Mississippi River - Headwaters Watershed Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities

Minnesota Pollution Control Agency

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Acronyms, abbreviations, and term definitions

AUID	Assessment Unit (Identification Number) MPCA's a pre-determined stream segments used as units for stream/river assessment – each has a unique number.
CALM	Consolidated Assessment and Listing Methodology. The protocol used in MPCA's assessment of designated use attainment for surface waters.
CR	County Road
CSAH	County State Aid Highway
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DNR	Minnesota Department of Natural Resources
DS	Downstream
GIS	Geographic Information System
HDS	Human Disturbance Score – a measurement of human disturbance at and upstream of a biological monitoring site.
HUC	Hydrologic Unit Code (a multi-level coding system of the US Geological Survey, with levels corresponding to scales of geographic region size)
HSPF	The hydrologic and water quality model **H**ydrologic **S**imulation **P**rogram **F**ortran.
IBI	Index of Biological Integrity – a multi-metric index used to score the condition of a biological community.
ISTS	Individual Sewage Treatment Systems
IWM	MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling.
LWH/LWD	Large Wood Habitat or Large Woody Debris
m	The abbreviation for meter
mg/L	Milligrams per liter
µg/L	Micrograms per liter (1 milligram = 1000 micrograms)
Macrophyte	Macro (= large), phyte (= plant). These are the large aquatic plants, such as *Elodea* and Coontail.
MRHW	Mississippi River-Headwaters Watershed
MSHA	Minnesota Stream Habitat Assessment
M&A Report	MPCA Monitoring and Assessment Report for the Bois de Sioux River Watershed
MS4	Municipal Stormwater Plan, level 4
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)
Palustrine wetland	A US Fish and Wildlife Service wetland classification which includes marshes, small ponds, wet meadows, fens, and bogs.
PJG	Professional Judgment Group – a multi-agency staff group which met to verify assessments.
SID	Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.

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
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 - a sensitivity value given to each taxon.
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
EPA	United States Environmental Protection Agency
WRAPS	Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.
WWTP	Wastewater Treatment Plant
10X	Ten times (chemistry samples collected on 10 dates)
303(d) list	The official, EPA-accepted list of impaired waters of the state.

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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-Headwaters Watershed (MRHW). 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 MRHW is situated within a mostly non-agricultural, forested region of north central MN. Agricultural land usage is primarily concentrated in the far northwestern part of the watershed and just east of Bemidji, where most of the agricultural land use is pasture/hay, with a relatively small amount of cultivated acreage. Remaining areas have much-less dense field acreage, which is predominantly pasture/hay. Major portions of the MRHW are within the Leech Lake Reservation, or the Chippewa National Forest, and most of Itasca State Park in contained within the MRHW. As such, development in much of the watershed is very low density. Bemidji is the largest city. Another major landscape factor in the MRHW is the extensive wetland acreage, much of it being the palustrine type.

Three Assessment Unit Identification (AUID) reaches on three streams were brought into the SID process because they had one or both of the sampled biological communities scoring below the impairment thresholds. A fourth AUID received additional monitoring in the SID process to examine a previously listed low dissolved oxygen (DO) impairment, that being the headwaters AUID of the Mississippi River. The 2015 Assessment phase of the Intensive Watershed Monitoring (IWM) portion of the Watershed Restoration and Protection Strategy (WRAPS) project determined that none of these streams were biologically impaired, due to stream conditions limited by natural factors. The Mississippi River AUID-753 historical DO impairment is being changed on the 2016 303(d) list to not accessible, with reasoning being heavy wetland influence per May 2015 guidance by MPCA's Assessment Policy Team.

Streams with low-scoring biological communities and other investigations:

- Sucker Creek (AUID 07010101-663) - Macroinvertebrates
- Gull River (AUID 07010101-551) - Fish
- Sugar Brook (AUID 07010101-692) - Fish
- Mississippi River (AUID 07010101-753) - 1994 Low-DO 303(d) listing

One lake had a fish IBI near the impairment threshold, and was investigated and included in this report:

- Grace Lake (29-0071-00) - Fish are nearing the impairment threshold, and the lake is considered vulnerable.

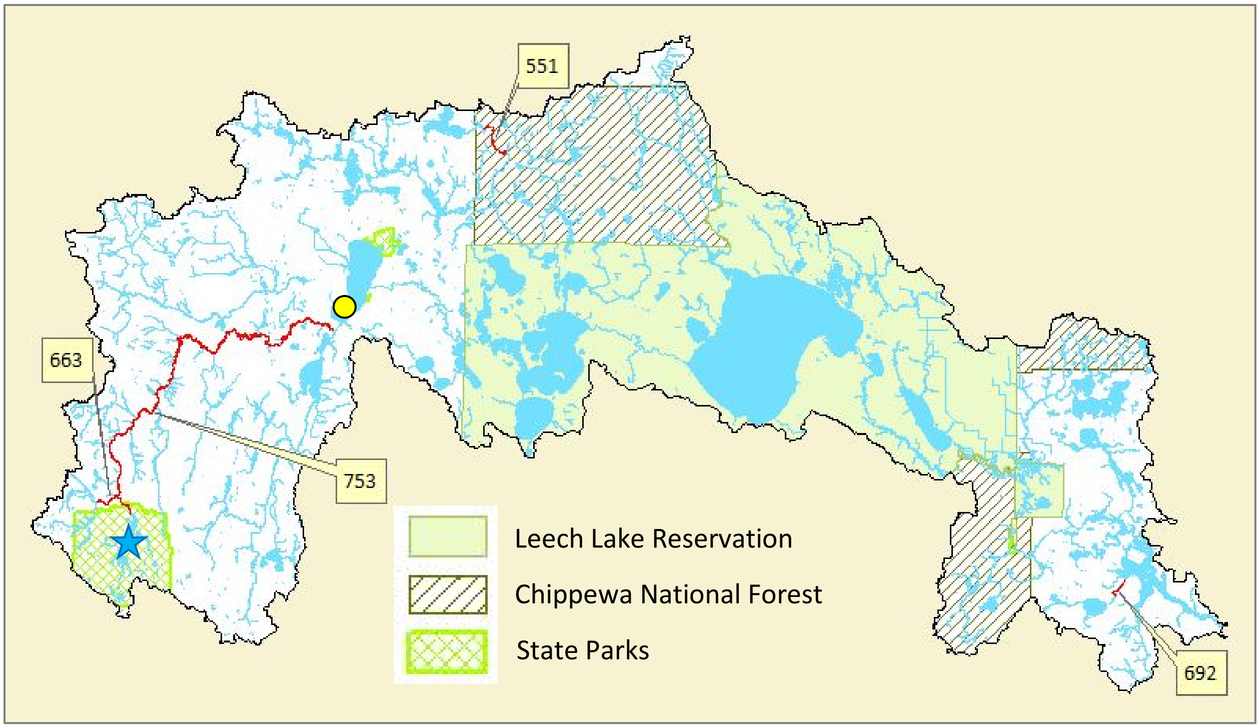

Figure 1. Stream reaches (in red) with SID investigations in the MRHW. Labels are AUID number. The blue star depicts Lake Itasca, and the yellow dot is the city of Bemidji.

Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed the Major Watershed Restoration and Protection Strategy (WRAPS) for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds. A WRAPS is comprised of several types of assessments. The MPCA conducted the Intensive Watershed Monitoring Assessment (IWM) part of the WRAPS during the summers of 2013 and 2014. The IWM assessed the aquatic biology and water chemistry of the Mississippi River-Headwaters Watershed (MRHW) streams and rivers. The SID builds on the results of the IWM. The MPCA conducted the SID assessment during 2014 - 2016. This document reports on this second step of the multi-part WRAPS for the MRHW.

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-Headwaters 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 MRHW webpage: https://www.pca.state.mn.us/water/watersheds/mississippi-river-headwaters.

Landscape of the MRHW

A detailed description of various geographical and geological features of the landscape of the MRHW is documented in the Mississippi River-Headwaters Monitoring and Assessment Report (MPCA, 2016). That information is useful and necessary for understanding the settings of the various MRHW's subwatersheds, and how various landscape factors influence the hydrology within the MRHW. The following information is intended to provide a basic description of the MRHW landscape.

The majority of the MRHW is relatively flat terrain. As such, the streams and rivers that run throughout the watershed are primarily low gradient. 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. Slow flows can influence the DO levels in the streams. Low gradient streams can also take on wetland characteristics. A large percentage of river miles within the MRHW have wetland riparian corridors, with either emergent wetland vegetation or palustrine wetlands (sedge meadows).

The original, pre-settlement landscape was almost exclusively forests, wetlands, and lakes (Figure 2). The forest types formed a complex mosaic. 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 landscape is still in a forested state. The primary area utilized for agriculture is in the far northwestern part of the watershed, in the area around the towns of Solway and Shevlin, and an area

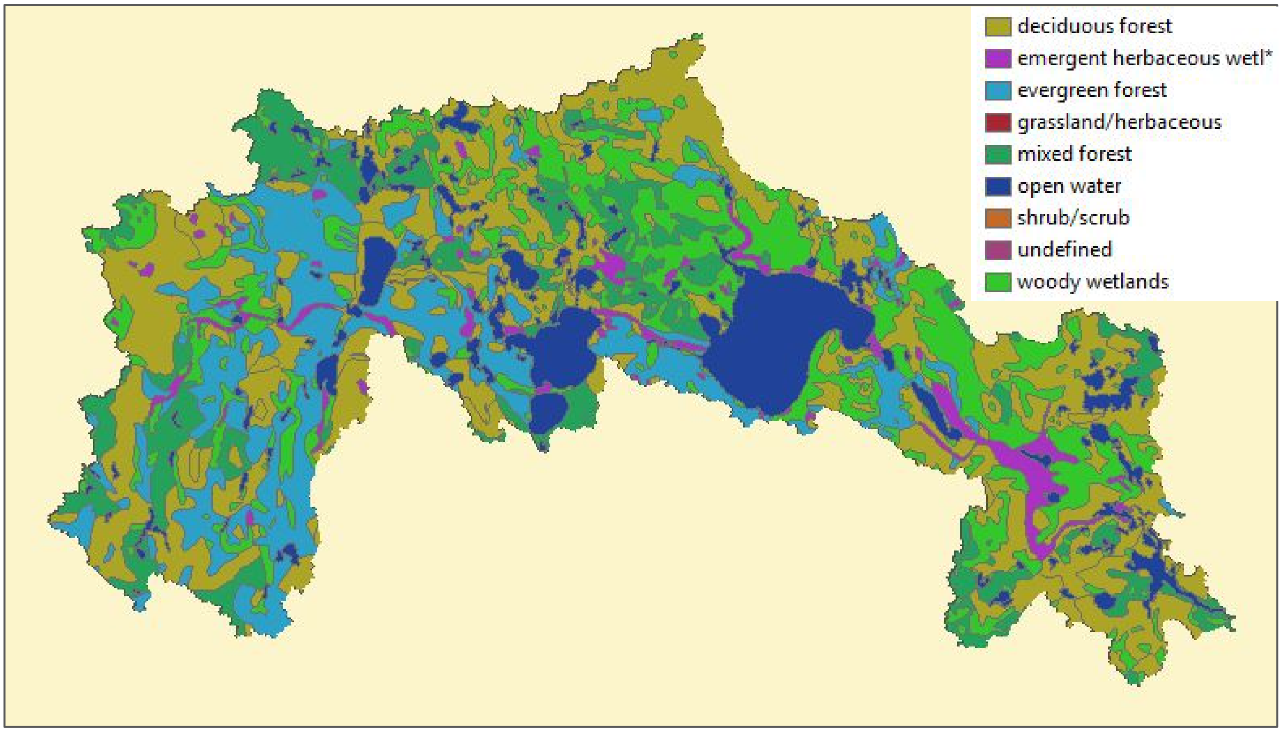

Figure 2. Original vegetation of the MRHW and adjacent watersheds, (Marchner, 1930).

just southeast of Bemidji. The agriculture occurring there is primarily hay and cattle production, with some row crop fields as well. The percentages of various categories of land cover are presented in Table 1. Figure 3 shows the extent of land area that is currently Palustrine wetland, especially abundant in the eastern two-thirds of the MRHW.

Table 1. Percentages of the various land cover types from 2011 NLCD GIS coverage (MPCA, 2016).

Land cover type	Percent of Land Area
Developed (all intensities grouped)	2.9
Cultivated Crops	1.2
Water, wetlands, and forest lands	87

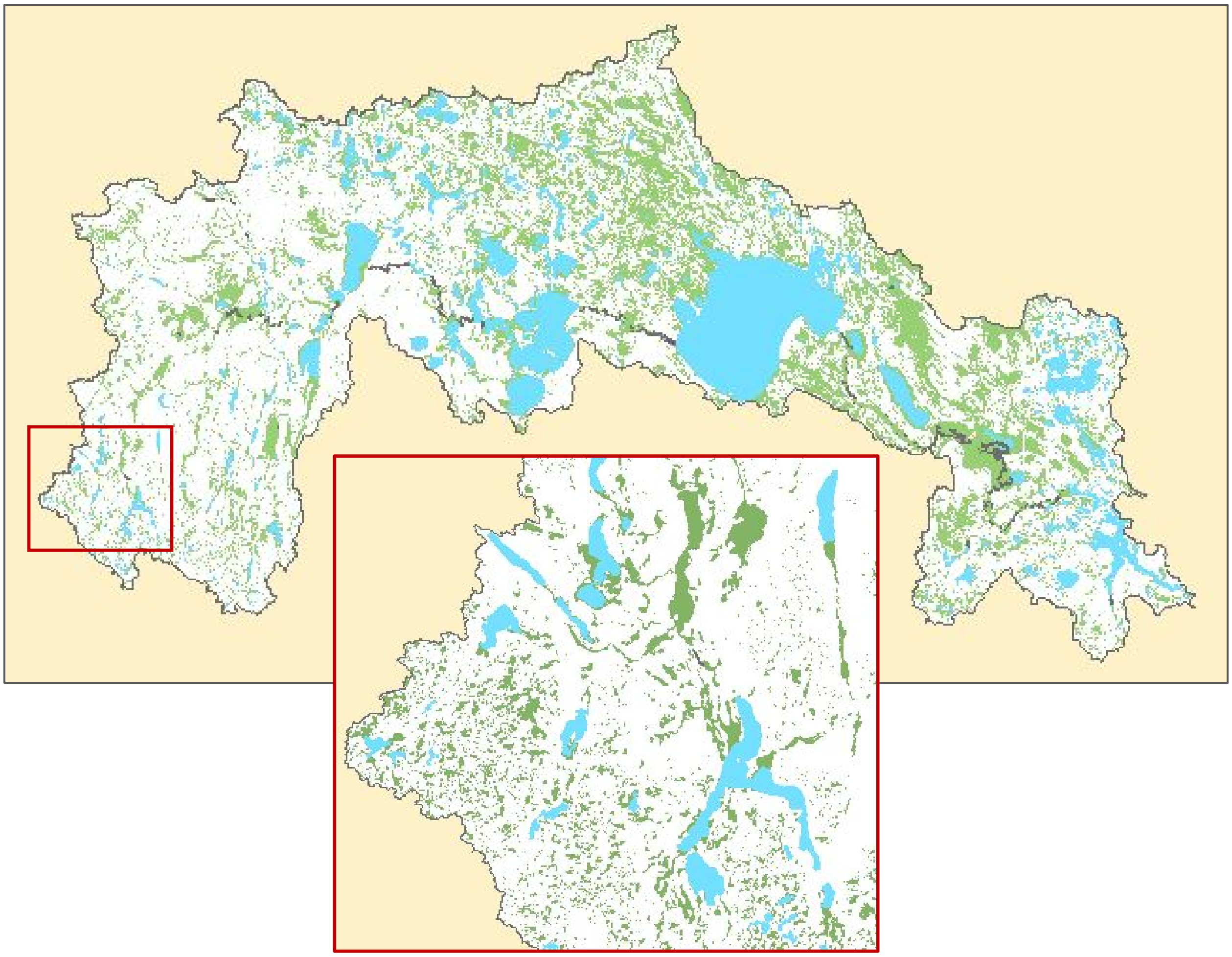

Figure 3. Wetland area as determined by the National Wetland Inventory. Blue is lakes, green is palustrine wetland, and dark purple (very limited) is riverine wetland (along the Mississippi River channel). The enlarged inset shows the dense pattern of small wetlands in the area around Lake Itasca.

