Stressor Identification

February 2018

Upper/Lower Red Lake Watershed Stressor Identification Report

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

MINNESOTA POLLUTION CONTROL AGENCY

Streams section

Author
Kevin Stroom (MPCA)

Contributors/acknowledgements
Kayla Bowe - Red Lake DNR
Lori Clark (DNR)
Jason Vinje (DNR)

Lake section

Author
Lucas Borgstrom (DNR)

Contributors/acknowledgements
Kevin Mott (DNR)
Jacquelyn Bacigalupi (DNR)

Manuscript reviewers
Chad Anderson (MPCA)
Kayla Bowe (Red Lake DNR)
Lorilynn Clark (DNR)
Kara Fitzpatrick (MPCA)
Corey Hanson - Red Lake Watershed District
Mike Sharp (MPCA)
Jason Vinje (DNR)

Editing and graphic design
Cover photo: Tamarac River
in Koochiching County, MN - MPCA

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Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

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Acronyms and term definitions

aquatic	In relation to the Score the Shore survey; an area that is defined as 100 feet along the land-water interface and 50 feet lakeward.
APM	Aquatic Plant Management
AUID	Assessment Unit (Identification Number) MPCA's pre-determined stream segments used as units for stream/river assessment – each has a unique number.
contributing watershed	In this report; the upstream catchments that drain or have the potential to drain to a lake.
CPUE	catch per unit effort
CSAH	County State Aid Highway
DO	Dissolved oxygen
DOW #	Division of Waters number; in this report, a unique identification number for water basins in Minnesota. They follow the format of XX-YYYY-ZZ where XX is a county code, YYYY is the basin number in that county, and ZZ is the sub-basin identifier.
DNR	Minnesota Department of Natural Resources
DS	Downstream
emergent	In this report; a plant that is rooted in lake substrate and has leaves and stems which extend out of the water. Floating bogs are considered emergent plant stands.
FIBI	Fish-based lake Index of Biological Integrity; An index developed by DNR that compares the types and numbers of fish observed in a lake to what is expected for a healthy lake (range from 0 – 100). More information can be found at the Lake Index of Biological Integrity website.
floating-leaf	In this report; a plant that is rooted in lake substrate and has its leaves and flowers floating on the water surface.
GIS	Geographic Information System
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.
impervious	A surface that promotes overland flow of precipitation as opposed to allowing it to seep into the ground.
insectivorous species	A species that predominantly eats insects.
intolerant species	A species whose presence or abundance decreases as human disturbance increases.
ISTS	Individual Sewage Treatment System
IWM	MPCA's Intensive Watershed Monitoring, which includes chemistry, habitat, and biological sampling.

littoral acres	In this report; the acres of a lake that are 15 feet deep or less.
m	The abbreviation for meter
mg/L	Milligrams per liter
µg/L	Micrograms per liter (1 milligram = 1000 micrograms), equivalent to parts per billion (ppb)
macrophyte	Macro (= large), phyte (= plant). These are the large aquatic plants, such as *Elodea* and Coontail.
MDA	Minnesota Department of Agriculture
MPCA	Minnesota Pollution Control Agency
MSHA	Minnesota Stream Habitat Assessment
M&A Report	MPCA Monitoring and Assessment Report for the Upper/Lower Red Lake Watershed
MS4	Municipal Stormwater Plan, level 4
nearshore survey	In this report; a fisheries survey conducted at evenly spaced, but random sites along the shoreline utilizing 1/8 inch mesh seines and backpack electrofishing to characterize primarily the nongame fish community of a lake.
NLCD	National Land Cover Database; A GIS database that utilizes remote sensing at a 30 meter spatial resolution to classify land cover into one of 16 classes.
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.
P	Phosphorus
palustrine wetland	A US Fish and Wildlife Service wetland classification which includes marshes, small ponds, wet meadows, fens, and bogs.
predator fish	A fish species that derives the majority of its energy and nutrients through the consumption of other vertebrate animals.
riparian	Situated on the bank of a watercourse or lake.
ULRLW	Upper/Lower Red Lake Watershed
shoreland	In relation to the Score the Shore survey; an area that is defined as 100 feet along the top of bank landward for either 100 feet or until the base of a structure such as a cabin, whichever is less.
shoreline	In relation to the Score the Shore survey; an area that is defined as 100 feet along the land-water interface and landward to the top of bank.
SID	Stressor Identification; The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.
small benthic-dwelling species	A species that is small and predominantly lives in close proximity to the bottom.
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.
species richness	A count of species.

StS	Score the Shore survey; a survey designed to be able to rapidly assess the quantity and integrity of lakeshore habitat so as to assess differences between lakes and detect changes over time.
submersed	In this report; a plant that has stems and leaves that grow entirely underwater, although some may have floating leaves or emergent flowers.
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
tolerant species	A species whose presence or abundance does not decrease, or may even increase, as human disturbance increases.
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)
EPA	United States Environmental Protection Agency
vegetative-dwelling species	A species that has a life cycle dependent upon vegetated habitats.
weight of evidence approach	A method of using multiple sources or pieces of information to classify a waterbody as impaired.
WRAPS	Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.
1X	One time (chemistry samples collected on 1 date)
10X	Ten times (chemistry samples collected on 10 dates)

Executive summary

This report documents the efforts that were taken to identify the causes, and to some degree the source(s) of impairments to aquatic biological communities in the Upper/Lower Red Lake Watershed (ULRLW). 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 ULRLW is situated within a mixed-landcover region of northwestern Minnesota, consisting of forests, massive wetlands, and agricultural fields and pastures. Agricultural land usage is primarily in the southern and southeastern part of the watershed. Much of the agriculture is related to animal rearing, with many of the fields being used for hay, rather than for row crops. However, row crop agriculture is present. A substantial portion of the ULRLW (about 1/3, including the area of the Red Lakes) is within the Red Lake Reservation, and this land is largely in a natural state. The Reservation surrounds all of Lower Red Lake, and the western half of Upper Red Lake. Also contributing to the relatively natural condition of much of the watershed is the extremely large peatlands found in the northern half of the ULRLW. A very small portion of the Chippewa National Forest falls in the ULRLW, as does about half of the Big Bog State Recreational Area. The density of residential and urban land use is very low in the ULRLW, with only four small incorporated towns - Blackduck, Funkley, Kelliher, and Northome. Stressors related to developed lands (impervious surfaces, stormwater runoff, wastewater facility discharges, etc.) are not expected to be a significant issue here; only Kelliher has a municipal wastewater treatment system that discharges to surface waters. There are no industrial effluent dischargers in the ULRLW. Given these landscape/land use attributes, the primary anthropogenic stressors in the ULRLW are likely to be non-point types, and most likely from agricultural activities. Some Individual Sewage Treatment Systems (ISTS) failure may be present as well. One stressor, which can occur anywhere roads are present, is barriers to fish migration caused by the structures used to place a road over a stream. Culverts, in particular, are commonly found to be at least partial barriers to fish passage.

Streams

Seven Assessment Unit (AUID) reaches on seven different streams were brought into the stream SID process (Figure 1), six because they were determined to have substandard biological communities via the 2014 Intensive Watershed Monitoring and Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. The seventh reach (North Cormorant River) was studied further due to observations of possible channel instability, which can influence biological communities.

- Tamarac River (AUID 09020305-501) - Fish
- Shotley Brook (AUID 09020305-502) - Invertebrates
- North Battle River (AUID 09020305-503) - Fish
- North Cormorant River (AUID 09020305-506) - Geomorphological issues
- Darrigan's Creek (AUID 09020305-508) - Invertebrates
- Lost River (AUID 09020305-602) - Fish
- Perry Creek (AUID 09020305-605) - Fish

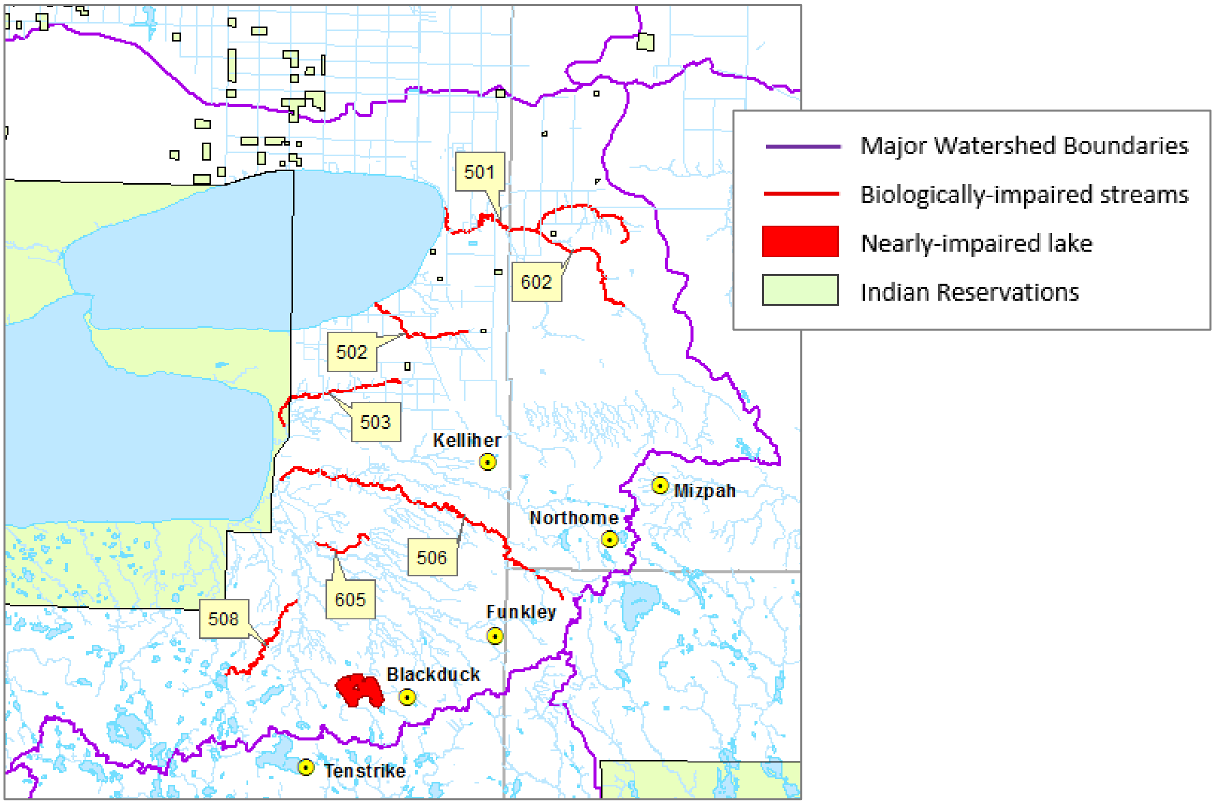

Figure 1. Map of the eastern portion of the Upper/Lower Red Lake Watershed showing stream reaches with biological impairments, and the nearly-impaired Blackduck Lake. Stream labels are AUID numbers. Note AUID-506 was not assessed as biologically-impaired, but has some issues that will be discussed in this report.

A number of stressors to the stream biological communities were found. These involved only non-point source pollution, infrastructure, or naturally-occurring circumstances. No point source pollution was associated with the biological impairments. The non-point source issue involved pasturing cattle in riparian zones (AUID 508). Infrastructure stressors were culverts that were installed such that fish passage is difficult or not possible (605). Included in the infrastructure category is legacy ditching projects, which in the early 1900s attempted to drain extensive bog areas in the northeastern part of the ULRLW. These ditches alter the hydrology downstream, and appear to have caused channel damage, leading to habitat loss (501, 502, 503). The natural stressors are low dissolved oxygen (DO) (501, 602), due to the extensive wetlands, and beaver dams (503), which block fish passage, preventing repopulation of streams in spring from downstream overwintering habitat.

Lakes

Of six ULRLW lakes that were sampled for an aquatic life assessment, one of these, Blackduck Lake (DOW 04-0069-00), had two Fish Index of Biological Integrity (FIBI) scores below (but very near) the impairment threshold, but insufficient information to warrant a not-supporting assessment of aquatic life use. This data suggests it is vulnerable to future Aquatic Life Use impairment. The main stressor contributing to the condition of the lake's fish community, as measured with the FIBI, is excess nutrients. The percent of the watershed that is a disturbed land class is below levels where effects are detected in the FIBI. The shoreline habitat has undergone some development, but is not at a level where the effects are detectable with the FIBI. The effects of connectivity and water level control on the FIBI are inconclusive. Dellwater Lake (DOW 04-0331-00) and Dark Lake (DOW 36-0014-00) were sampled but not assessed due to a recent winterkill and a lower than standard sampling effort respectively.

Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds, known as Major WRAPS. A WRAPS is comprised of several types of assessments. For the ULRLW, MPCA and partners from state and local agencies conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2014 and 2015. The IWM assessed the aquatic biology and water chemistry of the ULRLW streams, rivers, and lakes. Following assessment, an effort known as the SID, builds on the results of the IWM and seeks to discover the cause(s) of impairments to the biological communities of streams and lakes. The MPCA (for streams), along with its partner, the Minnesota Department of Natural Resources (DNR) (for lakes), conducted the SID assessment during 2015 – 2016. This document reports on this second step of the multi-part WRAPS for the ULRLW.

It is important to recognize that this report is part of a series for the ULRLW, and thus not a stand-alone document. Information pertinent to understanding this report can be found in the Red Lake 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 ULRLW webpage; https://www.pca.state.mn.us/water/watersheds/upperlower-red-lake.

Landscape of the Upper/Lower Red Lake Watershed

A detailed description of various geographical and geological features of the landscape of the ULRLW is documented in the Upper/Lower Red Lake Watershed M&A Report (MPCA, 2017b). That information is useful and necessary for understanding the settings of the various ULRLW's subwatersheds, and how various landscape factors influence the hydrology within the ULRLW. The following information is intended to provide a basic description of the ULRLW landscape.

The majority of the ULRLW is relatively flat terrain. As such, the streams and rivers that run throughout the watershed are primarily low gradient, though some exceptions occur in the southern half of the ULRLW. In the northern half of the ULRLW, streams flow through extensive wetland and bog habitat. This situation affects many other characteristics of the streams and aquatic biological communities. The streams and rivers flow slowly, and thus accumulate fine grained or organic particulate material as their primary substrate. Slow flows can influence the DO levels in the streams both due to lower mixing of water that aids contact with the atmosphere, and because low gradient streams can take on wetland characteristics, having accumulations of organic particulate sediment. The amount of DO in the water column is reduced as bacteria consume oxygen as they decompose this organic material.

The original, pre-settlement landscape was almost exclusively forests, wetlands, and lakes (Figure 2). Though the original forest harvest at the turn of the century changed much of the forest from older growth to the younger forests that exist now, a large percentage of the originally-forested landscape is still in a forested state. The primary area that contains lands utilized for agriculture is in the south-central part of the watershed, and the agriculture occurring there is primarily hay and cattle production, rather than row crops. The percentages of various categories of land cover are presented in Table 1. Figure 3 shows the extent of land area that is currently wetland (48% of the ULRLW). The ULRLW contains part of the largest bog complex in the lower United States, called the Big Bog.

