Stressor identification

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Mississippi River-Grand Rapids Watershed Stressor Identification Report

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Acronyms, abbreviations, 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, a computer mapping of ditches and straightened streams.

Contributing watershed.. All upstream areas bounded peripherally by a divide that ultimately drain into a particular watercourse or water body

CR .... County Road

CSAH .... County State Aid Highway

DO .... Dissolved Oxygen

DOC .... Dissolved Organic Carbon

DOW .... Division of Waters number; in this report, a unique identification number for water basins in Minnesota. Numbering follows the format of XX-YYYY-ZZ where XX is a county code, YYYY is the basin number in that county, and ZZ is the sub-basin identifier

DNR .... Minnesota Department of Natural Resources

DS .... Downstream

EPA .... United States Environmental Protection Agency

FIBI .... Fish-based Index of Biological Integrity - stream and lake versions.

fps .... Feet per second, a measure of stream flow velocity

GIS .... Geographic Information System

HDS .... Human Disturbance Score – a measurement of human disturbance at and upstream of a biological monitoring site; scores range from 1-81

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

IBI .... Index of Biological Integrity – a multi-metric index used to score the condition of a biological community, either fish or macroinvertebrates in this report.

Insectivorous species ... A species that predominantly eats insects

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

ISTS .... Individual Sewage Treatment System

IWM .... MPCA's Intensive Watershed Monitoring, which includes chemistry, habitat, and biological sampling.

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

m .... The abbreviation for meter

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

MPCA .... Minnesota Pollution Control Agency

MPN .... Most Probable Number (bacteria per 100 mL)

MRGRW .... Mississippi River Grand Rapids Watershed

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

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

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.

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

P .... Phosphorus

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, here relating to fish

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

StS .... Score the Shore survey; a survey designed by the DNR to be able to rapidly assess the quantity and integrity of lakeshore habitat so as to assess differences between lakes and detect changes over time

TALU .... Tiered Aquatic Life Uses, a new process of setting standards for different categories of streams. MPCA plans to implement this approach around 2015.

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

TMDL .... Total Maximum Daily Load

Tolerant species .... A species whose presence or absence does not decrease, or may even increase, as human disturbance increases

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.

10X .... Ten times (chemistry samples collected on 10 dates)

Executive summary

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 Mississippi River - Grand Rapids Watershed (MRGRW). 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/ .

The MRGRW (Figure 1) is situated within a mixed-landcover region of north central Minnesota, consisting of forests, large bog-type wetlands, and agricultural fields and pastures. The watershed also contains the western portion of the Mesabi Iron Range, where open pit mining has occurred for many decades. Agricultural land usage is not concentrated in any one part of the MRGRW, though the greatest density occurs along the Mississippi River, and around the towns of Remer and Palisade. Much of the agriculture is related to animal rearing, with many of the fields being used for hay, rather than for row crops. Most of the cultivated agriculture is wild rice. There are two parcels of Reservation lands in the MRGRW, though these comprise a very small portion of the watershed; each contains a small number of residences. Also contributing to the relatively natural condition of much of the watershed are the large peatlands found in the southern and central parts of the MRGRW. The MRGRW contains numerous public/protected lands; parts of the Chippewa National Forest in two locations along the western edge of the MRGRW, parts of eight state forests, two state parks, two large and several small state wildlife management areas, and one small Scientific and Natural Area (Figure 1).

The density of residential and urban land use is very low in the MRGRW, with the exception being Grand Rapids, and the string of towns along the Iron Range. The other somewhat dense, localized developments are the shoreline properties around many of the MRGRW's lakes. Stressors related to urbanized lands (impervious surfaces, stormwater runoff, wastewater facility discharges, etc.) are not expected to be a common issue; there are no permitted municipal wastewater or industrial effluent dischargers on any of the AUIDs with biological impairments. Some unknown amount of ISTS failure may be present as well, though there has been general progress on this situation over the years.

Given these landscape/land use attributes, the primary anthropogenic stressors in the MRGRW are likely to be non-point types, and most likely from mining, agricultural activities, or areas of more dense residential development (such as around lakeshores). A somewhat unique landscape disturbance in the MRGRW is the extensive ditching of wetlands during the homesteading period. One stressor, which can occur anywhere roads are present, is road-crossing infrastructure, which can be a barrier to fish migration. All across the state, culverts in particular, are commonly found to be at least partial barriers to fish passage, while most bridges allow fish to pass easily.

Streams/Rivers

Fourteen Assessment Unit (AUID) reaches from 13 different streams were brought into the SID process (Figure 1) because they were determined to have substandard biological communities via the 2015 Intensive Watershed Monitoring (IWM) and the subsequent 2017 Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. Two other biological impairments on small, wetland-influenced streams in the far northern part of the MRGRW were determined by an assessment committee to be due to natural background conditions of low DO (AUIDs 717 and 719). The pattern that stands out amongst the impairments is that nearly all are small streams and short reaches, the exception being the Sandy River. Another commonality to most of them, including the Sandy River, is the presence of ditching in the AUID's subwatershed. Though not biologically impaired, Split Hand Creek was studied further due to observations of channel instability (eroding banks and excess-bedded sediment) and high levels of bacteria. Studying streams that are experiencing somewhat less stress than the degree that would cause impairment is part of the “P” in the acronym WRAPS (P being “protection”). Moderately degraded streams without official impairment can also be improved ecologically with proper BMPs.

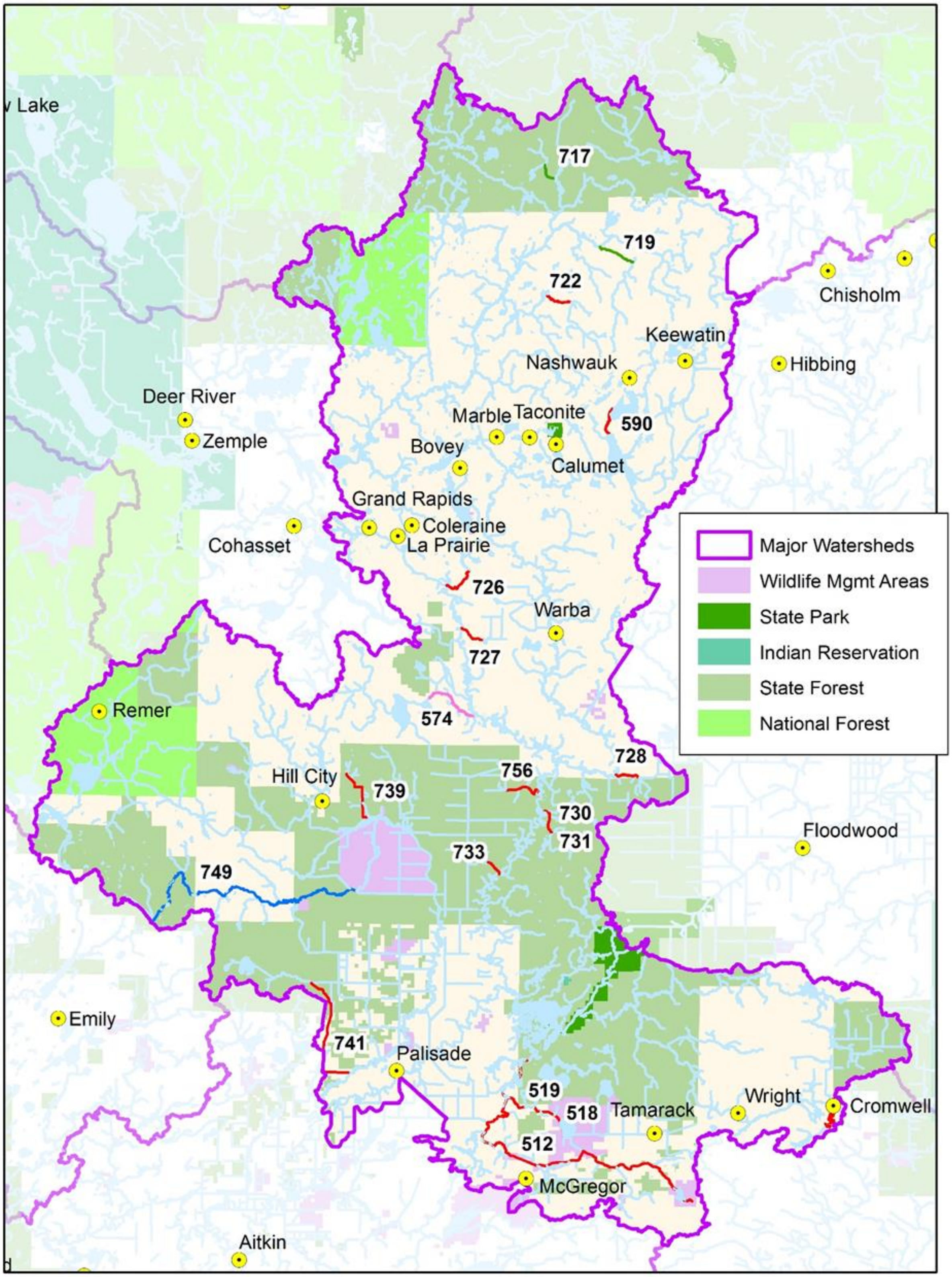
- Sandy River (AUID 07010103-512) - Fish and Invertebrates
- Minnewawa Creek (AUID 07010103-518) - Fish and Invertebrates
- Minnewawa Creek (AUID 07010103-519) - Fish
- Split Hand Creek (AUID 07010103-574) - Not biologically impaired, but some problem signs in water chemistry and physical parameters.
- Pickerel Creek (AUID 07010103-590) - Fish and Invertebrates
- Tributary to Bray Lake (AUID 07010103-722) - Fish
- Tributary to Mississippi River (AUID 07010103-726) - Fish and Invertebrates
- Tributary to Mississippi River (AUID 07010103-727) - Fish
- Tributary to Swan River (AUID 07010103-728) - Fish
- Tributary to Mississippi River (AUID 07010103-730) - Fish
- Tributary to Unnamed Creek (AUID 07010103-731) - Fish
- Pokegama Creek (AUID 07010103-733) - Fish and Invertebrates
- Tributary to Hill River Ditch (AUID 07010103-739) - Fish
- White Elk Creek (AUID 07010103-741) - Fish
- Unnamed Ditch to Mississippi River (AUID 07010103-756) - Fish and Invertebrates

A number of stressors to the 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. A non-point source issue involving pastured cattle in riparian zones (AUID-574) has caused some habitat alteration but has not yet resulted in an aquatic life use impairment. A culvert on AUID-756 was found to be a fish passage barrier. Included in the infrastructure category are legacy ditching projects, which in the early 1900’s attempted to drain extensive bog areas in the southern and central parts of the MRGRW. These ditches altered the hydrology downstream, and caused channel damage that lingers to this day, leading to habitat loss (512, 519, 728, 731, 733, and 756). The ditches also contribute to low DO levels in streams due to the wetland-sourced water they convey to the streams. The natural stressor at AUIDs 717 and 719 is low DO, due to the extensive wetlands in those subwatersheds. No explanation was found for the fish impairment in the tributary to Bray Lake (AUID-722). One potentially significant stressor not found in most Minnesota watersheds is large-scale mining, though most of the biological impairments were not associated with the Iron Range area, the exception being Pickerel Creek (AUID-590), which has some plausible mining influence due to a large tailings pond and surrounding area that is largely un-vegetated.

Lakes

Of the fish communities sampled to evaluate biological health in 52 lakes within the MRGRW, only one lake, Lower (South) Island (DOW# 09-0060-02), was assessed as not supporting aquatic life use based on a fish-based index of biological integrity (FIBI) score that was below the impairment threshold established for similar lakes. The primary candidate stressor contributing to the condition of the lake’s fish community, as measured with the FIBI, is eutrophication resulting from excess nutrients.

Figure 1. Map of the MRGRW showing stream reaches with biological impairments (in red), natural background stream impairments in green, Aquatic Life Use stream chemistry impairments (blue), and Aquatic Life Use lake impairment (red; found at extreme south-eastern edge of the MRGRW boundary at Cromwell).



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). A WRAPS is comprised of several types of assessments. The MPCA conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2015 and 2016. The IWM assessed the aquatic biology and water chemistry of the Mississippi River - Grand Rapids Watershed (MRGRW) streams and rivers. The second assessment, known as the Stressor Identification Assessment (SID), builds on the results of the IWM. The MPCA, along with its partner the Minnesota Department of Natural Resources (DNR), conducted the SID assessment during 2016 - 2017. This document reports on the second step of a multi-part WRAPS for the MRGRW.

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 Mississippi River - Grand Rapids 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 MRGRW webpage; https://www.pca.state.mn.us/water/watersheds/mississippi-river-grand-rapids .

Landscape of the MRGRW

A detailed description of various geographical and geological features of the landscape of the MRGRW is documented in the Mississippi River - Grand Rapids Watershed Monitoring and Assessment Report (MPCA, 2018). That information is useful and necessary for understanding the settings of the various MRGRW's subwatersheds, and how various landscape factors influence the hydrology within the MRGRW. The following information is intended to provide a basic description of the MRGRW landscape.

Much of the MRGRW is relatively flat terrain, with some exceptions in the northern third of the watershed. As such, the streams and rivers that run throughout the watershed are commonly low gradient. Streams in the southern and central MRGW flow through extensive wetland and bog habitat. This situation affects many other characteristics of the streams and aquatic biological communities. The streams and rivers flow slowly, and thus accumulate fine grained or organic particulate material as their primary substrate. Low 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 original, pre-settlement landscape was almost exclusively forests, wetlands, and lakes (Figure 2). Though 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 is still in a forested state. In general, the agriculture occurring in the MRGRW is hay and cattle production, though a small amount of row crop agriculture exists. Acreage used for agriculture is sprinkled throughout the MRGRW, but is relatively more dense in the southern and central parts of the watershed, such as around Palisade, Tamarack, and Remer, as well as all along the corridor of the Mississippi River. The corridor of the Swan River upstream of Warba to its headwaters at Swan Lake also has more abundant agricultural land. A rather unique type of agriculture exists in the MRGRW, that being farmed wild rice, which occurs almost completely in the McGregor area. The percentages of various categories of land cover are presented in Table 1, and notably Figure 3 shows the extent of land area that is currently wetland (37.4 % of the MRGRW).

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

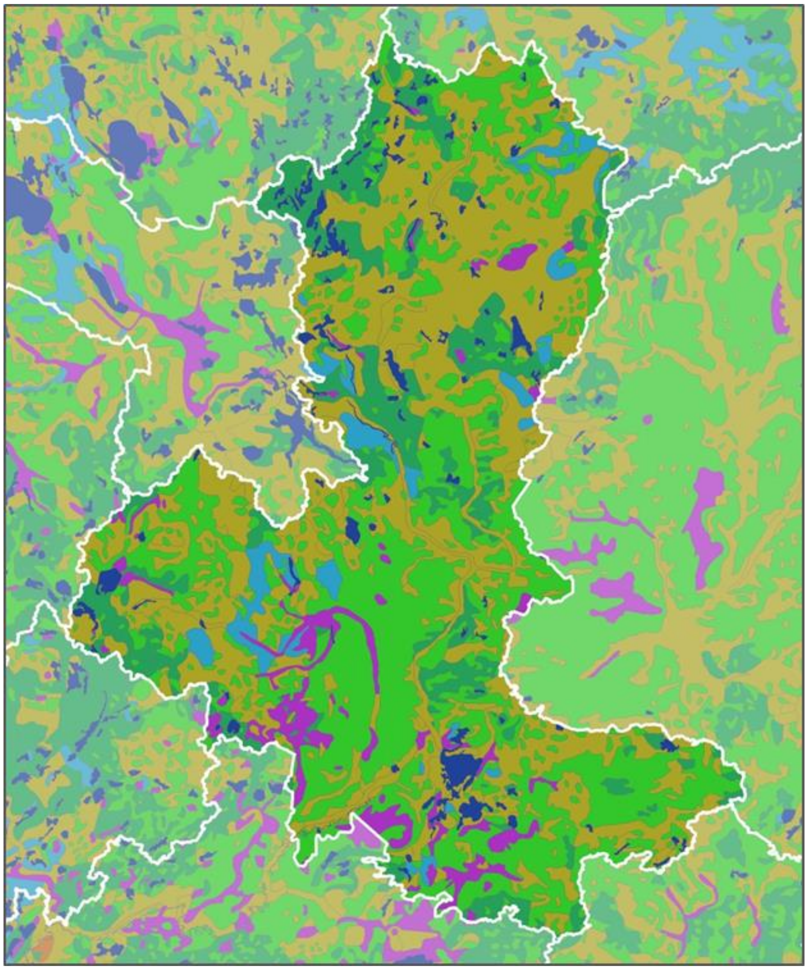
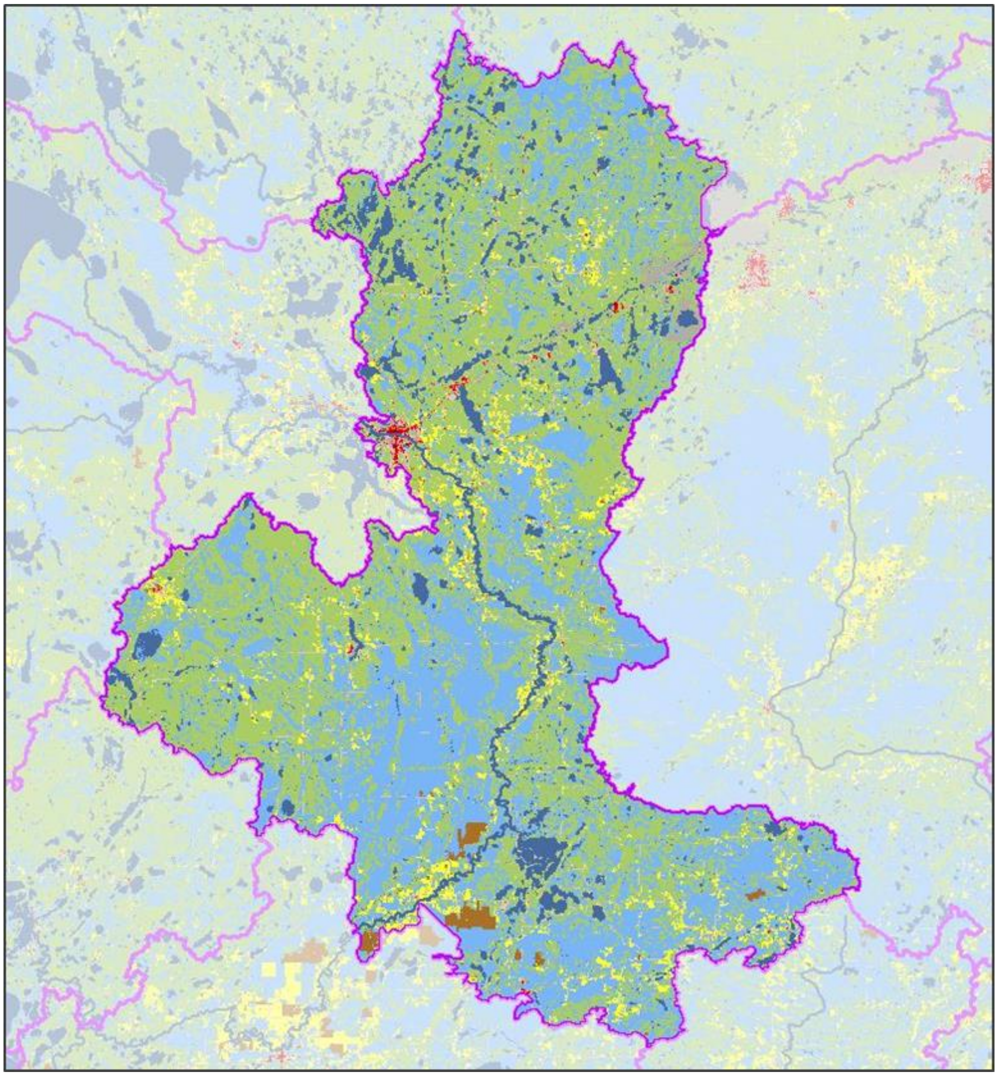


Table 1. Percentages of the various land cover types from 2011 NLCD GIS coverage (MPCA, 2018a).

Land cover type	Percent of Land Area
Developed (all intensities grouped)	3.3
Cultivated Crops	0.9
Rangeland	5.2
Barren/Mining	0.7
Water, wetlands, and forest lands	89.8

Figure 3. MRGRW land use/cover as determined by the 2011 National Land Cover Dataset. Key: green = forest/shrub, yellow = hay/pasture, brown = row crop agriculture, light blue = combined wetland types, dark blue = open water, reds = developed.



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 MRGRW for many years. The determination of candidate stressors used both the historical data and data collected during the 2015 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

The 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 five major components; Biology, Hydrology, Geomorphology, Water Quality, and Connectivity. Each of these five major components consist of a number of related sub-components, and finally, a set of individual metrics that comprise each sub-component. Scores are available for each metric, sub-component, major component, and then the overall major watershed score. Scores can be compared to other watersheds in the state to assess the relative health of each, at that scale of geography. Some of the metrics and sub-components are also scored at a smaller geographic scale, that of the 12HUC watershed.

A few of the metrics that are pertinent to stressor identification are highlighted here. An assessment of the “nonpoint source pollution threat” to water quality within the water quality component of the WHAF, shows non-point pollution, relative to other parts of the state, is likely not a widespread stressor in the MRGRW Figure 4. According to the Non-Point Source Pollution Index, the MRGRW ranks as tied for 14th out of the 80 watersheds in Minnesota (where 1st is best, or has least threat). This equates to the 83.5th 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 MRGRW (with the exception of Grand Rapids), this threat is fairly low (Table 2). There are 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 MRGRW generally do not have the same degree of shoreline development as area lakes, and thus this near-shore threat is more particular to lakes, and less of an issue with rivers and streams. None of the stream impairments has a town located on the stream channel.

The Point Source Index 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 MRGRW. Several industrial and municipal wastewater plants discharge wastewater to surface waters, though many discharge to the Mississippi River, and thus do not affect the smaller rivers and streams included in this report.

The Localized Pollutant Source Index (LPSI) scored at the high end of the middle 1/3 of Minnesota’s major watersheds. The septic system metric, part of the LPSI, showed localized hot spots of concern, primarily the area around Big Sandy Lake, and the area just east of Grand Rapids (Figure 5), with moderate concern in the areas around Swan Lake (near Pengilly) and Big Thunder Lake (along State Hwy 6, south of Remer) . The overall MRGRW “Water Quality” WHAF Component score was 76, tied for

12th best of Minnesota's 80 major watersheds. The overall "Watershed Health Score" is 69, tied for 11th best of Minnesota's 80 major watersheds. The overall WHAF scorecard, which includes many more metrics, can be found at: http://www.dnr.state.mn.us/whaf/index.html.

The main message provided by this WHAF analysis, which showed good or very good scores for many of the metrics and components, is that there are likely not going to be systematic stressors occurring broadly over the MRGRW, and that stressors are more likely going to be of a local nature.

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

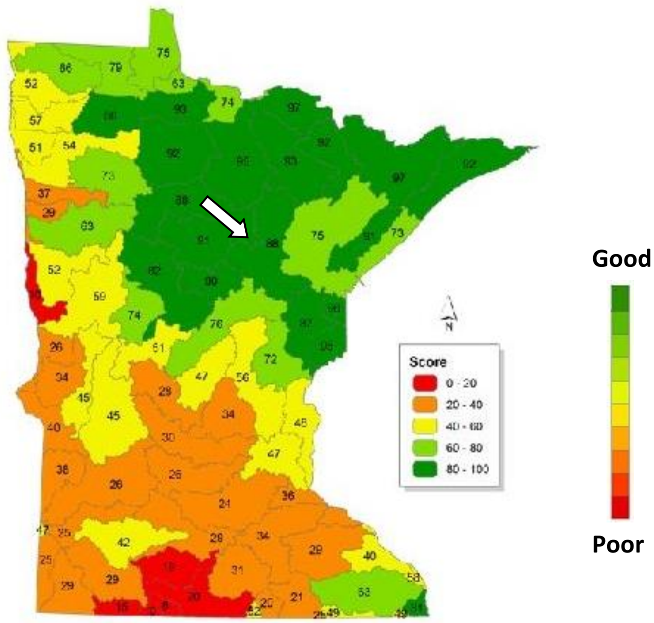


Figure 5. The WHAF Septic System metric within the Nonpoint Source Index for the MRGRW showing scoring categories for the catchment scale. (Graphic is output from the scorecard page of the WHAF website).

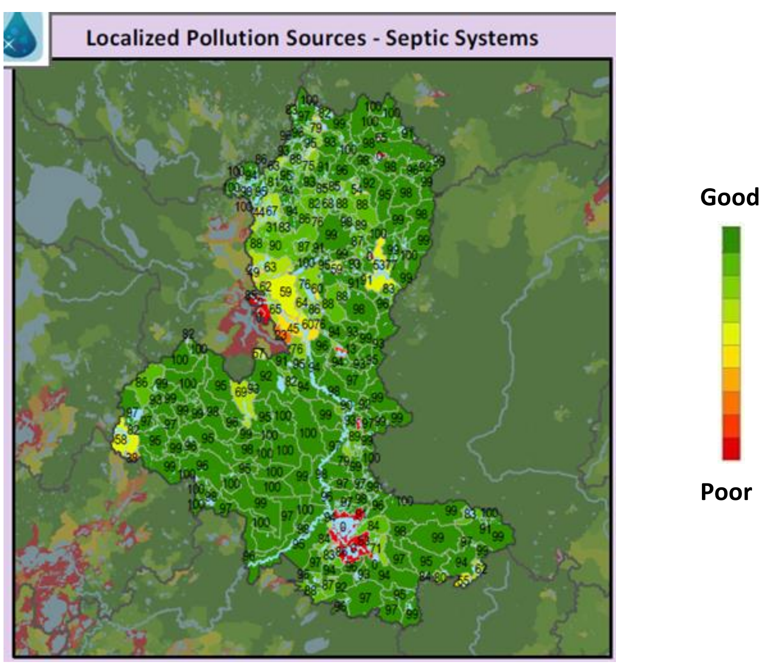


Table 2. Ranking of several WHAF metrics or indices for the MRGRW relative to Minnesota's other 80 watersheds (1st is best for water quality).

	Impervious Surface	Nonpoint Threat Index	Localized Pollution Sources	Perennial Cover	Flow Variability Index	Water Storage Loss	Aquatic Connectivity
Rank	25th (t)	14th (t)	30th (t)	14th	80th *	19th	14th (t)

(t) = tied with other watersheds for this rank.

*This is likely because of the large reservoir system on the Mississippi River and periodic flow releases, upstream of Grand Rapids.

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 wastewater permit requirement. Recent trend data for phosphorus originating from wastewater discharges is available for the major watersheds of Minnesota. 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 8HUC 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. According to the 2010 census data, the MRGRW is quite sparsely populated relative to the state as a whole. Localized exceptions are the areas around Grand Rapids (pop. 10,869), and the chain of towns along Hwy 169 between Grand Rapids and Hibbing (Coleraine, Bovey, Taconite, Marble, Calumet, Pengilly, Nashwauk, and Keewatin), the largest population being Coleraine at 1,970. Several small towns are also located along the Hwy 200 corridor, which include: Cromwell (234), Wright (127), and Tamarack (56) and McGregor (391). Four other towns are found scattered across the watershed; Remer (370), Palisade (167), Hill City (633), and Warba (181) - Population data presented here is from 2010 US Federal Census (MSDC, 2015). Only Grand Rapids is large enough to meet the MS4 Stormwater Permit requirements, which manage surface runoff.

Recent GIS-derived land use statistics showed that 3.3 % of the watershed area is categorized as Residential/Commercial (MPCA, 2018). The MRGRW ranks 25th (at the 66th percentile) 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, near one of the larger towns/cities).

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 MRGRW 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. Somewhat-recent septic system statistics for Aitkin, Itasca, and Carlton Counties estimate that 3%, 27%, and 14% respectively of the individual treatment systems were "Failing" systems in these counties (MPCA 2013a). "Imminent Public Health Threats" (IPHT; i.e., systems with direct discharge to a stream), were estimated respectively at 1%, 3%, and 4%. Some progress on failing or IPHT systems have likely been made since the report was published with data through 2012. These statistics for Aitkin County are very good relative to the other counties of Minnesota, while Itasca's and Carlton's are more average.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The MRGRW has relatively little manufacturing industry, with the very significant exception of forest products, for which much activity exists, from supplying this industry's raw materials (trees harvested from the MRGRW) to production of paper and lumber. There are a number of industrial NPDES permits and industrial stormwater permits in the MRGRW. Thus, industrial discharges and stormwater could possibly be a source of pollutants (stressors) to streams in the MRGRW. However, none of the streams that were assessed as impaired had an associated discharger.

Forestry

Forestry and forest products have been, both historically and currently, very significant industries in the MRGRW. Nearly all of the non-wetland land area in the MRGRW was originally forested (Marchner, 1930). Forest harvest can create stress on water resources. Historical large-scale forest removal occurred in the watershed, which may have created legacy effects still being experienced by streams today (e.g., channel damage due to significantly altered hydrology resulting from the clearcutting of old growth pine forests). Forest harvest continues as a major activity within the MRGRW in current times, though much more carefully than the original logging. Stressors related to forest harvest (primarily changes in runoff volumes to streams) are possibly occurring in the MRGRW due to contemporary harvesting, though BMPs are required on public lands that help mitigate impacts. Tools to examine forest harvest impacts are somewhat limited currently, but the new Scenario Application Manager tool used with MPCA's HSPF modelling does include the ability to look at how new forest harvest of various amounts and locations could affect hydrology.

Agricultural activities

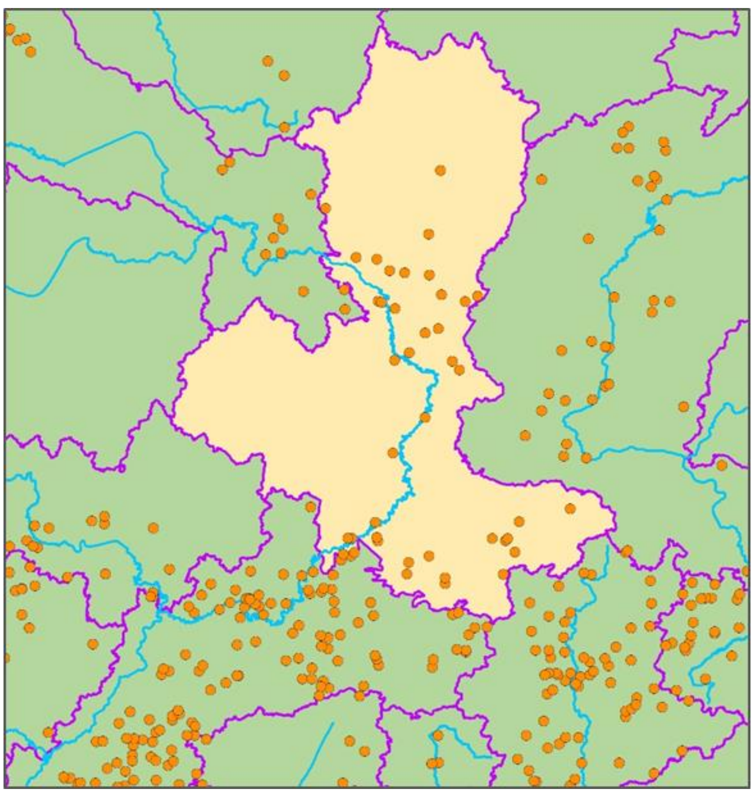
The lands of the MRGRW, as with those in much of northcentral Minnesota, are not extensively used for row crop agricultural production. Acreage used for agriculture is sprinkled throughout the MRGRW, but is relatively denser in the southern and central parts of the watershed, such as around Palisade, Tamarack, and Remer, as well as all along the corridor of the Mississippi River. The corridor of the Swan River upstream of Warba to its headwaters at Swan Lake also has more abundant agricultural land. Animal agriculture is relatively sparse, compared to watersheds just to the south. There is an east-west line where the density of feedlots changes abruptly, and this line is just about at the southern edge of the MRGRW, extending north into the MRGRW a short distance and located along the Hwy 210 corridor (Figure 6). There is also somewhat of a cluster in the Grand Rapids and Iron Range area. The review of the MRGRW's land use, shown previously (Table 1) indicates that approximately 0.9 % of the land cover is in cultivated crops.

It is reasonable to consider whether agricultural activities are a possible contributor to water quality problems in the described part of the watershed, though their overall contribution would be expected to be much less than in more southern and western parts of Minnesota. A large quantity of professional research exists with study results associating 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, 2013b). With the substantially lesser degree of agriculture occurring in the MRGRW relative to some other Minnesota regions, elevated nutrients from agriculture will not be a systemic issue in the MRGRW, but could occur in localized areas.

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

Figure 6. Registered feedlot locations ≥ 50 animal units (orange dots) in the MRGRW. Purple lines are major watershed boundaries.



Pesticides

Given that the MRGRW 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 regarding 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 stream stressor review

Based on the review of human activity in the MRGRW in general, and then specifically the areas in close proximity to the fifteen 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 MRGRW, resulting in eight of the 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, specific conductance via effluent discharges). There are no urbanized areas within the subwatersheds studied in this report.
- Pesticides - Impacts from pesticides are deemed unlikely due to small human population and little agricultural land use.
- Elevated nitrogen - nitrate and ammonia. IWM sampling revealed extremely low concentrations in the MRGRW.
  - Ammonia
  - Nitrate as nutrient
  - Nitrate as a toxicant

Inconclusive causes

- Forest management stressors - historical/legacy effects are difficult to determine. Impaired subwatersheds have had some recent forest harvest activity, though understanding and quantifying the effects of forest harvest, and threshold levels for stress to occur to streams is not well known.

Candidate causes

- Low dissolved oxygen
- Excess sediment (both suspended and deposited)
- Altered hydrology (non-urban sources)
- Altered geomorphology
- Habitat loss
- Connectivity loss
- Elevated phosphorus leading to eutrophication
- Mining/Industrial stressors (i.e., toxic chemical, high conductivity discharges)

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 (2012) 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 or lake'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 MPCA assessment process. An internet search using "MPCA biological monitoring" and "MPCA index of biological integrity" will bring up the MPCA webpages that discuss the stream biological monitoring program and information about the MPCA's stream Indices of Biological Integrity, respectively.

Metrics calculated from biological data can also 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 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. 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 (TIV) for many water quality parameters and habitat features for species of fish, and genera of macroinvertebrates. This is a take-off on the well-known work of Hilsenhoff (1987; EPA, 2006). 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 a sampled community being found at a site meeting the TSS and/or DO state 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 state 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 biological metrics and/or biological 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 also include field observations, chemistry samples, and physical data from the impaired reach in determining the stressor(s).

Similar to the above approach used for stream biological monitoring, the DNR has developed biological monitoring approaches for lakes, currently using the fish community, and also eventually the aquatic macrophyte (plant) community. More information can be found on the DNR webpages by an internet search using "Minnesota DNR index of biological integrity".

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 date. Some of the standards that are referred to commonly in this report are:

- Northern TP River standard - 50 mg/L
- Northern TSS standard - 15 mg/L
- Warmwater DO standard - 5.0 mg/L
- Coldwater DO standard - 7.0 mg/L
- Un-ionized ammonia standard - 0.04 mg/L

Notes on analysis of physical data

The DNR staff provided assistance in the SID process by collecting physical data (e.g., Pfankuch assessments, Rosgen geomorphology studies) about the stream channel and interpreting resulting measurements to describe channel stability and habitat quality. MPCA SID staff assisted in the collection or analysis of some of these data. Summary information about geomorphology is included in this report. Detailed survey data is available from DNR Watershed Specialists in the Grand Rapids DNR office.

Investigations organized by impaired stream reach

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 collected during the SID process; and 3) a discussion of the conclusions for the AUID based on all of the data reviewed.

Note: From this point on, the AUIDs referred to in the text (except main headings) will only include the unique part of the 11-number identifier, which is the last three digits.

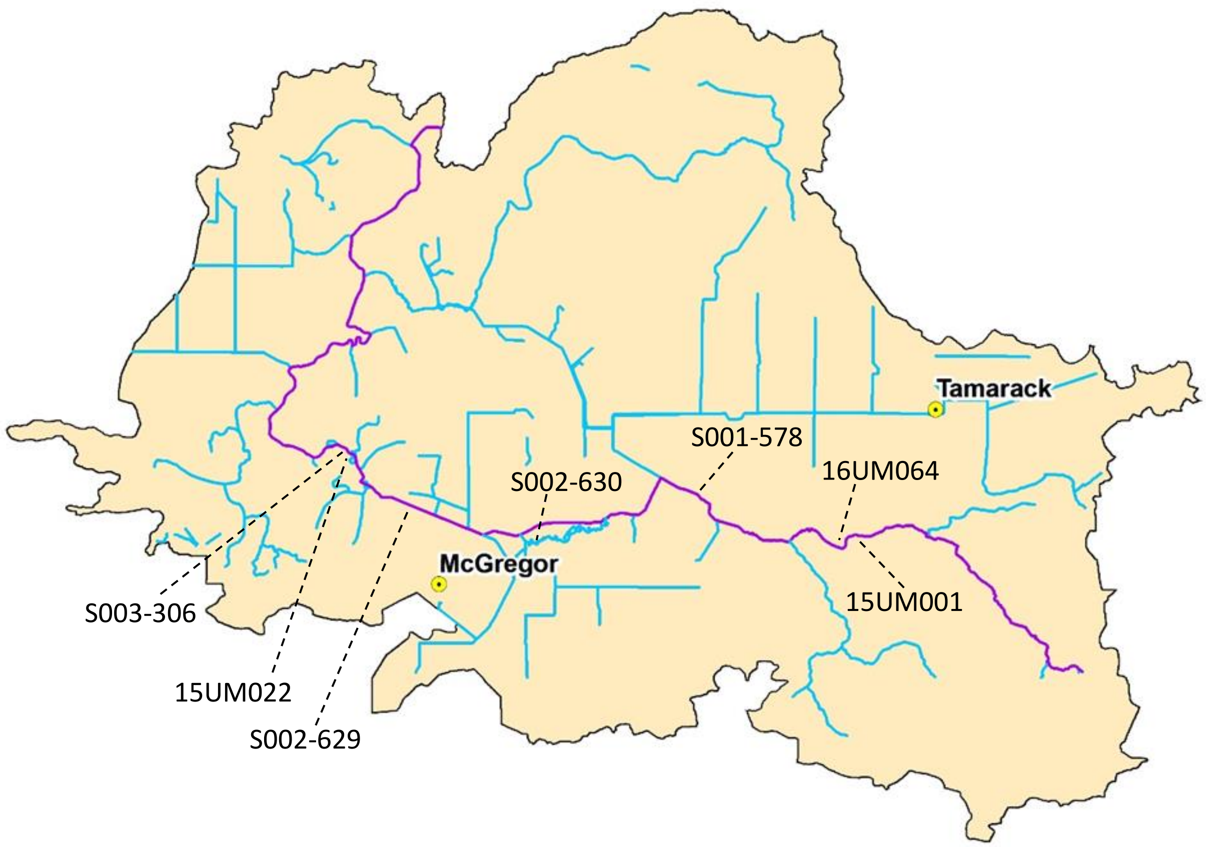
Sandy River (AUID 07010103-512)

Impairment: The river was assessed as impaired for not meeting fish and macroinvertebrate community expectations. The AUID contains three biological sample sites, 15UM001 (upstream, and only macroinvertebrates sampled), 15UM022 (downstream), and 16UM064 (close by 15UM001, and only fish sampled). Dissolved oxygen (DO) does not meet the standard, but streams with heavy wetland influence are not currently assessed for DO, awaiting possible development of a new standard for this stream type. AUID-512 contains sites of Fish Classes 5 (Northern Streams) and 6 (Northern Headwaters) and Macroinvertebrate Classes 3 (Northern Forest Streams - Riffle/Run) and 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

The southern part of the MRGRW, where the Sandy River flows, has extensive wetlands, and the river was straightened in several areas in settlement times or soon after, including the creation of ditches that began to function as tributaries. The human activities in the subwatershed are primarily animal husbandry agriculture (pastures and hay fields). This southern part of the MRGRW also has some wild rice farms, which take advantage of the wetland character of the area. Some of these rice farms appear to no longer be functioning. More on the alteration of hydrology is found in the "Hydrology" section below. US Highway 2 runs through this AUID, and near the downstream end of the AUID is McGregor, the only town within the Sandy River subwatershed.

Figure 7. Sandy River subwatershed, showing the AUID-512 channel in purple, and biological and chemical sampling locations presented in this report.



Data and analyses

Chemistry

Much chemistry data exists for AUID-512. The AUID has four stations that have at some point been monitored for chemistry, often with numerous visits, in addition to the IWM chemistry sampling done at the biological monitoring visits.

A summary of the results of water chemistry monitoring at 15UM001, 16UM064, and 15UM022 from the 2015-2016 IWM visits are shown in Table 3. TP in AUID-512 was right at the regional threshold in both samples. Nitrate was very low, as is common for North Central Minnesota streams, and ammonia and unionized ammonia were also at non-problematic levels. Neither of the two TSS samples exceeded the regional standard, nor did any of the five DO samples, though one was right at the standard.

Table 3. Water chemistry measurements collected at 15UM001, 16UM064, and 15UM022 during the 2015-2017 IWM and SID work. Values in mg/L. Data from a 2017 longitudinal monitoring event along the AUID is presented in Table 8 farther below.

Biological site	Date	Time	Water Temp.	DO	TP	Nitrate	Ammonia	Un-ionized Ammonia	pH	TSS	TSVS
15UM001	June 11, 2015	11:04	18.9	7.99	0.047	< 0.05	< 0.1	< 0.001	7.04	< 4	< 4
15UM001	Aug. 31, 2015	13:12	19.5	6.28	*	*	*	*	6.99	*	*
16UM064	Sept. 19, 2016	15:50	17.1	7.61	0.052	0.023	< 0.1	< 0.001	7.33	14.2	< 1.8
15UM022	Aug. 22, 2016	9:02	19.6	5.01	*	*	*	*	7.06	*	*
15UM022	Aug. 31, 2016	12:30	18.6	5.47	*	*	*	*	6.33	*	*
15UM022	Aug. 23, 2017	16:00	18.4	6.53	*	*	*	*	*	*	*

*Not collected.

Historical data is available from this AUID, of varying amounts depending on the parameter and location. These sites (from downstream to upstream) include: S003-306 (10X), S002-629, S002-630, and S001-578. Much of this data is older than data usable for the river's current assessment; however, it still is informative in determining issues in the stream. Data are presented by EQuIS site, starting farthest downstream, then in an upstream direction.

S003-306

This is the farthest downstream chemistry data in the AUID collected from stream-like habitat. Data does exist between this site and Big Sandy Lake, but those sites are more like flowages than streams. DO levels in summer are routinely below the standard, and can get quite low (Figure 8). From the recent data (Table 4), TP is elevated relative to the northern region river standard, ammonia is at non-problematic levels, TSS is generally very low, and nitrate levels are extremely low. TP concentrations show a strong peak in late July (Figure 9). Peak TP concentrations are higher here than at the chemistry monitoring sites farther upstream in AUID-512 (Figures 10, 11, and 12). There are larger amounts of bogs/fens in the downstream half of the subwatershed, which may explain this pattern in TP levels.

Figure 8. DO measurements at S003-306. Dataset includes roughly equal numbers of measurements from 2011, 2012, 2015, and 2016. The red points are measurements made by 9:00 am. The line is a 4th order polynomial regression line with an R^2 of 0.5399. The red line is the state DO standard.

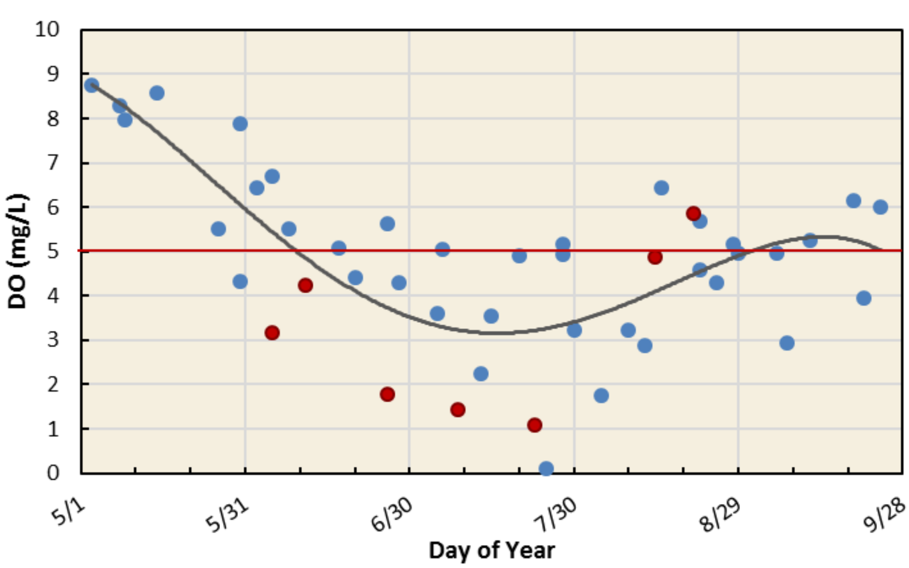
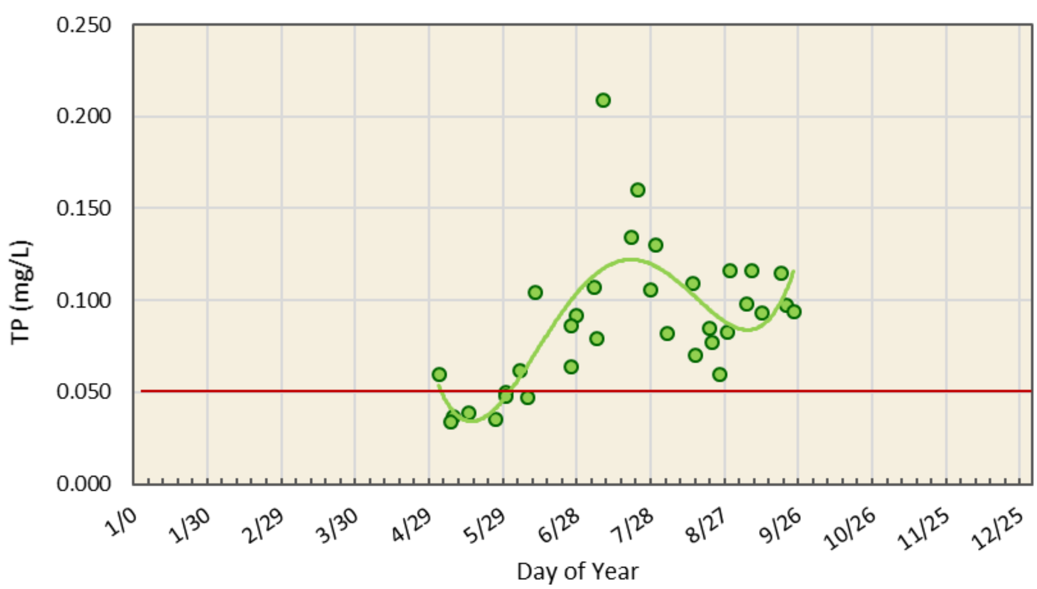


Table 4. Historical chemistry measurements at S003-306 (15UM022) from 2011, 2012, and 2015. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate	34	< 0.045	0.128	< 0.01*
Ammonia	10	0.119	0.377	< 0.04*
Total Phosphorus	34	0.088	0.209	0.034
TSS	34	6.2	18	2

* These values are below the lab detection limit.

Figure 9. TP data for site S003-306, 2011-2012 and 2015. The green line is a 4th order polynomial regression line, having an R^2 value of 0.5438. The red line is the TP threshold for this region's river nutrient standard.



S002-629

This site is upstream of S003-306 about 1.5 miles, and has a very large dataset (Table 5). TP levels during summer are always at or above the River Nutrient standard (Figure 10), and usually somewhat lower than S003-306. Nitrate levels were very low, and ammonia was at non-problematic levels. There were only five exceedances of the TSS standard in 91 samples. DO concentrations were often below the standard in data collected from 2004 - 2008 (Figure 11), but appear to be better than downstream (compare to Figure 8).

Table 5. Chemistry data at S002-629 from years 1994-1998 and 2004-2008. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate*	27	0.12	0.291	0.01
Ammonia*	33	0.132	0.380	0.020
Total Phosphorus	94	0.067	0.146	0.026
TSS	91	6.99	23	1

*Only 1994-1998.

Figure 10. TP data for site S002-629 (near 15UM022), 1994-1998 and 2004-2008. The green line is a 4th order polynomial regression line, having an R^2 value of 0.2269. The red line is the TP threshold for this region's river nutrient standard.

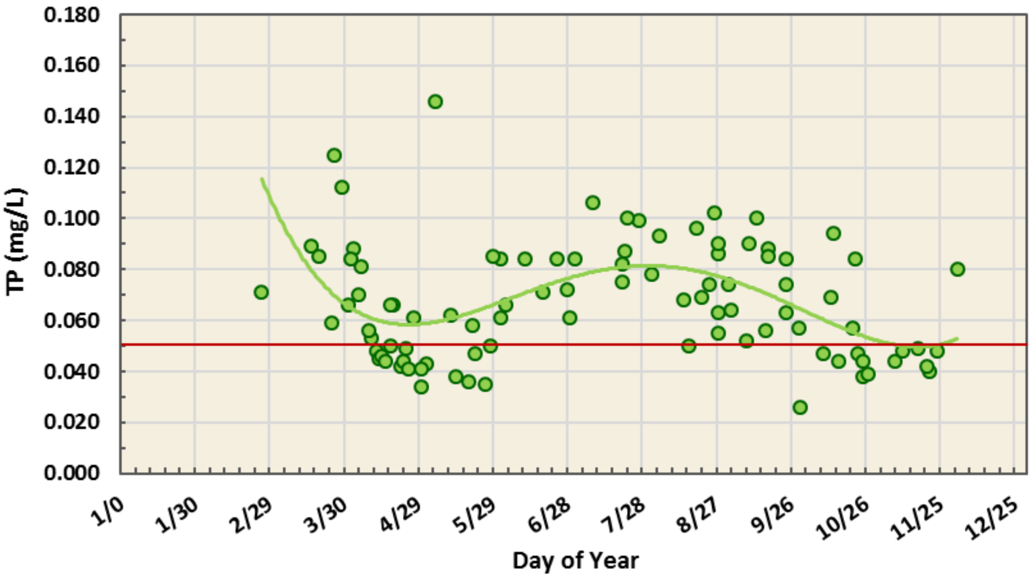
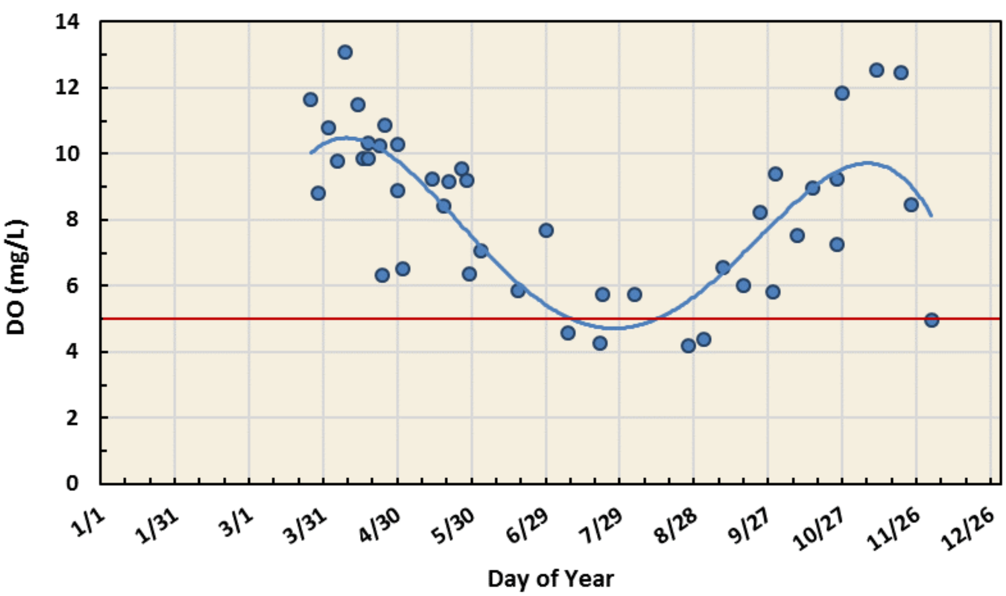


Figure 11. DO data for site S002-629 (near 15UM022), from 2004-2008. Most measurements were taken between 9:30 - 11:30. The blue line is a 4th order polynomial regression line, having an R^2 value of 0.5763. The red line is the DO standard.



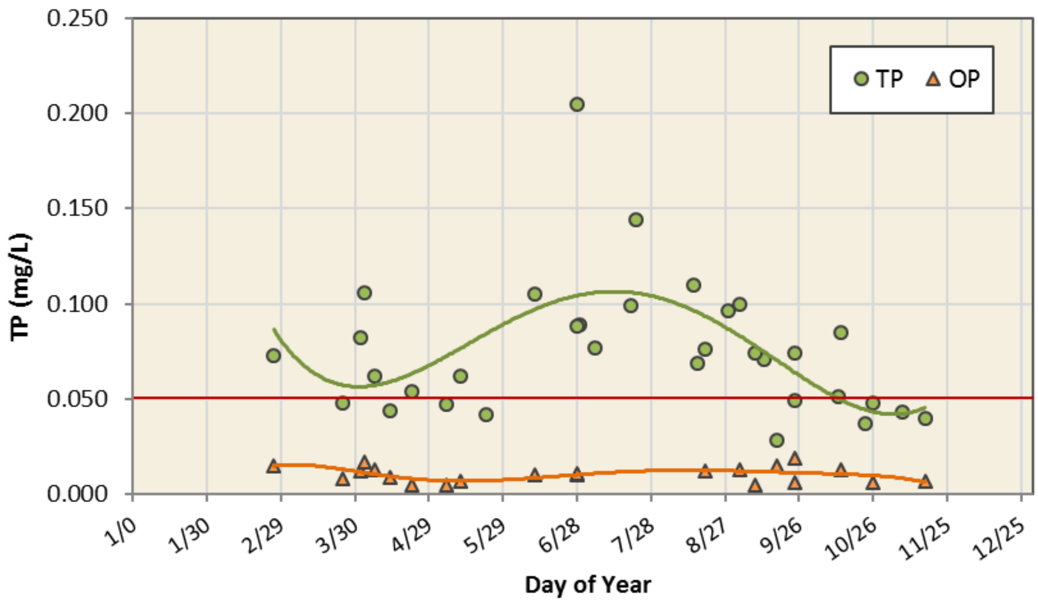
S002-630 (This is the old, natural channel that is partly cut off from the AUID channel)

This channel is about 2.25 miles upstream of S002-629 and has been largely bypassed by ditching, but does sometimes have flowing water. This site's chemistry samples are too old to be used in the current assessment of AUID-512; however, they still are somewhat insightful. No DO data was collected at this site. A summary of common parameters are shown in Table 6. The average TP was elevated relative to the River Nutrient standard and as with other sites on this AUID, TP levels peaked in the second half of July (Figure 12). Levels of OP did not change much relative to the sample date (no mid-summer peak), though mid-summer samples were few. OP concentrations ranged from about 0.005 to 0.019 mg/L (Figure 12). Of the 33 TSS samples, 12 exceeded the North TSS standard and two more were at the standard. Nitrate levels were low to very low, and ammonia levels were below the standard for unionized ammonia.