Determination of candidate 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, mining, 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. The data sources include numerous GIS coverages, aerial photography, and the Minnesota Department of Natural Resources (DNR) Watershed Health Assessment Framework. Additionally, census records and various MPCA records, such as National Pollutant Discharge Elimination System (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, 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 MRHW for many years. The determination of candidate stressors used both the historical data and data collected during the 2013 IWM. Preliminary hypotheses were generated from all of these types of data, and the SID process (including further field investigations) sought to confirm or refute the preliminary hypotheses.

DNR Watershed Health Assessment Framework

DNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The WHAF includes an assessment of the nonpoint source pollution threat to water quality within the water quality component. The data shows non-point pollution, relative to other parts of the state, is not a widespread stressor in the MRHW Figure 4. According to the Non-point Source Pollution Index, the MRHW ranks as tied for 14th out of the 80 watersheds in Minnesota (where 1st is best, or has least threat). This equates to the 84th percentile. A major urban source of non-point pollution is runoff from impervious surfaces. Due to the small sizes of most of the cities/towns in the MRHW, this threat is very low overall (Figure 5). There are localized situations, such as the area near Bemidji or even more localized area such as immediate shoreline properties of lakes with significant development, where impervious surfaces may be an important water quality issue. Streams and rivers in the MRHW generally do not have anywhere near the degree of shoreline development as area lakes, and thus this threat is particular to lakes.

The Localized Pollutant 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 due to the very low numbers of point source dischargers. The WHAF map for the Localized Pollutant Source Index showed that all of the subwatersheds are among the green scale colors (in the good range) except for a few subwatersheds in and around Bemidji, and one very small subwatershed near Grand Rapids. The index score for the MRHW was > 90 out of 100. There are only two municipal wastewater dischargers, and these discharge to larger river reaches (the Bemidji WWTP discharges to the Mississippi River channel between Lake Irving and Lake Bemidji, and the Deer River WWTP discharges to an intermittent stream channel/wetland that flows to the Deer River), so smaller streams are not affected by point source effluent. There are some specific locations that have relatively high septic system densities per the WHAF tool output (Figure 6); these locations coincide with Lake Bemidji and Lake Pokegama, and are likely septic systems from lakeshore properties, and thus may cause very localized lake concerns, while not affecting the MRHW streams). Additional statistics for several stressors are presented in Table 2.

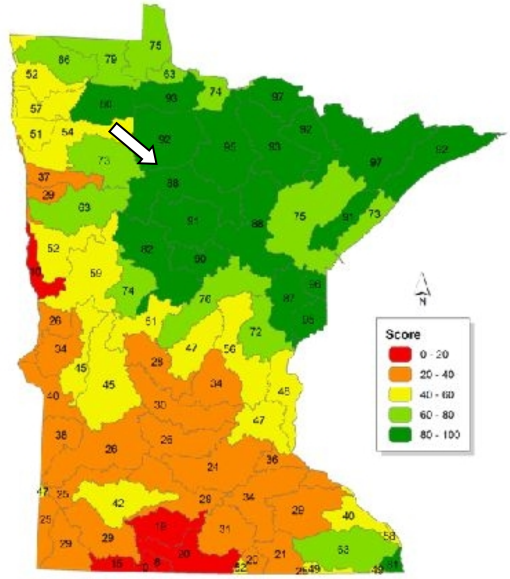

Figure 4. Scores and categorical ranking of the 80 Minnesota Major Watersheds for the DNR Non-point Source Pollution Index.

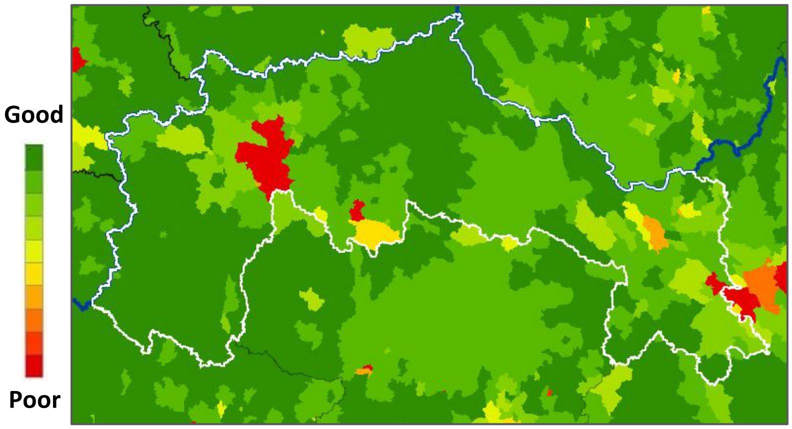

Figure 5. Catchment-scale impervious surface scores for the MRHW (white boundary) and surrounding watersheds.

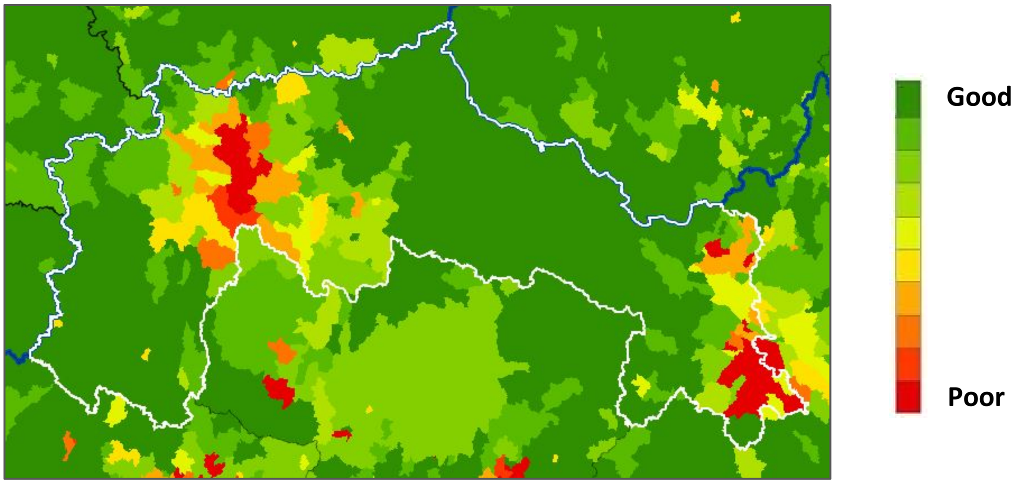

Figure 6. The WHAF Septic metric within the Nonpoint Source Index for the MRHW.

Table 2. Ranking of several attributes of the MRHW relative to Minnesota's 80 watersheds. A low rank number is a positive, while a higher rank is a negative for water quality. Phosphorus Risk pertains to upland sources. Calculations used data from DNR's WHAF, downloaded on Jan. 6, 2016.

	Impervious Surface (2011)	Nonpoint Threat	Point Sources	Water Storage Loss	Perennial Cover	Phosphorus Risk	Aquatic Connectivity
Rank	29 (t)	14 (t)	33 (t)	12 (t)	15 (t)	20 (t)	19

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

The overall WHAF scorecard, which includes many more metrics, can be found at:

http://www.dnr.state.mn.us/whaf/explore/index.html

Non-IWM MPCA monitoring programs

Aside from the IWM monitoring, the 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. The MPCA also provides water quality monitoring grants to local organizations; in addition, this data, as well as all of the MPCA-collected data, are 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 are 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 MRHW is quite sparsely populated (aside from the Bemidji area) relative to the state as a whole. A majority of the MRHW is located in Itasca and Beltrami Counties, with lesser amounts in Cass and Hubbard Counties, and a very small piece in Becker County. Though relatively sparsely-populated relative to some parts of Minnesota, recent population trends show both of these two primary counties have experienced substantial population growth from 1990 – 2010 (10.3% and 29.3% respectively) according to U.S.

Census data (MSDC, 2015). This likely means stress to the MRHW's waterbodies has and may continue to increase.

A relatively small number of towns are within the MRHW; with the exceptions of the cities of Bemidji (pop. 13,431), and Cohasset (2698), all are fairly small communities. Other towns include Shevlin (176), Solway (96), Wilton (204), Turtle River (77), Tenstrike (201), Cass Lake (770), Deer River (930), and Zemple (93) - population data from the 2010 US Federal Census. Only Bemidji is large enough to require an MS4 stormwater plan. Recent GIS-derived land use statistics showed that 2.9% of the watershed area is categorized as Residential/Commercial (MPCA, 2016). Statistics for urban stressors such as impervious cover and point source pollution were shown above. The census and urbanization information suggests that most stressors related to population density are likely only active at highly localized areas (e.g., Bemidji, or lakeshore development acting on a particular lake).

One potential source of water resource stressors in rural areas is subsurface sewage treatment systems. Unsewered areas can have old septic systems that are either failing or not conforming to current design standards. Most rural homes/cabins in the MRHW are not connected to a municipal sewer system, and thus have individual treatment systems. Rural areas may also have some residences that discharge wastes directly to streams, though this is unlawful, and the numbers of such systems are declining. These systems can contribute significant levels of nutrients and other chemicals to water bodies. Recent septic system statistics for Itasca and Beltrami (only the “Greater Bemidji” area) Counties estimate 3 and0% of the individual treatment systems to be “Imminent Public Health Threats” (i.e., direct discharge to stream), 27 and 7% “Failing”, and 70 and 93% of systems in compliance (MPCA 2012). These statistics are somewhat average for Itasca Co. and quite good for “Greater Bemidji”, relative to many of Minnesota’s counties. Data for other parts of Beltrami County. are not available. Given that a many of these systems are on lakeshore properties, failing septic systems could be a problem for lake water quality, but should not be a significant contributor to water quality problems in MRHW streams, except perhaps in very localized places.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The MRHW has relatively little industry except in Bemidji and Cohasset, and there are four industrial NPDES permits within the MRHW. Thus, industrial discharges should not be a source of pollutants (stressors) causing stream impairment in the great majority of the MRHW.

Forestry

Forest harvest can stress on water resources if practices reduce stream shading or lead to erosion. Some lands within the MRHW are used for timber production and historical large-scale forest removal occurred in the watershed in the late 1800s and early 1900s. Most of the non-wetland land area in the MRHW was originally forested (Marchner, 1930). Therefore, stressors related to historical and current forest management practices are possibly occurring in the MRHW, and conversions of forest to non-forest landcover may still occur. A good discussion of the history of logging in the MRHW can be found in the MRHW M&A Report (MPCA 2016).

Agricultural activities

The lands of the MRHW, as with those in much of north central Minnesota, are not extensively used for row crop agricultural production. The area of the MRHW that has more than just sparse agriculture fields is the far northwestern part of the watershed, in the area around the towns of Solway and Shevlin, and just southeast of Bemidji. The agriculture occurring at these locations is primarily hay and cattle production, with some row crop fields as well. Animal agriculture is strongly correlated to these same areas, with most registered feedlots occurring in the western half of the watershed (Figure 7). The review of the MRHW’s land use, shown previously (Table 1), indicates that approximately 1.2% of the land cover is in cultivated crops. It is reasonable to consider whether agricultural activities might be a possible contributor to water quality problems in the locations specified above, though their 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). Known agriculture-related stressors include nutrients, sediment, and altered hydrology.

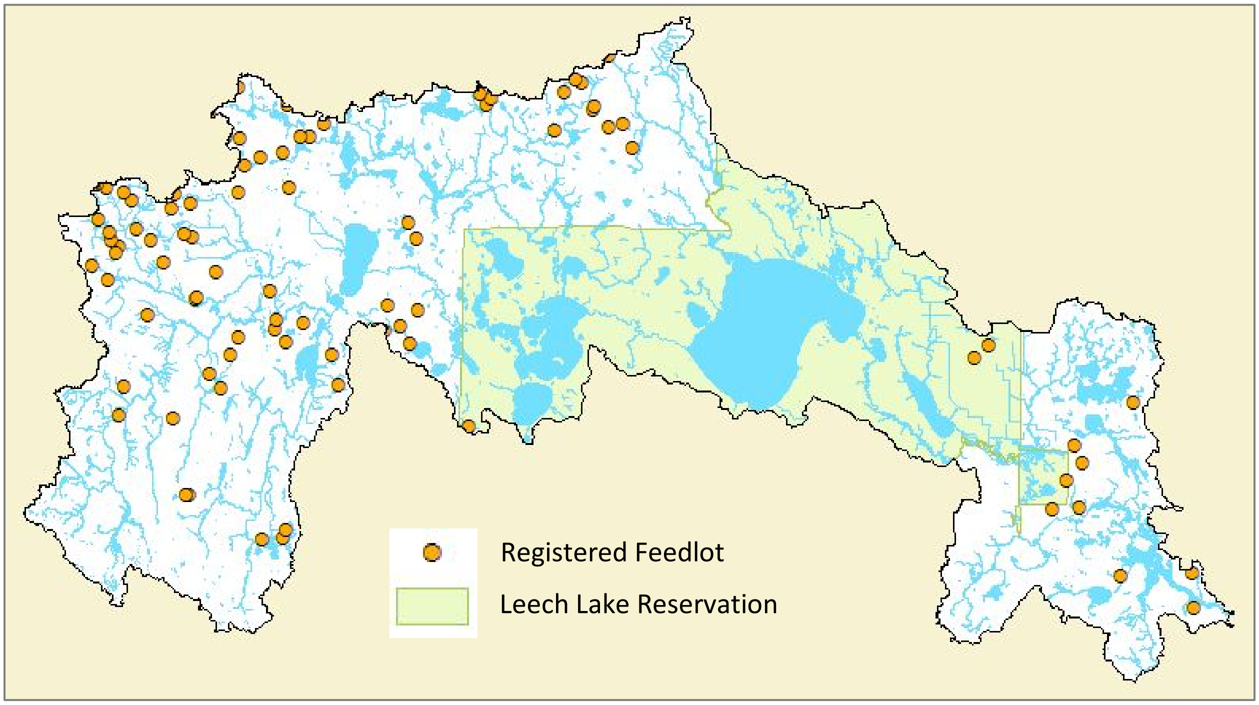

Figure 7. Registered feedlot locations (≥ 50 animal units) in the MRHW.

Another common result of agricultural activity is elevated nutrients in the water resources located in or downstream from those areas (Sharpley et al., 2003, Riseng et al., 2011, MPCA, 2013). With the substantially lesser degree of agriculture occurring in the MRHW relative to some other Minnesota regions, elevated nutrients from agriculture will not be a systemic issue in the MRHW, but could occur in localized areas.

Pesticides

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. Minnesota Department of Agriculture (MDA) conducts Minnesota pesticide monitoring, and no sampling has been done in the streams discussed below. More information about 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.

It should be noted that this area has potential for agricultural expansion. Areas in watersheds just south of the MRHW watershed have seen significant acreage of forest land converted to irrigated corn, soybean, and potato fields in recent years. This conversion trend has the potential to expand into this watershed.

Summary of Candidate Stressor Review

Based on the review of human activity in the MRHW in general, and then specifically in the two locations with biological impairment, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the MRHW, resulting in seven of the candidate causes moving forward for more detailed investigation.

Eliminated causes

- Industrial stressors (i.e., toxic chemical, high conductivity discharges)
- Mining stressors
- 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 from historical and IWM sampling revealed extremely low concentrations in the MRHW.
- 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 current forest harvest, though understanding and quantifying the effects of forest harvest, and threshold levels for stress to occur to streams is not well known. There are current efforts underway or planned to better understand the effects of forest harvest impacts on streams.

Candidate causes

- Low dissolved oxygen
- Excess sediment (both suspended and deposited)
- Altered hydrology
- Altered geomorphology
- Habitat loss
- Connectivity loss
- Elevated phosphorus

Mechanisms of candidate stressors and applicable standards

This section presents a brief overview of the pathway and effects of each candidate stressor. EPA (2012a) has additional information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on their CADDIS website at http://www.epa.gov/caddis/ssr_home.html.

Dissolved oxygen

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

Human activities can alter many of these driving factors and change the DO concentrations of water resources. Increased nutrient content of surface waters is a common human influence, which results in excess aquatic plant growth. This situation often leads to a decline in daily minimum oxygen concentrations and an increase in the magnitude of daily DO concentration fluctuations due to the decay of the excess organic material, increased usage of oxygen by plants at night, and their greater oxygen production during the daytime. Humans may directly add organic material by municipal or industrial effluents. Other human activities that can change water temperature include vegetation alteration and changes to flow patterns.