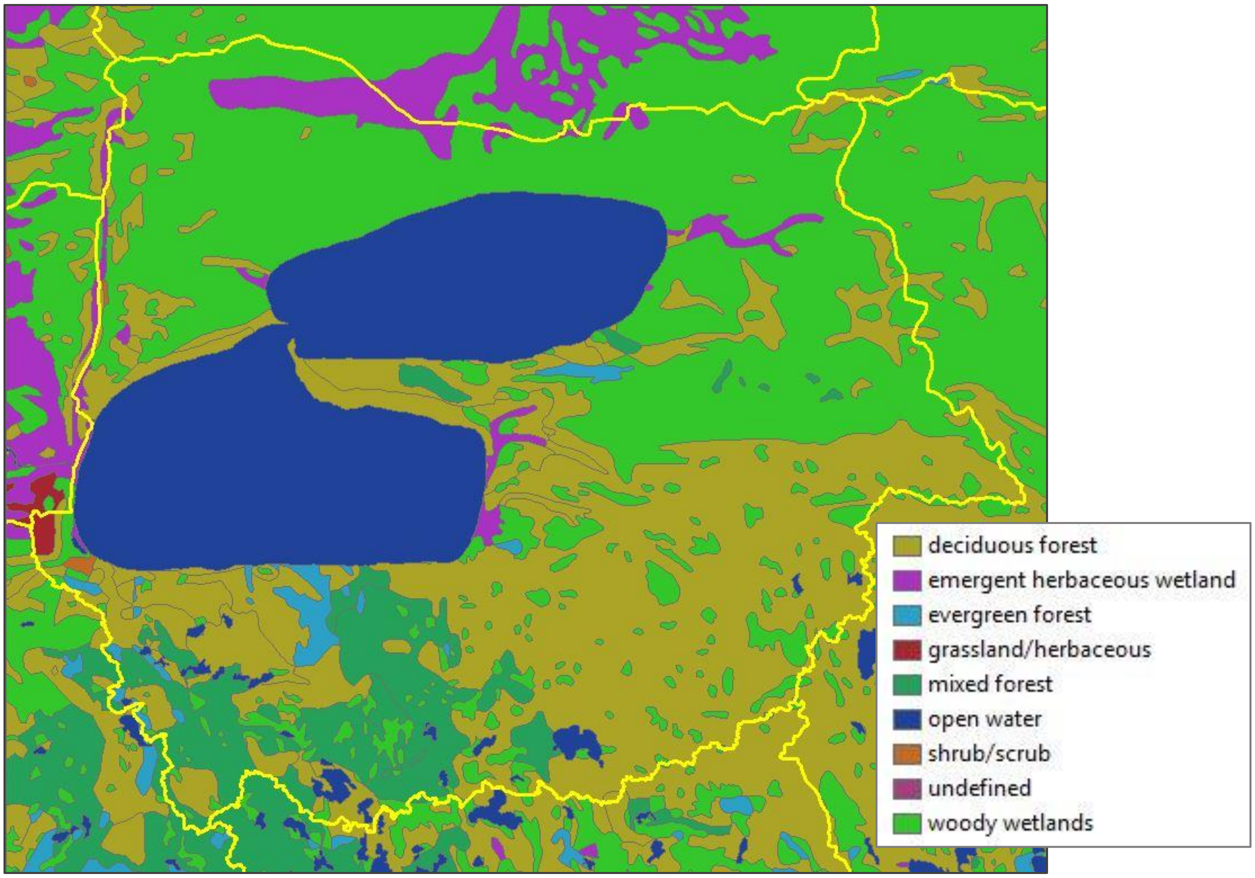

Figure 2. Original vegetation of the ULRLW and adjacent watersheds, (Marchner, 1930). The yellow line is the boundary of the ULRLW (and parts of adjacent watersheds).

Table 1. Percentages of the various land cover types from 2011 NLCD GIS coverage (MPCA, 2017b).

Land cover type	Percent of Land Area
Developed (all intensities grouped)	1.5
Cultivated Crops	0.8
Rangeland	6.1
Water, wetlands, and forest lands	91.5

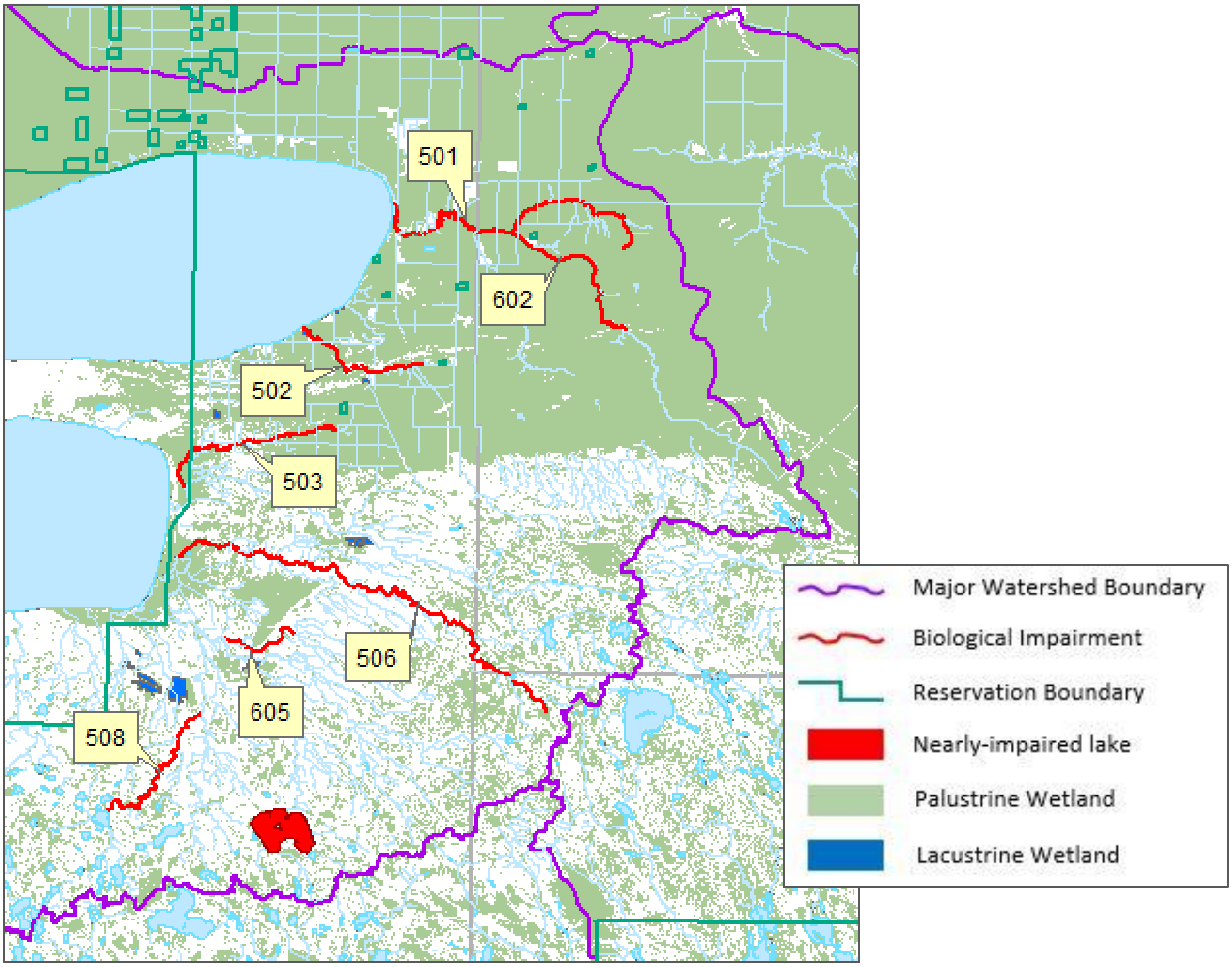

Figure 3. Wetland area as determined by the National Wetland Inventory (only the eastern 2/3 of the ULRLW is shown). AUID-506 is not biologically-impaired, but has some issues that will be discussed in this report.

Determination of candidate stream stressors

The process

A wide variety of human activities on the landscape can create stress on water resources and their biological communities, including; urban and residential development, industrial activities, agriculture, and forest harvest. An investigation is required in order to link the observed effects on an impaired biological community to the cause(s), 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 those stressors are associated with unique human activities (e.g., specific types of manufacturing and mining) and can be readily eliminated from consideration due to the absence of those activities in the watershed. The initial step in the evaluation of possible stressor candidates was to study several existing data sources that describe land usage and other human activities. These sources included numerous GIS coverages, aerial photography, and the 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, actual water quality, habitat, and biological data were analyzed to make further conclusions about the likelihood of certain stressors impacting the biological communities. Water chemistry and flow volume data has been collected within the ULRLW for many years. The determination of candidate stressors used both the historical data and data collected during the 2014 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.

Department of Natural Resources Watershed Health Assessment Framework

The DNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The WHAF includes an assessment of the nonpoint source pollution threat to water quality within the water quality component of watershed health. That assessment shows non-point pollution, relative to other parts of the state, is not a widespread stressor in the ULRLW (Figure 4). According to the Non-point Source Pollution Index, the ULRLW ranks as tied for 8^{th} out of the 80 watersheds in Minnesota (where 1^{st} is best, or has least threat). This equates to the 89.7^{th} percentile. A major urban source of non-point pollution is runoff from impervious surfaces. Due to the low number and small sizes of the cities/towns in the ULRLW, this threat is very low (Figure 5).There are localized situations, such as the immediate shoreline properties of lakes with significant development, where impervious surfaces may be an important water quality issue. The analysis scale of this map does not show those locations. Streams and rivers in the ULRLW generally do not have the degree of shoreline development as area lakes, and thus this near-shore threat is particular to lakes, while much less of an issue with rivers and streams. None of the stream impairments has a town located near the stream channel.

The Point Source Index in the WHAF captures possible impact from point source and similar types of pollution sources, including pollutant contributions from animal husbandry, hazardous waste and superfund sites, wastewater treatment effluent, mining, and septic systems. Point source pollution is also not a significant source of stream stressors in the ULRLW. There are no permitted industrial dischargers and only Kelliher discharges wastewater to surface waters. The WHAF map for the Localized Pollutant Source Index (LPSI) showed all of the subwatersheds being among the least impacted rankings, and mostly from the best rank category. Some of the subwatersheds are potentially moderately affected by the density of agricultural animals and septic systems. Notably, the subwatersheds that contain the impaired streams are all in the best category for LPSI score. The Point Source score for the overall ULRLW was 96 out of 100. There are almost no locations that have relatively high septic system densities per the WHAF tool output (Figure 6). The only subwatersheds that aren't in the best category are right along the southern boundary of the ULRLW, and almost all of those still get fairly high scores. The exception, with a medium score, is the subwatershed around Lake Julia/Puposky. The overall ULRLW "Water Quality" WHAF Component score was 70 out of 100.

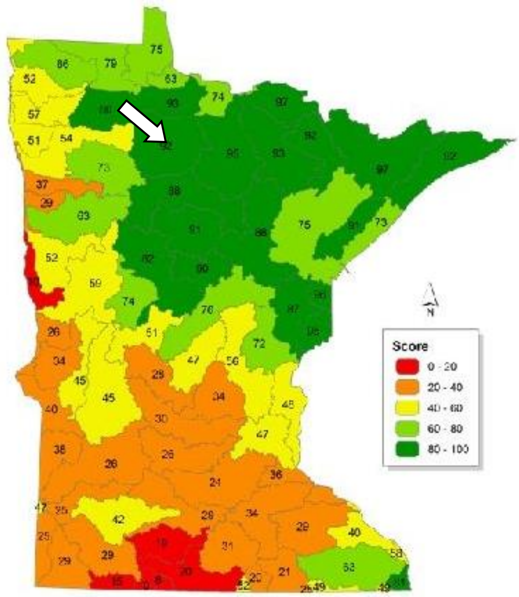

Figure 4. Scores and categorical ranking of the 80 Minnesota Major Watersheds for the DNR Non-point Source Pollution Index.

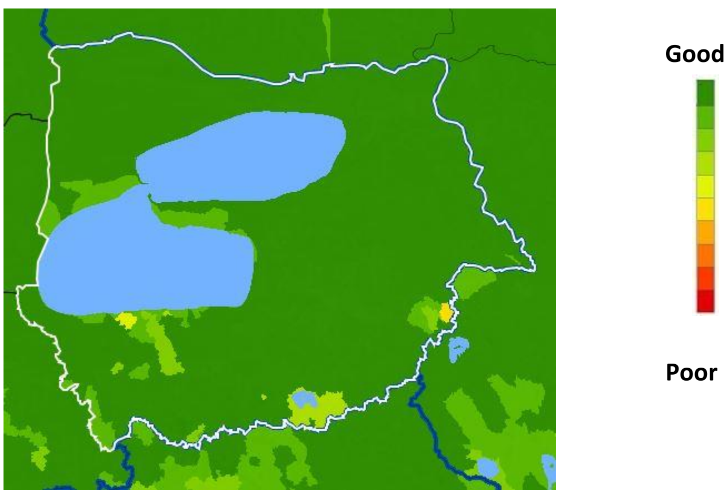

Figure 5. Catchment-scale impervious surface scores for the ULRLW (white boundary) and surrounding catchments.

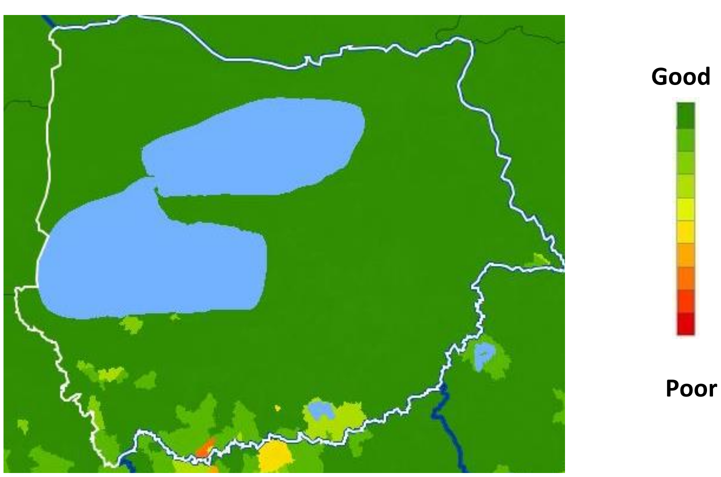

Figure 6. The WHAF Septic metric within the Nonpoint Source Index for the ULRLW.

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

	Impervious Surface	Nonpoint Threat	WWTP*	Storage Loss	Perennial Cover	Flow Variability	Ag. Chem. Use	Aquatic Connectivity
Rank	77	73	80 (t)	61	75	16 (t)	68 (t)	73

*WWTP = Wastewater Treatment Plant influence.
(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/index.html

Other MPCA and local government water monitoring programs

Aside from the IWM, 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 (Watershed Pollutant Load Monitoring Network), where numerous water quality parameters are frequently monitored, with sample sites near the pour point of each of Minnesota's 80 8-HUC scale watersheds. Phosphorus loads from each of Minnesota's 8-HUC watersheds are found on MPCA's webpage: http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=c53c280bb959419e891aaebfc1da9bb4. MPCA also provides water quality monitoring grants to local organizations (e.g., county soil and water conservation districts and watershed districts), and this data, as well as all of the MPCA-collected data, is stored in the publically-available EQuIS database, at the following webpage: http://www.pca.state.mn.us/index.php/data/environmental-data-access.html. Data from these other programs is included in the water chemistry discussions of individual AUIDs that follow later in the report, if applicable to the site.