Table 6. Historical chemistry measurements at S002-630 (CR-73) from 1996-1998. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate	15	0.103	0.690	0.003
Ammonia	22	0.067	0.36	0.02
Total Phosphorus	33	0.075	0.205	0.028
TSS	33	13.2	34	1

Figure 12. TP and OP data for site S002-630, 1996-1998. The green line is a 4th order polynomial regression line, having an R^2 value of 0.3757. The orange line is a 4th order polynomial regression line, having an R^2 value of 0.2695. The red line is the TP threshold for this region's river nutrient standard.



S001-578

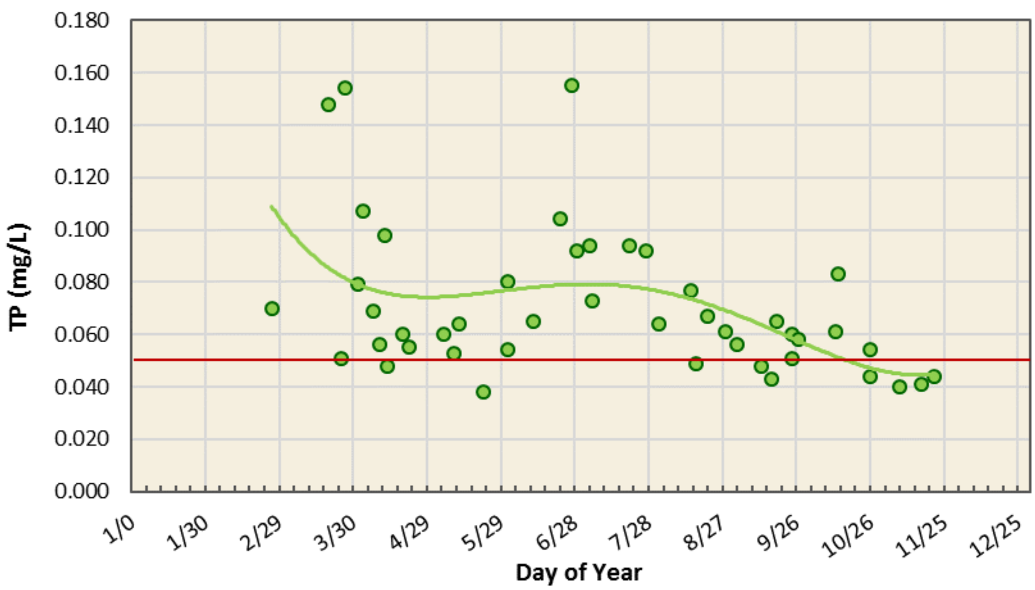
Few DO data points exist for S001-578, particularly for the warmer parts of summer when DO is generally at its lowest concentrations. One data point, from August 23, 2010, suggests that DO may drop to below standard during mid-summer. That reading was 5.39 mg/L, slightly above the standard, but the time of collection was 11:20 am, by which time there have been many hours of daylight and DO is often significantly higher than at its early-morning low point. TP was nearly always above the River Nutrient Standard (Figure 13). TP levels dropped in late summer quicker than they did at downstream sites. Many TSS samples were collected (Table 7). Of the 48 samples, 12 exceeded the TSS standard; including readings of 72, 55, 48 mg/L, and three more were at the standard. Most of these samples are too old to be used in the current assessment of AUID-512. Ammonia levels were at concentrations that would have associated unionized ammonia concentrations well below the standard.

Table 7. Historical chemistry measurements at S001-578 (at 15UM001/16UM064) from 1994-1998 and 2010 (TSS only). Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate	30	< 0.078	0.610	< 0.03*
Ammonia	37	0.054	0.23	0.02
Total Phosphorus	45	0.071	0.155	0.038
TSS	48	13.0	72	2

* Value is below the lab's detection limit.

Figure 13. TP data for site S001-578 (Hwy 210), 1994-1998. The green line is a 4th order polynomial regression line, having an R^2 value of 0.2109. The red line is the TP threshold for this region's river nutrient standard.



SID Chemistry monitoring

On July 21, 2017, a synoptic longitudinal sampling of the AUID was conducted. This date is at the approximate point when north-central Minnesota stream phosphorus levels hit their peak in mostly-natural watersheds. Longitudinal sampling can help pinpoint sources by finding where along the stream's path problems begin.

Sites sampled were (from US to DS) 15UM002, 15UM001 (S003-524), 15UM003 (S002-630), and 15UM022 (S003-306). Findings are presented in Table 8. DO levels showed a decline moving in the downstream direction. This may be a combination of more groundwater (conductivity increased opposite DO levels), and the fact that water temperature was quite a bit warmer at the most-downstream site.

TP was at or above the northern river standard at all sites, with the lowest concentration occurring in the headwaters, and the highest in the middle section of the AUID. Nitrate concentrations were extremely low at all sites, but did increase by a very small amount moving from headwaters to the farthest downstream sample. The water temperature at 15UM003 was lower than either upstream or downstream locations. This suggests greater groundwater inputs, which may be influencing the higher

TP levels found at this site, as some of this groundwater has first moved through anoxic peat soils, where it picks up phosphorous from the decaying plant material.

Table 8. Sandy River longitudinal sampling on July 21, 2017, presented in US to DS order. Values in mg/L.

Biological site	Time	Water Temp.	DO	DO % Saturation	Cond.	TP	Nitrate
15UM002*	11:15	--	--	--	--	--	--
15UM001	11:35	21.69	7.33	83.3	94.6	0.050	< 0.05
S001-578	13:45	--	--	--	--	0.086	< 0.05
15UM003	12:00	20.83	5.56	62.1	117.8	0.106	0.06
15UM022	12:25	23.33	5.25	61.6	160.8	0.080	0.07

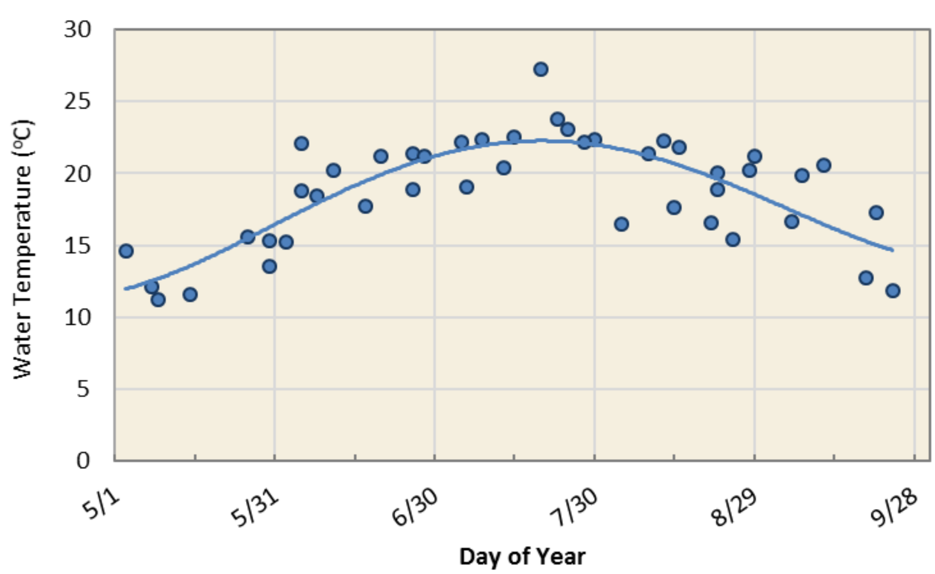
*No samples taken - water present but stagnant.

On August 23, 2017, a Chl-a sample was collected at 15UM022 (S003-306) to determine if suspended algae might be partially to blame for low oxygen levels (i.e., eutrophication). The Chl-a sample result was 2.27 µg/L, which is quite low (i.e., good; the river standard is 10 µg/L). Accompanying data collected with the Chl-a sample were Time = 16:00, DO = 6.53, DO % saturation = 69.6, and Temperature = 18.41°C.

Temperature

The farthest-downstream biological site 15UM022 (S003-306) has a significant water temperature dataset that shows that temperature peaks during mid-July (Figure 14). The caveat with this temperature dataset is that the majority of the measurements were taken between 10:00 and 14:00, with a small number before 10:00, and one at 14:44. Temperatures were probably not at their peaks for the day, but since many samples were from the 12:00 - 13:30, the temperatures were probably not far from their days' maximums. The longitudinal water temperature measurements made on July 21, 2017 suggest water is cooler upstream of 15UM022 (Table 8). Warmwater fishes begin to experience temperature stress when temperatures are at about 30°C (86°F) for extended period of time. Therefore, water temperature does not appear to be a stressor to fish in AUID-501.

Figure 14. Water temperature measurements at 15UM022 (S003-306) during 2011, 2012, 2015, and 2016. The line is a 4th order polynomial regression line with an R^2 of 0.6369.



Biology

Fish

The fish community collected in 2016 at 15UM022 was dominated by central mudminnow. Most of the other taxa present were those tolerant of low DO, including yellow perch, northern pike, black bullhead, fathead minnow, and golden shiner. The fish community collected in 2016 farther upstream, at 16UM064, was dominated by white sucker, with two other taxa present, central mudminnow and northern pike, both low-DO tolerant.

The 15UM022 community is highly tolerant of low DO based on the low score of the Community DO Index for Class 5 streams, and that the probability of the sampled community coming from a stream meeting the DO standard is very low (Table 9). The community is only at the third percentile of Class 5 streams for the DO TIV Index score. The upstream site has a better DO TIV Index score and percentile within its class, suggesting DO levels are somewhat better upstream. In both cases however, the probability of the community being found at a site with a standard-meeting DO regime is quite small, particularly downstream. The percentage of low-DO Tolerant individuals is high at 16UM064 (Table 10).

The TSS levels in AUID do not appear to be a stressor to the fish community. Though the TSS TIV Index score is about the median for the class, this is actually quite good because as a class, these streams tend to have lower TSS than some other fish classes. Hence the quite high probability, based on all stream sites statewide, of the 15UM022 community coming from a stream meeting the TSS standard (Table 9). This is somewhat different for the 16UM064 community, which scores at the 30th percentile for its class, though the probability of this fish community coming from a site meeting the TSS standard is still fairly good. The fish community suggests that this site likely has greater TSS than the majority of Class 6 streams, which typically have relatively low TSS due to their low gradients. There were no TSS Tolerant species found at either site (Table 10). At these locations on AUID-512, evidence is good that the fish are being negatively influenced by low DO concentrations, while only slightly by TSS.

Table 9. Fish Community DO and TSS Tolerance Index scores in AUID-512. 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 (2017 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.

Date	Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/22/2016	15UM022	5	5.82	6.99/7.11	3	9.7	13.10	13.85/12.99	48	82.1
9/19/2016	16UM064	6	6.70	6.55/6.61	55	34.6	14.29	13.98/13.28	30	76.9

Table 10. Metrics involving DO tolerance for the sampled fish community at 15UM022 and 16UM064.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	15UM022	0	0	1	1	0	2.13
DO	16UM064	0	0	2	1	0	32.56
TSS	15UM022	0	0	0	0	0	0
TSS	16UM064	0	0	0	0	0	0

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

Macroinvertebrates

The macroinvertebrate communities were very different at the two sites sampled on AUID-512. Both sites were sampled on August 31, but one year apart. The two locations have different stream class assignments, with 15UM001 being a riffle/run type, and 15UM022 a glide/pool type. The macroinvertebrate community at 15UM001 was dominated by the genus *Simulium* (commonly called blackflies or gnats). It did contain a number of taxa typically found in sites with very good water quality, such as *Optioservus*, *Tipula*, *Protoptila*, *Helicopsyche borealis*, and *Boyeria vinosa*. Few slow/stagnant water taxa were present. In contrast, site 15UM022 had a wetland/stagnant water community, with abundant *Chironomus*, five Hemipteran taxa, seven Coleopteran taxa (beetles; including 5 genera of Dytiscidae), and four gastropod taxa, fingernail clams, and only two EPT taxa, with only three EPT individuals. The single *Simulium* individual (as opposed to the abundance at upstream site 15UM001) is also a sign of slow flow velocity, as they are filter feeders and require flow to deliver their food. The community contained only one intolerant taxon at 15UM022, and the percent of tolerant individuals was very high at 86.2 percent.

The fact that the macroinvertebrate DO TIV Index is somewhat counter to the fish DO TIV result (i.e., the macroinvertebrates do not show a signature of being composed of taxa with low-DO tolerance - Table 11) is probably in part due to the dominance of *Simulium*, which has a species DO TIV in the 74th percentile of all macroinvertebrate taxa (meaning *Simulium* is typically found where DO is at a good level). *Simulium* may be thriving here for a different habitat-related reason (as filter feeders, they are sensitive to flow velocity and permanence of that flow), and just coincidentally inflate the DO TIV index due to their dominance in numbers here. This same effect of *Simulium* is also, what is probably inflating the probability value in comparison to the other sites. The downstream site 15UM022 was heavily skewed toward both low-DO and TSS tolerant taxa, both in terms of the species present, and the percentage of tolerant individuals (particularly for low-DO - Table 12).

Table 11. Macroinvertebrate Community DO and TSS Tolerance Index scores in AUID-512. 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 (2017 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.

Date	Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/31/2016	15UM022	4	5.22	6.28/6.47	11	33	15.32	13.59/13.72	15	72
8/31/2015	15UM001	3	7.48	7.02/7.15	81	78	14.08	13.42/13.47	32	81

Table 12. Metrics involving DO tolerance for the sampled macroinvertebrate community at 15UM001 and 15UM022.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	15UM001	10	2	4	2	13.78	1.28
DO	15UM022	0	0	15	7	0	43.28
TSS	15UM001	4	0	13	4	5.13	20.19
TSS	15UM022	0	0	19	14	0	31.80

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

Taking the analyses for fish and macroinvertebrates together, DO is the strong stressor to both communities in the more downstream areas of the AUID. It also appears that TSS is affecting the macroinvertebrate community, given the ratio of TSS Tolerant to TSS Intolerant taxa. The habitat at the upstream site is better for macroinvertebrates owing to better flow velocities, while the fish are probably limited there due to their seasonal migration from downstream, which, since downstream areas are limited by poor DO levels, makes the downstream reaches a poor source area for fish to populate the reaches higher up in the subwatershed.

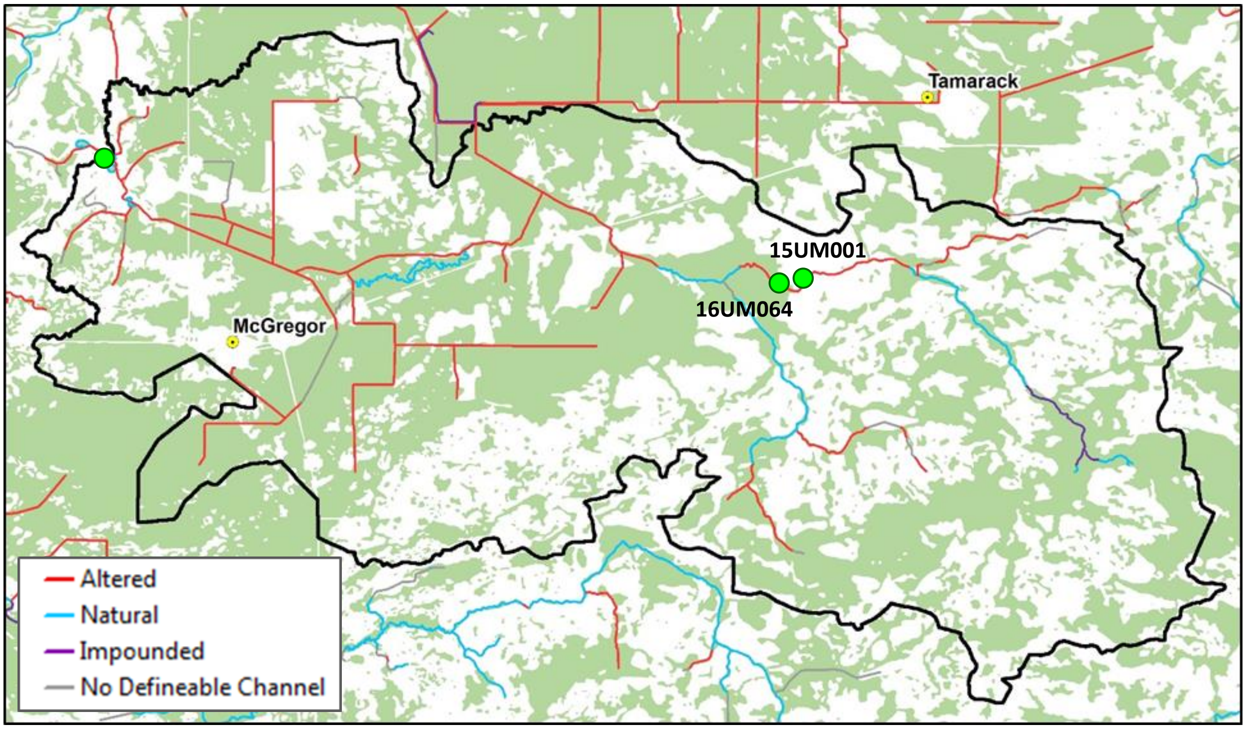
Habitat

The MSHA scores at the biological sites were: 15UM001 = 42 (in "Poor" category), 15UM022 = 56.5 ("Fair"), and 16UM064 = 57 ("Fair"). Among the MSHA subcomponent scores, "Instream" features (substrate and cover) and "Channel Morphology" were the component parts of the MSHA that were poorer scoring, as opposed to riparian and land use scores that scored relatively well. These scores are reflective of typically poorer instream and morphology features of straightened channels. Substrates consist of sand and gravel at all three sites. Embeddedness was recorded as "severe" at 15UM001, and light at the other two biological sites.

Hydrology

The Sandy River subwatershed has been substantially altered by drainage. The landscape in this area has extremely low relief, and trenches were dug in the early 1900's through the peatland soils in attempt to lower the water table and make the land available for farming (Figure 15). Numerous ditches, where no channels originally occurred, form tributaries into the Sandy River and drain water originating in peatlands into the Sandy River. The headwaters of the Sandy River is dammed to form a reservoir created for wildlife management purposes, while a majority of the river's course has been either straightened within the original river's valley, or a new non-meandering channel has been created, replacing the original river channel. Such changes have altered the river's flow patterns. Straightening sinuous channels increases gradient, meaning water will move off the landscape quicker, and may lead to higher peak flow volumes and reduced minimum flows. Wild rice farming, which caught on in the 1970s and has waned somewhat currently, also has likely altered the hydrology, perhaps in the opposite way the ditching has, as water is retained by dike systems for much of the summer in the rice fields and then released prior to rice harvest.

Figure 15. The Sandy River subwatershed for the point at the crossing of CR-62 (15UM022) at the far left. Water flow moves from right to left (east to west). There are many private ditches (particularly associated with wild rice fields) that are not shown in this figure. Wetland data is from the National Wetland Inventory dataset.



Two features of peatlands combine to contribute to low DO in the adjacent streams they feed. One is their high water table, and the other is the deep, organic soil they form. Groundwater is typically low in DO as it has been separated from the atmosphere for significant time, and bacteria decaying the organic material consume oxygen for their respiration from the groundwater moving through the peat to the stream channel. A substantial amount of water input to the Sandy River originates in these naturally low-DO environments. Channelization of these peatlands probably increases the ratio of shallow groundwater to surface runoff in the Sandy River, moving it to a lower DO level than would occur if water seeped from these peatlands more naturally and slowly.

Because low DO problems often have excess nutrients (particularly phosphorus) as their root cause, and TP has been shown to be above the North Region River Nutrient Standard in AUID-512, it is prudent to consider landscape factors (both natural and anthropogenic) that may be contributing nutrients (particularly phosphorus) to the river. It is also prudent to assess whether other conditions for eutrophication exist here, or whether naturally high phosphorus is essentially benign (though it may be problematic to downstream receiving waters).

It is difficult to investigate many of the tributaries to the Sandy River, several of which are ditches, due to their remoteness and lack of access. However, other recent MPCA studies have found streams draining from natural areas with wet-meadow habitats can have relatively high levels of TP (MPCA 2014, MPCA 2016). The ditching of wetlands in the subwatershed may be contributing greater amounts of phosphorus to the Sandy River than if these wetlands were in their un-ditched natural state. In the chemistry section above, it was shown that phosphorus-driven eutrophication is not occurring in the river. However, the export of phosphorus to farther downstream water resources makes unnatural phosphorus export a concern, even if it is not affecting the immediate waters near where the phosphorus originates.

Alteration of hydrologic patterns of rivers (e.g., increased runoff leading to higher stream flow volumes) is also an issue that can have negative consequences for biological communities due to the channel instability and habitat alteration it can cause. Minnesota has started experiencing larger storm events (DNR, 2019), a result of climate change, which could exacerbate the influence of ditches on stream channel stability and habitat health. Assessment of the physical attributes of the channel are discussed in the section that immediately follows.

Geomorphology

Map and aerial photography review

The majority of the AUID is channelized/ditched, with some of this constructed channel being some distance from where the original channel flowed (as opposed to being cut through the meandering stream pathway). See also large-scale channel details discussed in the Hydrology section above.

Field assessments of channel condition

In 2016, DNR Watershed Specialists investigated bank erosion along nearly four miles of river upstream of 15UM022. The study utilized the Bank Assessment for Non-point source Consequences of Sediment (BANCS) protocol, which assesses the sediment contribution from stream banks (Rosgen 2011). Part of the benefit of the BANCS assessment is to locate hotspots of sediment input where BMPs could be implemented to maximize the cost benefit ratio of restoration funding.

Along the straight section of the study reach, the banks are fairly uniform and not large contributors of sediment (Figure 16). However, the mile of river east of CR-62 meanders through a forested area with higher surrounding terrain where the banks are contributing greater amounts of sediment. In this section, there are several banks on the outside of meanders or that are part of the valley wall, which are experiencing higher erosion rates. Survey results revealed four reaches within the forested section comprising 4.8% (1,898’) of the total length contributing 16.2% of the total tons/year of sediment from the surveyed reach.

The DNR staff further commented that; “Many banks in the forested section had bare sediment exposed but it was unclear if it was the result of a recent flood or longer term instability. There were several trees fallen down in the stream, some spanning the entire width and causing flow restrictions and local scour, a sign of instability and widening. More investigation is needed to determine if excess sediment is entering the stream from other sources and if so, what those sources are. We did observe sediment plumes entering the Sandy from a couple ditches/tributaries during our survey, so runoff and/or upstream factors may be contributing sediment.” Beaver dams were encountered which were holding back sediment. While potentially detrimental to the locality of deposition, this retention of sediment may be protecting other downstream environments.

Figure 16. BANCS categorizations of streambank sections upstream of 15UM022. Colors represent categories of estimated sediment input from a given stream bank section. Erosion increases as colors move from green to yellow to orange to red to pink.

Connectivity

There are no downstream crossings that prevent fish from entering AUID-512 from the downstream end. All road crossings below CR-62 (15UM022) are bridges, and thus not barriers. No beaver dams were located in that portion of the AUID. Moving farther upstream, the first culvert is at CR-73, then at 185th Place, the railroad crossing, Hwy 210, two private drives, 420th St., and CR-16 (Kestrel St.). These were visited, and none are barriers to fish migration, with possible exception of the culvert crossing 420th St, which is quite long due to crossing the road at an angle. No beaver dams are seen in the AUID on the 2015 aerial photos moving upstream until two beaver dams are found near the right angle channel bend north of Hwy 210. The DNR geomorphology crew found beaver activity in the reach they studied, which may impede fish movement if they are long-term dams. Connectivity is at least not an issue in the lower half of AUID-512, where a failing fish site does exist. In addition, the connectivity issues are not human-caused.

Conclusions

The fish and macroinvertebrate impairments are driven primarily by low DO levels in the AUID, particularly in the more downstream reaches. In addition, habitat is relatively poor, due to the unnatural form of the current Sandy River channel.

The low-DO situation is not a result of eutrophication. The dark, tannic water of the river and its sandy nature are poor habitat for periphyton (algae attached to the stream bottom material), and it is very unlikely that significant periphyton could be responsible for eutrophication. The non-elevated DO and low DO % saturation (well under 100%) in the afternoon of August 23, 2017, a mostly-sunny day, along with the low Chl-a concentration that day, are further evidence against eutrophication being the cause of the low DO in this AUID. There is some wetland agriculture (wild rice) in the subwatershed, but it would require very detailed research to determine if those wetlands paddies were functioning differently (with regard to influence on DO in the river) than their original natural wetland state.

Other explanations exist for why DO is problematically low in this AUID. There is a large amount of wetland (bog/wet meadow) in this subwatershed. Shallow groundwater moving through the organic soils of these wetlands will be quite anoxic in summer, due to the use of DO by microorganisms decaying the organic material. This water is part of what contributes to the river's flow. The ditching of bogs in this subwatershed may be exacerbating the contribution of low DO water, due to the potentially greater delivery of wetland-sourced water to the river. Finally, the low-gradient nature of the river contributes to naturally lower DO relative to rivers and streams with a higher gradient, due to poor mixing of water from a lack of turbulence, meaning water is less-frequently in contact with the atmosphere, where oxygen can diffuse into the water.

TSS measurements were occasionally very high in the mid-1990's, but the more recent data shows lower TSS levels. The macroinvertebrate community was quite skewed toward TSS Tolerant taxa. A suggestion for determining the extent of current TSS issues would be to sample during higher flow events, since the TSS is not continuously high.

Habitat is mediocre in this AUID. The change from a very sinuous original channel pattern to straightened, ditched channels nearly always leads to loss of microhabitats necessary for species diversity. This is a common finding regarding habitat quality of ditches (Lau et al., 2006). The stream is dominated by fine particulate sediment, which both the geomorphology and biological crews observed to be excessive. Homogeneous, fine particle sediment is poor habitat for most species.

Recommendations

Slowing the entrance of wetland-sourced water inputs to the Sandy River by eliminating some of the unneeded legacy ditches would likely benefit the river and the habitat it produces for aquatic organisms. Baseflow volumes may be increased, and flow volume in general would become more stable. The fact that the original channel still exists in some places in unaltered form, though cut off from flow by ditch diversions, means that flow could fairly easily be re-connected to the natural channel, which would improve habitat for aquatic organisms (see more about this topic in the "Legacy Ditching" section below, beginning on Page 122). Existing ditches could be retained and used as overflow channels to carry excessive flow volumes, which may be desired by local landowners. The excessive wetlands in this watershed are probably a limiting factor as to how much DO levels could be improved, but the above changes would likely help.

There are a few notable, localized ditch banks (see geomorphology section) that would benefit from stabilization, which would reduce some sediment input in the lower parts of the AUID. Elimination of unnecessary tributary ditches through wetlands, including abandoned wild rice production areas, would likely reduce the amount of phosphorus in the river, which could have benefits to downstream waterbodies (see Figures 56 and 59).

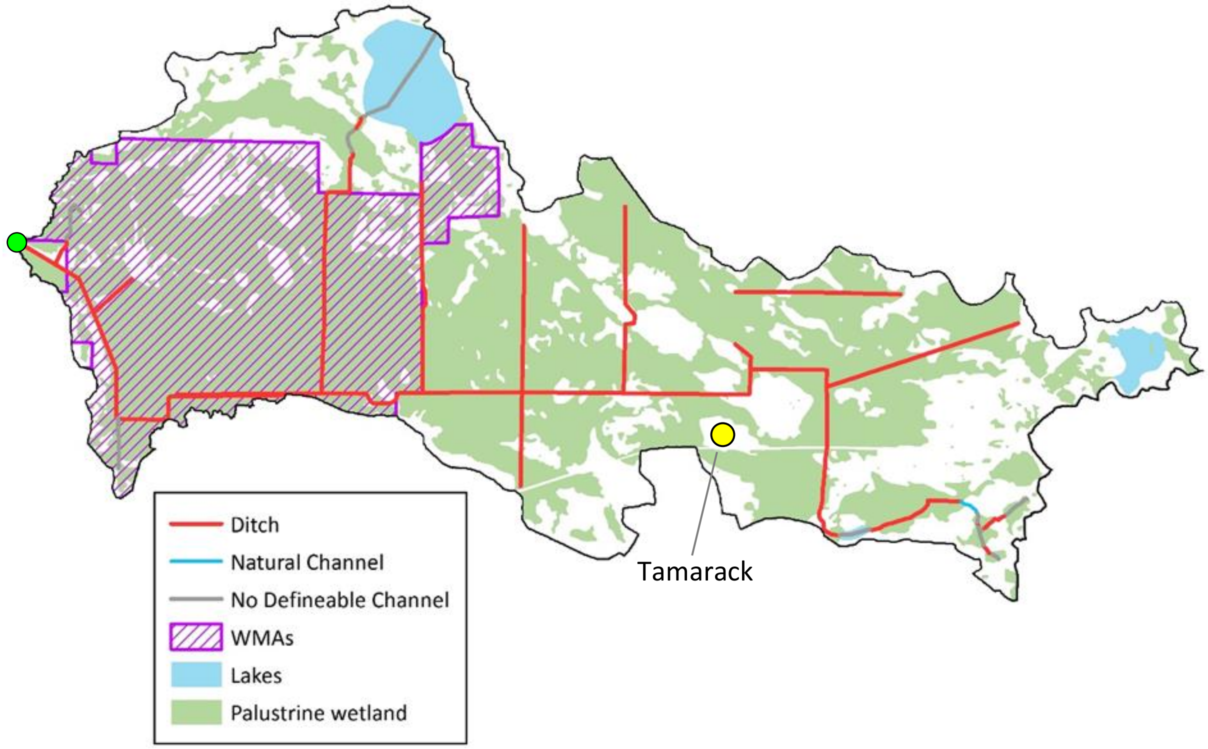
Minnewawa Creek (AUID 07010103-518)

Impairment: The creek was assessed as impaired for not meeting both the macroinvertebrate community and fish community IBI thresholds at site 15UM004, located at CR-73, 5 miles north of McGregor. The thresholds applied in the AUID-518 assessment are for modified use streams, which have a lower impairment threshold IBI score. The biological site in AUID-518 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool). After the SID process, this AUID was proposed to be moved into impairment category 4C. The MPCA review team agreed that 4C is the proper impairment category, and a final decision is awaiting EPA review.

Subwatershed characteristics

The subwatershed contributing to 15UM004 is highly dominated by peatlands (Figure 17). A matrix of drainage ditches exists within these wetland areas. The town of Tamarack is the only town within the subwatersheds boundaries. The nearest edge of Tamarack is 0.29 miles distant from the nearest waterway, one of the ditch branches leading to 15UM004. A few smaller-scale farm operations (animals and hay fields) are found in the extreme eastern side of the subwatershed. The subwatershed contains a sizeable area of Wildlife Management Area (the Grayling Marsh WMA).

Figure 17. The subwatershed area for AUID-518 at point 15UM004 (green dot at far left).



Data and analyses

Chemistry

The chemistry data that was collected at the fish and macroinvertebrate sampling visits in 2015 is shown in Table 13. Most of the parameters were at good levels, though TP was a bit higher than the northern region river standard. The DO readings, though some were above the standard when they were collected, suggest low DO levels occur here. One measurement was below the standard, and two were slightly above it, but the time of day they were collected does not correspond to the typical time of lowest daily DO concentration (at sunrise), and thus the DO was probably lower earlier on those mornings, and likely below the standard. Nitrate was extremely low relative to levels that are toxic.

Historical data exists for the same sampling location (Table 14). TP is commonly above the north region river TP standard (Figure 18). Nitrate was quite low, though somewhat higher than typical natural background levels for the area. Two ammonia levels were high relative to what is normally seen in Central Minnesota. These measurements of 1.29 and 1.13 mg/L may have had associated unionized ammonia levels exceeding the state standard, though the requisite pH and temperature for calculating it were not collected. TSS was typically very good (i.e., low), though two of the 33 samples did exceed the northern standard, and one was at the standard. DO was not collected in this historical sampling effort.

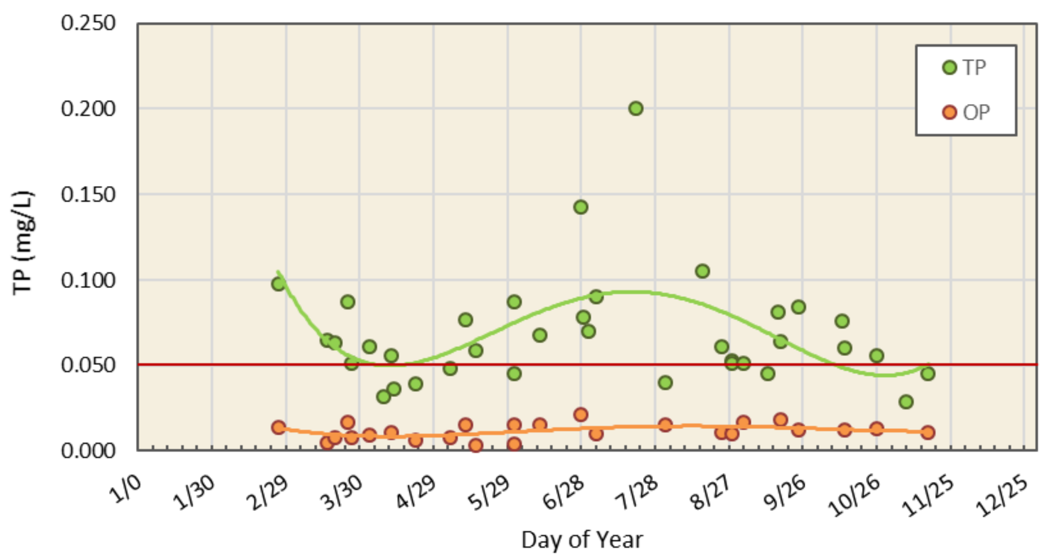
Table 13. Chemistry measurements from IWM sampling at 15UM004. Values in mg/L.

Date	Time	Temp. (ºC)	DO	DO % Sat.	pH	Cond. (µS/cm)	S-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
June 11, 2015	9:10	15.0	5.21	57	6.76	98.9	88	0.056	0.05	0.368	4.8	< 4
June 16, 2016	9:13	13.7	8.78		6.55	81	--	0.066	0.02	0.331	10	5.6
Aug. 27, 2015	10:02	13.2	5.42	59	6.65	97.4	> 100	--	--	--	--	--
Aug. 25, 2016	10:15	18.9	3.64	39	7.01	93	23	--	--	--	--	--

Table 14. Summary of historical chemistry data at S002-631 (at 15UM004) from 1995-1998. Values in mg/L.

	# Samples	Average	High	Low
Nitrate	19	0.148	0.46	0.003
Ammonia	27	0.239	1.29	0.03
Total Phosphorus	36	0.068	0.200	0.029
TSS	33	7.97	36	< 1*

Figure 18. TP and OP data for Minnewawa Creek at S002-631 (15UM004) from 1995-1998. The green curve is a 4th order polynomial regression line with an R^2 value of 0.2702. The orange line is a polynomial regression line with an R^2 value of 0.2160. The red line is the MN regional TP river standard.



Biology

Fish

The fish had a relatively small number of individuals collected. The sample contained only tolerant taxa, and was dominated by the ubiquitous species, central mudminnow, and also included four black bullhead and one white sucker. The DO and TSS metrics for the fish community were explored to add insight into possible stressors. The fish community DO TIV Index scores were very low, while the TSS TIV Index scored above average within its class (Table 15). Based on the probabilities shown in Table 15, it appears the fish community is strongly influenced by low oxygen levels and not significantly by elevated suspended sediment. Additional fish metrics related to DO add to the evidence that the fish community is very skewed toward species that can live in low-DO waters; over 80% of the individuals were in the Very Tolerant to low DO category (Table 16).

Table 15. Fish Community Tolerance Index scores at 15UM004 for DO and TSS. "Percentile" is the rank of the Index score within the fish Class 6 streams (2017 version). "Prob." is the probability a community with this Index score would come from a stream reach with TSS or DO that meets the appropriate standard.

Date	DO TIV Index	Class avg./median	Percentile w/in class	Prob. as %	TSS TIV Index	Class avg./median	Percentile w/in class	Prob. as %
June 16, 2016	5.70	6.55/6.61	12	8.0	12.68	13.98/13.28	66	83.6

Table 16. Metrics involving DO tolerance for the sampled fish community at 15UM004.

# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
0	0	3	3	0	81.3

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

Macroinvertebrates

The 2015 macroinvertebrate community was dominated by fingernail clams, which are commonly found in wetlands. A number of other wetland taxa were present, including the snails *Physella*, *Planorbella*, *Micromenetus*, and *Gyraulus,* the beetles *Haliplus, Laccobius,* and *Tropisternus*, and the Hemiptera Corixidae and *Belostoma*. The tolerant mayfly species *Caenis diminuta* was also present as the only mayfly taxon. The pond-dweller *Glyphopsyche irrorata*, was one of only two Trichoptera taxa. The 2016 macroinvertebrate community was dominated by two midge genera. The MPCA sampling protocol typically does not produce a sample dominated by midges, as many of the midge taxa live in fine sediments, which are not targeted for sampling. The taxa in the sampled community were those found typically in relatively stagnant or wetland habitats, including the beetles Haliplidae, *Gyrinus*, and *Tropisternus*, leeches, and a number of mollusks; fingernail clams, *Physella*, *Helisoma anceps*, and *Gyrinus,* and the amphipod *Crangonyx*.

Table 17 shows DO- and TSS Community Index data for 15UM004. The community scores for DO were about at the average or median for Class 4 streams; with a slightly better than even chance that, the sampled communities would be found in a DO standard-obtaining stream. The TSS Index scores were quite different, about equally distant from the median of all Class 4 scores, but in opposite directions, one above and one below the median. For both samples though, the probability that the community would come from a site meeting the TSS standard is quite good.

Table 18 shows tolerance metrics for DO and TSS at 15UM004. The community is skewed toward low-DO tolerant taxa, both in terms of the contrasting numbers of tolerant and intolerant taxa present, but also in the abundance of individuals from each of those classes. However, low-DO Tolerant individuals made up no more than 30% of the sample. The community is also skewed toward TSS Tolerant taxa, but the abundance of Tolerant individuals is quite low, meaning the community is largely composed of taxa that are ambivalent to TSS levels.

Taken together, these metric data suggest that DO is very likely a stressor, while the TSS concentrations here are at most a very secondary stressor. The fish community metrics above corroborate this conclusion about low DO as the primary stressor, and actually reduces evidence of TSS being a secondary stressor.

Table 17. Macroinvertebrate Community DO and TSS Tolerance Index scores in AUID-518 at 15UM004. 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 (2017 version). “Prob.” is the probability a community with this score would come from a stream reach with DO or TSS that meets the appropriate standard.

M-Invert Class	Comm. DO Index score	Class avg./median	Percentile	Prob. as %	Comm. TSS Index score	Class avg./median	Percentile	Prob. as %
4 (2015)	6.30	6.28/6.47	40	56	14.41	13.59/13.73	33	79
4 (2016)	6.49	6.28/6.47	52	60	12.95	13.59/13.73	69	87

Table 18. Metrics involving species tolerance for the sampled macroinvertebrate community at 15UM004.

Parameter	Sample Year	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	2015	1	0	7	4	3.2	15.4
DO	2016	0	0	8	5	0.0	29.4
TSS	2015	2	0	7	4	0.0	9.3
TSS	2016	0	0	6	2	0.0	3.6

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

Temperature

Water temperature was quite cool on the June 16 fish sample date. The water temperatures at the two invertebrate visits (late August of 2015 and 2016) were cold and in the range that would be found in a cold water stream. No mid-summer temperature data was collected, but the August data suggests the water does not warm up excessively to be problematic to either community.

Connectivity

There are only two road crossings downstream of 15UM004, one at the downstream end of the sample reach, and one in the next downstream AUID. Both are culverts and neither of these crossings appear to be problematic as barriers in aerial photos (e.g., minimal scour pool development) or from ground photos taken by the biological crew at CR-73. There were no beaver dams evident in the aerial photos. Therefore, impedances of fish migration from downstream do not appear to be present, and fish should have easy access to 15UM004 from larger, downstream habitat.

Habitat

Habitat scored as “Poor” (Table 19), with the worst performing components of the MSHA being Substrate and Channel Morphology. These both are typically poor features in ditched channels.

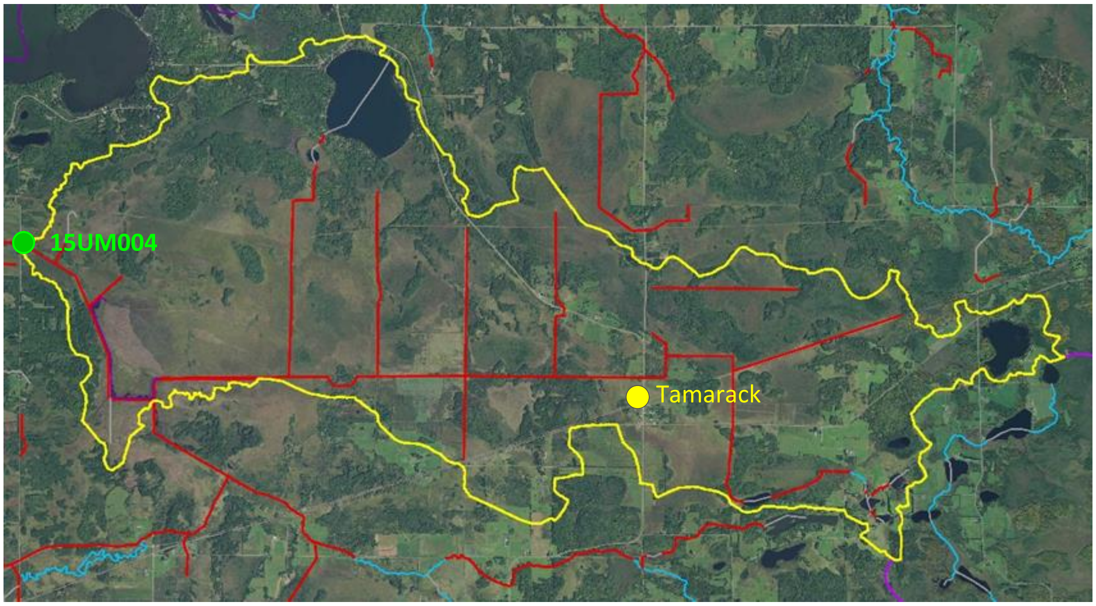
Table 19. Averaged sub-component scores for four MSHAs conducted at 15UM004 in 2015 and 2016.

MSHA Component	Avg. Score	Maximum Poss. Score	Percent of Maximum
Land Use	4.6	5	92.5
Riparian	11.8	14	83.9
Substrate	7.5	28	26.8
Cover	9.0	18	50.0
Channel Morphology	5.3	35	15.0
Total MSHA Score	38.1	100	38.1 = “Poor”

Hydrology

Hydrology in the AUID-518 subwatershed has been altered significantly (Figure 19). In fact, it is composed of > 95% ditched channel, where no stream channel originally existed. Trenches were dug through peatlands in the early 1900's to create this portion of Minnewawa Creek. See the discussion of peatland drainage in the "Hydrology" section on Pages 24-26.

Figure 19. The subwatershed of Minnewawa Creek for sample point 15UM004 is outlined in yellow. The red lines are created channels. There is only one very short natural channel segment, located in the extreme southeastern part of the subwatershed.



Geomorphology

Because there was no channel here originally, some of the ditch does not follow landscape slope, and was constructed through land having somewhat higher elevation than the peatlands. The location of the biological sample is such a case. Here, instead of a trench through peat, it is a constructed ditch with high banks (Photo 1), providing no access to a floodplain, meaning the channel was entrenched from its beginning. Unlike many constructed agricultural ditches, AUID-518 appears to have quite stable banks. The fact that this ditch appears stable is probably due to less surface runoff than occurs where these ditches are adjacent to agricultural fields combined with very low slope. No exposed soil, bank sloughing, or bank scour was seen along this reach. A small floodplain is slowly forming in the bottom of the ditch, which is a beneficial feature to have occur in a large, high-bank ditch, as it creates a more stable channel and better aquatic habitat. No formal geomorphological surveying was done at this location, in part, because constructed ditches were intentionally made with dimensions that do not mimic natural channels.

Photo 1. The constructed ditch that forms AUID-518 in the biological sample reach, a trapezoidal channel with high banks.

Conclusions

Analyses of biological data show that low DO levels in AUID-518 are problematic (a stressor) for both fish and macroinvertebrates. Direct measurements of DO levels have sometimes been found to be below the standard, and those that are not were collected at times of the day that do not represent the minimum daily DO level. The low DO is not due to eutrophication, but rather the peatland sources of the stream water. Abnormal/excessive algae that signify eutrophication were not observed. Some evidence from the macroinvertebrate data also hints that TSS may be a less significant stressor. Many of the TSS measurements found TSS below the standard, though two samples did exceed it. Habitat was also poor, and a stressor to the biological communities. The typical major issues of ditches, homogeneous, fine substrate and poor channel morphology (including relatively uniform depths), were present in AUID-518.

This AUID, and the stream system upstream of it, is a constructed channel system where none existed prior to the homesteading period, and which travels almost exclusively through peatland. There probably has not been a time when it would have had biological communities that would meet the passing IBI thresholds due to a combination of the unnatural physical configuration of the constructed channel and natural limitations related to DO. There is little that could feasibly be done to change these stressors and bring the stream to a condition that would support healthy aquatic communities.

Minnewawa Creek **(AUID 07010103-519)**

Impairment: The river was assessed as impaired for not meeting the fish community threshold at site 07UM082, located on the upstream side of State Hwy-65, eight miles east of Palisade. The biological site in AUID-519 is Fish Class 5 (Northern Streams) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

The creek flows through a mostly natural area with much more forest cover than the upstream AUID-518, though it is still low gradient, and the immediate riparian vegetation is not woody. At the downstream end, AUID-519 returns to flowing within a large peatland area. Regarding development, about a dozen homes are found in the subwatershed, along with one farm with a large pasture, a relatively small amount of hayfield acreage, and one business. State Highway 65 and paved County Road 6 also cross the subwatershed.

Data and analyses

Chemistry

AUID-519 had a 10X IWM chemistry monitoring site, S002-442, co-located with the biological monitoring site. The chemistry data that was collected at the fish and macroinvertebrate sampling visits in 2015 and 2016 is shown in Table 20, as is a prior biological sampling visit by MPCA in 2007. The historical and 10X chemistry data is summarized in Table 21.

Table 20. Chemistry measurements from biological sampling visits at 07UM082.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	S-tube (cm)
July 30, 2007	15:00	28.4	9.39	--	7.75	253	--
June 10, 2015	12:56	21.7	7.5	90	7.39	--	> 100
Aug 27, 2015	11:04	16.8	4.51	53	6.46	85.2	> 100
June 14, 2016	17:37	18.21	7.88	83	7.30	99	> 100

Table 21. Summary of nutrient and TSS data at S002-442 (at 07UM082) from 1994-1998, 2004-2006, 2008, and 2015. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate ('94-'98, '15)	31	< 0.089	0.400	< 0.01*
Ammonia ('94-'98, '15)	39	< 0.090	0.290	< 0.02*
Total Phosphorus	79	0.058**	0.134**	0.029
TSS	79	7.25**	37**	2

* These values are below the lab detection limit.
**One outlier removed from dataset.

Dissolved Oxygen

The DO measured at two of the three biological sampling visits were at a good level, with one being below the standard. However, these measurements were not taken at the time of daily minimum DO levels. In addition, the two better measurements were in early to mid-June, when water is still relatively cool, and thus holds more oxygen. In addition to these instantaneous measurements, there are other historical and IWM 10X instantaneous DO measurements (Figure 20) which, while not taken at the time of day that minimum concentration occurs, still clearly show a problem with DO in the summer months. Additionally, a continuous-monitoring sonde was deployed from August 20 - September 1, 2015 (Figure 21). That data revealed that the DO does indeed drop below the standard, and during this period, it did so every day. On four of the 13 days, the DO never reached 5.0 mg/L. Most often, the daily DO flux was between 2-2.5 mg/L, much lower than would be expected if eutrophication was the cause of low DO. In addition, DO never had a daily peak higher than 6.3 mg/L, much lower that mid-day peaks in streams experiencing eutrophication, which often have summertime peaks in the mid- to upper-teen mg/L range.

Figure 20. Instantaneous DO data for Minnewawa Creek at S002-442 (07UM082) from 2004, 2005, 2006, 2008, 2015, and 2016. The red line is the state DO standard.

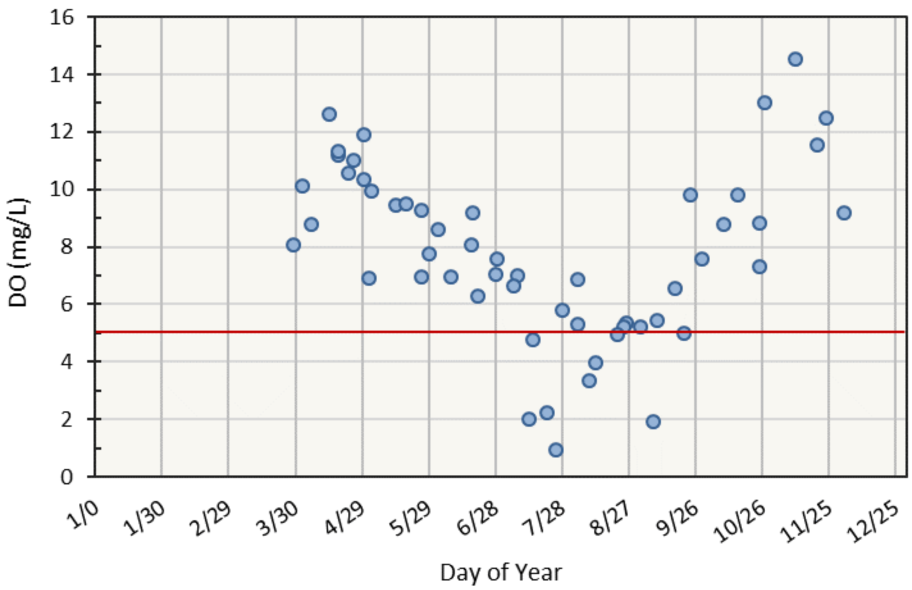
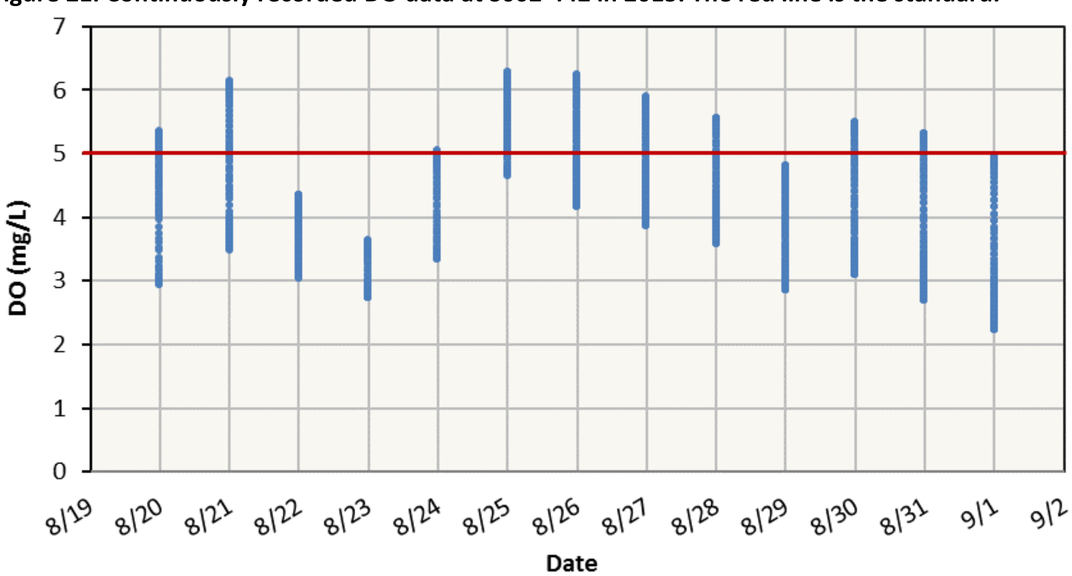


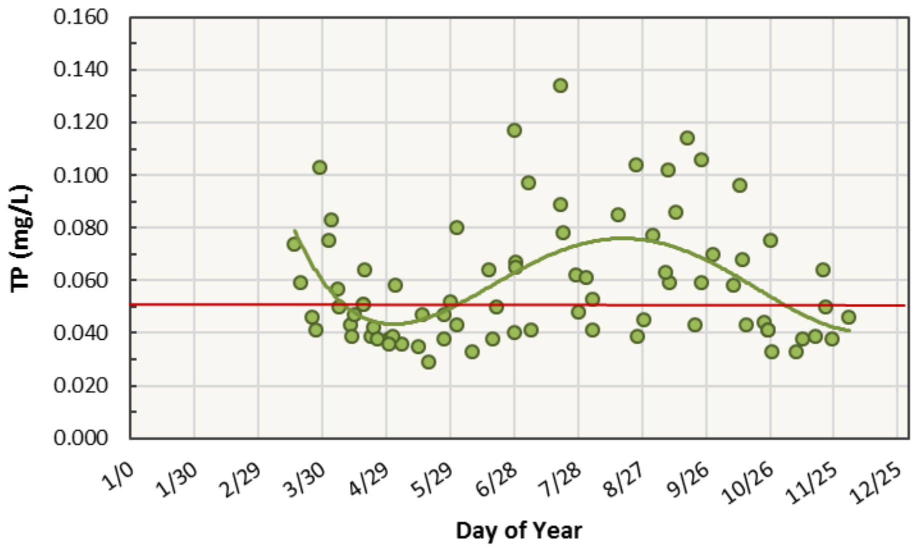
Figure 21. Continuously recorded DO data at S002-442 in 2015. The red line is the standard.