Aquatic organisms require oxygen for respiration. Inadequate oxygen levels can alter fish behavior, such as moving to the surface to breathe air, or moving to another location in the stream. These behaviors can put fish at risk of predation, or may hinder their ability to obtain necessary food resources (Kramer, 1987). Additionally, low DO levels can significantly affect fish growth rates (Doudoroff and Warren, 1965). Fish species differ in their preferred temperature ranges (Dowling and Wiley, 1986), so alterations in water temperature (and DO) from the natural condition will alter the composition of fish communities. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1992). Heiskary et al. (2013) observed several strong negative relationships between fish and macroinvertebrate metrics and higher daily DO fluctuations. Increased water temperature raises the metabolism of organisms, and thus their oxygen needs, while at the same time, the higher-temperature water holds less oxygen. Some aquatic insect species have anatomical features that allow them to access atmospheric air, though many draw their oxygen from the water column. Macroinvertebrate groups (Orders) that are particularly intolerant to low DO levels include mayflies (with a few exceptions), stoneflies, and caddisflies.

Minnesota dissolved oxygen standards

The DO standard (as a daily minimum) is 5 mg/L for class 2B (warmwater) streams and 7 mg/L for class 2A (coldwater).

Types of dissolved oxygen data

1. **Point measurements**

   Instantaneous (one moment in time) DO data has been collected at numerous locations in the MRHW and used as an initial screening for low DO reaches. Because DO concentrations can vary significantly with changes in flow conditions and time of sampling, conclusions using instantaneous measurements need to be made with caution.

2. **Longitudinal (synoptic)**

   This sampling method involves collecting simultaneous (or nearly so) readings of DO from several locations along a significant length of the stream path. It is best to perform this sampling in the early morning in order to capture the daily minimum DO readings.

3. **Diurnal (continuous)**

   Short interval, long time period sampling using deployed YSI™ water quality sondes (a submerged electronic sampling devise) provides a large number of measurements to reveal the magnitude and pattern of diurnal DO flux at a site. This sampling captures the daily minimum DO concentration, and when deployed during the peak summer water temperature period, also allows an assessment of the annual low DO levels in a stream system.

Altered hydrology

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

Reduced Flow

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

Increased flow

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

Water quality standards

There currently is no applicable standard for flow alteration. However, flow changes may alter the concentrations of other chemical parameters that do have standards and improving flow volumes may resolve a failing chemical standard.

Types of flow alteration data

Stream gaging stations are located in each major watershed of the state. The stations have differing lengths of monitoring history, and some are very new. Models can be used to predict the degree of hydrologic alteration in a watershed or subwatershed when measured data are not available. An indirect determination of flow alteration can be found via geomorphological measurements, as channel form and dimensions are related to flow volumes.

Increased sediment (suspended and deposited)

Sediment and turbidity have been shown to be among the leading pollutant issues affecting stream health in the United States (EPA, 2011). Recent studies in Minnesota have demonstrated that human activities on the landscape have dramatically increased the sediment entering our streams and rivers since European settlement (Triplett et al., 2009; Engstrom et al., 2009). Sediment can come from land surfaces (e.g., exposed soil), or from unstable stream banks (see geomorphology section for details). The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently-vegetated pastures. Human actions on the landscape, such as channelization of waterways, riparian land cover alteration, and increased impervious surface area can cause stream bank instability leading to sediment input from bank sloughing. Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can be detrimental to aquatic organisms.

Suspended sediment

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

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

Deposited sediment

Whereas suspended sediment is a stressor operating in the water column, sediment is also deposited onto the stream bottom, and thus can have different effects on organisms oriented to living on or within the streambed substrate (this includes many of the macroinvertebrate taxa). Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refuge, and/or reproduction (Newcombe et al., 1991). Excessive deposition of fine sediment can degrade macroinvertebrate habitat quality, reducing productivity and altering the community composition (Rabeni et al., 2005, Burdon et al., 2013). Aquatic macroinvertebrates are affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance behavior, using current to seek a new suitable location) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Pekarsky 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman, 1988); and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985; Gray and Ward, 1982). Fish species that are simple lithophilic spawners require clean, coarse substrate for reproduction. These fish do not construct nests for depositing eggs, but rather broadcast them over the substrate. Eggs often find their way into interstitial spaces among gravel and other coarse particles in the stream bed. Increased sedimentation can reduce reproductive success for simple lithophilic spawning fish, as eggs become smothered by sediment and become oxygen deprived.

Water quality standards

The previous water quality standard for suspended sediment was based on turbidity. Minnesota has recently completed the process of moving to a standard based on TSS. The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The new TSS standard for the MRHW is 15 mg/L. A Secchi tube measurement of 40 cm of visual transparency is a surrogate for the TSS standard. There is no current standard for deposited sediment in Minnesota.

Types of sediment data

Particles suspended in the water column can be either organic or mineral. Generally, both are present to some degree and measured as TSS. Fine mineral matter generally comes from soil erosion of land surfaces or stream banks. TSS is determined by collecting a stream water sample and having the sample filtered and weighed to determine the concentration of particulate matter in the sample. To determine the mineral component of the suspended particles, a second test is run using the same procedure except to burn off the organic material in an oven before weighing the remains, which are only mineral material. Quantitative field measurement of deposited sediment (bedload) is very difficult. Deposited sediment is estimated by measuring the degree to which fine material surrounds rock or woody substrate within the channel (embeddedness). Deposited sediment is also analyzed by randomly measuring numerous substrate particles (Wolman pebble count) and calculating the D_{50} (diameter of the 50th percentile particle) size.

Elevated nutrients (phosphorus)

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

Water quality standards

The MPCA has developed standards for P designed to protect aquatic life (Heiskary et al., 2013). Total Phosphorus (TP) criteria were developed for three geographic regions (Table 3). The TP standard is a maximum concentration also requiring at least one of three response variables exceeding its threshold.

Table 3. River eutrophication criteria ranges by River Nutrient Region for Minnesota. The MRHW is placed in the North Region.

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

Types of phosphorus data

Phosphorus samples have been collected from streams and rivers throughout the MRHW, both prior to and as part of the IWM process. Samples are analyzed by a state certified laboratory and the data is stored in a publicly available database: http://cf.pca.state.mn.us/water/watershedweb/wdip/search_more.cfm

Elevated nutrients (nitrate nitrogen)

Nitrate (NO_3) and nitrite (NO_2) forms of nitrogen are components of the natural nitrogen cycle in aquatic ecosystems. NO_2 anions are naturally present in soil and water, and are readily converted to NO_3 by microorganisms as part of the denitrification process of the nitrogen cycle. As a result, nitrate is far more abundant than nitrite. Although the water test commonly used measures, both nitrate and nitrite, because a very large percent is nitrate, from here on this report will refer to this data as being nitrate. Nitrogen is commonly applied as a crop fertilizer. Nitrogen transport pathways can be different depending on geology and hydrology of the watershed. When water moves quickly through the soil profile (as in the case of watersheds with surficial sand, karst geology, or heavily tiled watersheds) nitrate transport can become very significant. Lefebvre et al. (2007) determined that fertilizer application and land-cover were the two major determinants of nitrate signatures observed in surface water and that nitrate signatures in surface waters increased with fertilization intensity. A statewide nitrogen study in Minnesota found that the breakdown of cropland nitrogen sources was: 47% commercial fertilizer application, 21% from cropland legume fixation, 16% from manure application, and 15% from atmospheric deposition (MPCA, 2013). These land applications can reach waterways through surface runoff, tile drainage, and leaching to groundwater, with tile drainage being the largest pathway (MPCA, 2013). Other nitrogen sources are non-compliant septic systems and municipal wastewater discharges. For more information on the sources and effects of nitrate, see the EPA's CADDIS webpages: http://www.epa.gov/caddis/ssr_nut_int.html .

Apart from its function as a biological nutrient, some levels of nitrate can become toxic to organisms. Nitrate toxicity is dependent on concentration and exposure time, as well as the sensitivity of the individual organisms. The intake of nitrate by aquatic organisms converts oxygen-carrying pigments into forms that are unable to carry oxygen, thus inducing a toxic effect on fish and macroinvertebrates (Grabda et al., 1974; Kroupova et al., 2005). Certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity according to Camargo and Alonso (2005), who cited a maximum level of 2.0 mg/L nitrate-N as appropriate for protecting the most sensitive freshwater species and nitrate-N concentrations under 10.0 mg/L to protect several other sensitive fish and aquatic invertebrate taxa. For toxic effects of chemicals, see EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_tox_int.html .

Water quality standards

Minnesota currently does not have an aquatic life use nitrate standard, though MPCA has an active program developing one.

Ecoregion information

As there is no current standard for nitrate, it can be helpful to compare sampled sites to area norms from streams that are minimally impacted by human activity. This allows some understanding of whether a parameter is elevated. McCollor and Heiskary (1993) compiled nitrate (+ nitrite) N data for minimally impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. The MRHW falls within the Northern Lakes and Forests ecoregion, which has an ecoregion norm of 0.09 mg/L for nitrate+nitrite, N.

Types of Nitrate Data

Nitrate (+ nitrite) samples have been collected from stream and river locations throughout the MRHW. Samples were analyzed by a state certified laboratory and the data is stored in a publicly available database: http://cf.pca.state.mn.us/water/watershedweb/wdip/search_more.cfm.

Candidate cause: Physical habitat loss

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. The focus here will be on physical habitat. USEPA's CADDIS website (2012a) lists six broad categories that form a stream's overall physical habitat: 1) stream size and channel dimensions, 2) channel gradient, 3) channel substrate size and type, 4) habitat complexity and cover, 5) vegetation cover and structure in the riparian zone, and 6) channel-riparian interactions. Physical habitat loss is often the result of other stressors (e.g., sediment, flow volumes, DO) and so the reader is directed to other stressor sections for more detail.

Degraded physical habitat is a leading cause nationally of impairment in streams on state 303(d) lists.

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on the landscape by way of resource extraction, agriculture, forestry, urbanization, and industry. Channelizing streams leads to an overall more homogeneous habitat, with loss of important microhabitats needed by particular species (Lau et al., 2006). These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat, or reduced habitat quality, such as embedded gravel/cobble substrates. In the past, it was common to remove large woody debris (LWD) from stream channels for various reasons. It has now been shown (Gurnell et al., 1995, Cordova et al., 2006, and Magilligan et al., 2008) that LWD is very important in creating habitat (causes scour pools, provides cover for fish and creates pockets of protection from faster currents, and a living surface for macroinvertebrates that cling to hard objects).

Just like for terrestrial settings and those animals, aquatic population and community changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (EPA, 2012a).To learn more about physical habitat see the EPA CADDIS webpage: http://www.epa.gov/caddis/ssr_phab_int.html .

Water quality standards

There are no state water quality standards for physical habitat.

Types of physical habitat data

MPCA biological monitoring crews conduct a qualitative habitat assessment using the MPCA Stream Habitat Assessment (MSHA) protocol at stream monitoring sites. The MSHA protocol can be found at: http://www.pca.state.mn.us/index.php/view-document.html?gid=6088 . MSHA scores can be used to review habitat conditions at biological sampling locations and compare those conditions against similar-sized streams. MPCA has explored the relationship between MSHA scores and Index of Biological Integrity (IBI) scores, developing a probability function of a stream meeting its IBI threshold, given the MSHA score it received. MPCA and DNR staffs are collecting stream channel dimension, pattern and profile data at impaired sites and some stream locations having very natural conditions. This data can be used to compare channel form departure from a reference condition (i.e., the norm). Habitat features can be analyzed to determine if a stream has reduced pool depth, incorrect pool spacing, adequate cross sectional area to convey discharge, and various other physical habitat features that are too numerous to list here. The MPCA/DNR use the applied river morphology method developed by Rosgen (1996) to collect and analyze this data.

Candidate cause: Elevated stream temperature

The factors that control streamwater temperature and the biological effects of elevated temperature are very complex. Stream temperature naturally varies due to air temperature, geological setting, shading, and the water inputs from tributaries and springs. Human activities can increase stream temperatures through altering riparian vegetation (loss of shading), urban runoff from warm impervious surfaces (e.g., parking lots), agricultural runoff, loss of landscape water storage and thus periods of reduced stream water volume, and direct discharges of warm wastewater to the stream. Warmer water holds less DO, and water temperature also affects the toxicity of numerous chemicals in the aquatic environment. Algal blooms are often associated with temperature increases (EPA, 1986). Water temperature affects metabolism (and thus food and oxygen needs) and regulates the ability of organisms to survive and reproduce (EPA, 1986). Different organisms are adapted to and prefer different temperature ranges, and will thrive or decline based on the temperature ranges found in a stream. For more information on the causes and effects of elevated temperature, see EPA's CADDIS website: http://www.epa.gov/caddis/ssr_temp_int.html.

Water quality standards

The standard for Class 2B (warmwater) waters of the state is not to exceed five degrees Fahrenheit above natural, based on a monthly average of maximum daily temperature. The maximum allowable average is 86 degrees Fahrenheit (30 degrees Celsius).

Types of temperature data

The majority of temperature data collected in the MRHW has been point (instantaneous). A small number of streams were monitored with continuous-recording sondes, which collect temperature and several other parameters.

Candidate cause: Ammonia (NH_3)

Ammonia is found in an ionized form (ammonium, NH_4^+) and the un-ionized form (ammonia, NH_3), with NH_4^+ being the prevalent form in natural waters. Ammonia is converted to nitrate in the natural nitrogen cycle. An increase in water temperature and/or pH increases the un-ionized ammonia (NH_3) concentration, which is toxic to aquatic organisms at certain concentrations. The fraction of unionized ammonia (NH_3) is not directly measured, but instead is calculated using measures of total ammonia, pH, temperature, and specific conductivity. Many human activities can contribute to elevated ammonia concentrations in streams. Sources of ammonia (NH_3) include human and animal waste, fertilizers, and natural chemical processes. Channel alteration can result in decreased natural conversion of ammonia to nitrate, and alteration or removal of riparian vegetation can reduce the interception of nitrogen compounds in runoff from the surrounding landscape. Channel alteration and water withdrawals can reduce ammonia volatilization by reducing the turbulence of the water. For a more detailed explanation of ammonia sources and causal pathways, see: http://www.epa.gov/caddis/ssr_amm4s.html .

Water quality standards

The ammonia-N (NH_3) standard for Class 2A (coldwater) and Class 2B (warmwater) streams is 0.016 mg/L and 0.040 mg/L respectively.

Types of ammonia data

Grab samples have been collected for ammonium and analyzed at a state-certified lab. The value of the toxic form, un-ionized ammonia, is calculated from the ammonium, temperature, and pH at the time of collection.

Candidate cause: Connectivity

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

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

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

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

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

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes within a river system (Annear 2004). Connectivity is thus the water-mediated transfer of energy, materials, and organisms across the hydrological landscape (Pringle 2003). The transport of these integral components within a river travel in four dimensions: longitudinal, upstream and downstream; lateral, channel to floodplain; vertical, hyporheic to groundwater zones; and temporal, continuity of transport over time (Annear 2004).

Longitudinal connectivity of flowing surface waters is of the utmost importance to fish species. Many fish species' life histories employ seasonal migrations for reproduction or overwintering. Physical barriers such as dams, waterfalls, perched culverts and other instream structures disrupt longitudinal connectivity and often impede seasonal fish migrations. Disrupted migration not only holds the capacity to alter reproduction of fish, it also impacts mussel species that utilize fish movement to disperse their *offspring. Structures, such as dams, have been shown to reduce species richness of systems, while also increasing abundance of tolerant or undesirable species (Winston et al. 1991, Santucci et al. 2005, Slawski et al. 2008, Lore 2011).*

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

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

Water quality standards

There is no applicable water quality standard for connectivity impacts. A road crossing design guide has been developed by MnDOT for fish passage http://www.dot.state.mn.us/research/TRS/2013/TRS1302.pdf

Types of physical connectivity data

Locations for dams are available on a DNR GIS coverage. Aerial photos are viewed to locate any undocumented structures. Pertinent culverts are visited to determine their organism passage capability. Because hydrological alteration leading to channel instability is not an issue in the streams discussed in this report, vertical and lateral connectivity were not studied or discussed below.