Desktop review

Urbanization/development/population density

Census data provides a way to look at human-induced stress or pressure on the water resources of a region. Stressor sources that are related to population density include: wastewater effluent, impervious surface areas, and stormwater runoff, which all increase with population density. According to the 2010 census data, the ULRLW is sparsely populated relative to the state as a whole. There are a relatively small number of incorporated towns in the eastern two-thirds of the ULRLW, all of which are small communities, which include: Blackduck (785), Funkley (5), Kelliher (262), and Northome (200) - data from 2010 U.S. Federal Census (MSDC, 2015). None of these towns is large enough to require an MS4 stormwater plan.

Recent GIS-derived land use statistics showed that 1.5% of the watershed area is categorized as Residential/Commercial (MPCA, 2017b). The ULRLW ranks at the 96th percentile of the state's 80 watersheds for the lack of impervious cover, only three other watersheds have a smaller percentage of impervious surface. The census and urbanization information suggests that most stressors related to population density are likely only active at highly-localized areas (e.g., lakeshore development acting on a particular lake), if at all.

One potential source of water resource stressors in rural areas is subsurface sewage treatment systems (SSTS), formerly known as ISTS. Unsewered areas can have old septic systems that are either failing, or do not conform to current design standards. Most rural homes/cabins in the ULRLW are not connected to a municipal sewer system, and thus have individual treatment systems. Rural areas may also have residences that unlawfully discharge wastes directly to streams, but the numbers are declining. These systems can contribute significant levels of nutrients and other chemicals to water bodies. Recent septic system statistics for Koochiching County are that 10% of the individual treatment systems were estimated to be “Imminent Public Health Threats” (i.e., direct discharge to stream), and 67% “Failing”, with 23% of systems in compliance (MPCA 2012). These statistics are quite poor relative to many of Minnesota’s counties. Statistics for Beltrami County are not available.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The ULRLW has relatively little industry and there are zero industrial NPDES permits within the ULRLW. No industrial stormwater permits exist in the ULRLW. Thus, industrial discharges should not be a source of pollutants (stressors) causing stream impairment in the ULRLW.

Forestry

Forest harvest can create stress on water resources. Some lands within the ULRLW are used for timber production and historical large-scale forest removal did occur in the watershed. Nearly all of the non-wetland land area in the ULRLW was originally forested (Marchner, 1930). Stressors related to forest harvest are possibly occurring in the ULRLW. Tools to examine forest harvest impacts are fairly limited currently.

Agricultural activities

The lands of the ULRLW, as with those in much of northcentral Minnesota, are not extensively used for row crop agricultural production. The area of the ULRLW that has more than just sparse field agriculture is predominantly the southern and southeastern portion of the ULRLW. This is also the part of the watershed that has nearly all of the ULRLW’s animal agriculture (Figure 7). The review of the ULRLW’s land use, shown previously (Table 1) indicates that approximately 0.8 % of the land cover is in cultivated crops. It is reasonable to consider whether agricultural activities are a possible contributor to water quality problems in the described part of the watershed, though their overall contribution would be expected to be much less than in more southern and western parts of Minnesota. A large quantity of professional research exists with study results associating landscape changes from natural to agricultural land uses with water quality degradation and/or negative affects to biological communities (e.g., Fitzpatrick et al., 2001; Houghton and Holzenthal 2010; Diana et al., 2006; Sharpley et al., 2003, Blann et al., 2011, Riseng et al., 2011). Well-documented agriculture-related stressors include nutrients, sediment, and altered hydrology.

Agricultural activity can result in elevated nutrients in the water resources located in or downstream from those areas (Sharpley et al., 2003, Riseng et al., 2011, MPCA, 2013). With the substantially lesser degree of agriculture, particularly cultivated agriculture, occurring in the ULRLW relative to some other Minnesota regions, elevated nutrients from agriculture won’t be a systemic issue in the ULRLW, but could occur in localized areas, particularly in the southern half of the watershed.

Some alteration of hydrology has occurred simply by changing the vegetation from original forest to open farmland. In addition, soil compaction from farm equipment or animal grazing can increase runoff. More sediment will move to streams from cultivated streams than from fields with perennial grasses.

Since farmland acreage overall is relatively light in the ULRLW, and with much of that acreage being hay or pasture, erosion and alteration of hydrology due to agricultural would not be a systemic issue in the ULRLW, though local hotspots may occur.

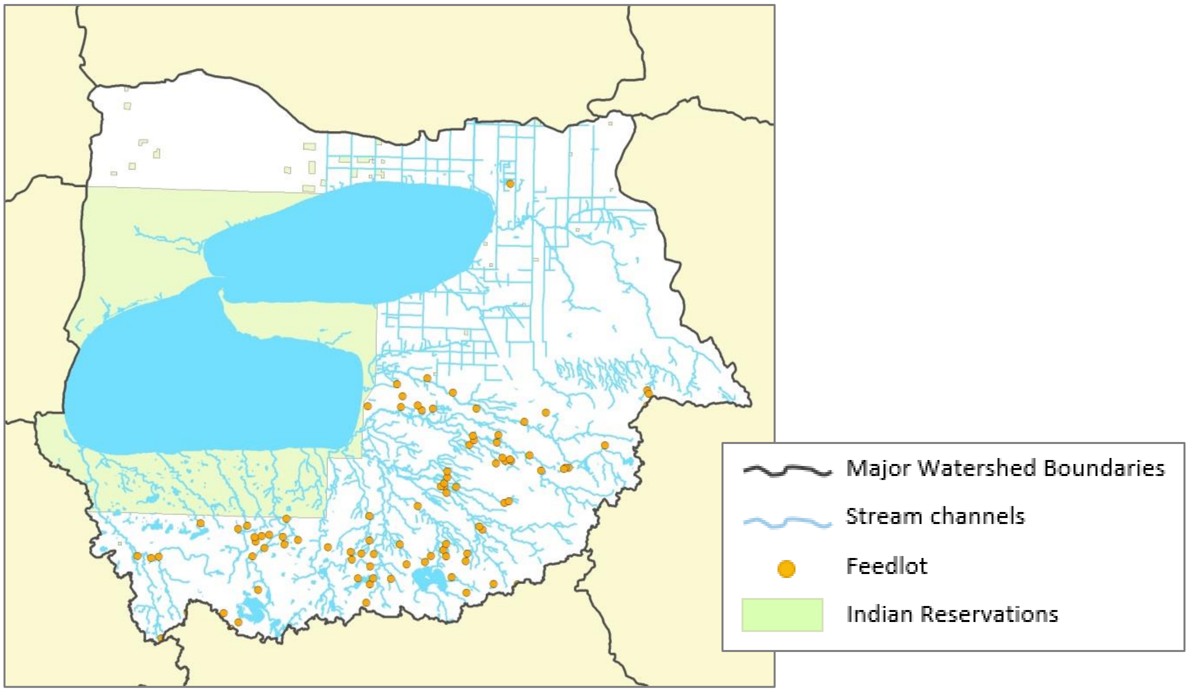

Figure 7. Registered feedlot (≥ 50 animal units) locations in the ULRLW. Note that unregistered feedlots likely exist and are represented on this map.

Pesticides

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

Summary of candidate stressor review

Based on the review of human activity in the ULRLW in general, and then specifically the areas in close proximity to the six locations with biological impairment, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the ULRLW, 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 Red Lake DNR sampling revealed extremely low concentrations in the ULRLW (data still presented in this report).
  - 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 planned or underway by MPCA to better understand the effects of forest harvest impacts on streams.

Candidate causes

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

Mechanisms of candidate stressors and applicable standards

A separate document has been developed by MPCA describing the various candidate stressors of aquatic biological communities, including where they are likely to occur, their mechanism of harmful effect, and Minnesota's standards for those stressors (MPCA, 2017a). Many literature references are cited, which are additional sources of information. The document is titled "Stressors to Biological Communities in Minnesota's Rivers and Streams" and can be found on the web at: https://www.pca.state.mn.us/sites/default/files/wq-ws1-27.pdf. Additional information on Stressor Identification in Minnesota can be found on MPCA's website: https://www.pca.state.mn.us/water/your-stream-stressed. EPA (2012) has yet more information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on their CADDIS website at https://www.epa.gov/caddis-vol5.

Notes on analysis of biological data

Biological data (the list of taxa sampled and the number of each) form the basis of the assessment of a stream's aquatic life use status. Various metrics can be calculated from the fish or macroinvertebrate sample data. An Index of Biological Integrity, a collection of metrics that have been shown to respond to human disturbance, is used in the assessment process (https://www.pca.state.mn.us/water/index-biological-integrity). Similarly, 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 species or genera (for macroinvertebrates) Tolerance Indicator Values for many water quality parameters and habitat features. This is a take-off on the well-known work of Hilsenhoff (1987; EPA, 2006), which has been further developed by USGS scientists (Meador and Carlisle, 2007). For each parameter, a relative score (a Tolerance Indicator Value [TIV]) is calculated for 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. The weighting factor is the abundance of that species or genera (for macroinvertebrates) at each site. Using those individual TIVs for the taxa present in a sample, a weighted average community score (a community index) can be calculated. 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 sampled to date. Such probabilities are only available for parameters that have established 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 community in an impaired reach. It is best, when feasible, to also include field observations, chemistry samples, and physical data from the impaired reach in determining the stressor(s).

Notes on analysis of chemical data

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

Notes on analysis of physical and hydrological data

Staff of the DNR provide assistance to the SID process by collecting physical data (e.g., Pfankuch assessments, Rosgen geomorphology studies) about the stream channel, and analyzing hydrological data. MPCA SID staff may also participate in the collection or analysis of this data. Summary information about these topics are included in this report, but a more thorough report was written by DNR for the ULRLW that presents much more data and nuanced discussion of interpretations of the data. The DNR report can be found at http://www.mda.state.mn.us/mnwrl.

Investigations organized by impaired stream reach

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

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

Tamarac River (AUID 09020302-501)

Impairment: The river was assessed as impaired for not meeting fish community expectations. The AUID contains two biological sites, 14RD139 (downstream) and 14RD143 (upstream). Site 14RD139 is non-wadeable, which prevented sampling for macroinvertebrates; site 14RD143 was sampled for macroinvertebrates. Fish data from 14RD139 will not be assessed due to the lack of an adequate FIBI for this site-type (predominant low gradient characteristics and a large drainage area). Neither the low gradient Index of Biological Integrity (IBI) nor the northern streams IBI are suitable for this stream type. However, fish did not meet the IBI standard at the upstream site, and thus the AUID was still determined to be impaired for aquatic life.

The AUID has a 10X chemistry site (S007-887) about one half mile downstream of 14RD139. The AUID does not meet Minnesota's statewide DO standard, but wetland-dominated streams such as the Tamarac River are being deferred for DO assessment at this time, awaiting possible development of a new standard for this stream type.

Subwatershed characteristics

The vast majority of the land within the Tamarac River subwatershed is wetland, with a majority being wooded wetland and most of the other being emergent herbaceous wetland. A minor amount of agriculture exists in the watershed, mostly in the form of hay fields which lie to the north of the lower part of the river, and are drained by ditching down into the Tamarac. The majority of the agricultural land is downstream of the upper biological sample site. There are three to four wild rice operations that exist in between 14RD139 and 14RD143, and have drainage to the Tamarac River.

Data and analyses

Chemistry

The results of water chemistry monitoring at 14RD139 and 14RD143 collected during IWM fish sample visits are shown in Table 3. A larger chemistry data set was collected at the Steel Bridge Road crossing (S007-887) near 14RD139.

Nutrients

TP in AUID-501 was moderately elevated relative to the region's river nutrient threshold of 0.050 mg/L during mid-summer (Figure 8). Phosphorus was not strongly related to flow (Figure 9), though more paired samples are needed to make a more definitive statement on this relationship. Nitrate was at very low levels, as is common for north-central Minnesota streams, and ammonia and unionized ammonia were also at non-problematic levels (Table 4).

Table 3. Water chemistry measurements collected at 14RD139 and 14RD143 during the 2014 IWM. Values in mg/L.

Biological site	Date	Time	Water Temp.	DO	TP	Nitrate	Ammonia	Un-ionized Ammonia	pH	TSS	TSVS
14RD139	July 29, 2014	18:10	21.6	4.84	*	*	*	*	6.78	*	*
14RD139	July 28, 2015	17:18	25.2	2.95	*	*	*	*	6.81	*	*
14RD143	Aug. 26, 2014	12:12	17.3	7.01	0.058	0.065	< 0.1	< 0.001	6.90	14.4	< 4
14RD143	Aug. 04, 2015	9:45	17.2	5.78	0.042	0.056	0.48	0.002	7.17	< 4	< 4

*These parameters were not collected, because a 10X chemistry location existed here - see Table 4.

Table 4. Chemistry measurements at S007-887 (near 14RD139) from 2014-2015. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate	16	< 0.032	0.046	< 0.03*
Ammonia	10	< 0.0772	0.250	< 0.04*
Total Phosphorus	16	0.052	0.102	0.023
TSS	10	< 1.9	4	1

* These values are below the lab detection limit.

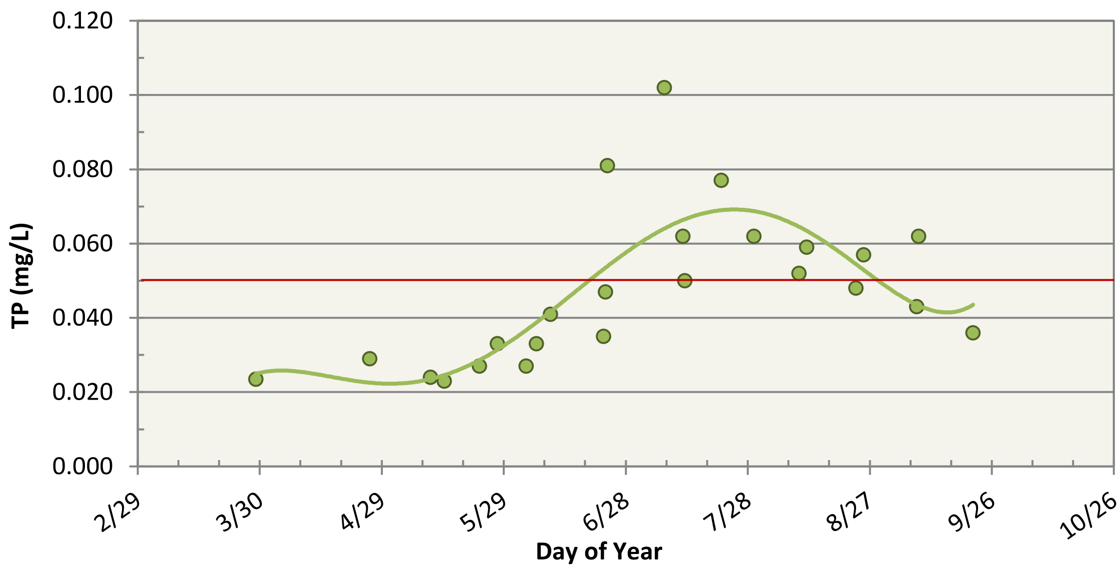

Figure 8. IWM and Red Lake DNR TP data for site S007-887 (14RD139) from dates during 2014, 2015, 2016. The green line is a 5th order polynomial regression line, having an R^2 value of 0.6046. The red line is the TP threshold for this region's river nutrient standard.