Phosphorus

TP is elevated above the regional threshold for most of the summer (Figure 22); though the DO readings do not suggest the occurrence of eutrophication, (midday concentrations are not high, typically in the 5-6 mg/L range - Figure 21).

Figure 22. TP data for Minnewawa Creek at S002-442 (07UM082) from 1994-1998 and 2015. The green curve is a 4th order polynomial regression line with an R^2 value of 0.2517 (excluding one outlier). The red line is the state standard.



Nitrogen

Nitrate was very low relative to its nutrient activity and extremely low relative to levels that are toxic (Tables 20 and 21). Ammonia was well below toxic levels.

Total suspended solids

The three dates on which water clarity was measured during IWM biological monitoring found very clear water (Table 20). The TSS average was quite low, well below the regional standard, with 8.9% of the 79 samples in the EQuIS database exceeding the northern TSS standard (Table 21). None of the 10 samples collected in 2015's IWM 10X monitoring were even half of the standard.

Conductivity

Conductivity is very low. The continuously collected sonde data during August 20, 2015 - September 1, 2015 ranged between 84.0 and 121.8 µS/cm. The maximum value measured from a data set including eight different years was 298 µS/cm. These concentrations are normal and not problematic.

Biology

Fish

The fish community was sampled in 2007, 2015, and 2016. The 2015 sample was deemed to be not representative due to drought conditions. The community found in samples from the three different years was fairly diverse (9-15 species) but was always dominated by tolerant species. The dominant species differed each time; black bullhead, central mudminnow, and hybrid sunfish. The only sensitive species caught at this location from three sampling visits were: stonecat, logperch, and Iowa darter, represented by two, one, and one individuals respectively.

Three of the four Community TIV Index scores for DO and TSS were below the 10th percentile of all scores within this stream class (Table 22). The TSS TIV Index score from the 2007 sample is skewed low due to the high numbers of young black bullheads caught. Young-of Year bullheads school together, and one or several schools were apparently caught in the sample. More weight should probably be placed on the 2016 sample, which did not collect large numbers of young black bullhead. In that case, the issue appears to be low DO. The probability that the sampled fish community would be found at a site with standard-meeting DO is very low, while the probability is quite high regarding TSS. Additional fish metrics related to DO add to the evidence that the fish community is highly skewed toward species that can live in low-DO waters (Table 23).

Table 22. Fish Community DO and TSS Tolerance Index scores in AUID-519 at 07UM082. 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 5 (2017 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.

Year	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2007	5.68	6.99/7.11	2	7.9	22.23	13.85/12.99	5	28.3
2016	6.13	6.99/7.11	6	15.9	12.99	13.85/12.99	50	82.5

Table 23. Metrics involving DO tolerance for the fish community in AUID-519.

Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant	% Intolerant Individuals	% Tolerant Individuals
2007	0	0	10	8	0.0	85.8
2016	0	0	11	6	0.0	97.4

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

Macroinvertebrates

The macroinvertebrates passed their IBI assessment. The same metrics that indicated a fish community that is very skewed toward tolerance of low DO were calculated for the macroinvertebrate community, to see if low DO also shows some influence on macroinvertebrates. The community DO TIV Index scores right about average for Class 4 streams (Table 24). Taxa-wise, the macroinvertebrates are also very skewed toward low-DO Tolerant taxa (Table 25), though not to a degree as to cause an impairment. The percent of low-DO tolerant individuals was much lower than it was for the fish community. As for the influence of TSS, the macroinvertebrate community had a fairly high likelihood of coming from a site with standard-meeting TSS levels (Table 24), as did the more-recent fish sample.

Table 24. Macroinvertebrate Community DO and TSS Tolerance Index scores in AUID-519 at 07UM082. 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 4 (2017 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.

Year	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2007	6.19	6.28/6.47	35	54	15.44	13.59/13.73	13	71
2015	6.31	6.28/6.47	41	56	14.00	13.59/13.73	42	81

Table 25. Metrics involving DO tolerance for the sampled macroinvertebrate community at 07UM082.

M-invert Class	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
4	2	1	15	4	1.6	42.5

*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. The lone crossing on AUID-519 is a paired culvert for Hwy 65, which is not a barrier. Review of recent aerial photos did not find any beaver dams downstream of Hwy 65 to Big Sandy Lake. Thus, there are no barriers preventing fish from migrating up from Big Sandy Lake and connectivity is not a stressor to the fish community.

Hydrology

AUID-519 is a relatively short reach that is immediately downstream from AUID-518. Thus, much of the altered-hydrology discussion presented on Page 34 is applicable to this downstream portion of Minnewawa Creek. See also the discussion of peatland drainage in the "Hydrology" section on Pages 24-26. This reach also receives the outflow of Minnewawa Lake (this is the point that separates AUID-518 and 519). Based on a qualitative look at the stream channel sizes, it appears the input from Minnewawa Lake approximately doubles the flow from the volume entering from AUID-518 upstream.

Habitat

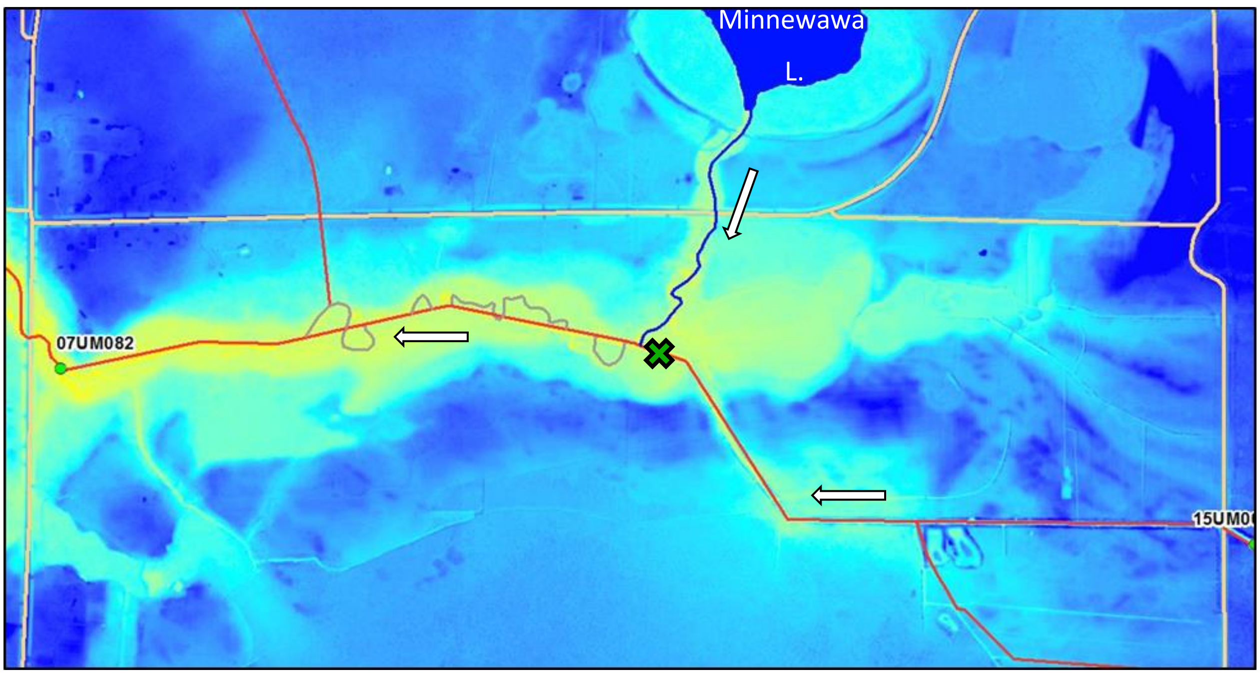
The MSHA scored at the middle part of the "Fair" range. The "Channel Morphology" and "Substrate" components were the poorest-performing of the five subcomponents of the MSHA. Sand and silt were the only substrate types found. Within "Channel Morphology", the metric that knocked the score down was "Channel Development", which scored zero of a possible nine points. The definition for this score (0 = Poor) is "Riffles are absent; pools if present are shallow or lack variation in depth." However, the model that has been developed from a large dataset determined that the overall habitat in this AUID should be sufficient for attaining a passing score. In mid to late summer, this reach can function more like a linear wetland with extensive emergent vegetation throughout the channel (Photo 2).

Photo 2. AUID-519 functions more like a wetland than a stream during some of the summer, as shown by the extensive emergent vegetation growth.

Geomorphology

AUID-519 from State Highway 65 and upstream is a ditch that was dug through the meandering stream, and flows through the original valley, without any parts being dug through upland areas. This makes the stream (ditch) somewhat more stable as there are no high banks. The original, uppermost parts of Minnewawa Creek are shown in Figure 23. The ditched part of AUID-519 (east of Hwy 65) runs through a naturally formed valley, with uplands fairly close to the channel. This differs from the expansive wetlands that are ditched farther upstream in this system. Unlike many agricultural ditches, the constructed ditch of AUID-519 appears to have quite stable banks. No exposed soil, bank sloughing, or bank scour was seen along this reach. The fact that this ditch appears stable is probably due to less surface runoff than occurs where these ditches are adjacent to agricultural fields combined with the low slope. No formal geomorphological surveying was done at this location, in part, because constructed ditches generally were not made to mimic natural channels.

Figure 23. LiDAR-derived elevations of the upper part of AUID-519 with darker blue being higher elevation and yellow being lower elevation. Flow channels are mostly ditches (red), with some of the original meanders showing (gray). Part of the stream flow is contributed by the outlet of Minnewawa Lake (blue), and the uppermost parts of the original drainages to Minnewawa Creek (green). Arrows show flow direction. There originally was no channel upstream of the X symbol in the area where the ditch now runs.



Conclusions

The primary stressor in AUID-519 is low DO, with mediocre habitat as a contributing stressor. This was found via the actual measurement of DO, as well as there being a strong signal of low-DO Tolerant fish and macroinvertebrates in those communities. There is much-drained wetland that contributes flow to the AUID, as well as a large wetland bay of Lake Minnewawa where the lake outlet and partial source of Minnewawa Creek flows. The channel itself becomes wetland-like during mid to late summer. The low gradient nature of the AUID does not produce much turbulence to the water, and thus does not help aerate it. The AUID ends as the channel enters a large wetland marsh habitat. The low DO found in the AUID is not caused by eutrophication. Nitrate concentrations are very low, and excess algae is not present. The daily swings in DO were relatively low; another signal that eutrophication is not occurring.

Being a ditched, straight channel reduces habitat variety in the channel. This ditch, as is normal for ditches, exhibits poor habitat feature differentiation (distinct riffles, pools, and runs), and contains mainly fine particle substrate, which produces few microhabitats. Substrate potential is partially limited by the naturally sandy conditions of the surficial geology in this area.

The low DO, wetland characteristics of the channel, and large downstream wetland/marsh habitats combine to produce fish and macroinvertebrate communities that are quite limited in diversity and lack species that require specific habitat characteristics.

Recommendations

There is not much that can be done to improve the poor dissolved oxygen conditions aside from decommissioning/plugging/filling ditches in the bogs upstream. This would require some study of hydrology of the system, and what the effects would be at localized areas that may be sensitive to changing the current drainage. Such ditch decommissioning can have other benefits as well, including likely reducing the phosphorus moving to downstream waters.

Habitat improvement will be fairly difficult here as well. Ditches are constructed in ways that produce homogeneous habitat, which results in poor biodiversity. Putting the stream back into its original channel would help achieve better habitat conditions. The old meanders can still be seen in the landscape. However, this may be problematic currently given the upstream alteration of hydrology, which delivers more water than the original channel formed to pass. Putting the increased flows into that original, smaller channel could lead to channel instability. If upstream ditching were reduced, this would be a more realistic tack to take. It would be wise to visit and examine the abandoned channel to see if there are any issues that would occur downstream of the renewed channel (i.e., an initial pulse of sediment or organic debris).

Pickerel Creek (AUID 07010103-590)

Impairment: The creek was assessed as impaired for not meeting both the cold water fish or macroinvertebrate community IBI thresholds at sites 15UM066 and 15UM067 located upstream of State Highway 65 at Pengilly. AUID-590 contains sites of Fish Class 11 (Northern Coldwater) and Macroinvertebrate Class 8 (Northern Coldwater).

Subwatershed characteristics

The creek's original headwaters area has been altered by mining activity (Figure 24). Part of this area is now a tailings storage area, while some adjacent area is cleared and is essentially a large, exposed gravel area. The remainder of the subwatershed is quite natural, until it reaches Pengilly and down the short remaining distance to Swan Lake, where it passes through residential areas and crosses local streets, and near State Highway 65. The natural area of the subwatershed is part forest, and part wetland (grass/willow shrub).

Figure 24. The Pickerel Creek subwatershed showing land cover and biological monitoring sites. The developed area in the center and to the east of the subwatershed is a mine tailings basin. Runoff moves from north to south, into Swan Lake at the bottom of the photo.

Data and analyses

Chemistry

The chemistry data that were collected at the fish and macroinvertebrate sampling visits in 2015 and 2016 are shown in Table 26. Sample results were generally good, with exceptions being DO and specific conductivity.

Table 26. Chemistry measurements from 2015-2016 IWM sampling and 2017 SID at 15UM066 and 15UM067.

Date and site	Time	Temp.	DO	DO % Sat.	pH	Cond.	S-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
June 10, 2015 (066)	15:17	19.6	--	--	8.21	860	> 100	0.034	< 0.05	< 0.1	5.6	< 4
Aug. 11, 2015 (066)	13:04	17.1	8.52	95	--	920	--	--	--	--	--	--
Aug 24, 2016 (066)	17:35	19.6	5.58	61	7.64	1030	> 100	--	--	--	--	--
June 19, 2015 (067)	17:28	21.1	9.69	116	7.98	995	> 100	0.068	< 0.05	< 0.1	< 4	< 4
Aug. 21, 2015 (067)	14:38	18.3	8.55	96	8.02	1080	> 100	--	--	--	--	--
Aug. 4, 2017 (067)	11:50	--	4.92	--	--	--	"clear"	--	--	--	--	--
Aug. 21,2017 (067)	14:35	16.4	3.71	38.1	--	817	"clear"	--	--	--	--	--

Nutrients - Phosphorus

One of the TP samples was above the northern river standard, while the other was significantly lower than the standard. There are no human activity sources of phosphorus upstream of the sample sites.

Nutrients - Nitrate and ammonia

Both samples for each parameter were at very low levels, and below the lab detection limit for nitrate.

Dissolved oxygen

Three of the six instantaneous DO measurements look fine, but three August measurements (2016 and 2017) were well below the cold water standard of 7 mg/L (Table 26). That these readings were taken in the late morning and mid-afternoon, when DO is nearing its daily peak, means the daily minimums on those days were even lower. Additionally, August 4, 2017 was a sunny morning, a good condition for algal production of oxygen (algae amounts are not at abnormal levels). August 21, 2017 was a very overcast day, perhaps the reason the DO concentration was lower than on Aug. 4, despite being collected in mid-afternoon.

Transparency and suspended solids

TSS was well below the cold water standard at both sites, though only one date was sampled for each. TSVS was below the lab's detection limit at both sites. Transparency sampling on four different dates found clear water of > 100 cm visibility, and observations at two visits by the author found the stream to be clear.

Conductivity

Most of the measurements were between 850 and 1080, which is much higher than the typical natural condition for north central and northeastern Minnesota.

Biology

Fish

The fish community passed the cold water IBI at site 15UM066, but failed farther upstream within AUID-590. At the downstream site (15UM066), the community was dominated by central mudminnow. Several cold water taxa were present, but in very low numbers, including mottled sculpin, burbot, brook trout, and longnose dace. The upstream site (15UM067) was dominated by fathead minnow, followed by central mudminnow, both highly tolerant species. No cold water species were present at the upstream site.

Based on the DO and TSS Community indices and scores relative to the class averages (Table 27), the fish community is certainly skewed toward a low-DO tolerant community at both sites. At each site, the DO TIV scores were only at the fifth percentile for Class 11 streams. There were a number of Low-DO Tolerant species at both sites, and at both sites the percent of individuals that are Low-DO Tolerant was fairly high.

The TSS metric also scores poorly, particularly at the upstream site, where it was 554th of 555 Class 11 streams in the MPCA database. That the fish communities at these two sites have a moderate probability of coming from a stream with passing TSS scores is due to the inclusion of data from other classes being included in this metric, which typically have much greater TSS loads than Class 11, low gradient cold water streams. Despite the very poor TSS result among cold water streams, there were no species present at either site that are tolerant to elevated TSS (Table 28). The information regarding TSS is somewhat unclear, but TSS may be a stressor in this AUID. All things taken into account, it appears that substandard DO levels for a coldwater stream is a primary stressor.

Since this stream is adjacent to a mine tailings deposit area, tolerance metrics related to conductivity were also examined (Table 28). Conductivity measurements (Table 26, above) were much higher than is typical for northeastern Minnesota. Few individuals were High Conductivity Tolerant, particularly at the more downstream site where only about 5% were such, though at the upstream site, considerably more individuals were High Conductivity Tolerant vs Intolerant. There is not a strong signal from the fish community sampled that conductivity is a significant stressor.

Table 27. Fish Community DO and TSS Tolerance Index scores at 15UM066 and 15UM067. 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 11 streams (2017 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.

Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
15UM066	11	6.18	7.61/7.55	5	3.8	12.7	10.84/11.25	27	56.5
15UM067	11	6.19	7.61/7.55	5	4.0	17.2	10.84/11.25	1	49.1

Table 28. Metrics involving DO, TSS, and conductivity tolerance for the sampled fish community at 15UM066 and 15UM067 utilizing MPCA species tolerance values.

Site and parameter	Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Intolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
15UM066 Low DO	6/10/2015	3	1	4	3	8.0	64.0
15UM067 Low DO	6/19/2015	0	0	4	4	0	75.0
15UM066 TSS	6/10/2015	4	3	0	0	5.3	0
15UM067 TSS	6/19/2015	2	1	0	0	9.2	0
15UM066 Cond	6/10/2015	3	2	2	1	5.3	5.3
15UM067 Cond	6/19/2015	2	1	2	1	9.2	39.7

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

Macroinvertebrates

The macroinvertebrate community also failed its coldwater IBI. Site 15UM066 was sampled in both 2015 and 2016. In both samples, the black fly *Simulium* dominated the community, with the mayfly *Baetis brunneicolor* being subdominant. *Simulium* individuals made up 40.1% and 33.3% of the 2105 and 2016 samples, respectively. There were a small number of coldwater obligate taxa present, including the midges *Brillia* and *Heterotrissocladius*, and the caddisfly *Lepidostoma*. All three taxa were represented by a single individual. The 2016 sample also contained one *Helicopsyche borealis*, another coldwater taxon. Coldwater streams typically have many more taxa from the EPT orders. The community upstream, at 15UM067, was much different, with zero *Simulium* and few *Baetis brunneicolor*, and instead was dominated by the mayfly *Caenis diminuta,* with the riffle beetle *Dubiraphia* being subdominant. These taxa suggest that the upstream site is a much more slow-flowing site, as does the presence of several mollusks; fingernail clams, and the snails *Planorbella* and *Gyraulus*.

Tables 29 and 30 show DO-, TSS-, and conductivity-related metric scores for the macroinvertebrate community at sites 15UM066 and 15UM067. The DO TIV Index is not very helpful here due to the dominance of *Simulium*. They have 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 at 15UM066 to be higher (better) than they ought to be. Note that at 15UM067, where there were no *Simulium*, the DO TIV score was quite a bit lower.

Specific metrics using DO tolerance values are shown in Table 30. These show a community skewed toward Low-DO Intolerant taxa and individuals at the downstream site, while the upstream site is skewed toward Low-DO Tolerant taxa. Note that *Simulium*, which confounds the DO TIV Index metric, are neither intolerant nor tolerant, and thus do not show up in the values in Table 30. The macroinvertebrate community shows that low-DO is more of a stressor at the upstream site. This may be due to the warmer water temperature upstream, which would increase metabolism of organisms, and thus increase their need for oxygen. For some organisms, there will not be enough to meet their needs.

The community index scores for TSS are significantly worse than average, while the tolerance metric scores show the community as being moderately skewed toward TSS Tolerant taxa, and more so at the upstream site. The TSS Index score may be confounded by the naturally sandy character of this stream, which likely should have taxa more oriented to fine substrate habitats. TSS does not appear to be a strong stressor, as the percent of Tolerant individuals is quite low, though TSS may be a minor stressor.

The community at both sites is somewhat skewed toward tolerance to elevated conductivity, particularly the upstream site, which had almost 40% of the individuals being tolerant to elevated conductivity levels. Less is known about the influence of conductivity on aquatic organisms, though research does suggest that some aquatic macroinvertebrates are essentially extirpated at levels lower than what was measured in Pickerel Creek (EPA 2011). There are multiple factors that can determine how a particular level of conductivity affects aquatic organisms, and research is still needed to better understand the effects of conductivity and which parameters are most influential (Pond et al., 2008, Zalizniak, 2006). Given the current partial understanding of the stress effect of conductivity, it is difficult to say what effect this parameter has on the community of Pickerel Creek.

Table 29. Macroinvertebrate Community DO and TSS Tolerance Index scores at 15UM066 and 15UM067. 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 8 streams (2017 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.

Site	Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
15UM066	8/11/15	7.58	7.32/7.46	59	74	14.10	12.25/12.29	14	51
15UM066	8/24/16	7.53	7.32/7.46	55	73	13.83	12.25/12.29	17	53
15UM067	8/20/15	6.50	7.32/7.46	12	55	14.68	12.25/12.29	7	46

Table 30. Macroinvertebrate metrics related to DO, TSS, and conductivity for 15UM066 and 15UM067 utilizing MPCA species tolerance values.

Site and parameter	Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
15UM066 Low DO	8/11/15	8	6	3	0	29.6	4.9
15UM066 Low DO	8/24/16	7	5	2	0	25.0	3.2
15UM067 Low DO	8/20/15	6	4	6	2	5.3	34.6
15UM066 TSS	8/11/15	4	2	4	1	2.0	12.2
15UM066 TSS	8/24/16	4	1	5	1	3.8	16.8

Site and parameter	Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
15UM067 TSS	8/20/15	2	1	6	1	1.0	11.6
15UM066 Cond	8/11/15	4	2	7	3	2.0	13.8
15UM066 Cond	8/24/16	2	1	7	4	2.5	10.1
15UM067 Cond	8/20/15	2	1	7	4	9.0	48.8

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

Temperature

Temperature loggers were deployed at both 15UM066 and 15UM067 for July and August in 2014, and for June, July, and August in 2015. Temperature statistics are shown in Table 31. Upstream site 15UM067 is consistently warmer than downstream site 15UM066. July has the highest average daily maximum temperatures at both sites, which is typical of Minnesota streams. A field visit in 2017 found numerous spring seeps just upstream of the driveway crossing where the sonde was deployed. Iron deposits were present in these seeps, and the riparian soil was peat.

The springs that are part of the source water for the creek may not be sufficient to allow coldwater species to thrive, at least along parts of the AUID. The July average temperature at the upstream site is slightly higher than the general guideline that this number be under 20^{o}C. Statistics calculated from the deployed temperature loggers show that that there are no lethal temperatures for trout, but that there are some periods where water temperatures are stressful to trout, particularly at the upstream site (Table 32).

Table 31. Temperature statistics for 15UM066 and 15UM067.

Site	Year	Summer Avg. Temp.	Summer Avg. Maximum Temp.	July Avg. Temp.	July Avg. Maximum Temp.	August Avg. Temp.
15UM066	2014	--	--	18.22	20.17	17.78
15UM067	2014	--	--	20.02	21.81	19.41
15UM066	2015	16.61	19.34	18.11	20.88	14.98
15UM067	2015	18.88	21.06	20.67	22.87	17.23

Table 32. Percentage of time during June, July, and August that measured stream temperature was within four ranges that are important for brook trout survival. Desired water temperature is within the “Growth” range.

Site	Year	Lethal	Stressful	Growth	No Growth
15UM066	2014	0.0	12.8	87.2	0.0
15UM067	2014	0.0	41.7	58.3	0.0
15UM066	2015	0.0	10.7	89.3	0.0
15UM067	2015	0.25	34.3	65.4	0.0

Habitat

Three MSHA scores were calculated from three visits for site 15UM066: 67.5 (June 10, 2015), 52 (August 11, 2015), and 52.75 (August 24, 2016). These scores are in the “Good” and “Fair” categories. The poorest-scoring subcategory scores, from a percentage of each category’s possible score, were

“Substrate” and “Channel Morphology”. One visit recorded embeddedness as “Light”, while the other two found no coarse substrate, which could be embedded. The MSHA scores at 15UM067 were 55.65 (June 19, 2015) and 49 (August 20, 2015), both in the “Fair” category. Embeddedness was considered “Light” and “Moderate”. The categories “Substrate”, and “Channel Morphology” again were the lowest scoring subcomponents.

Geomorphology

The channel at the downstream biological site (15UM066) appears to be an E5 channel (relatively narrow and deep, sand substrate). The banks appeared to be relatively stable at 15UM066. There does appear to be significant mobility of the streambed sands, because a deployed sonde became somewhat buried over just a one week period.

Rosgen method

The DNR staff conducted geomorphological surveying on a reach downstream of 15UM066. The following contains their conclusions: “We assessed a reach of Pickerel Creek upstream of E Shore Drive in Pengilly. We surveyed over 300’ of stream and determined that the reach transitions from an E5/6 stream to C5/6. The E characterizes the stream as narrow, deep, and sinuous while the 5/6 signifies the reach is primarily sand but that silt is also prevalent. The C describes a wider, shallower stream.

It appears that historic and current impacts from mining and local development have altered stream hydrology causing instability and stream type succession. The stream is widening from an E into a C channel, but the transition is slow due to the low slope, well-vegetated banks, and accessible floodplain. So far, the stream has not down cut and is not incised or entrenched except where it has been ditched around the hockey rink. The instability is affecting the biota. For example, there is not a lot of habitat diversity in the channel bottom. We found no in-channel vegetation and minimal undercut banks. The other main geomorphic stressors to biology are the mobile channel bed, small particle size, and a lack of deep pools.

We used the prevalent floodplain for our bankfull measurements. Given this height, the E channel is deeply incised where it is straightened and channelized around the hockey rink. As it transitions into a C channel, it gains access to the bankfull floodplain and is not incised. However, ArcMap and Streamstats calculated different drainage areas, 2.3 and 4.15 sq. mi. respectively, leading to conflicting cross-sectional areas from the regional curve. Since the mining impacts on hydrology aren’t well known and there were not indicators of incision for most of the reach, we stayed with the higher cross sectional area of around 15 sq. ft. that matched the floodplain. If the lower drainage area were correct, then the stream would be slightly too moderately incised. During the survey, a layer of compacted clay beneath the sand/silt was observed. This clay may be helping to keep the stream from down cutting and forcing it to widen, although we do not know how prevalent the layer is.

The stream is generally unconfined through the AUID but has sections of confinement. A stream is confined when seven times the bankfull width is less than the valley or flood prone width. The channel is only slightly entrenched throughout the reach so it reaches its floodplain in small to medium floods. A bridge reducing the bankfull cross-sectional area, an intake pipe, and an artificial rock wall were located downstream of the hockey rink and could be affecting local stream stability.

Pfankuch method

The Pfankuch score for this reach was 101, a poor (unstable) score for an E5 stream and a fair (moderately unstable) score for a C5 stream. It scored poor primarily due to the predominance of sand in the stream channel and a lack of stable material or in-channel vegetation on the channel bottom. Four out of the five categories of the lower banks rated as good. The scores were affected by a higher width depth ratio than expected, pool filling and minor bank cutting, and some new point bar deposition. The upper banks rated as excellent in three out of four categories. The upper banks had low slopes, no mass erosion potential, and good plant density and vigor. Other level III indicators such as meander patterns, depositional patterns, and BANCS raise no lateral stability concerns. Furthermore, the banks appeared to be in good shape so there likely are upstream sediment sources."

Conclusions

Pickerel Creek, in its upper reaches, often has temperatures that exceed those found in healthy coldwater streams. DO levels are also not meeting the coldwater standard during the mid-summer period for at least much of the day as measured at the downstream site in 2017. These are two stressors to Pickerel Creek.

The condition of low DO may be in part due to the un-natural open exposure of the headwaters area adjacent to mine tailings ponds, combined with natural groundwater inputs that move through riparian peat soils from adjacent wetlands. Such groundwater seepages were observed in organic riparian soils just upstream of the driveway crossing in Pengilly. This groundwater is quite anoxic in summer and its addition to the stream will depress the oxygen levels of the stream water; a low-gradient stream, like much of Pickerel Creek, is less able to mitigate this condition by aerating the water with turbulent flow.

The stream has much higher conductivity than undisturbed streams of northeastern Minnesota, likely due to seepage into the stream of water originating in the tailings pond. The fish community data did not show much of an influence of conductivity. Analysis of the macroinvertebrate data appears to show some influence of conductivity, as both the number of taxa and individuals were higher for those tolerant to higher conductivity. However, the science on the actual influence of moderately higher conductivities on aquatic organisms is not fully developed, so it is difficult to determine if the elevated conductivity observed in Pickerel Creek is a stressor. In addition, other stressors, particularly DO, are present here, making it difficult to determine the degree to which elevated conductivity is altering the aquatic communities in Pickerel Creek.

The two primary stressors that appear to be negatively influencing the biological communities of Pickerel Creek are substandard DO concentrations and water temperature that can exceed healthy levels for coldwater communities. Elevated water temperature may be part of the cause of insufficient DO levels, though it is difficult to determine the amount of human contribution to water temperature in this AUID. Elevated conductivity as a stressor is deemed inconclusive, but possible.

Recommendations

Because water temperature is too warm in the upstream portions of Pickerel Creek, establishing some riparian vegetation in the artificially open headwaters area adjacent to the mine tailings ponds to provide shading and some runoff-erosion protection would cool the water and keep excess sediment from entering the creek. This has been discussed with the mining hydrologist in the DNR Grand Rapids office. Dropping the water temperature should also help increase DO concentrations.

Additionally, it would be of benefit in managing the stream to locate significant spring inputs. From reviewing topography, it appears there is a steeper gradient section with higher adjacent uplands between the two biological sample sites. This may be a significant groundwater source area for the stream. If so, perhaps there is only a portion of the stream that is truly suitable for management as a coldwater stream, that being the lower portions of the AUID.

Tributary to Bray Lake (AUID 07010103-722)

Impairment: The creek was assessed as impaired for not meeting the fish community IBI threshold at site 15UM056, located adjacent to CR-56, six miles northwest of Nashwauk. The biological site in AUID-722 is Fish Class 11 (Northern Coldwater) and Macroinvertebrate Class 8 (Northern Coldwater).

Subwatershed characteristics

The creek flows through a very natural, forested area in its lower reaches, while upstream, it is lower gradient, and the riparian vegetation is not woody, as it flows within a wetland/wet meadow corridor. Several beaver dams exist in the upstream portions of the creek. Numerous roads, as well as a significant number of hay fields exist on the landscape, particularly in the upper half of the subwatershed. The stream has never been managed for trout by DNR.

Data and analyses

Chemistry

The only chemistry data collected from AUID-722 is from IWM biological sampling visits (Table 33). All of the parameters are at healthy levels.

Table 33. Chemistry measurements from 2015-2016 IWM sampling and 2017 SID at 15UM056.

Date	Time	Temp	DO	DO % Sat.	pH	Cond.	S-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
June 10, 2015	18:57	19.9	11.68	135	7.20	70	> 100	0.044	< 0.05	< 0.1	< 4	< 4
Aug. 18, 2015	17:24	16.3	9.48	102	7.86	419	95	0.034	< 0.05	< 0.1	< 4	< 4
June 14, 2016	16:48	16.8	9.27	96	7.39	114	> 100	0.052	0.02	< 0.1	4.0	3.2
Aug. 21, 2017	15:15	16.7	8.50	88	--	113	--	--	--	--	2.8	--

Dissolved oxygen

DO levels were good at the four biological sampling visits (Table 33). One of the readings was somewhat high, with a corresponding saturation level of 135%. Percentages of DO saturation well above 100% are often the result of excessive algae or plant material in the stream. However, the water clarity and low TSS/TSVS rule out suspended algae as a cause, and the extensive shading due to the riparian tree canopy rule out periphyton as an explanation.

The author, in August 2017, trekked the river from CR-56A to Bray Lake and saw no aquatic macrophytes, and the abundant cobble substrate was very clean. Some filamentous algae was seen just above the culvert where the canopy was more open due to the road. In this case, the high DO saturation is likely due to the water turbulence from the cascading flow here relating to the boulders present in the stream and relatively high gradient. The froth shown in Photo 3 is flocculated DOC, which happens with turbulent flow conditions.

Photo 3. DOC foam on the stream surface is evidence of turbulent flow; an explanation for the high % saturation of DO sometimes found in AUID-722.

Nutrients - Phosphorus

TP levels are good except for one sample that was very slightly above the regional river standard. That TP level is probably natural, as the other parameters do not signal anthropogenic pollution of the water.

Nutrients - Nitrate and ammonia

Nitrate and ammonia concentrations were extremely low.

Transparency and suspended sediment

Secchi-tube readings were excellent. TSS and TSVS concentrations were extremely low. A TSS sample was collected during the SID process, on August 21, 2017, four days after a significant rain event (1.45" and 1.02" at the nearest two Weather Underground stations for August 17, 2017), in order to determine whether there are temporary suspended sediment issues associated with rain events. The water was observed as "clear" (though tannin-stained), and the TSS value was a very low 2.8 mg/L.

Biology

Fish

The fish community was sampled three times; June 10, 2015, August 18, 2015, and June 14, 2016. In the first sample, only five individual fish of two species were captured. This sample was determined to be flawed due to poor effectiveness of the electrofishing gear. In the second sample, six species were collected, with creek chub dominant, followed by white sucker. The last sample collected six species, with creek chub and white sucker being most abundant, but not dominant. With the exception of one finescale dace, the species collected are ubiquitous, found in a wide range of habitats. Finescale dace was the only sensitive species.

Metrics related to DO and TSS are shown in Tables 34 and 35. The poor or mediocre probabilities for both DO and TSS do not agree with the actual measured values of these parameters, which both show very good water quality (good DO levels and very low TSS). However, these are only three measurements of each parameter, and for DO, two of the sampled dates are in late spring (early-mid June), when water temperatures are still fairly cool in all streams, which leads to better DO concentrations. There are more low-DO tolerant than intolerant taxa, though the percent of tolerant individuals is fairly low. The fish community shows a modest bias to being tolerant of lower DO levels.

There are almost no TSS Tolerant or Intolerant taxa in the two fish samples, so TSS levels are not strongly skewing the community, though compared to other class 11 streams, the TSS Index scores are extremely poor, at the 2nd and 5th percentiles of all class 11 streams. The fish community does seem to be affected by DO and moderately by TSS levels present in the AUID, though low numbers of fish caught in the samples might be causing an incorrect conclusion.

In August 2017, the author walked the stream channel from CR-56A downstream to the mouth at Bray Lake (a section of about 0.3 channel miles in length, downstream of the biological sample reach). Very few fish were observed, even though conditions were at base flow, and the water was clear and shallow. Only one northern pike (~ 6 in.) and about ten 1.5-inch minnows were seen.

Table 34. Fish Community DO and TSS Tolerance Index scores in AUID-722 at 15UM056. 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 (2017 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 appropriate standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/18/15	7.11	7.61/7.55	23	44.1	15.5	10.84/11.25	2	52.0
6/14/16	6.81	7.61/7.55	15	23.1	14.5	10.84/11.25	5	53.4

Table 35. Fish metrics related to DO for 15UM056 utilizing MPCA tolerance values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO 2015	0	0	3	1	0	8.4
Low-DO 2016	0	0	2	2	0	23.3
TSS 2015	1	0	0	0	0.84	0
TSS 2016	0	0	0	0	0	0

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

Macroinvertebrates

The macroinvertebrate community was assessed as meeting the standard. In fact, the IBI score was close to attaining the "Exceptional Use" status threshold. Numerous coldwater taxa were found, some of which included the caddisflies *Glossosoma*, *Goera*, and *Nyctiophylax*, the stoneflies *Paragnetina media* and *Isoperla*, the mayfly *Leucrocuta*, the midge *Doncricotopus*, the fly *Tipula*, and the fishfly *Nigronia*. This is one of only 33 streams (out of approximately 268 northern coldwater streams sampled across Minnesota at the time of this writing), where the caddisfly genus *Goera* has been collected. It is the only stream in the MRGRW where it has been found in IWM and previous MPCA sampling efforts. And within the Mississippi River Basin (above the Twin Cities), it has been found by MPCA at only four sites, the three others all being in the Leech Lake River Watershed: Bungashing Cr., Necktie R., and the Kabekona R., all three being healthy coldwater streams.

Macroinvertebrate metrics were evaluated to see if there might be some signal in the community to confirm that low DO and TSS are not stressors (Table 36). For both parameters, the sampled community is more likely than not to come from a site that passes those water quality standards. Based on the numbers of low-DO Intolerant and Tolerant taxa present, which is greatly skewed toward taxa that require good oxygen levels, the signal from the macroinvertebrates is that DO levels in AUID-722 are very good (Table 37).

The tolerance metrics for TSS show some evidence that TSS could be a minor stressor. Though there were more than twice as many TSS Intolerant taxa as TSS Tolerant taxa, there were more individuals that are TSS Tolerant than TSS Intolerant. The percentage of TSS Tolerant individuals was not high however.

The macroinvertebrate metrics do not confirm that DO is a likely stressor to the fish community, while they add some fairly weak evidence to the weak evidence provided by the fish analysis that TSS might be a light stressor.

Table 36. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-722 at 15UM056. 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 (2017 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 %
7.53	7.32/7.46	55	73	13.1	12.45/12.28	29	59

Table 37. Macroinvertebrate metrics related to DO for 15UM056 utilizing MPCA tolerance values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	19	10	1	0	42.1	31.0
TSS	11	7	5	2	19.5	28.8

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

Temperature

Water temperature was not problematic for fish at any of the three dates with temperature measurements (Table 38), though the June 10, 2015 temperature is very close to being outside of what is commonly considered coldwater by MPCA biologists. Oddly, that is a time of year when stream temperatures are usually still fairly cool. A continuous temperature logger was deployed in 2016, which recorded a summer average temperature of 18.7°C, meaning the stream is fit to support a coldwater fish assemblage based on water temperature requirements of those species. The fact that numerous cool/coldwater macroinvertebrate taxa were collected also suggests that the stream temperature remains quite cool.

Table 38. Water temperature readings at biological sampling visits at 15UM056, in degrees Celsius.

Date Year	Time	Water Temp.
June 10, 2015	18:57	19.9
Aug. 18, 2015	17:24	16.3
June 14, 2016	16:48	16.8

Habitat

The MSHA protocol was conducted at three visits to 15UM056. The MSHA scores of 85.7 (June 10, 2015) and 76.6 (June 14, 2016) are well into the "Good" range, with the 85.7 being exceptionally high, while the score of 65.2 (August 18, 2015) is right at the line between "Fair" and "Good". The two early-summer scores might be better due to better flow conditions. None of the five subcomponents of the MSHA scored particularly low, except that the three subcomponents dealing directly with the channel scored lower than the “Riparian” and “Land Use” scores. Embeddedness was rated “Light” at two visits, and “Moderate” at one. Substrate was excellent with boulder, cobble, gravel, and sand present. Woody debris and macrophytes were also present, and cover for fish was rated as “Moderate” or “Extensive”.

Connectivity

The only road crossing within AUID-722 downstream of 15UM056 is the cabin-access road (56A) on the east side of Bray Lake. This culvert was visited during general SID assessment, and though it appears by its construction as being quite old (thick, riveted steel), it was found to be a well-functioning culvert on that date (not a fish migration barrier). At the base flow conditions that existed during that day, there was about 10 inches of water in the culvert, with a flow velocity approximated at 0.5 fps. Smaller fish species would have no difficulty moving through the culvert in these conditions. DNR staff did a more thorough assessment of the culvert and found it to be somewhat undersized, and its placement elevation is not ideal (culvert bottom is above stream bottom and no substrate is present inside, Photo 4), but it is not perched above the water level. It should not be a barrier to fish passage, except at higher flows, when it would be a velocity barrier. Very little channel alteration was seen at the downstream end of the culvert. The small amount of effect on the downstream channel by the culvert is caused by the curve of the stream channel, such that the bank is somewhat perpendicular to the outflow from the culvert (somewhat incorrect alignment of the culvert). Data from this culvert assessment has been archived in the DNR Culvert Database.

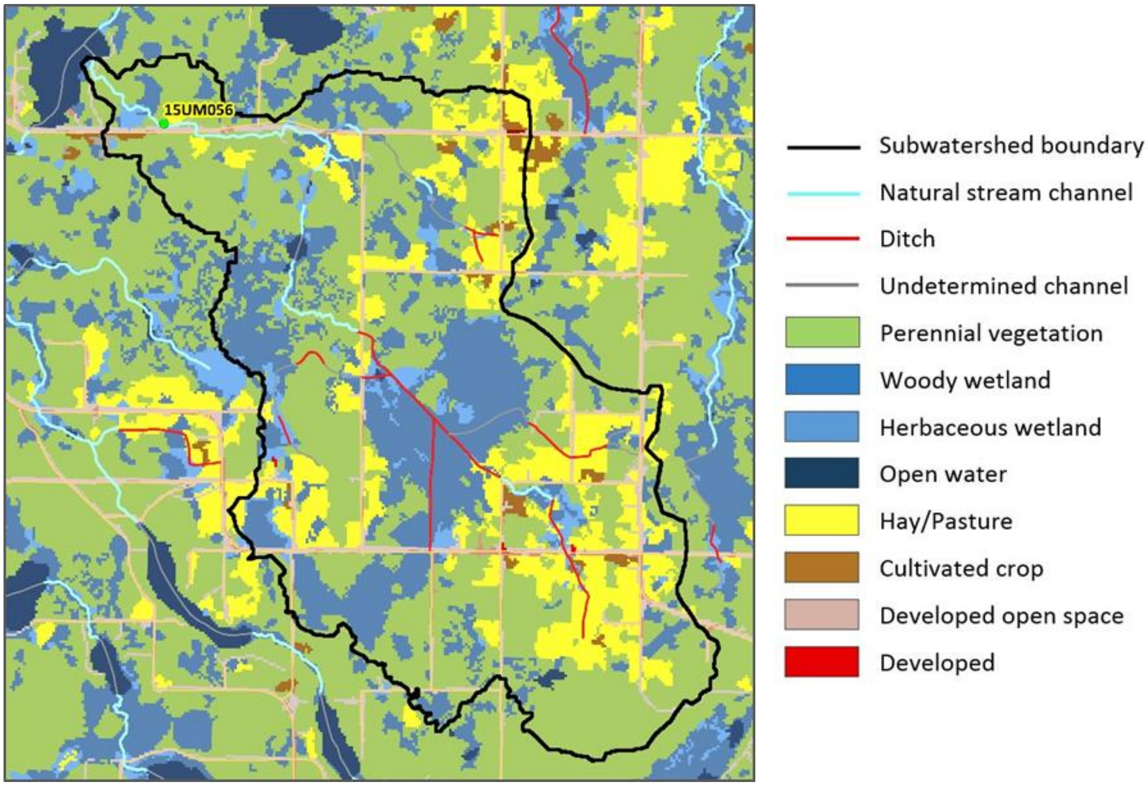
Photo 4. Upstream invert of culvert at the cabin access road along the east side of Bray Lake.

The author walked the stream channel from the culvert on 56A down to the mouth of the creek at Bray Lake to look for any other potential barriers, and none were found. There does not appear to be any beaver activity between 56A upstream to 15UM056 via aerial photography review (probably related to the higher gradient in this part of the stream). There is one riparian meadow in this part of the creek, though aerial photos from 1991 to 2015 do not show beaver activity there. The only beaver activity was in the creek’s headwaters area upstream of CSAH-56. Migration barriers do not explain the lack of fish at 15UM056.

Hydrology

There is some potential for altered hydrology occurrence in the subwatershed of AUID-722. In the headwaters, there has been a fairly significant conversion of original forest to hay fields and a small amount of cultivated cropland. There is a small amount of ditching in this agricultural area. That upper part of the landscape all drains into a large wetland, which may somewhat attenuate the speed at which runoff makes it to the natural channel section lower in the subwatershed, where the biological sample was collected. Road ditches also likely contribute some runoff to the stream, as there are numerous road crossings of the stream network.

Figure 25. The AUID-722 subwatershed and its land use/land cover.



Geomorphology

A review of the channel photos taken at the biological sampling visits, along with the stellar MSHA score, suggested that channel instability was not a significant problem along AUID-722. In addition, the author walked the channel from the cabin access road down to Bray Lake and found the channel in a healthy state. Due to these findings, no formal geomorphological assessment was conducted in AUID-722.

Conclusions

Physical habitat is not a limiting factor in AUID-722. Without a physical barrier to fish migration into the stream and that, the MSHA scores show excellent habitat in the reach, it is odd that the fish community here was poor, while the macroinvertebrate community was stellar, nearly at the "exceptional use" threshold. Water chemistry parameters were all at healthy levels. There is a modest signal in the macroinvertebrate data that TSS may be a minor stressor.

The DNR has not managed this stream for trout, and since trout are not native to this part of Minnesota, the absence of them does influence the ability of the community to meet the coldwater IBI threshold. However, there are other native species found in coldwater streams, particularly sculpin, which were not present either. No other explanation has been found as to why the fish community does not meet the IBI threshold. There remains the possibility that the sampled fish community is essentially, what this stream, in its natural landscape setting, always supported. Its isolation from other coldwater streams, being that it is bounded downstream by Bray Lake may have prevented colonization (or recolonization after extreme droughts) by coldwater species from other areas. However, two coldwater species that are often found in streams, burbot and sculpin, are also found in lakes. The fact that the macroinvertebrate community was in very good health here provides some evidence to support this conclusion.

Recommendations

Without having pinned down a stressor, it is difficult to recommend a strategy to improve the fish community. It would be worth making observations at road crossings in the headwaters portion of the subwatershed, where more land cover change has occurred, to see if there are any signs of excess runoff or erosion issues as another way to check for possible TSS issues in the stream.

Tributary to Mississippi River (AUID 07010103-726)

Impairment: The creek was assessed as impaired for not meeting both the fish and macroinvertebrate community IBI thresholds at site 15UM048 located just upstream of Bluebird Drive, one mile west of Blackberry. The biological site in AUID-726 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 3 (Northern Forest Streams - Riffle/Run).

Subwatershed characteristics

The creek runs a short distance, beginning as the outflow of Blackberry Lake and flowing directly to the Mississippi River. The subwatershed land use is a mix of forest and hayfield, with a significant number of residences. The stream is crossed by US Highway 2, a railway, and several underground pipelines.

Data and analyses

Chemistry

This site's chemistry data is limited to monitoring done at three biological sampling visits, with some instrument measurements at two additional visits (Table 39). The results are generally very good.

Table 39. Chemistry measurements from 2015-2016 IWM sampling at 15UM048.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
June 10, 2015	11:08	18.2	7.75	92	7.9	155	0.040	< 0.05	< 0.1	11.6	4.8	> 100
July 15, 2015	17:55	19.8	8.35	97	8.2	--	0.042	0.438	< 0.1	< 4	< 4	> 100
Aug. 13, 2105	8:14	18.0	9.05	100	--	232	--	--	--	--	--	--
June 15, 2016	10:38	15.2	9.20	92	7.6	168	0.032	0.059	< 0.1	8.2	6.0	> 100
Aug. 25, 2016	8:15	17.0	9.62	89	8.0	188	--	--	--	--	--	> 100

Nutrients - Phosphorus

The TP concentrations are very moderate, and quite consistent among the three measurements over two years.

Nutrients - Nitrate and ammonia

Two of the nitrate concentrations were extremely low, and while the one sample was considerably higher relative to the other two measurements, it was still very low relative to levels that are problematic. Ammonia levels are very low and at levels that would have associated unionized ammonia levels much below the standard.

Dissolved oxygen

The five measurements of DO all look very good. Two pre-9am measurements, when daily DO concentrations are lowest, were well above the standard. There are no signs of a DO problem.

Transparency and suspended solids

The TSS and TSVS concentrations are fairly low, and below the standard. The July 2015 samples are perhaps lower than normal, due to extremely low flow volumes during that time. All four Secchi-tube readings were excellent.

Biology

Fish

Site 15UM048 was sampled three times, though two of the samples were determined to be not assessable, due to flow conditions out of the normal base flow range. Sample one (June 10, 2015) contained five species but only eight individuals, which is an extremely low number. Two of the species are classified as sensitive: blacknose shiner and burbot (also a cold water species). In sample two (July 15, 2015), a very dry period with low water level, only 14 individuals of one species (white sucker) were caught. Sample three (June 15, 2016), five species were collected, and again, very few individuals were caught (seven). A lone burbot was the only sensitive species.

With so few individuals collected, it is not prudent to calculate community or tolerance metrics, or statistics. The fish community is not very amenable for use to ascertain a signature of a specific stressor in this instance.

Macroinvertebrates

Site 15UM048 was sampled twice, though the 2015 sample was not considered to be assessable due to the low stream level. Sample one (August 13, 2015) had three taxa that were somewhat dominant; the midge Polypedilum, the black fly Simulium, and the midge Rheotanytarsus. Several cool-to-coldwater taxa were present, notably 16 Isoperla stoneflies, a very sensitive taxon. Others in this category included stonefly Perlesta, empidid fly Hemerodromia, riffle beetle Optioservus, midge Brillia, and caddisfly Glossosomatidae, all in very low abundance. Sample two (August 25, 2016) was moderately dominated by Simulium, mayfly Baetis brunneicolor, and caddisfly Cheumatopsyche. Again, several cool-to-coldwater taxa were collected, including: Isoperla, Tipula, Optioservus, Lype diversa, Neoplasta, Baetis brunneicolor, and Ptilostomis.

Tables 40 and 41 show DO- and TSS-related metric scores for the macroinvertebrate community at sites 15UM048. The DO TIV Index is possibly somewhat confounded here due to the abundance of *Simulium*. They have 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 may be skewing the DO TIV Index score to be a bit higher (better) than it ought to be. Specific metrics using DO tolerance values are shown in Table 41. These show a community quite strongly skewed toward low-DO Intolerant taxa and individuals. Note that *Simulium*, which confounds the DO TIV Index metric, are neither intolerant nor tolerant, and thus do not show up in the values in Table 41.

The community index scores for TSS are somewhat below the class average, while the tolerance metric scores show the community as being fairly skewed toward TSS Tolerant taxa. That there are a number of TSS Tolerant taxa may be due to the naturally sandy character of this stream, which should have some taxa somewhat more, oriented to fine substrate habitats. The macroinvertebrate community does not show evidence of inadequate DO, while there is some evidence that TSS may be a minor stressor.

Table 40. Macroinvertebrate Community DO and TSS Tolerance Index scores for the 2016 sample at 15UM048. 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 3 streams (2017 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 %
7.51	7.02/7.15	84	78.8	14.1	13.42/13.47	33	81.0

Table 41. Macroinvertebrate metrics related to DO and TSS for 15UM048 utilizing MPCA tolerance values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	8	5	0	0	31.0	0
TSS	2	0	7	1	0.6	25.5

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

Temperature

Temperature measurements taken at the biological visits are quite cool, though they were generally in the morning of early and late summer days, which don't represent the highest temperature periods of the days (which is late afternoon) nor the warmest period of summer (mid-late July). However, one measurement does represent both the near high point of both the day and warmest time of summer, that being the sample from July 15, 2015, at 5:55 pm. That measurement was slightly under 20^{o}C, which is quite cool for this date/time-of-day combination. There are some springs located in the upper part of the subwatershed that appear to keep stream temperatures running in between a coldwater and warmwater streams. These springs are located about 0.65 miles north on CR-71 from US Highway 2.

Habitat

The MSHA protocol was conducted at five visits to 15UM048. The MSHA scores of 49.0, 50.6, 53.38, 57.1, and 59.5 average to a score of 54.0, which lies right at the middle of the range of scores in the "Fair" category. The MSHA's five sub-component scores are shown in Table 42.

The sub-component that scored substantially poorer than the other four was "Channel Morphology", which achieved only about 37% of the possible points. Interpreting the scoring of the facets within this subcomponent, the picture is of a reach with fairly poor habitat diversity. The distinct riffle/run/pool features of streams were negligible here, with little overall depth variability. The "Substrate" subsection also scored rather poorly. Pictures and the MSHA suggest that sand is the predominant substrate, and that it is highly mobile. The stream facet breakout of riffle/run/pool proportions is rather variable among the MSHAs, suggesting the habitat diversity is either extremely water level dependent, and/or that the streambed is highly mobile.

Protective cover objects for fish received a "sparse" rating (Photo 5). The predominant sand and gravel also means less protective refuge areas for macroinvertebrates. Without the habitat diversity of all these varied channel and substrate features create, there are fewer microhabitats, which leads to a less diverse biological community. These missing habitat features do not seem to be strongly associated with human disturbance, as the channel does not show significant signs of instability/bank erosion due to altered hydrology.

Table 42. Averaged sub-component scores for five MSHAs conducted at 15UM048 in 2015 and 2016.