Analysis of biological data

Biological data (the list of taxa sampled and the number of each) form the basis of the assessment of a stream's aquatic life use status. Various metrics can be calculated from the fish or macroinvertebrate sample data. An IBI, a collection of metrics that have been shown to respond to human disturbance, is used in the assessment process (https://www.pca.state.mn.us/water/index-biological-integrity). Similarly, metrics calculated from biological data can be useful in determining more specifically the cause(s) of a biological impairment. Numerous studies have been done to search for particular metrics that link a biological community's characteristics to specific stressors (Hilsenhoff, 1987, Griffith 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 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 the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites to date. Such probabilities are only available for parameters that have developed standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

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

Analysis of chemical data

Seasonal patterns of several chemical parameters were 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.

Stream investigations organized by AUID

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.

Sucker Creek (AUID 07010101-663)

Assessment: Sucker Creek was sampled just upstream of State Hwy 200 (09UM083), just north of the northern boundary of Itasca State Park. The creek was assessed as meeting biological standards, though the macroinvertebrate community was somewhat below the threshold for Northern Coldwater Streams. A determination of a natural lack of important habitat commonly found in the coldwater streams (particularly rocky substrate) was the reason stated for the non-passing macroinvertebrate community. The discussions during the assessment also inquired about a somewhat opaque cast to the water. The few chemistry samples also showed TP concentrations above the region's river nutrient standard. The SID process included sampling to better understand the chemistry dynamics of Sucker Creek, including the coloration of the stream water and TP.

Subwatershed characteristics:

The Sucker Creek subwatershed (the land contributing to flow at the biological site) is a very natural landscape, with densely forested uplands and numerous depressional wetlands and small kettle lakes. Large parts of the subwatershed are within the Clearwater County Memorial Forest, and Lake Itasca State Park. A couple small DNR Wildlife Management Area plots also lie in this subwatershed. Iron Springs Bog Scientific and Natural Area is directly adjacent to the subwatershed. The HDS score for biological site 09UM083 is 79.19, an extremely high score for "absence of human disturbance". Sucker Creek begins as the outflow of Sucker Lake.

Data and analyses

Chemistry

Chemistry data collected during biological monitoring visits are shown in Table 4. These chemistry data were generally good: TSS on June 10, 2013, was a bit over the coldwater standard, but was composed mostly of organic particles, which were likely flushing from winter decay of plant material, and not mineral particles from erosion, as evidenced by the high percentage of TSVS on this sample date. TP was elevated above the region's river nutrient standard, though no anthropogenic sources seemed likely based on aerial photography review and the extent of public, forested land.

Table 4. Water chemistry measurements collected at 09UM083 prior to and during the 2013 IWM. Values in mg/L, NC = not collected.

Date	Time	Water Temp.	DO	TP (µg/L)	Nitrate	Ammonia	Un-ionized Ammonia	pH	TSS	TSVS
July 20, 2010	18:15	20.9	7.42	0.097	0.056	< 0.1*	**	7.91	6.2	< 4*
June 10, 2013	17:47	18.5	7.78	0.063	< 0.05*	< 0.1*	**	7.42	12	8
August 27, 2013	9:39	13.8	7.92	NC	NC	NC	NC	7.7	NC	NC
Sept. 3, 2014	9:07	13.3	9.29	NC	NC	NC	NC	7.76	NC	NC

* These values are below the lab detection limit.

**Cannot be calculated without a specific ammonia value, but would be far less than the standard.

SID chemistry data was collected at 09UM083 (EQuIS # S008-492) and at a new second station, upstream at the Anchor-Mattson Road crossing (EQuIS # S008-491). The reasoning for adding this second site was to isolate the landscape between the sites as a source of phosphorus. The new upstream site is a short distance from Sucker Lake, and as such is likely mostly lake water. Numerous springs are known to occur between Anchor-Mattson Road and the biological site on Hwy 200. There is also significant wetland acreage on the landscape of the subwatershed between the two sites. Some of the groundwater enters within the bed of the stream channel, and some enters via seeps emerging from wetland near the bank. In the second scenario, the groundwater interacts with organic, wetland soil.

The parameters collected at the two sites were specific conductance, water temperature, DO, DO % saturation, TP, dissolved organic carbon (DOC), and total iron. The SID sampling was designed to do more monitoring of iron and get a better understand the phosphorus dynamics. At a certain level, iron can become a stressor of macroinvertebrates, and was also considered to be the likely the cause of the observed cloudiness of the water.

The DO, DO % saturation, water temperature, conductivity, and iron data all provide evidence that significant groundwater enters the stream after it crosses Anchor-Mattson Road. Groundwater is typically lower in DO, higher in specific conductivity, lower in temperature, and higher in iron than surface water. So the biological site at Hwy 200 would be expected to have lower DO (Figure 8) and DO % saturation (Figure 9), lower temperature (Figure 8), higher conductivity (Figure 10), and higher iron (Figure 11), than the Anchor-Mattson Road site. This is exactly what the data shows. The DO% saturation at the upstream site is higher than what would typically be expected from a healthy lake, and is likely high because the stream channel above Anchor-Mattson Road is very exposed to sunlight, and supports significant macrophyte growth due to the open canopy and gentle stream gradient.

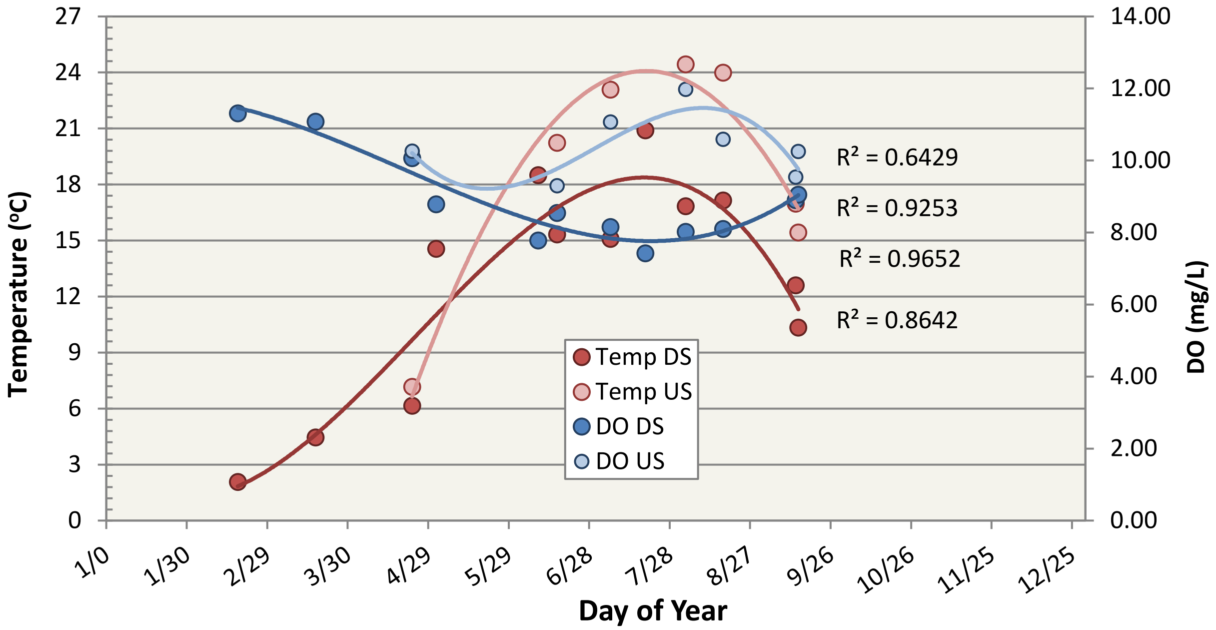

Figure 8. Water temperature and DO for upstream (S008-491) and downstream (S008-492) sites on Sucker Creek. Curved lines are 2nd or 3rd order polynomial regression lines for each site.

The somewhat opaque, "milky" look to the water was hypothesized to be due to colloidal iron particles. This same phenomenon has been seen at sites in the Crow Wing River Watershed, in groundwater-fed streams high in iron (see the Crow Wing River Stressor Identification Report - MPCA, 2014). Upon visiting Sucker Creek, two springs were immediately seen from the upstream side of the Highway 200 culverts, one on each side of the stream, each having significant iron floc along their flow paths (photo 1). It was also learned that just across Highway 200, there is a DNR Scientific and Natural Area named Iron Springs Bog SNA. Stream water samples collected and analyzed for total iron confirmed that there is a fairly high concentration of iron in Sucker Creek (Figure 11) and there is a very significant seasonal pattern to the iron concentrations.

Photo 1. Streamside spring with high iron content at the upstream side of the Hwy 200 culverts.

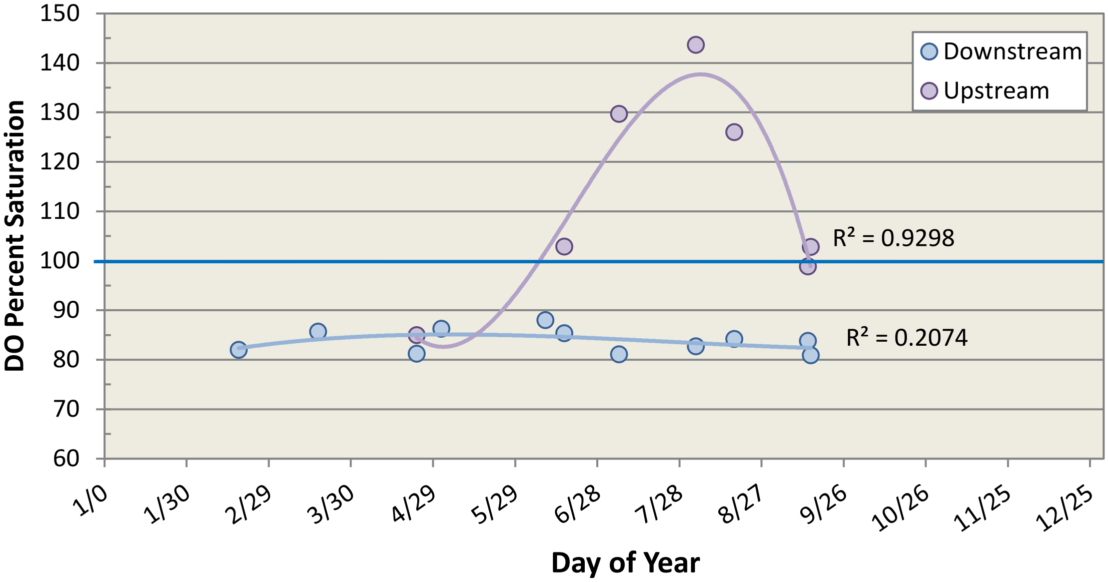

Figure 9. DO % saturation for upstream (S008-491) and downstream (S008-492) sites on Sucker Creek. The curved lines are polynomial regression lines for each site. The blue horizontal line highlights 100% saturation.

DOC is a result of plant breakdown, which occurs more significantly in wetlands than in streams, due to the typical abundance of aquatic plants that grow in wetlands, the hydric soils that form in wetlands, and the relatively stagnant water that resides in wetlands. Thus, DOC concentration can be a good indicator of the input of wetland-sourced water to streamflow. DOC samples were taken at the two locations, and were hypothesized to be higher at the downstream site, since there are significant riparian wetlands along the channel between the sites. However, the data show the opposite of this expectation (Figure 12). A plausible reason that there is a lower DOC concentration downstream could be because there may be significant deep groundwater input to the stream channel that doesn't pass through any riparian peat soil (in addition to the shallow groundwater moving through the wetland soils). There is plausibility in this explanation, because DNR puts out a warning buoy for quicksand in the stream channel in at least one location, that being a short distance upstream of the Highway 200 crossing, upstream of the water sampling location of the downstream site. This deep groundwater input, which lacks any DOC, may be diluting DOC inputs from the wetlands between the two sample sites.

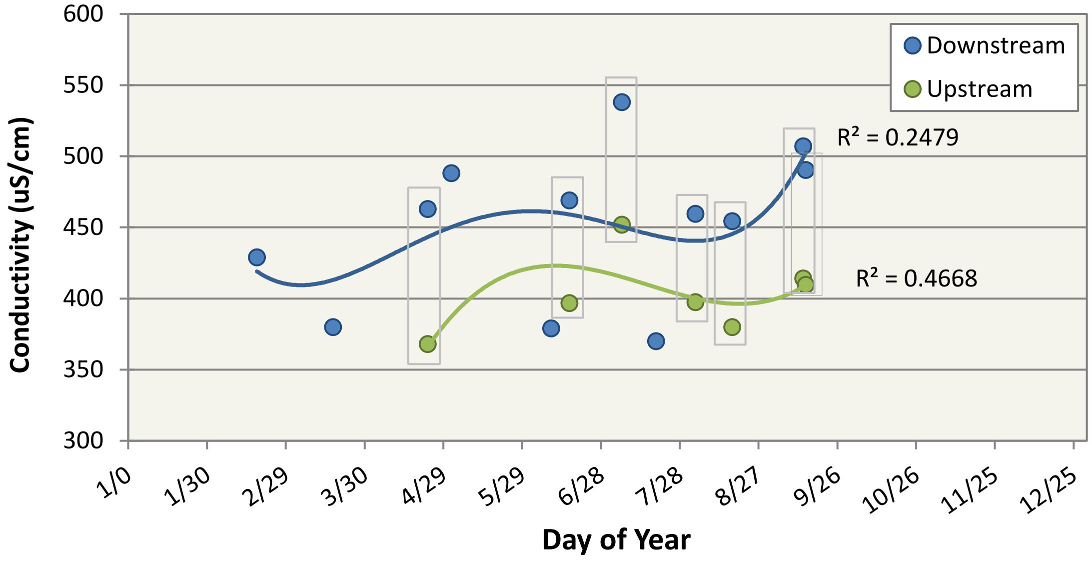

Figure 10. Specific Conductance for upstream (S008-491) and downstream (S008-492) sites on Sucker Creek. Curved lines are polynomial regression lines for each site. The boxed pairs of data were samples collected on the same date.

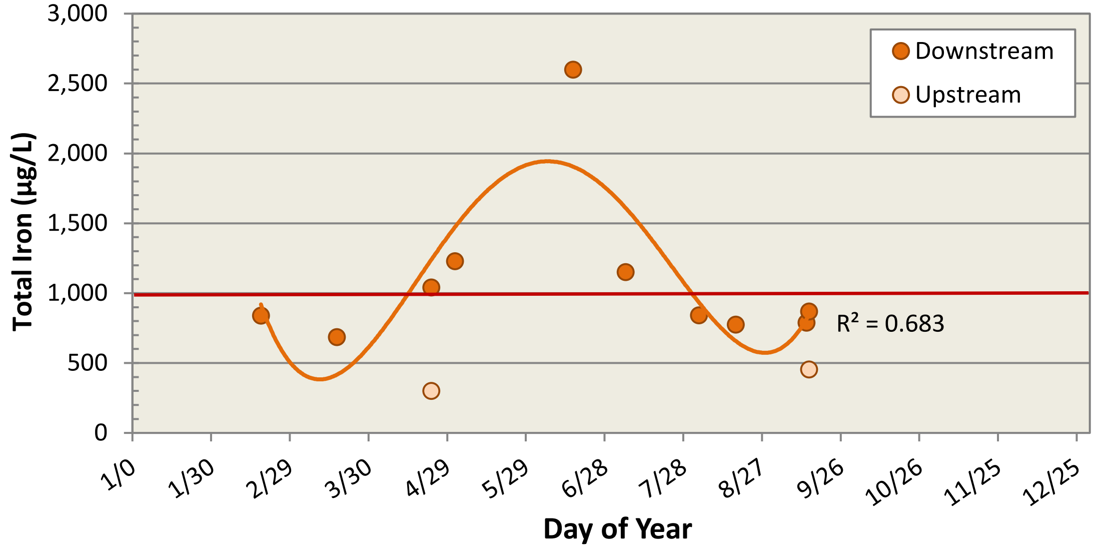

Figure 11. Total iron concentrations in Sucker Creek at 09UM083 (S008-492), 2015 and 2016. One sample was collected upstream at S008-491. The orange curve is a polynomial regression line with R^2 of 0.6728. The red line is the EPA aquatic life standard for iron concentration.

