwater (Table 67) do not agree with the actual measured values of these parameters, which both show very good water quality (above-standard DO levels and very low TSS). Using the appropriate classification, the DO TIV Index is much better than the class average, and sits at the 78th percentile, with a fairly strong probability that this community would be from a standard-passing situation, even though the community is skewed toward one with tolerance to low DO. There are more low-DO tolerant than intolerant taxa, though the percent of tolerant individuals is not high. The fish community shows a modest bias to being tolerant of lower DO levels. The TSS Index is much better than the class average, there was no TSS Tolerant species in the fish sample, and two Intolerant species were found, so TSS levels are not likely influencing the community negatively. The fish community may be affected by DO levels present in the AUID, but not to a degree that impairs the community.

Table 67. Fish Community DO and TSS Tolerance Index scores in AUID-543 at 16SC081. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 11 (2018 version). "Prob." is the probability a community with this score would come from a class 11 stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Aug. 17, 2016	7.16	7.61/7.55	27	64.7	12.0	10.84/11.25	40	29.0

Table 68. Fish Community DO and TSS Tolerance Index scores in AUID-543 at 16SC081. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 6 (2019 version). "Prob." is the probability a community with this score would come from a class 6 stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Aug. 17, 2016	7.16	6.61/6.68	78	77.5	12.0	13.92/13.27	83	90.5

Table 69. Fish metrics related to DO and TSS for 16UM081 utilizing MPCA tolerance values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	7	5	0	13.3
TSS	2	0	0	0	7.0	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Macroinvertebrates

The macroinvertebrate community did not meet the coldwater MIBI. Few coldwater taxa were found, and those were in very low abundance (*Lepidostoma*, *Potthastia*, *Helicopsyche borealis*). The community did however meet the warmwater IBI (Class 3).

Macroinvertebrate metrics related to low DO and TSS tolerance were evaluated to see if there might be a signal in the community to confirm that one or both parameters are stressors (Table 70 and 71). This analysis was run for inclusion of 16SC081 as a coldwater stream, and as a warmwater stream. For both parameters, the sampled community is more likely than not to come from a site that passes those water quality standards, and more so when the stream is in the warmwater class 3. Based on the numbers of low-DO Intolerant versus Tolerant taxa present, which is quite skewed toward taxa that require good oxygen levels, the signal from the macroinvertebrates is that DO levels in AUID-722 are adequate (Table 72), slightly more so when the site is considered warmwater. The tolerance metrics for TSS show little evidence that TSS is a stressor. There were twice as many TSS Intolerant taxa as TSS Tolerant taxa. There were more individuals that are TSS Tolerant than TSS Intolerant, though the percentage of TSS Tolerant individuals was not high. The macroinvertebrate metrics do not suggest that either DO or TSS is a likely stressor to the community.

Table 70. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-543 at 16SC081 when placed in the northern coldwater class. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 8 (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meets the appropriate standards.

DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
6.98	7.33/7.36	26	64	13.45	12.23/12.24	24	56.4

Table 71. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-543 at 16SC081 when placed in the warmwater class. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 3 (2018 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the appropriate standards.

DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
6.98	7.02/7.14	38	70	13.45	13.41/13.46	50	84.5

Table 72. Macroinvertebrate metrics related to DO and TSS for 16SC081 utilizing MPCA tolerance values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	9	6	3	0	6.3	6.0
TSS	14	6	7	2	14.2	27.8

*Includes # Very Intolerant or # Tolerant taxa as part of the count.

Temperature

A continuous temperature logger was deployed in 2016 at 16SC081, which took temperature measurements every 15 minutes throughout the summer, from which summary statistics were calculated (Table 73). Two loggers were deployed in summer of 2018, one a short distance downstream of Grindstone Lake at Grindstone Lake Road and the other at the same location as in 2016 (Figure 37 and Table 74). These statistics provide evidence that this is not a coldwater system. A small number of cool/coldwater macroinvertebrate taxa were collected, which suggests that the stream temperature is a cool-water stream.

Table 73. Water Temperature statistics for deployed data logger at 16SC081 in 2016, in degrees Celsius.

Summer Ave.	June Avg.	July Avg.	July Max. Avg.	Aug. Avg.
22.26	21.03	22.49	24.74	22.46

Table 74. Water Temperature statistics for deployed logger data at two sites in 2018, in degrees Celsius. The percentages in the last three columns are the percentages of time in the June - August period that temperatures are lethal, stressful, or allow growth for brook trout.

Site	Summer Avg.	June Avg.	July Avg.	Aug. Avg.	Lethal %	Stress %	Growth %
Grindstone Lake Road	22.8	20.7	24.3	23.4	19.7	68.1	12.1
16SC081	21.8	20.1	23.4	21.8	11.0	63.8	25.2

Habitat

The MSHA protocol was conducted and scored of 63.5 (8/18/16) and 81.1 (8/17/16), near and well into the “Good” range. Because the water temperature is the factor that has been determined to be the reason that coldwater communities do not exist in this AUID, and that the fish community passes the warmwater IBI, further assessment of the habitat is not needed for this report.

Connectivity

The fish IBI passes, so there is not a migration barrier problem. There is a barrier just downstream of the bio site, a cement mini-dam that is in place to prevent carp migration into Grindstone Lake to protect the lake’s trout fishery.

Geomorphology

Photographs taken by the fish samplers in 2016 show a very healthy channel condition with well vegetated and very healthy banks and easy access for high water to spill out onto the floodplain. No evidence of altered hydrology is found on this reach. The lake above this stream reach likely provides some buffering during high flows by temporarily storing runoff from the landscape.

Conclusions

The DNR manages Grindstone Lake as a trout lake, and has also protected, but not managed, this stream for trout, as trout have been found in the stream near the lake when water temperatures drop in the fall. Detailed water temperature sampling has shown that temperatures are too warm to support coldwater fish or most coldwater macroinvertebrate species during the summer. A use class change (for MPCA purposes) from coldwater to warmwater was made so that the stream was assessed with the appropriate IBIs. The new warmwater stream class assignments (fish - class 6, macroinvertebrates - class 3) for AUID-543 resulted in passing scores for both biological communities, and the stream is not biologically impaired. Physical habitat is not a limiting factor in AUID-722, and water chemistry parameters were all at healthy levels, though there is some indication that DO levels may be preventing even better biological communities in AUID-543. This condition is likely natural however, as some riparian wetlands along the channel, and a tributary with multiple beaver impoundments probably both contribute some low-DO water to the stream.

Recommendations

North Branch Grindstone River is a healthy ecosystem. The landscape surrounding AUID-543 is relatively natural, particularly the riparian corridor. As such, there is really no particular action that would improve the biological communities in the stream. Protecting the forested riparian corridor of the river will help keep it in a healthy state.

Larson's Creek (AUID 07030003-548)

Reason for study: The creek was initially assessed as impaired for not meeting the fish community FIBI threshold at site 16SC068, located on the upstream side of CR-154, three miles east of Kerrick. The macroinvertebrate community passed the coldwater MIBI threshold. Continued investigation of the creek following the assessment led to a reconsideration of the situation and a decision to not consider the fish community impaired due to decades of beaver influence, extending to the present, in this reach. The full rationale for this changed assessment is documented in the comments section of the MPCA's assessment database CARL. Stream conditions are documented and discussed here to provide information on the current water chemistry and habitat to characterize the reasons that a strong coldwater fish community is not found.

Subwatershed characteristics

The creek flows through a very natural landscape of forest and peatland. There has been significant logging over time in the subwatershed, as various patches of tree types and age-classes can be seen on aerial photography. Permanently altered acreage (hay fields) is a very small percentage of the subwatershed area. Road density is very low, with only one road (gravel) in close proximity to the channel of the AUID, and a few gravel roads near the periphery of the subwatershed. The HDS score for this subwatershed is 79.7, which is nearly the best score possible.

Data and analyses

Chemistry

AUID-548 has had little chemistry monitoring, the only recorded samples being the IWM biological sampling visits in 2016 (Table 75).

Table 75. Chemistry measurements from IWM and SID sampling at 16SC068.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	T-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
June 22, 2016	17:55	18.3	6.93	78	6.7	76.5	> 100	0.039	< 0.05*	< 0.05*	2.4	2.4
Aug. 4, 2016	8:55	18.5	6.30	71	6.8	88.0	77	--	--	--	--	--
Aug. 31, 2016	8:10	16.0	7.39	77	6.8	71.2	> 100	0.041	0.07	< 0.05*	4.0	2.8
Aug. 23, 2018	16:10	12.8	6.43	61	--	143	--	--	--	--	--	--

* These values are below the lab detection limit.

Dissolved Oxygen

The DO measured at two of the three biological sampling visits, as well as the SID visit were slightly below the coldwater standard.

Phosphorus

TP is fairly low for a small wetland-influenced stream, and with the measured nitrate levels, should not be problematic in regard to stimulating algal growth.

Nitrogen
Nitrate was very low relative to its nutrient activity, and extremely low relative to levels that are toxic. Ammonia was well below toxic levels.

Transparency and suspended solids
On two of the three dates sampled, the water was very clear (Table 75). The TSS concentrations on these two dates was very low, with most or all of it being organic particles. The August 4 observation was somewhat turbid. The water levels were much higher on this visit and flow was more turbulent based on review of biological sampling photos. No TSS was collected on August 4. A visit on August 23, 2018 found the water to be a fairly opaque orange color due to colloidal iron particles (Photo 8). This same situation has been found by the author in numerous streams fed by groundwater that interacts with organic riparian soils, and observed at this particular time of the summer. This opaque orange color was also observed at the adjacent headwater areas of the Willow and Little Willow Rivers in August 2018.

Photo 8. Larsen Creek, August 23, 2018. Water was a semi-opaque orange color with chunks of floating iron floc. An organic oil sheen can be seen on the water surface in the right half of the photo.

Conductivity
Conductivity is very low, as naturally occurs in this part of the state.

Temperature

A continuous temperature logger was deployed in 2016, which took temperature measurements every 15 minutes throughout the summer, from which summary statistics were calculated (Table 76). These statistics suggest that temperature is borderline for being considered a coldwater system. However, the July temperatures were likely higher than normal, due to the extreme rainfall event in mid-July 2016, and so this data should be used with that caveat.

Table 76. Summary statistics for continuous temperature measurements at 16SC068 in 2016.

Summer Ave.	June Avg.	July Avg.	July Max. Avg.	Aug. Avg.	Aug. Max. Avg.
17.63	15.92	19.88	21.92	17.03	18.87

Stressor signals from biology

Fish

The fish community was sampled on two dates in 2016. June 22 and August 31. The June sample contained eight species, but none were those most oriented to cold water (trout, sculpin, longnose dace, and burbot). The sample was dominated by pearl dace, which is a sensitive species, a good sign for water quality. Three other dace species were present, most notably finescale dace, another sensitive species, and blacknose and northern redbelly. Most of the other species present are ubiquitous - brook stickleback, creek chub, common shiner, central mudminnow, and white sucker. The August sample contained relatively few fish, 41 in total. No pearl dace, finescale dace, or northern redbelly dace were caught. The only sensitive species was blacknose shiner, with three individuals.

The two Community TIV Index scores for DO were at or below the 20^{th} percentile of all scores within the Northern Coldwater stream class (Table 77). The two TSS TIV Index scores had slightly better percentile scores, but still quite low. The community was quite skewed toward low-DO Tolerant individuals, while showing only slight weighting toward TSS Intolerant species and individuals, with no TSS Tolerant taxa present in either sample (Table 78). It appears that low-DO is one reason for the mediocre fish community.

Table 77. Fish Community DO and TSS Tolerance Index scores in AUID-548 at 16SC068. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within fish class 11 (2018 version). "Prob." is the probability a community with this score would come from a class 11 stream reach with DO or TSS that meet the standards.

Sample date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
June 22, 2016	6.51	7.62/7.60	11	43.1	12.3	10.75/11.17	32	26.2
Aug. 31, 2016	6.99	7.62/7.60	20	59.4	12.9	10.75/11.17	20	22.1

Table 78. Metrics involving DO and TSS tolerance for the sampled fish community.

Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
6/22/16	0	0	3	3	0	42.9
8/31/16	0	0	3	5	0	58.6
6/22/16	0	0	0	0	0	0
8/31/16	2	0	0	0	16.7	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Connectivity

When the fish community IBI fails, while the macroinvertebrate community IBI passes, one factor to investigate is whether there might be a migration barrier preventing fish from gaining access to the sampled location. There is a big beaver impoundment a short distance upstream of site 16SC068, but a review of 2017 aerial photos did not find any beaver dams downstream of the sample site that are active and impounding water. It is the downstream direction (toward larger waterbodies with overwintering habitat) in which barriers are problematic. However, the upstream dam may be preventing some species from getting to an important spawning habitat. The lone road crossing, immediately downstream of 16SC068, was observed and assessed as excellent for fish passage, and thus connectivity is not the fish limiting stressor. Thus, there are no barriers preventing fish from migrating up from Willow River and connectivity is not thought to be a stressor to the fish community.

Habitat

The habitat as a coldwater stream has been significantly altered by beaver in the last few decades. Streams in this area without beaver removal typically lose their trout populations, due to water temperature increase, dams as barriers to fish migration, potential isolation from spawning locations, and the siltation of the streambed that occurs in waters slowed by the beaver dams. Decades ago, when trout were present, DNR had special funding for beaver management that does not exist now, and beavers are no longer managed.

Hydrology

Based on the high percentage of forest and wetland cover in this subwatershed, alterations to hydrology should be relatively minor, and primarily due to forest harvest.

Geomorphology

No geomorphology work was conducted as there was no likely cause of alteration of natural flow patterns in the AUID, based on a review of land cover.

Conclusions about stressors

The subwatershed of AUID-548 is a very natural landscape, with little human landscape disturbance. Only a few residences are located in the subwatershed, and no agriculture occurs here. Thus, the likelihood of significant anthropogenic stress here is low. After the stressor identification process, it was determined that the fish data should not be used to assess this stream for use support, due to the prevalence of beaver impoundments and the well-known negative effect that beavers have on trout streams (Johnson-Bice et al, 2018). Active trout management by DNR was stopped in 1975 due to persistent beaver activity. Sub-standard DO was found during 2016 IWM, though the levels were not far below the coldwater standard. The beaver alterations may be responsible for lower DO levels than would be found if the stream were free-flowing. A visit by the author in late summer 2018 found the biological site almost stagnant and the water column was a turbid orange from colloidal iron particulates. Such a situation in not conducive to a thriving trout stream.

Recommendations

Active stream management involving continual beaver removal would be required to create a coldwater fishery again in the creek. Other habitat features (such as gradient) may be less than sufficient to create a blue-ribbon trout stream. Changes in management would in this case be under the jurisdiction of DNR.

Heikkila Creek (AUID 07030003-616)

Impairment: The creek was originally assessed as impaired for not meeting both the fish and macroinvertebrate community IBI thresholds at site 16SC036 located upstream of CR-129, six miles north of Kettle River. Upon further consideration of the unusually large precipitation event that occurred prior to sampling, the biological assessments were changed to "insufficient information". Thus, there is not currently an aquatic life impairment listing for AUID-616.

Stream and subwatershed characteristics

Hiekkila Creek (AUID-616) is a direct tributary to the Kettle River, in the headwaters area, and is a Fish Class 7 (Low Gradient) and Macroinvertebrate Class 4 (Northern Forest - Glide/Pool) stream. The great majority of the riparian corridor is covered by natural vegetation, either woody wetland or wet meadow (peatland). A significant amount of the overall subwatershed's acreage is interconnected wetland. Smaller amounts of low-intensity agriculture (hay and pasture) are found scattered throughout the subwatershed. Development and landscape alteration is quite light, as no cities or towns exist in the subwatershed. A small number of tributary trenches were long ago dug through the peatlands in attempt to create land for agriculture, though these are less abundant than those found just north, in the Mississippi River - Grand Rapids Watershed. These small ditches do not appear to have been maintained regularly over the decades since they were dug. The HDS score was 56.80 (at the 57th percentile statewide).

Data and analyses

Chemistry

This site only had chemistry monitoring done at one biological sampling visit, with instrument measurements at two visits (Table 79). The results are a mix of poor and good.

Table 79. Chemistry measurements collected at the biological sampling visits at 16SC036, values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	T-tube (cm)
Aug. 2, 2016	9:39	20.2	0.85	10	6.7	185	--	--	--	--	--	30
Aug. 24, 2016	2:19	21	1.15	14	6.6	170	0.166	0.05	0.11	7.6	4.4	28

Nutrients - Phosphorus
The single TP concentration was very high. The large acreage of wetland in this subwatershed is likely responsible for a significant portion of the phosphorus.

Nutrients - Nitrate and Ammonia
The single samples of nitrate and ammonia concentrations were very low, with the nitrate being below the lab's detection limit, and ammonia nearly so.

Dissolved oxygen
The two instantaneous DO measurements were extremely low (poor), even though not collected at the time of the daily minimum. The sample taken in mid-afternoon certainly did not show the high mid-day DO readings that can signal eutrophication. DO %-saturation measurements did not signal eutrophication, as these levels were also extremely low.

Total suspended solids

The TSS sample was well below the north region standard, and 58% of the material was organic. The Secchi-tube readings were very consistent, and quite poor. The field notes by the biology crew noted extensive iron floc. Some streams in north central Minnesota can become turbid, with an orange color, in the latter parts of summer due to colloidal iron particles originating as dissolved iron in the groundwater inputs to the stream.

Stressor signals from biology

Fish

Eight species were collected at 16SC036. Central mudminnow was strongly dominant, with brook stickleback subdominant. All other species were in low abundance. Most species collected are extremely ubiquitous ones, with the exception being brassy minnow and pearl dace, the latter of which was the lone sensitive species, and with an abundance of one.