MSHA Component	Avg. Score	Maximum Poss. Score	Percent of Maximum
Land Use	4.1	5	81.0
Riparian	11.3	14	80.7
Substrate	15.4	28	55.1
Cover	10.2	18	56.7
Channel Morphology	13.0	35	37.1
Total MSHA Score	54.0	100	54.0 = "Fair"

Photo 5. Example of the sand-dominated, mobile streambed with very little protective cover for either fish or macroinvertebrates.

Connectivity

Aerial photos were reviewed to look for potential barriers to fish passage, especially downstream of 15UM048. The stream flows into the Mississippi River almost exactly one mile from the sample site, and so there should be a good source of fish to populate the stream if barriers are not present. There is only one road crossing between 15UM048 and the Mississippi River, immediately downstream of the site Photos of these culverts show them to be passible for fish (Photo 6). No beaver dams or impoundments were seen between the Mississippi River and the site. It does not appear that connectivity is compromised in this AUID.

Photo 6. Downstream end of culverts on Bluebird Drive showing that they are set at a good elevation, and are not causing downstream scour, suggesting that in-culvert velocity is not prohibitive of fish migration.

Geomorphology/Hydrology

A review of the stream channel photos taken at the biological monitoring visits determined that channel dimensions and banks looked healthy and do not show signs of channel instability from altered hydrology. Thus, no field measurements of geomorphology were conducted on this AUID. One anomalous location was found (Photo 7) where the channel nears the road. The channel bank may be artificially high here due to road grade fill, or the bank has become unstable due to riparian vegetation alteration, probably due to the road ditch. The sandy soil of the bank, without deep root protection, is quite easy to erode. This would be a local area that could benefit from bank stabilization.

Photo 7. Bank erosion at a location along the biological sample reach which is near the road. The soil is mostly sand, which has little cohesiveness to resist being eroded by the streamflow.

Conclusions

There was no single significant stressor found for this AUID. There are a number of sensitive taxa here, particularly among the macroinvertebrates, and the IBI scores are just below the passing threshold. The chemistry data was generally good. In looking over the chemistry and aerial photos, this situation looks like it might just be the combination of a number of possible minor issues that contribute just enough stress to tip this into impairment. There is a pastured reach upstream, some hayfields, several pipeline crossings, and several roads, including US Highway 2. These factors may have altered the hydrology enough to cause some reduction in habitat. In addition, temperatures show this to be teetering on being a coldwater stream, possibly making the AUID less habitable for warmwater taxa. This stream seems analogous to a few other biologically-impaired streams for which no significant stressor was found, AUID 07010106-687, Tributary to Crow Wing River (MPCA 2014) and in this report, AUID 07010103-722, Tributary to Bray Lake, as being near-coldwater streams with fairly good habitat, but are devoid of fish without seeming to have a barrier (and all three flow into a radically-different habitat (much bigger river or a lake).

Recommendations

It is recommend that work be done to stabilize the eroding bank shown in Photo 7, using a natural restoration or bioengineering technique (as opposed to riprap). This was an anomaly for the AUID, and may be related to the road grade's construction/configuration. Working with animal farmers to exclude livestock access to the stream would be of benefit also, even if this is not the cause of the impairment. The significant change of the riparian area that occurs with pasturing will have some effect on the stream.

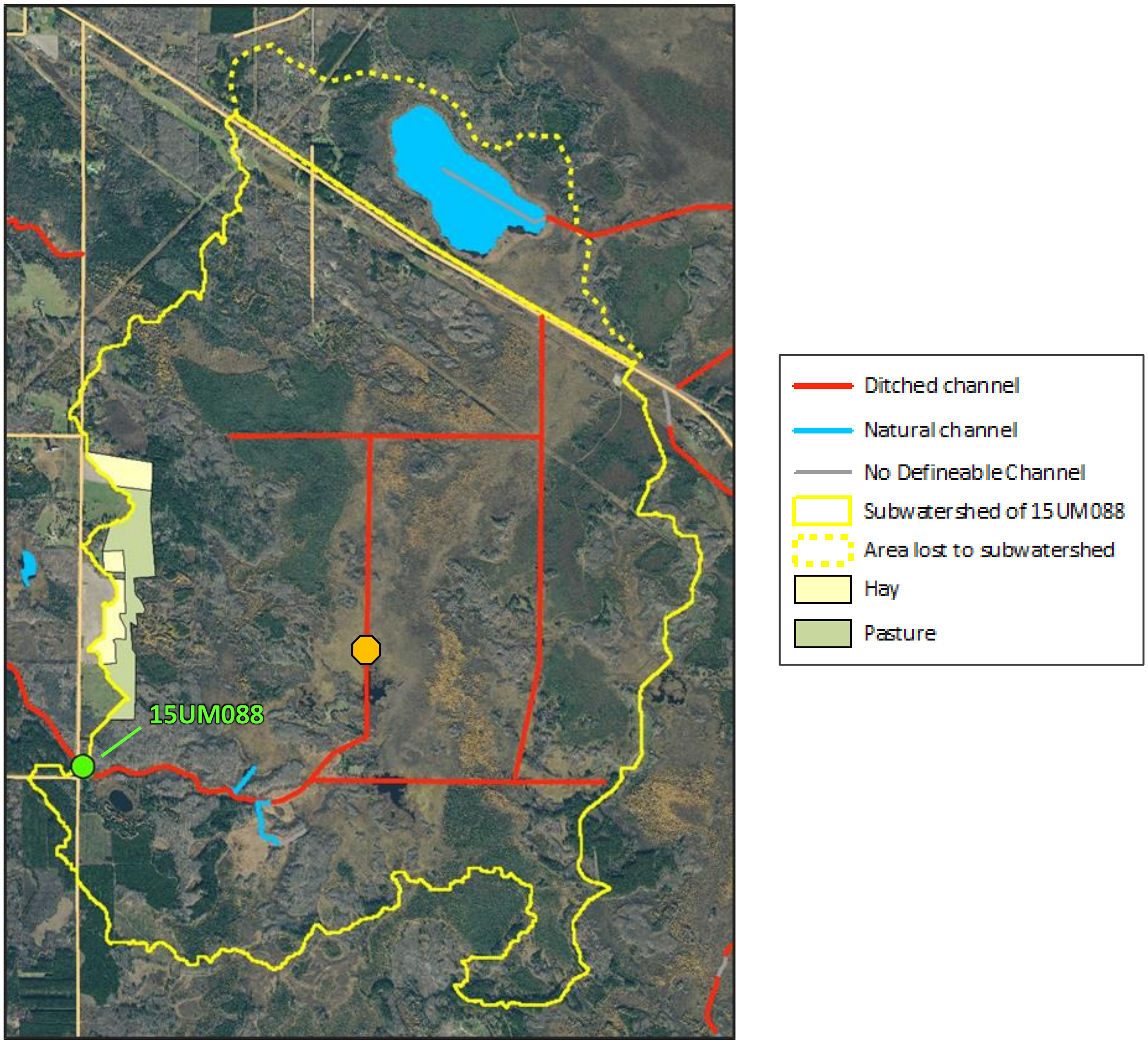
Tributary to Mississippi River (AUID 07010103-727)

Impairment: The creek was assessed as impaired for not meeting the fish community IBI threshold at site 15UM088 located upstream of CSAH-72, three miles southwest of Philbin. The macroinvertebrate community scored right at the passing IBI threshold. The biological site in AUID-727 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

The great majority of the subwatershed is covered by natural vegetation. Much of the subwatershed that drains to 15UM088 is bog/fen peatland. Small-acreage forested uplands are present in the bog as small islands. Development and landscape alteration is extremely light - only forest roads are present in the subwatershed upstream of the biological monitoring site, as well as one residence, which looks like it is occupied only periodically. The exception is that trenches were long ago dug through the peatlands in attempt to create land for agriculture. The main ditch that extends the original natural channel upstream has partly naturalized (some sinuosity present) over the decades since it was dug. It appears that a relatively small part of the original subwatershed was separated from the main part of the subwatershed by construction of Federal Highway 2. These landscape characteristics are shown in Figure 26.

Figure 26. Characteristics of the AUID-727 subwatershed upstream of the biological sampling site. An original, small, sinuous channel can be discerned from LiDAR elevation data upstream to the orange hexagon. No evidence of a natural channel was seen upstream of this location, nor was there a channel where the ditch comes in from the eastern parts of the subwatershed.



Data and analyses

Chemistry

This site only had chemistry monitoring done at three biological sampling visits, with field parameter measurements at two additional visits (Table 43). The results are generally good; with the exception of TP and that, the S-tube reading was fairly low on August 19, 2015. One sampling visit was also made during SID in 2017, with only instrument measurements, and a grab sample for DOC.

Table 43. Chemistry measurements collected at the biological sampling visits at 15UM088, values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)	DOC
June 8, 2015	18:46	20.3	6.89	80	7.09	88.9	0.054	< 0.05	< 0.1	12	5.2	82	--
July 15, 2015	16:21	22.0	5.96	73	8.17	--	0.073	< 0.05	< 0.1	7.2	< 4.0	81	--
Aug. 12, 2015	16:20	21.5	7.32	89	7.65	282	0.066	< 0.05	< 0.1	8.8	< 4.0	81	--
Aug. 19, 2015	8:56	16.8	6.77	73	7.33	294	--	--	--	--	--	46	--
Aug. 21, 2017	13:35	15.6	7.15	71.9	--	80	--	--	--	--	--	--	27.6

Nutrients - Phosphorus

All three TP levels were above the regional river nutrient standard. The large acreage of wetland in this subwatershed is likely responsible for a significant portion of the phosphorus, as are the eroded soils scoured from the banks at un-natural levels.

Nutrients - Nitrate and ammonia

Both the nitrate and ammonia samples were consistently at very low concentration, below the lab's detection limit.

Dissolved oxygen

All instantaneous DO measurements were above the standard, though only one was a pre-9am sample. Without early morning samples, which reveal the daily minimum, DO concentrations, and 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 can signal eutrophication. DO %-saturation measurements also did not signal eutrophication (all were < 100%).

Transparency and suspended solids

Secchi-tube readings were very consistent, with one exception. The three TSS samples were well below the north region standard, though a TSS sample was not collected on the fourth date when the Secchi-tube reading was much lower. The summer of 2015 was a dry one, and flow volumes were likely below average. More-normal flow volumes may create more TSS, because the banks are quite raw and scoured.

DOC

On August 21, 2017, a DOC sample was collected to add insight into wetland contribution to the stream flow, particularly because of the legacy ditching of the upstream wetlands. The result of 27.6 mg/L is somewhat high, meaning there is significant wetland-sourced water, but perhaps somewhat less than some of the other peatland-influenced streams in this report, as they had even higher DOC and TP concentrations.

Biology

Fish

Three species were collected at 15UM088. White sucker was the dominant species, with relatively small numbers of central mudminnow and brook stickleback. These are all extremely ubiquitous species. No sensitive species were collected.

Metrics related to DO and TSS are shown in Tables 44 and 45. The DO TIV Index score is well above the class average. The moderate probability of this community coming from a site passing the DO standard is due to streams in this class having relatively lower DO than some other stream classes; thus, these streams tend to naturally have species somewhat more tolerant to lesser DO concentrations.

The opposite is true for TSS, as the TSS TIV Index was worse than the class average. Again, due to low stream gradient, streams in this class as a whole have relatively low TSS levels relative to other classes. This means that even a community at low in-class percentile for the TSS TIV Index in Class 6 are likely to score relatively well compared to communities from higher gradient streams regarding the TSS TIV index. This is revealed in the fairly good probability of this community coming from a stream that has standard-meeting TSS concentrations.

The moderate probability of this community being found in a DO standard-meeting stream and the presence of two low-DO Very Tolerant and no low-DO Intolerant species, argue that DO levels could be a stressor here, but the quite low percentage of low-DO Tolerant individuals also suggests that DO levels are not very problematic. The fish show little influence of either low-DO or elevated TSS being a stressor to the fish community.

Table 44. Fish Community DO and TSS Tolerance Index scores in AUID-727 at 15UM088. 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 (2017 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.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/12/2016	7.08	6.55/6.61	76	51.1	14.99	13.98/13.28	21	73.4

Table 45. Fish metrics related to DO and TSS at 15UM088 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	2	2	0	10.9
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 assessed as meeting the standard. The sample was dominated by the black fly *Simulium*, followed by a relatively large number of the Isopod *Caecidotea*. All other taxa were present in much smaller numbers. Few sensitive taxa were found, though two that are generally found in high quality streams, the cranefly *Tipula* and the small empidid fly *Hemerodromia*, were present.

Macroinvertebrate metrics were evaluated to see if there might be some signal in the community to confirm that low DO and TSS are not stressors here (Tables 46 and 47). For both parameters, the sampled community is more likely than not to come from a site that passes those water quality standards. The metrics assessing low-DO effects did not show the community to be skewed toward either intolerance or tolerance. Relative to the DO metrics (particularly the percent of tolerant and intolerant individuals), it appears that elevated TSS may be a stressor, though the probability of this community coming from a site with standard-meeting TSS levels is high. The DO TIV Index scored much better than its class average for both samples, opposite the fish community. The macroinvertebrate metrics do not show an influence from problematic DO levels, while there is some evidence that TSS does somewhat shape this community's composition.

Table 46. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-727 at 15UM088. 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 4 (2017 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.

M-invert class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
4	7.27	6.28/6.47	92	75	13.47	13.59/13.73	55	85

Table 47. Macroinvertebrate metrics related to DO for 15UM088 utilizing MPCA species tolerance assignments.

Tolerance Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	2	1	0	0	3.73	0
TSS	0	0	6	1	0	18.94

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

Temperature

Water temperature was not problematic for fish at any of the four dates it was measured (Table 48). The July and August measurements were in late afternoon, when stream temperature is at its daily peak, so these readings are especially useful in ruling out a temperature issue.

Table 48. Water Temperature readings at 15UM088, in degrees Celsius.

Date Year	Time	Water Temp.
June 8, 2015	18:46	20.3
July 15, 2015	16:21	22.0
Aug. 12, 2015	16:20	21.5
Aug. 19, 2015	8:56	16.8

Habitat

The MSHA protocol was conducted at four visits to 15UM088, providing scores of 44.5, 48, 52, and 57. These scores range from the very top of the "Poor" category, to the middle of "Fair". The two lowest scores were from the August visits, and may have been negatively influenced by low water levels. Nonetheless, the habitat was still very mediocre at the better-scoring visits.

The poorest-scoring subcategory scores, based on a percentage of each category's possible score, were "Substrate" and "Channel Morphology". There was no coarse substrate, only sand and clay (though these are the substrates expected here due to the soil and surficial geology). Within the Channel Morphology subcategory, the Channel Development and Channel Stability components were the most influential in dragging down the score. The water depth is very shallow at times (Photo 8), probably a result of the channel being constructed larger than the original channel (see the following geomorphology section). As is common with ditches, it appears that this one is lacking a diverse set of microhabitats that support a diverse biological community, though the habitat model used for determining TALU classification suggests that habitat alone likely does not fully explain the biological impairment.

Photo 8. Section of stream that is only 1-2 inches deep, with a barren, sand bottom.

Connectivity

The only road crossing within AUID-727 downstream of 15UM088 to the Mississippi River is CSAH-72. Based on high-resolution aerial photography, the crossing looks fish-passible, as the channel, width is not changed on either the upstream or downstream sides of the crossing. Absence of a scour pool suggests that the velocity in the culvert is similar to the stream. A field inspection of the crossing verified the aerial photo assessment. The culvert was properly sized, and set at a proper elevation. It was placed low enough so that some sand has been deposited on the culvert bottom, a positive situation which makes the culvert bottom continuous with the natural stream bottom. There was ample depth for fish passage, velocity in the culvert was modest, and the culvert was not a barrier in any other physical way. No beaver dams could be found via aerial photography between the mouth of AUID-727 at the Mississippi River, and site 15UM088. Migration barriers do not appear to be a stressor.

Hydrology

This subwatershed has been highly altered hydrologically, not so much by a change in landscape vegetation cover type, but by the ditching of peatlands decades ago, in areas where channels did not originally occur (Figure 26). See the discussion in the “Hydrology” section on Pages 23-24.

Geomorphology

This is a ditched channel along its whole route. It is in an unhealthy geomorphological state, as most ditches are - it is intentionally incised. The original, natural channel was very sinuous, much narrower, and the bed elevation would have been higher relative to the floodplain (Figure 27). Channels that are incised typically experience bank instability and erosion. This is occurring in this location as seen in photos taken by the biological samplers (Photo 9). Some sod clumps with live grasses can be seen to have recently fallen from the upper banks down to the streambed. It has been in this incised condition for decades, and it is difficult to say if the incision is getting worse. It may have reached somewhat of an equilibrium. The banks are very raw under the root level of the riparian grasses. Because this is an incised and straight channel, much work would be required to recreate a healthy, stable geomorphological condition.

Figure 27. LiDAR elevation map, showing the ditched channel (wide, darker red) and original, meandering channel on the left side of the ditched channel (arrows). The lighter red of the original channel means the bed elevation was higher than the current ditch channel.

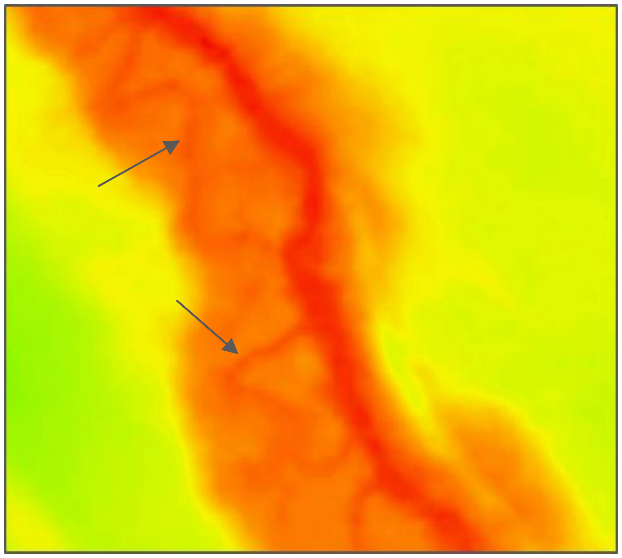
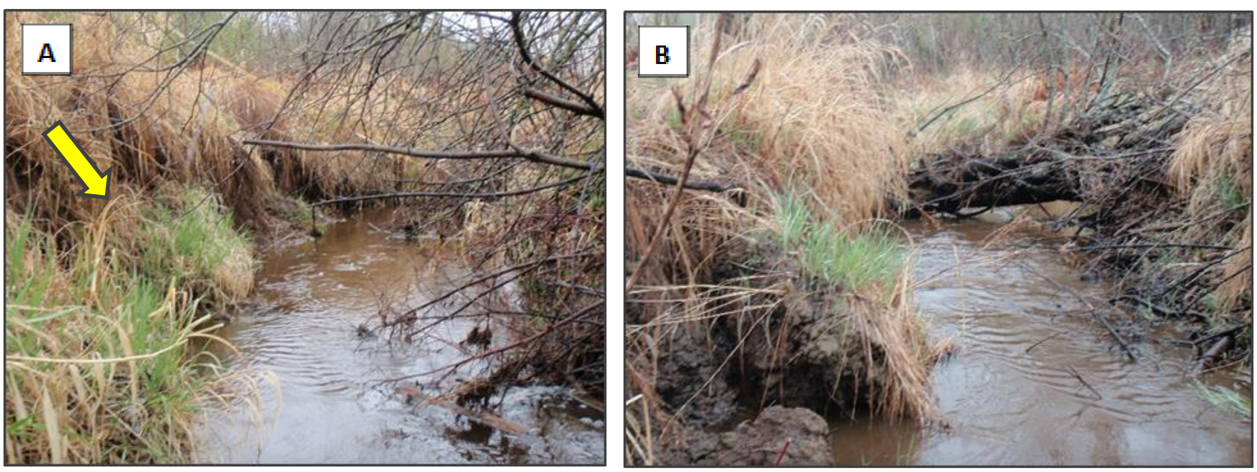


Photo 9. A and B. Bank instability is evident in the mass wasting seen along the reach. Photo A shows chunks of sod and soil that have dropped down into the channel on the left side. Photo B also shows a large chunk of bank that is gone in the left-front corner of the photo, leaving raw exposed soil that will erode further.



Conclusions

Ditching has reduced habitat quality by the elimination of sinuosity, and altering the patterns of hydrology. These contribute to channel instability and the follow-on habitat issues such as less stable substrate, and a general loss of microhabitats. There may be lower base flow volumes due to headwaters ditching (less upstream water storage that slowly feeds the stream). DO may be a problem too per fish community data and late-afternoon measurements not much over 5 mg/L. Low DO does not appear to be related to eutrophication based on a lack of any notable algae presence, and extremely low nitrate levels. It is most likely to be caused by enhanced drainage of the peatland soils, which are relatively anoxic in summer.

Recommendations

A restoration of the hydrologic regime in the subwatershed to more closely match the historical hydrological pattern would likely benefit the stream by stabilizing flow conditions, reducing peak flow volumes, providing better base-flow volumes, and allowing banks to stabilize and reduce their contribution of sediment to the stream. The stream would likely eventually form a channel with a smaller width/depth ratio, producing better habitat. Reduction of ditched channel footage within the subwatershed would be the most direct way to accomplish this goal. This restoration would likely also have benefits to the Mississippi River's water quality by reducing sediment inputs from high flows in this unstable artificial channel system.

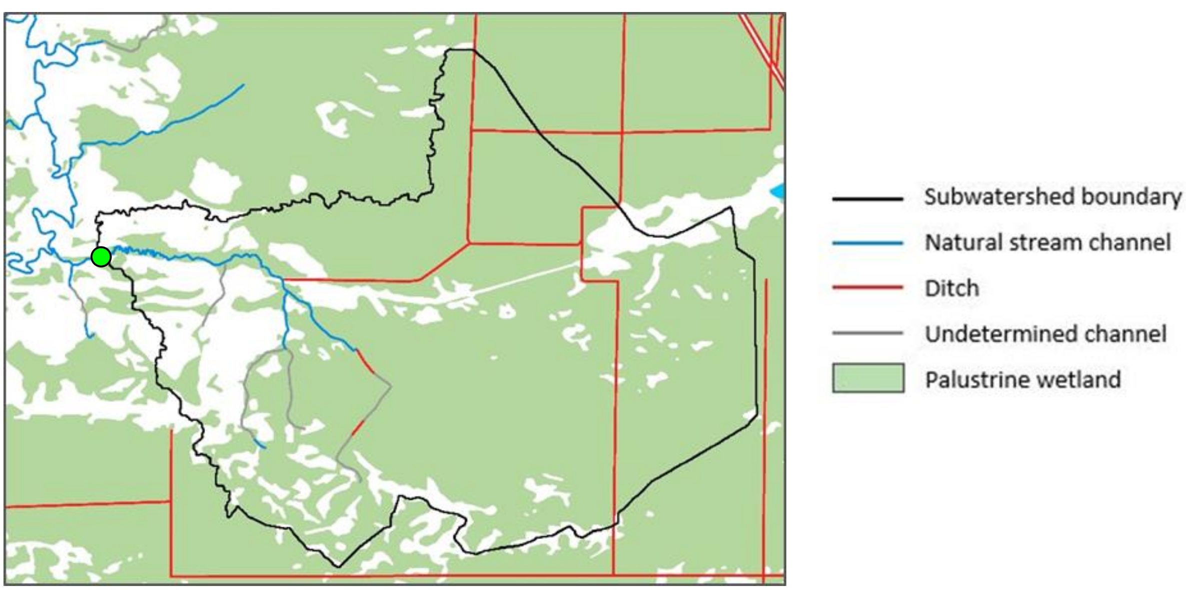
Tributary to Swan River (AUID 07010103-728)

Impairment: The creek was assessed as impaired for not meeting the fish community IBI threshold at site 15UM089 located upstream of 154th Ave, seven miles east of Jacobson. The macroinvertebrate community scored well above the passing IBI threshold. The biological site in AUID-728 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool). After the SID process, this AUID was proposed to be moved into impairment category 4C. The MPCA review team agreed that 4C is the proper impairment category, and a final decision is awaiting EPA review.

Subwatershed characteristics

Most of the subwatershed that drains to 15UM089 is bog/fen peatland (Figure 28). The area around the sampled reach is heavily forested. There is only one residential property in the subwatershed, and one small hay field. Some logging has occurred over time, including one recently cut plot. State Highway 200 (undivided, two lane type) bisects the subwatershed. A matrix of ditches that feed into the AUID were dug in the early 1900s, some of which cross the subwatershed boundary, making it difficult to determine which direction some areas of these ditches flow.

Figure 28. Extent of the AUID-728 subwatershed wetlands. The green dot is sampling site 15UM089.



Data and analyses

Chemistry

This site only had chemistry monitoring collected at the fish sampling visits (Table 49). The results are generally good, with the exception that the S-tube reading was fairly low on August 23, 2016. Photos show that the AUID's water can be quite darkly stained, which may have resulted in the low depth visibility measurement.

Table 49. Chemistry measurements collected at the biological sampling visits at 15UM089, values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
Aug. 11, 2015	17:10	22.6	7.22	87	--	103	--	--	--	--	--	--
Aug. 12, 2015	14:03	22.0	8.07	97	7.42	81	0.049	< 0.05	< 0.1	4.8	< 4.0	83
June 15, 2016	14:12	15.7	8.77	89	7.01	115	0.041	0.02	< 0.1	4.8	2.8	> 100
Aug. 23, 2016	14:42	21.2	5.44	61	6.88	75	--	--	--	--	--	42

Dissolved oxygen

All instantaneous DO measurements were above the standard; though no pre-9, am samples were collected. Without early morning samples, which reveal the daily minimum, DO concentrations, and 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. The sample from August 23, 2016 was low for that time of day, and was probably below the standard early that morning. Samples taken in mid-afternoon during summer did not show high DO readings that can signal eutrophication. DO %-saturation measurements also did not signal eutrophication (all were < 100%).

Nutrients - phosphorus

TP levels were below, but near, the regional river nutrient standard. Sampling photos show the water was darkly stained (tea-colored). This is a sign of abundant wetland-sourced water, which can contain significant phosphorus due to plant material breakdown.

Nutrients - nitrate and ammonia

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

Transparency and suspended solids

Secchi-tube readings were inconsistent. Both TSS samples were well below the north region standard, though a TSS sample was not collected on the day when the S-tube reading was lowest.

Biology

Fish

There were six species collected in total from the three visits, four of them ubiquitous. The two sensitive species were pearl dace and burbot, both collected at only one visit. Metrics pertaining to DO and TSS are shown in Tables 50 and 51. The metric scores were fairly average for DO and fairly good for TSS on the probability of the fish community coming from a site that meets the DO and TSS standards. There were no low-DO Intolerant species captured, nor was the percent of tolerant individuals very high, suggesting the DO levels are mediocre - neither very good, nor strongly problematic. As the fish community from several other class 6 AUIDs in the MRGRW have been, the percentiles of the TSS TIV scores are fairly low, while the probability of the community coming from a TSS standard-meeting site is relatively high. From the presented metrics as a whole, DO concentrations may be a stressor to the fish community, while TSS does not appear to be.

Table 50. Fish Community DO and TSS Tolerance Index scores at 15UM089. 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 (2017 version). "Prob." is the probability a community with this score would come from a stream reach with DO or TSS levels that meet the appropriate standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/2015	7.07	6.55/6.61	75	50.1	14.29	13.98/13.28	30	76.9
6/2016	7.02	6.55/6.61	72	48.5	14.51	13.98/13.28	27	75.8

Table 51. Fish metrics related to DO for 15UM089 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO 2015	0	0	3	2	0	18.6
Low-DO 2016	0	0	1	1	0	13.5
TSS 2015	0	0	0	0	0	0
TSS 2016	1	1	0	0	2.7	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 fairly significantly between the two years. The 2016 sample was dominated by the black fly *Simulium*, followed by a relatively large number of the mayfly family Leptophlebiidae. All other taxa were present in much smaller numbers. A relatively moderate number of sensitive taxa were found, though three that are generally found in high quality streams, the cranefly *Tipula*, the dragonfly species *Boyeria vinosa,* and the small empidid fly *Hemerodromia*, were present. The leptophlebiid mayflies are also fairly sensitive. The 2015 sample did not have any taxa that were strongly dominant in abundance. The most abundant taxa was the fingernail clam Pisidiidae. There were few *Simulium* and Leptophlebiidae, the two dominant taxa in 2016.

Macroinvertebrate metrics were evaluated to see if there might be some signal in the community to confirm that low DO is a stressor (Tables 52 and 53). 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. The metrics assessing low-DO effects show the community to be somewhat skewed toward intolerant taxa and individual abundance, especially in the 2015 sample. The 2016 sample was very even between intolerant and tolerant taxa. The DO TIV Index scored much better than its class average for both samples, as did the fish. The macroinvertebrate metrics do not show an influence from problematic DO or TSS levels.

Table 52. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-728 at 15UM089. 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 (2017 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.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2015	7.03	6.28/6.47	83	71	13.65	13.59/13.73	51	83
2016	7.09	6.28/6.47	86	72	12.10	13.59/13.73	83	91

Table 53. Macroinvertebrate metrics related to DO for 15UM089 utilizing MPCA species tolerance assignments.

Date	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
2015	6	3	3	1	19.60	5.03
2016	4	1	4	1	1.53	1.84

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

Habitat

The biological sampling crews conducted the MSHA protocol on five different dates during 2015-2016. Total scores, listed in order of date collected, were 57.0, 45.0, 48.5, 62.15, and 44.0. Three of these scores were at the borderline of "Poor" and "Fair"; one was in the middle of the range for "Fair", and one at the upper end of the "Fair" category. An average of each of the five MSHA subcomponents was calculated. The five averages were summed to give an average total score, which equaled 51.3 (Table 54). The subcomponent score averages were used to calculate a percentage of that subcomponent's possible score. This analysis suggested that it was the channel itself, and the features in the channel that drag down the habitat score, as opposed to adjacent riparian features/condition. In particular, this analysis suggested that "Substrate" and "Channel Morphology" are the aspects most problematic among the habitat components. In four of the five-substrate observations, only fine particulate substrates were noted. One of the visits recorded finding some gravel. Among the other Channel Morphology measurements, "Channel Development" (presence of distinct riffle/pool/run features) and channel stability were consistently rated low.

Table 54. Averaged sub-component scores for five MSHAs conducted at 15UM089 in 2015 and 2016.

MSHA Component	Avg. Score	Maximum Poss. Score	Percent of Maximum
Land Use	5	5	100
Riparian	11.6	14	82.9
Substrate	11.5	28	41.2
Cover	10.8	18	60.0
Channel Morphology	12.4	35	35.4
Total MSHA Score	51.3	100	51.3 = "Fair"

Connectivity

Beavers and their dams (which can be barriers to fish migration) are common in the MRGRW landscape. In smaller streams like AUID-728, where overwintering conditions are inhospitable, fish move downstream to larger waters in the winter and travel up smaller streams to repopulate them in spring. Beaver dams can prevent this springtime migration. Though there are a number of beaver dams upstream of sample site 15UM089, there do not appear to be any (per aerial photo review) between the confluence of AUID-728 at the Swan River and 15UM089. This part of the AUID is higher gradient, not the type of setting beavers typically choose to build their dams.

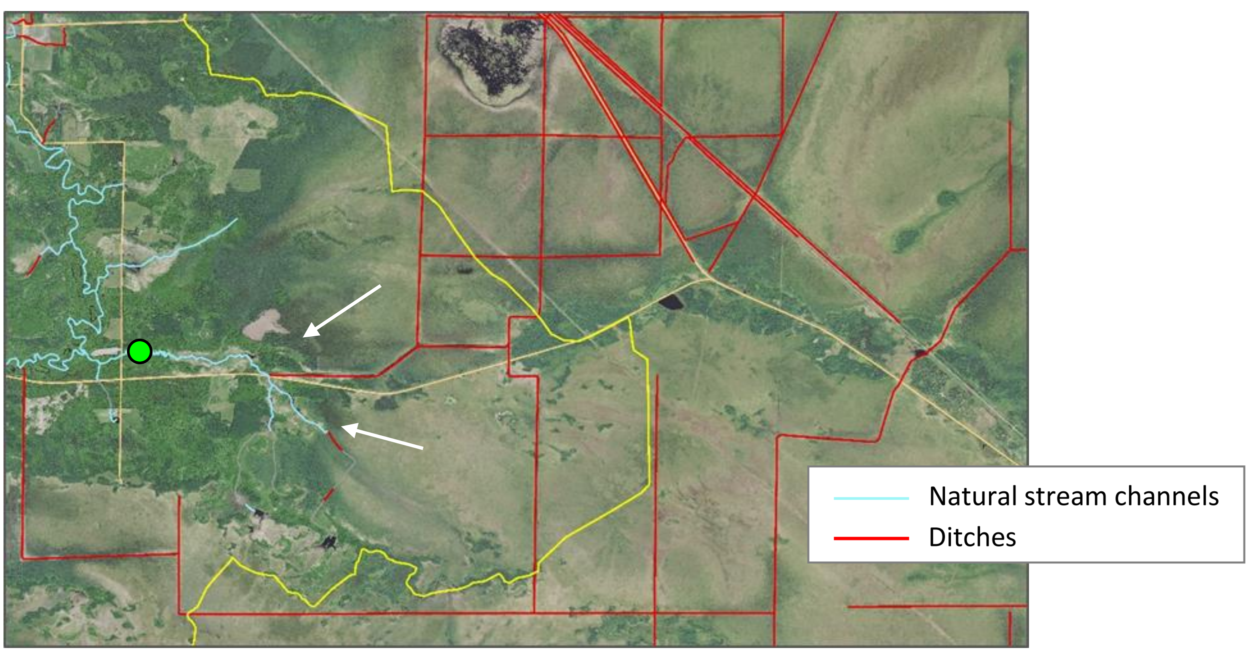
There is a road crossing (154th Ave.) just downstream of the 15UM089. The culvert was visited by DNR staff in 2017 to assess it for fish passability. It was determined that the culvert is not a barrier to fish migration. Two MPCA fish sampling sites on the Swan River quite near the mouth of AUID-728 had fish communities with very good IBI scores, and thus there is a good source community of fish to venture up into AUID-728. No barriers to fish entry into AUID-727 to site 15UM089 were found.

Hydrology

The hydrology of the subwatershed of AUID-728 has been significantly altered. The majority of the alteration is due to attempts to drain the massive bog/fen area at the headwaters of this creek (Figure 29). The construction of drainage channels occurred many decades ago. Some vegetation alteration has occurred on the landscape, primarily logging (including a very recent clear cut), and one small farm with hayfields. The ditches speed up contributions to stream flow coming from the wetlands, and cause larger volumes of water to flow during peak flow periods than what the original, natural channel of AUID-728 was formed to handle.

The constructed channel matrix is connected to a wetland area lying in the St. Louis River Watershed, and water that would have drained east to the St. Louis River, may now be draining west through AUID-728. Drainage can also lead to lower flow during the drier periods as water that would have been slowly released from wetlands to the stream is now drained away more quickly. This exacerbated low flow issue may be less problematic here if additional land (from within the St. Louis River Watershed) is being drained to the creek. Regardless, this altered flow regime causes habitat instability, which in general makes life more difficult for stream organisms. It also alters available physical habitats within the stream, which will be discussed in the following paragraphs in the Geomorphology section. See also the discussion of peatland drainage in the "Hydrology" section on Pages 24-26.

Figure 29. Subwatershed of site 15UM089 (green dot). The yellow line is the major watershed boundary between the MRGRW and the St. Louis River Watershed. Note that numerous ditches cross the major watershed boundary, making the actual size of the subwatershed contributing flow to AUID-728 difficult to determine. Arrows denote direction of flow.



Geomorphology

Numerous signs are evident that significant channel damage has occurred. The MSHA found that stream stability was poor, owing to the raw, eroding banks. This erosion is evident as are areas of recent deposition of significant amounts of fine particle material (as seen on the left side of Photo 10). Signs of channel evolution are evident as well, such as floodplain building within the channel (Photos 10, 11, 12).

Photo 10. Channel damage was found in the reach sampled for biology. Raw banks were prevalent. The channel has incised within the original floodplain, such that some of the higher flows are now retained in the channel, which results in excess erosion from the banks and streambed.

Photo 11. Bankfull marks show channel incision. In the foreground at right, there is a small terrace about half way up the bank (dotted yellow line). The solid yellow line shows the profile of the bank up onto the floodplain. The dotted line in the background is at the top of a mound of sand piled upstream of a logjam (seen closer in Photo 10). The elevations depicted by the dotted lines are approximate bankfull elevations under current conditions.

Photo 12. Another indicator of the bankfull elevation (yellow dotted line) is the sand piled on the left side of the channel. A healthy stream's bankfull height is at the elevation of the floodplain (while dotted line). The new bankfull elevation is much lower than the pre-settlement floodplain elevation.

The DNR staff did a thorough assessment of the physical channel conditions in the AUID at the biological site in 2017.

Rosgen Assessment

From DNR (unpublished communication, 2018a): "This stream is unstable, but it is transitioning back to a more stable condition. The major geomorphic stressors to biology in this reach are the lack of defined stream features (riffles and deep pools), lack of undercut banks, lack of instream vegetation, and the excess fine particles throughout the system. These combine to create a lack of quality habitat.

A 700-foot reach of AUID-728 (Tributary to Swan River) east of 154th Avenue was assessed, and measurements indicated the stream to be an E5/6 Type. An E stream is narrow, deep, and sinuous while the 5/6 signifies the reach is primarily sand but that silt is also prevalent. The stream has good pattern and decent pool depth; however, some lateral scour pools were not as deep as expected. In-channel debris is also affecting pool size and location. The culvert on 154th Avenue is undersized and backs up water at high flows, but it is not generally a fish barrier.

At first glance, this site appears to be unstable and deeply incised. Our assessment indicates that the reach is unstable, but only slightly incised. Ditching has altered the stream hydrology and while headwater ditches do cross major watershed boundaries, they do not appear to be contributing significant flow to this stream at low flow. Staff visited several of the ditches in the Wawina Bog to check water elevations and for any obvious direction to flow. Little evidence of the ditches directing large amounts of water into this tributary was found for conditions during the visits. There are ongoing efforts to place plugs to break the hydrologic connections between the major watersheds. Even if the plugs are installed, there are obvious legacy impacts from the changed hydrology such as the potential for increased flashiness and higher peak flows in this system.

During the level two survey, bankfull indicators at or just below the floodplain pointed to a channel that was slightly incised. While the banks were frequently bare, the fine particles looked to be recently deposited. Further evidence was noted on a site visit a few weeks prior during a near bankfull event in the area and the stream was just below the tops of its banks. Even though it is not very incised, the altered hydrology has caused the stream to widen. There were many fallen trees in the stream causing local cutting and scour. Several 5-10 foot tall eroding banks were also present and contributing to the excess sediment. The stream was only slightly entrenched, so it had good access to its floodplain, even in small floods. Furthermore, it was unconfined within its valley, yet we found that the channel had historically migrated and cut off meanders, another sign of instability."

Pfankuch Assessment

From DNR (unpublished communication, 2018a): "The Pfankuch score for this reach was 110, a poor (unstable) rating for an E5 stream. It scored poorly in all areas: upper banks, lower banks, and channel bottom. In the upper banks, the large material present could cause debris jams and the poor vegetation cover and vigor were the biggest factors. In the lower banks, the small particle sizes present, obstructions causing cutting and pool filling, significant raw banks, and extensive deposition of fine particles influenced the poor rating. The channel bottom contained many unconsolidated fines generating areas affected by scour or deposition. The stream channel also lacked any vegetation. Additionally, meander and depositional patterns raise lateral stability concerns in this reach."

The MPCA's MSHA ratings and the DNR's geomorphology assessment had very similar findings; that the channel has experienced instability, has excess fine particle sediment, and relatively homogeneous bedform habitat. These physical issues have altered hydrology as their base cause.

Conclusions

Historical alterations to the hydrology of this subwatershed have clearly damaged the channel and habitat features within the channel. Additional damage may not be continuing to occur, and there are signs that the stream is in the process of evolving to a new stable state (see Rosgen 1996), where a new floodplain is created within the over-widened channel. The point of reaching a new stable channel may be decades away. Substandard dissolved oxygen levels also are in evidence in the fish data. Early morning DO sampling would likely provide confirmation regarding DO as a stressor in AUID-728.

Recommendations

Steps could be taken to help restore the creek. One aspect of the fix for this situation restoration of a more historically natural hydrological pattern reducing or eliminating the wetland-draining ditches currently feeding this creek. Additional in-channel work could be done to try to raise the elevation of the streambed (such as with some riffle grade controls). Completing both measures would reduce the flow volumes carried by the channel at high flows, and allow for high flows to again be distributed onto the floodplain. Both results would protect the channel from the erosive forces of those high flow volumes, allowing the channel to heal over time, and create better and more stable habitat. Eliminating the ditches that were created in the upstream areas also would likely improve the DO levels in the stream.

Tributary to Mississippi River (AUID 07010103-730 and -731)

Impairment: Two impaired AUIDs will be discussed together in this section, as they are adjacent parts of the same creek. The creek was assessed as impaired for not meeting the fish community IBI threshold at site 16UM151 located downstream of State Highway 65 (AUID-730), and at 15UM091, a short distance upstream of State Highway 65 (AUID-731), both one mile north of Ball Bluff. The macroinvertebrate community scored well above the passing IBI threshold at both 16UM151 and 15UM091. The biological sites in AUIDs-730 and 731 are Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

These AUIDs are both short, with AUID-730 being about 0.75 miles long, and AUID-731 about 2.0 miles long. AUID-731 begins as the outlet of Little Ball Bluff Lake, while AUID-730 is fed by AUID-731 and a tributary, which is the outlet of Vanduse Lake. The downstream end of AUID-730 joins the Mississippi River. There are two short straightened sections of channel within AUID-731, while the AUID-730 channel is all-natural.

Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 55). The results are generally good.

Table 55. Chemistry measurements collected at the sampling visits from 16UM151 and 15UM091, values in mg/L.

Site and Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
15UM091 6/9/2015	13:19	19.3	6.81	78	8.45	255	0.046	< 0.05	< 0.01	6.4	< 4	> 100
15UM091 9/23/2015	12:03	21.2	7.87	94	7.84	289	0.062	< 0.05	< 0.01	4.4	< 4	> 100
15UM091 8/24/2016	13:30	19.9	7.14	78	7.79	494	0.050	0.237	< 0.01	6.8	< 2	> 100
15UM091 9/13/2016	10:13	13.6	8.24	79	7.46	479	--	--	--	--	--	> 100
16UM151 6/16/2016	12:07	17.0	8.47	88	7.66	290	0.051	0.02	< 0.01	14.8	3.2	> 100
16UM151 8/24/2016	12:19	19.1	7.77	84	7.88	341	--	--	--	--	--	75

Dissolved oxygen

All instantaneous DO measurements were above the standard; though no pre-9, am samples were collected. Without early morning samples, which reveal the daily minimum, DO concentrations, and these data cannot determine that the stream is meeting the DO standard. They do however show that there are very healthy DO levels during the day. Samples taken in mid-afternoon during summer did not show high DO readings that can signal eutrophication. DO %-saturation measurements also did not signal eutrophication (all were < 100%).

Nutrients - Phosphorus

TP levels hovered right around the regional river nutrient standard. From viewing the human activities on the surrounding landscape, the most likely anthropogenic sources of phosphorus would be septic systems or farm animal manure, but these also would contribute nitrogen, and nitrate and ammonia are extremely low, suggesting the source of the phosphorus is not septic systems or manure.

Nutrients - Nitrate and ammonia

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

Transparency and suspended solids

Secchi-tube readings were generally excellent, with five of six samples exceeding 100 cm visibility. Three of the four TSS samples were very low, while one was just slightly below the north region standard. A TSS sample was not collected on the day when the S-tube reading was lower.

Biology

Fish

At 16UM151, there were five species collected, four of them ubiquitous. Three blacknose shiners were collected, which is a less-frequently encountered species. The July 15UM091 sample contained five species, all quite ubiquitous and dominated by white sucker. The August 15UM091 sample contained four species, with johnny darter dominating, and one sensitive individual present, a burbot.

Metrics pertaining to DO and TSS are shown in Tables 56 and 57. There was a moderately skewed low-DO tolerance in the fish community in AUID-731, and to a lesser degree in AUID-730. The DO TIV Index scores were above class average in both AUIDs, though for AUID-731, the probability that the fish community found would come from a DO-passing stream is fairly low, and the percentage of individuals that are Low-DO Tolerant was relatively high.

There is not strong consistency for the TSS TIV Index, which had samples both well above and well below the class average. The probability of the communities coming from a TSS-passing stream were quite good for both AUIDs. There were no TSS Tolerant species collected in either AUID. The aggregation of all this information makes it look as if DO is a more likely stressor, but that TSS may be a minor contributor to stress for the fish community.

Table 56. Fish Community DO and TSS Tolerance Index scores at 16UM151 and 15UM091. 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 (2017 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.

Site	Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16UM151	6/2016	7.17	6.55/6.61	81	55.2	14.94	13.98/13.27	21	73.6
15UM091	6/2015	6.74	6.55/6.61	58	36.5	14.21	13.98/13.27	31	77.2
15UM091	8/2016	6.67	6.55/6.61	53	33.1	12.20	13.98/13.27	78	85.3

Table 57. Fish metrics related to DO and TSS for 16UM151 and 15UM091 utilizing MPCA species tolerance assignments.

Site	Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
16UM151	Low-DO	0	0	3	0	60.0
15UM091	Low-DO 7/2015	0	0	2	0	29.1
15UM091	Low-DO 8/2016	0	0	1	0	27.4
16UM151	TSS	0	0	0	0	0
15UM091	TSS 7/2015	0	0	0	0	0
15UM091	TSS 8/2016	1	1	0	0.6	0

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

Macroinvertebrates

The macroinvertebrate community scored very well in AUID-730 and -731. Because the fish community showed a moderate sign of being influenced by low-DO levels, the macroinvertebrate community was analyzed by the same metrics to see if DO levels also were influencing the macroinvertebrate community, as a confirmation of the conclusion for the fish impairment. The DO TIV Index scored better at both sites than the class average. The probabilities that the sampled communities come from sites with healthy DO levels are fairly good. (Table 58). The community has more Low-DO Intolerant taxa than Low-DO Tolerant taxa (particularly at the downstream AUID-730), and at both sites, the percentage of individuals that are Low-DO Tolerant is very low (Table 59). The TSS metrics give some evidence of a TSS influence, as both sites had more TSS Tolerant than TSS Intolerant taxa. However, there were still at least five Intolerant taxa at each site, and the probability of these communities coming from TSS standard-meeting waters is very high. The macroinvertebrates do not show signs of being stressed by low DO conditions, suggesting that low-DO levels are not severe. Macroinvertebrates also confirm that the TSS levels are likely not the cause of the fish impairment.

Table 58. Macroinvertebrate Community DO and TSS Tolerance Index scores at 16UM151 and 15UM091. 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 (2017 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.

Site	Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
16UM151	2016	6.81	6.28/6.47	72	67	12.71	13.59/13.73	68	88
15UM091	2016	6.94	6.28/6.47	78	69	13.01	13.59/13.73	73	87

Table 59. Macroinvertebrate metrics related to DO for 16UM151 and 15UM091 utilizing MPCA species tolerance assignments.

Parameter	Site	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	16UM151	11	5	2	0	15.8	4.0
DO	15UM091	6	2	4	1	4.1	8.2
TSS	16UM151	6	2	11	5	6.3	21.4
TSS	15UM091	5	1	12	5	11.6	12.6

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

Habitat

The biological sampling crews conducted the MSHA protocol on four different dates. Total scores were 48.5, 50.5, 53.1, and 56.5. These scores are all at the lower part of the "Fair" category. An average of each of the five MSHA subcomponents was calculated. The four averages were summed to give an average total score, which equaled 52.2. The subcomponent score averages were used to calculate a percentage of that subcomponent's possible score. These percentages were: Land Use = 77.5%, Riparian = 84.8%, Substrate = 38.9%, Cover = 55.6% and Channel Morphology = 44.3%. In general, this suggested that it was "instream" features that are missing, as opposed to adjacent riparian features. In particular, this analysis suggests that Substrate and Channel Morphology are the aspects most problematic among the habitat components. Interestingly, this was the same case for AUID-728, located nearby. Biological Unit staff recorded that sand and silt were the exclusive substrate types, except for a small amount of pea gravel. The MSHA observed decent pool development, but little velocity variability. Among the other Channel Morphology measurements, "Channel Development" was consistently rated low. "Channel Development" is strongly related to stream geomorphology, as is bed substrate, both of which are further discussed in the "Geomorphology" section below.

Connectivity

No barriers could be seen on aerial photos from the mouth of the creek at the Mississippi River, to upstream of 16UM151. Both sites are connected to upstream lakes (Vanduse L. and Ball Bluff/Little Ball Bluff L), which could serve as a source of fish to the stream. Reviewing multiple years of aerial photos show that beaver dams sometimes occur near the upstream end of AUID-731, between the two biological sites and Ball Bluff/Little Ball Bluff Lakes, which may eliminate the upstream lakes as fish sources to downstream reaches in some years.

The first two road crossings upstream of the confluence of AUID-730 with the Mississippi River are private crossings with culverts a short distance upstream of 16UM151, at the upper end of AUID-730 and the downstream end of AUID-731. Therefore, connectivity is not a stressor in AUID-730, since there is open access to the Mississippi River; bit is possibly a stressor in AUID-731. The DNR staff visited the private crossings to assess the culverts for fish passability. It was determined that both culverts are somewhat problematic: "There were two culverts on private drives (north culvert at 479142.676, 5201045.116; south culvert at 479148.391, 5200846.996.) We only assessed the northern culvert but the south culvert was clearly perched and at least a seasonal fish barrier due to water depth, it is undersized, and the outlet drop. The assessment on the north culvert characterized the culvert as at least a seasonal fish barrier due to water velocity, water depth, and the lack of substrate. The culvert was also partially plugged by debris. The bankfull width upstream of the culvert was 11.5' while the culvert width was only 3.5', meaning the culvert is vastly undersized for the stream" (DNR - unpublished report, 2018a).

There is some evidence that some fish are able to pass these culverts in some flow conditions. An early-season fish sample (June 9, 2015) at 15UM091 (upstream of the two culverts) found only central mudminnow. A reasonable explanation is that the seasonal fish migration into small creeks had not happened yet. A later sample that same year at 15UM091 (July 23, 2015) found five species, and so apparently, these fish were able to pass through the culverts, though they may have only been able to do so at a certain flow condition. Sampling of 16UM151 and 15UM091 in 2016 found similar numbers of species above and below these culverts, suggesting again that there is at least a limited situation at which they can pass the culverts. There are several additional driveway or road crossings on AUID-731 upstream of 15UM091 that were not examined for passability, and which could restrict how much of AUID-731 is accessible to fish.

Hydrology

The hydrology of the subwatershed of AUID-728 has been somewhat altered with conversion of originally forested land to hay fields, though this is not extensive. Some changes have been temporary, but contribute effects for a time, as areas in the subwatershed can be seen from aerial photos where clear-cut harvests and forest regrowth have occurred. Though the reduction of forestland is moderate here, streams in sandy soils are more prone to instability due to the streambed and banks having a less cohesive nature, and less land cover alteration is needed to lead to channel instability. This instability may well have started with the original clearcutting in the early 1900's. An additional contribution to flow comes from road runoff, especially State Highway 65, which runs through this subwatershed. An altered flow regime (higher peak flows) causes habitat instability and alters available physical habitats within the stream, which will be discussed in the following paragraphs in the Geomorphology section.

These AUIDs are fairly small channels, and it appears there may be times when the stream has little water or flow. On September 24, 2015, a fish-sampling visit was canceled when the crew found very low water levels, such that the water was no longer visibly moving. Coupled with connectivity issues, this may be a contributing natural stressor to the fish community.

Geomorphology

Signs are evident in both AUIDs that the channel has experienced some instability due to altered hydrology and that damage has occurred (incision). Raw banks were seen all along the reach. The stream appears to have been over-widened and is now evolving a new floodplain in the channel (Photos 13, 14, and 15). The MSHA rated the channel stability as moderate. Channel incision can be seen in Photo 16. The bank erosion contributes to excessive fine sediment on the streambed, which is poor habitat for stream organisms (Photo 14 and 15).

Photo 13. The dotted line is drawn along the bank features at 15UM091 that suggest is the current bankfull flow elevation, which is lower than the historical floodplain (arrows at top of solid yellow bank profile lines).

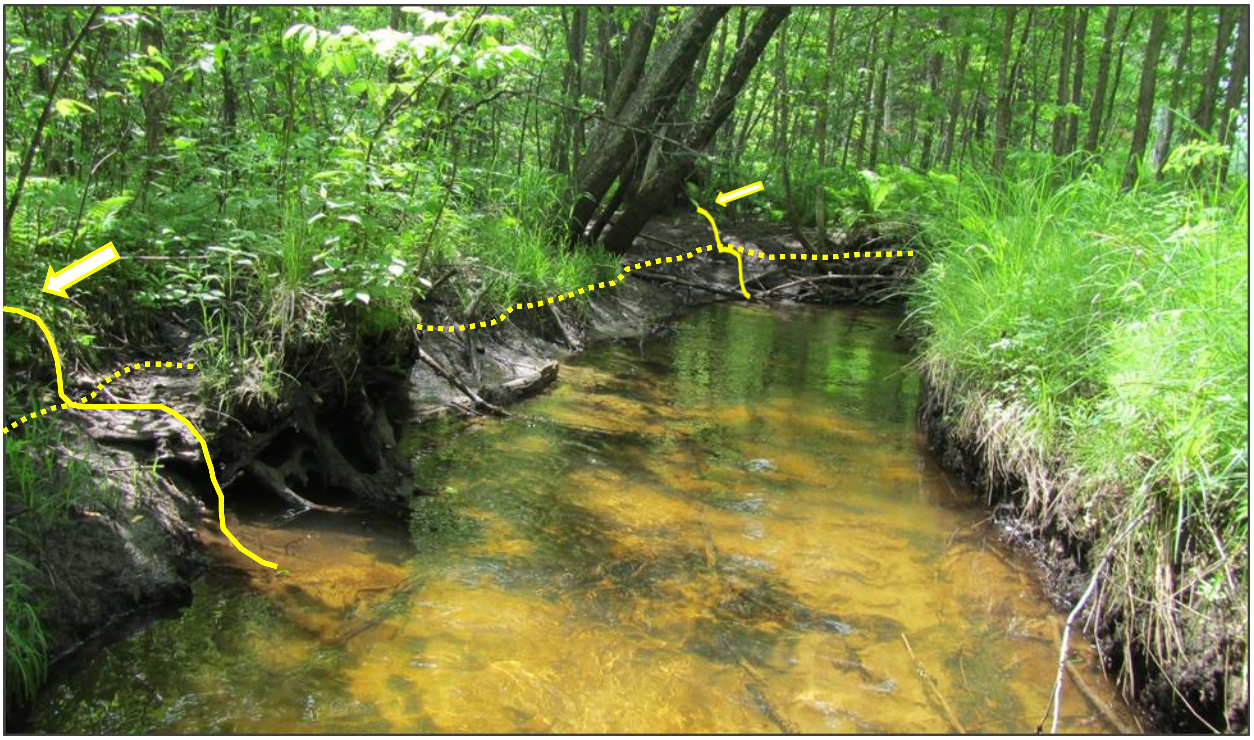


Photo 14. Sandy sediment deposition at 15UM091 forming a bar/new floodplain at the front-right side of the photo.