Phosphorus levels in Sucker Creek were elevated above the region's river nutrient standard. Wetlands can be a source of phosphorus as they accumulate organic matter, which undergoes decay in the wetland, releasing phosphorus that was in the live plants. Through the IWM, a significant number of smaller streams in quite natural watersheds have been found to have high levels of phosphorus in the north central part of the state, including streams in the Crow Wing and Leech Lake River Watersheds. Several of these are undergoing study to better determine their phosphorus dynamics. Sucker Creek provides another good stream to study in this way because of the naturalness of its contributing landscape. Total phosphorus levels differ between the upstream, lake-sourced water, and that of the downstream site, with higher levels occurring downstream (Figure 13). The likely source of this phosphorus is the wetland-influenced shallow groundwater that contributes water to the creek between the sites. There are no anthropogenic sources to contribute phosphorus. This information will be contributed to the larger set of streams being studied to provide insight into natural phosphorus sources in north-central Minnesota small streams.

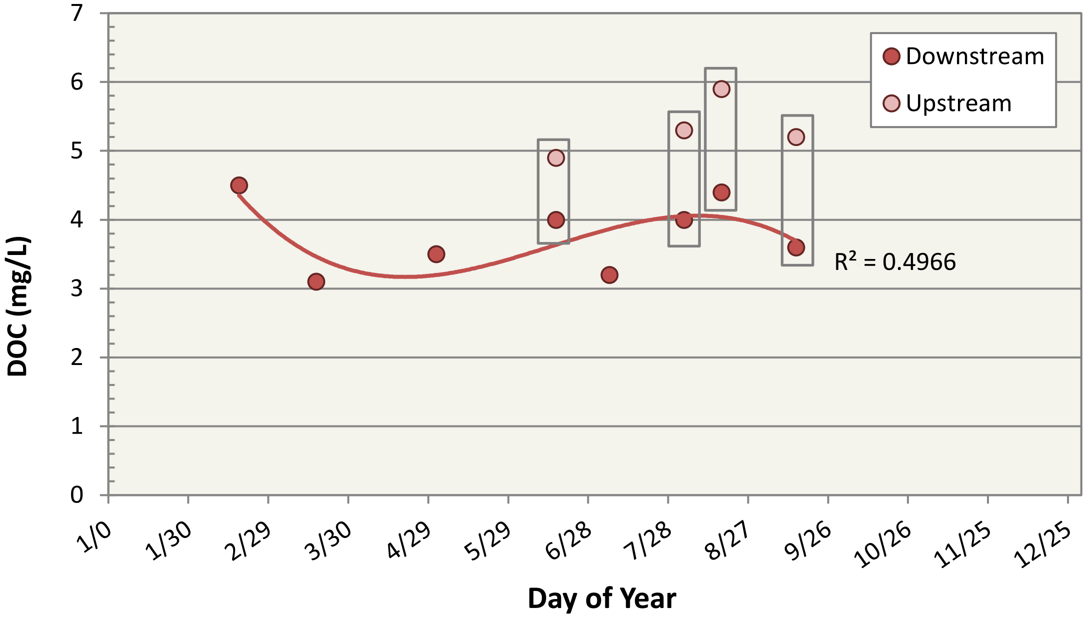

Figure 12. DOC concentration at S009-491 (upstream) and S009-492 (downstream) in Sucker Creek. The curved line is a 3rd order polynomial regression line. The boxed pairs of data were samples collected on the same date.

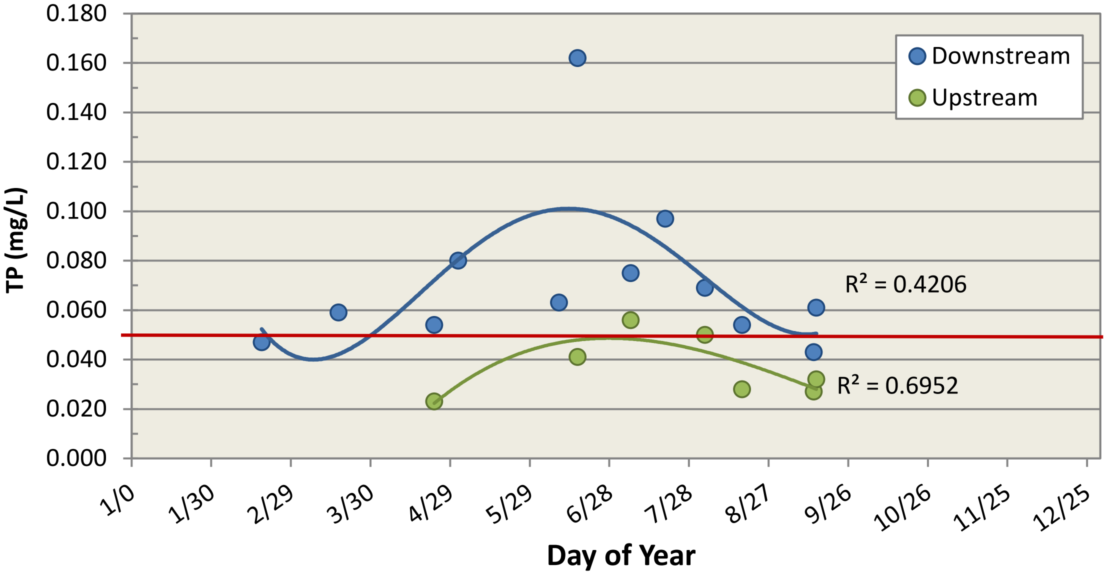

Figure 13. TP for upstream (S008-491) and downstream (S008-492) sites on Sucker Creek. The curved lines are polynomial regression lines for each site. The red line is the regional river nutrient standard.

Temperature

The temperatures measured at the various visits were within the range acceptable to most coldwater macroinvertebrates, generally considered to be below 20 - 22°C. Visits throughout the summer months found temperatures ranging in the mid-upper teens Celsius.

Habitat

The MSHA score (78) at 09UM083 was very good, well above the score of 66 which is the beginning of the "Good" range. The MSHA is geared more to assessing fish habitat, and one important macroinvertebrate habitat feature (particularly for many of the coldwater taxa) is naturally missing here, that being gravel/cobble substrate. This may in part explain why some of the invertebrate samples were below the Coldwater IBI threshold.

Geomorphology and hydrology

No geomorphology fieldwork was done on AUID-501 due to the natural character of the subwatershed and thus the unlikely occurrence of altered hydrology leading to channel instability. A visit by DNR hydrologists concluded that the stream was physically in very good condition.

Conclusions

No anthropogenic causes were found to explain the below-threshold score for the macroinvertebrate community in AUID-663.

The water cloudiness observation is explained by the iron concentrations found in the water samples, and in the observations of iron accumulations around spring inlets. The source of this iron is geologic strata having high iron content, which is in contact with groundwater that eventually enters Sucker Creek. Levels of iron are often above the EPA iron threshold for aquatic life. It is possible that this natural iron is a stressor to the macroinvertebrate community. Several streams in the Crow Wing River Watershed with similar iron concentrations also had macroinvertebrate communities that did not meet the IBI threshold, while the fish community did. Not enough is known about the effects of iron on macroinvertebrates to make a certain determination at this point. However, mechanisms of iron stress to macroinvertebrates have been proposed and discussed (Vuori, 1995), such as gill clogging by iron compound deposition on gill surfaces.

TP concentrations are likely caused by the shallow groundwater seeping through peat soil and picking up soluble phosphorus during the soil's anoxic period of mid-summer. This phenomenon has been described in numerous studies (Dillon et al, 1997; Carlyle and Hill, 2001; Banaszuk et al, 2005). Because there is no anthropogenic activity or development on the landscape that contributes water between the two sample locations, while there is significant riparian wetland, it is logical to conclude that the elevated summer phosphorus is a natural phenomenon. No significant algal growth was seen on stream substrates. This elevated phosphorus is not causing a eutrophication problem for likely several reasons: the water is cold, and thus holds more oxygen, some of the riparian corridor is forested and trees shade the channel (reducing algal growth), and nitrate levels (also needed for algal growth) are extremely low. TP levels significantly higher than the region's river nutrient threshold do not have an anthropogenic cause in Sucker Creek, but can be explained by hydrological pathways (particularly the groundwater component) and wetland location.

Gull River (AUID 07010101-551)

Assessment: The creek was under consideration as impaired for not meeting the fish community threshold at site 13UM116 located upstream of Nelson Lake Road, 1.5 mi. east of Tenstrike. After further investigation by the SID effort, and more discussion in the assessment process, the fish data was not used in the biological assessment because the site was bracketed by beaver dams, causing connectivity issues for fish to reach other habitats necessary to maintain good populations. The data collected in IWM and the SID process is presented here for documentation for future use, as well as to present evidence that the decision to ascribe the poor fish community to natural connectivity issues is a sound one.

Data and analyses

Chemistry

The chemistry data existing for this AUID is limited to that collected in the biological sampling visits (Table 8). All of the parameters are indicative of a healthy stream. Nutrients (phosphorus and nitrate) were in very low concentrations, and water clarity was excellent. Even so, a sonde was deployed to record continuous DO, DO saturation, temperature, specific conductance, and pH. The data for DO and water temperature are presented in Figure 14. DO levels over the July 29 - August 19 period were very good; at no point did they approach the minimum standard of 5.0 mg/L. The daily flux was also low (i.e., good), being generally about 2.5 - 3 mg/L.

Table 5. Chemistry data from IWM sampling at 13UM116.

Date	Time	Temp.	DO	DO % Sat.	pH	TP	Nitrate	TSS	TSVS	T-tube (cm)
June 12, 2013	10:52	19.2	7.94	91	7.56	0.038	< 0.05*	8.8	< 4*	> 100
Aug. 28, 2013	8:21	22.4	6.38	78	8.01	NC	NC	NC	NC	> 100
Aug. 6, 2014	13:15	NC	NC	NC	NC	0.025	< 0.05*	< 4*	< 4*	NC

*Less than the lab is reporting limit.
NC = not collected.

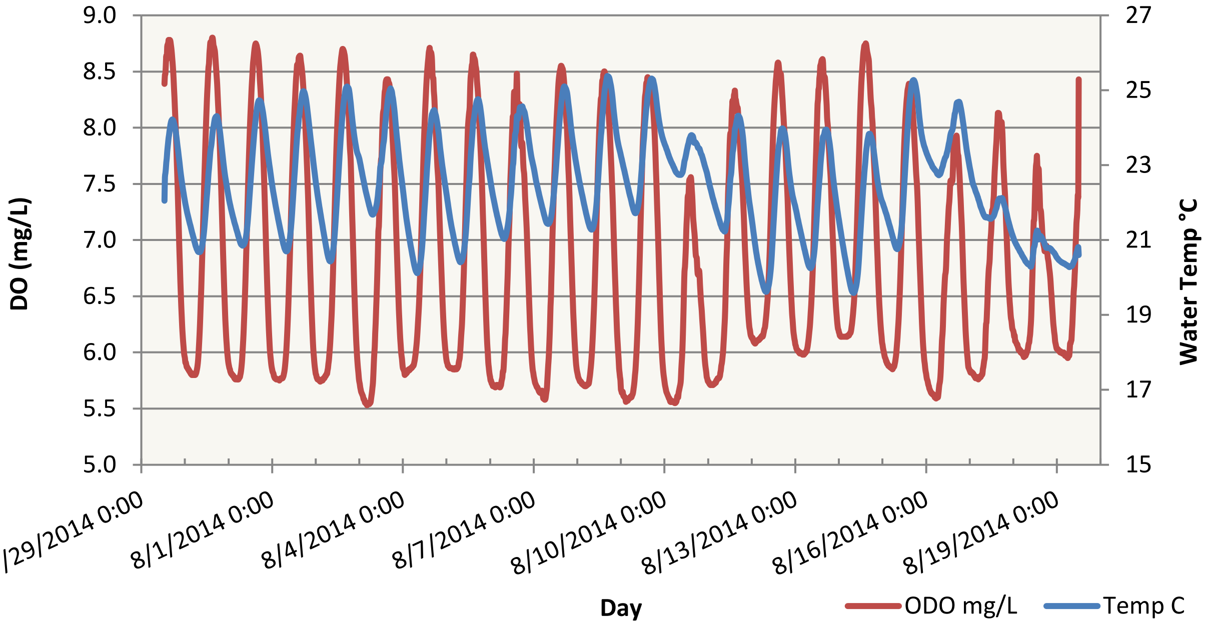

Figure 14. Sonde readings from the Gull River at 13UM116 from July 29 – August 19, 2014.

Temperature

Water temperatures were fairly cool and in no way, reaching stressful levels for warmwater stream fish species. The range during the three weeks of sonde deployment in 2014 was between approximately 20 - 26°C (Figure 14). The sonde deployment covers the typical hottest air temperature period of the year, so the recorded temperatures are likely the highest this stream location generally experiences.

Biological response

Fish

In smaller streams that are quite reliant on seasonal migration to repopulate summer fish communities, it is probably not a good idea to calculate and analyze metrics that are linked to other stressors (such as Tolerance Value metrics for particular parameters like DO) when migration barriers are deemed to be present, since those metrics may well be confounded by the migration barrier(s). Therefore, TIV metrics will not be analyzed for the fish community in AUID-551.

Macroinvertebrates

The macroinvertebrate community was assessed as healthy in AUID-551. Macroinvertebrates are much less affected by small barriers such as culverts and beaver dams than fish. While such barriers potentially confound analyzing these metrics for fish, they do not confound the interpretation of macroinvertebrate data. Macroinvertebrate metric scores were examined to confirm that neither DO levels nor excess sediment are likely causing a problem for the fish community. The macroinvertebrate community scored quite well on the DO Index metric (at the 80th percentile) and had more than twice as many low-DO intolerant taxa as low-DO tolerant ones. The TSS Index score was a bit closer to average, but still at the 69th percentile. The number of TSS intolerant taxa was just slightly higher than the number of TSS tolerant taxa. This analysis suggests that neither DO nor TSS levels are problematic for the macroinvertebrate community, and add evidence to the conclusion that physical barriers, not water chemistry parameters, are impairing the fish community.

Table 6. Macroinvertebrate metrics related to DO for 13UM116 utilizing MPCA tolerance values (using the 2016 version of the metrics). The percentile rank is based on the Community DO Index score.

M-Invert Class	# Low-DO Intolerant Taxa	# Low-DO Tolerant Taxa	% Low-DO Intolerant Individuals	% Low-DO Tolerant Individuals	Community DO Index score	Class DO Index average	Percentile within stream class
3	7	3	25.8	3.4	7.42	6.96	80

Table 7. Macroinvertebrate metrics related to TSS for 13UM116 utilizing MPCA tolerance values (using the 2016 version of the metrics). The percentile rank is based on the Community TSS Index score.

M-Invert Class	# TSS Intolerant Taxa	# TSS Tolerant Taxa	% TSS Intolerant Individuals	% TSS Tolerant Individuals	Community TSS Index score	Class DO Index average	Percentile within stream class
3	7	6	11.7	13.8	12.90	13.26	69

Connectivity

Fish in smaller streams migrate to find suitable habitat for various parts of the year. In fall, they generally migrate downstream to larger water bodies to overwinter. Beaver have created numerous dams in this AUID, which occur both upstream and downstream of the biological sampling site, thus isolating the reach where fish were sampled. MPCA biologists determined that the location of these dams likely impedes the migration of fish species in this AUID and has probably affected the fish community and IBI score negatively. MPCA does include migratory behavior among a list of fish species traits, which can be used to investigate suspected migratory problems (are migratory species present or absent?), but most of the migratory species live in larger streams or rivers, and would not be found here even if the beaver dams were not present. Thus, such an analysis was not done for AUID-551.

Hydrology and geomorphology

No specific investigations into altered hydrology or unstable geomorphology were done for the Gull River. Aerial photography did not suggest that significant hydrologic alteration would be occurring due to relatively low human landscape alteration. The great majority of the contributing land area is forested. There are a couple trenched wetlands in the headwaters, which have very small channels and have likely changed the stream hydrology in AUID-551 only a small degree. Also, there were no signs of stream channel instability upon general observation by staff familiar with symptoms of instability.