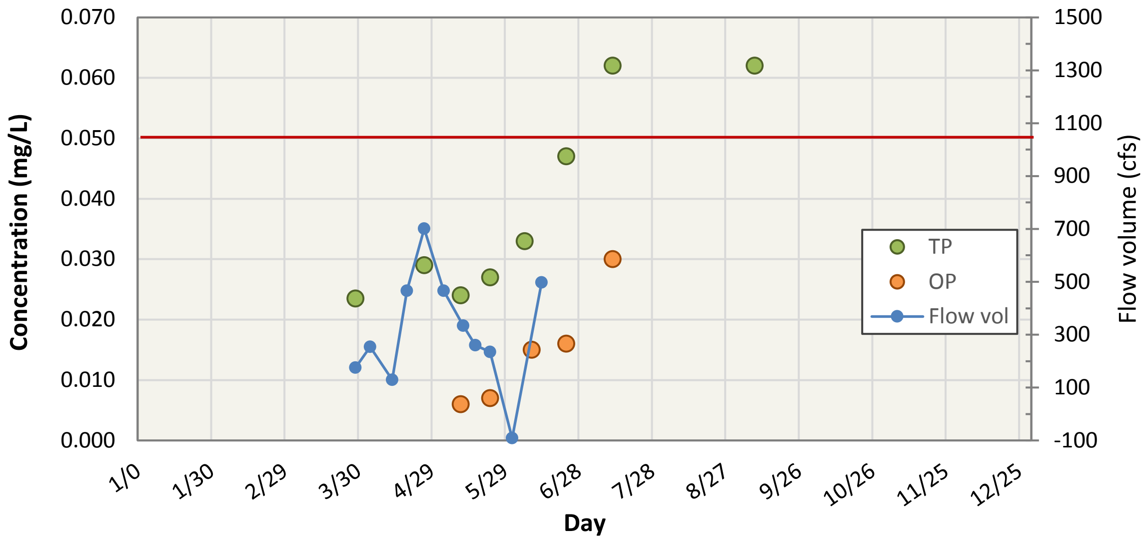

Figure 9. Red Lake DNR phosphorus and flow data for site S007-887 (14RD139) in 2016. The red line is the region's TP river standard.

Dissolved oxygen

DO data shows numerous measurements below the DO standard (Table 3 and Figure 10), and these readings occurred on many occasions from the beginning of June until mid-September. In 2017, the Red Lake DNR deployed a continuous DO monitoring device a short distance upstream of the Steel Bridge for the latter half of the summer, which showed that DO was above 5 mg/L for only a very small percentage of the time from July 19 to about August 28, nearly 6 weeks (Figure 11). Many days in this 6-week period had minimum DO levels below 3 mg/L.

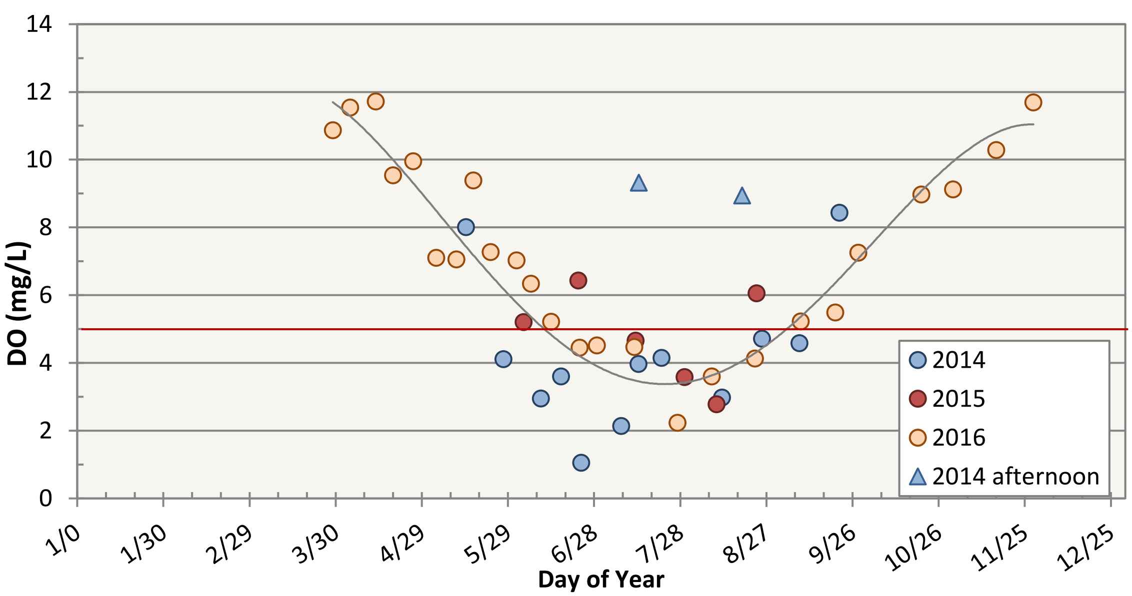

Figure 10. IWM and Red Lake DNR DO data from 2014, 2015, and 2016 for the Tamarac River at site S007-887 (near 14RD139). The red line is the DO standard. The black curve is a 4th order polynomial regression line with an R^2 of 0.8346. The data were predominantly collected in the 9:00 am - 12:00 range, except the two points denoted by triangle points, which were mid-afternoon points (those were not included in the regression).

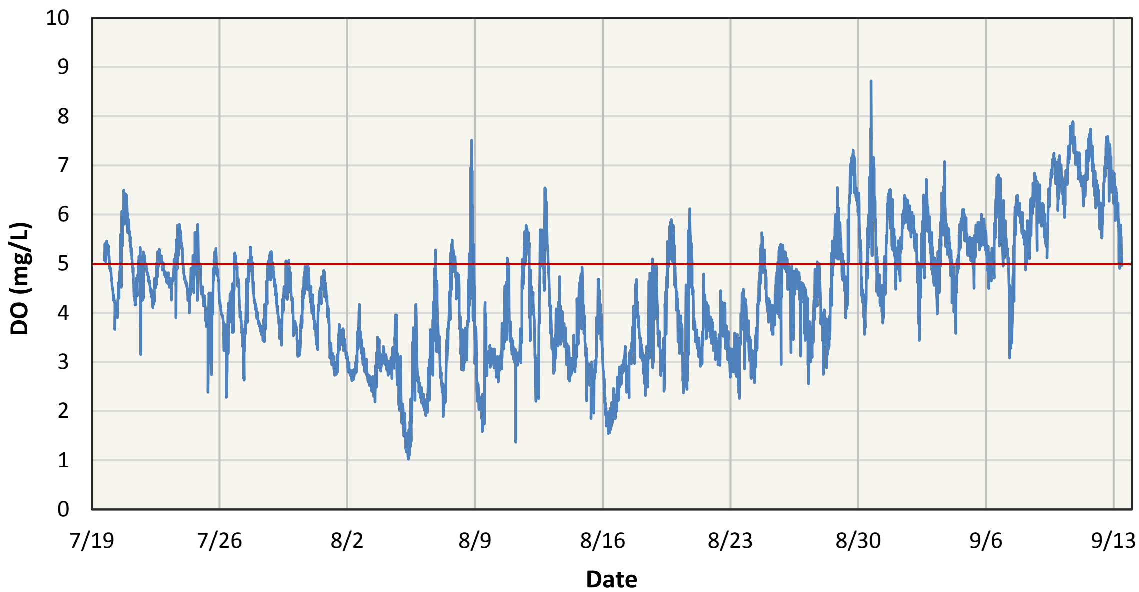

Figure 11. Tamarac River continuous DO data from summer 2017, just upstream of the Steel Bridge near 14RD139. Collected by the Red Lake DNR. The red line is the DO standard.

Temperature

Water temperature at S007-887 (14RD139) peaks during mid-July (Figure 12). Warmwater fishes begin to experience temperature stress when temperatures are at about 30°C (86°F) for extended periods of time. Water temperature is not a stressor to fish in AUID-501.

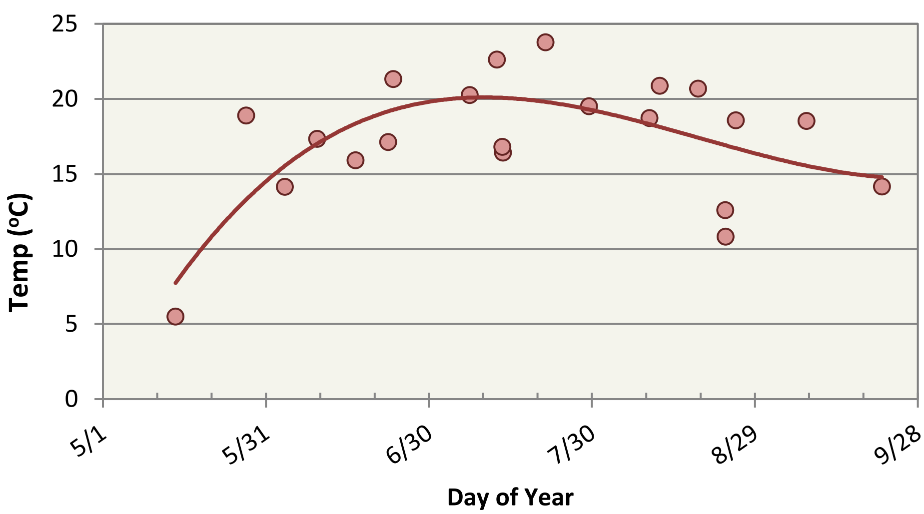

Figure 12. Late spring and summer water temperature readings at S007-887 during 2014-2015. The curved line is a 3rd order polynomial regression line with an R^2 of 0.4811.

Habitat

The Minnesota Stream Habitat Assessment (MSHA) scores at the biological sites were: 14RD139 = 46.3 (the bottom of the "Fair" category) and 14RD143 = 54 (the middle of the "Fair" category). Among the MSHA subcomponent scores, the "Substrate" was the poorest-scoring, followed by "Channel Morphology". Only sand and silt were noted as substrate materials. Within the "Channel Morphology" metrics, velocity variability was very low, and depth variability was moderate. Channel Development was rated fair. These pieces of information can be summed up by saying that the habitat lacked significant diversity. Reduced habitat diversity translates to reduced organism diversity.

Hydrology

Aerial photography review found significant amounts of landscape-related hydrological alterations. These alterations included some harvested forest parcels, but are primarily a network of land drainage systems (i.e., trenches cut through bogs). These activities, particularly the drainage, suggest a hydrological alteration to the river's original flow patterns, and in specific, greater peak flows that are more erosive. The observations of somewhat unhealthy channel stability/geomorphology downstream of these trench/ditch networks support this conclusion. Two recent studies have investigated the hydrology of peatlands with ditch systems in northwestern Minnesota (Gerla et al., 2009; DNR 2015). These studies have shown that the ditches are hydrologically connected to the groundwater in the peatlands and do influence drainage of the peatlands. Conclusions about how these ditches affected downstream channels were not specifically determined, though alteration of hydrologic patterns in the peatlands were discovered (e.g., water table changes became greater the closer the location to the ditch channel). Gages are in place on downstream channels in the DNR's Winter Road Scientific and Natural Area restoration study so that hydrologic changes to the stream flows will eventually be available.

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

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

Geomorphology

DNR geomorphology specialists completed a Pfankuch stream stability assessment at the two biological sites on AUID-501, and a Rosgen level II assessment at the upstream site (14RD143), which classified as borderline E5/C5 stream type. The upstream Pfankuch score was 66, meaning it is a stable channel, and high flow volumes are able to escape the channel and spread out onto a wide floodplain. The downstream site (14RD139) was too deep to effectively conduct the Pfankuch assessment. The low TSS results from the IWM sampling provide some evidence that there are not significant soil erosion problems happening here. This finding may be due to the sandy nature of the soil, in contrast to silt/clay soils which suspend easier. However, the Rosgen II survey did find some bank cutting, and an excess of fine particle deposition. Localized (rather than systemic) channel instability (due to beavers) and its accompanying sediment appear to be somewhat problematic, leading to some habitat loss in AUID-501.

Connectivity

There are only two road crossings of AUID-501, at State Highway 72 and Townghip-506. Both crossings are bridges and do not impede fish migration from downstream. Fish can readily move between Upper Red Lake and the Tamarac River, as far upstream as desired. Beaver dams were not observed along the AUID except in the very headwaters portion upon review of high-resolution aerial photography. Beaver activity (dens, chewed sticks, and remnants of dams) was seen by DNR staff during geomorphology work. Since functioning dams are not present, there may be frequent trapping here. Thus, connectivity restrictions of both human and natural origin are non-existent and fish are freely able to move throughout the AUID, though there remains the possibility of beaver dams being constructed at any time.

Biology

Fish

The fish community collected in 2014 at 14RD143 was dominated by central mudminnow and small northern pike, with small numbers of fathead minnow, white sucker, and yellow perch. The first three species listed are quite tolerant to low dissolved oxygen. The 2015 sample was dominated by brook stickleback and central mudminnow, with small numbers of white sucker, northern pike, fathead minnow, blackside darter, golden shiner, and one fingerling walleye.

The community is skewed toward species that can tolerate low DO, based on the low score of the Community DO Index for class 5 streams, the probability of the community coming from a stream meeting the DO standard is very low (Table 5), and the tolerance metrics (Table 6). The community is about neutral in terms of tolerance/intolerance to total suspended solids (TSS) as the TSS TIV Index is about average or slightly better among class 5 streams. The probability of the community coming from a stream meeting the TSS standard is quite high. There were also almost no TSS Tolerant fish species at 14RD143 (Table 6). For this location on AUID-501, evidence points to the fish being negatively influenced by low DO concentrations.

Farther downstream on AUID-501, two fish sampling visits were made to 14RD139, on July 29, 2014, and a year later, July 28, 2015. The fish community collected in 2014 scored very poorly, in large part due to the very small number of fish caught (only 15 individuals). No species was dominant, and perch, freshwater drum, and walleye were the main catch, along with a single golden shiner. In 2015, more individual fish were caught (53), though this is still a quite low number for this size of river. The same species were caught as in 2014, and in addition were fathead minnow, common shiner, and white sucker. Yellow perch was the dominant species, followed by golden shiner. The remaining species were all represented by fewer than five individuals.

Metric scores for DO tolerance suggest that DO concentrations are somewhat better here than at the upstream site, though the 2015 sample's score was still quite low (Table 5). Note that the DO measurements for the two sites in Table 3 above cannot be directly compared because they were collected on different days, and different times of the day. The TSS metric scores suggest that TSS is likely not a significant issue, and all of the actual TSS measurements here were very low. The strongly tannin-stained water here may have a bit of influence on the TSS metric scores, as the condition mimics one of the effects of TSS (reducing underwater light levels), and some of the species in the sample are those that can tolerate lower light conditions. This information confirms that low DO is the likely reason for the impaired fish community at 14RD139. With both sites in agreement, and with the numerous measurements of sub-standard DO levels, low DO is a stressor in AUID-501.

Table 5. Fish and Macroinvertebrate Community DO and TSS Tolerance Index scores in AUID-501. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined. The 2016 versions of both the fish and macroinvertebrate index metrics were used.

Biology Type (Year)	Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Fish (2014)	14RD143	5	5.83	6.97/7.09	3	9.9	13.34	13.99/13.06	44	81.1
Fish (2015)	14RD143	5	5.79	6.97/7.09	2	9.3	13.96	13.99/13.06	34	78.4
MI (2014)	14RD143	4	7.21	6.26	92	75	13.36	13.58/13.69	57	85
MI (2015)	14RD143	4	7.29	6.26	94	74	15.19	13.58/13.69	17	73
Fish (2014)	14RD139	5	7.24	6.97/7.09	70*	58.2*	30.08	13.99/13.06	1*	4.6*
Fish (2015)	14RD139	5	6.57	6.97/7.09	20	29.4	15.60	13.99/13.06	19	70.1

*These values differ substantially from the other values in their respective columns. This may be related to the fact that few fish were caught at this sampling visit.