Photo 15. 16UM151 - Extensive bank erosion on both sides of the channel and excess sediment deposition on the left side of the photo.

Photo 16. 16UM151 - The channel is incised, with steep high banks on both sides of the channel, preventing high flows from spilling out onto the floodplain to dissipate energy.

The DNR staff did geomorphological surveying in AUID-730, and walked the downstream section of AUID-731 making observation of channel conditions. Their summary is presented here:

AUID-730 Tributary to Mississippi (16UM151)

The stream has slight to moderate incision and entrenchment. It is unstable and has little floodplain access during small to medium floods. The instability is causing channel widening and bank erosion. A possible culprit of the instability is land use change within the watershed. It seems the major geomorphic stressors to biology in this reach are the lack of deep pools, lack of instream vegetation, and the excess fine particles throughout the system.

We assessed a 550’ reach of the Trib. to Mississippi in a forested section over 2000’ upstream of its confluence with the Mississippi River. The stream typed out to an E5. The E characterizes the stream as narrow, deep, and sinuous while the five signifies the reach is primarily sand.

The reach ranges from slightly too moderately incised and the stream is still trying to create a new small floodplain at a lower elevation. It appears to have previously down cut and is now widening making it slightly too moderately entrenched. This means that it takes higher flows for the stream to access its floodplain and when high flows are concentrated in the channel, shear stress on the banks increase and further destabilization can occur. Until the stream can reform its floodplain, it will remain unstable and continue to transition from a low W/D E channel to either the high W/D E channel it currently is or a C channel. It should eventually transition back to a narrow W/D E channel.

Just upstream of the surveyed reach, the stream is a stable E channel flowing through a grassy meadow with densely vegetated banks. There is a stark change once the stream leaves the meadow and enters the forested area where the vegetation and root systems on the banks are not as dense. The stream transitions to a higher W/D channel with several signs of instability. There are places where the stream is up against the valley wall resulting in 8’ eroding banks, which is not surprising since the stream is mostly confined within its valley. The banks are also bare in several other places throughout the reach. The channel itself lacks deep pools other than one caused by a downed tree in the stream. The lateral scour pools have partially filled with sediment and do not have much depth, despite some tight meanders. In addition, there are a couple slope reversals where there are riffles present when you would expect to find pools and vice versa.

The Pfankuch score was 102, a poor (unstable) score for an E5 stream. The upper banks scored good to fair due to their good vegetative protection, yet having some mass wasting potential and having steeper overall landform slope. The lower banks scored low marks for the bank rock content, the significant bank cutting, and higher bank height ratio. The channel bottom scored poorly due to the small particles sizes and the amount of cutting and scouring. In addition, Rosgen level III indicators of lateral channel stability suggest it is moderately unstable.

AUID-731 Tributary to Mississippi River (15UM091)

Much of the stream length below Little Ball Bluff Lake meanders through a meadow landscape. The dense grasses protect the banks well and the stream appears to be a stable E stream. The last 1,500’ of the AUID becomes forested however, and the bankfull width becomes much wider, many of the banks have exposed roots and soil, and there is lots of sand deposition in the channel. This paints a picture of a very incised stream, but a second visit during high flow revealed the stream nearly at bank height through the forested section. This means the stream is still connected to its floodplain and only slightly incised, if at all. Yet, due to the less dense root mass protecting the banks and the excess amount of sand moving and being deposited on the channel bottom, the downstream portion of this AUID is likely unstable. Furthermore, the landowner has heard of people intentionally damming the river upstream and also seen low flow conditions where surface flow becomes intermittent. We did not find any evidence of water control structures upstream other than beaver dams. It seems that degraded habitat, culverts preventing fish passage and low flow conditions are the primary stressors to fish.

Conclusions

Fish impairments in AUID-730 and AUID-731 are caused by a combination of stressors. Based on several visits to the location by the MPCA fish crew, water levels can occasionally become quite low. This may only happen in years with relatively less rain. There were identified fish migration barriers, both natural (beaver dams) and anthropogenic (improperly designed culvert crossings). Occasional low flow conditions may exacerbate the effect of these barriers if conditions within isolated reaches are not suitable for sustaining fish, particularly over winter. Altered hydrology has caused channel instability, leading to habitat degradation (i.e., a wide channel with shallow water depth, excess fine sediment, unstable substrate). The destabilized channel may be tied as far back as to the time of original clearcutting of the forest over 100 years ago, which drastically changed the landscape for a period of time, and has not returned to that historical condition since. Current, relatively moderate levels of un-forested lands in the subwatershed do not seem to be sufficient to have caused this degree of channel instability.

Recommendations

The primary fixable situation here would be a replacement of culverts on private drives to re-establish connectivity within more of the stream system. Given the poor habitat here, potentially due to legacy effects of original forest clearing, replacement of culverts alone will not likely restore a healthy fish population. Over a long period of time, the channel will restore itself to a healthier condition. Small check dams/berms in the road ditch to slow rain runoff entry into the stream may help to reduce peak flow volumes from heavy rains. Installation of certain in-stream structures may help narrow the stream width (see the stream restoration section in the Mississippi River - Grand Rapids WRAPS document).

Pokegama Creek **(AUID 07010103-733)**

Impairment: The creek was assessed as impaired for not meeting both the fish and macroinvertebrate community IBI thresholds at site 16UM167 downstream of Pokegama Creek Forest Road spur, five miles east of Ball Bluff. The biological site in AUID-733 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 3 (Northern Forest Streams - Riffle/Run). After the SID process, this AUID was proposed to be moved into impairment category 4C. The MPCA review team agreed that 4C is the proper impairment category, and a final decision is awaiting EPA review.

Subwatershed characteristics

Much of the subwatershed that drains to 16UM167 is bog/fen peatland. The area around the sampled reach is heavily forested. Not a single building could be found in the subwatershed via aerial photography review. No permanently non-forest cover is maintained (i.e., no fields of any type, including hay, were found in aerial photography review). Some logging has occurred over time, including a few recently cut plots. Some pine plantations are found in the subwatershed. One non-forest road crosses the subwatershed, along with CSAH-10 at the mouth of Pokegama Creek.

Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 60). The results are good for some parameters (nitrate, ammonia, TSS, TSVS) but problematic for others (DO, phosphorus, and S-tube). Additional monitoring was done in the 2017 SID work.

Table 60. Chemistry measurements collected at 2016 IWM and 2017 SID visits from 16UM167. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)	DOC
June 13, 2016	18:18	18.2	5.50	58	6.9	145	0.126	0.02	0.194	6.4	3.2	45	--
Aug. 24, 2016	17:50	21.8	4.88	56	7.27	128	--	--	--	--	--	28	--
Aug. 4, 2017	14:30	--	--	--	--	--	0.124	--	--	--	--	--	--
Aug. 21, 2017	12:00	15.9	6.78	68.5	--	64	0.087	--	--	--	--	--	59.7

Dissolved oxygen

Two of the three instantaneous DO measurements were above the standard; though no pre-9, am samples were collected. Given the time of day the June sample was collected (at the typical late afternoon peak of daily DO flux); the early morning DO was likely below the standard. The low DO concentrations in late afternoon, when DO levels typically peak for the day, are much lower than are found in cases of eutrophication, when plants add much DO to the water via photosynthesis. DO % saturation measurements also did not signal eutrophication (all were << 100%).

Nutrients - Phosphorus

The TP concentrations of all samples were well above the regional river nutrient standard. Sampling photos show the water was darkly stained (tea-colored). This is a sign of abundant wetland-sourced water, which can contain significant phosphorus due to plant material breakdown. Whole-season sampling in many other northcentral Minnesota streams has shown TP peaks in late July.

Nutrients - Nitrate and ammonia

Nitrate concentration was extremely low, and ammonia was a bit elevated for northern Minnesota, but not to problematic levels. Quite often early season samples have higher ammonia than mid-summer and fall samples.

Transparency and suspended solids

Secchi-tube readings were low at both visits. The fish sampling crew noted that the water was heavily tannin-stained, which probably is responsible for the low S-tube visibility, given that TSS was low. Both TSS samples were well below the north region standard. The author participated in geomorphology work in this reach in 2017 and also observed heavily stained water with low visibility, which made wading difficult. The water was not cloudy due to suspended sediment.

Dissolved organic carbon

A sample was collected on August 21, 2017 in order to provide insight into upstream wetland contribution to stream flow. DOC concentration on this date was very high, at 59.7 mg/L. Concentrations of DOC may be even higher than this in late July, as shown from season-long DOC sampling in other MRGRW streams (see the Study of tributaries of nutrient-impaired lakes section).

Biology

Fish

There were few individual fish collected from the four species in the sample. All four species are ubiquitous and non-sensitive. White sucker dominated the sparse sample, with a few creek chubs, and a single central mudminnow and northern pike.

Metrics pertaining to DO and TSS are shown in Tables 61 and 62. The DO TIV Index score was well above the class average and the probability metric is neither likely nor unlikely. The TSS TIV Index was well below (i.e., poorer than) average for this stream class, however, the probability of this community coming from a TSS standard-meeting site is fairly good. There were no low-DO Intolerant species captured, though the percentage of low-DO Tolerant individuals was very low, suggesting the DO levels are mediocre - neither very good, nor problematic. The TSS-related metrics also showed the community was not skewed toward either TSS Intolerant or TSS Tolerant species.

Table 61. Fish Community DO and TSS Tolerance Index scores at 16UM167. 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 (2017 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 %
7.13	6.55/6.61	79	53.3	15.10	13.98/13.28	19	72.8

Table 62. Fish metrics related to DO and TSS for 16UM167 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	2	1	0	10.0
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 black fly *Simulium*, followed by the caddisfly species *Hydropsyche betteni*. That both of these taxa are filter feeders suggests that there is nice flow velocity in this stream reach. In a stream having good velocity, it would be expected that more taxa from the EPT orders would be found. Most of those taxa require hard substrates to cling to, and a note from the macroinvertebrate samplers suggested little of such material was present. Most of the wood they found in the stream was buried in fine sediments. This is a sign that there is excess sediment in the stream, burying important habitat features that are exposed and available in healthy streams.

Tables 63 and 64 show DO- and TSS-related metric scores for the macroinvertebrate community at site 16UM167. The community is quite balanced between low-DO Intolerant and Tolerant taxa, and the probabilities that this community would be found at a site with standard-meeting DO levels is fairly high.

Regarding TSS, there are no Intolerant species, and seven Tolerant ones, though the percent of individuals that are tolerant is still a minority of the sample. The probability that this community would come from a site with standard-meeting TSS is quite high. While TSS does not appear to be a major stressor, excess sediment in the heavier form of sand can creep along the bottom of the stream, moved by the flow, while the water column is still relatively clear. This can result in habitat that is relatively unstable.

Table 63. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-733 at 16UM167. 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 (2017 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 %
7.18	7.02/7.15	53	74	13.83	13.42/13.47	39	82

Table 64. Macroinvertebrate metrics related to Low-DO and TSS for 15UM056 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	4	1	3	0	1.9	7.0
TSS	0	0	7	1	0	21.6

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

Habitat

The biological sampling crews conducted the MSHA protocol on two different dates. Total scores were 63.7 and 65. These scores are at the top of the scoring range of the "Fair" category. 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 = 85.7%, Substrate = 60.1%, Cover = 72.2% and Channel Morphology = 50.0%. In general, this suggests that it is "instream" features that are missing, as opposed to adjacent terrestrial features. In particular, this analysis suggests that Substrate and Channel Morphology are the aspects most problematic among the habitat components. There was not anything very noteworthy as problematic from the individual components assessed in the Substrate component. Sand, gravel, and cobble were the prevalent substrates. The embeddedness of hard substrates was rated as light. Among the "Channel Morphology" component, the individual scores that limited the component score were only moderate stability, somewhat shallow pool depth, and narrow pool width. It is possible that fine sediment from the somewhat unstable banks has partially filled pools.

During the geomorphology work, the author was in the stream at many locations at the chosen site (located just upstream of CSAH-10, which is about 0.4 miles downstream of site 16UM167). Very little gravel or cobble was encountered. Substrate and bank material were sand and clay. Some of the clay bottom was very hard and erosion-resistant. It may be that the cobble found near the culvert crossing at the biological sampling site was placed there for road stability purposes.

Connectivity

No barriers could be seen between the Mississippi River (overwintering habitat) and the sample reach (16UM167) on aerial photos nor on the recent LiDAR elevation map. The culvert at CSAH-10, which lies between 16UM167 and the Mississippi River, was checked for adequacy of fish passage. The culvert is properly sized and at the higher flow level on the day of viewing, was not at all problematic from a velocity standpoint. The DNR staff visited the culvert and confirmed that the culvert is not a barrier to fish passage. The water in the culvert was deep, and there was no sign of the culvert being perched. No other crossings occur between site 16UM167 and the Mississippi River. Migratory barriers are not a stressor to the fish community sampled at 16UM167.

Hydrology

The hydrology of the subwatershed of AUID-728 has been altered by trenches dug (ca. 1910's) through the headwaters bog/fen areas, extending the channel system much farther upstream (Figure 30). Originally, no channel existed where most of the ditches are located (Figure 31). In addition, the ditch network crosses the subwatershed boundary in several locations, and so water from land areas originally outside of the Pokegama Creek subwatershed may now be draining through Pokegama Creek, adding even more water to the creek. Originally, water falling on the wetlands and uplands of the subwatershed would have slowly seeped into Pokegama Creek, coming to the surface to form the headwaters of Pokegama Creek at the location of the white dotted box in Figure 30. The ditch network drains this originally channel-lacking area much quicker, leading to increased peak flow volumes in Pokegama Creek. An altered flow regime (higher peak flows) causes habitat instability and alters available physical habitats within the stream, which will be discussed in the following paragraphs in the Geomorphology section. See also the discussion of peatland drainage in the "Hydrology" section on pages 24-26.

Figure 30. Outline of the Pokegama Creek subwatershed (yellow line) for the biological sampling point 16UM167 (green dot). The white dotted box is the approximate extent of the area shown in Figure 31 following.

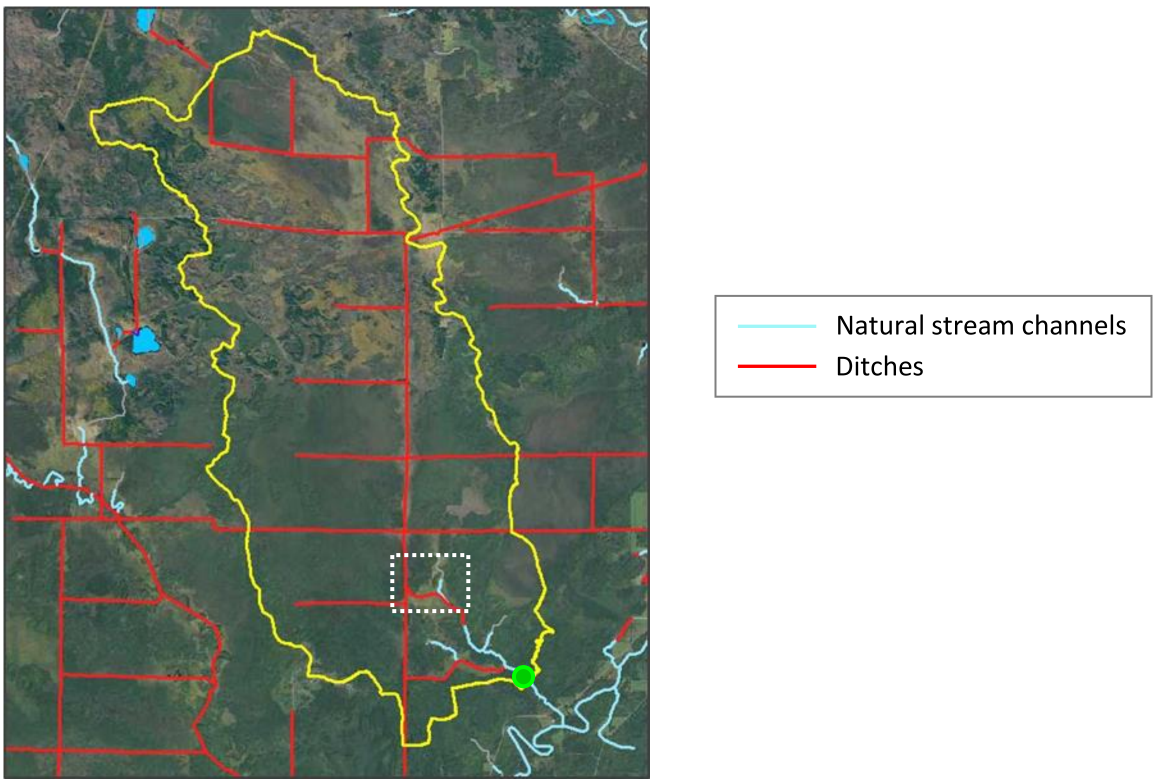
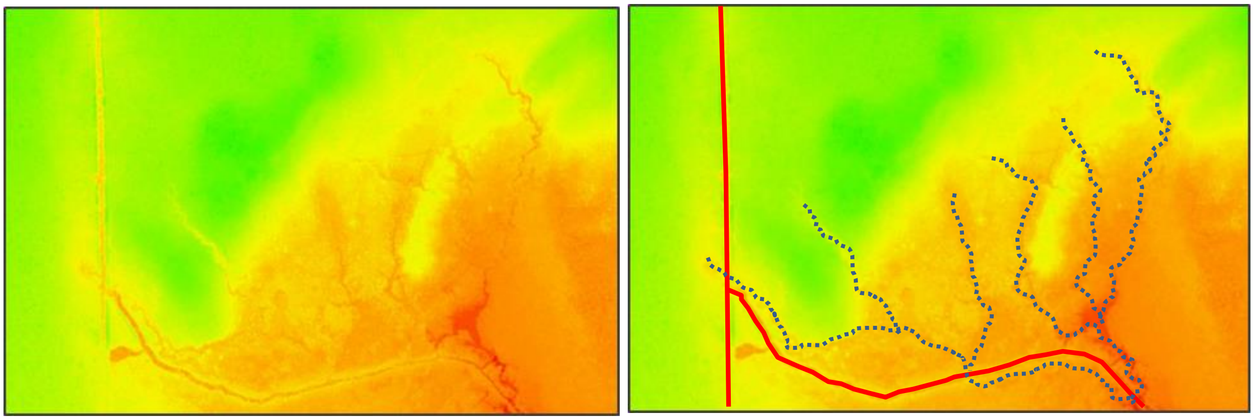


Figure 31. LiDAR elevation map of the area of the original headwaters of Pokegama Creek. The dotted lines on the right trace the original natural channels at the uppermost end of Pokegama Creek, where peatland seepage emerged from the wetlands in multiple small channels and coalesced to form the main channel of Pokegama Creek. The solid red lines in the right graphic are ditched channels. The extent of this piece of the subwatershed is shown in Figure 30.



Geomorphology

The DNR staff did a thorough assessment of channel conditions in the AUID, a short ways downstream from the biological monitoring site on down to CSAH-10, where the channel has not been altered by excavation/re-routing (except right near CSAH-10).

Pfankuch Assessment

From DNR (unpublished communication, 2018a): "The Pfankuch score for this reach is 102, a poor (unstable) score for an E5 stream. The upper banks received poor to good ratings due to the debris jam potential, landform slope, potential for mass wasting where the stream is against its valley wall, and for the lack of dense vegetative cover. The lower banks rated mostly fair due to obstructions to flow, cutting, and deposition throughout the reach. The channel bottom scores were primarily impacted by the small particles, lack of consolidation, and the amount of scour and deposition occurring."

Rosgen Assessment

Signs are evident that the channel has experienced some instability due to altered hydrology and that damage to the physical channel has occurred (incision). Channel (water level) elevations, as captured by LiDAR, are evidence of the incision (Figure 32). Raw banks were seen along the sample reach and their severity quantified by DNR in 2016 (Figure 33). The DNR geomorphology specialists studied a 1000-foot long reach upstream of CSAH-10 more intensively in 2017.

The following is from the DNR geomorphology summary (unpublished communication, 2018a); "Altered hydrology has caused Pokegama Creek to down cut and widen, going from a low width/depth 'E' channel to a high width/depth E channel. The stream is now deeply incised and any additional down cutting could cut the stream off from the floodplain entirely. While stretches of the stream are rebuilding a new lower floodplain, others are still widening. In addition, Rosgen Level III indicators such as meander and deposition patterns point to the stream being laterally unstable, suggesting it could take decades to stabilize. The primary geomorphic stressors to biology include the mobile bed materials and lack of in-channel vegetation."

Figure 32. Valley and channel elevations at 16UM167 (green dot). Green is highest elevation, and dark red is the lowest elevation. Channel elevation changes at the forest access road (dotted line) crossing, as seen by the darker red color change in the channel, right at the crossing, suggesting a nickpoint has worked its way up the channel due to excess flow volumes eroding the bed up to the point where there is a grade control structure (a culvert in this case).

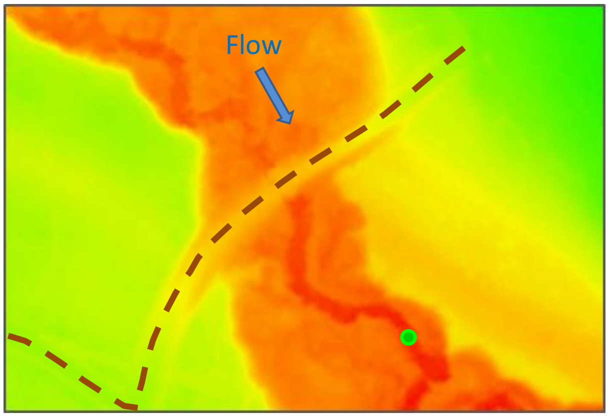
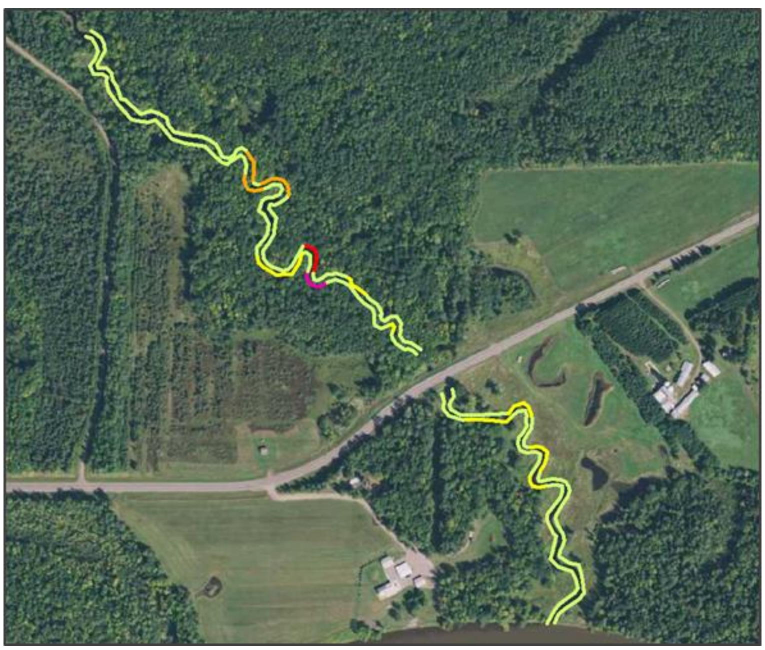


Figure 33. BANCS categorizations of streambank sections a short distance downstream of 16UM167. Colors represent categories of estimated sediment input from a given stream bank section. Bank erosion estimates increase as colors move from green to yellow to orange to red to pink.



Conclusions

The initial suspicion, via examination of aerial photos and maps, was that altered hydrology due to extensive addition of stream channel from historical ditching of the subwatersheds peatlands is the main stressor, or root cause of other stressors of AUID-733. A thorough study of the geomorphology of the channel upstream of CSAH-10 was conducted by DNR staff, which confirmed that altered hydrology has indeed caused significant channel instability, with its resulting streambank erosion, streambed sedimentation, and alteration of specific stream channel habitat features.

Suspended solids are one of the subsequent effects of channel instability, due to excess bank erosion and flashy peak flows. Analysis of TIV metrics for TSS showed some influence on inverts, but not the fish community. The author did observe the stream during a high-flow period, and did not observe significant cloudiness of the water due to suspended material. The majority of the substrate in the reach studied by DNR was sand or clay, and wading found many soft patches of sediment, suggesting this material moves frequently in periods of higher flow. It may be that consisting of mostly sand, the substrate creeps along the bottom with only smaller amounts suspended higher up in the water column.

Periods of low DO concentrations occur, though this is not well quantified. It is common for wetland-dominated systems to experience low DO, particularly after rain events. No low-DO Intolerant fish species were present. However, there were several low-DO Intolerant macroinvertebrate taxa, so this is probably a less significant contributor to stress than degraded habitat, but still a stressor.

DOC is very high in this stream, and it is possible it is a contributor to the fish impairment, as many species feed by sight, and this water is darkly stained. Effects of DOC on fish communities is not well studied, but it is logical to suspect it may interfere with foraging success of fish. The upstream ditching of peatland has potential to exacerbate levels of DOC in this stream. Because of a lack of scientific knowledge of the influence of DOC on fish community composition, it is not possible to say whether DOC is a stressor, though it is plausible when levels create dark water, such as exists in Pokegama Creek.

Recommendations

This sub-watershed has a systemic problem, which being the extensive channelization of upstream peatlands leading to excess water in the downstream, natural channel of Pokegama Creek. The primary solution for this AUID is to restore the current hydrological patterns to a more natural condition (Poff et al., 1997), which would mean plugging and/or filling peatland ditches. DO levels might also be improved with removal of the ditches. Some recent examples of this type of project have been completed in Minnesota in recent years (e.g., the Sax-Zim Restoration (Myers, 2015)). As most of this subwatershed is state-owned, and undeveloped, it would be easier to do such a restoration here. The creek could then be left to begin healing itself, though this is a long process and it would probably take decades to fully naturalize to a healthy channel. Coupled with naturalizing the hydrology, some in-stream work could be done to speed the healing of the channel, such as efforts to raise the incised channel bed. In-stream efforts alone without some restoration of hydrology would not be very helpful. The accompanying MRGRW WRAPS document presents some guidance for working channel/habitat improvements.

Tributary to Hill River Ditch **(AUID 07010103-739)**

Impairment: The creek was assessed as impaired for not meeting the General Use fish community IBI threshold at site 15UM044 located downstream of Annie Dagel Road, 4.5 miles southeast of Hill City. The biological site in AUID-739 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

As described in the MPCA assessment database; “This assessment unit represents a small channelized tributary to the Hill River, which stems from a small wetland north of Highway 200, just East of Hill City and joins up with the Hill River in the Moose-Willow wildlife management area. The watershed is relatively undisturbed tax forfeit lands, largely composed of forested wetland habitats and numerous beaver dams.” There was no channel here until it was dug.

Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 65). The results are good for some parameters (nitrate, ammonia, S-tube) but sometimes problematic for others (DO, phosphorus, TSS, and TSVS).

Table 65. Chemistry measurements collected at IWM and SID visits from 15UM044. Values in mg/L.

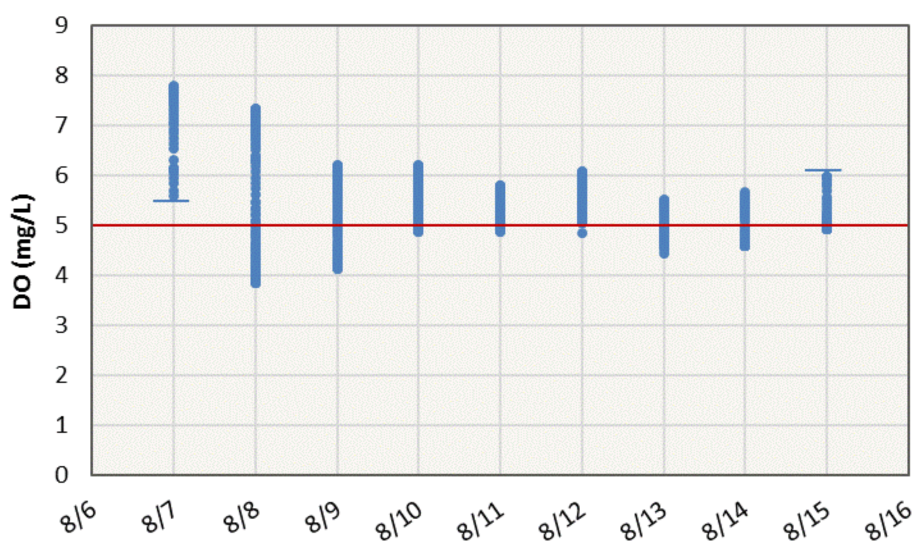
Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
June 30, 2015	11:50	21.3	5.89	70	7.4	278	0.059	< 0.05	< 0.1	4.4	< 4	> 100
Aug. 26, 2015	18:05	16.9	7.27	79	7.5	295	--	--	--	--	--	> 100
June 16, 2016	10:10	14.8	4.63	46	7.3	236	0.067	< 0.02	0.117	24	9.2	81
Aug. 15, 2017	14:05	22.8	5.91	67.8	--	312	--	--	--	--	--	"Clear"

Dissolved oxygen

One of four instantaneous DO measurements was below the standard; though no pre-9, am samples were collected. Without early morning samples, which reveal the daily minimum, DO concentrations, and these data cannot determine that the stream is meeting the DO standard. Given the time of day the June 30, 2015 and August 15, 2017 samples were collected (near or past noon) and that the DO was still between 5-6 mg/L, the early morning DO was likely below the standard. The DO concentration slightly above 7 mg/L on Aug. 26, 2015 is a good concentration, and is not at an unnaturally-elevated level, as it would likely be at this time of day if eutrophication were occurring. The DO %-saturation measurements also did not signal eutrophication (all were << 100%). There are some organic sediments on the stream bottom (as well as soft sand), which may be sapping some oxygen from the water column.

In order to better understand the DO regime, a sonde was deployed over August 7 - 15, 2017 (Figure 34). DO concentrations on all eight days with early morning measurements dipped below 5.0 mg/L. The DO minimum concentrations on four of the days were right about 5.0, two days were about 4.5, and two days were about 4.0 mg/L. The diurnal flux of the DO concentrations were often less than 1.5 mg/L, which is quite small. Three days had higher flux with the greatest at about 3.5 mg/L.

Figure 34. DO concentrations (daily ranges) from August 7 - 15, 2017 at the road crossing a short distance upstream of 15UM044. The red line is the DO standard. The small blue bars note that the end of the day's range was truncated due to when the sonde was deployed or retrieved.



Nutrients - Phosphorus

The TP concentration was above the regional river nutrient standard. Sampling photos from June show the water was moderately stained (tea-colored). This is a sign of wetland-sourced water, which can contain significant phosphorus due to plant material breakdown. The author's observations from later in summer (mid-August) were of unstained water. Whole-season sampling in many other north-central Minnesota streams has shown TP peaks in late July, so chances are good that mid-summer TP concentrations are even higher than the levels found in the two June samples.

Nutrients - Nitrate and ammonia

Nitrate concentration was extremely low, and one of the ammonia sample results was a bit elevated for northern Minnesota, but not to problematic levels. Quite often early season samples have somewhat higher ammonia than mid-summer and fall samples.

Transparency and suspended solids

Secchi-tube readings were stellar at two visits, and OK at the June 16, 2016 visit. At this last visit, the biological sampling crew observed that the water was higher than normal. That same visit showed high TSS (above the northern region standard of 15 mg/L). It appears that at higher flows (e.g., after some rain events), TSS becomes elevated to a level that exceeds standards.

Biology

Fish

There were relatively few individual fish collected at each of the two sampling visits, and each visit recorded only four species, which differed somewhat between visits. The first visit was dominated by white sucker. Central mudminnow, creek chub, and burbot were also present. The 2016 visit contained three different species, with the common species between samples being central mudminnow. Northern redbelly dace dominated the sample, while the other two new species were brook stickleback and pumpkinseed sunfish. Of the seven species collected in the two samples together, most are ubiquitous and non-sensitive, with the exceptions being burbot and northern redbelly dace.

Metrics pertaining to DO and TSS are shown in Tables 66 and 67. The TIV Index metrics for both DO and TSS varied substantially between the two samples. The community metric scores were average and below average for DO. For TSS they were average and much better than average. The probability of the fish community coming from a site that meets the DO standard was overall much less likely than for TSS, which had quite high probabilities. There were no low-DO Intolerant species captured in either sample, and in 2016, all four species collected are low-DO Tolerant (Table 67). The percentage of low-DO Tolerant individuals was moderate in 2015, but was 100% in 2016, suggesting DO levels can be problematic. The TSS-related metrics showed the community to be somewhat skewed toward TSS-intolerance, particularly in the 2016 sample, due to the abundance of northern redbelly dace. Based on these metrics, DO appears to be a stressor to the fish community, while TSS does not.

Table 66. Fish Community DO and TSS Tolerance Index scores at 15UM044. 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 (2017 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.

Year	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2015	6.70	6.55/6.61	55	34.5	14.07	13.98/13.28	34	77.9
2016	5.63	6.55/6.61	10	7.2	10.01	13.98/13.28	97	91.3

Table 67. Fish metrics related to DO and TSS for 15UM044 utilizing MPCA species tolerance assignments.

Parameter	Year	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	2015	0	0	1	1	0	29.7
Low-DO	2016	0	0	4	4	0	100
TSS	2015	1	1	0	0	2.7	0
TSS	2016	1	0	0	0	79.1	0

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

Macroinvertebrates

The sampled macroinvertebrate community was moderately dominated by four taxa, listed here in order of abundance; *Caenis*, *Simulium*, Pisidiidae, and *Hydraena*. The mayfly *Caenis* is more tolerant of abundant fine sediment and lower DO than most other mayflies. The taxa list for this site shows several that favor more wetland-like conditions (including lower DO), including the mayfly *Caenis*, the fingernail clam Pisidiidae, and the beetles *Anacaena*, *Hydraena*, *Laccobius*, and *Platambus*.

The macroinvertebrate community does not show influence of low DO conditions (Tables 68 and 69). The DO TIV Index score is better than the class average, and there are twice as many more low-DO Intolerant than Tolerant taxa present. There are however, more tolerant individuals. With the wetland-oriented species present and the more abundant Tolerant individuals, there is some reason to suspect that DO levels get somewhat low at times.

Table 68. Macroinvertebrate Community DO Index statistics at 15UM044. For DO, a higher index score is better. "Percentile" is the rank of the index score within stream class 4 (2017 version). "Prob." is the probability a community with this score would come from a stream reach with DO that meets the appropriate standard.

DO TIV Index	Class avg./median	Percentile	Prob. as %
6.81	6.28/6.47	68	66

Table 69. Macroinvertebrate metrics related to Low-DO 15UM044 utilizing MPCA species tolerance assignments.

# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
6	4	3	1	6.71	17.57

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

Temperature

The temperatures measured at the biological sampling visits were at non-stressful levels, though no visits were in the period (late July) of typically warmest temperatures. The temperatures measured with the sonde deployed over Aug 7-15, 2017 were also at non-stressful levels. During that period, the temperature ranged from 15.53 to 21.72, with the average temperature being 18.62°C. Water temperatures during the warmest time of summer would likely be 2-3°C higher than the sonde temperatures, which would not cause thermal stress in this case.

Habitat

The biological sampling crews conducted the MSHA protocol on three different dates. Total scores were 49, 36.6, and 48. Two of these scores are near the bottom of the scoring range of the "Fair" category, and the third is well into the "Poor" category. The "Riparian" and "Land Use" MSHA components received most of the points possible, while the three-instream components scored poorly. 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 = 78.5%, Substrate = 38.8%, Cover = 48.1% and Channel Morphology = 25.7%. In particular, this analysis suggests that "Substrate" and "Channel Morphology" are the aspects most problematic among the habitat components.

There was little substrate size diversity, as sand and silt were the predominant substrates. The embeddedness of hard substrates was rated as light or moderate. Among the "Channel Morphology" component, there was low diversity of velocity at two visits, and all three visits noted mediocre variability in water depth. It is possible that fine sediment from the somewhat unstable banks has partially filled pools. The subcomponents "Channel Development" and "Channel Stability" each received few points. Taken together, these various aspects suggest an overall lack of habitat diversity, which generally translates to low biological diversity. It appears that the stream often has homogeneous flow velocities, homogeneous substrate, and fairly homogeneous depth.

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 was a dam just upstream of the upper end of the sample reach.

Connectivity

There are no road crossings downstream of 15UM044 to the end of the AUID, where it meets the Hill River. As mentioned, beaver activity is significant in the subwatershed. Numerous dams can be seen on recent aerial photos upstream of 15UM044. No beaver dams could be found between 15UM044 and the mouth at the Hill River. However, the Hill River itself is a ditch in both the upstream and downstream directions from the mouth of AUID-739 for significant distances, and so it too may be providing poor habitat in the area where fish using AUID-739 would seek overwintering habitat. Thus, the source area for fish in AUID-739 may be a mediocre one and there is possibly a blockage of connectivity to healthy downstream habitat due to the ditching of the Hill River.

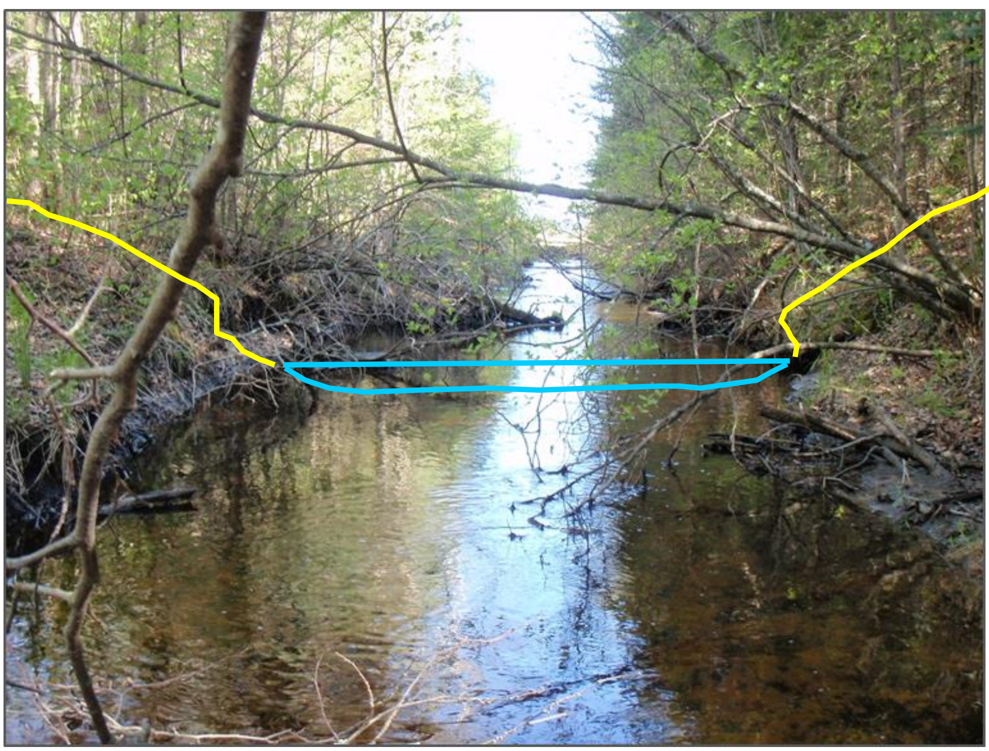
Hydrology

This AUID is a created channel, which diverted a natural stream that drained this area. This is not a case where a stream channel was straightened within its valley, but was cut through upland areas some distance from the valley. Additionally, more tributaries (ditches) were created that flow into the main constructed channel. Together, these have changed the original hydrology of the area. This is not a case where a natural stream channel is degraded by increased flow, since the channel was constructed. It is worth noting that the original natural channel has been cut off by this ditch system, and thus natural habitat has been lost for fish and macroinvertebrates in this subwatershed.

Geomorphology

This channel was dug through an upland area where no channel naturally existed, and as such, no floodplain exists, and high flows stay within the channel due to the elevation of the dug channel relative to the upland ground level (Photo 17). An entrenched channel like this is going to have some instability, and such instability was noted in the MSHA observations: the raw lower banks can be seen in Photo 17. The contained high flows, with the increased sheer stress on the bed, are also likely to be moving the sand substrate and keeping it too in an unstable condition. The low gradient of this constructed channel saves the erosion and instability from being worse than it is.

Photo 17. The sample reach at 15UM044, showing the high, unnatural banks of the channel (yellow lines), due to the channel being cut through this upland area.



Conclusions

AUID-739 is primarily a ditch, with part of it in the original stream valley, and other parts of it significantly distant from the original creek channel. As such, some of the channel runs through places where there was not a channel originally, which is the case at 15UM044. Cutting a straight channel into an upland area is generally not going to replicate a healthy, natural channel in terms of habitat. This is the case here, as MSHA scored habitat as “Poor”. Ditching through peatland areas has likely reduced the DO levels, which showed frequent concentrations below the standard. The stream/ditch also flows into a highly modified channel (the Hill River), which also had a poor MSHA score, though the fish community scored well and passed the FIBI. Thus, it is unclear how the lack of connectivity to downstream healthy habitat affects the fish community in AUID-739. Poor habitat and insufficient DO levels are the two stressors contributing to the fish impairment in AUID-739.

Recommendations

AUID-739 and its stream connections downstream are highly modified as a system of ditches, and as such, there is no easy solution to improving the fish community and removing the impairment. Routing AUID-739, and connected downstream AUIDs, back into their original channels, and plugging or filling un-needed ditches draining wetlands would be the way to improve or restore biological health to this stream system. This would be expensive, and may not reach the same priority as other projects in the MRGRW. However, there may be other resource benefits beyond fish habitat that could occur with hydrological restoration of this area (e.g., reducing this area’s contribution to Mississippi River flooding downstream).

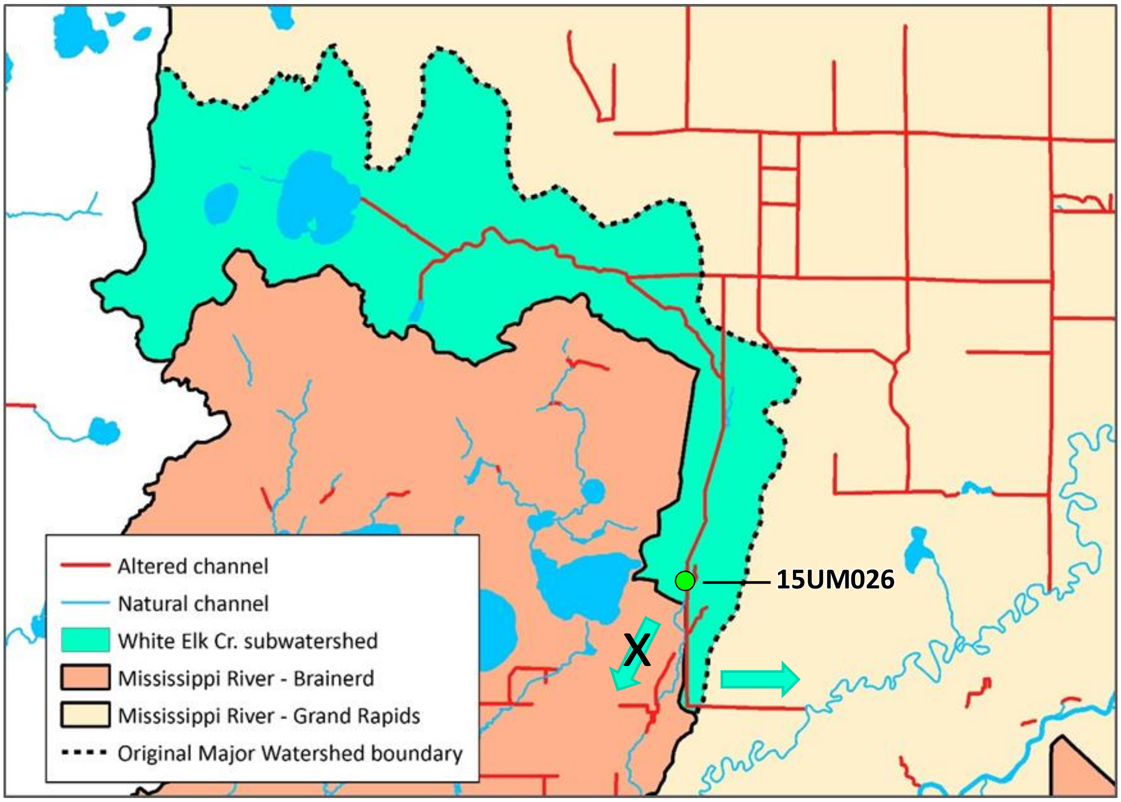
White Elk Creek (AUID 07010103-741)

Impairment: The creek was assessed as impaired for not meeting the fish community IBI threshold at site 15UM026 located downstream of 500th Lane, 0.5 miles east of Waukenabo. The macroinvertebrate community passed the IBI threshold. The biological site in AUID-741 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool).

Subwatershed characteristics

The subwatershed contains much wetland acreage. There are numerous cattle operations, and significant land area is open or partially forested pasture. In the upper parts of the AUID, cattle have full access to the channel. The full length of the AUID is channelized, as is the channel upstream that feeds AUID-741. Additional tributary ditches feed into AUID-741 as well. In some places, the ditch lies in the original drainage valley, and in other locations, it cuts across upland areas where there was no channel originally. The AUID-741 subwatershed was originally part of the neighboring HUC8 watershed to the west, the Mississippi River - Brainerd Watershed (Figure 35). A diversion ditch that runs to the east along CSAH-3 is the reason this subwatershed is now in the MRGRW.

Figure 35. Approximate original subwatershed boundary for White Elk Creek, which naturally would be contained in the adjacent HUC-8, the Mississippi River - Brainerd Watershed. The arrow shows where the water flows into the Willow River currently via a ditch. The crossed-out arrow shows the original flow path.



Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 70), though four visits were made to this site. The results are good for most parameters (nitrate, ammonia, TSS, TSVS, and DO). TP was somewhat above the northern river nutrient standard, and may be due to significant wetland acreage in the subwatershed, given that other nutrients and suspended particulates are very low.

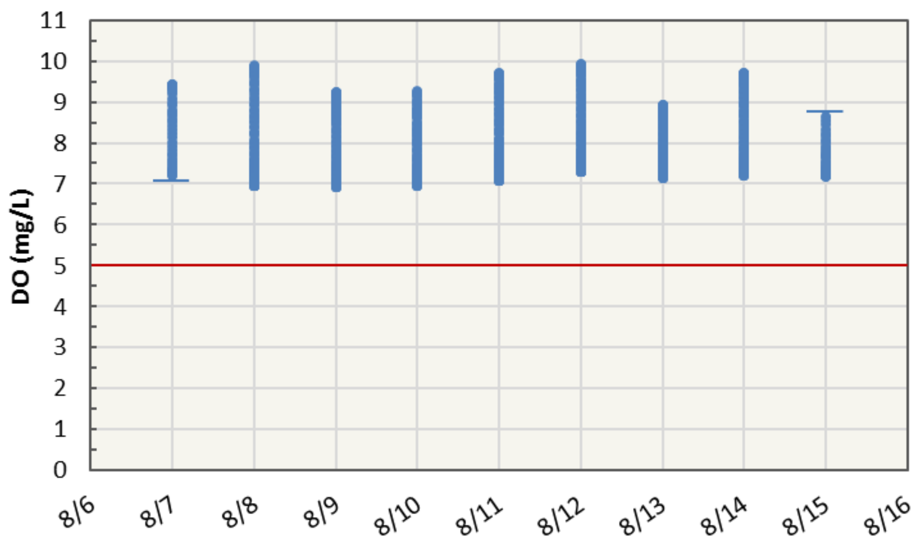
Table 70. Chemistry measurements collected during 2015-2016 IWM and 2017 SID from 15UM026. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
July 20, 2015	13:29	23.8	8.82	104	7.8	77	0.085	< 0.05	< 0.1	< 4	< 4	70
June 16, 2016	12:32	16.58	7.80	80	6.8	59	0.054	< 0.02	< 0.1	7.6	3.2	80
Sept. 1, 2016	9:45	15.9	7.80	79	7.4	57	0.078	< 0.02	< 0.1	7.0	3.8	64
Sept. 19, 2016	13:10	16.33	7.72	79	7.7	59	0.066	< 0.02	< 0.1	2.6	1.0	80
Aug. 15, 2017	12:53	19.51	8.63	94.1	--	80	--	--	--	--	--	--

Dissolved oxygen

DO levels from the IWM sampling were fine, though no pre-9am measurements were taken to determine the daily minimum. Therefore, a sonde was deployed during the dates of August 7 - 15, 2017 (Figure 32). Daily minimum DO concentrations were always well above the DO standard, and were right about 7.0 mg/L every day of the deployment. The daily flux of the DO concentrations were quite similar among days, and typically ranged between about 2.0 - 3.0 mg/L, with one day being less than 2.0. These are healthy ranges for the daily flux.

Figure 36. DO concentrations from August 7 - 15, 2017 at 500th Lane (15UM026). The red line is the DO standard. The small blue bars note that the end of the day's range was truncated due to when the sonde was deployed or retrieved.



Nutrients - phosphorus

The higher values in late July particularly, as well as the Sept. 1 sample, reflect a pattern seen in many north central Minnesota small streams with significant wetland influence, where TP levels rise through the first half of the summer, and then begin to decline. TP levels generally peak in late July per seasonal sampling in numerous north central Minnesota streams.

Nutrients - nitrate and ammonia

Both nitrate and ammonia concentrations were extremely low (always below the lab detection limit).

Transparency and suspended sediment

TSS levels were much lower than the standard at all samplings. S-tube transparency measurements were somewhat low given the low TSS, and were likely caused by staining of the water dissolved organic compounds from wetland plant decay (sampling photos showed tea-colored water).

Biology

Fish

There were four fish sampling efforts at this site, but two were deemed to be defective due to gear issues (the low conductivity in this reach required a gear change). Only the two effectively sampled efforts (which still failed the IBI threshold) are discussed. The 2015 visit captured only two species, and the community was dominated by central mudminnow (with white sucker also present). The September 19, 2016 visit captured many more species (11). The community was dominated by central mudminnow again, with many creek chubs, johnny darters, and white suckers. Even though 11 species were captured, they were all ubiquitous, non-sensitive species, with the exception of a single small walleye.

The Community Index scores were poor for DO, but somewhat better for TSS (Table 71). The sampled fish communities show a low probability of coming from a stream reach meeting the DO standard. Both samples scored below the class average, and the 2015 sample was only at the 8th percentile. Tolerance metric scores were skewed toward low-DO Tolerant species, while for TSS, the community was not skewed (Table 72). There were no low-DO Intolerant species captured; four of the six low-DO Tolerant species from the 2016 sample are ones considered "Very Tolerant" to low-DO. Evidence from the various fish metrics suggests that low DO concentrations are a potential stressor to the fish community. This, however, is in disagreement with the DO measurements that are available, though the fish samples and the sonde deployment occurred in different years, and differing flow levels (and possibly different DO levels) may explain this discrepancy.

Table 71. Fish Community DO and TSS Tolerance Index scores at 15UM026. 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 (2017 version). "Prob." is the probability a community with this score would come from a stream with DO or TSS that meet the appropriate standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
7/20/2015	5.59	6.55/6.61	8	6.6	12.42	13.98/13.28	73	84.6
9/19/2016	6.44	6.55/6.61	42	24.9	13.70	13.98/13.28	39	79.5

Table 72. Fish metrics related to DO and TSS for 15UM026 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO (2015)	0	0	1	0	85.4
Low-DO (2016)	0	0	6	0	44.5
TSS (2015)	0	0	0	0	0.0
TSS (2016)	0	0	1	0	0.5

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

Macroinvertebrates

The macroinvertebrates passed their IBI assessment. The same metrics that indicated a fish community that is very skewed toward tolerance of low DO were calculated for the macroinvertebrate community, to see if low DO also shows some influence on macroinvertebrates (Table 73). The macroinvertebrates did not show an influence of low DO; the DO TIV Index was quite a bit better than the average for the stream class. As with fish, no significant signal showed for influence of elevated TSS.

Table 73. Macroinvertebrate Community DO and TSS Tolerance Index scores at 15UM026. 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 4 (2017 version). "Prob." is the probability a community with this score would come from a stream with DO or TSS that meet the appropriate standards.

Date	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
8/25/2016	6.76	6.28/6.47	68	65.6	13.37	13.59/13.73	57	85.0

Temperature

Temperature measurements at the biological sampling visits were at healthy levels, with the July 20 measurement occurring at the typically warmest part of the season, and thus representing an approximation of peak seasonal temperature. The temperatures recorded by the sonde in August of 2017 ranged from 14.28 to 24.78°C, with the average being 18.40°C. Again, these are healthy temperatures for warmwater fish species.