Habitat

The MSHA score for 13UM116 was extremely good at 83.1, well above the bottom of the “Good” range that starts at a score of 67. None of the five subcategories had low scores, indicating habitat is suitable and not a stressor to the fish community.

Conclusions

A group of biological monitoring and SID staff met to discuss this AUID and its under-threshold fish community. Both the water chemistry and physical channel appear healthy, and the habitat score is very good. Given those findings, and that beaver activity (damming) is significant, both upstream and downstream of the biological sample site, the group determined that beavers are having an influence on the fish community via blocking migration, and therefore, the fish community was not used for the aquatic life assessment in the Gull River. The macroinvertebrate community, which had a passing IBI score, was used alone in assessing the aquatic life use attainment.

Sugar Brook (AUID 07010101-692)

Assessment: The creek was initially assessed as impaired for not meeting the fish community threshold at site 13UM141 located just downstream of Sugar Hills Road. After further investigation by the SID effort, the reason for the fish impairment was concluded to be beaver activity causing connectivity blockage, and the fish community was ultimately not used to determine the aquatic life use attainment for the stream. The macroinvertebrates scored in the healthy range. The data collected in IWM and the SID process is presented here for documentation for future use, as well as to present evidence that the decision to ascribe the poor fish community to natural connectivity issues is a sound one.

Data and analyses

Chemistry

The source-water for Sugar Brook comes from one of Minnesota's highest quality lakes, the exceptionally clear Siseebakwet Lake. Sugar Brook is the lake's outlet and there are no tributaries that enter Sugar Brook between the lake and the biological sites. Therefore, one would expect the brook to have stellar water quality as well. Water chemistry data for two sites are presented in table 8, and does indeed show very excellent water quality. An EQuIS water quality site that has previously collected data exists downstream of the biological site, at Moose Point Road (S006-968). That dataset contains many TP samples, which had similar concentrations to those in table 8, with the exception of a few storm event samples, which still only slightly exceeded the region's river nutrient standard.

Table 8. IWM chemistry data from 13UM141, 15UM400 and 15UM401 (in mg/L). NC = not collected.

Site	Date	Time	Temp.	DO	DO % Sat.	pH	TP	Nitrate	TSS	TSVS	T-tube (cm)
13UM141	6/12/2013	16:27	18.7	8.56	97	7.81	0.020	< 0.05	7.8	< 4	> 100
13UM141	8/28/2013	18:34	23.1	7.05	87	7.90	NC	NC	NC	NC	> 100
13UM141	7/15/2014	12:19	18.6	9.65	109	7.50	0.016	0.10	6	< 4	> 100
13UM141	6/9/2015	13:09	19.0	10.01	110	7.95	0.018	< 0.05	< 4	< 4	> 100
Moose Point Rd.	6/9/2015	8:41	17.3	8.72	96	8.05	0.018	< 0.05	7.2	< 4	> 100

Temperature

Water temperatures were quite cool at all visits (Table 8). That is somewhat to be expected in early June, but it was also the case on July 15 and to a lesser degree on August 28. Temperature is not a concern as a stressor to the fish community in AUID-692.

Biological response

Fish

In smaller streams reliant on seasonal migration to repopulate summer fish communities, analysis of fish diversity metrics that are linked to other stressors (such as Tolerance Indicator Value metrics for particular parameters like DO) can be misleading when migration barriers are present. Metrics may well be confounded by the migration barrier(s). Therefore, TIV metrics will not be calculated for the fish community in AUID-692.

Macroinvetebrates

The macroinvertebrate community was assessed as healthy in AUID-692. Macroinvertebrates are much less affected by small barriers such as culverts and beaver dams than fish. While such barriers potentially confound analyzing these metrics for fish, they do not confound the interpretation of macroinvertebrate data. Macroinvertebrate metric scores were examined to confirm that neither DO levels nor excess sediment are likely causing a problem for the fish community. The macroinvertebrate community scored extremely well on the DO Index metric (at the 99th percentile) and had more than five times as many low-DO intolerant taxa as low-DO tolerant ones. The TSS Index score was a fairly close to average, but still at the 61st percentile. The number of TSS intolerant taxa, however, was only half of the number of TSS tolerant taxa. This analysis suggests that neither DO (particularly) nor TSS levels are problematic for the macroinvertebrate community, and add evidence to the conclusion that barriers, and not a water chemistry parameter, are impairing the fish community.

Table 9. Macroinvertebrate metrics related to DO for 13UM141 utilizing MPCA tolerance values (using the 2016 version of the metrics). The percentile rank is based on the Community DO Index score.

M-Invert Class	# Low-DO Intolerant Taxa	# Low-DO Tolerant Taxa	% Low-DO Intolerant Individuals	% Low-DO Tolerant Individuals	Community DO Index score	Percentile within stream class
3	11	2	26.85	0.93	7.77	99

Table 10. Macroinvertebrate metrics related to TSS for 13UM141 utilizing MPCA tolerance values (using the 2016 version of the metrics). The percentile rank is based on the Community TSS Index score.

M-Invert Class	# TSS Intolerant Taxa	# TSS Tolerant Taxa	% TSS Intolerant Individuals	% TSS Tolerant Individuals	Community TSS Index score	Percentile within stream class
3	4	8	4.01	8.64	13.34	61

Connectivity

Fish in smaller streams migrate to find suitable habitat for various parts of the year. In fall, they generally migrate downstream to larger water bodies to overwinter. Beaver have created numerous dams in this AUID, which occur both upstream and downstream of the biological sampling site (Figure 15, Photos 2 and 3), thus isolating the reach where fish were sampled from downstream areas. MPCA biologists determined, in part by interviewing local citizens, that the location of these dams likely impedes the migration of fish species into AUID-692 and has affected the fish community and IBI score negatively. Discussion with a local resident revealed that beaver dams have been present in this stream for the past 40 years. He recalled that in the 1970s the DNR would annually breach the dams. In the mid 1980s the County would annually inspect but no longer remove the dams. Since the mid 1980s the beaver dams have been in tact in some fashion. This landowner hires a beaver trapper every few years to reduce the beaver population. In the fall of 2014, a trapper removed the majority of the beavers downstream of CR 17. As of spring of 2015, the dams are not maintained by beavers. However, they are still likely posing a partial fish passage barrier, and were definitely a fish barrier in 2013 and 2014 before the beavers were trapped.

There is a human-caused barrier that could be playing a part in the connectivity problem. The culvert at Sugar Hills Road is perched and represents a barrier to fish migration at some water levels (Figure 15, Photo 4). Because it is located just upstream of the original biological monitoring site (13UM141), it would not impede fish migrating up from Lake Pokegama in spring. However, it is possible that it acts as a barrier to fish that might move upstream in fall into the small lake that lies just downstream from the

Lake Siseebakwet outflow point. Because there is, also a beaver dam at the outlet point of the small lake, correcting the culvert situation is unlikely to help fish migration into the site unless the beaver are trapped annually to prevent their dam building.

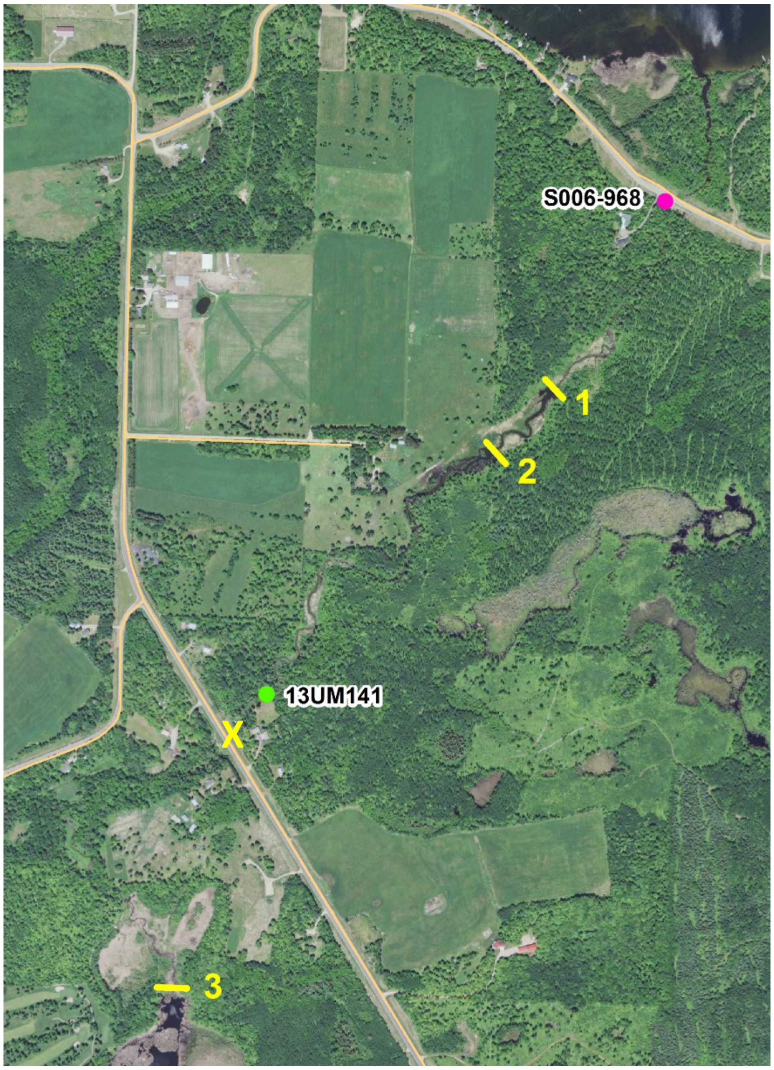

Figure 15. Biological sampling site (green dot), EQuIS station (pink dot), beaver dams (yellow bars), and perched culvert (yellow X) on Sugar Brook.

Photo 2 and Photo 3. Sugar Brook. At left is beaver dam 1. At right is dam 2 viewed from upstream. Photos taken in May 2015, after fall 2014 trapping.

Photo 4. Perched culvert at Sugar Hills Road is an impassible barrier to fish migration.

Hydrology and geomorphology

No specific investigations into altered hydrology or unstable geomorphology were done for Sugar Brook. Aerial photography did not suggest significant hydrologic alteration, due to relatively low level of human landscape alteration. The great majority of the contributing land area is forested. Also, there were no signs of stream channel instability upon general observation by staff familiar with symptoms of instability. Habitat scores, discussed next, confirm the health of the stream channel.

Habitat

The MSHA score for 13UM141 was extremely good at 88.5, well above the bottom of the “Good” range that starts at a score of 67. None of the five MSHA subcategories had low scores, indicating habitat is suitable and not a stressor to the fish community. The substrate was predominantly gravel and cobble, which is very good habitat for many fish and macroinvertebrate species.

Conclusions

The water chemistry and macroinvertebrate community statistics point to a non-water quality factor stressing the fish community. Investigation by SID staff found that fish migration, as indicated by walleye presence or absence observations by local residents, correlates with whether the beaver dams are breached or not. DNR has historically breached the dams, but has not done so in the latter years. When the dams are intact, interviewed residents say walleye are not observed upstream in AUID-692. It is likely that other fish species are not able to seasonally migrate into Sugar Brook when the dams are intact. The dams were indeed in place and functional in the 2013 season. A passing IBI score was achieved at 13UM141 in June 2015 when the dams were in breached condition following fall 2014 beaver trapping.

Mississippi River (AUID 07010101-753)

Assessment: This AUID of the Mississippi River was assessed in 1994 as impaired for not meeting the Minnesota DO standard. In 2016, the original determination of DO impairment in this AUID was submitted to EPA as an incorrect determination due to new assessment guidance by MPCA’s Assessment Policy Team for qualifying streams with significant wetland connections. EPA approval of this change is pending. Some study for SID was conducted as part of an effort to better understand the dynamics of these wetland-influenced streams.

Data and analyses

Chemistry

Data was collected in the SID process in 2015 at two locations on AUID-753; site S001-894 (at CSAH-40), and site S001-903 (at Becida Road), with the latter being farther downstream. One sample visit was also made to S001-894 in early 2016. Parameters collected were: instantaneous DO, water temperature, conductivity, TP, and nitrate. Only DO, TP, and nitrate are discussed here. Historical data was also available from these two sites and was included in the analyses. The water volume in the river is much greater at S001-903 than at S001-894.

Dissolved oxygen

DO concentrations were lower in the downstream part of AUID-753 during the summer months. The measurements during 2015 were taken during the afternoon hours, so they do not represent the daily minimum concentrations. Based on this small 2015 dataset, DO is in a healthy range at both sites during midday time period (Figure 16). Data from the early 2000s did show a number of low DO measurements, mostly at the downstream site S001-903 (Figure 17). Few of these data points were collected in the early morning period when DO is at a minimum. A study of where the additional water is coming from at the downstream site would provide insight into why the DO is less farther downstream (i.e., is the source wetlands, groundwater, etc.).

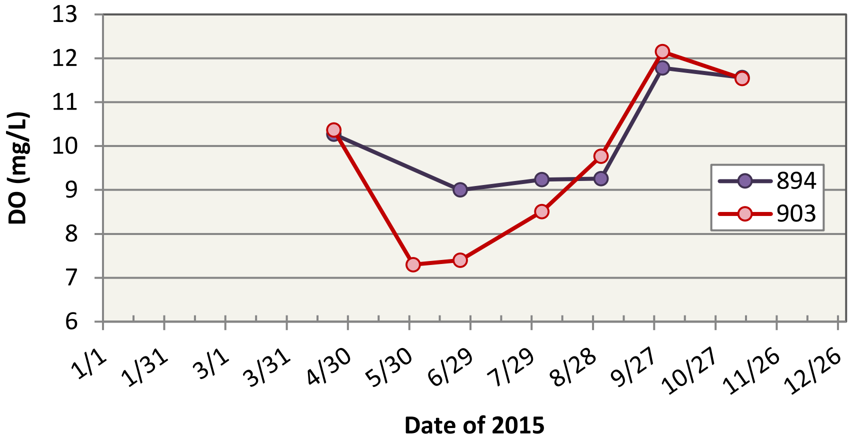

Figure 16. Instantaneous DO measurements collected during 2015 at two locations within AUID-753. Station S001-894 is upstream of station S001-903.

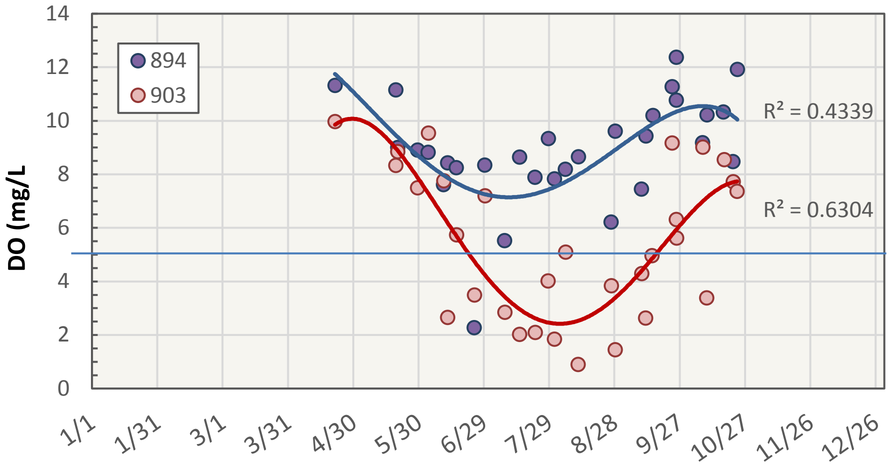

Figure 17. Instantaneous DO measurements from 2000 - 2003 at two locations within AUID-753. Station S001-894 is upstream of station S001-903. The curved lines are 4th order polynomial regression lines. The blue horizontal line is the DO standard. Note that the two sites were often sampled a few hours apart, which makes the patterns of DO less comparable between sites for a given date.

Phosphorus

TP data has been collected at site S001-894 in numerous past years (Table 11, Figure 18), and augmented by sampling in 2015, which happened to be a low-water year all through summer and fall. The 2015 data points for each comparable period of the year are low (i.e., all 2015 points are at or below the regression line - Figure 18). There is a fairly broad spread of values for any particular time during the mid-April to late-September period, but the regression line does show a summer hump with a peak value of approximately 0.078 mg/L occurring at about July 15th. This pattern and time of peak is quite similar to other smaller streams that are being studied in north central Minnesota (see the Crow Wing River and Leech Lake River SID reports - MPCA, 2014, 2016b).