Table 6. Fish Tolerance metrics for DO and TSS in AUID-501.

Site	Year	Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
14RD139	2014	DO	1	0	2	1	26.7	46.7
14RD139	2015	DO	1	0	3	2	1.9	83.0
14RD143	2014	DO	0	0	4	2	0	97.2
14RD143	2015	DO	0	0	5	4	0	81.4
14RD139	2014	TSS	0	0	2	1	0	53.3
14RD139	2015	TSS	0	0	2	1	0	9.4
14RD143	2014	TSS	0	0	0	0	0	0
14RD143	2015	TSS	0	0	1	0	0	0.9

*Includes Very Intolerant or Very Tolerant taxa.

Macroinvertebrates

The macroinvertebrate community sampled at 14RD143 in 2014 was dominated by the genus *Simulium* (commonly called blackflies or gnats). The community contained no intolerant taxa, and the percent of tolerant individuals was high at 66.7%. Another macroinvertebrate sample was collected the following summer (Aug. 4, 2015). That sample had significantly more taxa, and the macroinvertebrates index of biological integrity (MIBI) scored better, this time above the threshold. It was still dominated by *Simulium*, but not nearly as strongly as the 2014 sample. The second-most dominant taxon in 2015 was the mayfly genus *Labiobaetis*. The fact that the macroinvertebrate TIV metrics are counter to the fish TIV results (i.e., the macroinvertebrates do not show a signature of being composed of taxa with low-DO tolerance) is probably substantially due to the dominance of *Simulium*, which has a species DO TIV in the 74th percentile of all macroinvertebrate taxa (meaning *Simulium* is typically found where DO is at a good level, and DO is often at good levels in faster-flowing streams). *Simulium* may be thriving here due to the preferable flow velocities, rather than the correlated better-DO levels (as filter feeders, they are sensitive to flow velocity and permanence of that flow). In this case, they just coincidentally inflate the

DO TIV index due to their dominance in numbers within the sample. With less macroinvertebrate data for this AUID relative to the fish data, conclusions based on information in Table 5 should lean toward what the fish community is signaling to be stressing the aquatic life in the AUID.

Upstream influences on phosphorus and DO levels in AUID-501

Because low DO problems often have as their root cause excess nutrients, particularly phosphorus, and total phosphorus (TP) has been shown to be above the North Region River Nutrient Standard in AUID-501, it is prudent to investigate conditions in the Tamarac River subwatershed upstream of 14RD143. There is very little human activity on the landscape upstream of 14RD143, because the area is a massive peatland. The only human activities are a scattering of forest harvest patches of various ages, and a matrix of old ditches (i.e., trenches dug in the early 1900s through the peat soils to attempt to lower the water table and make the land available for farming - Figure 13. Though the landscape here has extremely low relief, these ditches are likely draining water from the peatlands (based on nearby research on bog ditches - DNR, 2015) into the upper reaches of the Tamarac River.

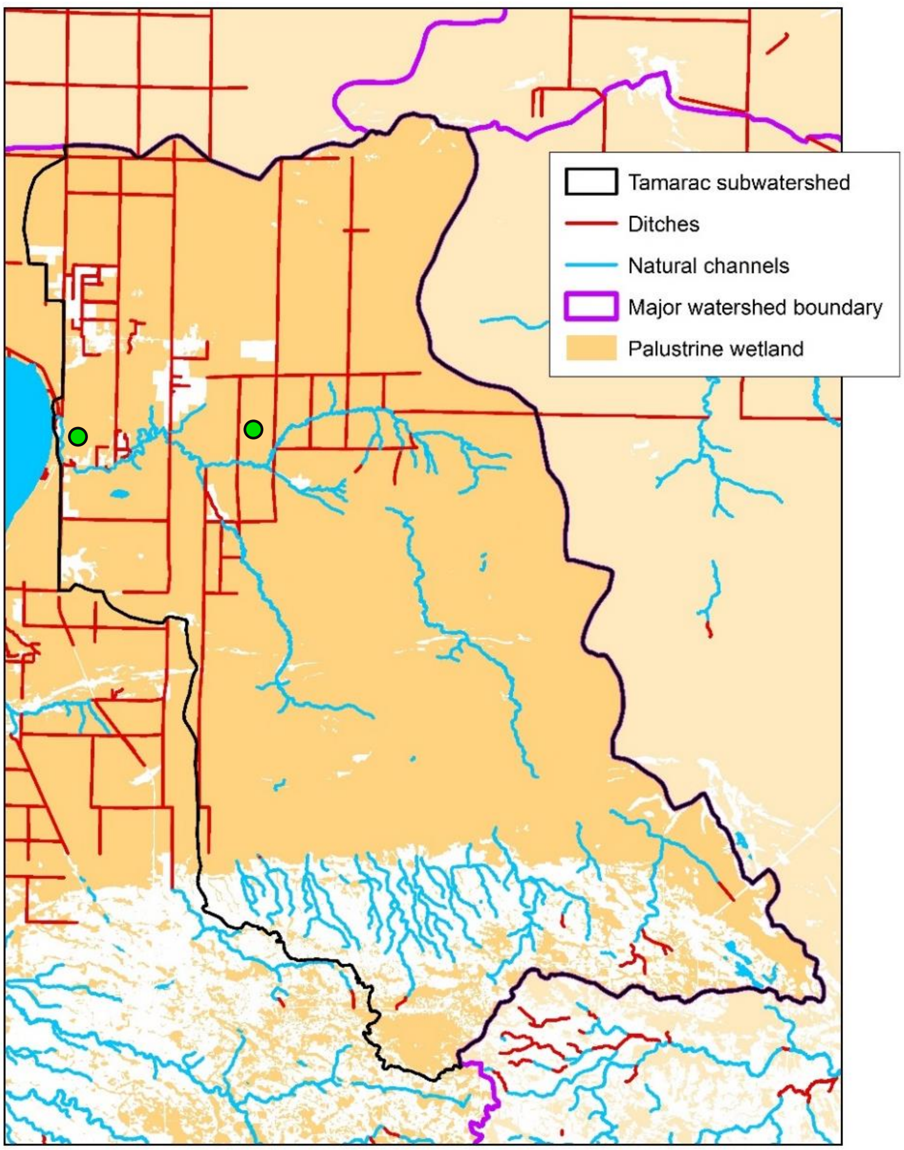

Figure 13. Map of the Tamarac River subwatershed, showing contributing trenches/ditches. Note that one ditch was cut across the watershed divide at the right side of the map, and may be bringing water into the Tamarac River from a neighboring watershed.

Upstream tributaries

Lost River

One tributary, the Lost River, AUIDs 602 and 603, enters the Tamarac River immediately downstream of 14RD143. There is a cluster of wild rice paddies immediately adjacent to AUID-602 near its mouth. Other than the rice fields, there are essentially no human activities on the Lost River - it emerges from a massive bog. This tributary has its own section later in this report.

Bog drainage ditches

A network of trenches dug through the adjacent peatlands, where no channels originally occurred, now exist in the headwaters of the Tamarac River (Figure 13). These ditches were dug early in the 1900s, in an effort to utilize these lands for agriculture. Such drainage attempts occurred in many of the extensive bog areas of northern Minnesota. These drainage networks likely speed flow into downstream stream reaches, altering the hydrological inputs to those streams and putting them at risk for developing channel instability and associated problems that affect the aquatic biology communities. See the discussion of peatland drainage in the “hydrology” section on page 16.

Conclusions

The fish impairment in AUID-501 is, in part, due to low DO. There is an extremely large amount of wetland (bog/wet meadow) in this subwatershed. Water moving within the organic soils of these wetlands will become quite anoxic in summer, due to the use of DO by microorganisms decaying the organic material. The ditching of bogs in this subwatershed is likely contributing to low DO, due to the potentially greater delivery of wetland-sourced water to the river. The shallow groundwater within these peat soils will eventually seep into the ditches and travel downstream. There is some wetland agriculture (wild rice) in the subwatershed, but it would require very detailed research to determine if those wetland paddies were functioning differently (with regard to influence on DO in the river) than if they were still in their natural wetland state. Low afternoon DO measurements in late-July suggest the low DO is not eutrophication-related. Rather, this late-July period is the time of the summer when peat soils are at their warmest and most anoxic condition. The low-gradient nature of the river contributes to naturally lower DO relative to rivers and streams with a higher gradient, because less mixing of water in contact with the atmosphere happens as gradient decreases. The great majority of the river network in this subwatershed has natural riparian conditions, and thus the best management practices (BMPs) of improved shading of river waters by encouragement of naturally-vegetated river banks is not applicable here as a means to improve DO in the river.

It would be helpful to monitor DO continuously through the second half of the summer in order to see if rice paddy de-watering for harvest has a strong effect on low DO levels. Such monitoring was conducted by Red Lake DNR in summer 2017, but water levels were very low in the river as northwestern Minnesota experienced a drought summer in 2017, which may have confounded the results. Rice paddy de-watering appeared to depress the streamwater DO level in a study in Clearwater County, Minnesota (Hanson, 2009).

Habitat is mediocre in this AUID. Sandy streams and rivers often have poorer habitat as substrate is very homogenous and produces few microhabitats. Low gradient streams also produce relatively homogenous habitat due to less velocity variability within the channel. These are natural factors that are likely contributing to the failing fish community. The geomorphology work suggested the river is technically stable (only the upper portion was assessed due to the size/depth of the lower reaches), though some of the Pfankuch metrics were still quite poor. This finding is likely due to the altered hydrology from historical (but still present) bog ditching. Reducing peak flows by eliminating some of the unneeded legacy ditches would likely benefit the river and the habitat it produces for aquatic organisms by creating more stable conditions and reduced fine sediment inputs from banks. Altered hydrology likely contributes to both of the stressors directly influencing the fish community - low DO and poor habitat.

Shotley Brook (AUID 09020302-502)

Impairment: The creek was assessed as impaired for not meeting the macroinvertebrate community threshold at site 14RD136 located at County State Aid Highway (CSAH)-23, 3.5 miles northeast of Shotley.

Subwatershed characteristics

The majority of the land within the Shotley Brook subwatershed is wetland, with much of it being wooded wetland and most of the other being emergent herbaceous wetland. The headwaters of the subwatershed is the northern edge of the uplands that surround Kelliher, north of which the vast wetland habitat begins. Originally, natural headwaters channels draining from this upland area diffused into the peatlands as they flowed north to the Shotley Brook channel and then came to the surface again in Shotley Brook. A minor amount of agriculture exists in the watershed, mostly in the form of hay fields which lie to the north of the lower part of the stream. The runoff from some of these agricultural lands is captured by an east-west running ditch, and carried to near the mouth of Shotley Brook before it enters the channel.

Data and analyses

Chemistry

The chemistry data that was collected at the fish and macroinvertebrate sampling visits in 2014 is shown in Table 7. These few measurements of these parameters are very good (healthy). AUID-502 also had a 10X chemistry monitoring site (S007-884) which is summarized in Table 8. These nutrient and suspended sediment readings are very good and do not suggest any problems. TP is elevated a small amount above the regional threshold for about 5-6 weeks in mid-summer (Figure 14), though the DO readings do not suggest eutrophication problems (Figure 15). Nitrate was extremely low relative to levels that are toxic.

Table 7. Chemistry measurements from IWM sampling at 14RD136.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	T-tube (cm)
July 16, 2014	9:38	15.8	8.44	90	7.65	310	> 100
Aug. 19, 2014	16:14	20.1	8.41	98	7.92	363	> 100

Table 8. Summary of 2014 chemistry data at S007-884 (at 14RD136) from 2014. Values in mg/L.

	# Samples	Average	High	Low
Nitrate	10	< 0.041	0.085	< 0.03*
Ammonia	10	< 0.057	0.128	< 0.04*
Total Phosphorus	10	0.0392	0.067	0.025
TSS	10	< 5.9	13	< 1*

* These values are below the lab detection limit.

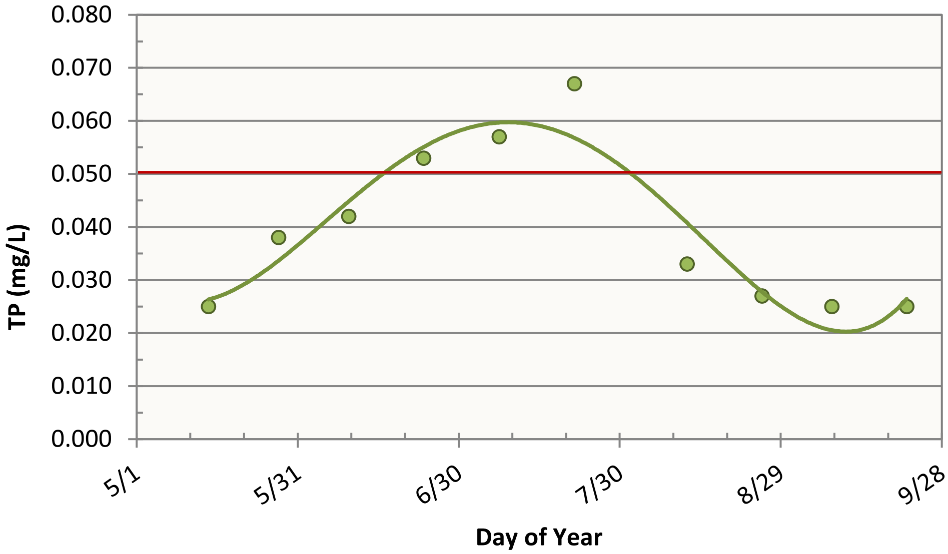

Figure 14. TP data for Shotley Brook, at S007-884 (14RD136) from 2014. The green curve is a 4th order polynomial regression line with an R^2 value of 0.8907 that shows a seasonal pattern in the fluctuation of TP concentrations. The red line is the state standard.

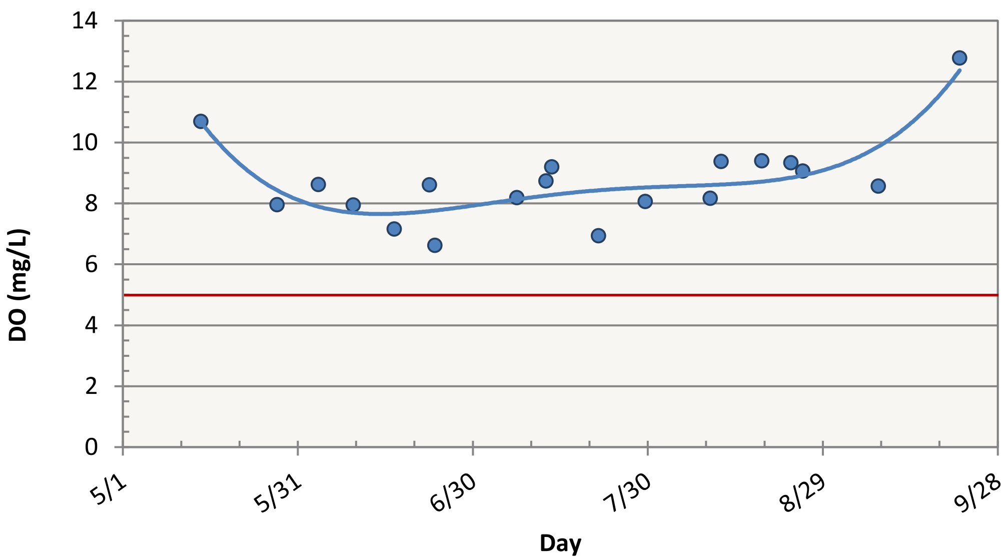

Figure 15. DO data for Shotley Brook at S007-884 (14RD136) from 2014. The blue curve is a 4th order polynomial regression line with an R^2 value of 0.7081 showing seasonal changes in DO concentrations. The red line is the state standard.