Habitat

The biological sampling crews conducted the MSHA protocol on five different dates. Total scores were 51.75, 40.5, 46.2, 64.75, and 58.9. One of these scores was in the "Poor" category, while the other four span the range of the "Fair" category. The average of these five scores is 52.4, which is in the lower half of the range of "Fair" category scores. An average of each of the five MSHA subcomponents was calculated, and these were used to calculate a percentage of that subcomponent's possible score. These percentages were: Land Use = 77.0%, Riparian = 67.9%, Substrate = 49.5%, Cover = 77.8% and Channel Morphology = 32.0%. In general, this suggests that it is "instream" features that are missing, as opposed to adjacent terrestrial features. In particular, this analysis suggests that Substrate and Channel Morphology are the aspects most problematic among the habitat components.

There is a significant amount of sand substrate in the stream, and it appears that it is quite mobile, depending on flow conditions. Some of the MSHA observations did not record the presence of gravel or cobble, while at other visits; these coarser substrates were somewhat abundant. Higher flows are likely scouring the coarser substrates free of sand, while at lesser flows, the sand creeps along the streambed and covers the gravel and cobble. Among the "Channel Morphology component, "Sinuosity" scores poorly, as this is a very straight ditch with only a very moderate degree of naturalization to a sinuous pattern, and "Channel Development" also scores few of its possible points.

Connectivity

Given that this AUID is a direct tributary to the lower parts of the Willow River, there should be a good source of fish to populate the reach. Aerial photography from October 2015 was examined from 15UM026 down to the Willow River, and no beaver dams could be seen. However, the macroinvertebrate sampling effort attempted on August 27, 2015 was canceled due to the finding of multiple beaver dams in the sample reach at that time. Dams either did not create a large enough impoundment to show up well on the October aerial photos, or the dams were breached between August and October. It is not likely that dams would be left alone in most of this reach, particularly downstream of 15UM026, because much the channel runs in the road ditch and several access driveways coming off CSAH-3 cross it and could be flooded out if dams were present. The dams were not present in 2016 during the fish sampling visits.

There are two road crossings and four property access crossings between 15UM026 and the mouth of AUID-741 at the Mississippi River (Figure 37). All are culvert crossings. Therefore, there does exist potential for connectivity barriers. Five of the six were visited on May 13, 2019 by the author and observed for fish passability. The six, the most upstream, was not visited due to being on a private roadway. Water was somewhat high, and probably about normal for spring flow, (the Mississippi was nearly to the top of its banks). Two were found to be partial barriers that might be passable for some species only at certain flow volumes. All are large, single steel culverts of adequate size. The upstream partial barrier is at too high an elevation, though was not perched at the May 13 flow. The partial barrier downstream near Willow River is set at too high a gradient and is a velocity barrier, at least for some species. Flow was much faster in the culvert than the open stream channel (Photo 18).

Barriers, both road crossings and to a lesser extent beaver dams are a stressor in AUID-741.

Figure 37. Location of the culverts on the lower portions of White Elk Creek, downstream of 15UM026. Dot colors: Gray = not visited, Green = Good fish passability, Yellow = Partial fish barrier.

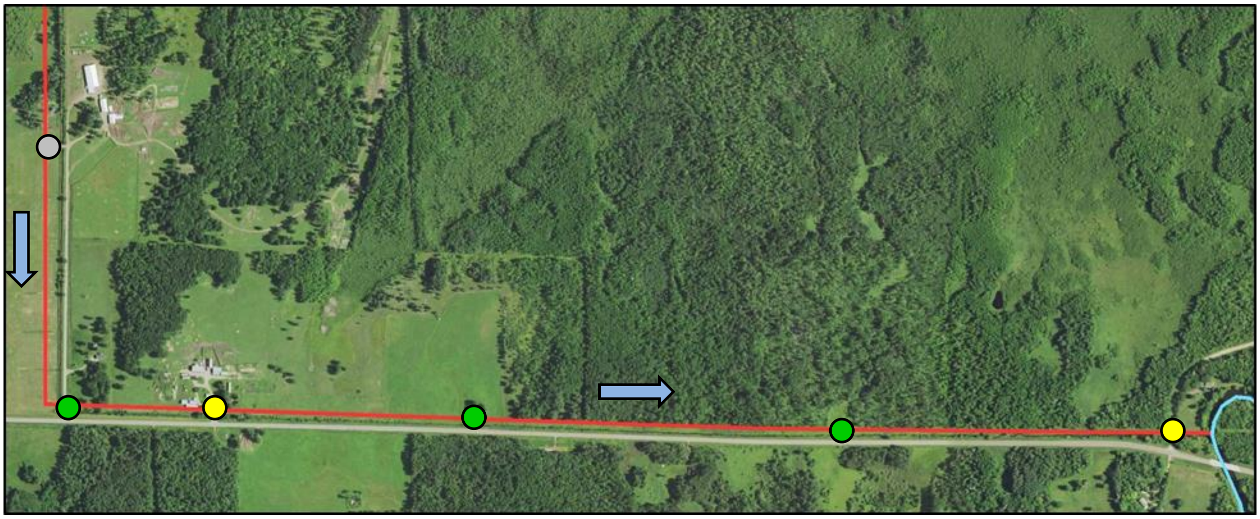


Photo 18. Upstream end of culvert on 334th Place is set too high, impounding water upstream and creating a sudden increase in velocity as water enters the culvert.

Geomorphology

In general, the channel along CSAH-3 was quite stable for a ditch. There was a bit of sinuosity forming, with narrow floodplain benches within the ditch banks. Such features improve biological habitat in ditches. Bank sloughing was occurring in a few locations, most notably in association with the two problematic culverts noted above (Photo 19).

Photo 19. Bank failure/erosion associated with the culvert on 334th Place.

Conclusions

The two stressors found for AUID-741 were connectivity and habitat. Fish community analyses also point to low DO as a possible stressor, though other evidence is lacking. Actual DO measurements show DO levels that are healthy. If there are periods of low DO levels, these do not appear to be eutrophication-related (based on chemistry data and stream observations). The MSHA aquatic vegetation observations note only sparse amounts of wild celery (*Vallisneria*), or sparse coontail (*Ceratophyllum*), and some of the observations noted sparse benthic algae, or sparse floating algae. One observation noted sparse duck weed. No duckweed or other plants were observed by the author in the stream immediately adjacent to 500th Lane during mid-summer 2017 sampling visits. Nitrate needed for plant/algae growth is extremely low in concentration.

The assessment of the habitat for the TALU assignment of the stream scored at a level that should be able to produce a fish community that meets the general use IBI threshold. However, habitat diversity is very likely a contributor to limiting the fish community, as the multiple MSHA procedures scored the habitat in the middle of the “Fair” range at best. In the lower parts of the AUID, the ditch is in places forming a bit of sinuosity with alternating small floodplain benches within the high-banked channel, which will likely continue evolving, a positive for creating more habitat diversity. From the standpoint of fish and macroinvertebrate habitat, it would be beneficial not to clean out the ditch. It currently appears to have plenty of transport capacity even with these floodplain benches. Collection of additional DO data would be helpful in determining whether insufficient DO is a third stressor.

Recommendations

Redesigning the configurations of the two of the culverts along CSAH-3 that were found to be set too high would improve the ability of fish to colonize White Elk Creek from the Willow River. Habitat improvement is needed as well, but the configuration of the channel as a straight ditch significantly limits what can be done. There may be places where the water can be re-routed back into the original channel, but in some locations, this appears to be limited due to development adjacent to the original channel.

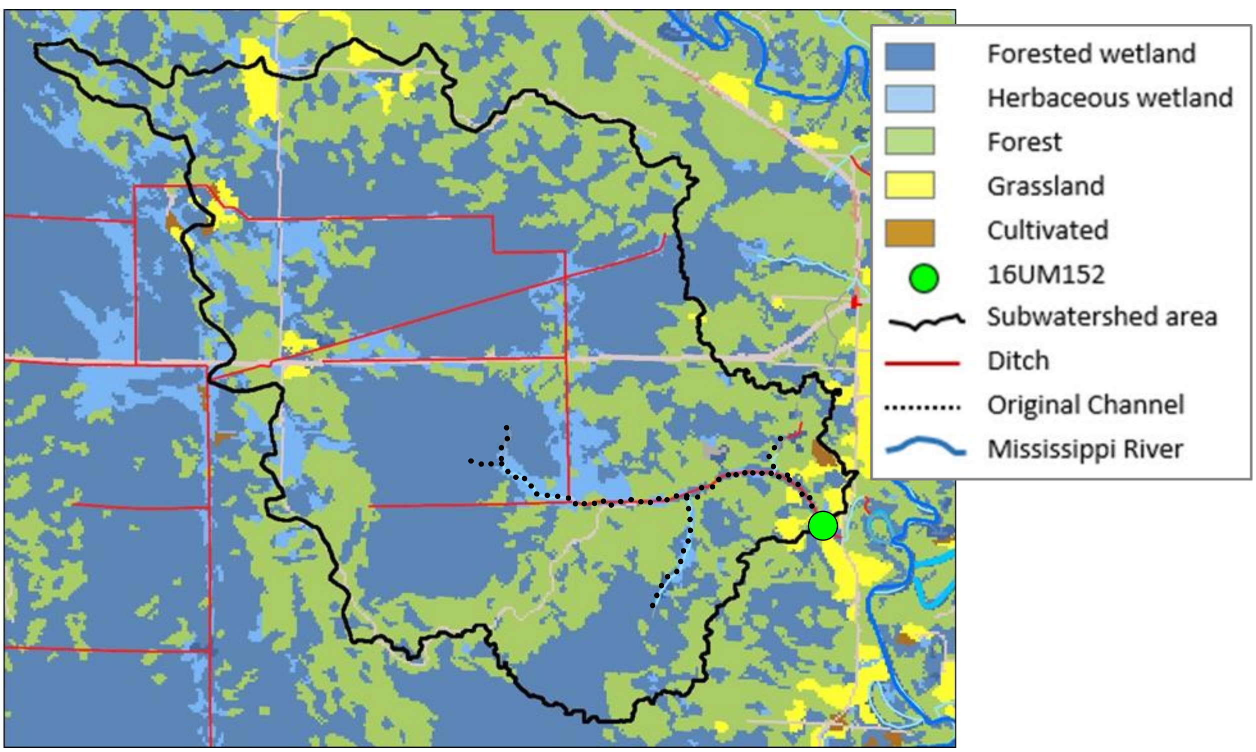
Unnamed Tributary to Mississippi River (AUID 07010103-756)

Impairment: The creek was assessed as impaired for not meeting the both the fish and macroinvertebrate community IBI thresholds at site 16UM152 located upstream of CSAH-10, 3 miles southwest of Jacobson. Both communities fell far below their respective IBI thresholds. The biological site in AUID-756 is Fish Class 6 (Northern Headwaters) and Macroinvertebrate Class 4 (Northern Forest Streams - Glide/Pool). After the SID process, this AUID was proposed to be moved into impairment category 4C. The MPCA review team agreed that 4C is the proper impairment category, and a final decision is awaiting EPA review.

Subwatershed characteristics

The subwatershed contains mostly forested wetland and upland forest, with some emergent wetland, and a small amount of pasture/hay acreage (Figure 38). The latter is mostly around the periphery of the subwatershed, either in the northwest headwater area or down near the Mississippi River. A few small farms have low numbers of livestock. Many previous timber harvest patches can be seen in aerial photos in various stages of re-growth. Ditches have been constructed through wetlands in areas where no flowing channel originally existed. These connect up to what was the original main channel, which started fairly close to the Mississippi River. Much more stream channel mileage exists now than existed in pre-settlement times.

Figure 38. Boundary of the subwatershed for 16UM152, showing land cover types and the current and original channel network.



Data and analyses

Chemistry

This site only had IWM chemistry monitoring (Table 74) and one sampling by SID staff. The results are poor for some parameters (DO, TP, TSS, and S-tube) and good for others (nitrate and ammonia).

Table 74. Chemistry measurements collected from 16UM152 at IWM and SID visits. Values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Amm.	TSS	TSVS	S-tube (cm)
Aug. 24, 2016	9:43	19.55	3.64	40	7.1	165	--	--	--	--	--	36
Aug. 25, 2016	8:05	18.80	4.01	43	7.4	168	0.198	< 0.02	< 0.1	32.4	8.4	40
Aug. 7, 2017	16:30	--	--	--	--	--	0.121	--	--	--	--	--

Dissolved oxygen

DO levels from the two IWM samples were well below the standard, suggesting DO is a stressor.

Nutrients - Phosphorus

The single TP sample was far above the north region river nutrient standard, which may be due to the significant wetland acreage in the subwatershed, and potentially exacerbated by the trench network upstream that drains those wetlands. Some of the phosphorus was likely contained in the organic material suspended in the water column (TSVS in Table 74). TSS was also high, with the mineral content of 24.0 mg/l (TSS minus TSVS), and mineral sediment particles can also have attached phosphorus.

Nutrients - Nitrate and ammonia

The nitrogen compounds nitrate and ammonia were at exceptionally low concentrations, below the laboratory detection limits for both.

Transparency and suspended sediment

The single TSS sample was more than double the north region standard. In addition, S-tube readings were quite poor. This clarity was likely influenced by dark tannin-stained water, which was noted by the fish sampling crew, but also by the high-suspended solids concentration. The majority of the suspended particles were mineral, rather than organic, and most likely coming from stream bank and bed erosion.

Dissolved organic carbon

Fish sampling photos show the water to be very darkly stained. Two samples were collected in 2017, on August 7 and August 21, with the results being 35.1 and 33.1 mg/L, which are fairly high concentrations. There is no standard for DOC but it is a sign of a strong influence by wetlands as a source of water.

Biology

Fish

There was one fish sampling effort at this site. Only three species were captured, and all were ubiquitous species. No intolerant or specialist species were caught. Central mudminnow was dominant in abundance, followed by brook stickleback, and a small number of white sucker.

The Community Index scores were very poor for DO, scoring only at the 5th percentile of Class 6 streams (Table 75). The TSS TIV Index score was quite good, at the 69th percentile. The sampled fish communities show a very low probability of coming from a stream reach meeting the DO standard. Tolerance metric scores were skewed toward low-DO Tolerant species and individuals, while for TSS, the community was not skewed (Table 76). There were no low-DO Intolerant species captured, and the two low-DO Tolerant species are ones considered “Very Tolerant”. Assessment of the fish community points to low-DO being a stressor, while there is no evidence that TSS is stressing the fish community.

Table 75. Fish Community DO and TSS Tolerance Index scores for AUID-756 at 16UM152. 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 (2017 version). “Prob.” is the probability a community with this score would come from a stream 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 %
5.50	6.55/6.61	5	5.7	12.59	13.98/13.28	69	84.0

Table 76. Fish metrics related to DO and TSS for 16UM152 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
Low-DO	0	0	2	2	0	92.5
TSS	0	0	0	0	0	0

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

Macroinvertebrates

The sampled macroinvertebrate community was highly dominated by the amphipod *Caecidotea*, followed by the midge *Paratanytarsus*. The isopod *Caecidotea* is not a commonly collected taxon in the MPCA stream monitoring samples, and it is extremely rare to have the sample be dominated by the taxon. Little ecological literature could be found that discussed the preferred habitat for *Caecidotea*, so it is a mystery as to why it is so prevalent here. The second through sixth most abundant taxa were midges. This too is uncommon among MPCA stream samples, because typical midge habitat (fine sediment) is not targeted for sampling. There were several taxa present that are typical of non-flowing, low-DO environments (e.g., wetlands), those being the beetles *Neoporus*, and *Enochrus*, and the fingernail clam Pisidiidae.

Tables 77 and 78 show DO- and TSS-related metric scores for the macroinvertebrate community at site 16UM152. The DO TIV Index score was better than the class average. However, the number of low-DO Tolerant and Intolerant taxa was skewed toward Tolerant, as was the percent of individuals. The probability of the community coming from a standard-meeting stream was mediocre. The situation is somewhat similar regarding TSS. Again, the TSS TIV Index score was better than the class average, though also again; the community was skewed toward TSS Tolerant taxa and individuals. Unlike for DO, the probability of the community coming from a TSS standard-meeting stream is quite high. The macroinvertebrate community shows a modest signal of being affected by low DO concentrations and also a weak signal of influence by elevated TSS.

Table 77. Macroinvertebrate Community DO and TSS Tolerance Index scores for AUID-756 at 16UM152. 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 4 (2017 version). “Prob.” is the probability a community with this score would come from a stream with DO or TSS that meet the appropriate standards.

Stream class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
4	6.64	6.28/6.47	61	63	12.90	13.59/13.73	70	87

Table 78. Macroinvertebrate metrics related to low-DO and TSS for 16UM152 utilizing MPCA species tolerance assignments.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	1	0	4	1	0.32	17.14
TSS	0	0	5	3	0	8.57

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

Temperature

The two temperature measurements were quite cool, but both were taken relatively early in the day, and not during the peak temperature period of mid to late afternoon. The riparian vegetation in the area of the biological sample site consists of large trees, giving significant shade to the stream channel. High stream temperature is not a likely stressor.

Habitat

The MSHA protocol scored 41.5 (average of two visits), which is in the “Poor” category. The percentage of possible points for the five MSHA subcomponents was calculated: Land Use = 80.0%, Riparian = 82.1%, Substrate = 35.7%, Cover = 72.2% and Channel Morphology = 5.7%. In general, this suggests that it is “instream” features that are missing, as opposed to adjacent terrestrial features. In particular, this analysis suggests that Substrate and Channel Morphology are the aspects most problematic among the habitat components. There was no gravel or rock material in the stream. Observers noted sand, silt, clay, and muck as the substrate types present in the reach, with the first two listed being dominant. Among the “Channel Morphology” component, six of the seven metrics scored very poorly, which, along with the dominant small particle substrate, essentially says that habitat is very homogeneous. Such conditions do not support diverse biological communities.

Connectivity

The culvert at the CR-10 crossing was assessed by DNR for fish passability. The culvert is undersized relative to the channel width, and flow velocity was quite fast within the culvert. A large scour pool below the culvert is additional evidence of fast moving water exiting culvert (Photo 20). In addition to the culvert being undersized, it has a higher gradient than the stream, exacerbating the effects of the constriction and increasing velocity in the culvert. This culvert is a migration barrier to smaller fish species, and at higher flow volumes, most species are probably prohibited from making it through the culvert.

Photo 20. View of the CSAH-10 culvert from downstream, at the downstream end of the scour pool.

Hydrology

Figure 30 shows the alterations done to the channel system in this subwatershed. Much channel length was added to the subwatershed by trenching through peatlands decades ago in attempt to drain land for farming. The original channel (Figure 38) was determined by LiDAR map analysis. The channel did not extend upstream into much of the wetland area. The added trenches now convey much water that originally would have seeped slowly from the peatlands. This has increased peak flows above those that created the original channel. In addition, most of the original channel was straightened. Increased flow volumes and increased gradient leads to greater sheer stress on the streambed and banks, causing channel incision and bank erosion. See also the discussion of peatland drainage in the "Hydrology" section on pages 23-24.

Geomorphology

Channel geomorphology has been greatly altered in this subwatershed as described in the preceding Hydrology paragraph, as well as shown in Figure 38 above. In addition to the hydrological effects on the channel, the original ditching likely created an incised channel that would be unstable. Stream features can currently be seen that show that flow volumes above the bankfull flow volume do not have access to the floodplain except in extreme events (Photo 21). Thus, high flow volumes scour the bed and banks and create unstable habitat by moving objects and substrate substantially. The loss of sinuosity by the channel straightening is also a known factor that reduces habitat complexity.

The DNR staff did a thorough assessment of channel conditions in the AUID, a short ways downstream from the biological monitoring site, just east of CSAH-10, where the channel has not been altered by excavation/re-routing.

Photo 21. A depositional feature on the right side of the stream shows the bankfull elevation (yellow line) is substantially lower than the height of the stream banks and original floodplain elevation (arrow).

Rosgen Assessment

From DNR (unpublished communication, 2018a): "A 700' reach of the stream was surveyed, just downstream of CSAH-10/Great River Road. Upstream of the road crossing, the stream is confined to a relatively straight ditch. Downstream of the highway, the stream follows a natural meander pattern, without being confined within its valley. The stream is an E5 stream type, meaning it is relatively narrow and deep composed primarily of sand. It is likely impacted by backwatering from the Mississippi river below CSAH-10.

The surveyed reach is unstable due to the incision and altered hydrology caused by ditching throughout the system. While the reach does have some deeper pools and undercut banks, it lacks diverse habitat, such as woody debris, in-channel vegetation, and habitat niches provided by large substrate. In addition, the predominance of fine particles that become mobile at higher flows likely affect fish reproductive success and habitat availability. Lastly, the culvert under the Great River Rd is improperly aligned and at a very steep gradient. It acts as a total fish barrier due to the velocity, depth, and a lack of sediment in the culvert.

The system is ditched for the majority of its length and ditching in the headwaters connects to adjacent watersheds. Once again, there is a large discrepancy between drainage area calculations. Looking at the regional curve, the higher drainage area matched the expected cross-sectional area with bankfull indicators we saw on site. The altered hydrology likely increased peak flows, causing the stream to down cut and widen, leading to incision. The surveyed reach ranges from slight to moderate incision, but is only slightly entrenched so it still accesses its floodplain in small to medium floods.

The surveyed reach, starting at the transition from a straight ditch to a more naturally meandering channel had decreasing bank height ratios moving downstream. The width to depth ratio also gets smaller moving downstream, a second sign that this reach is re-stabilizing. While the banks appear raw in spots, further inspection showed that the loose material was actually deposition along the banks and on bars. In over wide stretches, the stream is actively rebuilding its floodplain and narrowing the active channel. It is likely the channel is in the late stages of stream succession and is either transitioning back to a stable E from either an over wide E or C channel."

Pfankuch Assessment

"The Pfankuch score was 98, a poor (unstable) rating for an E5 stream. It was close to a fair (moderately unstable) score, which is 97. The upper and lower banks mostly scored fair to excellent while the channel bottom scored mostly poor to good. The small particles composing the channel bottom and banks heavily affected the score."

Conclusions

Almost all of AUID-756 is excavated channel, with numerous ditches feeding into it from upstream. These upstream ditches run through peatland where there were not stream channels prior to the digging of the ditches. These ditches enhance the draining of the peatlands, influencing the chemistry and habitat of AUID-756. Low DO concentrations were found at the biological monitoring site, and there was a signature of the influence of low DO in both the fish and macroinvertebrate communities. The excess water draining from the peatlands is low in DO, and reduces the DO levels in the AUID channel. The channel of most of the AUID also has poor geomorphological characteristics due to the creation of a channel that is incised into the landscape and not in connection with its floodplain. The constrained channel and excess water draining from the upstream peatlands scours the channel, resulting in poor habitat features and an inhospitable environment for aquatic organisms. An additional stressor is the culvert at CSAH-10, which is inadequately sized, perched, and set at too high a slope, making it a barrier to fish migration into the channel from refuge areas in the adjoining Mississippi River.

Recommendations

The landscape and stressors of AUID-756 are essentially the same as for the adjacent subwatershed, Pokegama Creek, with the additional migration barrier at CSAH-10. Thus, improving the biological communities of AUID-756 would involve the same recommendations that were presented for Pokegama Creek, AUID-733 (i.e., disconnecting/pulling/filling upstream wetland ditches), and the design and installation of a passable culvert under CSAH-10. Guidance for culvert installation that allows fish passage can be found in a MNDOT (2013) publication. The incised nature of the channel upstream of CSAH-10 may require additional work to raise the channel bed to reconnect high flows with the floodplain to dissipate the high energy during those periods. Such work would require guidance by stream restoration professionals.

Other stream investigations

Split Hand Creek **(AUID 07010103-574)**

Reason: AUID-574 is about four miles long, starting as the outlet of Little Split Hand Lake. There was one biological monitoring site (15UM047) on the AUID, about half way between Little Split Hand Lake and the mouth at the Mississippi River. Overall, the biological communities passed the IBI thresholds, and this reach was not assessed as impaired for aquatic life, but there are some signs of channel instability and habitat measures that suggest this stream is likely not achieving its biological potential.

Field assessments of channel condition

The DNR Watershed Specialists conducted Rosgen classification protocols and Pfankuch assessment at 15UM047 in 2016.

Rosgen measurements

The stream at this location is an E5 channel type. There is evidence that the stream is aggrading (accumulating excess sediment on the channel bottom) and eroding a wider channel. Trees have toppled into the channel as their root structure has been undermined by erosion. Additional bank instability/erosion was observed, caused by cattle trampling, grazing of near channel vegetation, and change in riparian vegetation type. Some pools were about the same depth as riffles, suggesting they have been filled in by fine, eroded sediments (a negative change for fish habitat).

Pfankuch assessment

Split Hand Creek scored 117, an unstable rating for an E5 stream type (also unstable for C5 and moderately unstable for F5). The rating is largely influenced by the lower banks and channel bottom, which contribute 100 to the cumulative score, while the upper banks only add 18 and are rated as good. The upper banks score well due to the low slope gradients, low mass erosion potential, low debris jam potential, and fairly robust vegetation composed of trees intermixed with grassy spaces. This suggests that the upper banks are not contributing significant sediment to the stream except where they are undermined by the lower banks, where runoff from outside the riparian buffer zone enters the stream, or in upstream reaches with different conditions. Upstream imagery shows there are areas present next to the stream with little or no riparian buffer that could be sediment sources.

Ratings for the lower banks range from good to poor, contributing 44 to the cumulative score. Within the lower banks, there were abundant obstructions causing bank cutting and pool filling, some spots with cuts of 12-24 inches high. The worst contributing factors are the small particle sizes (predominantly sand and small gravels) and the deposition of sand and silt particles on channel and point bars. Due to the dominance of sand particles, the channel bottom is not able to maintain a stable form and is in flux yearlong. There is minimal aquatic vegetation present, and overall the channel bottom rated as poor, contributing 55 to the cumulative score.

Conclusions

Stream channel instability was found through geomorphological assessments. The increase of channel width/depth ratio is a very well documented consequence of cattle trampling of stream banks (Kauffman and Krueger, 1984). Streams flowing through areas of sandy surficial geology are also more sensitive to alterations of hydrology. This part of the MRGRW has relatively greater amounts of agriculture (pasture, hayfields, and row crops), and thus the hydrology (runoff amounts, precipitation infiltration, peak flow volumes) has changed from what it was originally, a heavily forested land cover.

Recommendations

Restoring native riparian vegetation and fencing cattle out of the immediate riparian area along the stream would be very helpful in improving channel stability and physical integrity. Such actions would improve habitat complexity and stability, which in turn would improve the health and diversity of the fish and macroinvertebrate communities. The problem of bacterial impairment would be largely solved with these actions as well. Farming methods that improve infiltration rates on farm fields (e.g., increasing soil organic material) would also benefit the stream by reducing peak flow volumes (which reduces erosive forces within the stream channel).

Bacterial Impairments

Additional sampling was conducted in several streams that were assessed as impaired for recreation due to *E. coli* levels above the state standard. The sampling was done in a longitudinal fashion at several locations along each river, to help in the source assessment and TMDL process.

Hasty Brook (AUID 07010103-603)

Reason: The brook was assessed in 2017 as impaired for recreation, due to exceedance of the *E. coli* bacteria standard.

Additional monitoring

Additional bacteria samples were collected in late summer/early fall 2017, in an attempt to locate possible sources of bacteria to the brook. Samples were collected longitudinally along Hasty Brook, all on the same day, in order to compare relative bacterial concentrations in various locations, which may suggest a source area. The originally sampled location at Ylen Road, near the mouth of Hasty Brook at Prairie Lake, was sampled, as were four new sites upstream (Figure 34). Some of the upper parts of the Hasty Brook subwatershed are very remote with very difficult access, so accessible sites were somewhat limited, but enough crossings were found to provide a good spread within the part of the watershed that has development.

Flow conditions were quite different on the two sample dates of September 2017. Sampling different flow conditions was intentional. The samples on September 6 were during base flow conditions, during a period without substantial rainfall. The samples on September 27 were collected the day after a 3-day period of rain, totaling an estimated one inch of rain (on soils that were already relatively damp). The stream was running quite high on September 27.

There were substantial differences among sites in the September 6 results (Table 79). Some of the sites most closely associated with human activity had the lowest bacteria concentrations, while the highest concentration came from a headwaters tributary that has no development, and comes through a wet meadow that has some beaver activity. The increase in *E. coli* between the two sites on Prairie Lake Road (from 20 upstream to 110 MPN/100mL downstream) may be due to the small tributary that enters Hasty Brook between those two sites. That tributary arises from a large bog/fen, and has a large beaver impoundment on it, a short distance upstream from where it enters Hasty Brook. Though there is a feedlot near the site measuring 110 MPN/100mL for *E. coli*, the sample was taken upstream (west side of road) of where any runoff from the farm would enter Hasty Brook. The other feedlots in the Hasty Brook subwatershed are quite a distance from the stream channel and have lesser ability to contribute runoff to the stream.

The results from the September 27 sampling showed a narrower range of values among sites. The upstream-most site again had the highest bacterial count, but by less of a margin that on Sept. 6. The three middle sites were nearly identical to each other in bacterial counts. At this second sampling, the Ylen Road site was higher than the Prairie Lake Road (North) site. A pasture near the stream lies between these two sites, and the higher counts after this rain event may reflect bacteria moving to the stream via surface runoff. There was no clear source found via the additional monitoring in 2017. The highest concentrations each time were at the uppermost site, which had no influence from animal farming, nor human residences.

Figure 39. Hasty Brook, with *E. coli* sample sites and feedlot locations. Flow direction is from lower right to upper left, where Hasty Brook enters Prairie Lake. Site 1 = Ylen Rd., Site 2 = Prairie Lake Rd. N, Site 3 = Prairie Lake Rd. S, Site 4 = State Hwy 73, Site 5 = Forest Rd. 388.

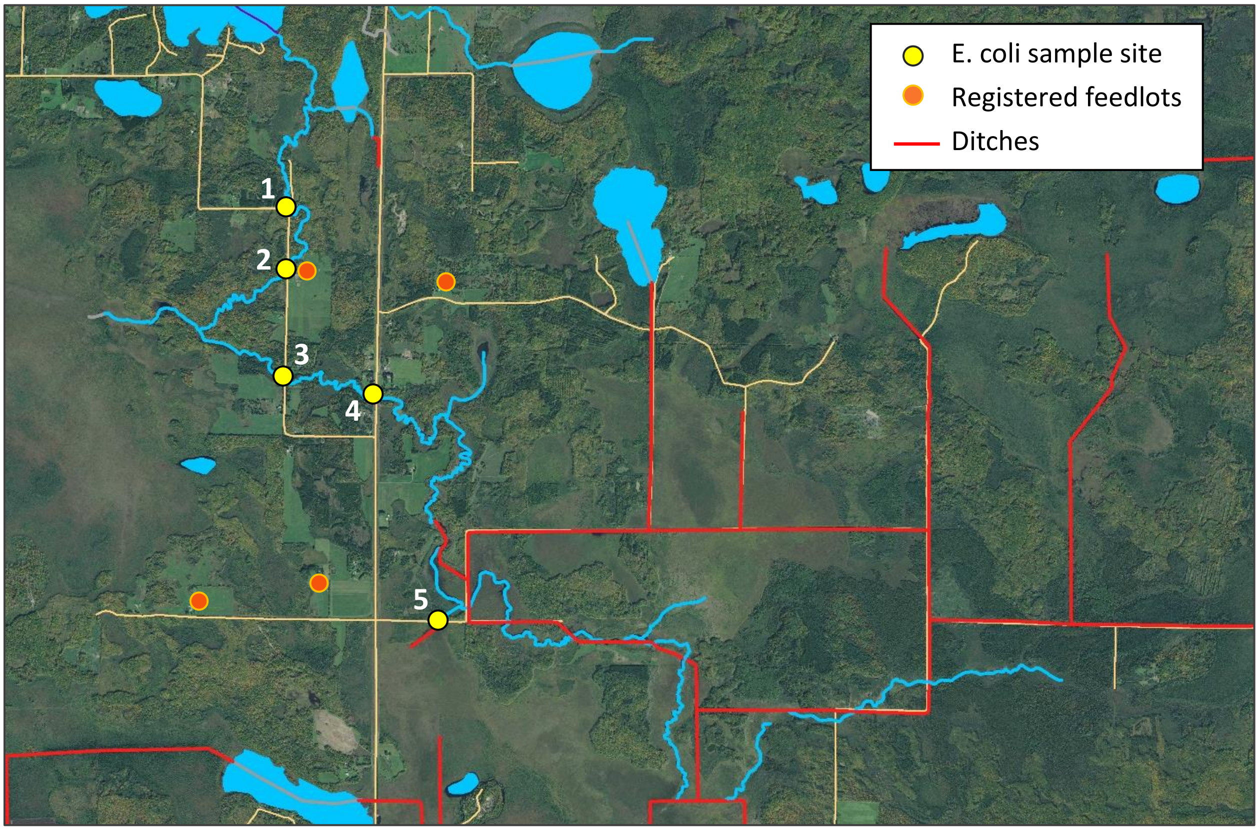


Figure 40. Hasty Brook, with *E. coli* sample sites and feedlot locations. Flow direction is from lower right to Table 79. Results of bacteria sampling (MPN/100ml) in the Hasty Brook subwatershed in 2017. Sites move upstream going from left to right in the table.

Date	Ylen Rd (1)	Prairie Lake Rd-North (2)	Prairie Lake Rd-South (3)	St Hwy 73 (4)	FR-388 (5)
September 6	52	110	20	20	200
September 27	120	75	73	75	130

Prairie River (AUID 07010103-760)

Reason: The river was assessed in 2017 as impaired for recreation, due to exceedance of the *E. coli* bacteria standard at Clearwater Road (S008-478).

Additional monitoring

Additional bacteria samples (*E. coli*) were collected on June 19, 2018 in an attempt to locate possible sources of bacteria to the river. Sampling included a site on Sucker Brook, a tributary of the Prairie River, that enters not far upstream of where the bacterial impairment was found. Three locations in all were sampled, and are labeled as 1, 2, and 3 in Figure 40. Site 1 (S008-478) is the original site where the IWM 2-year bacteria monitoring was conducted; the Clearwater Road crossing. Site 2 (S007-944) is at the crossing of CSAH-7, and just downstream of where Sucker Brook enters. Site 3 (S013 -323) is on Sucker Brook at the crossing of CR-336. A significant rainfall occurred a few days before the 2018 sample, and water levels in the streams were relatively high, but dropping. Waters were tannin-stained but clear.

None of the sites had *E. coli* levels that are standard-exceeding (Table 80). The Prairie River sites had identical results, and were lower than the count from Sucker Brook. This is an interesting finding, given that Sucker Brook drains a landscape with very little human activity, while there is a fair amount of human activity near the Prairie River in the areas sampled. Additional monitoring at various flow levels may add more insight into sources of bacteria.

Figure 41. The 2018 samples sites for *E. coli* on the Prairie River and its tributary Sucker Brook. Arrows show flow direction. There are no registered feedlots within the pictured area.

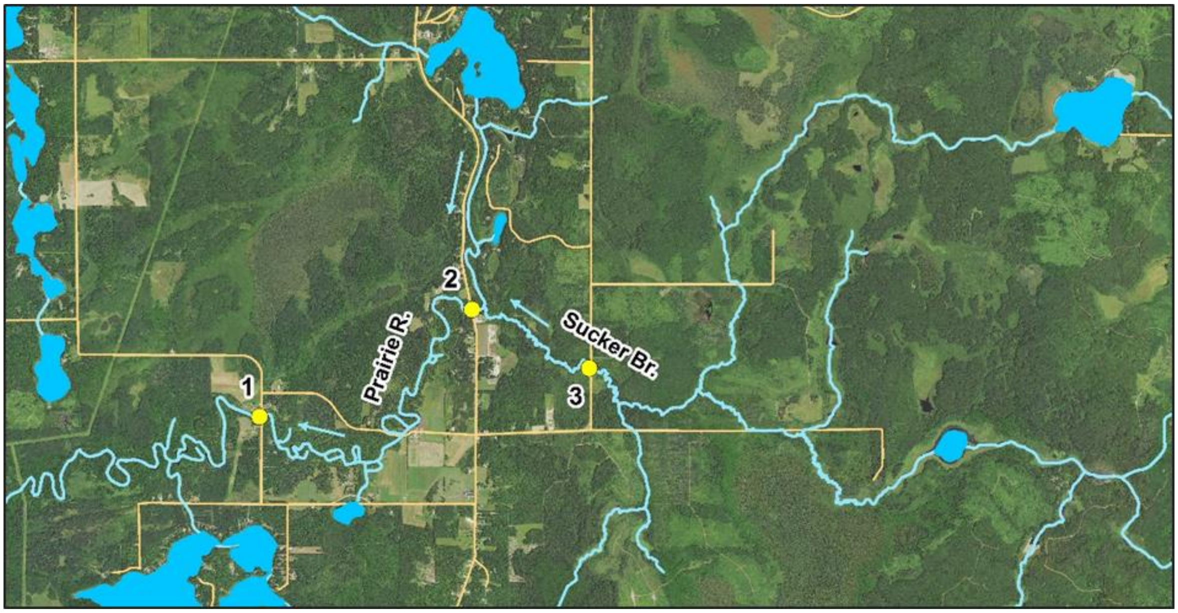


Table 80. *E. coli* results for Prairie River follow-up monitoring. Sites correspond to labels in Figure 35. Result units are MPN/100 mL.

Date	Site 1 (Prairie R.)	Site 2 (Prairie R.)	Site 3 (Sucker Br.)
June 19, 2018	41	41	73

Swan River (AUID 07010103-754)

Reason: The river was assessed in 2017 as impaired for recreation, due to exceedance of the *E. coli* bacteria standard at CSAH-10 (S000-936).

Additional monitoring

Additional bacteria samples (*E. coli*) were collected on June 12, 2018 in an attempt to locate possible sources of bacteria to the river. Sampling included the site where the bacterial impairment was found, at CSAH-10 (S000-936), and a site one mile north (upstream), at CSAH-70 (S003-666), labeled as 1 and 2 respectively in Figure 41. At the time of sampling, water levels were somewhat high, but not turbid, though some larger particulate organic material was seen in the water column. The Bovey-Coleraine WWTP effluent discharge point is at the CSAH-70 Bridge at point 2. The sample taken there was collected about 15m upstream of the effluent outlet.

Neither of the sites had *E. coli* levels that are standard-exceeding (Table 81), though they differed substantially, with site 1 (the IWM monitoring site downstream of site 2) having more *E. coli*. The Bovey-Coleraine WWTP effluent discharge point, some fields, and several houses are all located in between the sampled sites, though it is not known whether any of these are a reason for the increased *E. coli* at site 1 relative to site 2.

Figure 42. The 2018 samples sites for *E. coli* on the Swan River. Arrow shows flow direction. There are no registered feedlots within the pictured area.

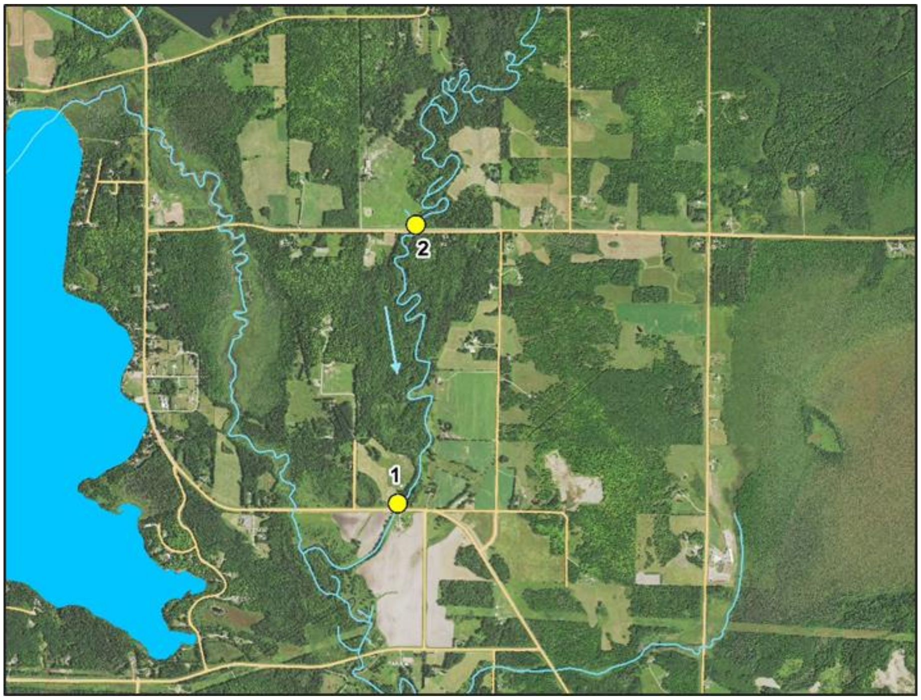


Table 81. *E. coli* results for Swan River follow-up monitoring. Sites correspond to labels in Figure 41. Result units are MPN/100 mL.

Date	Site 1 (S000-936)	Site 2 (S003-666)
June 12, 2018	63	10

Study of tributaries of nutrient-impaired lakes

Reason for study: In order to better understand phosphorus dynamics in some MRGRW lakes, a tributary to each of three nutrient-impaired lakes (Horseshoe L., Big Sandy L., and Split Hand L.) were monitored for TP, OP, total iron, and DOC, as well as temperature, DO, DO % saturation, and conductivity (Figure 42). All of these parameters have potential to provide insight into phosphorus dynamics on the landscape that contribute to the lakes via their tributaries. Flow monitoring gaging stations were set up at the three sites so that loads of phosphorus entering the lake from these tributaries could be determined. This information is intended to aid in the TMDL studies for these impaired lakes. A summary of the water chemistry results is presented in Table 82.

Figure 43. Tributary subwatersheds that were monitored for phosphorus input into nutrient-impaired lakes. The top is Tributary to Split Hand Lake, the middle is Vanduse Creek, a tributary to Big Sandy Lake, and the lower is Musselshell Creek, tributary to Horseshoe Lake.

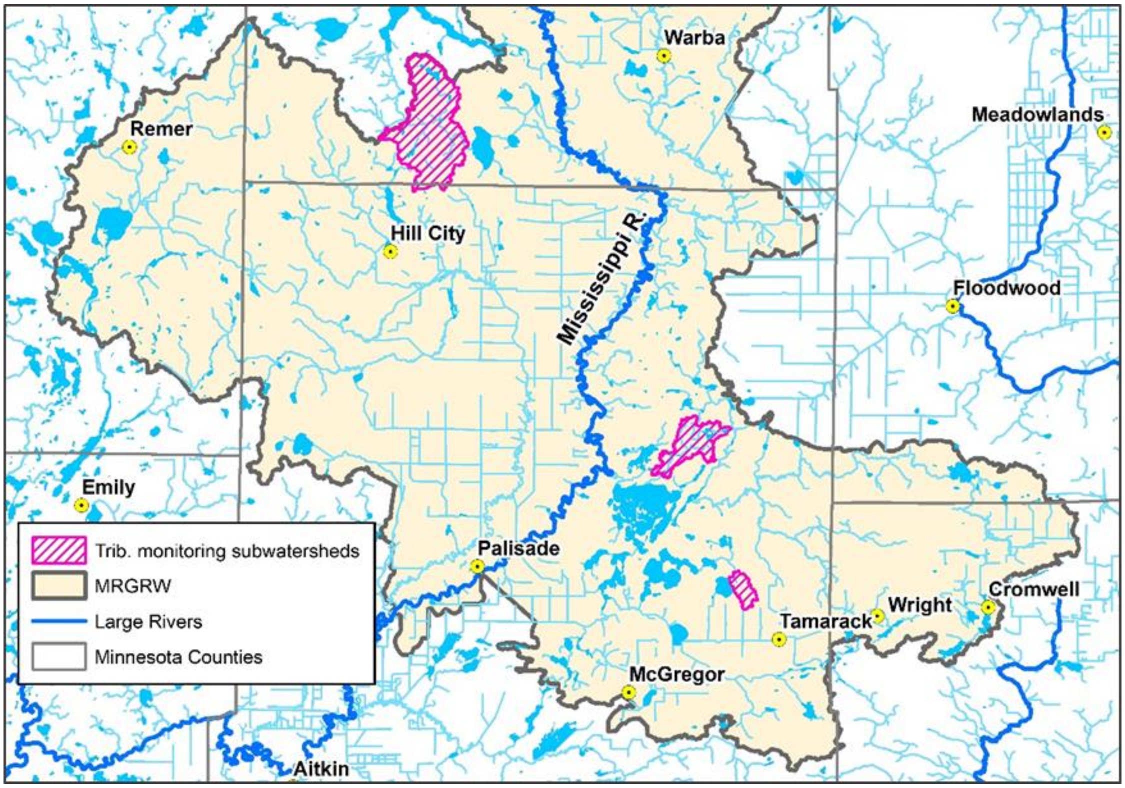


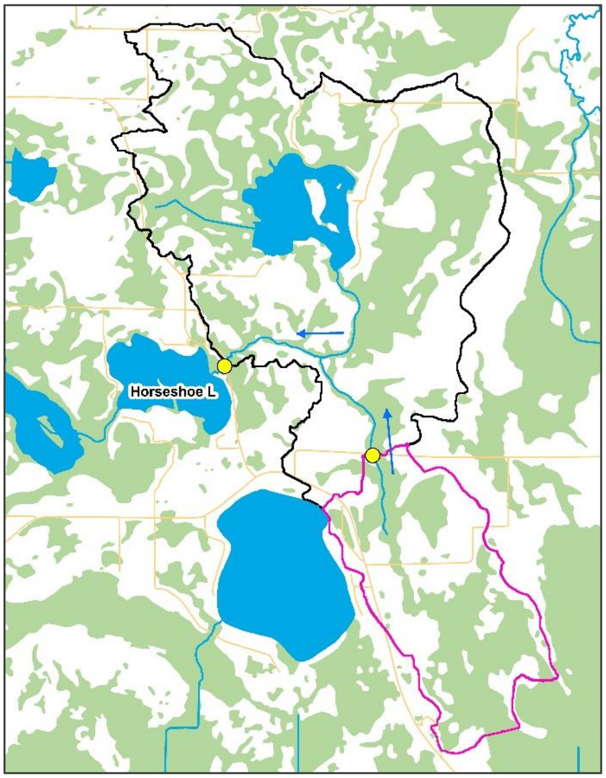
Table 82. Chemistry sample results for impaired lake tributary monitoring, primarily 2017 and 2018 samples. Numbers in each column are number of samples (n), minimum, maximum, and average. Monitoring may continue after completion of this report.

Tributary	TP (mg/L)				Iron (µg/L)				DO (mg/L)			
	n	Min	Max	Avg	n	Min	Max	Avg	n	Min	Max	Avg
Musselshell Cr.	21	0.008	0.110	0.052	21	442	18500	5616	16	0.19	5.82	2.60
Musselshell Cr. at Hrsh. Lake	14	0.028	0.069	0.052	2	1220	4990	3105	--	--	--	--
Vanduse Cr.	15	0.025	0.145	0.058	15	741	2730	1693	12	2.26	7.77	4.16
Tributary to Split Hand Lake	19	0.024	0.063	0.038	19	411	1060	667	13	4.91	9.52	7.04

Musselshell Creek (tributary to Horseshoe Lake)

Musselshell Creek was sampled at CSAH-32 (S008-505). This site takes in only part of the tributary that enters Horseshoe Lake (Figure 43). A crossing very close to the lake (on CSAH-40) was examined but determined to be an improper site to place a gaging station due to possible backup from the lake. Musselshell Creek is strongly hydrologically connected to peatlands.

Figure 44. Sample sites for landscape input of TP via stream to Horseshoe Lake. The principal site on CSAH-32 drains from the pink-bounded area. The site just before Horseshoe Lake on CR-40 drains from both the pink and black-bounded areas. Arrows show flow direction.



Musselshell Creek had a very strong seasonal pattern regarding phosphorus, with peak concentrations occurring at about the first week of August for TP, and mid-August for OP (Figure 44). There was no seasonal pattern in the ratio of OP/TP (Figure 45). This ratio ranged from 14.3 - 37.6 percent. Musselshell Cr. at S009-505 had very high levels of total iron in the summer, and its seasonal pattern was very similar to TP. The correlation of TP and total iron was very strong statistically (Figure 46). It was visually obvious that iron concentrations were high, as the water had an opaque orange coloration in mid-summer, and much iron floc coated aquatic vegetation and the streambed (Photo 22).

DO levels in the stream are highly suggestive of redox-controlled phosphorus and iron concentrations, as DO plunges to less than 1 mg/L in late July (Figure 47), signaling an anoxic condition in the contributing wetlands.

Figure 45. Phosphorus data for Musselshell Creek, a tributary to Horseshoe Lake, 2017 - 2018. TP and OP were sampled at the upstream site, S009-505, while only TP was collected at the site near Horseshoe Lake, S003-319. The curved lines are polynomial regression lines; R^2 values for the S009-505 site were 0.8233 for TP, and 0.8088 for OP. The red line is Minnesota's River Eutrophication TP standard.

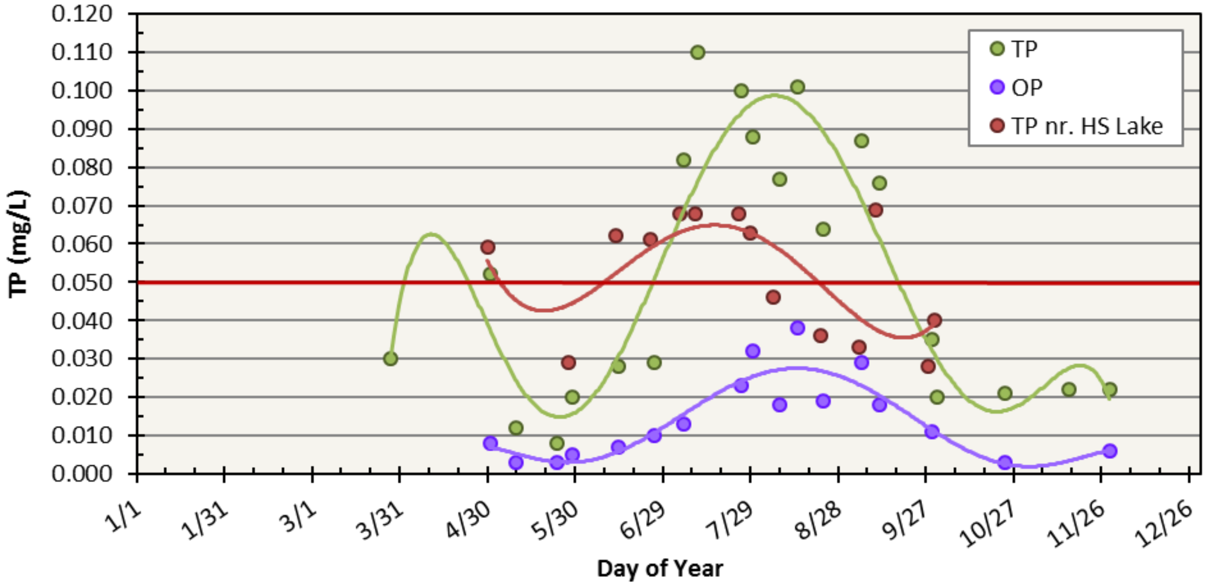


Figure 46. Ratio of OP/TP in Musselshell Creek at S009-505.

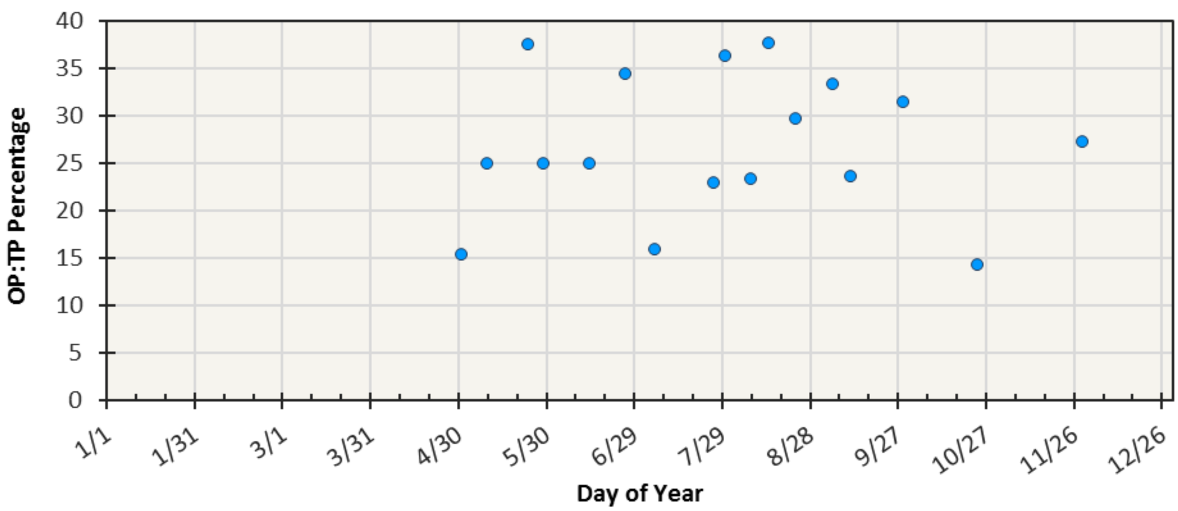


Figure 47. Correlation of TP with Total Iron in Musselshell Cr. at S009-505. The linear regression line has R^2 of 0.8434, while the power regression line (dotted) has R^2 of 0.8669.