Metrics related to DO and TSS are shown in Tables 80 and 81. The DO TIV Index score is substantially below the class average. This fish community has an extremely low probability of coming from a class 7 site passing the DO standard. The opposite is true for TSS, as the TSS TIV Index was much better than the class average (and slightly better than the class median), and there is a very high probability of this community coming from a class 7 site that has passing TSS levels. This same pattern shows up in the DO and TSS-specific tolerance metrics shown in Table 81, where the community is shown to be comprised mostly of low-DO Tolerant individuals, and has no TSS Tolerant ones.

Table 80. Fish Community DO and TSS Tolerance Index scores in AUID-616 at 16SC036. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within stream class 7 (2018 version). "Prob." is the probability a community with this score would come from a class 7 stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/24/2016	5.62	6.22/6.21	17	7.0	13.14	15.10/13.92	55	88.3

Table 81. Fish metrics related to DO and TSS for 16SC036 on August 25, 2016 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	5	2	0	90.3
TSS	0	0	0	0	0	0

*Includes # of Very Intolerant or Very Tolerant taxa as part of the count.

Macroinvertebrates

The macroinvertebrate community was extremely dominated by the midge *Chironomus*, which are notorious for living in low oxygen conditions. There are a number of wetland-oriented taxa in the sample, such as the beetles *Liodessus*, *Hydrobaenus*, *Hygrotus*, and *Tropisternus*. There are zero EPT taxa, most of which require good levels of DO. Even the few mayfly and caddisfly taxa that can be found in aquatic environments of somewhat lower oxygen were not found here.

Macroinvertebrate metrics related to DO and TSS were evaluated as per the fish community (Tables 82 and 83). The DO TIV Index scored extremely poorly, with a very low probability that this community would be found in a site with standard-meeting DO levels. The TSS TIV Index scored quite well, with a high probability that this community could be found in a site with standard-meeting TSS levels. The set of tolerance metrics in Table 83 supports these conclusions, as the community is highly skewed toward low-DO Tolerant taxa and individuals. Though the ratio of TSS Tolerant to Intolerant taxa suggests TSS may be a problem, the percentage of the TSS Tolerant individuals is very low. Taken together, the analysis done with community metrics provides strong evidence for concluding that low DO levels are stressing the macroinvertebrate community, while there is not significant evidence that elevated TSS is a stressor.

Table 82. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-616 at 16SC036. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score stream class 4 (2018 version). "Prob." is the probability a community with this score would come from a class 4 stream reach with DO or TSS that meet the standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/2/2016	3.85	6.30/6.49	2	12.9	13.22	13.63/13.77	62	85.8

Table 83. Macroinvertebrate metrics related to DO and TSS for 16SC036 utilizing MPCA species tolerance assignments.

Tolerance Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	0	0	6	4	0	92
TSS	0	0	6	2	0	4

*Includes # Very Intolerant or Very Tolerant Taxa as part of the count.

Temperature

The two water temperature measurements show relatively cool water, nowhere near temperatures problematic for fish.

Habitat

The MSHA protocol was conducted at two visits to 16SC036, providing scores of 42.9 and 57.2, which when averaged equals 50.5. The first score is within the range of "Poor", while the second score is about at the middle of the range of scores for "Fair". Differences in scores may be due to different observers and differences in flow conditions at the different dates of observation. The average score is at the lower end of the ranges of scores for "Fair". Scores for each of the five subcomponents of the MSHA were averaged, and the percentage of the score relative to the subcategory maximum was calculated (Table 84). The poorest-scoring subcategory by far (by percentage of each category's possible score) was "Channel Morphology". Development of riffle/run/pool features was poor and there was little variability in both depth and flow velocity - in other words, habitat diversity was poor with limited microhabitats present. Embeddedness of larger stones and cobble was fairly significant here (50 - 75%).

Table 84. Averaged sub-component scores for MSHA at 16SC036.

MSHA Component	Avg. Score	Maximum Poss. Score	Percent of Maximum
Land Use	4.5	5	90.0
Riparian	10	14	71.4
Substrate	18.1	28	64.5
Cover	10.5	18	58.3
Channel	7	35	20.0
Total MSHA Score	50.5	100	50.5 = "Fair"

Connectivity

There is one road crossing downstream of 16SC036 to the mouth of AUID-616 at the Kettle River. This culvert is classified in the DNR survey as Level 3, a "partial or seasonal" barrier. There is a road crossing upstream of 16SC036 that also has a Level 3 culvert. A large beaver dam can be seen in the 2017 aerial photography a relatively short distance upstream from the biological site, though this would not prevent fish from migrating into the lower parts of the AUID, where the fish sample was collected, from overwintering habitat in the Kettle River.

Hydrology

This subwatershed has been somewhat altered hydrologically by the straightening of the main channel, and cutting trenches into adjacent peatland areas for drainage. Since the drainage area of this subwatershed is fairly small, these alterations are not as significant as larger subwatersheds with greater amounts of ditching. The beaver dams that exist above this site also create some storage that moderates flow volumes and lessens the effects of the legacy ditching.

Geomorphology

This AUID is a combination of natural and straightened channel. The location of the biological samples was straightened decades ago. Though it has somewhat naturalized, it is in an unhealthy geomorphological state, lacking much sinuosity and flowing right up against the road grade (CR-129). Sinuosity creates the habitat features that were shown to be missing in the above paragraph on habitat.

Conclusions about stressors

This site received an assessment of "insufficient information" due to the potential confounding situation of the extremely high rainfall event that occurred in mid-July of 2016. Low DO levels are clearly a strong stressor of the fish and macroinvertebrate communities in AUID-616 at the time of sampling. Low DO levels are often seen following high precipitation events, due to flushing of poorly oxygenated wetland waters. Though the TP reading was very high, there are no signals suggesting that the low DO levels are related to eutrophication, based on a lack of any notable algae presence, extremely low nitrate levels, and extremely low DO %-saturation levels. Beaver impoundments upstream of 16SC036 can be seen in 2017 aerial photographs, and these impoundments are likely exacerbating the low DO by creating stagnant water where organic material collects and decays. Measurements of DO from two visits in early/mid-August, 2018 again found very low levels of DO, much below the standard, suggesting that low DO might be a regular condition of the creek.

The low clarity of the water was likely due to colloidal iron particles, a phenomenon that is not uncommon in north central Minnesota streams receiving groundwater input that has significant dissolved iron content. It is especially evident in streams that have extensive riparian peatlands which turn anoxic in mid-summer. Both phosphorus and iron become soluble under anaerobic conditions. This scenario likely explains the low DO, high TP, and turbidity in the August stream samples. Connectivity issues involving the culverts may be contributing to the failing fish IBI, though with the apparent prevailing DO regime, correcting the culverts are not likely going to be a wise use of limited project funding. Ditching of parts of the channel has also likely reduced habitat quality by the reduction of sinuosity and the subsequent losses of related habitat features such as variety in depth and velocity.

Recommendations

With the likely cause of low DO being the peatlands, with exacerbating consequences of the ditches through the peatlands, it is likely that low DO will be difficult to correct. If this creek is deemed to be of significant local interest, it would be advised to collect more DO data, which can be submitted to MPCA with a request to give the stream a new assessment.

Little Willow River (AUID 07030003-573)

Reason: The author has found numerous locations across northern Minnesota where small streams are orange in color, and sampling has shown the reason to be very high iron content, with the source of the iron being from groundwater inputs to the stream. This same phenomenon was observed while doing fieldwork in the KRW in a few locations (Photo 9). It generally occurs where streams flow through peatlands, as is the case here. This is a natural condition that develops in summer, and might concern citizens thinking that there is something very wrong with the stream’s water quality.

Photo 9. Little Willow River at State Highway 23 on August 16, 2018, showing the very turbid orange color of the water. The arrow points to a groundwater seep with iron floc.

Chemistry

Field parameters and a water grab sample for iron were collected on August 13, 2018 (Table 85). As expected, the iron concentration was extremely high. It is typical for these high iron streams to have dissolved oxygen concentrations lower than the state standard, as was the case here.

Table 85. Water quality sampling on the Little Willow River at State Highway 23.

EQuIS #	Date	Time	DO	DO%	Water Temp.	Cond.	Sp. Cond.	Iron (µg/L)
S015-196	8/16/2018	13:05	4.85	53.5	19.89	126	139	9850

Conclusions about stressors

This was not the site of a biological sample. However, high iron is believed to be a stressor to biological communities, particularly macroinvertebrates. As the groundwater in the stream is exposed to more oxygen, iron compounds precipitate on stream surfaces, which can include the bodies and sensitive anatomy (such as gills) of macroinvertebrates. It would not be surprising if fish and macroinvertebrate communities do not meet the IBI standards at this location due to the extremely high iron content of the stream. As the iron naturally occurs in the groundwater feeding part of the stream flow, this turbidity of the water in natural and there are no management implications.

Local issues for protection work

Streams that have passing scores are not necessarily at their full potential biologically. Most streams that surpass their biological impairment thresholds are less healthy than they were in their native condition in pre-settlement times. Thus, there is often room for improvement even on streams that are deemed to be unimpaired using current MPCA standards. Near the end of the allotted SID work period for the KRW, MPCA completed its prioritization tool for helping direct protection work. It came about too late in the process for SID staff to investigate these streams, but the list of these streams will be found in the Kettle River WRAPS document, along with a prioritization ranking. Protection can also involve working to preserve the status of streams with exceptional biological communities. Other opportunities found during SID work for protection work are presented below.

Kettle River mainstem channel

In areas where streams and rivers become larger, their shoreline areas become attractive for residential or recreational development, much like occurs on lakes. Property owners generally like to be able to see the river from their homes and thus alter the natural riparian vegetation significantly. This can make the riverbank much less resilient to erosion, as deeper root structure from woody plants is lost and often replaced with lawn grasses with very shallow root systems that do not protect and hold the bank soils well. Not all bank erosion situations can be blamed on this situation, but it is extremely common (Figure 41, 42, and 43). Keeping the riparian and bank vegetation in their natural, wooded state will prevent bank erosion (and loss of property) and the sediment input to the stream channel that harms aquatic habitat.

Figure 41. This location on the Kettle River shows erosion of a bank where woody vegetation has been removed for a pasture. The landowner here is losing property due to erosion of the unprotected bank.

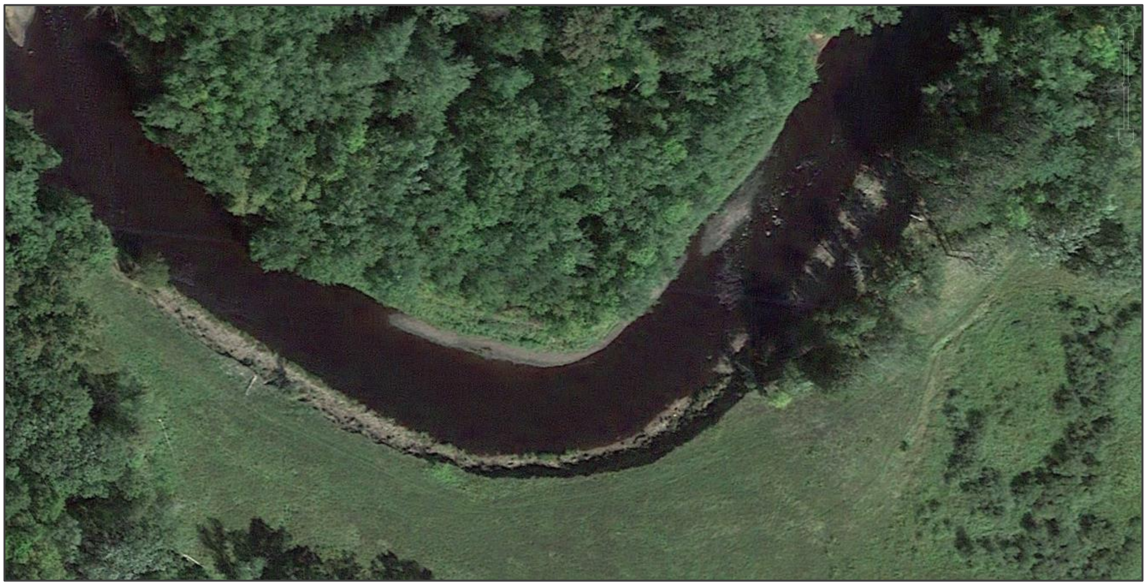


Figure 42. Local area of bank erosion where woody bank vegetation has been removed and replaced with grasses.

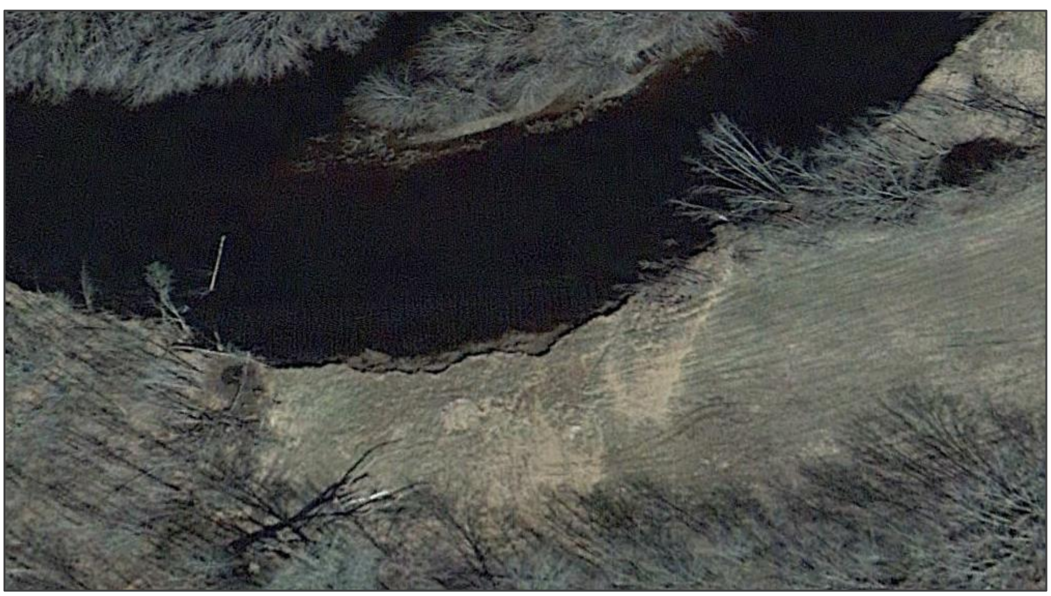


Figure 43. Bank erosion all along the outside bend where trees have been cleared and replaced with grasses, which have far less capability of providing erosion resistance to the riverbank.

Exceptional streams

Minnesota has tiered biological standards, including one that recognizes streams having exceptional biological communities and which protects these streams with a higher standard. To achieve this status, both the fish and macroinvertebrate communities must meet the health thresholds determined for their appropriate stream classes. Streams that only have one of the two communities meeting the exceptional threshold are kept in the General Use class, but they are still noteworthy and special given that one of the communities is extremely healthy.

The KRW has many ecologically-stellar streams and rivers, more so than a majority of Minnesota's major watersheds. The KRW had seven AUID reaches that achieved the Exceptional Aquatic Life Use designation (Figure 44). These were:

- Kettle River (AUID-503)
- Kettle River (AUID-505)
- Little Pine Creek (AUID-560)
- Willow River (AUID-622)
- Pine River (AUID-624)
- West Branch Moose Horn River (AUID-628)
- Moose Horn River (AUID-629)

All of these stream reaches, and their adjacent upstream and downstream channel connections could be considered worth special attention to protect their ecological health. If they were to drop in their IBI scores under the Exceptional Use threshold, they will be assessed as impaired. Of these streams, using MPCA's protection criteria, Little Pine Creek cannot drop much in biological quality before it would not meet the criteria to be an Exceptional Use stream.

Though the macroinvertebrates did not quite make the Exceptional Use designation (fish did), the Little Willow River quite likely would have met that criterion if it were not for the extreme rainfall event and torrential stream flows that occurred in this area in July 2016, only about a month prior to the macroinvertebrate sampling. The channel scouring and substrate rearrangement likely swept many organisms away, and it is quite likely that the macroinvertebrate IBI score would have been better had that event not recently occurred (this was seen at several resampled sites in the KRW). The habitat score was excellent, even with the channel damage that happened in streams of the area.

Many streams had one of the two communities scoring in the Exceptional range, and/or one of several sites within the AUID that scored in the Exceptional range (Table 86). These are also worthy of special protection to keep them in fine condition.

Figure 44. KRW assessed AUIDs that met Exceptional Use designation. The three digit numbers are AUID numbers. Colored patches are state lands.

Table 86. Streams that had at least one biological community with its IBI score in the Exceptional Use range (X), though the stream did not meet full criteria for placement into the Aquatic Life Exceptional Use category. Note: Some AUIDs have multiple sample sites, and those that do not have unanimous exceptional scores may not result in an AUID assessment of "Exceptional Use", even if the set of sites on an AUID includes both a fish and macroinvertebrate exceptional score.

Stream Name	AUID #	Fish	Macroinvertebrate
Grindstone River	501	X	
Kettle River	502	X	
Willow River	504	X	X
Gillespie Brook	509	X	
Kettle River	510	X	
Kettle River	512		X
Split Rock River	513	X	
Pine River	515	X	X
Branch Creek	516		X
Moose Horn River	521	X	
West Fork Moose Horn River	536	X	
Dead Moose River	537	X	
North Branch Grindstone River	544	X	
Moose Horn River	545	X	X
King Creek	547		X
Kettle River	552	X	
Little Pine Creek	560	X	
Little Willow River	575	X	
Trib. to Split Rock River	598	X	
Trib. to Birch Creek	604	X	
Rhine Creek	609		X

Conclusions for KRW streams and rivers

The impairments found in the KRW are listed with associated stressors in Table 87. The impairments are mostly on small streams or the headwater areas of larger streams/rivers. This suggests that there are not widespread, systematic stressors throughout the watershed, but rather ones that are more local in both cause and effect. One stressor involves the historical ditching of peatlands, which are a common landscape feature of the KRW. This ditching has caused and is causing multiple follow-on stressors, including low dissolved oxygen, water highly-stained with dissolved organic compounds, physical damage to the channel via increased erosion, and degradation of habitat by sedimentation and instability of channel features. In a few cases, cattle pastured in riparian areas have caused channel instability and habitat degradation.