Biology

Fish

The fish sample scored above (passed) the IBI threshold, but DO and TSS metrics for the fish community were explored to add insight into possible stressors. The fish community at 14RD136 was quite evenly distributed among the 10 species caught, with white sucker, northern pike, and yellow perch the most abundant species. The fish community scores were mid-range for the DO TIV Index (a bit better than average) but the TSS community index scored poorly within its class. However, this class has little issue with TSS, so the probability of the sampled community coming from a stream having passing TSS levels is still fairly good (Table 9). Based on the probabilities in Table 9, it appears the fish community is more influenced by oxygen levels than it is by suspended sediment. However, based on the percentile of the index score for the stream class, TSS looks to be a more likely stressor than DO. This contradiction is likely due to the fact that this stream class typically has relatively lower DO and lower TSS. The within-class comparison is probably the better statistic to use, and thus elevated TSS (or a related factor of unstable fine-particle bed material) is more of an influence.

Table 9. Fish Community Tolerance Index scores at 14RD136 for DO and TSS (2016 version of the metrics). "Percentile" is the rank of the index score within the fish class 6 streams. "Prob." is the probability a community with this Index score would come from a stream reach with TSS or DO that meets the standard, based on all stream classes combined.

Date	DO TIV Index	Class avg./median	Percentile w/in class	Prob. as %	TSS TIV Index	Class avg./median	Percentile w/in class	Prob. as %
July 16, 2014	6.72	6.51/6.56	59	35.4	15.83	14.08/13.30	15	68.7

Macroinvertebrates

The macroinvertebrate community was dominated by two mayfly genera, *Baetis* (*brunneicolor*) and *Caenis* (*C. diminuta* and *C. hilaris*), and the midge *Rheotanytarsus*. Though most mayflies require relatively high DO concentrations, *Caenis* is able to live in slow or stagnant waters and can be found in wetlands, which typically are lower-DO environments. Table 10 shows DO-related metric scores for the macroinvertebrate community at site 14RD136. Despite the abundant *Caenis* mayfly, the community is not skewed toward low-DO Tolerant taxa. There were more low-DO Intolerant taxa than Tolerant, and the percentage of Intolerant individuals was also higher than the percentage of low-DO Tolerant individuals. The within-class percentile of the Community DO Index is well above the class average. Table 11 shows TSS-related metric scores for the macroinvertebrate community. These metrics reveal a community that is somewhat skewed toward being tolerant of higher TSS concentrations. The within-class percentile is fairly low, though the probability of this community coming from a site meeting the TSS standard is fairly high. Taken together, these metric data would suggest that TSS is possibly a moderate stressor, while the DO concentrations here are not negatively affecting the macroinvertebrate community. The abundant count of the mayfly *Caenis* mentioned above also provides some evidence of a TSS influence, as this taxon lives on fine-particulate bed material, which can often be associated with elevated TSS. The fish community metrics data from Table 9 corroborates this conclusion. However, none of the ten TSS samples from 2014 exceed the state TSS standard, though one sample was quite close. Visual observations of the stream do show evidence of significant sand movement in the channel (Photo 1).

Table 10. Macroinvertebrate metrics related to DO for 14RD136 utilizing MPCA tolerance values (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 avg./median	Percentile within stream class	Probability (%) of meeting the standard
4	6	4	24.9	20.6	7.09	6.26/6.43	87	72

Table 11. Macroinvertebrate metrics related to TSS for 14RD136 utilizing MPCA tolerance values (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 avg./median	Percentile within stream class	Probability (%) of meeting the standard
4	2	4	1.2	17.9	14.60	13.58/13.69	27	77

Temperature

Water temperatures were quite cool as determined by 17 samples from June - August 2014-2015, with a maximum of 22.41. These temperatures are far from close to levels considered stressful to fish.

Connectivity

There are only two road crossings downstream of 14RD136 (small roads used to access lake properties), and both crossings are bridges that allow boat traffic to pass. So, impedances of fish migration from downstream do not exist, and fish have easy access to 14RD136 from Upper Red Lake. Upstream crossings are culverts, and from aerial photos, do not show signs of altering the stream flow (e.g., minimal scour pool development). Upstream crossings would be less important to analysis of the fish community at 14RD136. Beaver activity is either naturally very low along the AUID or they are consistently removed, as the review of high-resolution aerial photography found no beaver dams along the entire AUID. With few road crossings upstream of 14RD136, and those culverts (at CSAH 23 and at Waldo Road) appearing properly sized and non-problematic for fish passage, along with the absence of beaver dams, fish appear to have access to a long stream reach above 14RD136. Thus, connectivity restrictions are non-existent and fish are freely able to move throughout the AUID.

Habitat

The MSHA protocol was conducted twice at 14RD136, in July and August of 2014. The scores were 53 and 59. The average of 56 is right at the midpoint of the "Fair" habitat category. Among the MSHA subcomponent scores in the July work, "Channel Morphology" was the poorest-scoring, followed by "Substrate", attaining 31 and 50% of their possible points respectively. In the August work, "Cover" and "Channel Morphology" were the poorest, attaining 44 and 49% of their possible points. Averaging the subcomponent scores of the two visits, "Channel Morphology", "Substrate", and "Cover", were the poorest three of the five subcomponents, attaining 40, 55, and 56% of each subcomponent's possible points, respectively. These three subcomponents are instream or channel-oriented metrics. The other two subcomponents are land-based metrics, which both scored very well.

The most influential metrics within the "Channel Morphology" subcomponent that dragged down the score for both visits were "Channel Stability" and "Channel Development", which denotes degree of habitat diversity due to the development of the three main channel features (riffles, runs, and pools). The lack of substrate diversity, along with the substrate being sand, resulted in the mediocre "Substrate" subcomponent scores. The July visit noted the presence of gravel, but rated it as severely embedded with sand. The "Cover" subcomponent is more re lated to fish habitat, but it was noteworthy that there was sparse aquatic vegetation, with only wild celery (*Vallisneria*) and Arrowhead (*Sagittaria*) present, neither of which create particularly good macroinvertebrate habitat. Unstable fine sediment substrate may be causing inhospitable conditions for plant growth, reducing plant diversity. These pieces of information can be summed up by saying that the overall habitat lacked significant diversity. Reduced habitat diversity translates to reduced organism diversity. A plausible cause of the observations in the MSHA is excess fine sediment, probably arising from channel instability, rather than inputs from the general landscape.

Hydrology

The hydrology of the headwater areas of the Shotley Brook subwatershed have been altered significantly. Several small channels, including Hoover Brook, flow north toward Shotley Brook in the area a short distance northeast of Kelliher, but dispersed into a large wetland, that had no channel (as analyzed with LiDAR as well as aerial photography). Numerous trenches were long ago dug through those peatlands to connect the Hoover Brook channel Shotley Brook. Others were dug into the wetland without connecting to an upstream channel. This allows water to move from the uplands to the Shotley Brook channel much faster than if the water had to seep through wetland soils before reaching Shotley

Brook. See the discussion of peatland drainage in the “hydrology” section on page 17. The effects of altered hydrology on the physical stream channel are discussed in the following section, “Geomorphology”.

Geomorphology

The channel at 14RD136 shows signs of instability, including fine sediment deposits, raw and scouring banks, and streamside trees being undercut and toppling into the stream (Photo 1). DNR staff performed a Pfankuch assessment here, as well as a Rosgen level II geomorphology measurements. The stream classified as an E5 stream type (low width-to-depth ratio, small gravel or sand bed stream), and scored 89 for the Pfankuch protocol, which puts it into a moderately-unstable class. Some excess sand deposition was noted. The bottom substrate was rated as fair to poor for stability. Some deeper (5-6 foot) pools were found, meaning excess sediments are not at a level at which pool-filling occurs. The fine sediments are likely coming from eroding stream banks, rather than from overland erosion, a conclusion based in part because eroding banks are observed, and in part because riparian land cover is very natural/forested and is in this natural condition for significant distances in lateral directions, both at the biological site as well as upstream from there. The observed instability is most likely simply from too much water (i.e., an unnatural amount for this channel) being routed through the stream, with the excess water coming from the drainage of peatlands in the headwaters. The excess water creates greater sheer stresses on the channel, causing erosion of banks and excess fine sediment in the stream, and resulting in an overwidened channel.

Photo 1. Shotley brook in the biological sampling reach. Arrows point to recent sand deposition areas. Also, note the trees beginning to fall into the stream on the left side.

Conclusions

Altered hydrology and sand-based TSS are problematic for macroinvertebrates, which require stable habitats for their community’s health. Suspended sand carried at times of higher flow volumes/velocities can be abrasive to the delicate tissues (e.g., exposed gills) of macroinvertebrates. Higher peak flows, leading to bank erosion, excess fine-particle deposition, and shifting sand substrates create unstable habitat. Physical features within the stream suggest that channel instability has and is occurring as a result of altered hydrology, and that the altered hydrology is mainly the result of the historical ditching in headwater wetlands. Streams in areas having sandy surficial geology and soils, as is found in the Shotley Brook subwatershed, are less resilient to alterations of their hydrological regime (Rosgen, 2009). Returning the stream's hydrology to a more natural flow regime of its past will create a more stable stream channel, reduce new fine sediments from entering the channel, and improve habitat stability for the macroinvertebrate community. As food items for many fish species, a healthier macroinvertebrate community benefits the fish community as well. Such restoration of the hydrology within the ditched peatlands will be challenging, but some examples of such restoration have occurred in recent years (DNR, 2015; Myers, 2016).

North Branch Battle River (AUID 09020302-503)

Impairment: The river was assessed as impaired for not meeting the fish community threshold at site 14RD130, located at CSAH-23, two miles north of Saum. An assessment of DO was deferred due to the heavy influence of wetlands in this subwatershed.

Subwatershed characteristics

The headwaters of the North Branch Battle River is an expansive bog/fen area, much of it with tree cover (wooded wetland). A minor amount of agriculture exists in the watershed, mostly in the form of hay fields. The majority of the agricultural land is downstream of the biological sample site. One large wild rice operation exists upstream of 14RD130, and has drainage to the North Branch Battle River. Some of the drainage from the rice paddies appears to drain to a tributary of the South Branch Battle River.

Data and analyses

Chemistry

AUID-503 had a 10X chemistry monitoring site, S003-962. The chemistry data that was collected at the fish and macroinvertebrate sampling visits in 2014 is shown in Table 12. The measurements of nitrate and ammonia parameters are very good (healthy). The 10X chemistry data is summarized in Table 13.

Table 12. Chemistry measurements from IWM sampling at 14RD130.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond. (µS/cm)	T-tube (cm)
July 15, 2014	16:17	18.6	7.61	86	7.53	289	90
July 27, 2015	10:20	21.7	6.48	79	7.63	291	98
Aug 19, 2014	14:59	20.3	8.49	98	7.94	350	> 100

Table 13. Summary of nutrient and TSS data at S003-962 (at 14RD130) from 1992 and 2014. Values in mg/L.

Parameter	# Samples	Average	High	Low
Nitrate	24	< 0.035	0.079	< 0.01*
Ammonia	24	< 0.049	0.189	< 0.02*
Total Phosphorus	27	0.058	0.122	0.030
TSS	24	< 4.5	16	< 1*

* These values are below the lab detection limit.

Dissolved oxygen

The DO values measured at the times of the three biological sampling visits were at a good levels. However, these readings were mid-morning and afternoon measurements, and so were not the days' minimums. DO measurements from 2014 and 2015 were collected throughout the growing season at this location, one of the IWM 10X monitoring sites (Figure 16). Red Lake DNR continued to monitor this site in 2016 and 2017, and those results are also shown in Figure 16. Of the 32 measurements from 2014-2016, only one did not meet the DO standard. Though these measurements look good, they were not taken in the pre-9:00am time period, and thus do not record the daily minimums or certify that the DO is meeting the standard. It is of note that none of the mid-summer measurements found high DO levels (such as 12+ mg/L) which can signal eutrophication, due to oxygen produced from photosynthesis of excess aquatic plant growth. DO measurements were fairly different in 2017, where for almost any given period throughout the season, the DO values were lower than they were in 2016, and these differences became very substantial after mid-July. This might be explained by the summer drought that occurred in northwestern Minnesota in 2017, resulting low, sluggish flows. Note that the DO level just after a significant precipitation event on September 20, 2017, was much higher (though still below 5 mg/L) than the DO value a week earlier, on September 13, 2017 (Figure 16). Thus, DO data from 2014-2016 is probably more appropriate to use in making conclusions about DO levels in this AUID.

Red Lake DNR also deployed a HOBO DO logger at this site from July 1, 2016, to September 30, 2016, to record continuous DO measurements. That data revealed that there are periods when the DO does indeed drop below the standard (Figure 17). Maximum DO concentrations during this 3-month period were about 8 mg/L. In 2016, this occurred in early July, the last week of July and first week of August, and in late August. On two days, the DO dropped below 2.0 mg/L for a short time. Most often, the daily DO flux was between 2-3 mg/L, lower than would be expected if eutrophication were occurring.

It appears as though DO is quite sensitive to stream flow volumes and the somewhat correlated water temperature. A continuous-recording water level and temperature logger was deployed over the summer of 2016. The times when DO concentrations were below the standard were followed by abrupt bounces up to good DO levels. These are well-correlated with precipitation events (Table 14) which caused flow volume increases (see especially August 2 in Figure 17 and Figure 18). The July 8-9 precipitation event initially bounced the DO concentration higher, quickly followed by a sharp decline in DO, and again by a sharp recovery. This may have been due to a flushing of nearby wetlands having low DO. The drop below the DO standard that occurred at about August 22 coincides with a trough in the flow volume and spike in water temperature (compare data under the bracket symbol in Figure 17and Figure 18). This data suggests that periods of low flow in summer may result in substandard DO conditions. Ambient air temperature likely plays a role in this relationship.