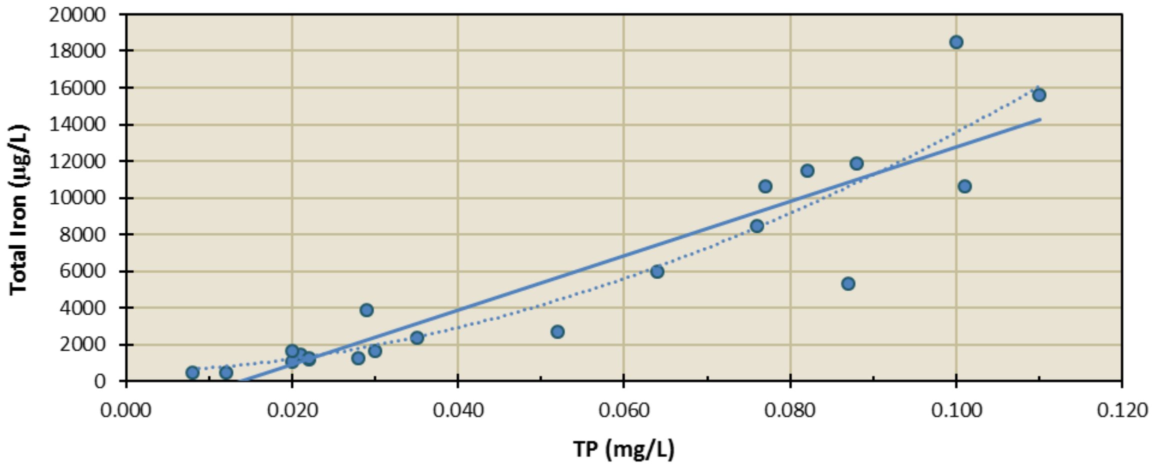
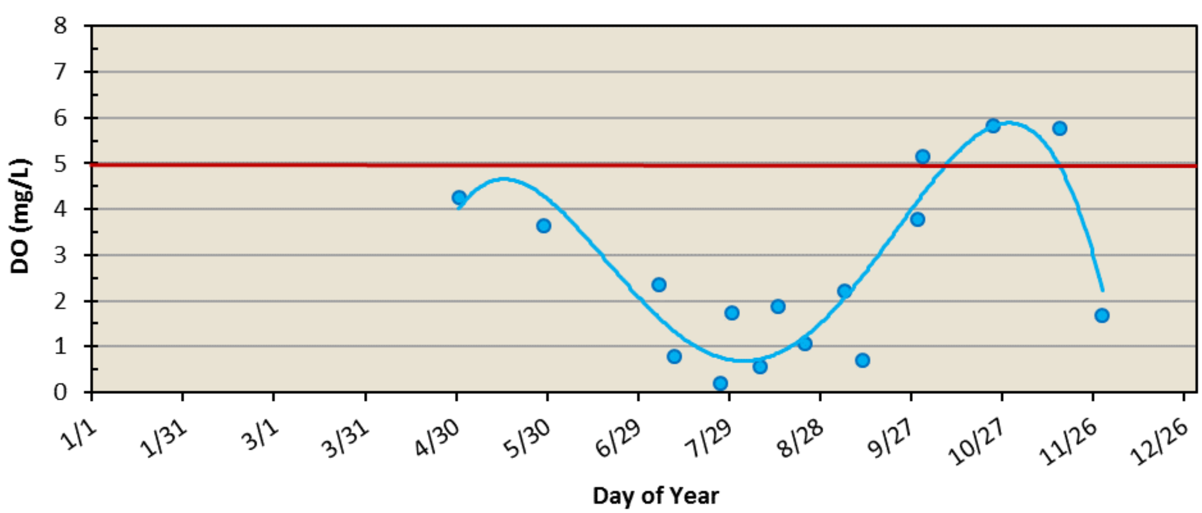


Photo 22. Musselshell Creek at S009-505 on August 6, 2018 showing the iron floc covering all stream surfaces.

Figure 48. Seasonal pattern of DO in Musselshell Cr. at S009-505. The polynomial regression line has R^2 of 0.8309. The red line is the DO standard.



Vanduse Creek (tributary to Big Sandy Lake)

Vanduse Creek had parameter values that were generally intermediate among the three sites. The exception was for TP, which had a slightly higher average, though this was influenced by one particularly high measurement (0.145 µg/L; Figure 48), which was the highest of any measurement among the three streams. There were moderately good relationships of iron with season and TP (Figures 49 and 50). Vanduse occasionally had periods where there was no or imperceptible flow. There was always water in the channel, but sometimes, no movement could be seen. Samples were not collected on dates with no perceptible flow, so there are somewhat fewer data points for Vanduse Creek.

Figure 49. TP and OP data for Vanduse Cr., 2017 - 2018 at S014-886. The curved lines are polynomial regression lines; R^2 values were 0.4850 for TP, and 0.2264 for OP. The red line is Minnesota's River Eutrophication TP standard.

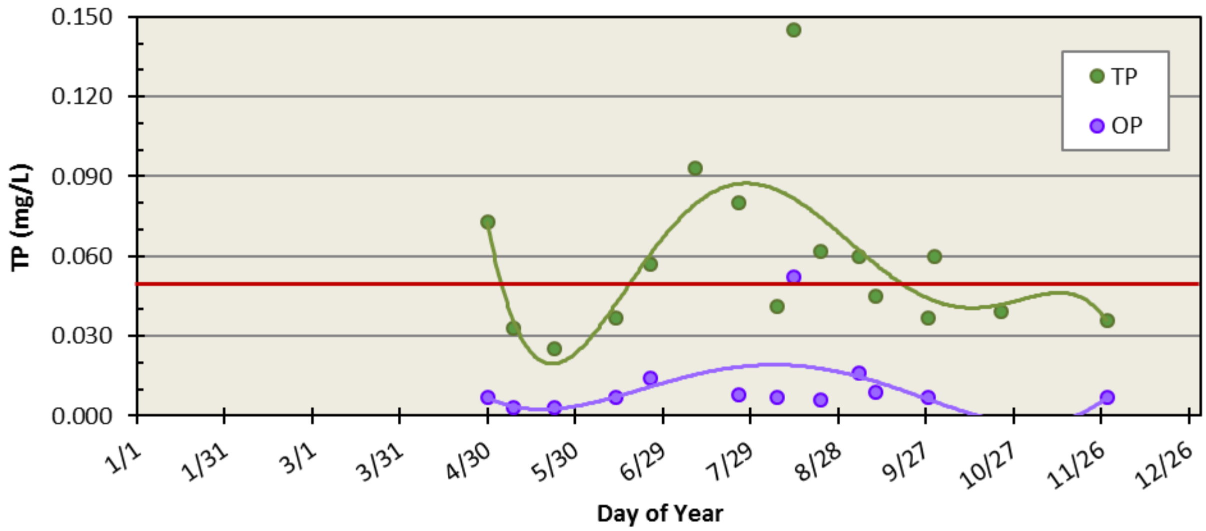


Figure 50. Seasonal pattern of Total Iron in Vanduse Cr. at S014-886 in 2017-2018. The polynomial regression line has R^2 of 0.4315.

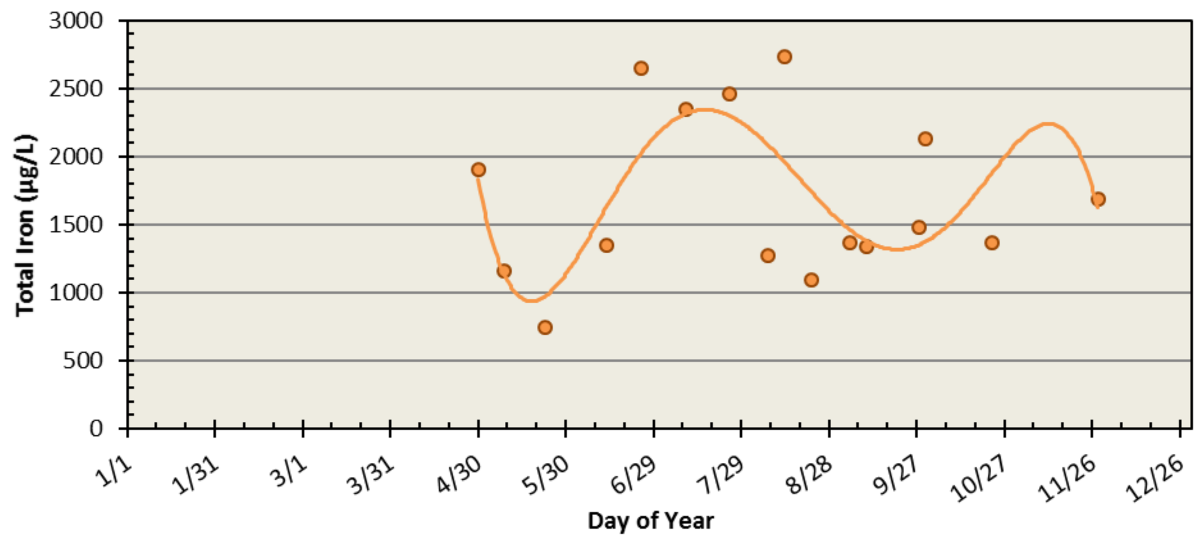
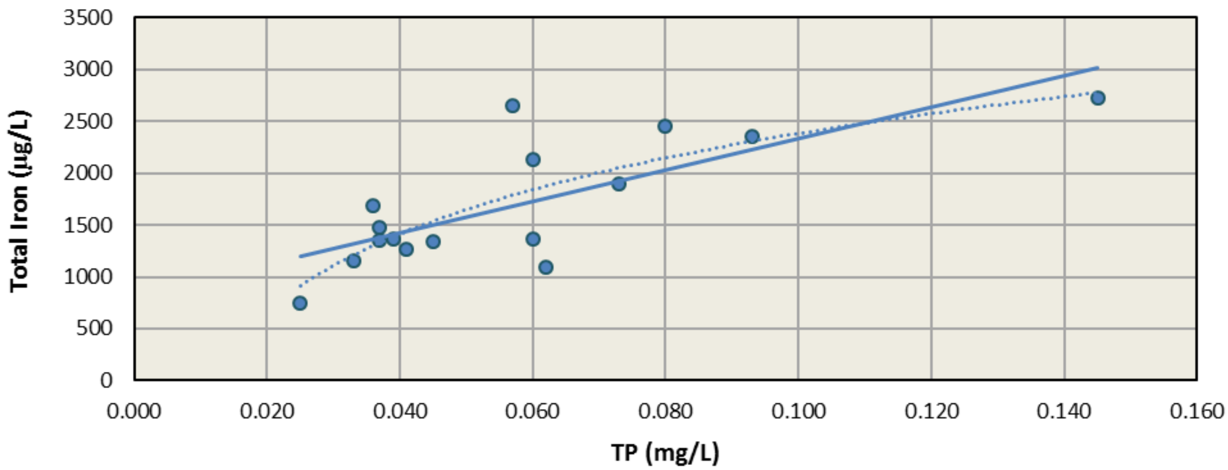


Figure 51. Correlation of TP with Total Iron in Vanduse Cr. at S014-886 in 2017-2018. The linear regression line has R^2 of 0.5688, while the logarithmic regression line (dotted) has R^2 of 0.6223.



Tributary to Split Hand Lake

Tributary to Split Hand Lake (TSHL) had the lowest average TP and OP concentrations among the three study streams. Peak TP values occurred earlier in the summer (early July) than they did at Musselshell Creek (Figure 51). Unlike in Musselshell Creek, TSHL does show a good trend of OP/TP seasonally (Figure 52). The average total iron concentration was least among the three study streams, and had a seasonal pattern that tracked TP fairly closely (compare Figure 44 and 48).

Figure 52. TP and OP data for TSHL, 2017 - 2018 at S009-506. The curved lines are polynomial regression lines; R^2 values were 0.4310 for TP, and 0.6523 for OP. The red line is Minnesota's River Eutrophication TP standard.

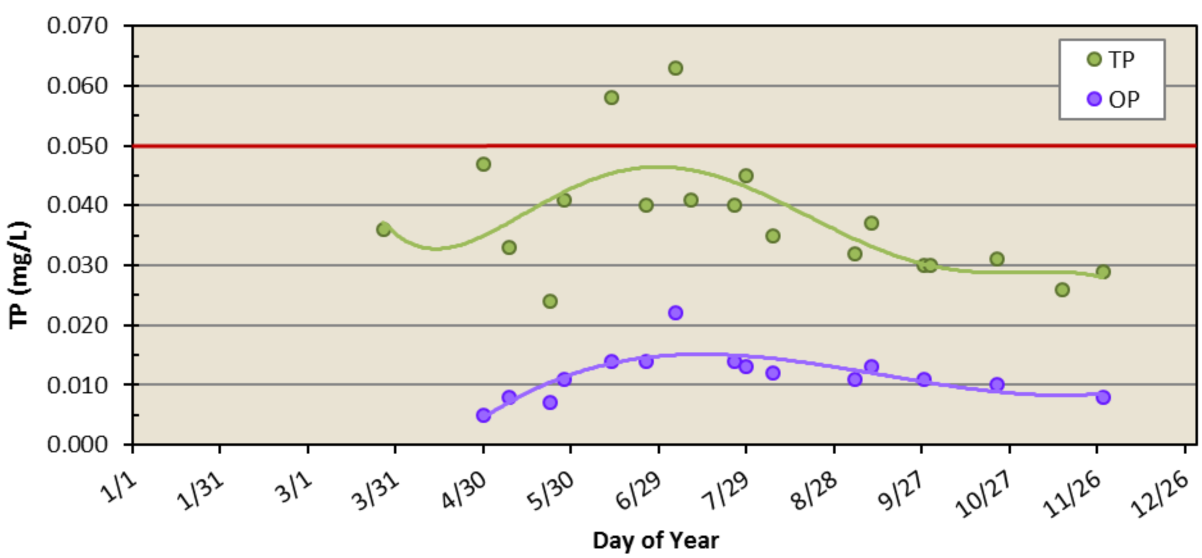


Figure 53. Ratio of OP/TP in TSHL at S009-506, with polynomial regression line having R^2 of 0.7391.

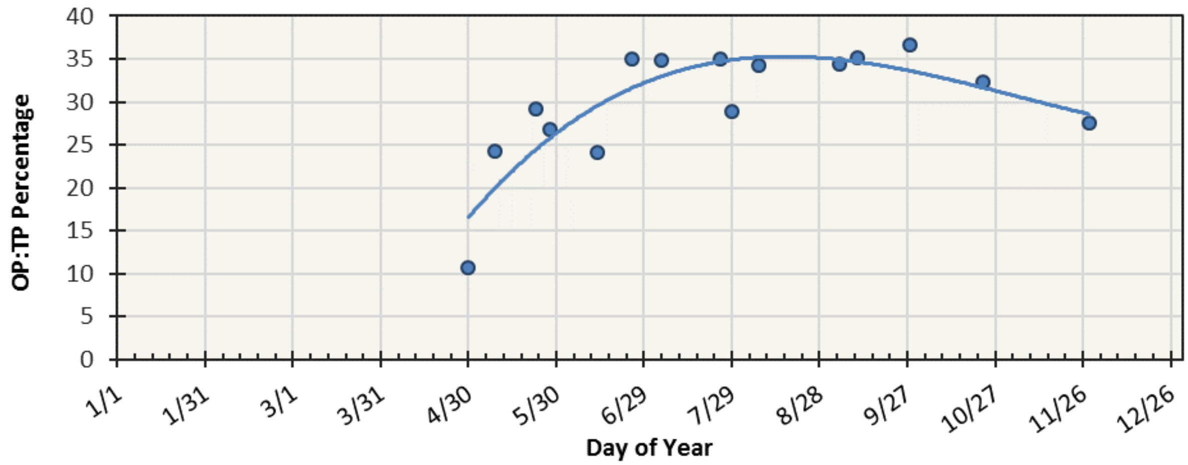


Figure 54. Seasonal pattern of Total Iron in TSHL at S009-506. The polynomial regression line has R^2 of 0.2912.

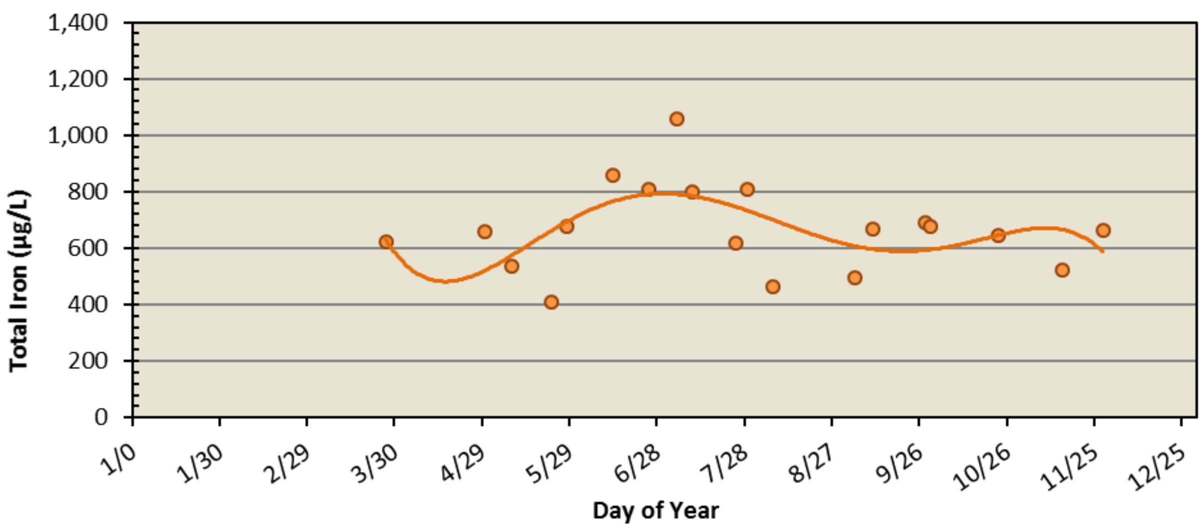
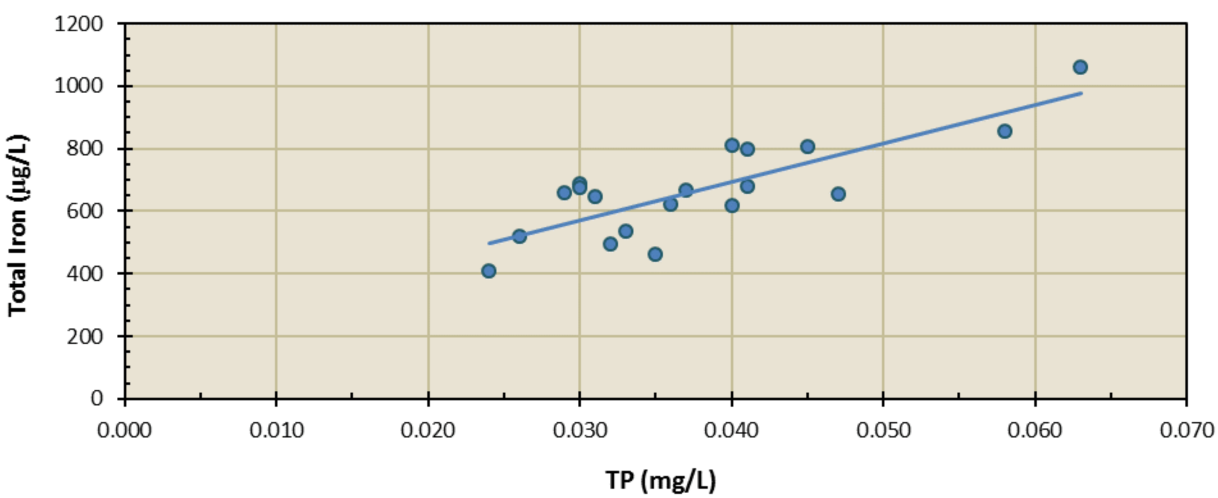


Figure 55. Correlation of TP with Total Iron in TSHL at S009-506. The regression line has R^2 of 0.6554.



Discussion on the chemistry of the three lake tributaries

The levels of TP, Total Iron, DO, and DOC were notably different among the three streams. Statistical testing was done to determine if differences can be considered so with high confidence. TP was not statistically different among the three sites using $p \leq 0.05$, probably owing to the wide seasonal range of TP in Musselshell Creek. However total iron, DOC, and DO can be considered different with extremely high statistical confidence ($p < 0.001$, $p = 0.002$, $p < 0.001$, respectively). In addition, the type of wetlands in each of the three watersheds were notably different. The types of wetlands contributing water to the streams is likely a big factor in the differences of the values of these parameters.

Table 83. Comparison of landscape and water chemistry among the three lake tributary sites.

	Average Concentration, mg/L (# samples)					
Stream	**TP**	**DO**	**Total Iron***	**DOC**	**Predominant Wetland Type**	**TP vs Iron (R^2)**
Musselshell Cr.	0.052 (21)	2.6 (16)	5616 (21)	29.6 (21)	Herbaceous peatland	0.8434
Vanduse Cr.	0.058 (16)	4.2 (12)	1692 (16)	25.6 (16)	Herb. and open water wetlands	0.5688
Trib. to S.H. Lake	0.038 (19)	7.0 (13)	667 (19)	18.9 (18)	Ash-forested	0.6554

*µg/L

Musselshell Creek's phosphorus concentrations were highly redox-driven. Evidence of this is seen in the very low DO levels and the simultaneous peaks of TP and total iron, high correlation of TP and Iron, and dramatic changes of these two parameters across the annual seasons. There was no relationship between time of year and OP: TP concentration ratio. Iron from groundwater precipitates in the peat during toxic times of the year (and sequesters phosphorus), while the peat releases much stored iron and soluble phosphorus in the anoxic time of the year (mid-late summer). Soluble phosphorus and iron become bound again in the stream when exposed to greater oxygen levels.

Vanduse Creek TP had a similar seasonal pattern to Musselshell Creek, and also had a fairly strong correlation to total iron concentrations, suggesting that landscape redox conditions were again controlling of TP levels in the stream. TP and total iron were fairly high in Vanduse samples, but lower than Musselshell Creek's levels. A difference in the landscape for Vanduse is that along its flow path are three very small lakes that it passes through, and these lakes may process TP and iron in ways that alter the downstream concentrations in Vanduse Creek at the sample area near Big Sandy Lake. There may also be a different amount of groundwater input to Vanduse, or the geology contains less iron than that interacting with the groundwater input to Musselshell Creek; iron is well known to influence the dynamics of phosphorus.

Tributary to Split Hand Lake had TP and total iron levels quite a bit lower than the other two streams. Peak TP and OP concentrations also occurred several weeks earlier than at the other two sites, suggesting that there were other influential TP-controlling factors in addition to redox conditions. For one, dissolved oxygen was much higher in TSHL than the other two streams, suggesting a much less anoxic condition of the landscape's soils. Redox conditions do seem to be involved however, as there was a strong correlation of TP and total iron, and these parameters varied seasonally. The wetlands present in the subwatershed contributing to flow at the sample site are also quite a bit different, with more area being forested wetland, which contains a different type and amount of organic soil (much of the source of TP) than herbaceous peatlands. Like Vanduse, the stream flows through a couple very small lakes. Notably, there was a well-defined seasonal pattern of the ratio of orthophosphorus to TP, which was lacking at the other two sites. This may be due to the limited amount of control of soluble phosphorus (OP) that iron has here due to its lesser presence.

Phosphorus levels of studied tributaries to the three nutrient impaired lakes showed that these tributaries were delivering concentrations of TP higher than the phosphorus standard for northern lakes, especially during mid or late summer. Geological conditions and wetland types are factors that appear to be influential in how much phosphorus is exported in these streams, with herbaceous peatlands contributing the highest concentrations of phosphorus. DOC concentrations followed the pattern of iron among the three streams, but not the pattern of TP (Table 83). The degree of contribution from natural landscape factors, in particular, wetlands, and their hydrologic connections with lakes was quantified in the TMDL document for the MRGRW (MPCA, 2019). The export of phosphorus from the natural landscape via streams can vary substantially within a watershed at the HUC-8 scale.

Discussion on the stressor of legacy ditching, altered hydrology, and restoration opportunities

In the early 1900's, peatlands were seen as having potential to be used as cropland, with the exception that they were far too wet. A vast amount of work was done to dig trenches through large areas of northern Minnesota's abundant peatlands in hopes of drying out the peatlands enough to grow crops. For the most part, this effort failed, and Minnesota is left with ditch systems in undeveloped lands that are source areas for a large number of streams and rivers. In some instances, ditching was also employed to expedite log drives down some of the larger streams.

The MRGRW is one of the major watersheds with a particularly high density of ditches, especially along the southern edge, and in the center of the Watershed. There are two primary scenarios of drainage ditch construction in northern Minnesota. One was the trenching of peatlands in areas where no stream channel naturally existed. The second was straightening stream channels downstream of the peatlands to speed the transport of water coming from the upstream trenched areas. Sometimes this straightening occurred by cutting a ditch through the meandering stream channel (Figure 55). Other times a straight ditch was constructed a short distance from the original channel and parallel to it within the same stream valley. In still other situations, large parts of channels that had a major bend in the valley were cut off by creating a "short cut" ditch. All three of these situations can be found in the MRGRW.

Alteration of peatland hydrology by ditching can result in numerous consequences. 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, ditched peatlands seemed to reduce the peak flows due to a lowered water table allowing for greater storage of rainwater. There are numerous variables that can influence how downstream hydrology is affected by ditching, and these factors are still being studied (Holden et al., 2004). Consequences of altered hydrology include channel instability characterized by bank erosion and streambed material alteration, leading to poor biological habitat. Channel instability was found at several streams with upstream peatland ditches in the MRGRW, and also in WRAPS projects in several other north central Minnesota watersheds. Increasing the flow from peatlands can also exacerbate flooding downstream. The ditched peatlands in the MRGRW add flow to the Mississippi River, which increases flooding to downstream areas such as the city of Aitkin.

In the case of peatland ditching, the export of water quality constituents can be altered in a negative way. Phosphorus export from organic peat soils may increase and create nutrient excesses downstream. Dissolved organic carbon export can be increased (Strack et al., 2008). Loss of carbon storage contributes to climate change. Elevated levels of TP and DOC have been found in drained peatland streams in the MRGRW.

The remedy for downstream channel instability and chemistry impacts 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 currently (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 not fully predictable since peatland hydrology and impacts of ditching are still being researched. Restoration decisions and attempts likely will involve public and local governmental participation, depending on land ownership. Ditch law may also come into play, depending on the jurisdiction of particular ditches.

In recent years, hydrology restoration projects involving ditched wetlands have begun to be completed in Minnesota, mostly in the northwest, but elsewhere too (e.g., Lawndale Creek channel restoration near Rothsay, MN - Aadland, 2012; Winter Road Peatland SNA restoration, DNR, 2015; Kingston Wetland restoration in Meeker Co., Loewen, 2015), as well as a very large project just reaching completion in northeastern Minnesota, the Sax-Zim Bog restoration (Myers, 2015). These completed projects can be used as examples for new projects. Aitkin County government has expressed interest in a peatland restoration in the Wawina area of the MRGRW and is seeking funding. Projects have also been done to re-route ditched streams back into their original channels. If this creates a local flooding concern, there are ways to put the flow back into the original channel and still use the ditch to carry excess high flow volumes. The project at Lawndale Creek is an example of such a design, as is the larger-scale Mississippi River diversion at Aitkin. Each case is unique, requiring proper considerations of local conditions to complete a successful design.

In order to assess the widespread nature and abundant quantity of ditched peatland channels in the MRGRW, an exercise was done by the author which tried to determine which ditches appear to have little to no positive benefit to private landowners, by reviewing aerial photography and looking at ditch proximity to residences, hay fields, or other non-natural land use (Figure 56). These determinations were made conservatively, and many more miles of ditch closure may be possible with no harm to landowners. **These are not official proposals to close/fill these ditches**. Each would need further assessment before any decision to do so should be made. However, this analysis does show how extensive and influential these ditches are just based on the extent of ditches with little or no positive benefit (Table 84), and likely causing negative consequences on downstream water quality and potentially to downstream landowners.

In addition to the bog hydrology restoration, there are also numerous non-wetland areas where stream/habitat restoration (i.e., returning flow back into the original stream channel) of substantial length could be achieved for ecological benefit (Figures 57 - 60). This type of project adds habitat in two ways, by providing a more diverse set of habitat features in the channel (these features, such as better depth variability, develop naturally due to sinuosity), as well as increasing stream channel length (between two points, a meandering channel is longer than a straight channel). Recommendations and guidance for stream restoration in the MRGRW is provided in the Mississippi River - Grand Rapids Watersheds WRAPS document (MPCA, 2019).

While general stream restoration protocols are well developed, the specific topic of bog hydrology restoration still lacks a full understanding. It would be of benefit to study a ditched peatland situation in the MRGRW to determine local and downstream effects of the peatland ditching in the setting of northern Minnesota. The very undeveloped Pokegama Creek subwatershed may be a great opportunity for such a study. Effects could be determined by scientifically studying those downstream areas by use of flow monitoring stations in combination with water table monitoring up in the peatlands and water chemistry parameter monitoring in both locations. Such a study, involving monitoring of pre- and postproject flow, chemistry, and physical channel characteristics would improve knowledge of how hydrology is quantitatively altered in ditched Minnesota peatlands, and how that alteration has affected habitat and water quality in and downstream of these peatlands. Better knowledge of drainage effects would benefit the management of many peatland-containing subwatersheds across the northern region of Minnesota, as similar peatland ditching is common across that area.

Figure 56. Ditch cutting off stream meanders - a location along the Hill River. The drawing at left points out the original channel (blue) and the current ditch (red).

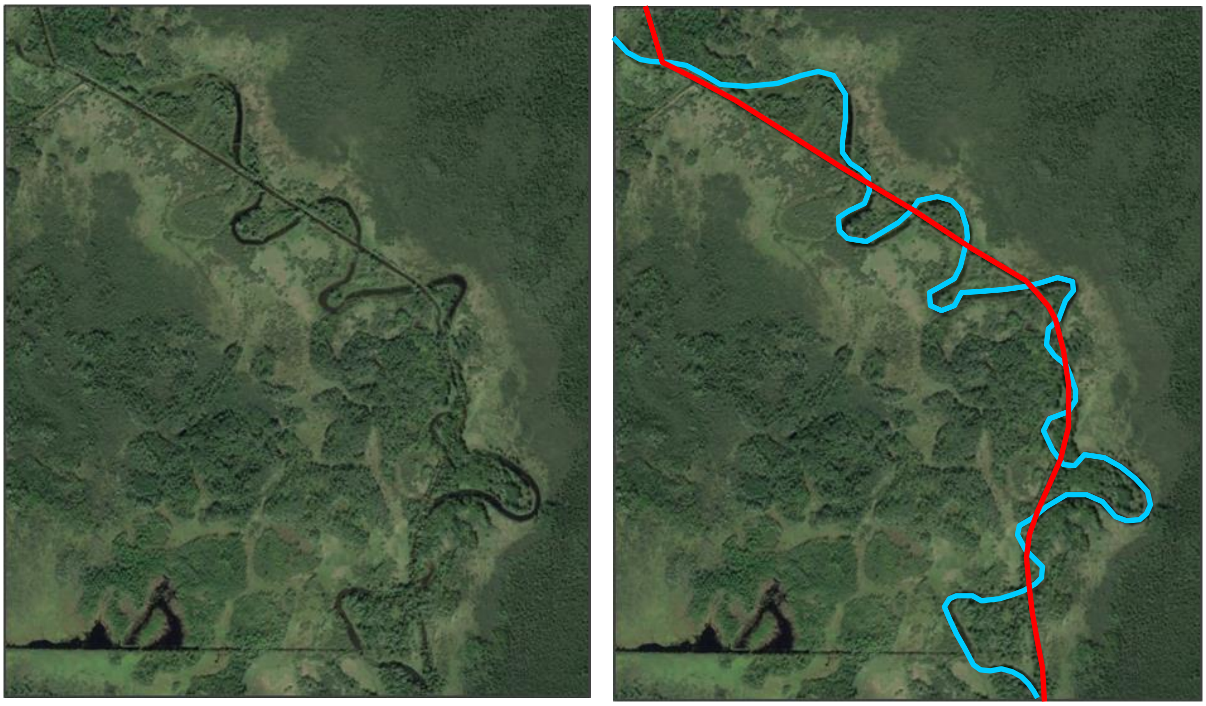


Figure 57. Tentative assessment of un-needed legacy ditches through peatlands. Portions of the MRGRW, which are not shown, have little of this ditching.

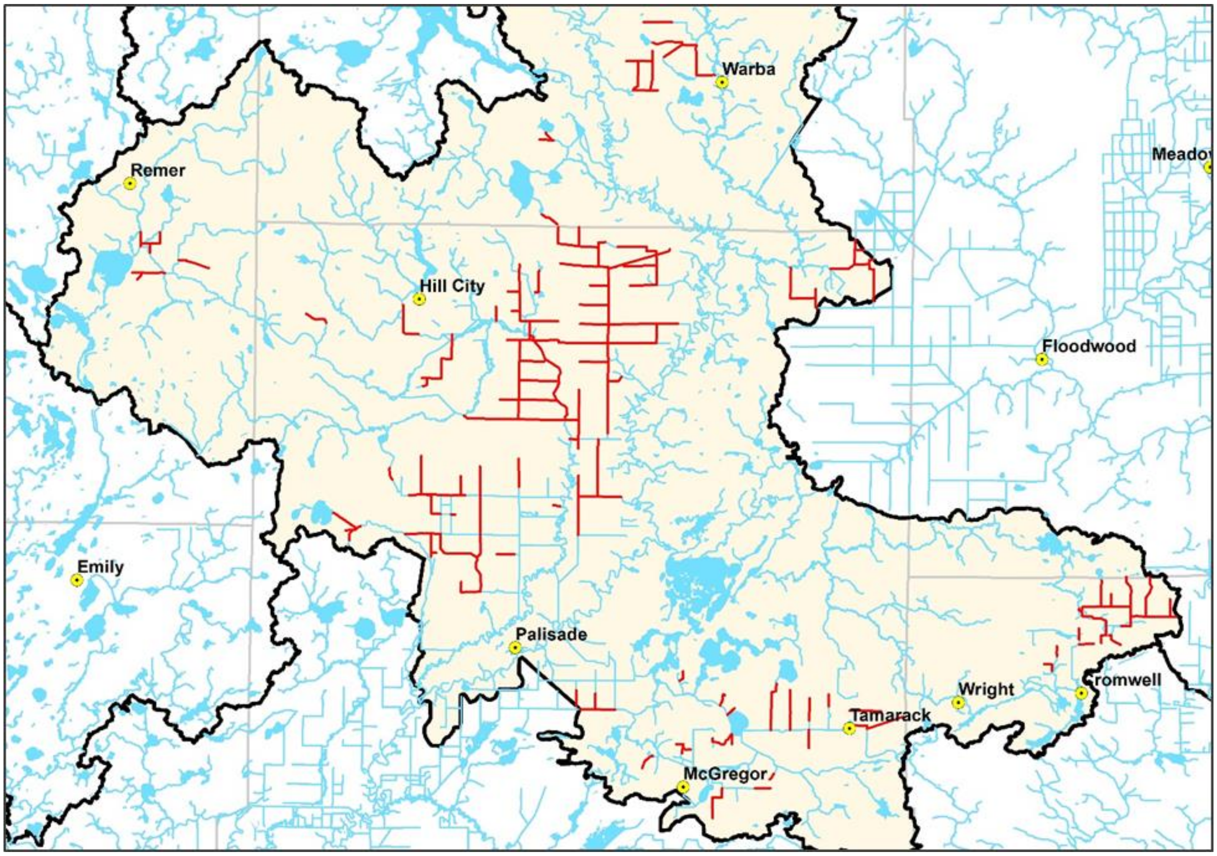


Table 84. Length of "un-needed" legacy ditching in each "aggregated HUC-12" subwatershed in the MRGRW.

Aggregated HUC-12 Name	Miles of "un-needed" ditch
Big Sandy Outlet	14.7
City of Palisade-Mississippi River	44.1
Hill River	33.8
Lower Swan River	17.9
Lower Willow River	39.4
Moose River	0.6
Prairie River	17.1
Sandy River	9.2
Split Hand Creek	2.2
Split Hand Creek-Mississippi River	6.3
Tamarack River	2.6
Upper Willow River	13.8

Figure 58. Reaches where significant stream channel straightening or abandonment has occurred on Birch Brook/Foley Brook/Willow River near Remer, which are areas for potential stream restoration. The arrows point to restoration reaches on Birch and Foley Brooks, and the yellow-boxed area is a potential stream restoration area on the Willow River.

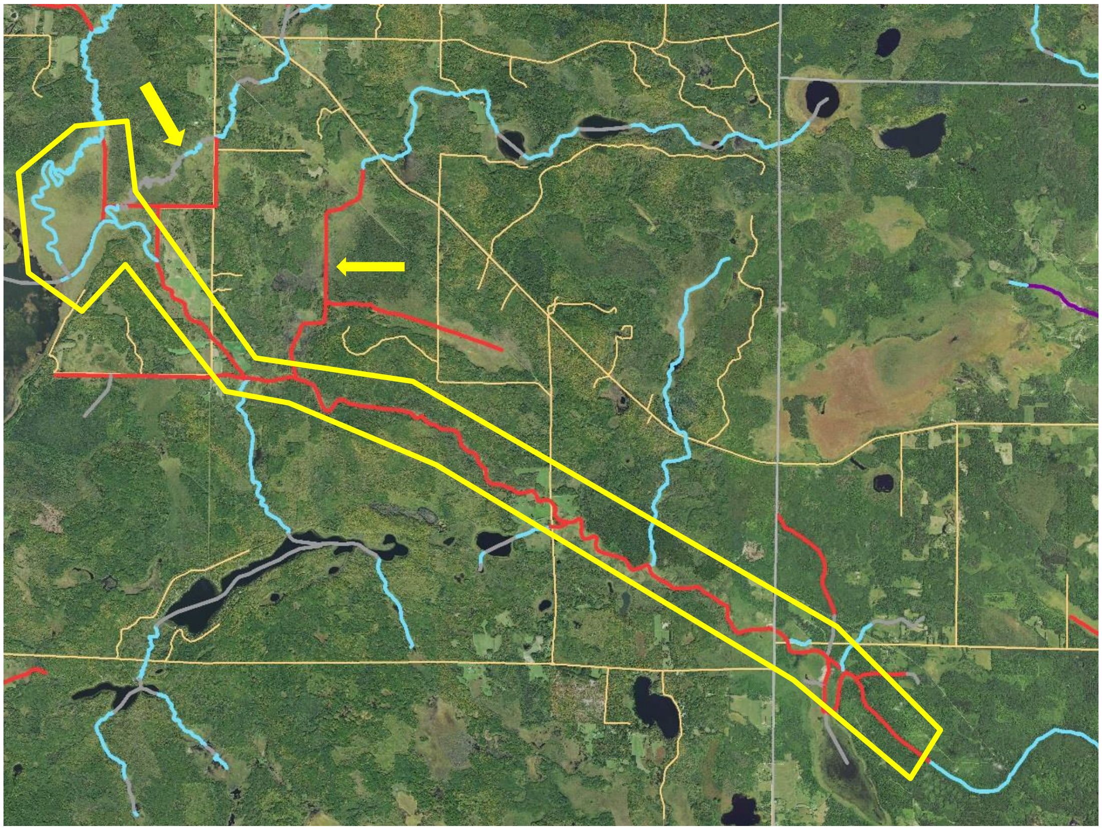


Figure 59. The Hill River/Willow River/Moose River (and several tributaries) river system near Hill City has many opportunities both ditch abandonment/wetland restoration and stream restoration. Red lines are ditches. A long reach of the Willow River particularly could be restored to natural condition.

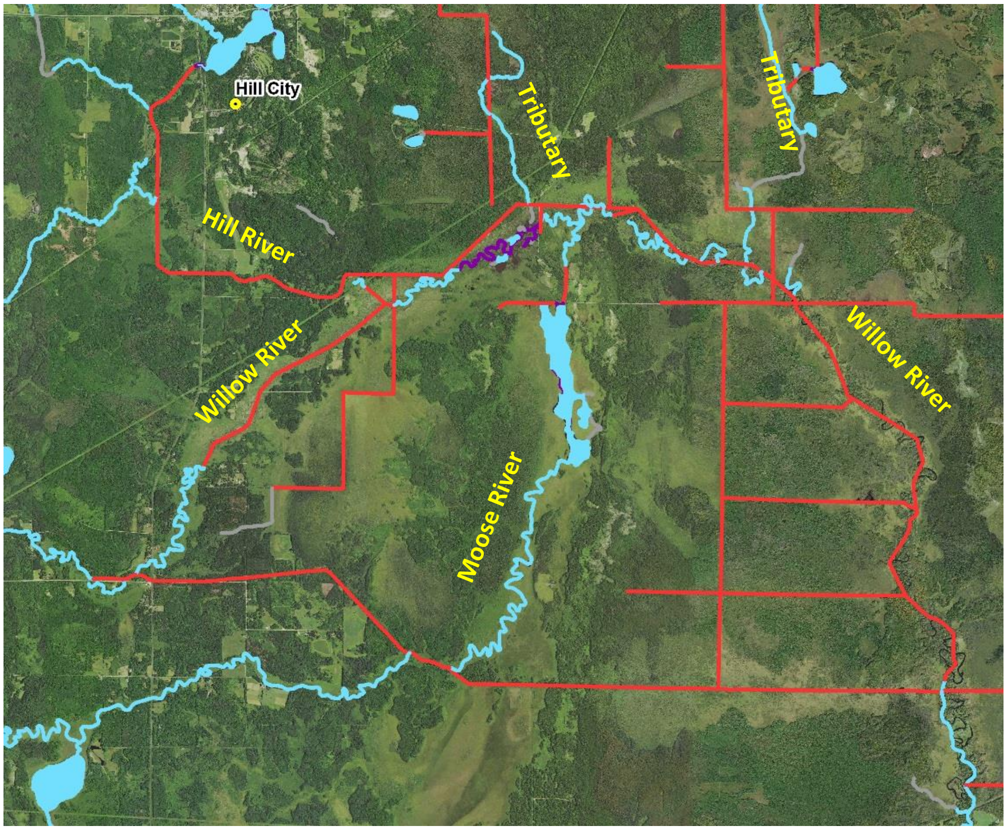


Figure 60. The Sandy River system in the Tamarack/McGregor area has many opportunities both ditch abandonment/wetland restoration and stream restoration. Red lines are ditches. The best opportunity to restore the stream channel of the Sandy River is within the yellow-boxed area.

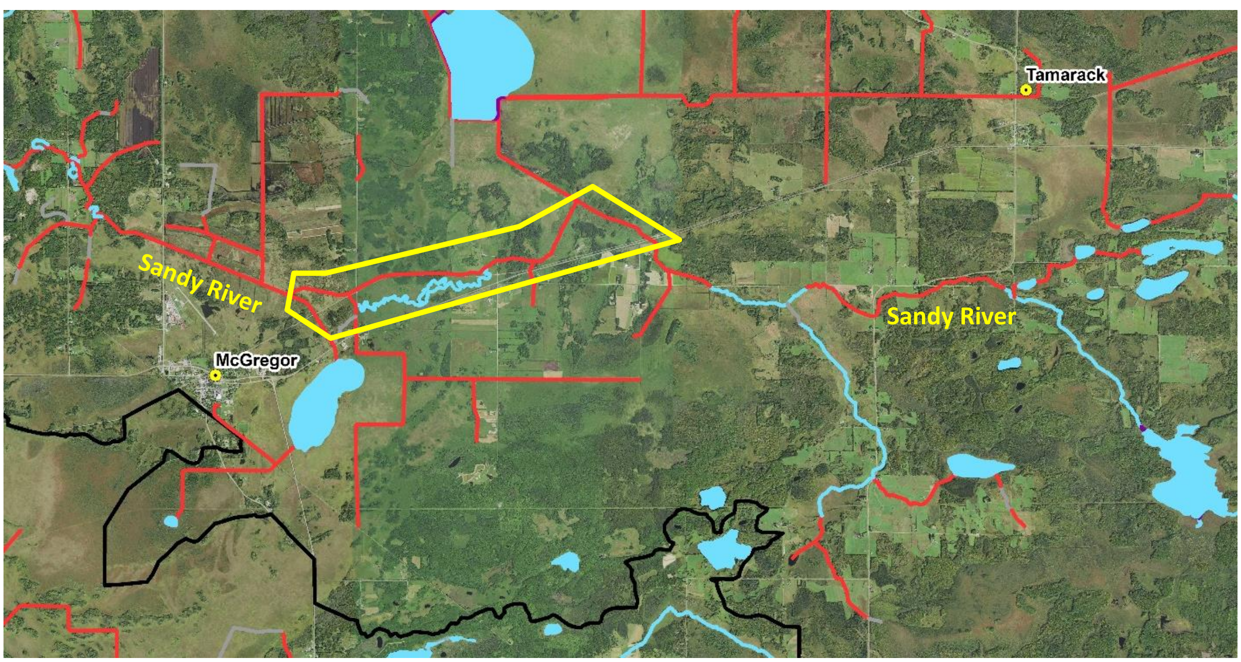
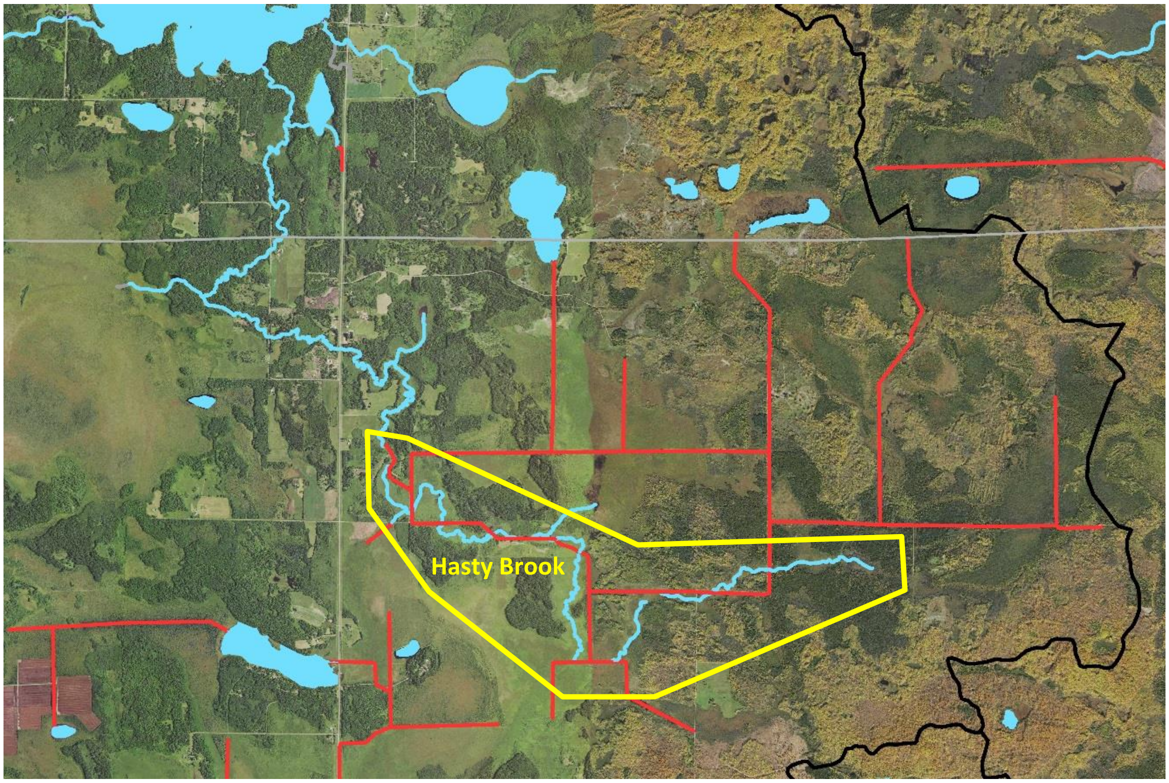


Figure 61. The Hasty Brook system in the Cromwell area has many opportunities both ditch abandonment/wetland restoration and stream restoration. Red lines are ditches. The opportunity for stream channel restoration is in the yellow-boxed area. Other ditches could be considered for abandonment/filling.



Overall Conclusions for MRGRW streams and rivers

A summary table of stressors to MRGRW impaired streams is presented in Table 83. The biological impairments found in the MRGRW are on small streams. This suggests that there are not widespread, systemic stressors throughout the Watershed, but rather ones that are more local in both cause and effect. No point-source effluents contribute to any of the biological impairments.

The most common stressor involves historical ditching of peatlands, which are an extensive landscape feature of the MRGRW. There are places within the watershed where these local stressors are more concentrated. For peatland ditching, this is along the southern edge between Cromwell and McGregor, and in the central area, near Jacobsen and Hill City. It is nearly non-existent in the upper 1/3 of the MRGRW. 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. Another stressor found in multiple locations is road infrastructure; culverts that are not adequately designed to allow good fish passability. In a few cases, cattle pastured in riparian areas have caused channel instability and habitat degradation.

Repairing local stressors, such as fencing cattle from stream access and replacing culverts using designs to allow fish passage, will allow biological communities to improve in places affected by those situations. Restoring a more natural flow regime in the heavily ditched portions of the MRGRW, where hydrological alteration has harmed the physical channel, will improve habitat for biological organisms.

In some cases (e.g., Pokegama Creek), there is a very slow process of healing of the physical channel occurring, as has been described by Rosgen (1996) and Simon (1989) as channel evolution, following a destabilizing disturbance (the upstream ditching in this case). New floodplain benches are naturally being formed within the channel. The elimination of the peatland ditches that feed into a number of these impaired streams would speed the healing process, as well as having downstream benefits by reducing sediment, phosphorus, and DOC export from these landscapes, and reduce water that contributes to downstream flooding. 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. Stream restoration guidance and strategies pertaining to the MRGRW can be found in the Mississippi River - Grand Rapids WRAPS Report (MPCA, 2019).

Table 85. Summary of stressors causing biological impairment in MRGRW streams by location (AUID).

Stream	**AUID Last 3 digits**	**Biological Impairment**	Stressor								
			Dissolved Oxygen	Phosphorus	Conductivity	TSS	Connectivity	Altered Hydrology	Channel alteration	Temperature	Habitat
Sandy River	512	Fish and MI	●			●		●	●		●
Minnewawa Creek	518	Fish and MI	●			?		◆			
Minnewawa Creek	519	Fish	●					◆	◆		●
Split Hand Creek	574	None							●		●
Pickerel Creek	590	Fish and MI	●		?					●	x
Trib. to Bray Lake	722	Fish				?					
Trib. to Mississippi	726	Fish and MI						?		?	
Trib. to Mississippi	727	Fish	●					◆	◆		●
Trib. to Swan River	728	Fish	●					◆			●
Trib. to Mississippi	730	Fish					●	●			●
Trib. to Unnamed Cr	731	Fish					●	●			●
Pokegama Creek	733	Fish and MI	●					◆	●		●
Trib. to Hill R Ditch	739	Fish	●				?	◆	◆		●
White Elk Creek	741	Fish	?				●		?		?
Unnamed Ditch	756	Fish and MI	●			x	●	◆	●		●

◆ A “root cause” stressor, which causes other consequences that become the direct stressors

● A direct stressor

x A secondary stressor

? Inconclusive

Monitoring and Assessment of Lakes

Overview of Mississippi River - Grand Rapids Watershed Lake Monitoring

The approach used to identify biological impairments in lakes includes the assessment of fish communities present in 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, an FIBI score can be calculated for each lake that 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 (Tables 86 and 87). More information on the FIBI tools and assessments based on the FIBI can be found at the DNR lake index of biological integrity website. Although an FIBI score may indicate that a lake fish community is impaired, a weight of evidence approach is still 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 86. Summary of lake characteristics and metrics for current FIBI tools.

Lake characteristics	Tool			
	2	4	5	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 (presence of bays, points, islands)	X		X	
Generally with simpler shape (lack of bays, points, and islands)		X		
Species richness metrics included in FIBI				
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 included in FIBI				
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

Lake characteristics	Tool			
	2	4	5	7
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 Mississippi River—Grand Rapids watershed	**27**	**12**	**12**	**1**

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. Oftentimes, 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 52 lakes in the MRGRW (Figure 61 and Table 88). A total of 41 lakes had FIBI scores at or above the impairment threshold and were assessed as fully supporting aquatic life use (Tables 87 and Table 88). Ten lakes were deemed to have insufficient information at the time of assessment to make an assessment decision (Table 88). Lakes considered to have insufficient information to make an assessment decision either lacked sufficient sampling effort or recent survey data, or lake characteristics did not facilitate use of one of the four FIBI tools. One lake, Lower (South) Island (DOW# 09-0060-02), had an FIBI score that was below the impairment threshold and was assessed as not supporting aquatic life use (Table 88).

Table 87. Lake FIBI Tools with respective FIBI thresholds and lower/upper confidence limits (CL) found in the MRGRW.

Lake FIBI Tool	FIBI Threshold	Lower CL	Upper CL
Tool 2	45	36	54
Tool 4	38	30	46
Tool 5	24	9	39
Tool 7	36	27	45

Figure 62. MRGRW land cover classes with lakes sampled and assessed with FIBI protocols.