As mentioned in the sections above, one possible result of peatland hydrologic alterations is an increase in peak flows in downstream channel reaches. This result was found in a number of studies in fairly analogous situations in European ditched peatlands (Holden et al., 2004). In some cases however, ditched peatlands seemed to reduce the peak flows due to greater storage for rain due to a lowered water table. There are numerous variables that can influence how downstream hydrology is affected, and these are still being studied (Holden et al., 2004). Therefore, downstream effects of the peatland ditching in this AUID could be determined by scientifically studying those downstream areas by use of flow monitoring stations in combination with monitoring up in the peatlands. Such a study would improve knowledge of how hydrology is quantitatively altered in ditched Minnesota peatlands, and how that alteration has affected water quality in and downstream of these peatlands. Such understanding would benefit the management of many peatland-containing subwatersheds across the northern parts of Minnesota, as similar peatland ditching is common across that area.

The remedy would seem to be a restoration of peatland hydrology where ditching has occurred. Restorations of peatlands are a complex task, and a standard template of peatland restoration does not exist (Price et al. 2003). Efforts to restore natural hydrology to stream channels by restoring upstream peatland hydrology should be done in consultation with experienced hydrologists, and it should be realized that attempts at the current time are guaranteed to succeed since peatland hydrology and impacts of ditching are still being researched.

Repairing local stressors, such as fencing cattle from stream access and replacing culverts using designs to allow fish passage (MNDOT, 2013) will allow biological communities to improve in places affected by those situations. Restoring a more natural flow regime in the more-heavily-ditched portions of the KRW, where hydrological alteration has harmed the physical channel, will improve habitat for biological organisms. As mentioned in the body of the report above, restoring drained-bog hydrology is complex, and requires professionals with strong knowledge of soils, hydrology and hydrogeology.

Table 87. Summary of stressors causing biological impairments in KRW streams by location (AUID).

Stream	AUID Last 3 digits	Biological Impairment	Stressor: Dissolved Oxygen	Phosphorus	TSS	Connectivity	Altered Hydrology	Channel alteration	Habitat	Toxic chemicals
Kettle River	511	Fish	•					•	•	
So. Br. Grindstone R.	516	Fish	•			•				
Cane Creek	525	MI					◊			
Spring Creek	550	Fish				•				
Friesland Ditch	617	Fish					♦	•	?	
Skunk Creek	618	Fish				•				?
Hay Creek	619	Fish					♦	•	•	
Pine River	633	MI	•							
Pine River	634	MI	•							

♦ A "root cause" stressor, which leads to consequences that become the direct stressors.

◊ Possible contributing root cause.

• Determined to be a direct stressor.

o A stressor, but anthropogenic contribution, if any, not quantified. Includes beaver dams as a natural stressor.

x A secondary stressor.

? Inconclusive

Monitoring and assessment of lakes

Overview of the Kettle River Watershed Lakes

The approach used to identify biological impairments includes the assessment of fish communities of lakes throughout a major watershed. The Fish-based lake Index of Biological Integrity (FIBI) utilizes fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From this data, a FIBI score can be calculated for each lake, which provides a measure of overall fish community health based on species diversity and composition. The DNR has developed four FIBI tools to assess different types of lakes throughout the state (Table 88). More information on the FIBI tools and assessments based on the FIBI can be found at the DNR lake index of biological integrity website. Assessing a lake as impaired for Aquatic Life Use is not based solely on a FIBI score that falls below the impairment threshold (Table 89). A weight of evidence approach is used during the assessment process that factors in considerations such as sampling effort, sampling efficiency, tool applicability, location in the watershed, and any other unique circumstances to validate the FIBI score.

Table 88. Summary of lake characteristics and metrics for current FIBI tools.

Lake Characteristics	Tool 2	Tool 4	Tool 5	Tool 7
Generally Deep (many areas greater than 15' deep)	X	X		
Generally Shallow (most areas less than 15' deep)			X	X
Generally with Complex Shape (with bays, points, islands)	X		X	
Generally with Simpler Shape (generally round)		X		
Species Richness Metrics	**Tool 2**	**Tool 4**	**Tool 5**	**Tool 7**
Number of native species captured in all gear	X			
Number of intolerant species captured in all gear	X	X	X	
Number of tolerant species captured in all gear	X	X	X	X
Number of insectivore species captured in all gear	X			X
Number of omnivore species captured in all gear	X	X	X	
Number of cyprinid species captured in all gear	X			
Number of small benthic dwelling species captured in all gear	X	X		X
Number of vegetative dwelling species captured in all gear	X	X		X
Community Composition Metrics	**Tool 2**	**Tool 4**	**Tool 5**	**Tool 7**
Relative abundance of intolerant species in nearshore sampling	X		X	
Relative abundance of small benthic dwelling species in nearshore sampling	X	X		
Relative abundance of vegetative dwelling species in nearshore sampling				X
Proportion of biomass in trap nets from insectivore species	X	X	X	X
Proportion of biomass in trap nets from omnivore species	X	X	X	
Proportion of biomass in trap nets from tolerant species	X	X	X	X
Proportion of biomass in gill nets from top carnivore species	X	X	X	X
Presence/Absence of Intolerant species captured in gill nets	X	X		
Total number of metrics used to calculate FIBI	**15**	**11**	**8**	**8**
Number of Lakes Assessed in the Kettle River Watershed	**3**	**5**	**5**	**0**

A common misconception regarding assessment decisions based on the FIBI is that if a lake supports a quality gamefish population (e.g. high abundance or desirable size structure of a popular gamefish species), that lake should be considered a healthy lake. This is not necessarily true because both game and nongame fish species must be considered when holistically evaluating fish community health. Often times, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. Likewise, high abundance or quality size structure of gamefish populations will not disproportionately affect the FIBI score because multiple metrics are used to evaluate different components of the fish community and each contributes equal weight to the total FIBI score.

The FIBI was used to assess thirteen lakes in the Kettle River Watershed (Figure 45; Table 90). Eight lakes had FIBI scores at or above the impairment threshold. Four lakes were deemed to have insufficient information to make an assessment (Table 90) and two of these lakes; Pine Lake (DOW 01-0001-00) and

Big Pine Lake (DOW 58-0138-00) are considered vulnerable to future impairment. Lakes that have insufficient information to make an assessment decision have circumstances such as low sampling effort, older survey data, or lake characteristics which do not facilitate use of one of the four FIBI tools. Oak Lake (DOW 58-0048-00) was listed as impaired for Aquatic Life Use. Oak Lake had two recent FIBI scores from the 2015 and 2017 surveys that were below the impairment threshold. The historical survey done in 2010 had a FIBI score slightly above the impairment threshold, which was attributed to the presence of fewer omnivore or tolerant species being sampled than in the surveys. The information from the recent surveys suggests Oak Lake is not supporting for assessment of Aquatic Life Use and is showing signs of impairment (Table 90). Three lakes were not assessed due to no FIBI tool developed for the lake class or the lake being less than 100 acres in size: Bear Lake (DOW 09-0034-00), Echo Lake (DOW 09-0044-00), and Five Lake (DOW 33-0003-00). This report will examine potential stressors to the fish community in Oak Lake (DOW 58-0048--00), Pine Lake (DOW 01-0001-00), and Big Pine Lake (DOW 58-0138-00) to better understand the lake impairments or lakes vulnerability to impairment.

Table 89. Lake FIBI Tools with respective FIBI thresholds and upper/lower confidence limits (CL) found in the Kettle River Watershed.

Lake FIBI Tool	FIBI Threshold	Upper CL	Lower CL
Tool 2	45	54	36
Tool 4	38	46	30
Tool 5	24	39	9

Figure 45. Kettle River Watershed and land cover classes with the lakes sampled with the FIBI protocols labeled and colored fuchsia (U.S. Geological Survey, 2011).

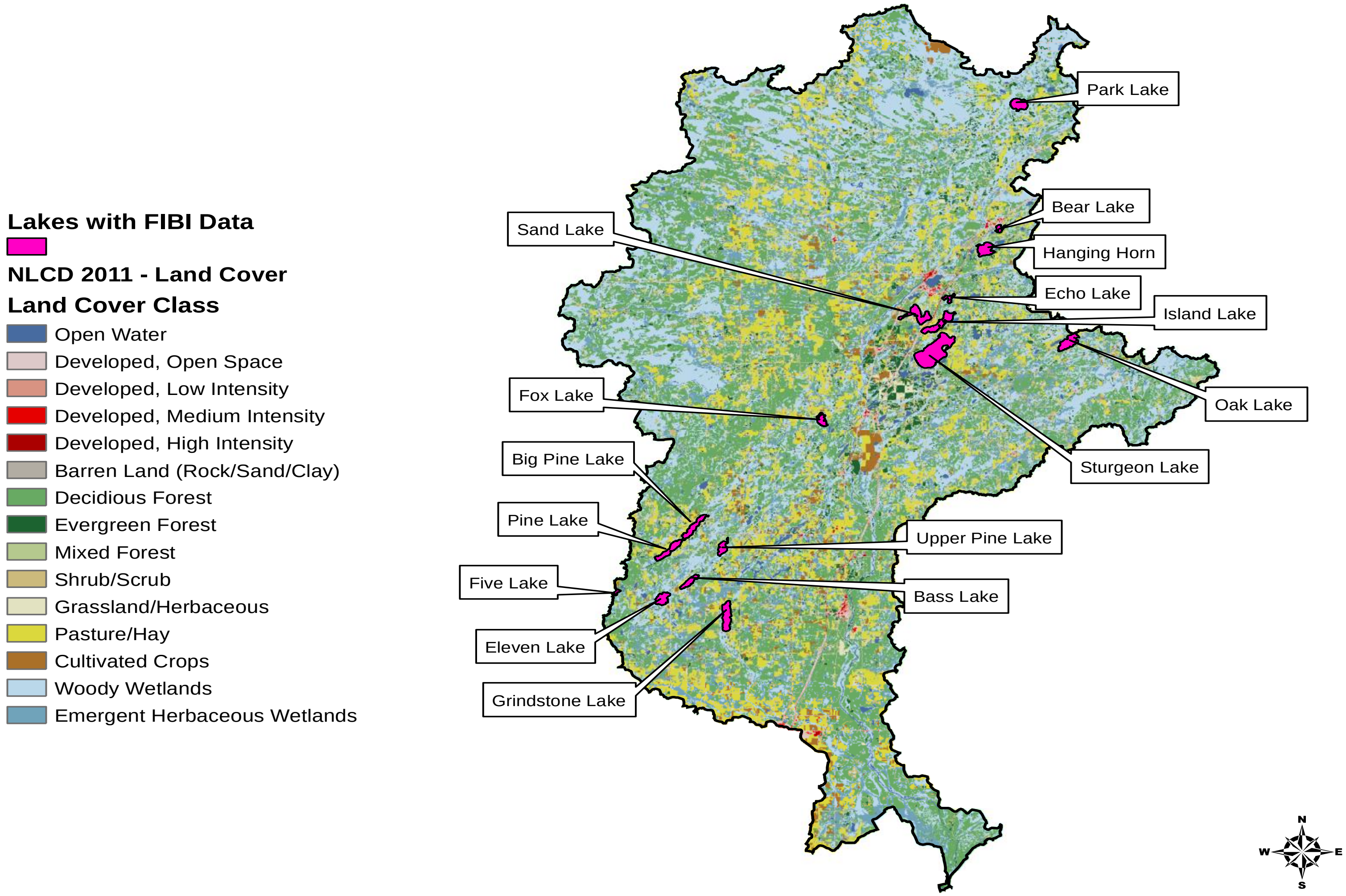


Table 90. Summary of lakes in the Kettle River Watershed assessed with FIBI Tools. The percent littoral is the percentage of the lake that is less than 15 feet deep calculated using the DNR GIS data. Color-coding is described at the bottom. The italicized information is old data that is used as supporting information for assessment. The asterisk indicates the lake is vulnerable to future impairment.

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	% Littoral	FIBI Tool	FIBI Score(s)	Below Impairment Threshold	Assessment Status
01-0001-00	**Pine**	Aitkin	2017, 2014	Low water temps (2014-Nearshore)	378	33	4	**50, 36**	Yes, No	Insufficient Information *
09-0029-00	**Park**	Carlton	2012 (2)	Repeated within the year (July)	381	100	5	**46, 36**	Yes, Yes	Full Support
09-0034-00	**Bear**	Carlton	2015	Not Assessable – No FIBI tool for Lake Class 11	100	77	NA	**NA**	NA	Not Assessed
09-0038-00	**Hanging Horn**	Carlton	2015, *2010 (2)*	Repeated within year 2010 (July)	409	23	2	**67, *66, 62***	No, *No, No*	Full Support
09-0044-00	**Echo**	Carlton	*2011*	Not Assessable - No FIBI tool for Lake Class 20	108	38	NA	**NA**	**NA**	Not Assessed
33-0001-00	**Eleven**	Kanabec	2015, *2008*		315	100	5	**59, *56***	No, *No*	Full Support
33-0003-00	**Five**	Kanabec	*2011*	Not Assessable – Less than 100 acres	44	52	NA	**NA**	**NA**	Not Assessed
58-0048-00	**Oak**	Pine	2017, 2015, *2010*		459	97	5	**20, 10, *28***	Yes, Yes, *No*	Non Support
58-0062-00	**Island**	Pine	2014 (2)	Repeated within the year (July)	536	55	4	**39, 48**	No, No	Full Support
58-0067-00	**Sturgeon**	Pine	2017, 2015, *2011*		1706	43	4	**47, 59, *41***	No, No, *Yes*	Full Support
58-0081-00	**Sand**	Pine	2016 (2), 2012, *2007*	High water levels in 2016	527	46	4	**33, 26, 48, *36***	Yes, Yes, No, *Yes*	Insufficient Information
58-0102-00	**Fox**	Pine	2014	Sampling effort might be low	200	100	5	**51**	No	Full Support
58-0123-00	**Grindstone**	Pine	2016, 2012 (2),	Repeated within year 2012 (July)	533	15	2	**74, 62, 63**	No, No, No	Full Support
58-0130-00	**Upper Pine**	Pine	2014		233	100	5	**38**	No	Full Support
58-0137-00	**Bass**	Pine	*2011 (2)*	Data is too old to use for assessment	229	82	4	***25, 27***	*Yes, Yes*	Insufficient Information
58-0138-00	**Big Pine**	Pine	2014	FIBI Score = impairment threshold	399	45	4	**38**	No	Insufficient Information *

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

Table 91. Summary of common fish species captured in KRW lakes assessed aquatic life use for each of the FIBI tools used. Tolerance, feeding, and habitat guilds are abbreviated as follows: Nat=Native, Int=Intolerant, Tol=Tolerant, Ins=Insectivore, Omn=Omnivore, TC=Top Carnivore, Smb=Small Benthic Dweller, Veg=Vegetative Dweller, and Cyp=Cyprinid. Guild abbreviations colored red contribute negatively to the FIBI score whereas those colored blue contribute positively to the FIBI score.

Species	Tolerance, Feeding, and/or Habitat Guild	Tool 2 Lakes	Tool 4 Lakes	Tool 5 Lakes
Banded Killifish	Nat, Int, Ins, Veg	X	X	
Black Bullhead	Nat, Tol, Omn	X	X	X
Black Crappie	Nat, TC	X	X	X
Blackchin Shiner	Nat, Int, Ins, Veg, Cyp	X	X	
Blacknose Shiner	Nat, Int, Ins, Veg, Cyp	X		
Bluegill	Nat, Ins	X	X	X
Bluntnose Minnow	Nat, Omn, Cyp	X	X	X
Brook Stickleback	Nat, Ins	X		
Brook Trout	Nat, Int, Ins, TC	X		
Brown Bullhead	Nat, Omn	X	X	X
Brown Trout	Int, TC	X		
Burbot	Nat, Int, TC	X		
Central Mudminnow	Nat, Ins, Veg	X	X	X
Chestnut Lamprey	Nat, TC	X		
Cisco	Nat, Int, Ins	X		
Common Shiner	Nat, Ins, Cyp	X	X	X
Creek Chub	Nat, Ins, Cyp	X		
Fathead Minnow	Nat, Tol, Omn, Cyp	X	X	X
Golden Redhorse	Nat, Ins	X		
Golden Shiner	Nat, Ins, Cyp	X	X	X
Greater Redhorse	Nat, Int, Ins	X		
Green Sunfish	Nat, Tol, Ins	X		
Hybrid Sunfish	Ins	X	X	X
Iowa Darter	Nat, Int, Ins, Smb, Veg	X	X	X
Johnny Darter	Nat, Ins, Smb	X	X	X
Lake Trout	Nat, Int , TC	X		
Largemouth Bass	Nat, TC	X	X	X
Logperch	Nat, Int, Ins, Smb	X		
Longnose Dace	Nat, Int, Ins, Smb, Cyp	X		
Mimic Shiner	Nat, Int, Ins, Veg, Cyp	X		
Mottle Sculpin	Nat, Int, Ins, Smb	X	X	
Muskellunge	Nat, Int, TC, Veg		X	
Northern Pike	Nat, TC, Veg	X	X	X
Northern Redbelly Dace	Nat, Veg, Cyp	X	X	

Species	Tolerance, Feeding, and/or Habitat Guild	Tool 2 Lakes	Tool 4 Lakes	Tool 5 Lakes
Pumpkinseed	Nat, Ins	X	X	X
Rainbow Smelt	Ins	X		
Rainbow Trout	Int, Ins, TC	X		
Rock Bass	Nat, Int, TC	X	X	X
Shorthead Redhorse	Nat, Ins	X		
Silver Redhorse	Nat, Ins	X		
Smallmouth Bass	Nat, Int, TC	X		
Spotfin Shiner	Nat, Ins, Cyp	X		
Spottail Shiner	Nat, Ins, Cyp	X	X	
Tadpole Madtom	Nat, Ins, Smb, Veg	X	X	X
Walleye	Nat, TC	X	X	X
White Sucker	Nat, Omn	X	X	X
Yellow Bullhead	Nat, Omn	X	X	X
Yellow Perch	Nat, Ins	X	X	X

Summary of lake stressors

DNR has developed a separate document that describes the various stressors of biological communities in lakes, including where they are likely to occur, their mechanism of harmful effect, Minnesota's Standards for those stressors where applicable, and the types of data available that can be used to evaluate each stressor (DNR, 2018b); Table 92). Many literature references are cited, which are additional sources of information. The document entitled "Stressors to Biological Communities in Minnesota's Lakes" and can be found on the DNR lake index of biological integrity website. Additionally, EPA has information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors to aquatic ecosystems on their CADDIS website.