The Mississippi River at site S001-903 is substantially larger in width and flow volume than site S001-894, and has much more macrophyte growth. The TP pattern is also quite a bit different, and appears to have a different seasonal pattern, a linear one, in which TP concentration is at its highest point in late winter/snowmelt and then gradually declines until into the fall (Figure 19). The river in the area of S001-

903 was exceptionally low at snowmelt and for the next couple of months. Some rain in early June brought the river's stage up, but it still appeared to be low for early summer. Interestingly, a pattern can be seen in the TP data for those abnormally low flow periods. This pattern supports the hypothesis of significant phosphorus sourcing from wetlands in the contributing upstream watershed and along the riparian corridor of the river. That hypothesis would predict lower TP during dry periods when the water table is depressed, and less water is saturating riparian wetland soils (a phosphorus source via organic decay). This is exactly what the data shows in comparing a dry year (2015) to a set of previous years (Figure 19), with much lower TP values for late winter/spring in 2015, and a moderately increase in the 2015 TP levels once the water level had risen some by late June through the remainder of summer (from some rain events, though 2015 continued to be relatively dry). Comparing just the 2015 data, there was much higher TP concentration in the upstream site (S001-894) than at the downstream site in spring through mid-summer, followed by quite similar concentrations from the July 29 sample and into fall (Figures 19 and 20). A full explanation of this pattern is not known, but it may be due to the significantly greater size of the river itself at the downstream site, as well as the significantly greater contributing watershed for that site. These factors may be responsible for diluting TP levels or aquatic macrophytes, which were abundant at the downstream site while nearly absent and the upstream site, may be taking up much of the phosphorus during the growing season. At both of these sites, phosphorus levels are above the Minnesota River Eutrophication Standard for this north region a majority of the time. It should be noted that the required response variables that are included in the eutrophication standard (Chl-a, DO flux, and BOD) were not measured. However, the author always observed clear water (little to no suspended algae) and no notable filamentous alage. The relatively natural landscape, lack of observable algal growth, moderate mid-day DO levels, and extremely low nitrate levels suggest this AUID is probably not experiencing cultural eutrophication and that elevated phosphorus levels are likely wetland-derived.

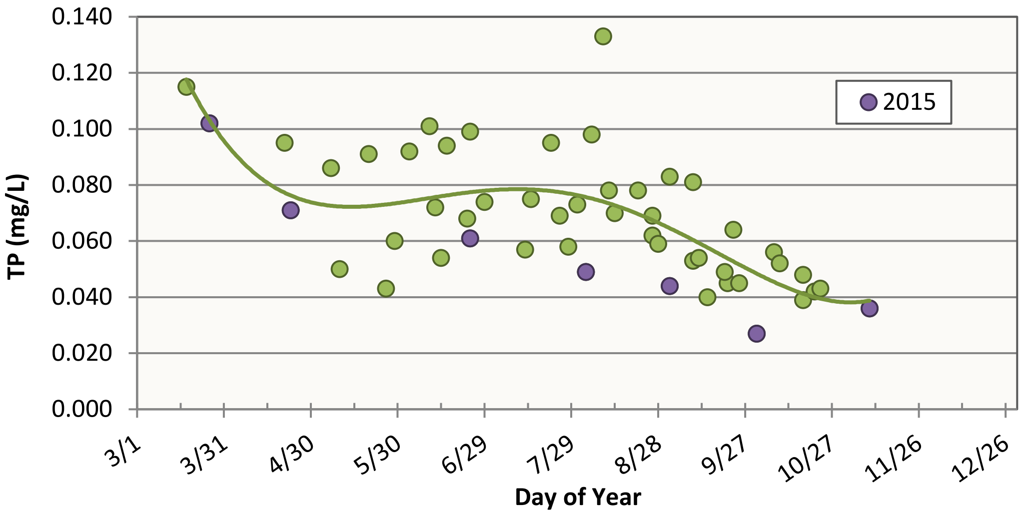

Figure 18. TP data for site S001-894. Includes data from years 1993, 2000, 2001, 2002, 2003, 2015, and 2016. Two outliers were removed from the graph and analysis. The polynomial regression line is for all data points, with R^2 = 0.4641.

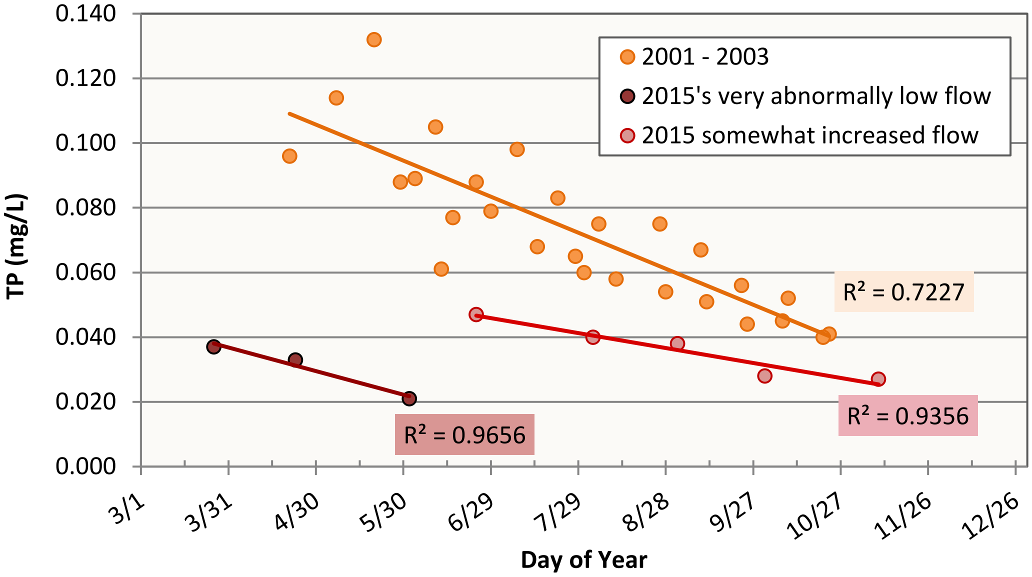

Figure 19. TP data for site S001-903. Includes data from years 2001, 2002, 2003, and 2015. One outlier was removed from the graph and analysis. The linear regression lines are done separately for the three groups of data points, with R^2 values shown on the graph.

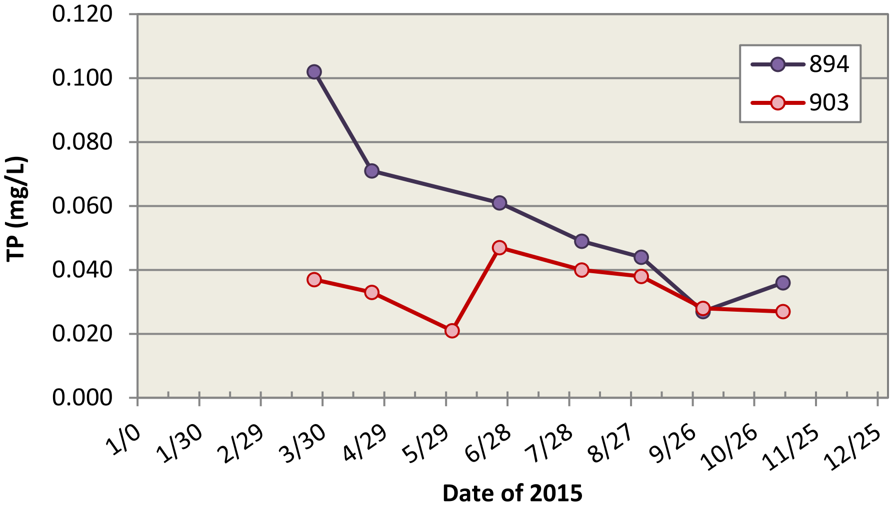

Figure 20. Upstream/Downstream same-day comparison of 2015 TP data.

Nitrogen

Nitrogen levels in the forms of nitrate and ammonia are both extremely low in both sites (Table 11). These extremely low nitrogen concentrations argue against an anthropogenic source for at least most of the phosphorus measured at in AUID-753.

Table 11. Summary statistics for nutrient concentrations at S001-894 and S001-903.

	Nitrate		**Ammonia**		**Total Phosphorus**	
Site	S001-894	S001-903	S001-894	S001-903	S001-894	S001-903
# samples	30	30	29	29	28	28
# above std.	0	0	0	0	25	24
% of # above std.	0.0	0.0	0.0	0.0	89.3	85.7
% of # above det. lim.	13.3	13.3	30.0	20.0	100	100
Average concentration	< 0.05	< 0.05	< 0.06	< 0.06	0.077	0.075

Conclusions

AUID-753 experiences periods of low DO and TP levels above the River Eutrophication Standard. There is no evidence of cultural eutrophication, for example, excess filamentous or water column algae. Nitrogen in the water, another potential result of anthropogenic activities on the landscape, is required for cultural eutrophication, but is at very low concentrations in AUID-753. Human landscape modification is relatively light in this subwatershed, with the headwater source being Lake Itasca inside Lake Itasca State Park. Low DO and elevated TP, which are commonly found together in heavily modified landscapes, do not seem to be the result of human activities in AUID-753. Hydrological connection between the river, riparian wetlands, and groundwater inputs more likely explains these phenomena, as wetlands are typically low DO waters and export phosphorus from plant material decay, and groundwater is generally also naturally low in DO. Springs were observed along the riverbank at both of the sample locations on AUID-753.

Multi-stream geomorphology assessments

Fluvial Geomorphology is the study of the physical form and functioning of stream channels. Human activity and land use change can alter stream channel processes, which can lead to degradation of habitat for aquatic biological communities. A group of DNR watershed specialists and hydrologists conducted geomorphology assessments at a number of streams in the MRHW. Sixteen sites were selected across the watershed to inform possible biological impairments and gather baseline data on stream channel condition. Based on the results of a qualitative assessment, nine of the 16 sites were selected to determine if the stream channels were unstable and gather reference condition data. Nearly all study sites were co-located with the biological sampling sites from the IWM effort. Seven sites received only Pfankuch assessments, and nine other sites received both Pfankuch and Rosgen (Level II) assessments. A short summary of the findings is presented here (Table 12), while a full report, written by the DNR and including detailed records of measurements/data will soon be found on the DNR website (at the time of this publication, a website had not been assigned for that report).

The assessment methodologies used for stream channel condition were the Pfankuch stream stability measurement (Pfankuch, 1975) and stream morphology protocols developed by Rosgen (1996, 2009). The Pfankuch stability ratings (for a given Rosegen stream type) of streams in unaltered landscapes should be “stable” (excluding very local situations where beaver activity may have caused instability). Streams or locations that do not score as “stable” have probably been influenced by human activity on the landscape (drainage, alteration of riparian or general landscape vegetation, etc.). Some streams are naturally more sensitive to disturbance than others and thus may require special protective measures to prevent damage. Rogen Type C and E channels, the typical stream types of north central MN, have very high sensitivity to disturbance when they have sand as their primary bank and bed material (Rosgen 2009). Many of the MRHW stream do flow through sand-dominated lands. Some measurements from both the Pfankuch and Rosgen protocols can inform a conclusion as to whether instability is human-caused, for instance, by alterations to runoff patterns that change flow regimes.

Table 12. Summary of findings of geomorphology assessments by DNR staff. The three right-most columns are intended to report results that can be linked to human activity. For more detail about the habitat and culvert problems found at these sites, see the full DNR report.

Site	Name	Pfankuch stability	Geomorphology result	Habitat problems?	Culvert issue?
13UM119	Island L. Creek	Moderately unstable	NA	Possibly	No
99UM001	Moose Creek	Moderately unstable	NA	Possibly	No
13UM160	Third R.	Moderately unstable	NA	Possibly	No
98UM003	Mississippi R.	Stable	NA	No	No
99UM021	Turtle R.	Moderately unstable	NA	No	No
13UM148	Tributary to L.	Stable	NA	Possibly	No
13UM100	Alcohol Creek	Stable	NA	Possibly	No
13UM145	Tributary to Deer R.	Unstable	Moderately	Yes	No
13UM102	Bear Creek	Stable	Good condition	No	Yes
13UM129	Moose Creek	Unstable	Moderately	Possibly	No
Other	Mississippi R.	Stable	Good condition	No	No
13UM117	Hennepin Creek	Stable	Good condition	Slight	Yes
13UM122	Little Mississippi R.	Moderately unstable	Good condition	No	No
00UM010 (1)	Mississippi R.	Stable	Good condition	No	No
00UM010 (2)	Mississippi R.	Stable	Good condition	No	No
13UM134	Schoolcraft R.	Stable	Good condition	Possibly	No

Geomorphology conclusions

A number of the streams had Pfankuch scores that put them into either the “moderately unstable” or “unstable” categories. Sand-dominated bank material and streambeds are naturally less stable than those made of cohesive materials (clay) or rocky material. Some surveyed streams did have cobble material in their banks and beds and those rated as stable. Changes in land use and vegetation, including the original historic logging of the watershed, may have affected (and be affecting currently) the more-sensitive sandy streams.

The Rosgen protocol to measure “channel incision” is one of the metrics that points to human-caused flow alteration resulting in degradation of the channel. Two streams (Tributary to Deer River and Moose Creek) were determined to have incised channels. Landscape alteration that leads to increased runoff rates and amounts, and thus increased peak flow volumes, results in the eroding of the streambed to a lower elevation, which in turn makes banks less stable. Incised streams generally have some level of water quality and habitat degradation, often related to fine sediment. The biological communities in these two streams, though not rated as impaired, are probably being limited from achieving their biological potential due to the channel alterations.

Two streams also had problematic culverts at the crossing adjacent to the monitored site (Bear Creek and Hennepin Creek). In both cases, the biological monitoring was done downstream of these culverts. The culverts at both sites are barriers to fish migration, and if fish sampling were done on the upstream side of the road crossing, the fish community may be found to be impaired.

MRHW hydrology

Hydrology, the input and movement of water through a watershed, is one of the base factors that influence water quality and habitat availability for aquatic biological communities. In addition to the geomorphology assessments, hydrology data (e.g., precipitation amounts, patterns, and trends, runoff amounts, stream discharge, etc.) was analyzed by the same group of DNR staff. A few of the main findings regarding hydrology in the MRHW:

1. Temperature and precipitation rates have fluctuated since 1894 (expected), but overall, both are increasing over the full period of record.
2. The Mississippi River from its origin to Grand Rapids, MN is a highly regulated system with 5 major dams to lake outlets in the river system.
3. These flow control structures appear to be diminishing the effect of the increased precipitation rates as the analysis of stream flow at Grand Rapids is not showing dramatic increases in peaks and flashiness of the system.

The DNR’s complete analyses and conclusions regarding hydrology can be found in the same report as the geomorphology assessments.

Overall conclusions for the MRHW streams

The MRHW has no streams that will be going onto the 303(d) list as having impaired biological communities. The Stressor Identification process identified connectivity as the only stressor for two of the three stream reaches, which have one of the biological communities below the passing threshold (Table 13). Beaver activity is high in MRHW, as it is in numerous of the other northern Minnesota watersheds. Their dams are migration barriers for fish in the Gull River and Sugar Brook. The stressor for the third stream discussed in this report may be high iron concentration. There is some uncertainty in that determination because the relationship of macroinvertebrates and iron is not well studied. There is however, some rationale in the research literature to suspect that iron may have detrimental consequences to some macroinvertebrates. Also, the EPA does have a recommended aquatic life standard for iron (1000 µg/L), which Sucker Creek does exceed at times.

As with some smaller streams in other north-central Minnesota watersheds (Crow Wing, Snake, Leech Lake), some streams situated in quite natural landscapes were again found in the MRHW to have TP concentrations above the north region river nutrient standard, and Sucker Creek and the headwaters AUID of the Mississippi River were studied in this SID effort to add to knowledge about these streams and their phosphorus dynamics.

Table 13. Summary of stressors causing biological impairment in MRHW streams by location (AUID).

Stream	AUID Last 3 digits	Reach Description	Biological Impairment+	Stressor: Dissolved Oxygen	Phosphorus	Sediment/Turbidity	Connectivity	Altered Hydrology*	Channel Alteration	Iron
Sucker Creek	663		MI							◊
Gull River	610		Fish				o			
Sugar Brook	612		Fish				o			

+These are not officially impaired but did have one of the two biological communities with IBI scores below the threshold value.