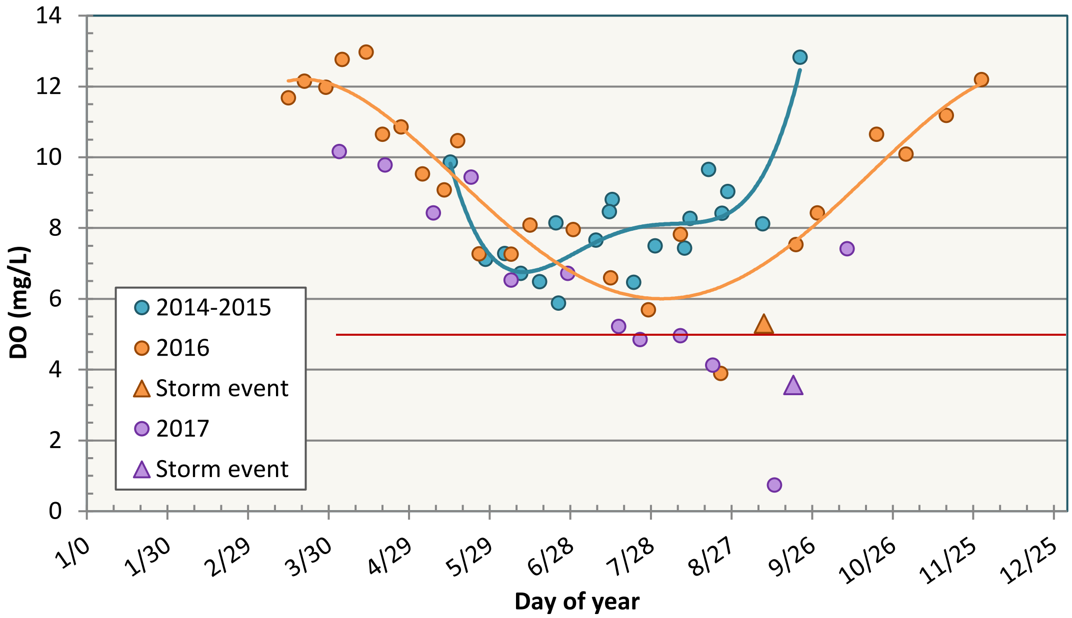

Figure 16. Seasonal pattern of DO levels for North Branch Battle River, at S003-962 (14RD130) from 2014, 2015, 2016, and 2017. The 2016 and 2017 data was collected by Red Lake DNR, generally a few hours earlier in the day than the 2014-2015 data. The blue curve is a 4th order polynomial regression line with an R^2 value of 0.7259. The orange line is a 4th order polynomial regression line with an R^2 value of 0.8443 (not including the storm event sample). The regression line should not be considered a predictive value for a particular day of the year, since these data were collected at variable times of day, and DO varies significantly within any given day. The data does show a definite seasonal pattern in 2016 however, with late-July through mid-August experiencing relatively low DO. The red line is the state DO standard.

Figure 17. Continuously-recorded DO data at S003-962 from July 1 - Sept. 28, 2016 - collected by Red Lake DNR. The orange arrow points to abrupt change on 7/8 - 7/9, and the blue arrow points to abrupt change on 8/2. Compare with Figure 16. The red line is at the standard, 5.0 mg/L.

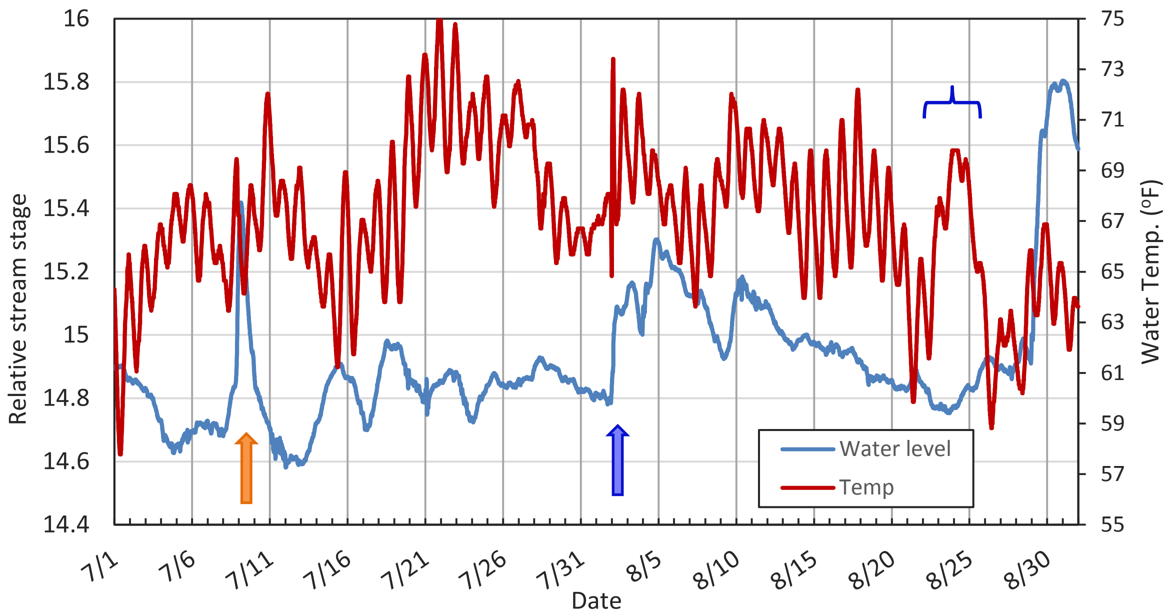

Figure 18. Stream stage and water temperature at S003-962 from July 1 - Aug. 31, 2016. The orange arrow points to abrupt change on 7/8 - 7/9, and the blue arrow points to abrupt change on 8/2. Compare with Figure 17.

Table 14. Precipitation in early August 2016 near NB Battle River.

Precipitation gage	August 2, 2016	August 3, 2016	August 4, 2016
Waskish	1.66 inches	0.46 inches	1.62 inches
Red Lake	1.45 inches	1.32 inches	--
Long Lake	0.57 inches	--	1.85 inches

Phosphorus

TP is elevated above the regional threshold for most of the summer (Figure 19). See the DO results above regarding the evidence against signs of eutrophication. Additionally, notes from the MSHA procedure conducted on three different visits found sparse, if any, plant-life in the stream, further evidence that eutrophication is not occurring, likely in part due to the low levels of nitrate that occur in this AUID.

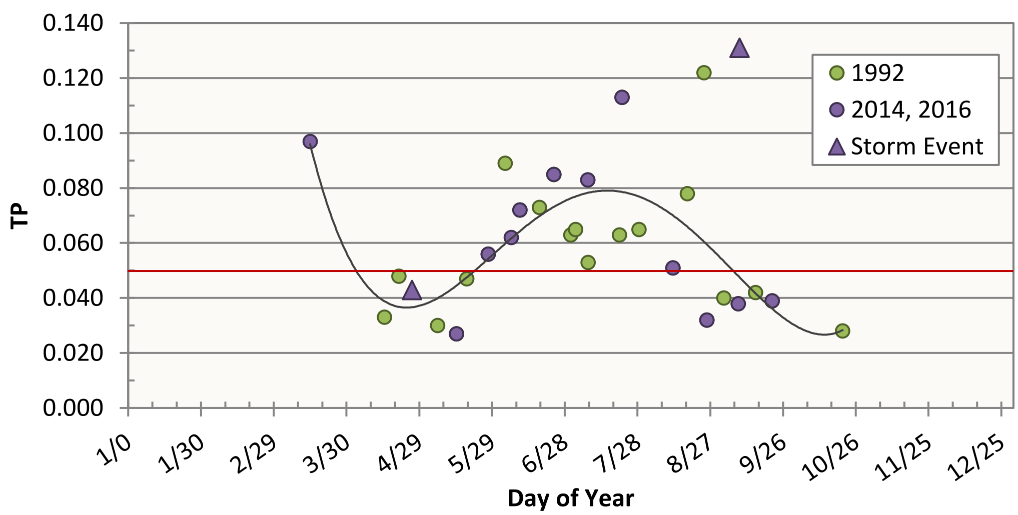

Figure 19. TP data for North Branch Battle River, at S003-962 (14RD130) from 1992, 2014, and 2016. The black curve is a 4th order polynomial regression line with an R^2 value of 0.4512 (excluding known storm event samples). The red line is the state standard.

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

Total suspended solids
The TSS average was quite low, well below the regional standard; however one sample was just above the standard. Without that one sample, the average dropped to less than 3.95 mg/L.

Biology

Fish
The fish community was sampled on July 27, 2015, and was comprised of six species, but was dominated by white sucker (65.7% of the individuals). The other two species with higher numbers were brook stickleback and central mudminnow. The only sensitive species caught was a single pearl dace.

The Community DO TIV Index scores for DO and TSS were at the 59th and 28th percentiles respectively (Table 15). This stream class tends to have relatively lower DO and lower TSS, so neither of these percentiles alone point strongly to either of these parameters being a stressor to the fish community. Based on metrics of tolerance assignment of the taxa present (Table 16), the community was skewed toward low-DO Tolerant species, with being neither skewed toward or away from TSS tolerance. Overall, the fish data shows some evidence of low-DO being a stressor, with perhaps a minor influence of TSS.

Macroinvertebrates
Though the macroinvertebrates passed their IBI assessment, some macroinvertebrate metrics were reviewed to assist in determining why the fish sample is scoring poorly. Both macroinvertebrate samples were above their class average for the DO community index (Table 15), and scored at relatively high percentiles for that metric, suggesting that low-DO was not stressing the macroinvertebrates. The low TSS percentile scores for the macroinvertebrates are probably the result of this being an extremely sandy stream, and not because there is high TSS in the water column (per the significant number of clarity measurements on hand - Table 13). However, there was one sample measurement that was slightly over the state TSS standard. Based on several tolerance metrics (Table 17), TSS appears to be influencing the macroinvertebrate community, with many more TSS Tolerant than TSS Intolerant taxa present, as well as the percent of individuals in those categories. The TSS may be more injurious to the macroinvertebrates, even if it is infrequently high, in this case due to the very sandy conditions - sand is more abrasive to delicate tissues (e.g., gills) than are other fine particulates, such as organic material or silt. It may also be the influence of the sand as a bedded material, as opposed to suspended, as in some streams, current is only sufficient to move the sand slowly along the bottom, which is where many macroinvertebrates live.

Table 15. Fish and Macroinvertebrate Community DO and TSS Tolerance Index scores in AUID-503 at 14RD130 (2016 version of the metrics). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined.

Biology Type	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
Fish (2015)	6	6.72	6.51/6.56	59	35.5	14.57	14.08/13.30	28	75.5
M-invert. (2014)	4	6.73	6.26	68	65	15.81	13.58	9	67
M-invert. (2015)	4	6.99	6.26	83	70	15.47	13.58	12	70

Table 16. Fish tolerance metrics for 14RD130.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	0	0	4	3	0	31.4
TSS	0	0	0	0	0	0

*Includes Very Intolerant or Very Tolerant taxa.

Table 17. Macroinvertebrate tolerance metrics for 14RD130.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa*	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO (2014)	5	1	2	0	2.94	2.61
DO (2015)	5	1	5	1	5.50	6.47
TSS (2014)	2	0	11	5	0.65	5.23
TSS (2015)	3	0	18	6	3.55	35.92

*Includes Very Intolerant or Very Tolerant taxa.

Connectivity

There is only one road crossing downstream of 14RD130, that being Reservation Highway 18, adjacent to the eastern shoreline of Lower Red Lake. The crossing is a bridge and has no barrier effect to fish migrating upstream from Lower Red Lake. There appears to be some kind of small dam a short distance downstream of site 14RD130 (Figure 20 and 21). It may well have blocked fish passage into the reach of 14RD130 in the spring of 2015, when fish move from overwintering areas in larger streams or in lakes, up into smaller streams. The stream itself is small enough that there are probably limited overwintering habitats, and so summer resident fish likely migrate up each year from in or near Lower Red Lake to inhabit the river each summer. Additional culvert assessment for fish passage was done by the Red Lake DNR at four crossings on this AUID, and only one was determined to have any problematic aspect. One of the culverts at the County Road 23 crossing (the upstream end of 14RD130) has some moderate sediment accumulation, but passage effects were determined to be minor.

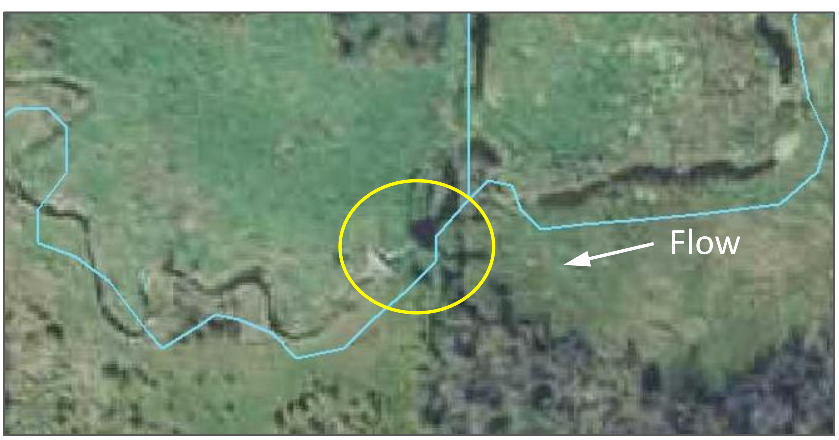

Figure 20. There appears to be a small dam structure above this little bridge, downstream of 14RD130. Note that the channel is at least twice as wide above the dam as below, meaning it is functioning to hold back significant water.

Figure 21. May 20, 2015 aerial photo of what appears to be a dam, but not of the typical appearance of a beaver dam. This photo is a closer view of Figure 20.

Hydrology

The hydrology in the northern (wetland-rich) half of the ULRLW has been highly altered, including the landscape surrounding the North Branch Battle River, with a matrix of trenches and ditches draining bog/fen lands (Figure 22). See the discussion of peatland drainage in the hydrology section on page 17.

The North Branch Battle River is a fairly small channel, and hydrological data was evaluated to determine whether flow volumes commonly reach a state where the river becomes stagnant or intermittent. Long term gage data is not available for this AUID, and so the Hydrologic Simulation Program Fortran (HSPF) model developed for the ULRLW was used to review predicted stream flows, using the average daily flow values for the 10 years most currently available, 2005 - 2014 (Table 18), and restricting the calculations to the “summer months” of May 1 - September 30 (a 153 day period). These values are modeled at the downstream end of AUID-503, which likely has a bit more flow volume than occurs at 14RD130, approximately 5 stream miles upstream.

Wide variations among years can be seen in the modelled data, such as the average cfs of 3.2 in 2012 versus 38.1 in 2014. Two of these 10 years may have had flow conditions that were poor for some species. Those years, 2006 and 2012, had average flows of 3.5 and 3.2 cfs, and 111 and 84 days of flow volume less than 3 cfs, respectively. Modeled flows for 2015 are not available to help in assessing the fish data, however, Red Lake DNR did manually collect flow on seven dates in 2015 (Table 19) That data showed a rather drastic decline in flow from May to mid-summer, with low flow volumes from late June through September. Two of the dates had essentially no flow movement, one of which was a few days after the 2015 fish sample was collected. The time period of the year’s minimum “summer” flow, is either early or late, based on the 10 year modelled period in Table 18. That day either occurred in May or September, and overall most often in the second half of September. May and later September are periods in northern Minnesota when many species may not be present, either not yet to have entered smaller streams, or have already migrated downstream for the winter. That these minimum flows occur at these points of the year are much better than if they occurred in mid-summer, when fish would definitely be using the stream as a living space. The presence of the ditch network upstream may be creating lower summer base flows than if water were being slowly released from the headwaters wetlands in an un-ditched condition.