Table 92. Summary of potential stressors of biological communities in Minnesota lakes.

Stressor	Examples of Anthropogenic Sources	Examples of Links to Aquatic Biology
Eutrophication	Inputs of excessive nutrients from agricultural runoff, animal waste, fertilizer, industrial and municipal wastewater facility discharges, non-compliant septic system effluents, and urban stormwater runoff	Detrimental changes to aquatic plant diversity and abundance, restructuring of plankton communities, detrimental effects to vegetation dwelling and sight-feeding predatory fishes
Physical Habitat Alteration	Riparian lakeshore development, aquatic plant removal, non-native species introductions, water level management, impediments to connectivity, sedimentation	Detrimental changes to aquatic plant diversity and abundance, reduced diversity and abundance of habitat specialists, reductions in spawning success
Altered Interspecific Competition	Unauthorized bait bucket introductions or unintentional transport, introductory and supplemental stocking activities by management agencies or private parties, angler harvest	Detrimental changes to energy flow, reductions in native species diversity and abundance through predation or competition for resources
Temperature Regime Changes	Climate change resulting from emission of greenhouse gases	Physiological stress and reduced survival, particularly for intolerant coldwater fishes, increases in aquatic plant biomass and distribution
Dissolved Oxygen	Inputs of excessive nutrients, climate change resulting from emission of greenhouse gases	Suffocation, detrimental effects to locomotion, growth, and reproduction of intolerant fishes
Pesticides	Herbicide applications to aquatic plant communities, runoff and drift from herbicide and insecticide applications to agricultural, suburban, and urban areas	Reduced aquatic plant biomass, reduced abundance and diversity of vegetation dwelling fishes
Ionic Strength	Road salt and de-icing product applications, industrial runoff and discharges, urban stormwater and agricultural drainage, wastewater treatment plant effluent	Detrimental effects to intolerant fishes and other aquatic organisms
Metals	Runoff and leaching from mining operations, industrial sites, firing ranges, urban areas, landfills, and junkyards	Reduced survival, growth, and reproduction of fishes
Unspecified Toxic Chemicals	Runoff and leaching from industrial sites, agricultural areas, mining, logging, urban and residential activities, and landfills, spills, illegal dumping, and discharges from industries, municipal treatment facilities, and animal husbandry operations	Altered food web dynamics, reduced fitness of fishes from chronic exposure

Possible stressors to lake fish community

Candidate causes

Physical habitat alteration

A review of DNR Score the Shore (StS) data indicates that lakes within the KRW have slightly more riparian shoreline disturbance than other lakes sampled to date statewide (Perleberg et al., 2016). The average StS score for lakes within the KRW was 71, which is slightly lower than the statewide average of 74. The average scores for developed and undeveloped sites in the KRW were 62 and 93, respectively. The undeveloped score was slightly higher than the statewide average of 92 for undeveloped sites. The developed score was lower than the statewide average of 63 for developed sites. A high StS score is indicative of relatively undisturbed riparian lakeshore habitat whereas a low StS score is indicative of highly disturbed riparian lakeshore habitat. Results indicate that habitat loss from riparian lakeshore development is generally higher on lakes within the KRW than lakes statewide and a few individual lakes within the KRW received lower scores. In addition, dock density on several lakes is above a level associated with lower FIBI scores (10 docks/km of shoreline), so riparian lakeshore development will be evaluated further as a potential stressor within the KRW.

A review of DNR Aquatic Plant Management (APM) program permitting information indicates that permits have historically been and are currently issued to mechanically remove or chemically treat emergent, floating-leaf, and submerged aquatic plants on at least five lakes within the KRW since 2000. There are additional mechanical removal methods of submerged aquatic plants that do not require a permit, in addition to any illegal removal of plants, which might have also occurred within the KRW.

A review of non-native species that would have the potential to alter physical habitat, including aquatic plant community structure, indicates that only two species - Eurasian Watermilfoil and Curly-leaf Pondweed are present in lakes of the KRW. Eurasian Watermilfoil is present in three lakes (Bear, Sand, and Sturgeon) and Curly-leaf Pondweed is present in six lakes (Big Pine, Eleven, Oak, Pine, Sturgeon, and Upper Pine). Both the Chinese mystery snail and Banded mystery snail are present in Oak Lake.

A review of the KRW stream crossing inventory and prioritization report indicates that there are six dams, 151 culverts, and 88 bridges (DNR, 2016). There is some information available on two dams that are complete barriers for fish migration within the KRW, which are the Sandstone Dam that has been removed and the Hinckley Dam that is planned for removal (Aadland, 2015). Minimal quantitative data is available describing fish habitat conditions prior to engaging in long-term water level management on lakes within the watershed and the effects of water level management on the FIBI score are unknown. Therefore, water level management is an inconclusive stressor.

A review of the DNR Watershed Health Assessment Framework (WHAF) tool indicates that the KRW has an overall average watershed health score (64) (DNR, 2018a). The hydrology component of the watershed health score is heavily influenced by flow variability and the watershed has minimal issues with hydrologic storage. The geomorphology component of the watershed health score is mainly influenced by climate vulnerability. The biology component of the watershed health score is severely affected by the terrestrial habitat quality and minimally influenced by a below average at-risk species richness index score. The connectivity component of the watershed health score is primarily influenced by the terrestrial habitat connectivity. The water quality component had a component health score of

76, with one individual index score for assessments that was below the average index score, which is likely due to heavy metal contaminants found in the watershed.

A review of sedimentation data indicates that measures such as total suspended solids or substrate embeddedness are lacking for most lakes within the KRW. Although sedimentation may contribute to lower than expected FIBI scores for some lakes, the lack of high quality quantitative data and scientific research on the topic makes it challenging to draw conclusions for lakes within the KRW at this time.

Eutrophication

A review of MPCA's Impaired Waters List indicates that one lake (Pine) within the KRW is currently listed as impaired for aquatic recreation based on MPCA's nutrient water quality standards and it has been listed since 2012 (MPCA, 2019c). The most recent assessment cycle added six new aquatic recreation impairments, which include Pine Lake (01-0001-00), Big Pine Lake (58-0138-00), Eleven (33-0001-00), Oak Lake (58-0048-00), Fox Lake (58-0102-00), and Grindstone Lake (58-0123-00). MPCA's nutrient water quality standards require that total phosphorus (TP) and either chlorophyll-a or transparency need to exceed the standard to be listed as impaired. These water quality standards were adopted to help improve phosphorus levels and recreational suitability of Minnesota lakes. Research shows phosphorus levels are known to significantly affect fish community structure and function in Minnesota lakes (Schupp & Wilson, 1993; Heiskary & Wilson, 2008). Some of the adverse effects of eutrophication include shifts in phytoplankton and zooplankton composition, and decreases in water transparency that lead to changes in the fish community. In the development of the FIBI, the metrics and the FIBI score were correlated with the Trophic State Index (TSI), TP, watershed disturbance, percent agriculture, and percent urbanization (Drake & Pereira, 2002; Drake & Valley, 2005). With increases in the TSI, a reduced or diminished abundance of intolerant fish can occur and then tolerant fish become more abundant (Jennings et al., 1999).

Inconclusive Causes

Altered interspecific competition

A review of DNR survey data indicates that the KRW is relatively unaffected by non-native species that would directly compete with native fish species for resources. Several lakes within the watershed contain Eurasian Watermilfoil, Curly-leaf Pondweed, Chinese mystery snails, and Banded mystery snails, but currently no lakes contain the non-native species Common Carp, Spiny Waterfleas, or Zebra Mussels.

A review of gamefish management activities indicates that stocking and harvest regulations occur in many lakes within the KRW. There are a couple lakes (Hanging Horn and Grindstone) in the KRW that are managed as stream trout lakes and sustain cold, well-oxygenated water. As for the majority of lakes within the KRW, they are primarily stocked with Walleye, with the exceptions of Island Lake which is stocked with Muskellunge and Sturgeon Lake that has had occasional stocking with Yellow Perch. While some gamefish management activities, like stocking, can result in changes to the fish community of a lake by altering fish species abundance, overall diversity of fish species, or increasing predatory fish species abundance, analyses to date do not suggest that stocking affects the FIBI scores. Typically, stocking occurs at rates that will sustain a fishery without impacting the abundance of other species. Therefore, gamefish management activities in lakes are likely not a potential stressor to the fish communities in the KRW.

Dissolved oxygen

Data regarding dissolved oxygen concentrations in lakes is generally limited to discrete profiles collected during periodic MPCA and DNR surveys or to anecdotal information related to summer or winterkill events. As such, limited information exists to indicate whether dissolved oxygen concentrations are changing in a manner that might result in changes to fish communities in the KRW at this time.

Temperature regime

Recent modeling indicates that forested and transition ecoregions have experienced the greatest warming and within the KRW, mean annual air temperatures have increased by 0.75 to 0.99°C over the last century due to climate change (Jacobson et al., 2017). The mean July temperature information in the KRW from 1895 to 2019 indicates an increase in temperature by 0.16°F per decade (DNR, 2019a). Minimal effects have been observed in the stream trout managed lakes of the KRW and these deep well-oxygenated lakes still support cold-water fish species. As for the other lakes in the KRW, which are shallower and experience more eutrophic conditions, these are the lakes that will likely indicate changes in fish communities due to climatic changes like warming temperatures. Although modeling evidence suggests that water temperature has increased in lakes within the KRW, limited research is available to demonstrate the magnitude of change needed to result in changes to the fish community as measured by the FIBI.

Eliminated Causes

Pesticide application

A review of Minnesota Department of Agriculture (MDA) incident reports indicated no agricultural chemical contamination in the quantity and proximity to any lake assessed that would impact the fish communities present (MDA, 2016). MDA also conducts sampling to monitor surface waters for pesticides. A summary of monitoring data from the 2012 National Lakes Assessment concluded that pesticide levels detected in lakes in the KRW were below applicable water quality standards and reference values (Tollefson et al., 2014).

Increased ionic strength

A review of MPCA's Impaired Waters List indicates that no lakes within the KRW were assessed as impaired for aquatic life use based on the chronic standard for chloride. Chloride concentrations that are toxic to fish and other aquatic organisms would need to exceed the current aquatic life use standards. Therefore, current standards and actions intended to address chloride impairments should provide adequate protection to eliminate chloride as a likely candidate cause for impaired fish communities in the KRW.

Metal contaminants

A review of MPCA's Impaired Waters List indicates that 13 lakes within the KRW are currently listed as impaired for aquatic consumption based on MPCA's water quality standards. MPCA's water quality standards state that a waterbody is impaired when, 10% of a fish species in a lake or river have a mercury concentration in fillets that exceeds 0.2 parts per million (MPCA, 2013b). Mercury concentrations that are toxic to fish and other aquatic organisms far exceed the current aquatic consumption standards. MPCA and local partners have developed a statewide mercury reduction plan approved by EPA to address these impairments (MPCA, 2007). The current standards and actions intended to address aquatic consumption impairment should provide adequate protection to eliminate mercury as a likely candidate cause for impaired fish communities in the KRW.

Unspecified toxic chemicals

A review of publicly accessible MPCA data also indicated hazardous chemicals were not likely a significant stressor to fish communities in the KRW (MPCA 2018a).

Evaluation of stressors for impaired lakes

Oak Lake (DOW 58-0048-00)

Oak Lake is 459 acres, with maximum depth of 20 feet, and is in Schupp Lake Class 39; these characteristics put it into a group scored with FIBI Tool 5. Lakes scored with Tool 5 often have lower numbers of individual fish per sample and a less diverse fish species assemblage than lakes in other classes. The management for this lake includes mainly gamefish species such as Walleye, Northern Pike, Bluegill, Black Crappie, and Largemouth Bass.

No stressors are present at levels as high as typically occur on impaired lakes. However, physical habitat alteration resulting from increased riparian lakeshore development and eutrophication are suspected stressors to the aquatic life use in Oak Lake. Further evaluation of these stressors will describe the available data and current perceptions believed to be affecting fish communities in addition to a discussion of each candidate.

Biological community

Oak Lake was assessed as non-supporting for aquatic life use. Three FIBI surveys were conducted on Oak Lake in 2010, 2015, and 2017 using multiple gears (backpack electrofishing, seines, trap nets, and gill nets). The 2015 and 2017 survey data is used for assessment. The 2015 survey included nearshore components, gill nets, and trap nets. Only the nearshore components and gill nets were repeated in 2017, therefore the 2015 trap nets were used for both scores. The most recent FIBI scores from 2015 and 2017 surveys are 10 and 20, which are both below the impairment threshold (24). Both FIBI scores are within the lower limit of the 90% confidence interval (9). The 2010 FIBI score was 28, which is above the impairment threshold (24) and within the upper limit of the 90% confidence interval (39). The two most recent FIBI scores for Oak Lake are now falling below the impairment threshold.

Oak Lake suffered nearly a complete winterkill during the winter of 1976-1977 but there is no evidence of winterkill since this event (DNR, 1984; DNR, 2017a). After the winterkill, the gamefish species were stocked again, with the exception of a few Northern Pike that likely migrated from the outlet of lake, which connects to the Willow River (DNR, 1984).

The FIBI survey from 2010 captured 16 species total, the 2015 FIBI survey captured 19 species total, and the 2017 FIBI survey captured 13 species total. See Table 93 for fish species captured in each survey type.

Table 93. Summary of fish species sampled across multiple years and the different types of surveys on Oak Lake.

Species	Nearshore Survey	Trap Net Survey	Gill Net Survey
Black Bullhead	2010	2010, 2015	2010, 2015, 2017
Black Crappie	2010, 2015	2010, 2015	2010, 2015, 2017
Bluegill	2015, 2017	2010, 2015	2010, 2015, 2017
Brown Bullhead		2015	2015
Central Mudminnow	2015		
Common Shiner	2010, 2015		
Fathead Minnow	2015		
Golden Shiner	2010, 2015		2017
Hybrid Sunfish	2015	2010	2010
Iowa Darter	2010, 2015		
Johnny Darter	2010, 2015, 2017		
Largemouth Bass	2010, 2015, 2017	2010, 2015	2010, 2015, 2017
Northern Pike	2010, 2015, 2017	2010, 2015	2010, 2015, 2017
Pumpkinseed	2010, 2015, 2017	2010, 2015	2010, 2015, 2017
Sunfish	2010		
Tadpole Madtom	2015		
Walleye	2015	2010	2010, 2015, 2017
White Sucker		2010, 2015	2010, 2015, 2017
Yellow Bullhead	2010	2010, 2015	2010, 2015, 2017
Yellow Perch	2010, 2015, 2017	2010, 2015	2010, 2015, 2017

Overall, the FIBI metric scores across the two most recent surveys were low. The most notable negative influences on the FIBI scores were the low number and proportion of intolerant species sampled in the nearshore gears and the high proportion of biomass captured with the trap net being from omnivore species (Black Bullhead, Brown Bullhead, White Sucker, Yellow Bullhead) (Table 91). Black Bullhead, Northern Pike, Walleye, White Sucker, and Yellow Bullhead were the most abundant species by biomass in the gill nets in the surveys. Bluegill, Black Crappie, White Sucker, and Yellow Bullhead were the most abundant species by biomass in the trap nets in the surveys. Black Crappie, Bluegill, and Largemouth Bass, were the most abundant species in the nearshore gears as well as moderate catches of Common Shiners and Golden Shiners.

DNR Fisheries currently stocks Walleye fry at a rate of 1,000 per littoral acre annually, as described in the current Oak Lake management plan (DNR, 2017a). No significant relationships between FIBI scores or metrics and the number of species stocked, relative abundance of stocked species, or Walleye stocking density have been observed in Minnesota lakes (J. Bacigalupi, unpublished data). The effects of fisheries management activities can vary from lake to lake, due to each lake having individual lake characteristics and biological communities.

Because this is the first time utilizing the FIBI protocols in the lake assessment process within the KRW, historical surveys of similar rigor are currently unavailable to facilitate comparison of fish species assemblages through time. However, historical data indicates that 22 species have previously been sampled in Oak Lake. There were two reports of lamprey, one noted that a Silver Lamprey was caught in Oak Lake back in 1949 and the other was an angler report of a lamprey species caught in 2008 (DNR, 2019c). Since 2000, there has not been any Shorthead Redhorse sampled. The most recent survey in 2017 had very low catches of Golden Shiners and Johnny Darters. The 2015 survey had very low catches of Common Shiners, Iowa Darters, Johnny Darters, and Tadpole Madtoms.