*Includes intermittency and/or geomorphology/physical channel issues

◆ A "root cause" stressor, which causes other consequences that become the direct stressors.

◊ Possible contributing root cause.

● Determined to be a direct stressor.

o A stressor, but determined to have very little to no anthropogenic cause. Includes natural wetland and/or groundwater inputs, and beaver dams as natural stressors.

+ Based on river nutrient concentration threshold (though necessary response variable thresholds were not collected), but not officially assessed and listed for this parameter.

? Inconclusive

Lake investigations

Grace Lake (Lake ID # 29-0071-00)

Assessment: An assessment conducted in 2014 determined Grace Lake was near the impairment threshold for Aquatic Life use based on the Fish-IBI. The FIBI Tool 2 was used to calculate a score using fish data collected from a June 2010 game fish survey and nearshore sampling components completed in July 2010 by area fisheries staff and resulted in a score of 43. Tool 2 includes 15 standardized metrics of the fish community used to compute an overall FIBI score that is responsive to human disturbances. Fish sampling was also completed in 2015 by area fisheries staff and resulted in a FIBI score of 43. This represents the lowest score of the 27 lakes assessed using FIBI Tool 2 in the Mississippi River Headwaters (Figure 21). The impairment threshold for Tool 2 is 45 and the 90% confidence interval is 36-54.

Data and analyses

Biological response

Overall diversity of native fish species (18 species) was low compared to other Tool 2 lakes based on 2015 sampling. Diversity of intolerant species, insectivores, cyprinids, and species associated with vegetation were also all comparatively low and influenced the score negatively. No species considered tolerant of disturbance were sampled and diversity of omnivorous species was comparatively low which influenced the score positively. High biomass of carnivores in the gill nets also had a positive influence on the score although walleye, which have been stocked annually since 1986, accounted for 39% of the sample.

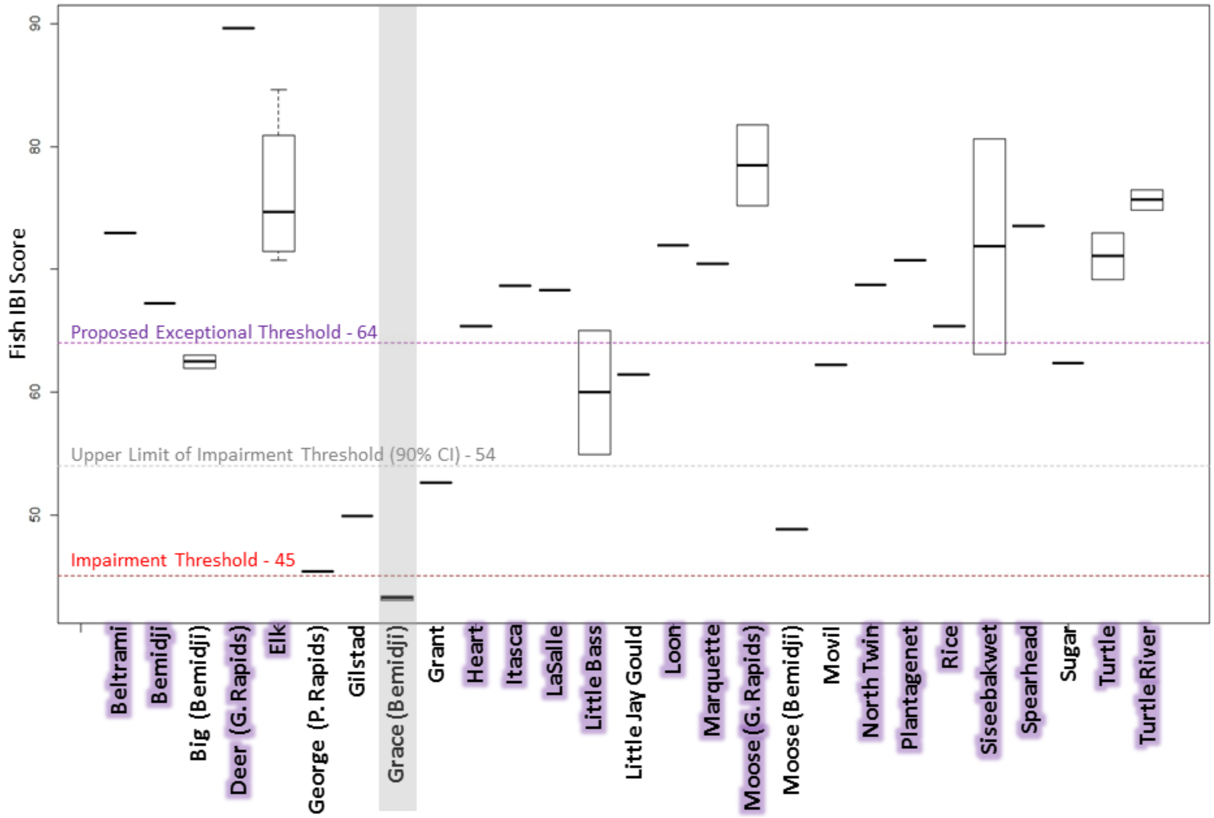

Figure 21. Boxplot of IBI scores for lakes in the MRHW using FIBI Tool 2.

Characteristics of the contributing watershed

The contributing watershed has a watershed to lake size ratio of about 7:1 (Figure 22). There are some shallow lakes located within the watershed that have no direct surface water connection and there are no other game fish lakes upstream. Watershed land cover remained stable between 2001 and 2011 based on National Land Cover Datasets (WHAF, 2015). Land cover within the watershed is primarily forest (34%) followed by agricultural land (30%) mainly in the form of uncultivated pasture and hay production (Figure 23). The remaining undeveloped land is a combination of open water (15%), wetlands (9%), and shrub or grassland (5%). Residential and commercial development (6.5%) including paved and unpaved roads account for the remaining land cover within the watershed.

Riparian habitat

Grace Lake is 860 acres in size with a maximum depth of 42 feet and 4.3 miles of shoreline. Publicly owned lakeshore (0.2 miles) includes a state owned public water access site along the west shore and an Aquatic Management Area in the southwest portion of the lake. The remaining lakeshore has a range of residential development density that has resulted in about 14 docks per kilometer based on 2013 FSA color aerial photography. An assessment of riparian habitat was conducted in May 2015 following “Score the Shore” survey protocols and resulted in an overall lakewide score (which range from 0 to 100) of 58 and 91% (31 of 34) of sample sites categorized as developed based on the land use observed.

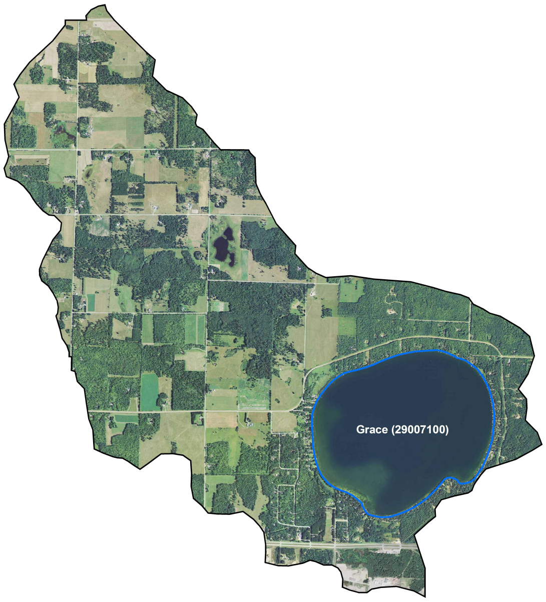

Figure 22. Grace Lake contributing watershed using 2013 FSA color aerial photography.

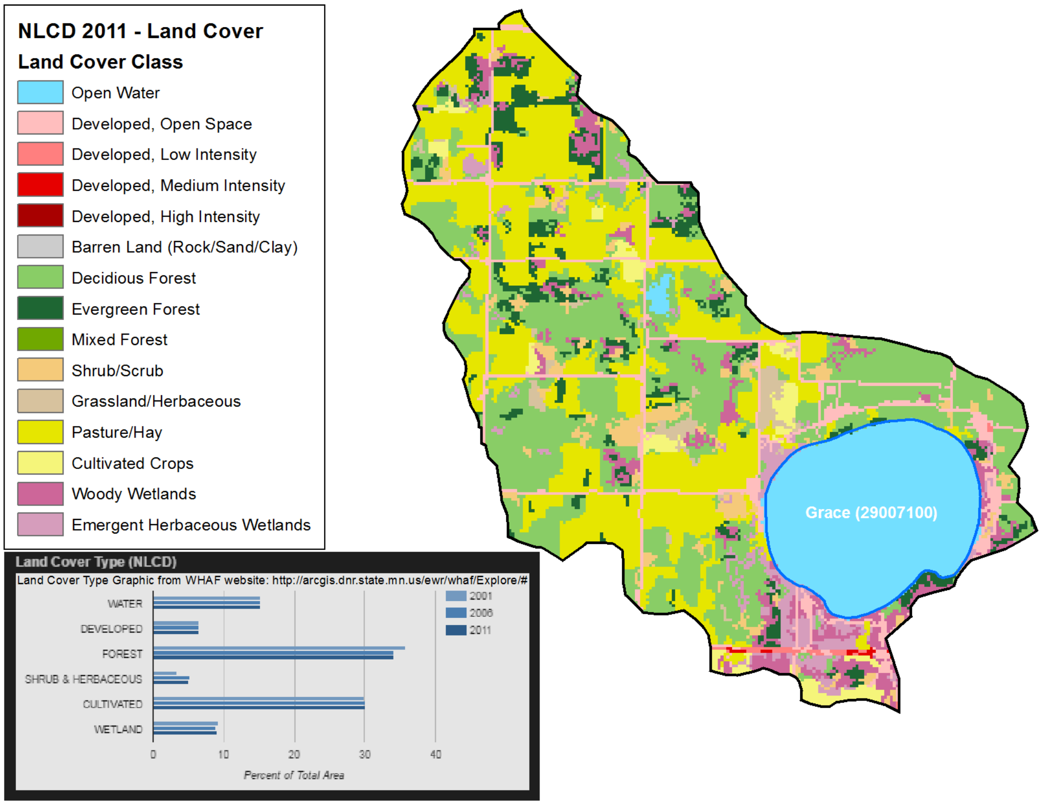

Figure 23. Grace Lake contributing watershed using 2011 NLCD Land Cover.

In-lake habitat

The DNR-Aquatic Plant Management program has never issued a permit for the removal of any aquatic vegetation and chemical control of snails to prevent swimmer's itch is rare with only four permits issued to individual properties in the past. Bulrush beds were surveyed in 2006 by DNR-EWR (Perleberg D., 2006) and emergent and floating-leaf plant stands were surveyed in 2015 by DNR-Fisheries. Visual comparison between surveys using GIS software suggests these stands have been stable for about the past decade.

Conclusions

Biological data indicate the fish community of Grace Lake is near the impairment threshold as measured by the FIBI Tool 2. Game fish management, aquatic habitat alteration, watershed and riparian land disturbance are stressors identified in this report that may be contributing to the current status of the fish community. Variables that measure the significance of each stressor have different data quality and confidence and will be discussed further. There is concern that additional stress from one or more of these variables may result in a designation of non-supporting for aquatic life based on the fish community in future assessments.

Previous DNR management efforts that have influenced the fish community include stocking Crappie (before 1945), Largemouth Bass (before 1945 and 1963), Muskellunge (1984), Northern Pike (regularly from 1945 to 1986) and Walleye (before 1945 to present). In addition, Bluegill were first sampled in fisheries surveys in 1989. They were likely introduced to the lake by humans although not as part of a formal stocking program (DNR-Fisheries Lake Files, 2015). DNR-Fisheries management activities directly impacting the current fish community include annual Walleye fingerling stocking and efforts to limit Northern Pike recruitment. Grace Lake receives the highest density walleye fingerling stocking in the DNR-Fisheries Bemidji management area. An evaluation of the FIBI Tool 2 has shown no difference in overall IBI score, or individual metric scores, between non-stocked and stocked walleye lakes. However, evaluation of fingerling stocking density in lakes assessed with Tool 2 showed some correlation to individual metrics but not to the overall IBI score. However, the high stocking densities used on Grace Lake were not well represented in the analysis (Bacigalupi J., 2015 personal communication). Further evaluation of the effects of walleye fingerling stocking density should be conducted as additional data becomes available. Based on these factors game fish management cannot be eliminated as a possible stressor of the fish community.

DNR-Fisheries Area Lake Files date back to the 1940's, but have limited information on historic emergent and floating-leaf plant distribution, which makes quantifying the amount of habitat loss difficult. Available information suggests these habitat types were present but not ubiquitous around the lake. Desktop visual analysis of historic air photography suggests the nearshore habitat has been significantly altered but it is unclear whether that has resulted in the loss of high quality fish habitat such as bulrush, or vegetation with secondary fish habitat value such as transition zone plants that stabilize soil and sediments. Although DNR has never issued any permits to remove aquatic vegetation on the lake, unpermitted activities have likely resulted in the loss of aquatic habitat. Based on these factors in-lake habitat alteration cannot be eliminated as a possible stressor of the fish community. Lakeshore activities that protect or enhance natural cover in the nearshore area will help to prevent further impact from this type of disturbance.

Watershed and riparian land disturbance are candidate stressors based on current conditions. Agricultural uses account for about 30% of the land within the watershed and although most is relatively low impact uncultivated, hay production the scale of these alterations has likely impacted the nutrient input to the lake. Residential and commercial development accounts for an additional 6.5% of the land cover within the watershed. Modeling in Minnesota lakes suggests that total phosphorus concentrations increase significantly over natural concentrations when land use disturbances occur in greater than around 40% of the watershed area and this relationship tends to be stronger in shallow lakes (Cross and Jacobson, 2013). This indicates the current level of land disturbance is approaching the level believed to have significant impact to aquatic life.

Water quality data collected to assess aquatic recreation use also appear to indicate that Grace Lake is near an impairment threshold. Chlorophyll-a levels exceeded the standard, total phosphorous concentrations were near the standard, and secchi depth measurements met the standard, which resulted in an assessment of "insufficient information" due to the mixed results. Further, modeling has also been used to identify lakes of phosphorous sensitivity significance and Grace Lake was classified in highest priority group, or greater than the 75th percentile of lakes assessed (DNR et al, 2015). These results support the concern for the potential increase in stress from watershed land disturbance in the future. At current development levels, DNR-Fisheries (2013) analysis classifies the lake's watershed as having the potential for full restoration based on the amount of land use disturbance and land protection.

In addition, riparian habitat variables suggest lakeshore development is near the level thought to impact the quality of the fish community. Dock density has been used as a measure of shoreline disturbance since dock placement is typically accompanied by riparian and nearshore habitat alteration. Dock density in Grace Lake is about 14 per kilometer and DNR-Fisheries research indicates that somewhere between 10 to 20 docks per kilometer has been the consistent breakpoint in several analyses where noticeable impacts to the lake are observed (Bacigalupi J., 2015 personal communication). "Score the Shore" survey protocols (Perleberg D. et al, 2015) were developed by DNR-EWR in 2013 and adopted for use by DNR-Fisheries for the 2015 field season to assess riparian lake habitat. Therefore, few lakes in the Mississippi River Headwaters have been surveyed using this technique. However, the scores from surveys completed statewide (184 surveys) have ranged from 37 to 99 with an average of 74 and the scores from surveys from the Mississippi River Brainerd watershed (53) have ranged from 60 to 90 with an average of 75. The lakewide score calculated from the 2015 survey of Grace Lake was 58.

Activities that protect, enhance, or restore watershed function and riparian habitat are the most beneficial to preserving the biological integrity of the fish community. An assessment of nutrient sources in the contributing watershed should be conducted and projects that buffer the lake from additional phosphorous loading should be considered. DNR-EWR (see DNR, 2012 for details) has also developed a Rapid Assessment Model to identify sensitive lakeshore areas that can help prioritize protection and restoration efforts at the shoreline scale (available online at: http://files.dnr.state.mn.us/eco/sli/grace_29007100.pdf). Shoreland management practices should be reevaluated as additional information regarding their impact to the fish community becomes available.

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