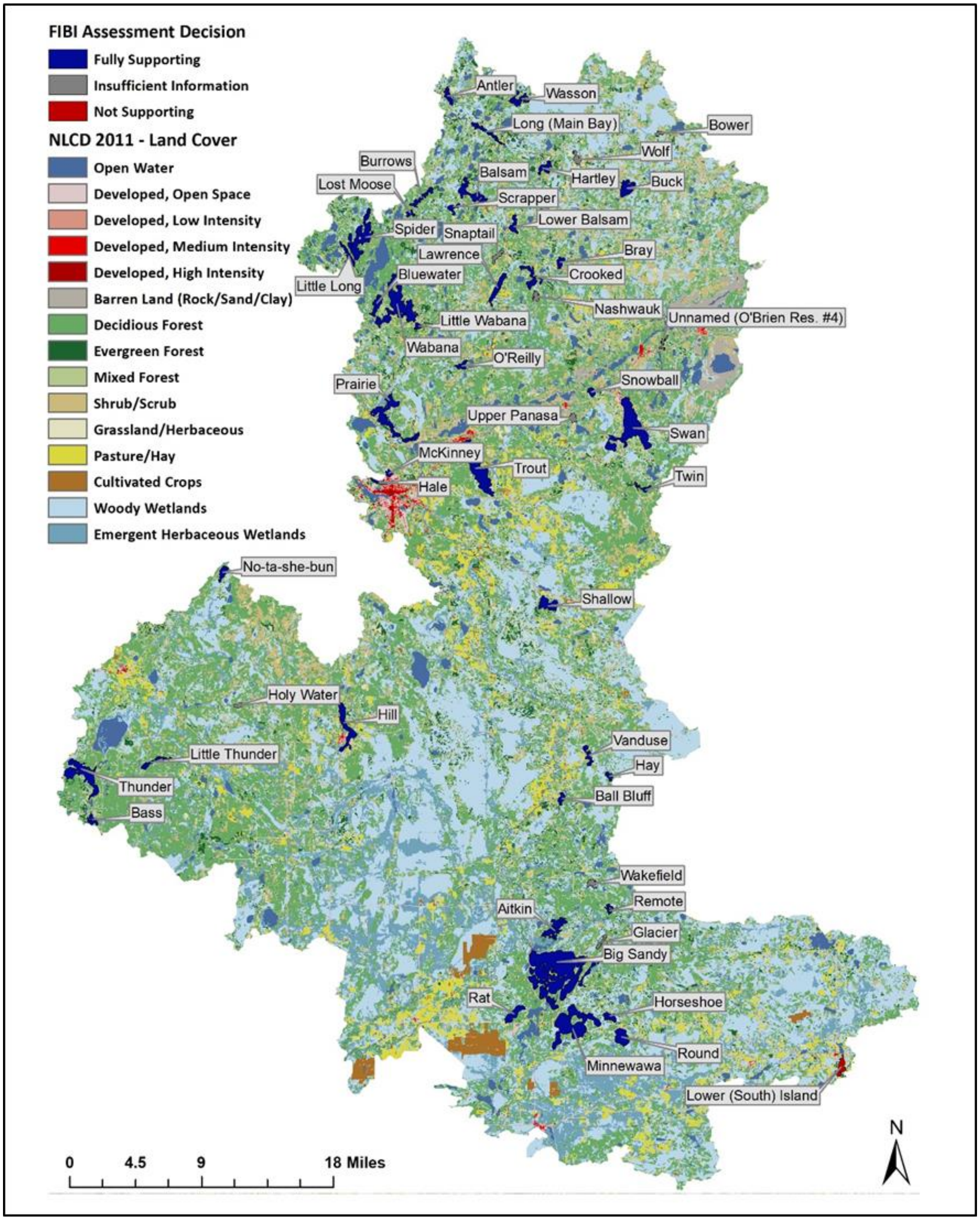


Table 88. Summary of lakes in the MRGRW assessed with FIBI Tools. The % littoral is the % of the lake that is less than 15 feet deep calculated using DNR GIS data. Color-coding is described at the bottom of the table.

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	FIBI Tool	% Littoral	FIBI Score(s)	Below Impairment Threshold	Within 90% CI of Impairment Threshold
01-0023-00	Round	Aitkin	2012		554	4	68	44	No	Yes
01-0033-00	Minnewawa	Aitkin	2012		2355	7	97	49	No	No
01-0034-00	Horseshoe	Aitkin	2015		240	5	100	49	No	No
01-0036-00	Wakefield	Aitkin	8/6/2013, 8/19/2013	No FIBI Tool- Schupp lake class 20	164	N/A	49	N/A	N/A	N/A
01-0038-00	Remote	Aitkin	2014	Low sampling effort	134	5	93	52	No	No
01-0040-00	Aitkin	Aitkin	7/13/2016, 8/15/2016		659	5	69	43, 43	No, No	No, No
01-0042-00	Glacier	Aitkin	2011	No FIBI Tool- Schupp lake class 20, Low sampling effort	135	N/A	44	N/A	N/A	N/A
01-0046-00	Ball Bluff	Aitkin	2011, 2016	Low sampling effort (2011)	168	2	19	44, 63	Yes, No	Yes, No
01-0058-00	Vanduse	Aitkin	2012		240	5	79	60	No	No
01-0059-00	Hay	Aitkin	2013	Low sampling effort	129	4	44	51	No	No
01-0062-00	Big Sandy	Aitkin	2011, 2013		6088	2	51	45, 55	No, No	Yes, No
01-0077-00	Rat	Aitkin	2011	Low sampling effort	431	5	90	44	No	No
01-0142-00	Hill	Aitkin	2008, 2009, 2010, 2011, 2015	Low sampling effort (2011)	792	2	45	68, 56, 62, 61, 62	No, No, No, No, No	No, No, No, No, No
01-0201-00	Holy Water	Aitkin	2010	No FIBI Tool- Schupp lake class 20, Low sampling effort, Smaller than 100 acres	91	N/A	38	N/A	N/A	N/A

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	FIBI Tool	% Littoral	FIBI Score(s)	Below Impairment Threshold	Within 90% CI of Impairment Threshold
09-0060-02	Lower (South) Island	Carlton	2013		320	4	65	26	Yes	No
11-0009-00	Little Thunder	Crow Wing	2006, 2014		258	2	31	60, 48	No, No	No, Yes
11-0062-00	Thunder	Crow Wing	2008, 2012		1347	2	17	69, 76	No, No	No, No
11-0069-00	Bass	Crow Wing	2006, 2012, 2016	Low sampling effort (2012)	193	2	22	63, 41, 57	No, Yes, No	No, Yes, No
31-0026-00	Twin	Itasca	2015		147	4	50	48	No	No
31-0052-00	Bower	Itasca	2010	No FIBI Tool- Schupp lake class 20, Smaller than 100 acres	93	N/A	42	N/A	N/A	N/A
31-0067-00	Swan	Itasca	2013		2456	2	21	71	No	No
31-0069-00	Buck	Itasca	2013		495	4	36	73	No	No
31-0084-00	Shallow	Itasca	2014	Low sampling effort	539	2	50	68	No	No
31-0108-00	Snowball	Itasca	2013		145	4	30	58	No	No
31-0111-00	Upper Panasa	Itasca	2014	Sampling difficulty, Uncertain mining history	148	5	100	10	Yes	Yes
31-0147-00	Bray	Itasca	2014		177	4	42	60	No	No
31-0152-00	Wolf	Itasca	2010	Winterkill, Fish identification concerns	197	5	100	61	No	No
31-0154-00	Hartley	Itasca	2011	Low sampling effort	288	2	34	56	No	No
31-0192-00	Nashwauk	Itasca	2005	Sampling completed outside of 10 year assessment window	159	4	28	60	No	No

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	FIBI Tool	% Littoral	FIBI Score(s)	Below Impairment Threshold	Within 90% CI of Impairment Threshold
31-0193-00	Crooked	Itasca	2005, 2012, 7/7/2015, 7/27/2015		465	2	22	52, 55, 51, 50	No, No, No, No	Yes, No, Yes, Yes
31-0216-00	Trout	Itasca	2006, 2010, 2013	Low sampling effort (2006)	1854	2	24	74, 62, 63	No, No, No	No, No, No
31-0219-00	O'Reilly	Itasca	2011		189	2	30	55	No	No
31-0231-00	Lawrence	Itasca	2010		437	5	72	64	No	No
31-0247-00	Lower Balsam	Itasca	2011	Low sampling effort	259	4	38	68	No	No
31-0255-00	Snaptail	Itasca	6/14/2010, 8/10/2010, 2016	No FIBI Tool-Schupp lake class 20, Sampling difficulty	170	N/A	34	N/A	N/A	N/A
31-0259-00	Balsalm	Itasca	2016		714	2	41	68	No	No
31-0266-01	Long	Itasca	2008		339	2	52	49	No	Yes
31-0281-00	Wasson	Itasca	2010		438	2	47	60	No	No
31-0345-00	Scrapper	Itasca	2016		172	5	71	89	No	No
31-0349-00	Antler	Itasca	2012		234	2	33	52	No	Yes
31-0370-00	McKinney	Itasca	2014		106	5	94	60	No	No
31-0373-00	Hale	Itasca	2014		130	2	28	76	No	No
31-0384-00	Prairie	Itasca	2008, 2012		1331	5	64	73, 58	No, No	No, No
31-0392-00	Wabana	Itasca	2015		2221	2	35	83	No	No
31-0395-00	Bluewater	Itasca	2015		364	2	20	84	No	No
31-0399-00	Little Wabana	Itasca	2009		116	2	27	75	No	No
31-0413-00	Burrows	Itasca	2010		306	4	74	50	No	No
31-0432-00	Lost Moose	Itasca	2011		112	5	100	79	No	No
31-0538-00	Spider	Itasca	2010		1392	2	53	59	No	No
31-0613-00	Little Long	Itasca	2015		305	2	51	64	No	No

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	FIBI Tool	% Littoral	FIBI Score(s)	Below Impairment Threshold	Within 90% CI of Impairment Threshold
31-0775-00	No Ta She Bun	Itasca	2011, 2013		239	4	30	78, 77	No, No	No, No
31-1225-00	O'Brien Reservoir #4	Itasca	2013	Low sampling effort, Sampling difficulties	102	4	10	45	No	Yes

≤ lower CL	**> lower CL & ≤ threshold**	**> threshold & ≤ upper CL**	**> upper CL**	**Insufficient Information**

Summary of lake stressors

The 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 89). Many literature references are cited, which are additional sources of information. The document is entitled "Stressors to Biological Communities in Minnesota's Lakes" and can be found on the DNR lake index of biological integrity website. Additionally, the United States Environmental Protection Agency (EPA) has information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors to aquatic ecosystems on their CADDIS website.

Table 89. 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 vegetative 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
Decreased 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
Increased 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
Pesticide Application	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 vegetative dwelling fishes
Metal Contamination	Runoff and leaching from mining operations, industrial sites, firing ranges, urban areas, landfills, and junkyards	Reduced survival, growth, and reproduction of fishes
Unspecified Toxic Chemical Contamination	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 Communities in the MRGRW

Candidate causes

Eutrophication

A review of MPCA's Impaired Waters List indicates that 11 lakes within the MRGRW are listed as impaired for aquatic recreation based on MPCA's nutrient water quality standards. 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. Excess nutrients such as phosphorus are a direct cause of eutrophication in lakes.

Inconclusive causes

Physical habitat alteration

A review of DNR Score the Shore (StS) data (Perleberg et al., 2016) indicates that lakes within the MRGRW have less riparian shoreline disturbance on average than lakes statewide. The average lake wide StS score for surveyed lakes within the MRGRW was 79, which is higher than the statewide average of 74. High StS Scores are indicative of relatively undisturbed riparian lakeshore habitat whereas low StS Scores are indicative of highly disturbed riparian lakeshore habitat. The average scores for developed and undeveloped sites in the MRGRW were 64 and 94, respectively. Both scores were only slightly higher than the statewide averages of 63 and 92 for developed and undeveloped sites, respectively. As such, lake wide StS scores in the MRGRW are generally higher because a smaller percentage of shoreline development has occurred around these lakes relative to lakes in other areas of Minnesota. Although these results indicate that habitat loss from riparian lakeshore development is generally lower on lakes within the MRGRW than lakes statewide, several individual lakes within the MRGRW received lower scores, and therefore riparian lakeshore development will be evaluated further as a potential stressor within the MRGRW.

A review of DNR Aquatic Plant Management (APM) program permitting information indicates that permits have historically been and are currently issued to mechanically and chemically remove emergent, floating-leaf, and submerged plants on at least 49 lakes within the MRGRW since 2000. Additional mechanical removal of submerged plants that does not require a permit, in addition to illegal removal of plants, has also occurred within the MRGRW.

A review of non-native species that would have the potential to alter physical habitat, including aquatic plant community structure, indicates that several species—Eurasian Watermilfoil, Curly-Leaved Pondweed, Flowering Rush, and Rusty Crayfish—are present in a small subset of lakes within the MRGRW.

A review of the Minnesota inventory of dams indicates that there are approximately 68 dams located within the MRGRW; however, not all water control structures may be identified or included in this inventory. 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 due to a lack of data from which to draw conclusions.

A review of the DNR Watershed Health Assessment Framework (WHAF) tool indicates that the potential for aquatic connectivity disruption from culverts, bridges, and dams is lower than the statewide average (DNR, 2018c). A higher score indicates lower potential for aquatic connectivity disruption, and the MRGRW scores 79 out of a possible 100 whereas the statewide average is 53. Preliminary data from a

DNR Culvert Inventory is also available for culverts that have been assessed to date. Although data is extremely sparse for culverts in the MRGRW currently, of the 23 culverts that have been assessed, 30% create a possible barrier to fish passage at some flows due to their size, function, or design (DNR, 2018d). Future standardized culvert inventory surveys conducted by DNR staff and external partners using the Culvert Inventory Application Suite (DNR, 2018d) should provide a more accurate and thorough assessment of culvert condition within the MRGRW.

Measures such as total suspended solids or substrate embeddedness, which can be used to evaluate sedimentation, are lacking for most lakes within the MRGRW. Although sedimentation may contribute to lower than expected FIBI scores for certain lakes, the lack of high quality quantitative data and scientific research on the topic makes it challenging to draw conclusions for lakes within the MRGRW at this time.

Altered interspecific competition

A review of DNR survey data indicates that the MRGRW is relatively unaffected by non-native species that would directly compete with native fish species for resources. Several lakes within the watershed contain Rusty Crayfish, Rainbow Smelt, or Chinese Mystery Snails but no lakes currently contain confirmed populations of non-native species such as Common Carp, Zebra Mussels, or Spiny Waterfleas that directly compete with native fishes.

A review of gamefish management activities indicates that stocking and harvest regulations occur in many lakes within the MRGRW. While some gamefish management activities can result in significant changes to the fish community of a lake, in general, there is an overall lack of conclusive evidence linking these changes to FIBI scores. Therefore, gamefish management activities are considered inconclusive as potential stressors to the fish community because the effects of gamefish management on the FIBI score are unknown.

Temperature regime changes

A review of research by Jacobson et al. (2017) indicates that mean annual lake-specific air temperatures within the MRGRW may have increased by an average of 1.6 °F over the last century as a result of climate change, which is 0.4 °F warmer than for other lakes included in the statewide dataset. Increases in lake-specific air temperature have been shown to be correlated with increases in water temperature (Robertson and Ragotzkie, 1990). Although modeling evidence suggests that water temperature has increased in lakes within the MRGRW, limited research is available to demonstrate the magnitude of change needed to result in changes to the fish community as measured by the FIBI.

Decreased dissolved oxygen

Data regarding dissolved oxygen concentrations in lakes is generally limited to discrete profiles collected during periodic MPCA and DNR surveys or is provided as anecdotal information when 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, and specifically cool- and warmwater species, in the MRGRW at this time.

Eliminated causes

Increased ionic strength

A review of MPCA's Impaired Waters List indicates that no lakes within the MRGRW were assessed as impaired for aquatic life use based on the chronic standard for chloride (MPCA, 2018b). 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 MRGRW at this time.

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 to 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 MRGRW were below applicable water quality standards and reference values (Tollefson et al., 2014).

Metal contamination

A review of MPCA's Impaired Waters List indicates that the MRGRW contains several lakes that have been identified as impaired for aquatic consumption based on mercury levels; however, MPCA and local partners have developed a statewide mercury reduction plan approved by EPA to address these impairments (MPCA, 2007). Mercury concentrations that are toxic to fish and other aquatic organisms would need to far exceed the current aquatic consumption standards. Therefore, current standards and actions intended to address aquatic consumption impairments should provide adequate protection to eliminate mercury as a likely candidate cause for impaired fish communities in the MRGRW.

Unspecified toxic chemical contamination

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

Evaluation of stressors for lower (South) Island Lake (DOW 09-0060-02)

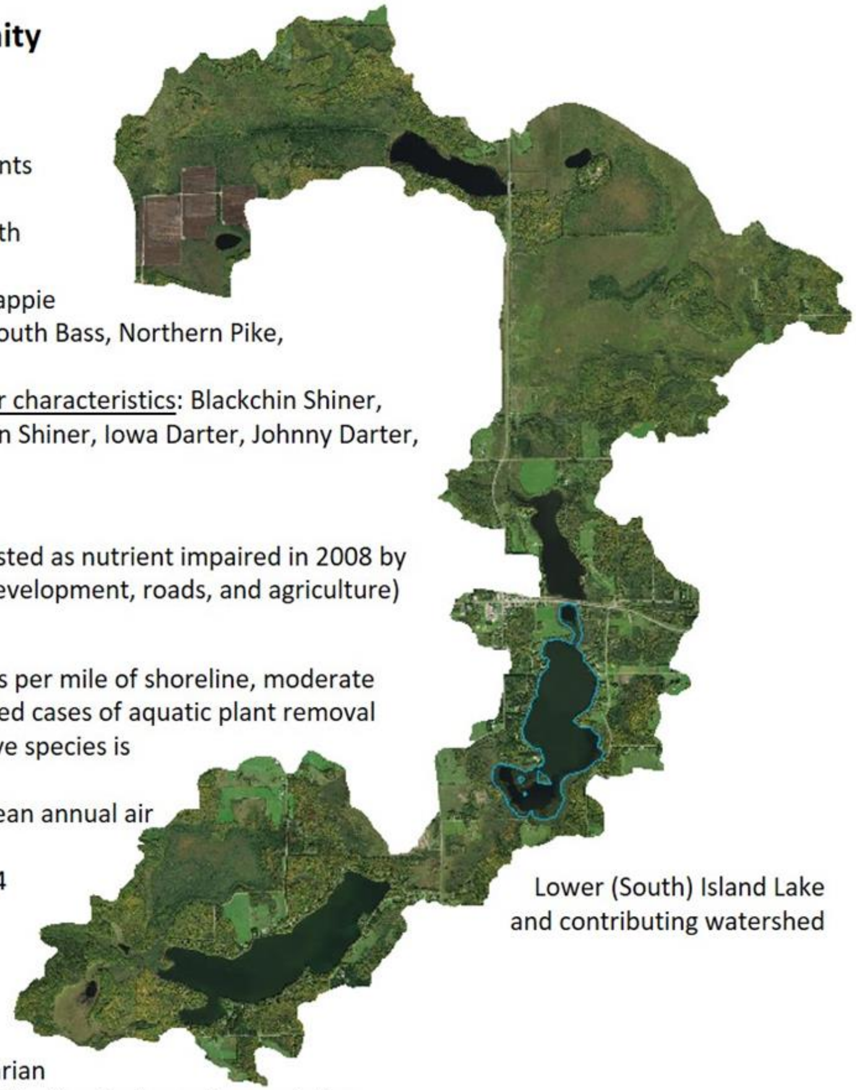
Lower (South) Island Lake is 320 acres in size and has a maximum depth of approximately 22 feet. The littoral zone of the lake covers approximately 65% of the lake area. Lower (South) Island Lake is scored with FIBI tool 4. Lakes scored with this tool are characterized as generally deep with simple (i.e., round) shorelines, less than 80% littoral area, and moderate species richness (Table 86).

Eutrophication has been identified as a likely stressor to aquatic life use in Lower (South) Island Lake and will be evaluated further. Physical habitat alteration, altered interspecific competition, temperature regime changes, and decreased dissolved oxygen have been identified as inconclusive stressors at this time (Figure 62). A description of available data and current understanding of levels believed to affect fish communities will be discussed.

Figure 63. Summary of Lower (South) Island Lake fish community and stressors.

Summary of Lower (South) Island Lake Fish Community and Stressors

- **Fish community:**
  - Fish-based index of biological integrity (FIBI) score: 26 (12 points below impairment threshold for similar lakes)
  - Species sampled that negatively affect the FIBI score: Bigmouth Buffalo, Black Bullhead, White Sucker, and Yellow Bullhead
  - Species sampled that positively affect the FIBI score: Black Crappie Bowfin, Bluegill Central Mudminnow, Hybrid Sunfish, Largemouth Bass, Northern Pike, Pumpkinseed, Rock Bass, Walleye, and Yellow Perch
  - Other species commonly sampled in healthy lakes with similar characteristics: Blackchin Shiner, Blacknose Shiner, Bluntnose Minnow, Brown Bullhead, Golden Shiner, Iowa Darter, Johnny Darter, and Tadpole Madtom
- **Candidate stressor:**
  - Eutrophication (excess nutrients): 29 ppb total phosphorus, listed as nutrient impaired in 2008 by MPCA, 15.5% watershed disturbance (primarily residential development, roads, and agriculture)
- **Inconclusive stressors:**
  - Physical habitat alteration: moderate dock density of 10 docks per mile of shoreline, moderate lakewide Score the Shore (StS) habitat score of 83, documented cases of aquatic plant removal
  - Altered interspecific competition: only documented non-native species is Chinese Mystery Snail
  - Temperature regime changes: estimated 1.6 °F increase in mean annual air temperature over last century
  - Decreased dissolved oxygen: adequate dissolved oxygen to 14 feet (thermocline) during summer months
- **Recommendations:**
  - Follow TMDL recommendations, inspect individual sewage treatment systems for compliance, limit fertilizer application on lawns and in agricultural areas, promote and maintain riparian buffer areas around shoreline, limit removal of emergent and floating-leaf aquatic vegetation



Biological community

The fish community in Lower (South) Island Lake was sampled using seining, backpack electrofishing during June 2013, gill netting, and trap netting during July 2013. The health of the fish community was evaluated using these data and FIBI tool 4. The FIBI uses fish community data to measure a lake's health, and the types of fish species present can help identify any stressors that may be negatively affecting the lake environment. The FIBI score composed of eleven fish community diversity and composition metrics for tool 4 lakes (Table 86), indicates the overall health of a lake by comparing it to what is expected for a healthy lake. The FIBI score of 26 was below the impairment threshold (38) developed for lakes that are similar to Lower (South) Island (Table 87).

During the 2013 FIBI survey, 14 fish species were captured (Figure 62 and Table 90). Backpack electrofishing and seining resulted in capture of Black Crappie, Bluegill, Bowfin, Central Mudminnows, Largemouth Bass, Northern Pike, Pumpkinseeds, Rock Bass, Yellow Bullheads, and Yellow Perch. Gill nets captured Black Bullheads, Black Crappie, Bluegill, Bowfin, Northern Pike, Rock Bass, Walleye, White Suckers, Yellow Bullheads, and Yellow Perch. Trap nets captured Bigmouth Buffalo, Black Bullheads, Black Crappie, Bluegill, Bowfin, Northern Pike, Pumpkinseeds, Rock Bass, Yellow Bullheads, and Yellow Perch.

Diversity of intolerant, tolerant, small benthic dwelling, and vegetative dwelling species, in addition to the proportion of small benthic dwelling species sampled in the nearshore gears (i.e., seining and backpack electrofishing), were below levels expected for similar lakes as measured by the respective FIBI metrics (Table 90). Only one intolerant species, Rock Bass, was sampled in the lake, whereas two tolerant species, Bigmouth Buffalo and Black Bullhead, were sampled. No small benthic dwelling species and only three vegetative dwelling species, Bowfin, Central Mudminnow, and Northern Pike, were sampled. Similar lakes within the MRGRW that contain healthy fish communities as measured by the FIBI tool 4 generally contained species such as Blackchin Shiners, Blacknose Shiners, Iowa Darters, Johnny Darters, and Tadpole Madtoms (Table 90), all of which positively affect several FIBI metric scores.

Metrics quantifying the proportions of biomass in trap nets from insectivores, omnivores, and tolerant species were also below levels expected for similar lakes. Insectivores such as Bluegill, Pumpkinseeds, and Yellow Perch only constituted 25% of the trap net biomass whereas omnivores such as Bigmouth Buffalo, Black Bullheads, and Yellow Bullheads constituted 19% of the biomass.

The DNR Fisheries currently stocks Walleye fry into Lower (South) Island Lake at a rate of 2,000 per littoral acre in even years, as described in the current Lower (South) Island Lake management plan (DNR, 2016). 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 (Drake and Pereira, 2002; J. Bacigalupi, DNR, unpublished data). However, effects in individual lakes are possible as management activities can vary considerably based on individual lake characteristics and 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 19 species have been sampled in Lower (South) Island Lake. Blacknose Shiners, Fathead Minnows, Johnny Darters, and Golden Shiners were sampled in a 1951 DNR Fisheries survey and Golden Shiners and Tadpole Madtoms were sampled in a 1989 DNR Fisheries survey, but these species have not been observed in DNR surveys in Lower (South) Island Lake since that time (DNR, 2016). These historically sampled species may be represented by only one or two occurrences and identification confirmation cannot occur due to the lack of vouchered specimens.

Table 90. Summary of all fish species captured in Lower (South) Island Lake (DOW 09-0060-02) in 2013 compared with most common fish species (i.e., sampled in >50% of lakes) in similar FIBI tool 4 lakes within the MRGRW during FIBI sampling. Tolerance, feeding, and habitat guilds are abbreviated as follows: Intol=Intolerant, Tol=Tolerant, Omni=Omnivore, TC=Top Carnivore, Veg=Vegetative Dweller, Smb=Small Benthic Dweller. 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	Lower (South) Island Lake	Similar Unimpaired MRGRW Lakes
Bigmouth Buffalo	Tol	X	
Black Bullhead	Tol, Omni	X	
Black Crappie	TC	X	X
Blackchin Shiner	Intol, Veg		X
Blacknose Shiner	Intol, Veg		X
Bluegill		X	X
Bluntnose Minnow	Omni		X
Bowfin	TC, Veg	X	X
Brown Bullhead	Omni		X
Central Mudminnow	Veg	X	X
Golden Shiner			X
Iowa Darter	Intol, Smb, Veg		X
Johnny Darter	Smb		X
Largemouth Bass	TC	X	X
Northern Pike	TC, Veg	X	X
Pumpkinseed		X	X
Rock Bass	Intol, TC	X	X
Tadpole Madtom	Smb, Veg		X
Walleye	TC	X	X
White Sucker	Omni	X	X
Yellow Bullhead	Omni	X	X
Yellow Perch		X	X

Data analysis/Evaluation for each candidate cause

Eutrophication

Lower (South) Island Lake was listed as nutrient impaired by the MPCA in 2008. Recent data collected and summarized by MPCA indicates that mean total phosphorus is 29 ppb, chlorophyll-a is 10 ppb, and Secchi transparency is approximately 6.6 feet (MPCA, 2018d). When compared with aquatic recreation use standards and other similar FIBI tool 4 lakes assessed as fully supporting aquatic life use (Table 91), water quality parameters within Lower (South) Island Lake indicate that the lake is likely receiving inputs of excess nutrients from the surrounding landscape. Of the 8,835 acres of land contained within the contributing watershed, approximately 15.5% is classified as unnatural land cover (i.e., 5.1% developed, 2.8% cultivated, and 7.6% hay and pasture land) and the remaining 84.5% is classified as natural land cover (i.e., 11.2 % water, 19.2% forest, 5.0% shrub and herbaceous, and 49.1% wetland; **Error! Reference source not found.**). Despite a relatively low percentage of unnatural land cover that could be contributing nutrients, the quantity of land within the contributing watershed was high relative to the size of Lower (South) Island Lake, as measured by a watershed-to-lake ratio of 27.6:1. With such a large contributing watershed, even relatively small percentages of urban, cultivated, or pasture and hay, land uses can contribute large inputs of nutrients into associated lakes and waterways.

Residentially developed land within the contributing watershed is predominantly located within the city of Cromwell and along Lower (South) Island, Upper (North) Island, and Eagle lakes, but also includes the network of roads, including Highway 210, and residences found throughout rural areas. Residential development can contribute excess nutrients to local waterways through several pathways, including septic system failure, lawn fertilization, and runoff from increased areas of impervious surfaces. In an effort to improve wastewater treatment and water quality, all lakeshore properties within Cromwell city limits gained access to the city managed sewer system in 2007. To date, all such residential properties within city limits have been connected. Conversely, residences located outside of Cromwell city limits, including those near Lower (South) Island, Upper (North) Island, and Eagle lakes, are generally connected to individual sewage treatment systems that vary in age and, quite possibly, structural integrity. Carlton County zoning records indicate that ten individual sewage treatment systems had been installed on lakeshore properties located outside of city limits on Lower (South) Island Lake between 1960 and 1990, and several have not been checked for compliance since the time of their install. Individual sewage treatment systems have also been installed on as many as 39 additional lakeshore properties on the lake since 1990.

Agricultural land within the contributing watershed consists primarily of hay and pasture land; however, small parcels have also been cultivated for soybeans and corn in recent years (DNR, 2018c). Cultivation of lands for agricultural purposes can contribute excess nutrients such as phosphorus to water bodies within a watershed.

An active peat mine is located off Highway 137 upstream of Cross and Upper (North) Island lakes and within Lower (South) Island Lake's contributing watershed (Figure 63 and Figure 64). Although approximately half of the peat mine operation is located within the contributing watershed, ditching activity has resulted in diversion of surface drainage from the mining area into two sedimentation basins and then into an entirely different watershed to the northwest that contains an unnamed wetland and the Little Tamarack River (MPCA 2004; Figure 64). The peat mining operation does have an emergency bypass that would divert surface drainage during catastrophic storm events into a ditch network that would flow into Cross and Upper (North) Island lakes; however, it has not been used. In order to ensure compliance and to meet water quality standards, the MPCA also requires monthly water quality samples be taken to monitor flow, mercury, pH, phosphorus, total suspended solids, specific conductance, and turbidity at four stations at the site, including the emergency bypass (MPCA, 2004). The water quality data indicates that surface drainage is not negatively affecting water quality within Lower (South) Island Lake's contributing watershed at this time. However, peat-mining activities, if not properly managed, can contribute to acidification and inputs of excess mercury and nutrients into surface waters (Winkler and DeWitt, 1985). Destruction of peatlands can also lead to increases in runoff during rain events and increases in suspended solids in peatland drainage that can contribute to sedimentation (Winkler and DeWitt, 1985).

A separate examination of many factors that could be contributing to the MPCA aquatic recreation nutrient impairment in Lower (South) Island Lake and other lakes within the MRGRW will be outlined in a total maximum daily load (TMDL) that will be published to the MPCA TMDL website (MPCA, 2018d).

Table 91. Ten year averages of all summer water samples collected from Lower (South) Island Lake and from similar FIBI tool 4 lakes within the MRGRW that were assessed as fully supporting aquatic life use (MPCA, 2018d).

Water Quality Parameter	Lower (South) Island Lake	Similar Unimpaired MRGRW Lakes
Total Phosphorus (ppb)	29.0	12.4
Chlorophyll-a (ppb)	10	3
Secchi Transparency (feet)	6.6	13.1

Figure 64. Land use (NLCD, 2011) in Lower (South) Island Lake's (DOW 09-0060-02) contributing watershed.

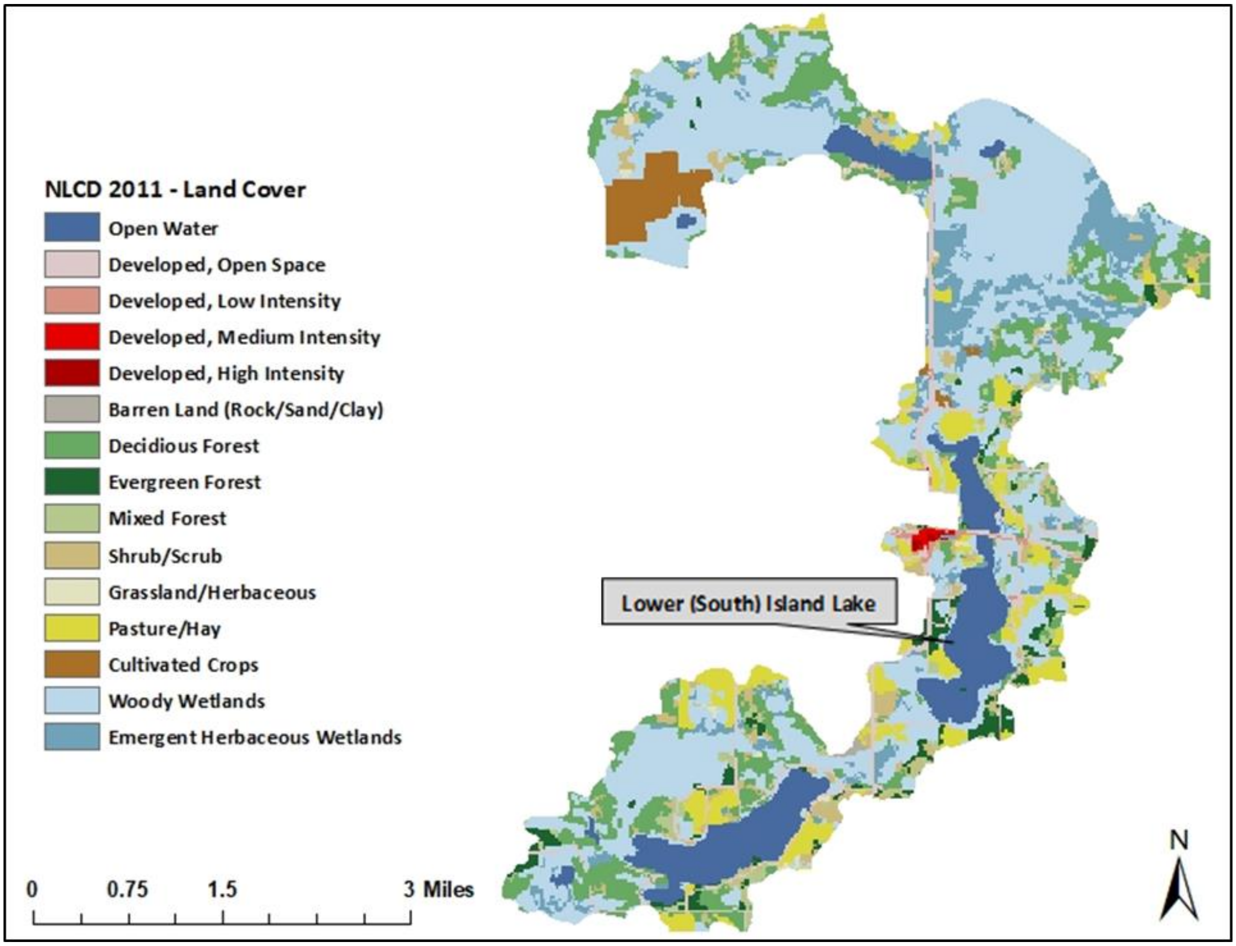
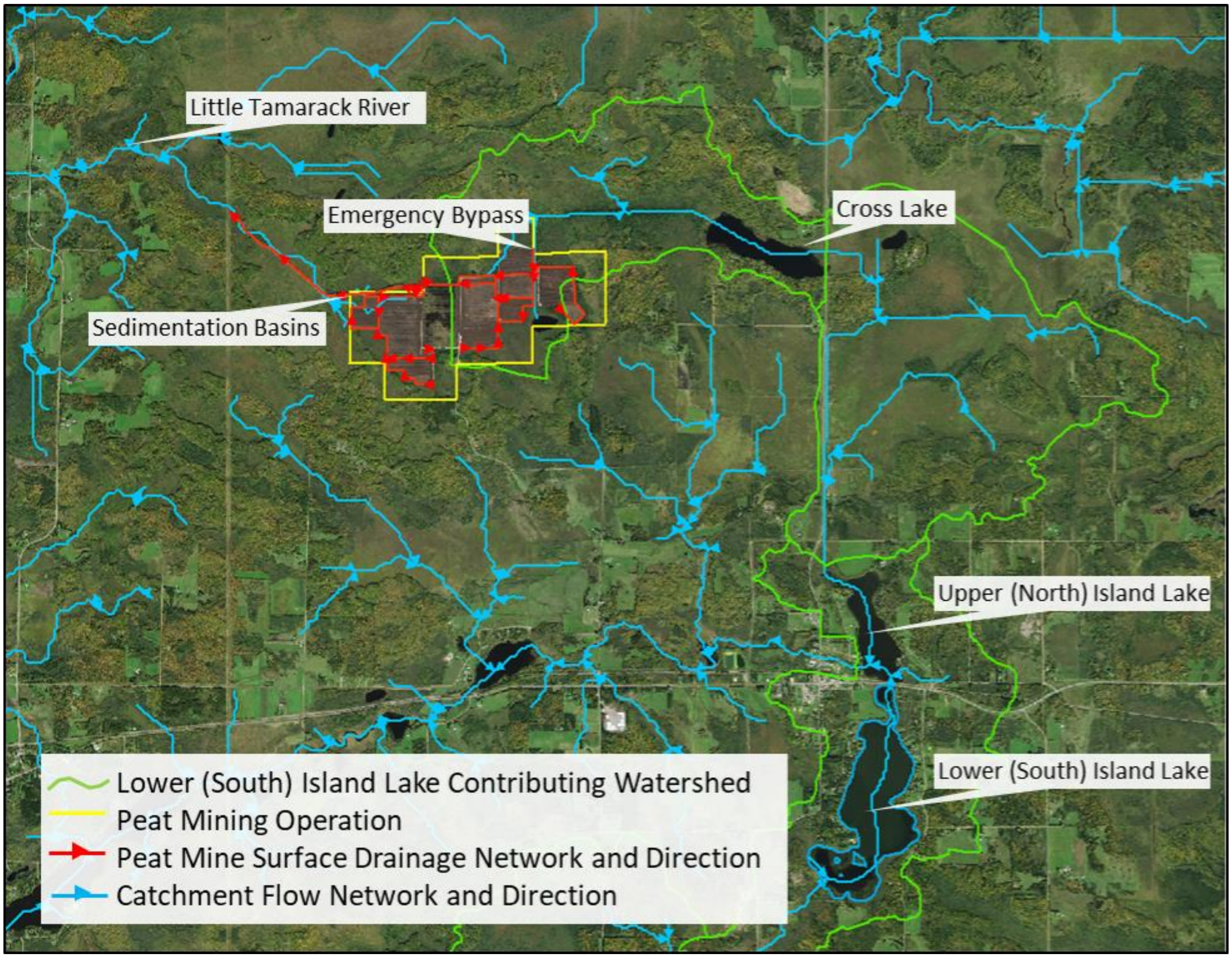


Figure 65. Map depicting Lower (South) Island Lake's contributing watershed, the flow network and direction, the peat mining operation, and the peat mine surface drainage network and direction. Also indicated are the locations of the sedimentation basins and the emergency bypass that would allow surface drainage to enter into the ditch network associated with Lower (South) Island Lake's contributing watershed in the event of a catastrophic storm event.



Information about select inconclusive causes

Physical habitat alteration

Physical habitat alteration within Lower (South) Island Lake appears to be relatively limited based on review of information reflecting riparian lakeshore development, aquatic plant removal, non-native species introduction, water level management, connectivity loss, and sedimentation.

Riparian lakeshore habitat quality, as measured by a June 2016 DNR StS score of 83 (Table 92), is moderate within Lower (South) Island Lake and scores well above the statewide average score of 73. However, the average developed site score (62) is low compared to the average undeveloped site score (96) within Lower (South) Island Lake indicating that habitat quality has been negatively affected where lakeshore development has occurred. A moderate lake wide StS score generally indicates that surveyed sites have a high percentage of unaltered habitat but that at least one zone (i.e., shoreland, shoreline, or aquatic) has lower habitat quality than a high scoring site. Developed sites that generally retain natural habitat areas may score in this range. In the case of Lower (South) Island Lake, residential development has had the largest effect on the shoreland and shoreline habitat components, which indicates that replacement of trees, shrubs, and natural ground cover with open lawns has most likely occurred at a number of sites. A DNR survey of watershed and shoreline characteristics conducted in 2007 indicated that 73 percent of lakeshore homes had open lawns extending to the water's edge. Replacement of riparian vegetation with open lawns oftentimes results in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake. In addition to residential development, agriculture and roads—most notably Highway 210—have also altered natural habitat around the lakeshore. These alterations have the potential to increase runoff and contribute excess nutrients into the lake.

According to APM permit activity, at least twelve properties on Lower (South) Island Lake are treated with chemical herbicide by a commercial applicator to remove aquatic plants, filamentous algae, or Chara and to treat for swimmer's itch. Several APM permits have also been issued to individual lakeshore property owners in recent years that would allow mechanical and chemical removal of aquatic plants to provide reasonable access. Furthermore, anecdotal information about potential plant removal activities within a lake can be inferred from dock counts, and a review from 2015 Google imagery indicates that approximately 50 docks (9.8 docks per mile of shoreline) were present in Lower (South) Island Lake at that time. Densities exceeding 16 docks per mile have been linked to changes in fish community composition, therefore, large-scale changes to fish community composition are not likely occurring within Lower (South) Island Lake strictly as a result of human activity around docks. Only one violation for illegal plant removal has been reported to date; however, illegal, unpermitted plant removal or lakeshore habitat destruction could negatively affect habitat quality within the lake, particularly if it has occurred at a larger scale. Unfortunately, the total amount of habitat loss from plant removal that has historically occurred and is presently occurring within Lower (South) Island Lake is difficult to quantify with any degree of accuracy. Although legal and illegal aquatic plant removal has contributed to some physical habitat loss within the lake, the magnitude of habitat loss that would result in large-scale changes to the fish community as detected by the FIBI remains unknown.

Chinese Mystery Snails are the only non-native species documented in Lower (South) Island Lake, and no changes to the physical habitat or fish community resulting from their presence have been observed. Likewise, the water level in Lower (South) Island Lake is unregulated (i.e. no water control structure) and varies by approximately 2.8 feet. Within the contributing watershed, only two culverts and bridges are documented in the MDOT Bridge and Culvert Inventory; however, visual assessment of 2015 Google imagery indicates that several additional culverts and bridges are also present. Data is lacking to evaluate whether these bridges or culverts are potential barriers to fish passage at this time; however, a recently developed MNDNR Culvert Inventory Application Suite (DNR, 2018d) will enable DNR staff and external partners the ability to collect this information in the future if of interest.

Table 92. Lower (South) Island Lake (DOW 09-0060-02) riparian lakeshore development as measured by a Score the Shore survey. Results are partitioned into undeveloped and developed land use types among shoreland, shoreline, and aquatic habitat zones.

Category	Survey Sites	Shoreland Score (33)	Shoreline Score (33)	Aquatic Score (33)	Mean Score Std Error	Mean Score (100)	Rating
Lake wide	**41**	**26.8**	**26.7**	**29.0**	**3.5**	**82.6**	**Moderate**
Developed	**16**	**16.6**	**20.6**	**24.8**	**5.8**	**62.0**	**Low**
Single-Family Residential	7	18.8	24.8	24.3	7.4	67.9	Moderate
Several Single-Family Residential Lots	5	11.3	10.7	23.3	8.9	45.3	Very Low
Agricultural	2	21.7	31.7	33.3	10.0	86.7	High

Category	Survey Sites	Shoreland Score (33)	Shoreline Score (33)	Aquatic Score (33)	Mean Score Std Error	Mean Score (100)	Rating
Roadway	1	13.3	6.7	13.3	0.0	33.3	Very Low
Boat Access	1	20.0	33.3	30.0	0.0	83.3	Moderate
Undeveloped	**25**	**33.3**	**30.7**	**31.7**	**1.1**	**95.7**	**High**
Undeveloped Wetland	14	33.3	29.0	31.4	1.5	93.8	High
Undeveloped Nonwetland	11	33.3	32.7	32.1	1.3	98.2	High

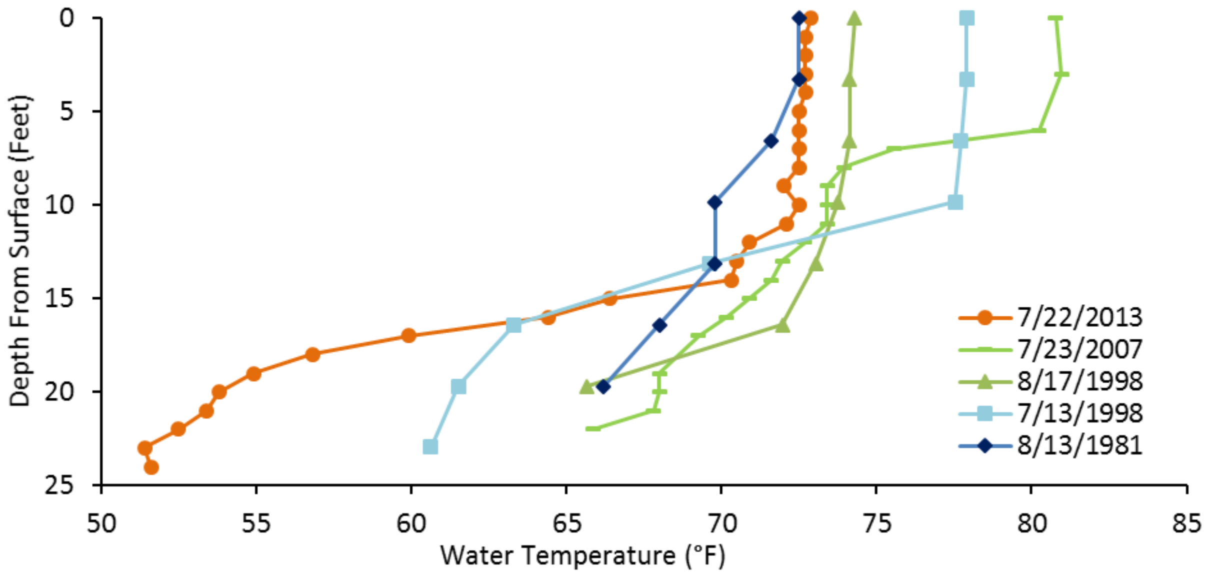
Altered interspecific competition

Altered interspecific competition is unlikely in Lower (South) Island Lake. To date, Chinese Mystery Snails have been the only documented non-native species in the lake, and their effects on the fish community are assumed to be negligible. Therefore, only gamefish management activities could have potential to alter interspecific competition at this time. Prior to 1948, Walleye, Largemouth Bass, Black Crappie, and sunfish species were stocked into Lower (South) Island Lake (DNR, 2016). Walleye fry, fingerlings, and yearlings were stocked at various densities and times between 1948 and 1994. Beginning in 1994, only Walleye fry have been stocked in even years, and in 2000, the stocking rate was increased from 1,000 to 2,000 per littoral acre to increase recruitment of Walleyes to the creel (DNR, 2016). Most Minnesota lakes that are stocked with Walleyes receive an average of 1,000 fry per littoral acre and negative changes to fish community composition have generally not been observed at that rate. Relative abundance of adult Walleye in Lower (South) Island Lake has not changed markedly and is within the inner quartile range for similar lakes, indicating that the fish community has not shifted towards being dominated by Walleye as a result of elevated stocking densities (DNR 2016). Conversely, Yellow Perch densities as measured by gill net catch have exhibited a declining trend in recent surveys, but the observed decline is consistent with the statewide trend (Bethke and Staples, 2015) and may not be a direct result of Walleye stocking. Angler effort and harvest have not been quantified for Lower (South) Island Lake or for many lakes statewide; therefore, no data exists with which to evaluate the effects of angling on fish community composition either within Lower (South) Island Lake or on lakes statewide. Nonetheless, no special regulations have been implemented on Lower (South) Island Lake that might reflect concerns about angler harvest or result in changes to fish community composition through altered interspecific competition.

Temperature regime changes

Modeling indicates that the mean annual air temperature and corresponding water temperature for Lower (South) Island Lake may have increased by an average of 1.6 °F over the last century as a result of climate change, which may be approximately 0.4 °F warmer than for other lakes in the state (Jacobson et al., 2017). Although modeling suggests that water temperature has increased in Lower (South) Island 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 also been measured intermittently during DNR and MPCA sampling between 1981 and 2013 (Figure 65), but the lack of continuous, seasonal, or annual data limits the ability to detect changes over time that could result in changes to the fish community. Because no coldwater species (i.e., Cisco, Lake Whitefish, Burbot, or Lake Trout) have historically been documented in Lower (South) Island Lake, the potential changes to the temperature regime at this time are unlikely to affect the present cool- and warmwater fish communities to the extent that changes to composition are occurring.

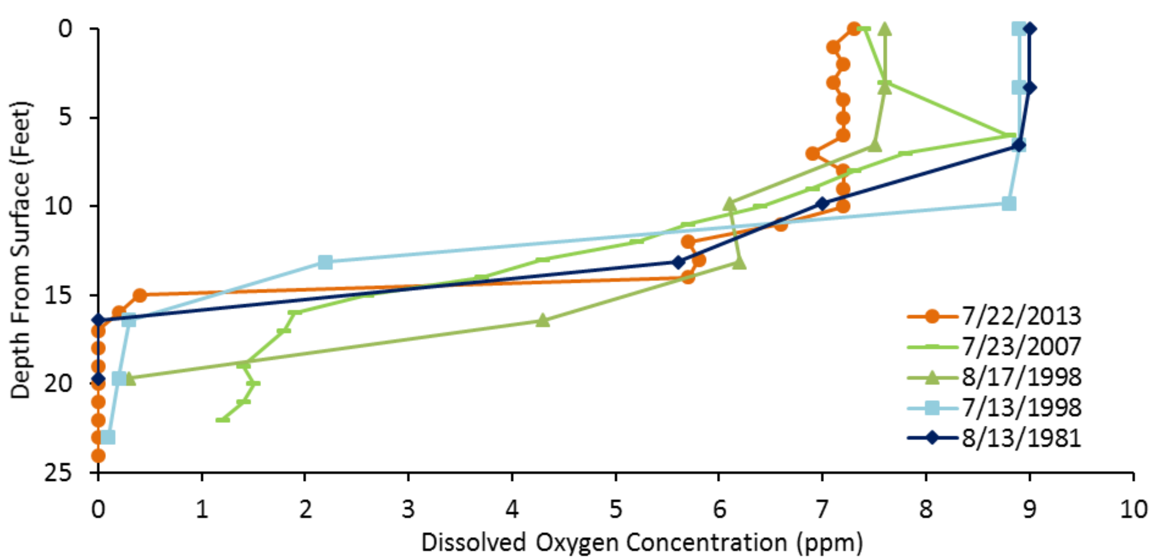
Figure 66. Water temperature (°F) by depth within Lower (South) Island Lake (DOW 09-0060-02) during July and August of 1981, 1998, 2007, and 2013.



Decreased dissolved oxygen

Anecdotal information provided by the DNR Duluth Area Fisheries Office indicates that a minor winterkill was observed in 2013 due to oxygen super-saturation but that changes to the fish community species assemblage were unlikely. No other summer or winterkill events have been reported to date. A review of dissolved oxygen profile data indicates that depths to approximately 14 feet contained adequate concentrations of dissolved oxygen (i.e., greater than 3 ppm) during the summer months when the lake was stratified (Figure 66), but data has not been collected annually or seasonally to more explicitly evaluate changes in dissolved oxygen concentration. Dissolved oxygen concentrations during the winter months have not been measured in recent surveys.

Figure 67. Dissolved oxygen concentration (ppm) by depth within Lower (South) Island Lake (DOW 09-0060-02) during July and August of 1981, 1998, 2007, and 2013.



Conclusions

Eutrophication from excess nutrient inputs is the most likely stressor to the fish community in Lower (South) Island Lake, the only lake in the MRGRW that is currently assessed as impaired for aquatic life use. Similar lakes within the MRGRW that were assessed as fully supporting aquatic life use with FIBI tool 4 had much lower total phosphorus and chlorophyll-a concentrations and much higher water clarity on average (Table 91). Other stressors, such as physical habitat alteration, altered interspecific competition, temperature regime changes, and decreased dissolved oxygen, have been identified as inconclusive causes within the MRGRW and specifically within Lower (South) Island Lake. Although inconclusive, these stressors are occurring at various levels within the watershed but likely, below levels at which changes to fish community health can be detected with the FIBI. Other lakes within the MRGRW have been assessed as impaired for aquatic recreation use and aquatic consumption use (MPCA, 2018b), but they have been or will be discussed in other reports (MPCA, 2018e and 2018f).

Recommendations

Future planning should focus on the prioritization of actions intended to reduce eutrophication and excess nutrient inputs into Lower (South) Island Lake, the surrounding lakes and contributing watershed, and the MRGRW as a whole. In addition to the recommendations outlined in this report, the concurrent TMDL study (MPCA, 2018e) should provide further guidance and recommendations. Actions outlined in both reports should be taken to reduce the effects of eutrophication on the health of fish and other aquatic life.

Further actions can be taken to reduce the effects of eutrophication and to minimize nutrient inputs into Lower (South) Island Lake from the surrounding landscape. Although agricultural land constitutes only a small percentage of the land within the contributing watershed, application of appropriate quantities of fertilizer, planting of cover crops, and maintenance of riparian buffer zones around lakes, rivers, and ditches can further minimize negative effects to lake health. Additionally, measures should continue to be taken to minimize potential negative effects of peat mining activity to surface water in the watershed. Examples of measures that have already been implemented include construction and maintenance of sedimentation basins to remove suspended solids and nutrients from peat mine surface drainage as well as ongoing monitoring of water quality in the area (MPCA, 2004). Furthermore, once peat associated with the mine area is depleted, the operation is required to leave a minimum of 16 inches of peat in the mining area and restore the land—including ditches, settling basins, and drainage outlets—with native vegetation (DNR, 1986). Proper reclamation activities will be important to minimize potential long-term effects to the surrounding watershed once mining ceases.

Future construction and restoration projects related to residential development, roadways, or agriculture in areas adjacent to the lakeshore should also be carefully planned to reduce nutrient inputs and promote high quality riparian habitat. Individual sewage treatment systems are present on many properties surrounding the lake, and all should be routinely inspected for compliance and maintained to minimize negative effects to lake health. Lakeshore property owners should also be mindful of the potential consequences that other activities such as application of lawn fertilizer, removal of natural shoreline buffers and aquatic plants, and addition of sand blankets for swimming beaches can have on water quality and important habitat for fish and other aquatic life. Lakeshore property owners should consider planting riparian buffer strips to replace open lawn areas immediately adjacent to the water's edge, implementing appropriate lakescaping habitat improvement techniques (DNR, 2018e), limiting the amount of fertilizer applied to lawns, and limiting removal of aquatic vegetation and woody habitat. Large tracts of undeveloped land, particularly along the southeastern shore of Lower (South) Island Lake can serve as an example of naturally occurring and ecologically important shoreline habitat.

Several projects have been implemented in recent years to reduce nutrient inputs, and they serve as great examples for future planning efforts. For example, in 2007, all lakeshore properties within Cromwell city limits gained access to the city sewer system, and to date, all associated properties have been connected. Likewise, in 2010, a shoreland improvement project was completed near the public swimming beach by the city of Cromwell and the Big Sandy Area Lakes Watershed Management Project. The project involved construction of a diversion and rain garden that are intended to reduce runoff, lawn clippings, and associated nutrient inputs directly into the lake from the swimming beach area. Continued support for similar activities that minimize inputs of excessive nutrients into Lower (South) Island Lake and the contributing watershed, including Eagle Lake, are encouraged. Furthermore, continued monitoring of water quality trends and fish community health should be supported to evaluate the effects of project implementation, particularly as improvements may take years to begin positively affecting water quality and fish community health.

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