Data analysis/Evaluation for each Candidate Cause

Based on existing relationships between the FIBI and stressors, Oak Lake performs poorer than expected as measured by the FIBI. This desktop review report cannot definitively state a specific stressor or stressors as the cause of the FIBI impairment on Oak and it could be the combination of multiple stressors. More investigation would be needed determine specific sources of stress for Oak Lake, such as sources of excess nutrients.

Information about select Inconclusive Causes

Physical habitat alteration-riparian disturbance

Minnesota DNR EWR Lake Habitat program staff conducted an assessment of lakeshore habitat on Oak Lake on 7/17/2016, following the Score the Shore survey protocols. The assessment consisted of 39 survey sites evenly spaced every 200 meters around the lake. The Score the Shore survey calculates a lakewide habitat score from an average of the individual survey site scores, which range from 0 to 100. Based on data collected through 2017, the mean lakewide scores can be categorized into descriptive habitat quality classes of High, Moderate, Low, and Very Low (Table 94). With higher scores indicating a more natural habitat or undeveloped areas and the lower scores generally identifying habitat that has been disturbed or altered by humans.

Table 94. Interpretation of Score the Shore survey data. The scoring ranges and ratings are calculated from all available StS data statewide to date.

Mean Lakewide Score	Mean Shoreland Score	Mean Shoreline Score	Mean Aquatic Score	Rating
86 - 100	29 - 33	29 - 33	29 - 33	High
66 - 85	22 - 28	22 - 28	22 - 28	Moderate
50 - 65	17 - 21	17 - 21	17 - 21	Low
< 50	< 17	< 17	< 17	Very Low

The assessments of the survey sites were categorized into three habitat zones: Shoreline Zone (the shore-water interface to the top of the natural bank), Shoreland Zone (landward from shoreline to development structure or 100 feet), and Aquatic Zone (lake-ward from the shoreline 50 feet). Table 95 depicts the scores calculated from the statewide StS survey efforts. The average lakewide habitat score for Oak Lake was 79 out of 100 possible; this is above the statewide average score (74.4) of the StS surveyed lakes to date (2018). Approximately 43% of the sites were developed with a mean score of 59, while undeveloped sites had a mean score of 95. During the StS survey, 64% of sites had visible downed woody habitat and 97% of the sites had at least some emergent vegetation in the aquatic zone. These results, along with observations during field surveys and review of aerial imagery, indicate that portions of the shoreline surrounding Oak Lake have been substantially altered but highly unlikely to be at levels detectable with the FIBI because of the naturally high level of emergent vegetation and high amounts of vegetated and woody habitats remaining. Research continues to develop and improve techniques to quantify the impact of riparian disturbance to FIBI scores.

Table 95. Breakdown of how Oak Lake (DOW 58-0048-00) scored utilizing the Score the Shore survey separated out by lakewide, undeveloped, and developed land use and each of the three zones (Shoreland, Shoreline, Aquatic).

Land Use Observed	Number of survey sites	Shoreland Zone Score (0-33.3)	Shoreline Zone Score (0-33.3)	Aquatic Zone Score (0-33.3)	Lakewide Mean Score (0-100)	Lakewide Habitat Rating
Developed sites	17	21	19	19	59	Low
Undeveloped sites	22	33	29	32	95	High
Total (all sites)	39	28	25	27	79	Moderate

DNR Fisheries staff delineated the floating leaf and emergent aquatic vegetation of Oak Lake on 07/28/2010, following the protocols listed in the DNR Lake Plant Mapping Manual. There were a total of 57.6 acres of floating and emergent plants mapped (Figure 46). This consisted of 44.1 acres of emergent dominated plant communities and 13.5 acres of floating leaf plant communities (Table 96).

A review of DNR Permitting and Reporting System (MPARS) information indicates that Oak Lake had nine APM permits issued since 2003, with only one permit currently active (DNR, 2018c). Several of the APM permits issued to individual lakeshore property owners have allowed mechanical control by hand removal or chemical control of aquatic plants with treatment to provide reasonable access. Most of the control or removal done through APM activities are targeting submerged, floating-leaved, and emergent vegetation stands. The only active permit is permanent and is for maintaining a 15-foot wide channel to open water through emergent vegetation. The earliest known record of APM activity on Oak Lake dates back to 1988 and it was for chemical control of submerged and emergent vegetation (A. Kuchinski, DNR, personal communication, February 14, 2018). To date, only one violation for illegal plant removal has been reported; however, illegal unpermitted plant removal or lakeshore habitat destruction could still exist and negatively affect habitat quality. Both legal and illegal aquatic plant removal has contributed to some of the physical habitat loss within the lake, but the extent of the habitat loss is almost certainly lower than would be detected with the FIBI.

More information about the potential plant removal activities within a lake can be inferred from dock counts. A review from 2017 Google aerial imagery counted 70 docks and 3 swim platforms in Oak Lake. A previous aerial review counted 73 docks and calculated a dock density of 9.6 docks per kilometer of shoreline on Oak Lake (Beck et al., 2013). Densities exceeding 10 docks per kilometer have been linked to changes in fish community composition (Jacobson et al., 2016), and in fewer numbers of intolerant species during FIBI development, therefore dock densities in Oak lake are approaching levels where changes have been seen to fish community composition.

The presence of large areas of emergent, submerged, and floating leaf vegetation and woody habitat in Oak Lake provides important fish habitat and although this section described some impacts to the shoreline, the natural character of the shoreline habitat and abundant native vegetation provide resiliency on Oak Lake.

Figure 46. Oak Lake (DOW 58-0048-00) floating and emergent vegetation map from 2010 data overlaid on an aerial image of the lake. Source: Minnesota Department of Natural Resources, Floating-leaf and Emergent Vegetation Summary Report, 2018.

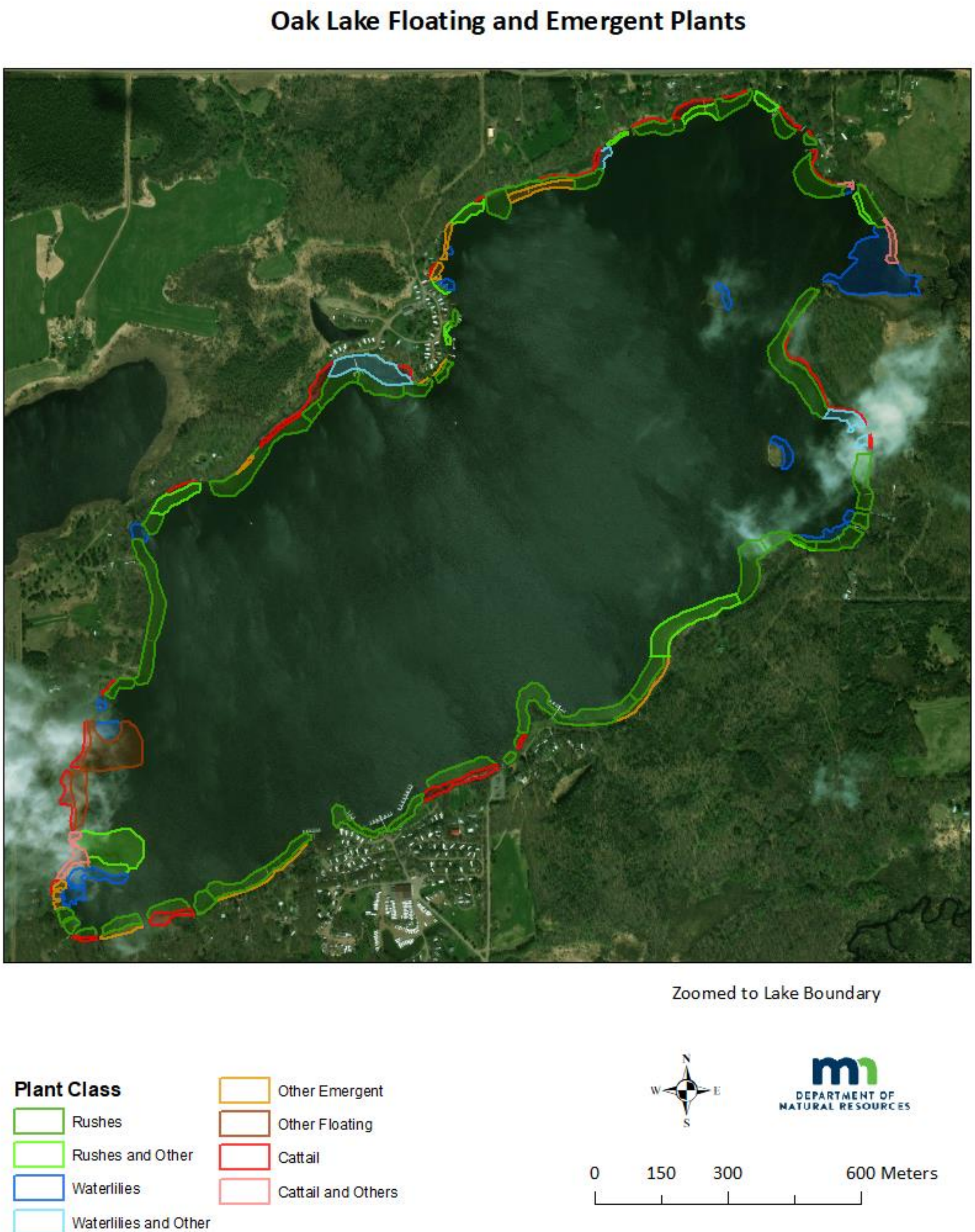


Table 96. Number of stands and area covered (Acres) broken out by stand type and primary species in that stand as determined by the emergent and floating-leaf vegetation mapping efforts.

Category	Number of Stands	Total (Acres)	Mean Acres (1 SE)
Combined Total	110	57.6	0.5 (+/-0.1)
Emergent	**91**	**44.1**	**0.5 (+/-0.1)**
Cattail	22	5.2	0.2 (+/-0.0)
Cattail and Others	3	1.0	0.3 (+/-0.1)
Other Emergent	13	2.7	0.2 (+/-0.0)
Rushes	41	27.9	0.7 (+/-0.1)
Rushes and Others	12	7.4	0.6 (+/-0.2)
Floating	**19**	**13.5**	**0.7 (+/-0.2)**
Other Floating	2	3.5	1.7 (+/-0.9)
Waterlilies	13	7.5	0.6 (+/-0.3)
Waterlilies and Others	4	2.5	0.6 (+/-0.3)

Eutrophication

Oak Lake is proposed for listing as impaired for aquatic recreation based on its nutrient levels. The most recent water quality monitoring found the mean TP to be 32.83 µg/L, the mean chlorophyll-a (corrected for pheophytin) was 16.97 µg/L, the mean Secchi depth reading was approximately 1.32 m, and a mean TSI of 58.37 (MPCA, 2018b). When compared with the typical Northern Lakes and Forest ecoregion ranges (Table 97), Oak Lake has slightly higher TP, a mean chlorophyll-a measurement that is higher than the ecoregion range value (10 µg/L), and Secchi measurements much lower than the ecoregion ranges (MPCA, 2018c). Of the 2,460 acres of land contained within the contributing watershed, approximately 9.81% is classified as unnatural land cover (i.e., 5.3% developed, 0.84% cultivated, and 3.67% hay and pasture land) and the remaining 84.5% is classified as natural land cover (i.e., 21.72% water, 18.05% forest, 14.58% shrub and herbaceous, and 35.83% wetland; Figure 47; U.S. Geological Survey, 2011). With the low rate of watershed disturbance, it is likely that increased TP might be the major contributor to the low FIBI scores observed in Oak Lake. The presence of tolerant fish species, such as Black Bullhead, in Oak Lake along with the changes in water quality may be an indication that eutrophication is causing stress to the fish community and the lake's ecosystem. In the FIBI development for the tool 5 lakes, metrics such as TSI are highly correlated to the FIBI score as seen below in Figure 48.

Table 97. Typical water quality measurements for lakes in the Northern Lakes and Forest Ecoregion (MPCA, 2018c).

Field pH	TSS (mg/L)	NO_X (mg/L)	TP (mg/L)	Turbidity (NTU)	Secchi (m)	Chl-a (µg/L)	TKN (mg/L)
7.2 - 8.3	<1 - 2	<0.01	0.014 - 0.027	<2	2.4 - 4.6	<10	<0.75

Figure 47. Land use (NLCD 2011) in Oak Lake's (DOW 58-0048-00) contributing watershed (U.S. Geological Survey, 2011).

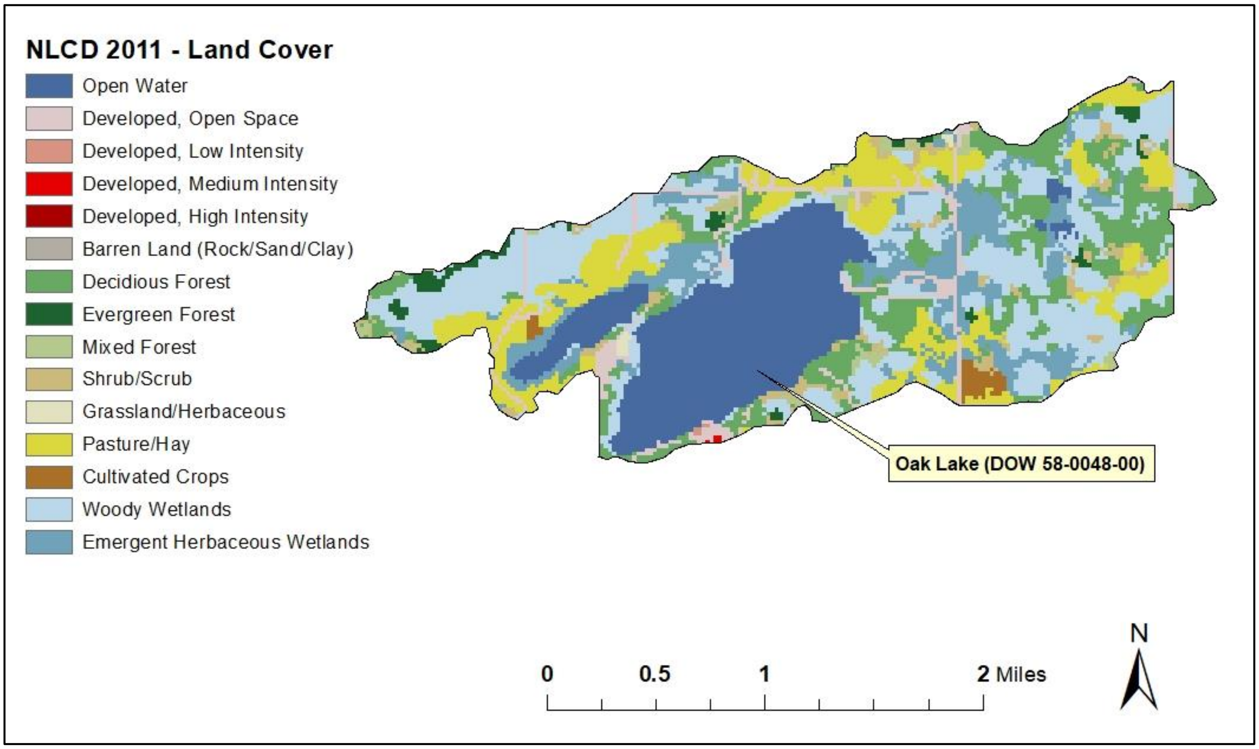
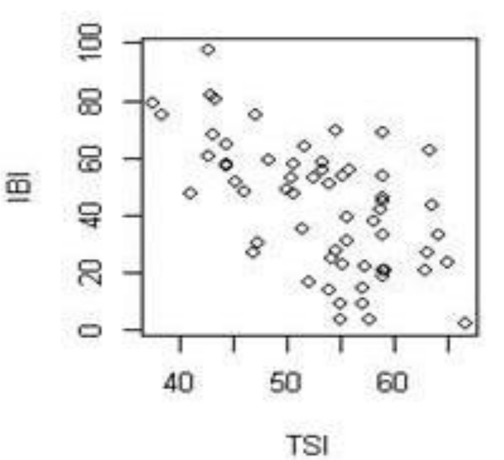


Figure 48: Relationship with FIBI Score and metrics (TSI) for FIBI Tool 5 development lakes.



Most the of the land use surrounding Oak Lake is residentially developed land and includes the network of roads and residences found throughout rural areas of the watershed. There are two resorts on the lake, one on the northwest shoreline and the other on the southeast shoreline of Oak Lake. Pine County zoning records indicate that there are 69 parcels located on Oak Lake and 12 of these parcels are undeveloped lots. There are approximately 63 homes on Oak Lake with private septic systems. Of the 63 known septic systems, 34 systems have been installed with compliance certificates after 2000 and 20 systems have been installed with compliance certificates after 2008. Currently, nine septic systems have no certificate of compliance associated with them (C. Anderson, Pine County Planning and Zoning, Unpublished data, March 3, 2019).

Altered interspecific competition

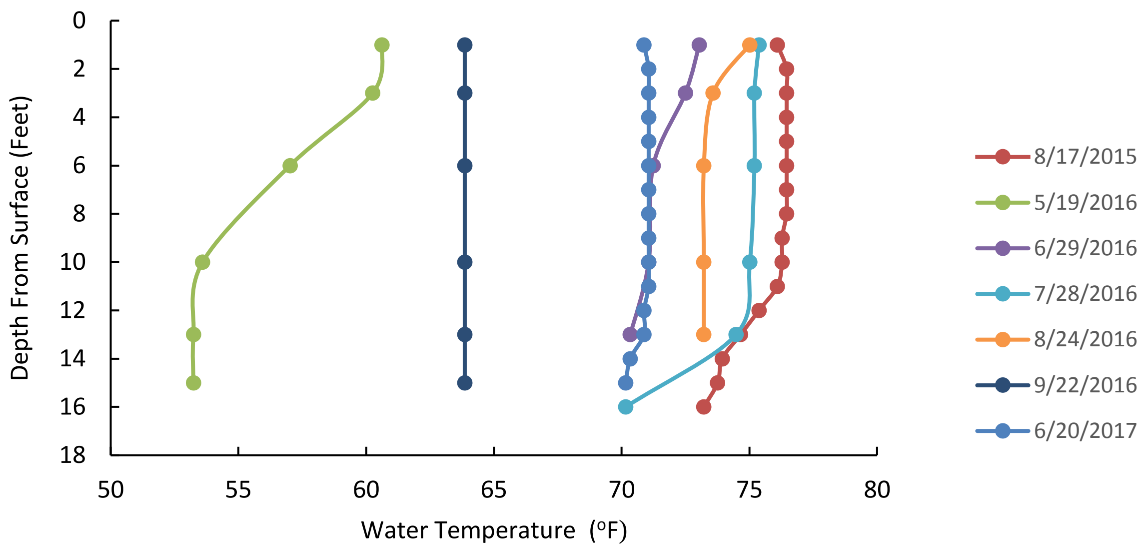
Altered interspecific competition is unlikely causing measurable changes to the fish community in Oak Lake. Currently, non-native fish or mussel species do not exist in the lake, but there have been observations of Chinese mystery snails and Banded mystery snails. Banded mystery snails have consumed Largemouth Bass embryos in a lab setting it was the only food item available and in the pond conditions the male Largemouth Bass allowed the Banded mystery snail to crawl over the mass of incubated eggs (Eckblad & Shealy, Jr., 1972). However, there is no documentation as to what kind of effects there are to the native fish communities.

Gamefish management activities, such as stocking, is another known cause of interspecific competition. The earliest documented gamefish survey occurred in 1959, which documented the presence of Northern Pike, Bluegill, Black Crappie, Largemouth Bass, and Walleye. After the winterkill in winter of 1976-1977, Oak Lake was re-stocked Walleye, Largemouth Bass, Bluegill, Black Crappie in 1977 as well as Northern Pike and Walleye in 1978. Stocking of Walleye still occurs due to the lack of natural reproduction, but is done at low levels (DNR, 2017a; DNR, 1984). Commercial Black Bullhead removal occurred historically, but no harvest has occurred since 1994 (DNR, 1984).

Temperature regime

Although modeling suggests that water temperature may have increased in Oak Lake, limited research is available to demonstrate the magnitude of change needed to result in changes to the fish community as measured by the FIBI. Summer water temperatures have been intermittently monitored by DNR and MPCA during 2015 and 2017 (Figure 49), but the lack of continuous or seasonal and annual data limits the ability to detect changes over time that could alter the fish community. There have been no cold-water species historically documented in Oak Lake, so the potential changes to the temperature regime at this time are unlikely to affect the present fish community composition.

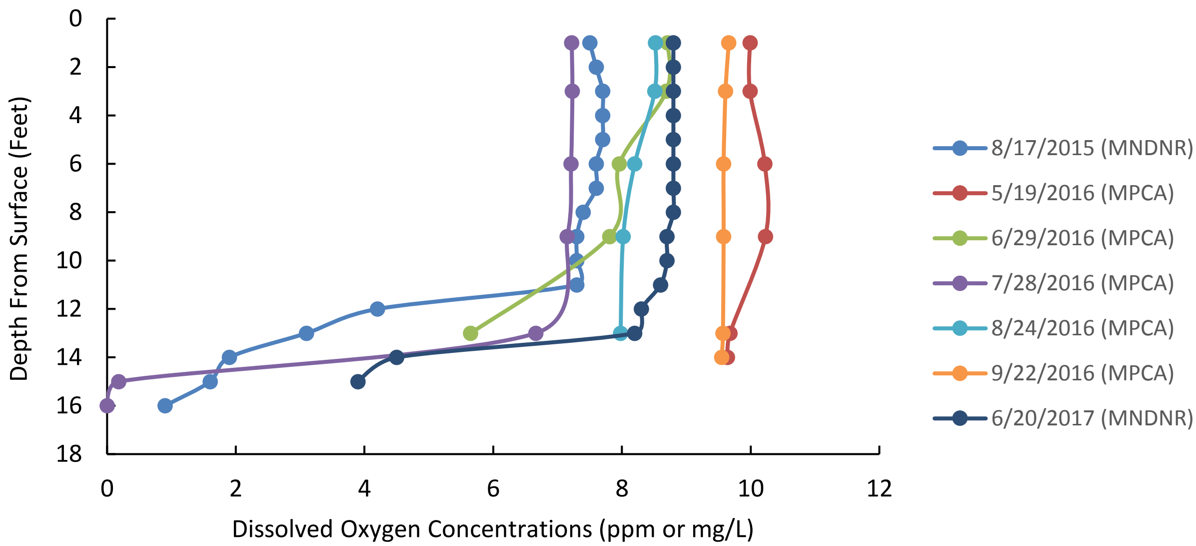
Figure 49. Water temperature (°F) by depth within Oak Lake (DOW 58-0048-00) during the months of May - September of 2015, 2016, and 2017.



Dissolved oxygen

A historical management plan provided by the DNR Hinckley Area Fisheries Office indicated a nearly complete winterkill in the winter of 1976-1977 and changes to the fish community included major loss of all species, leaving only a few Northern Pike (DNR, 1984). No other summer or winterkill events have been reported since. A review of dissolved oxygen profile data during winter months monitored from 1986 to 1997 indicates that depths from 10-15 feet sometimes contained very low concentrations of dissolved oxygen (i.e., Less than 2 ppm) during the late winter months, but nothing that is likely indicative of a winterkill. The most recent dissolved oxygen monitoring was conducted during the summer months of May - August in 2015 to 2017 (Figure 50). The lack of continuous, seasonal, and annual data limits the ability to detect changes over time that could result in changes to the fish community.

Figure 50. Dissolved oxygen concentrations by depth within Oak Lake (DOW 58-0048-00) during the months of May - September of 2015, 2016, and 2017.



Evaluation of stressors for vulnerable lakes

Pine Lake (DOW 01-0001-00)

Pine Lake is 378 acres and has a maximum depth of 28 feet. The littoral zone of the lake covers approximately 25% of the lake. Pine Lake is in Schupp Lake Class 31; these characteristics put it into a group scored with FIBI Tool 4. Tool 4 lakes are generally deep with a simple shape (Table 88). The management of Pine Lake focuses on gamefish species such as Walleye, Northern Pike, Bluegill, Black Crappie, and Largemouth Bass.

Biological community

Pine Lake was assessed as insufficient information and vulnerable to future impairment for aquatic life use based on the Fish IBI (FIBI) surveys. Two FIBI surveys were conducted on Pine Lake in 2014 and 2017 using multiple gears (backpack electrofishing, seines, trap nets, and gill nets). All gears were repeated between surveys except for trap nets in 2017. The 2017 nearshore sampling information was combined with the gill net and trap net sampling completed in 2014. The 2014 FIBI score was 36, which is below the impairment threshold (38) and within the lower limit of the 90% confidence interval (30) (Table 89). The 2017 FIBI Score was 50, which is above the impairment threshold (38) and outside of the upper limit of the 90% confidence interval (46). These FIBI scores are showing mixed results within the 90% confidence interval range, indicating the lake is showing some potential vulnerability to future impairment.

The FIBI survey from 2014 captured 14 species and the 2017 FIBI survey captured 15 species total. See Table 98 for fish species captured in each survey type.

Table 98. Summary of fish species sampled across multiple years and the different types of surveys on Pine Lake.

Species	Nearshore Survey	Trap Net Survey	Gill Net Survey
Banded Killifish	2017		
Black Crappie	2014, 2017	2014	2014, 2017
Bluegill	2014, 2017	2014	2014, 2017
Central Mudminnow	2014		
Common Shiner	2014		
Golden Shiner	2014	2014	2017
Hybrid Sunfish	2017		
Iowa Darter	2014		
Johnny Darter	2017		
Largemouth Bass	2014, 2017		
Mottled Sculpin	2017		
Northern Pike	2014, 2017	2014	2014, 2017
Northern Redbelly Dace	2014		
Pumpkinseed	2017	2014	
Rock Bass	2017		
Tadpole Madtom	2017		
Walleye	2017	2014	2014, 2017
White Sucker		2014	2014, 2017
Yellow Bullhead	2014	2014	
Yellow Perch	2014, 2017	2014	2014, 2017

The most notable negative influences on the 2014 FIBI score is the low diversity of small benthic dwelling species (Iowa Darter) and the low catches of the small benthic dwelling species sampled in the nearshore gears. The absence of tolerant species and low number of omnivore species (Yellow Bullhead and White Sucker) sampled across all gears positively influenced the 2014 FIBI score. The 2017 FIBI score was negatively influenced by the low diversity of vegetative dwelling species (Northern Pike and Tadpole Madtom) sampled across all gears and the high proportion of biomass in the trap nets from omnivore species (White Sucker and Yellow Bullhead). The absence of tolerant species, the low number of omnivore species (White Sucker and Yellow Bullhead), and high diversity of small benthic dwelling species (Johnny Darter, Mottled Sculpin, and Tadpole Madtom) most positively influenced the 2017 FIBI score. Both scores were negatively impacted by the relatively low diversity of intolerant species sampled (Iowa Darter, Mottled Sculpin, and Rock Bass). Northern Pike were the most abundant species by biomass in the gill nets in the surveys. Bluegill, Black Crappie, and White Sucker were the most abundant species by biomass in the trap nets in the surveys. Black Crappie, Bluegill, Largemouth Bass, and Yellow Perch were the most abundant species in the nearshore gears as well as a moderate catch of Common Shiners.

DNR Fisheries currently stocks Walleye fingerlings at a rate of 1.3 lbs. per littoral acre on a biennial basis, as described in the current Pine Lake management plan amendment (DNR, 2017b). No significant relationships between FIBI scores or metrics and the number of species stocked, relative abundance of stocked species, or Walleye stocking density have been observed in Minnesota lakes (J. Bacigalupi, unpublished data). The effects of fisheries management activities can vary from lake to lake, due to each lake having individual lake characteristics and biological communities.

Because this is the first time utilizing the FIBI protocols in the lake assessment process in the KRW, historical surveys of similar rigor are currently unavailable to facilitate comparison of fish species assemblages through time. However, historical data indicates that 22 species have been sampled in Pine Lake. Since 1989, there have not been any Shorthead Redhorse sampled. From 1980 to the present, very sporadic catches of Banded Killifish, Blackchin Shiner, Brown Bullhead, Golden Shiner, Iowa Darter, Johnny Darter, and Tadpole Madtom have been noted in fisheries surveys (DNR, 2019c). Banded Killifish and Blackchin Shiner are vegetation dwelling intolerant species that rely on high quality vegetated shoreline habitat. It is notable that neither of these fish species were sampled in the two recent surveys. Pine Lake has been reported as slightly bog-stained. Bog-stained lakes are more acidic with darker watercolor and the fish communities can be somewhat variable (Pierce et al., 2003). Another limiting factor to fish in bog-stained lakes is a low pH, which can also affect species richness (Rahel, 1984).

Data analysis/Evaluation for each Candidate Cause

Physical habitat alteration

The DNR's EWR Lake Habitat program staff conducted an assessment of lakeshore habitat on Pine Lake on 06/14/2017, following the Score the Shore survey protocols. The assessment consisted of 40 survey sites evenly spaced 200 meters around the lake. Assessments were made in three habitat zones: Shoreline Zone (the shore-water interface to the top of the natural bank), Shoreland Zone (landward from shoreline to development structure or 100ft), and Aquatic Zone (lake-ward 50ft of shoreline). The average lakewide habitat score was 64.4 out of 100 possible (Table 99); this is below the state average score (74.4) of lakes surveyed through 2018. Approximately 85% of the sites were developed with a mean score of 58.4, while undeveloped sites had a mean score of 98.3. During the StS survey, 50% of the sites had visible downed woody habitat and 95% of the sites had at least some emergent or floating-leaf vegetation in the aquatic zone. These results, along with observations during field surveys and review of aerial imagery, indicate that much of the shoreline surrounding Pine Lake has been substantially altered. The aquatic zone seems to be less impacted than the shoreline or shoreland zones.

Table 99. Breakdown of how Pine Lake (DOW 01-0001-00) scored utilizing the Score the Shore survey separated out by lakewide, undeveloped, and developed land use and each of the three zones (Shoreland, Shoreline, Aquatic).

Category	Survey Sites	Shoreland Score (33.3)	Shoreline Score (33.3)	Aquatic Score (33.3)	Mean Score Std Error	Mean Score (100)
Undeveloped Total	6	33.3	33.3	31.7	1.1	98.3
Developed Total	34	15.2	18.5	24.6	3.6	58.4
Lakewide	40	18.0	20.8	25.7	3.8	64.4

DNR Fisheries staff delineated the floating leaf and emergent aquatic vegetation of Pine Lake on 07/24/2008, following the protocols listed in the DNR's Lake Plant Mapping Manual. There were a total of 41.7 acres of floating and emergent plants mapped. This consisted of 14.6 acres of emergent dominated plant communities and 27.1 acres of floating leaf plant communities. For more information, see map in Figure 51 and summary Table 100 below.

Figure 51. Pine Lake (DOW 01-0001-00) floating and emergent vegetation map from 2010 data overlaid on an aerial image of the lake. Source: Minnesota Department of Natural Resources, Floating-leaf and Emergent Vegetation Summary Report, 2019.

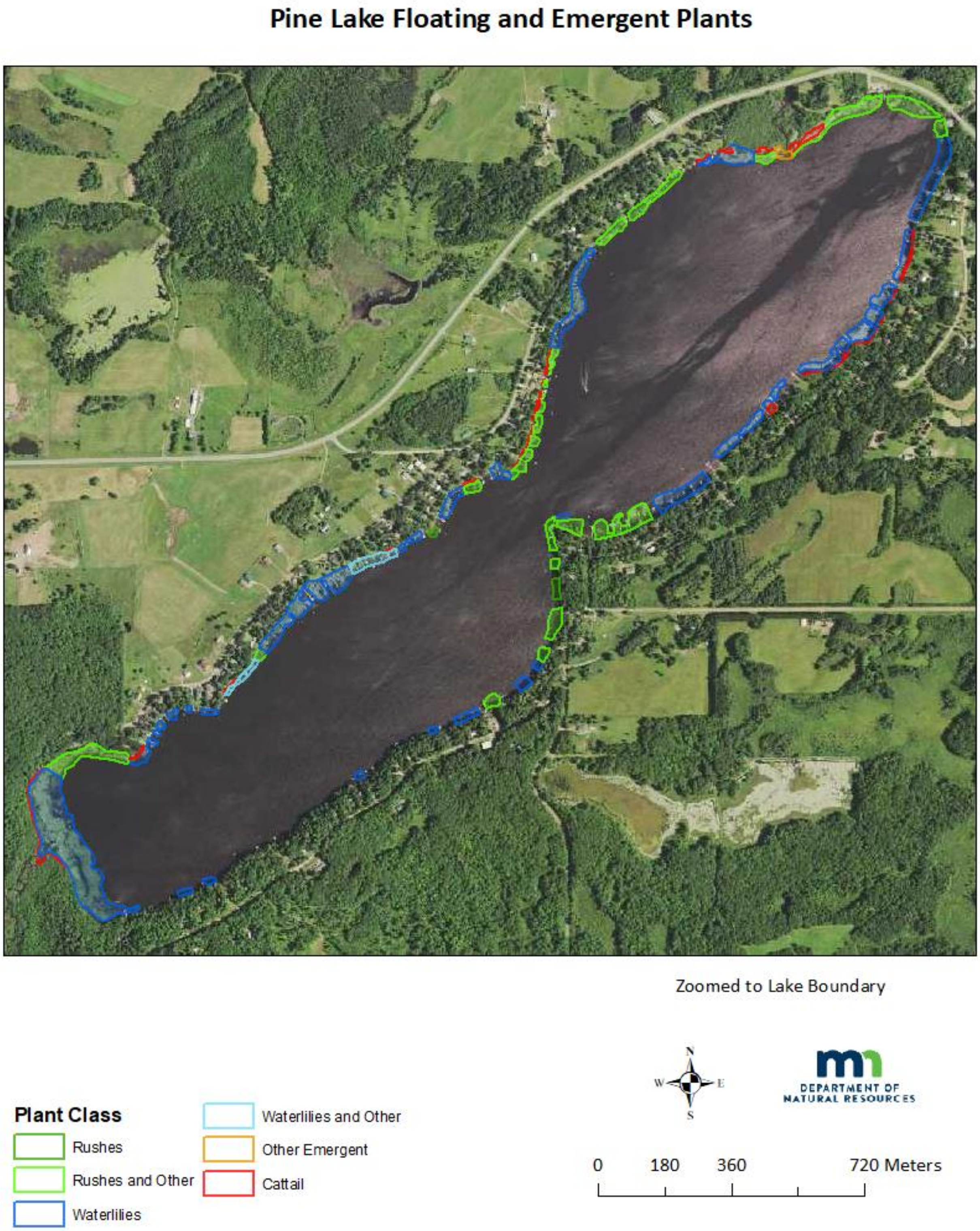


Table 100. Number of stands and area covered (Acres) broken out by stand type and primary species in that stand as determined by the emergent and floating-leaf vegetation mapping efforts.

Category	Number of Stands	Total (Acres)	Mean Acres (1 SE)
Combined Total	88	41.7	0.5 (+/-0.1)
Emergent	**53**	**14.6**	**0.3 (+/-0.1)**
Cattail	25	2.4	0.1 (+/-0.0)
Other Emergent	1	0.3	0.3 (+/-0.0)
Rushes	2	0.4	0.2 (+/-0.1)
Rushes and Others	25	11.6	0.5 (+/-0.1)
Floating	**35**	**27.1**	**0.8 (+/-0.3)**
Waterlilies	33	26.0	0.8 (+/-0.3)
Waterlilies and Others	2	1.1	0.6 (+/-0.2)

According to MPARS permit activity, Pine Lake has had 132 APM permits issued since 2010, with 20 permits currently active (DNR, 2018c). Several of the APM permits issued to individual lakeshore property owners have allowed automated aquatic plant control by device or chemical control of aquatic plants with treatment allowed to provide reasonable access. Most of the control or removal done through APM activities are targeting submerged, floating-leaved, and emergent vegetation stands. The 20 active permits are for automated aquatic plant control devices.

More information about potential plant removal and other shoreline activities within a lake can be inferred from dock counts. A review of 2017 Google imagery indicates approximately 145 docks in the water, 4 docks located on onshore, and 8 swim platforms were present in Pine Lake. A previous aerial review of Pine Lake counted 123 docks and calculated a dock density of 15.43 docks per kilometer of shoreline (Beck et al., 2013). Densities exceeding 10 docks per kilometer have been linked to changes in fish community composition (Jacobson et al., 2016) and FIBI metrics (J. Bacigalupi, DNR, unpublished data). The density of docks on Pine Lake is above a level associated with changes seen in fish community composition.

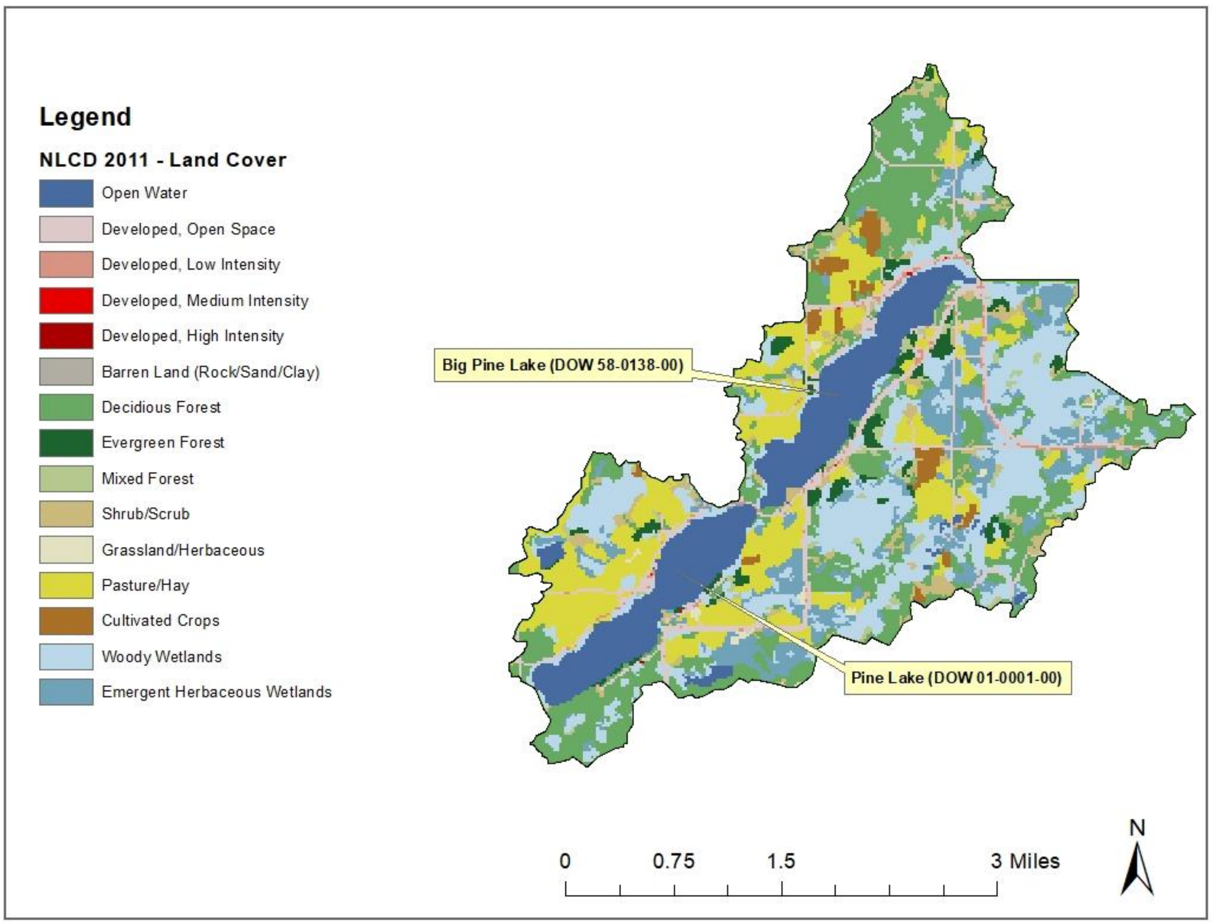
No known violations for illegal plant removal have been reported to date; however, undocumented illegal unpermitted plant removal or lakeshore habitat destruction can still occur, which negatively affects habitat quality in lakes. The legal and undocumented illegal aquatic plant removal has likely contributed to some physical habitat loss within Pine Lake, but the level of habitat loss that would result in significant changes to the fish community that can be detected with the FIBI is currently unknown.

The inlet to Pine Lake from Strawberry Creek has a culvert crossing on the northwest shoreline of the lake that is located on County Road 23 (Alder Street), which is of interest due to the scouring, sediment deposition, and stream bank erosion visible from Google Earth. This inlet could be a potential source of sediment or other pollutants, leading to habitat loss or degradation.

Eutrophication

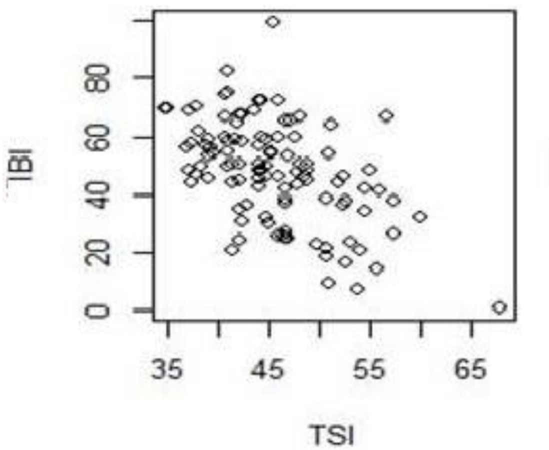
Pine Lake has a current nutrient impairment according to the MPCA's recent impaired waters list (MPCA, 2018a) and will continue to have an impairment listing for nutrients. The 10-year averages of all summer samples included a mean TP of 37.19 µg/L, a mean chlorophyll-a (corrected for pheophytin) of 10.47 µg/L, a mean transparency of 1.85 meters, and a mean TSI of 53.64 (MPCA, 2019d). When compared with the typical Northern Lakes and Forest ecoregion ranges (Table 97), Pine Lake has higher mean TP and transparency lower than the expected range, but the mean chlorophyll-a is within the range of values for this ecoregion (MPCA, 2018c). Of the 2,139 acres of land contained within the contributing watershed, approximately 9.16% is classified as unnatural land cover (i.e., 5.57% developed, 0.34% cultivated, and 3.25% hay and pasture land) with the remaining 90.83% being natural land cover (i.e., 19.29% water, 22.25% forest, 23.9% shrub and herbaceous, and 25.39% wetland; Figure 52; U.S. Geological Survey, 2011). With the small amount of watershed disturbance, it is likely that the more localized disturbance could be a source for the increased TP, which might be the major contributor to the low FIBI scores observed in Pine Lake. In the FIBI development for the tool 4 lakes, metrics such as TSI were highly correlated to the FIBI score as seen below in Figure 53.

Figure 52. Land use (NLCD 2011) in Pine Lake (DOW 01-0001-00) and Big Pine Lake (DOW 58-0138-00) contributing watershed (U.S. Geological Survey, 2011).



Much of the developed or unnatural land cover within the contributing watershed around Pine Lake is residential and a rural network of roads. Aitkin County zoning records indicate that there are approximately 223 parcels of land, which share a boundary with Pine Lake or have direct access to lake (S. Westerlund, personal communication, March, 4, 2019). About 62 parcels are vacant or have no record of a septic system. Currently, there are 161 known individual sewage treatment systems (ISTS) and 44 of these systems have received a compliance inspection. Of the 161 known ISTS, 45 systems have been installed before 1996 and 116 systems have been installed after 1996.

Figure 53: Relationship with FIBI Score and metrics (TSI) for FIBI Tool 4 development lakes.



Information about select Inconclusive Causes

Altered interspecific competition

Altered interspecific competition is unlikely causing measurable changes to the fish community in Pine Lake. Currently, the only non-native species in the lake is Curly-Leaf Pondweed, which has little known impact on the native fish community (Valley et al., 2004). The earliest recorded fisheries management activity on Pine Lake dates back to 1938 and this was only to create a habitat map. The first fish information is from 1956 and 1958 surveys (Minnesota Division of Game and Fish, 1958). This lake is also located in the 1837 Treaty Area, where there is a collaborative effort to monitor the Walleye population to ensure state and tribal allocations are appropriately set within safe harvest levels (DNR, 2017b).

Big Pine Lake (DOW 58-0138-00)

Big Pine Lake is 399 acres and has a maximum depth of 25 feet. The littoral zone of the lake covers approximately 34% of the lake. Big Pine Lake is in Schupp Lake Class 31; these characteristics put it into a group scored with FIBI Tool 4. Tool 4 lakes are generally deeper with simple shape (Table 88). The management of Big Pine Lake focuses on gamefish species such as Walleye, Northern Pike, Bluegill, Black Crappie, and Largemouth Bass.

Biological community

Big Pine Lake was assessed as insufficient information and vulnerable to a future aquatic life use impairment, based on the FIBI survey completed in 2014. The survey used multiple gears; backpack electrofishing, seines, trap nets, and gill nets. The FIBI score was 38, which is equal to the impairment threshold (38), which indicates the lake is vulnerable to future impairment (Table 89). The FIBI survey from 2014 captured 17 species (Table 101).

Table 101. Summary fish species sampled with multiple survey types on Big Pine Lake.

Species	Nearshore Survey	Trap Net Survey	Gill Net Survey
Banded Killifish	2014		
Black Crappie	2014	2014	2014
Bluegill	2014	2014	2014
Central Mudminnow	2014		
Common Shiner	2014	2014	
Golden Sunfish	2014	2014	
Hybrid Sunfish	2014		
Jonny Darter	2014		
Largemouth Bass	2014		
Northern Pike	2014	2014	2014
Pumpkinseed	2014	2014	
Rock Bass	2014		
Tadpole Madtom	2014		
Walleye		2014	2014
White Sucker		2014	2014
Yellow Bullhead	2014	2014	
Yellow Perch	2014	2014	2014

The FIBI score was positively influenced by the absence of tolerant species in all the sampling gears, and the low diversity of omnivore species (White Sucker and Yellow Bullhead) observed across all gears. The low proportion of biomass in the gill nets from top carnivore species (Black Crappie, Northern Pike, and Walleye) most negatively influenced the FIBI score. Only two intolerant species (Banded Killifish and Rock Bass) were sampled in the nearshore gears and the proportion of individuals of these intolerant species sampled was low. Northern Pike, White Sucker, and Yellow Perch were the most abundant species by biomass in the gill net sampling. Black Crappie, Bluegill, and White Sucker were the most abundant species by biomass in the trap net sampling. Bluegill and Largemouth Bass were the most abundant in the nearshore sampling, with moderate catches of Black Crappie and Yellow Perch.

DNR Fisheries currently stocks Walleye fingerlings at a rate of 1.3 lbs. per littoral acre on a biennial basis, as described in the current Big Pine Lake management plan amendment (DNR, 2017c). No significant relationships between FIBI scores or metrics and the number of species stocked, relative abundance of stocked species, or Walleye stocking density have been observed in Minnesota lakes (J. Bacigalupi, DNR, unpublished data). The effects of fisheries management activities can vary from lake to lake, due to each lake having individual lake characteristics and biological communities.

Because this is the first time utilizing the FIBI protocols in the lake assessment process, historical surveys of similar rigor are currently unavailable to facilitate comparison of fish species assemblages through time. However, historic data indicates that 20 species have been sampled in Big Pine Lake. Since 2004, no Shorthead Redhorse sampled have been sampled. Brown Bullhead have not been sampled since 1999. Big Pine Lake has been reported as slightly bog-stained. Bog-stained lakes are more acidic with darker watercolor and the fish communities can be somewhat variable (Pierce et al., 2003). Another limiting factor to fish in bog-stained lakes is a low pH, which can affect the fish species richness (Rahel, 1984).

Data analysis/Evaluation for each Candidate Cause

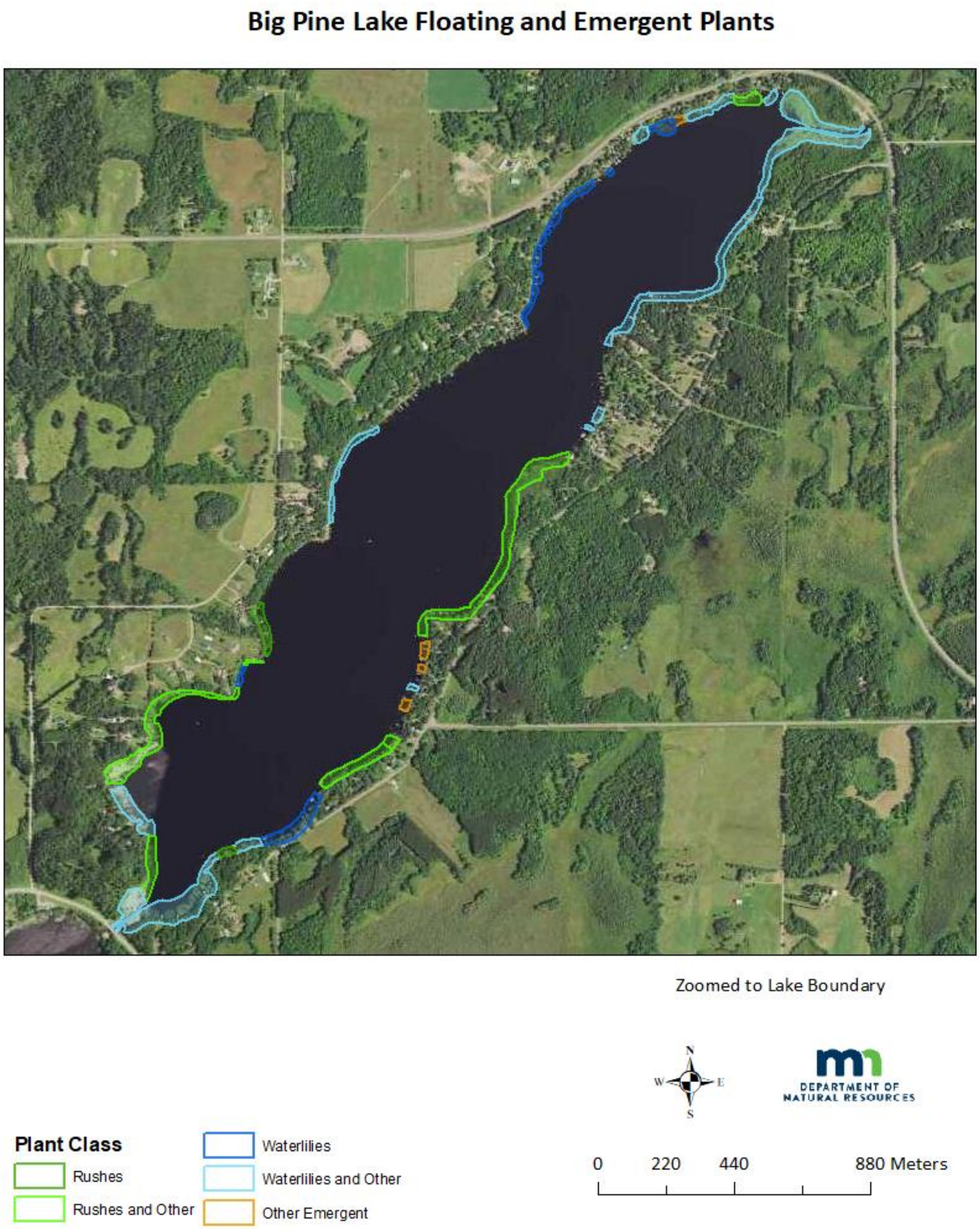
Physical habitat alteration-riparian disturbance/connectivity

Minnesota DNR Fisheries Area staff delineated the floating leaf and emergent aquatic vegetation of Big Pine lake on 07/24/2008, following the protocols listed in the DNR Lake Plant Mapping Manual. There were a total of 48.8 acres of floating and emergent plants mapped. This consisted of 18.3 acres of emergent dominated plant communities and 30.5 acres of floating leaf plant communities. For more information, see map in Figure 54 and summary Table 102 below.

Table 102. Number of stands and area covered (Acres) broken out by stand type and primary species in that stand as determined by the emergent and floating-leaf vegetation mapping efforts.

Category	Number of Stands	Total (Acres)	Mean Acres (1 SE)
Combined Total	32	48.8	1.5 (+/-0.3)
Emergent	**13**	**18.3**	**1.4 (+/-0.6)**
Other Emergent	4	0.9	0.2 (+/-0.0)
Rushes	2	1.4	0.7 (+/-0.4)
Rushes and Others	7	16.0	2.3 (+/-1.0)
Floating	**19**	**30.5**	**1.6 (+/-0.4)**
Waterlilies	5	5.8	1.2 (+/-0.5)
Waterlilies and Others	14	24.7	1.8 (+/-0.5)

Figure 54. Big Pine Lake (DOW 58-0138-00) floating and emergent vegetation map from 2010 data overlaid on an aerial image of the lake. Source: Minnesota Department of Natural Resources, Floating-leaf and Emergent Vegetation Summary Report, 2018.



A review of MPARS permit information indicates that Big Pine Lake has had 107 APM permits issued since 2006, with nine permits currently active. Several of the APM permits issued to individual lakeshore property owners have allowed automated aquatic plant control by device, mechanical control by hand removal, or chemical control of aquatic plants with treatment to provide reasonable access. Most of the control or removal done through APM activities is targeting submerged, floating-leaved, and emergent vegetation stands. The nine active permits are for one permanent maintenance of a 15-foot channel to open water and eight automated aquatic plant control devices. No violations for illegal plant removal have been reported to date; however, illegal unpermitted plant removal or lakeshore habitat destruction could negatively affect habitat quality. Aquatic plant removal has contributed to some physical habitat loss within the lake, but whether the extent of habitat loss is detectable with the FIBI is unknown.

A review from 2017 Google imagery counted 171 docks and 10 swim platforms in Big Pine Lake. A previous aerial review counted 137 docks and calculated a dock density of 9.6 docks per kilometer of shoreline on Big Pine Lake (Beck et al., 2013). Densities exceeding 10 docks per kilometer have been linked to changes in fish community composition (Jacobson et al., 2016) and to FIBI metrics (J. Bacigalupi, unpublished). It is possible that changes to fish community composition are occurring within Big Pine Lake because of human activity around docks and in the riparian area.

There is an outlet on the north end of Big Pine Lake which is the headwaters of the Pine River. The outlet contains a dam, which was built in 1937 by a power company for lake water level management. The dam was eventually sold by the power company and purchased by the state in 1936 (D. McNeil, DNR, personal communication, March 21, 2019). This dam is a barrier to fish migration most of the time and has been identified as a potential project for modification or removal efforts (L. George, DNR, personal communication, March 21, 2019; DNR, 2016). According to the lake management plan for Big Pine Lake, there is limited Northern Pike and Walleye spawning habitat available and this has contributed to low population levels in past (DNR, 2017c). According to Aadland (2015), migration barriers such as dams, can cause basin wide extirpations as they block access to areas of critical spawning habitat. Removal of this barrier could potentially improve access for spawning and access for small-bodied fishes from tributaries to recolonize.

Eutrophication

Big Pine Lake is proposed for listing as not supporting aquatic recreation and impaired for nutrients. The 10-year averages of all summer samples included means for TP of 32.49 µg/L, chlorophyll-a (corrected for pheophytin) of 16.02 µg/L, transparency of 1.61 meters, and TSI of 57.81 (MPCA, 2019d). When compared with the typical Northern Lakes and Forest ecoregion ranges (Table 97), Big Pine Lake has higher mean TP with the mean chlorophyll-a value and transparency outside the expected range values for this ecoregion (MPCA, 2018c). This lake does experience some heavy summer algae blooms, which impacts water recreation (DNR, 2017c). In the FIBI development for the tool 4 lakes, metrics such as TSI are highly correlated to the FIBI score as seen in Figure 53. Of the 3,962 acres of land contained within the contributing watershed, approximately 15.48% is classified as unnatural land cover (i.e., 7.86% developed, 2.57% cultivated, and 5.05% hay and pasture land) and the remaining 84.51% is classified as natural land cover (i.e., 10.39% water, 27.58% forest, 12.42% shrub and herbaceous, and 34.12% wetland; Figure 52; U.S. Geological Survey, 2011).

Residentially developed land within the contributing watershed is primarily located around Big Pine Lake, but also includes the network of roads and residences found throughout rural areas of the watershed. Pine County zoning records indicate there are approximately 156 parcels on Big Pine Lake and 33 of those parcels are undeveloped. There are approximately 148 homes on Big Pine Lake with private septic systems. Of these, 81 systems have been installed with compliance certificates after 2000 and 36 systems have been installed with compliance certificates after 2008 (C. Anderson, Pine County Planning and Zoning, Unpublished data, March 3, 2019). Currently, there are 31 septic systems on Big Pine Lake with no records or certificate of compliance.

Information about select Inconclusive Causes

Altered interspecific competition

Altered interspecific competition is unlikely a cause of measurable stress to the fish community in Big Pine Lake. The only non-native species that has been sampled in the lake is Curly-leaf Pondweed. The earliest gamefish survey occurred in 1956, which documented the presence of Northern Pike, Bluegill, Black Crappie, and Walleye (DNR, 2017c). Fingerling Walleye are regularly stocked, but adult Walleye are sampled in low numbers. This lake is also located in the 1837 Treaty Area, where there is a collaborative effort to monitor the Walleye population to ensure state and tribal allocations are appropriately set within safe harvest levels (DNR, 2017c).

Conclusions and recommendations

Conclusions

Table 103 summarizes the probable stressors and related information in the KRW for each lake identified as vulnerable to impairment or impaired based on the FIBI. This report has presented and identified the potential stressors influencing the FIBI on Oak Lake, Pine Lake, and Big Pine Lake in the KRW. Oak Lake scores below the FIBI impairment threshold and has been assessed as not supporting for aquatic life use. It is difficult to determine which stressors or combination of stressors are contributing to the aquatic life impairment on Oak Lake, but the nutrient levels and dock density are near levels at which lower numbers of intolerant species and lower FIBI scores are observed (Figure 48). Pine Lake was assessed as insufficient information and vulnerable to future impairment; the two FIBI scores being below and above the impairment threshold. Pine Lake has two primary stressors, eutrophication and physical habitat alteration. The connecting Big Pine Lake was also assessed as insufficient information and vulnerable, with the FIBI scoring right at the impairment threshold. The primary stressors identified for Big Pine Lake were also eutrophication and physical habitat alteration.

Several other stressors, such as altered interspecific competition, dissolved oxygen, and temperature regime changes have been identified as inconclusive causes within Oak Lake, Pine Lake, and Big Pine Lake. Even though these stressors are inconclusive, they cannot be eliminated as potentially impacting the fish communities and FIBI scores. In all three lakes, the main methods to improve fish community composition and the FIBI scores would be to restore altered shoreline, protect undeveloped shoreline and aquatic vegetation stands, and reduce phosphorus inputs. Additional lakes within the KRW were assessed as being impaired for aquatic recreation and aquatic consumption uses, but they have been or will be discussed in other reports (MPCA, 2019a; MPCA, 2018e).

Table 103. Summary of primary stressors by lake for lakes impaired based on the FIBI.

● = probable stressor; o = inconclusive stressor; NA = no or insufficient data

AUID (DOW #)	Lake Name	Water Quality Habitat limiting	Physical Habitat limiting		Fish	Comments on historical winterkill	Other Considerations and comments
		Poor water quality-eutrophication	Poor Shoreline habitat condition	Lack of Physical Aquatic Plant Habitat	Abundant Carp and/or Bullhead		
58004800	Oak	o	o	o	o	Historical, none documented since 1976-1977.	Past management included bullhead removal, bullhead population remains low, potential to winterkill
01000100	Pine	●	●	●			Nutrient Impaired, moderately high dock density (15), some aquatic plant removal activity, slightly bog-stained water
58013800	Big Pine	●	●	●			Moderately high dock density (15), some aquatic plant removal activity, Big Pine Dam is fish barrier most the time, slightly bog-stained water

Recommendations

Future planning for eliminating or reducing stressors to biological communities within KRW lakes should focus on actions that reduce eutrophication and physical habitat disturbance to the lakes with impairments or lakes that are vulnerable to impairment. Efforts to reduce eutrophication in lakes includes reducing nutrient loading and sedimentation through maintaining natural shorelines or buffers around lakes, management of sources of sediment from lake inlets, outlets, or areas with erosion, as well as proper septic design or inspection. Leaving a natural shoreline undisturbed or planning a restoration project are actions that can be implemented to protect the existing stands of emergent vegetation and other aquatic vegetation, which are essential for the health of the fish communities and other aquatic life.

Several projects have taken place over the last seven years to address physical habitat disturbance. For example, in 2013, the Pine County Soil and Water Conservation District (SWCD) received two Clean Water Fund grants (Pine County Soil and Water Conservation District, 2019). One grant was used in Robinson Park in the City of Sandstone, to install a vegetated buffer and educational signs along the banks of the Kettle River. The other grant project was used in the City of Askov, to install a rain garden and signage to educate the public on rain garden benefits, as well as other low impact development practices and educational signs. There should be continued support for activities like these mentioned above, which promote the use of buffers along shoreline and encourage low impact development practices along important waterways. In addition, things such as, best management practices (BMP) would be an option to potentially reduce stressors like physical habitat alteration and eutrophication in lakes at an individual catchment scale or even a major watershed scale.

The Oak-Willow River subwatershed has had at least two best management practices (BMP) in place from 2004-2017 (MPCA, 2019e). One BMP dealt with practice standard 647, which uses early successional habitat development or management by using manipulation of a stand of plants in croplands, pastures, old fields, wildlife, or forestland in order to create and maintain early successional characteristics the benefit wildlife as well as natural communities (NRCS, 2012a). The conservation benefits include; creation of a desired plant community, reduced soil erosion and sedimentation, improved water quality, increased streamflow, improved wildlife habitat, improved forage, and reduced wildlife hazard (NRCS, 2012a). The other BMP used practice standard 642, which involves use of a water well that can provide water for livestock, wildlife, irrigation, fire control, and other agricultural uses (NRCS, 2014). The water well can be used to provide an alternative water source for livestock, which minimizes the need to water livestock with use of a stream or lake and can reduce sedimentation from livestock grazing along stream banks or lake shoreline. Within this catchment, there are more opportunities to apply BMP's to help reduce the nonpoint pollution, restore altered habitat, and protect existing habitat.

Within the Big Pine Lake subwatershed, which includes both Pine Lake and Big Pine Lake, there were 19 best management practices in place from 2004 to 2017 to help reduce nonpoint pollution sources from agricultural and urban areas (MPCA, 2019e). There were three Critical Area Plantings, three Prescribed Grazing areas, two Riparian Herbaceous Cover areas, one area of Streambank and Shoreline Protection, and ten other BMP's including; Hedgerow Planting, Roof Runoff Structure, Tree/Shrub Site Preparation, and Well Decommissioning.

BMPs provide a wide range of benefits. The practice standard of Critical Area Plantings (342), allows permanent vegetation to be planted on sites that have or are expected to have high erosion rates or on sites with conditions that prevent the establishment of vegetation with normal practices. This practice provides benefits such as, reduced sheet and rill erosion, reduced transport of sediment, and stabilizes slopes, road banks, stream banks, shorelines or sand dunes (NRCS, 2016).

Prescribed grazing (528) manages the harvest of vegetation with grazing or browsing animals for specific ecological, economic, and management objectives. This practice standard is used for many purposes such as improvement or maintenance of desired plant species composition, providing quality forage for animals, improving or maintaining both surface or subsurface water quality or water quantity, improving or maintaining riparian or watershed function, reduction of soil erosion, improving or maintaining quality of food or cover available for wildlife, and reducing fine fuel loads to achieve a desired condition (NRCS, 2017).

The Riparian Herbaceous Cover practice standard (390) uses grasses, grass-like plants, and forbs that are tolerant of intermittent flooding or saturated soils to establish cover in the transitional zone between terrestrial and aquatic habitats. This practice standard is beneficial for the following reasons: providing food, shelter, shade, and access to adjacent habitats, serving as a nursey habitat or pathway for movement of aquatic, semiaquatic, and terrestrial organisms, improving and protecting water quality, stabilization of streambanks or shorelines, and increasing net carbon storage in the biomass and soil (NRCS, 2012b).

Streambank and Shoreline Protection (580) uses vegetative or structural measures to stabilize and protect streambanks, lakes, estuaries, or excavated channels from scouring or erosion. Most of the time this practice standard is used to prevent loss of land adjacent to the water, but it can also be used to regulate water flow, erosion damage, offset sediment loss from banks, and provide an improved stream corridor for fish or wildlife habitat, as well as for aesthetics or recreational purposes (NRCS, 2012c). The subwatersheds of the impaired and vulnerable lakes, and the whole KRW, could benefit substantially by improving or restoring the quality of riparian areas, reducing runoff, limiting the amount of APM activity, and better management of the lake inlets and outlets.

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Appendix 1: Summary Stressor Identification Pages for KRW Lakes

Summary of Oak Lake Fish Community and Stressors

- **Fish Community:**
  - Fish-based index of biotic integrity (FIBI) scores: 20 (2017), 10 (2015), *28 (2010)*
    Impairment threshold = 24
    Italicized information is out of assessment window, older data, and used as supporting information
  - Species sampled that negatively affect the FIBI score: Black Bullhead, Brown Bullhead, Fathead Minnow, White Sucker, and Yellow Bullhead
  - Species sampled that positively affect the FIBI score: Black Crappie, Bluegill, Central Mudminnow, Common Shiner, Golden Shiner, Hybrid Sunfish, Iowa Darter, Johnny Darter, Largemouth Bass, Northern Pike, Pumpkinseed, Tadpole Madtom, Walleye, Yellow Perch

Oak Lake's Contributing Watershed

- **Inconclusive stressors:**
  - Physical habitat alteration: 9.6 docks/km of shoreline, Score the Shore (StS) score of 79 (moderate habitat quality), documented cases of aquatic plant management (APM) activities (one violation reported since 1988)
  - Eutrophication: 34.69 µg/l total phosphorus, nutrient impairment listing by MPCA, approximately 21% watershed disturbance (residential development, agriculture, roads)
  - Altered interspecific competition: Chinese mystery snail, Banded mystery snail, and stocking (gamefish management activities)
  - Temperature regime changes: 0.75 to 0.99°C increase in annual lake-specific air temperatures, 0.16°F increase in July average air temperatures within the Kettle River Watershed since 1895
  - Decreased dissolved oxygen: Historical winterkill 1976 to 1977 but nothing documented since
- **Recommendations:**
  - More research on sources of nutrient increases and efforts to reduce nutrient levels
  - Promote and maintain riparian areas with use of shoreline buffers or shoreline restoration projects
  - Limit removal of aquatic plant communities (submerged, floating leaved, and emergent)
  - Collect more information on dissolved oxygen and water temperature

Summary of Pine Lake Fish Community and Stressors

- **Fish Community:**
    - Fish-based index of biotic integrity (FIBI) scores:
      50 (2017), 36 (2014), Impairment threshold = 38
    - Species sampled that negatively affect the FIBI score: White Sucker and Yellow Bullhead
    - Species sampled that positively affect the FIBI score: Black Crappie, Bluegill, Central Mudminnow, Common Shiner, Golden Shiner, Hybrid Sunfish, Johnny Darter, Iowa Darter, Largemouth Bass, Mottled Sculpin, Northern Pike, Northern Redbelly Dace, Pumpkinseed, Rock Bass, Tadpole Madtom, Walleye, Yellow Perch
    - Other species commonly sampled in nearby healthy lakes within the watershed not sampled: Banded Killifish, Blackchin Shiner, Bluntnose Minnow, Spottail Shiner
    - Slightly bog-stained water: can limit species richness and cause variability in fish community
- **Candidate stressor:**
    - Physical habitat alteration: 15 docks/km of shoreline, Score the Shore (StS) score of 64 (low habitat quality), documented cases of APM activities
    - Eutrophication: 37 µg/l total phosphorus, nutrient impairment listing by MPCA, approximately 18% watershed disturbance (residential development, agriculture, roads), only 26% of ISTS have been inspected since 1996
- **Inconclusive stressors:**
    - Altered interspecific competition: game fish management activity (stocking), Curly-leaf Pondweed
    - Temperature regime changes: 0.75 to 0.99°C increase in annual lake-specific air temperatures , 0.16°F increase in July average air temperatures within the Kettle River Watershed since 1895
- **Recommendations:**
    - More research on sources of nutrient increases and efforts to reduce nutrient levels
    - Promote and maintain riparian areas with use of shoreline buffers or shoreline restoration projects
    - Limit removal of aquatic plant communities (submerged, floating leaved, and emergent)
    - Increase efforts to gain compliance on all individual septic treatment systems (ISTS) that exist on lake

Summary of Big Pine Lake Fish Community and Stressors

- **Fish Community:**
  - Fish-based index of biotic integrity (FIBI) scores: 38 (2014), Impairment threshold = 38
  - Species sampled that negatively affect the FIBI score: White Sucker, Yellow Bullhead
  - Species sampled that positively affect the FIBI score: Banded Killifish, Black Crappie, Bluegill, Central Mudminnow, Common Shiner, Golden Shiner, Hybrid sunfish, Johnny Darter, Largemouth Bass, Northern Pike, Pumpkinseed, Rock Bass, Tadpole Madtom, Walleye, Yellow Perch
  - Other species commonly sampled in nearby healthy lakes within the watershed not sampled: Blackchin Shiner, Bluntnose Minnow, Iowa Darter, Spottail Shiner
  - Slightly bog-stained water: can limit species richness and cause variability in fish community
- **Candidate stressor:**
  - Eutrophication: 32.5 μ/L total phosphorus, nutrient impairment listing by MPCA, approximately 15.5% watershed disturbance (residential development, agriculture, roads), 45 parcels with no individual sewage treatment system (ISTS) records since 2000
  - Physical habitat alteration: 15 docks/km of shoreline, no Score the Score (StS) score, documented cases of APM activities (no violations reported), Big Pine Lake Dam affects the connectivity to the headwaters of Pine River
- **Inconclusive stressors:**
  - Altered interspecific competition: Curly-leaf Pondweed, game fish management activity (stocking)
  - Temperature regime changes: 0.75 to 0.99°C increase in annual lake-specific air temperatures, 0.16°F increase in July average air temperatures within the Kettle River Watershed since 1895
- **Recommendations:**
  - More research on sources of nutrient increases and efforts to reduce nutrient levels
  - Promote and maintain riparian areas with use of shoreline buffers or shoreline restoration projects
  - Limit removal of aquatic plant communities (submerged, floating leaved, and emergent)
  - Increase efforts to gain compliance on all individual septic treatment systems (ISTS) that exist on lake