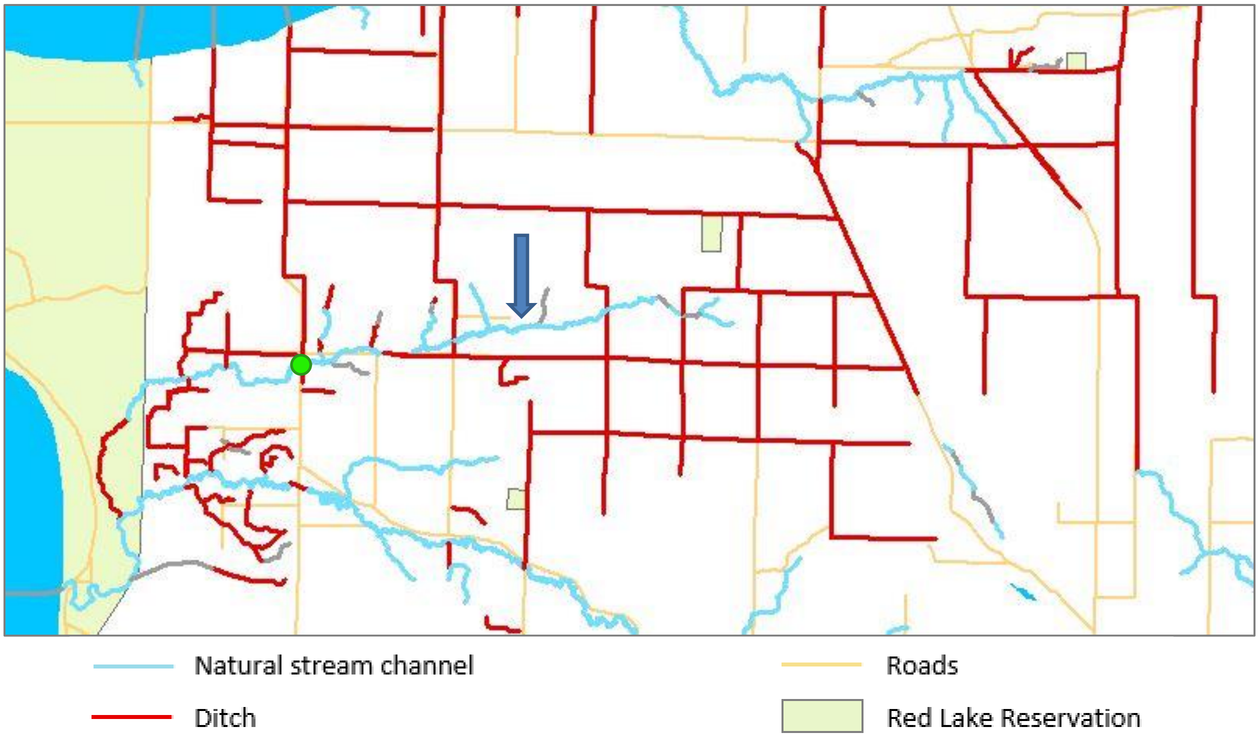

Figure 22. Map of the North Branch Battle River (arrow). Trenches/ditches conduct water to the North Branch Battle River and neighboring streams. The green dot is both the biological site (14RD130) and chemistry sampling site (S003-962).

Table 18. Synthetic flow data from the ULRLW HSPF model for the 10 year period of 2005-2014. These statistics are for the periods of May 1 through September 30 of each year, capturing the "summer" months when more fish will be living in the stream.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Average	25.0	3.5	5.8	6.5	11.6	7.9	12.2	3.2	35.6	38.1
Min	4.2	0.9	2.4	2.5	3.4	2.9	4.0	1.0	6.5	6.2
Max	106.1	15.6	13.3	14.4	41.7	54.0	33.5	8.8	106.1	131.5
Below 3	0	111	21	5	0	2	0	84	0	0
Date of Min	5/8	9/15	9/5	5/29	9/30	5/23	9/30	9/30	9/27	9/18

Table 19. Flow values (cubic feet/sec) measured by Red Lake DNR at CSAH-23 (14RD130) in 2015, the year the fish sample was collected.

April 9	May 18	June 4	June 23	July 31	August 10	Sept. 10
1.13	281.53	53.64	9.68	0.15	5.49	0.13

Habitat

The MSHA scored right at the bottom of the "Good" range. The "Surrounding Land Use" and "Riparian Zone" components received nearly maximum points. The two components that did not score well were "Substrate" and "Channel Morphology", with the "Substrate" receiving only half the possible points. Sand was most predominant, with gravel and silt also noted to be present. Within "Channel Morphology", the metric that depressed the score was "Channel Stability", which scored three of a possible nine points.

Though the landscape along the river is natural where the biological sample and MSHA were conducted, there are areas in AUID-503 both upstream and downstream of 14RD130 where the MSHA riparian/land-use component scores that did well at 14RD130 would have scored lower, due to vegetation removal and grazing of livestock in the riparian corridor.

Geomorphology

DNR geomorphology specialists completed both a Pfankuch assessment (score = 95) and Rosgen level II survey of the stream at the biological sample site. The stream classified as an E5 stream type, which means the Pfankuch score classified the stream stability as “moderately unstable”. The stream has significant signs of excess scouring from high flows. Some banks are raw, and bank cutting was noted by the DNR staff. Trees are being undermined by this cutting/scour and toppling into the river (Photo 2). There are signs that the channel receives large flow volumes, as grasses are caught on tree branches high above baseflow water elevation (Photo 3). Mid-channel bars are also a sign of a stream receiving excess fine sediment (Photo 4). There was some evidence of channel incision per DNR staff. Bottom substrates were predominantly sand with some small gravel, and were rated as poor to fair in terms of stability. Some deep pools were found, but some lateral pools were shallow, which can be

Photo 2. The left bank is raw and much sand is deposited on the point bar on the right bank. The tree roots are being undermined by scour of high flows, leading to the trees toppling into the channel.

Photo 3. Dead organic matter is caught on riparian brush as high up as the dashed red line, indicating flows of many times greater volume than the baseflow condition in this photograph.

Conclusions

Regarding potential chemical or water-column stressors, there is a bit of a signal of TSS being a stressor to both the fish and the macroinvertebrates, but that signal is fairly weak for fish, which is the impaired community. In addition, actual TSS measurements were nearly all better than the standard. No other chemistry parameter appeared to be elevated except TP, but eutrophication effects were not found. A review of photos taken in July and August did not show evidence of problematic algal growth, and no high DO readings were measured. DO is often in the healthy range, but continuous monitoring showed that DO does occasionally drop to well below the state standard. Whether this happens on an annual basis is not known. Data from 2017 suggest this is more likely to happen in drier years. Fish metrics shown above do provide some evidence that DO is a contributing stressor to the community. Flow data suggests that DO levels are related to flow. Flow tends to get low in mid-late summer, as does DO, and DO rebounded after precipitation events, when flow volumes increased. Reduced baseflow due to upstream wetland ditching may be related to DO issues occurring in this AUID.

Whenever a site scores well for macroinvertebrates, and poorly for fish, particularly when the stream is relatively small, one reasonable hypothesis to explore is that there is a connectivity blockage somewhere downstream of where the impaired fish community was sampled. Using high resolution aerial photography available on the internet showed a new beaver dam that was developed between the 2013 and 2015 photo editions a fairly short distance downstream of the biological site 14RD130. It is likely that a contributing cause of the fish impairment is a downstream barrier, in this case a beaver dam.

Photo 4. The arrow points to a mid-channel bar of fine sediment.

AUID-503 is probably not achieving its biological capability, given the overall instability of the channel and the habitat problems instability causes (unstable bed materials, fine sediment smothering habitat features, etc.). This instability has likely been occurring for decades, caused by altered hydrology (increased peak flows leading to channel damage/instability), ultimately due to the trenches dug for drainage purposes in the extensive headwaters-area bogs in the early years of European settlement. Similar trenches in this part of Minnesota have been hydrologically studied, and can contribute significant flow (DNR, 2015), stressing stream channels and biological communities farther downstream. Plugging of the most-contributing trenches would likely benefit AUID-503.

Darrigan's Creek (AUID 09020302-508)

Impairment: The creek was assessed as impaired for not meeting the macroinvertebrate community IBI threshold at site 14RD112 located at CSAH-23, 5.5 miles south of Quiring.

Subwatershed characteristics

Darrigan's Creek originates as outflow from several lakes in its headwaters. The subwatershed landcover is predominantly deciduous forest (particularly in the upper half of the subwatershed), hay fields, and pasture, with a modest amount of cultivated agriculture. Much of the riparian corridor is somewhat forested pasture.

Data and analyses

Chemistry

The chemistry data that was collected at the fish and macroinvertebrate sampling visits in 2014 is shown in Table 20. AUID-508 also had 10X chemistry monitoring at this location (EQuIS # S004-832). Chemistry data has also been collected previously at S004-832. The 10X, long-term monitoring, and 2016 SID data are presented in Table 21. Additional parameters from SID sampling are found in Table 22.

Table 20. Chemistry measurements from IWM sampling at 14RD112.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	T-tube
June 9, 2014	18:24	21.2	8.34	98	8.02	289	> 100
Aug 20, 2014	12:11	20.2	9.84	112	8.21	425	> 100

Table 21. Summary of chemistry data at S004-832 (at 14RD112) from 2008 - 2016. The river nutrient standard applies to the growing season, May - September, and is shown in the "Summer Average" column. Values in mg/L.

	# Samples	Average	Summer average	High	Low
Nitrate	36	< 0.028	--	0.033	< 0.02*
Ammonia	29	< 0.043	--	0.115	< 0.04*
Total Phosphorus	38	0.065	0.070	0.132#	0.028
TSS	42	< 6.36	--	46	< 1*

* These values are below the lab detection limit.

A rain-event sample collected on Sept. 8, 2016 was higher, 0.166 mg/L.

Table 22. Darrigan's Creek samples collected in 2016. The August 3rd sample was a baseflow sample, while the September 8th sample was a rain event sample. DO, TP, TSS, and TSVS values are mg/L.

Date	Site	EQuIS	Time	Temp.	DO	DO %	Cond.	TP	TSS	TSVS
Aug. 3, 2016	US	S009-251	15:59	24.61	5.90	70.7	353.3	0.064	--	--
Aug. 3, 2016	DS	S004-832	16:25	24.05	6.39	76.0	368.4	0.110	--	--
Sept. 8, 2016	US	S009-251	9:34	16.31	4.15	42.2	293	0.083	4.0	2.8
Sept. 8, 2016	DS	S004-832	9:50	16.34	5.81	59.4	295	0.166	10	3.2

Nutrients

The data shows very low levels of nitrate and ammonia, but significantly elevated TP for all of the summer (Figure 23). In 2016, an additional site was added for monitoring on AUID-508; upstream at CSAH 32 (Nebish Rd.), EQuIS # S009-251. These upstream/downstream samples show that TP increases significantly between these sites (Table 22).

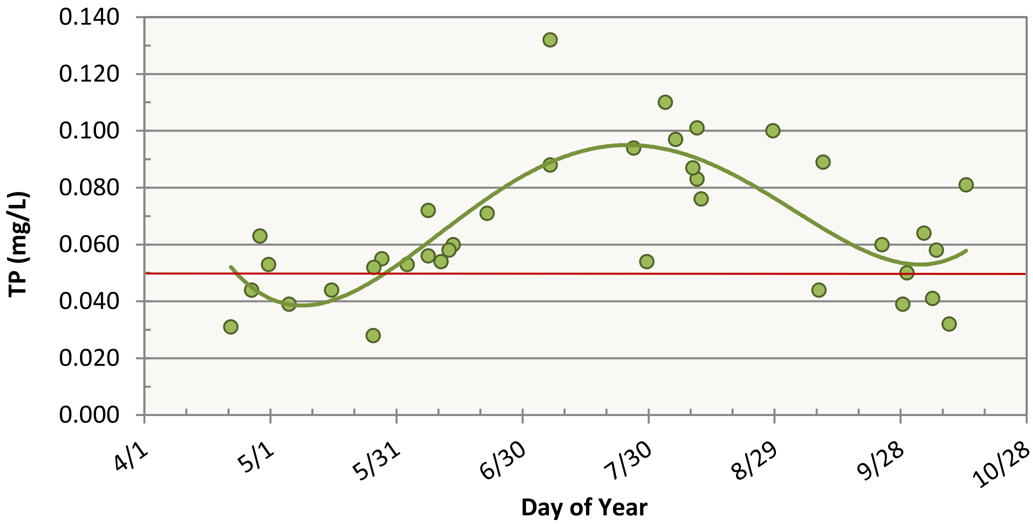

Figure 23. TP data for Darrigan's Creek, at S004-832 (14RD112) from 2008 - 2014. The green curve is a 4th order polynomial regression line with an R^2 value of 0.5699 that shows a seasonal pattern and relative variability of TP levels. The red line is the regional state standard.

Dissolved oxygen

The instantaneous DO measurements from S004-832 look fine, with no measurements below 6 mg/L (Figure 24). However, most measurements were taken in early afternoon, and thus do not record that day's minimum DO concentration, which is the basis of the DO standard. Thus, the early morning DO readings could have been below the 5 mg/L standard. The mid-day DO readings from mid-summer can also be informative in gauging whether eutrophication is occurring. Such readings often are quite high (above 10 mg/L) in eutrophic streams, because excess algae and/or macrophytes pump significant amounts of oxygen into stream water as a result of photosynthesis, which will be at its daily peak in the early-midafternoon time period. None of the mid-summer readings were above 10 mg/L, and most were between 6-8 mg/L, which are very healthy levels for mid-afternoon. The DO saturation measurement from August 20, 2014, (Table 20) was over 100% (112), suggesting significant DO inputs from aquatic plants, causing a supersaturated oxygen level, and thus it appears that there are times when the stream might be on the edge of becoming eutrophic.

Suspended solids

The average TSS concentration is low and the two T-tube readings during the biological sampling visits were very good (Table 21). However, one TSS value from a late July 2010 sample was extremely high for this region. The sampler's note from that day said that cattle were in the creek upstream of the sample, which explains the suspended sediment as their hooves kick up sediment. The flow this day was at about the midpoint of its typical range of volumes, so the elevated TSS was not the result of a large rain event. Overall, TSS was assessed as meeting the standard, with one exceedance in 37 samples.

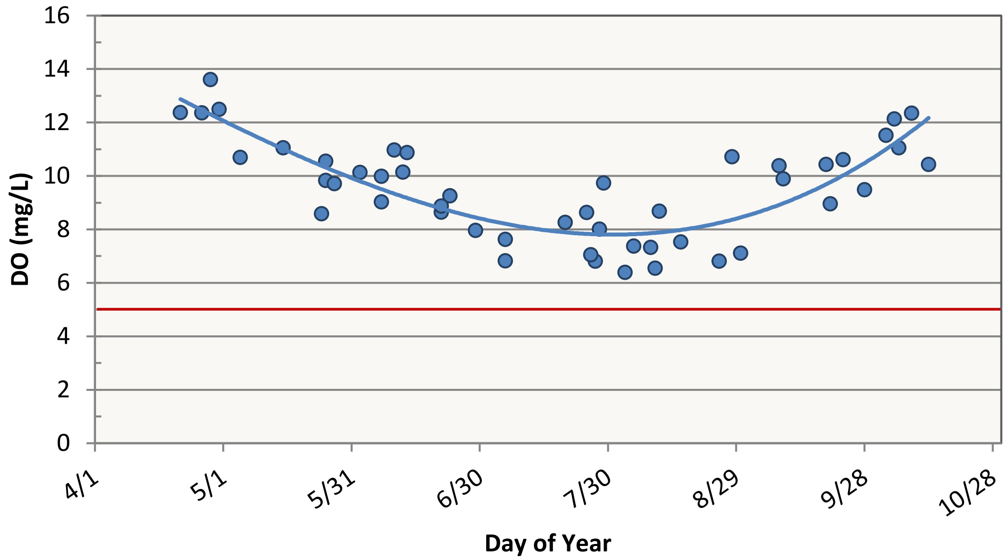

Figure 24. DO data for Darrigan's Creek, at S004-832 (14RD112) from 2008 - 2016. The blue curve is a 3rd order polynomial regression line with an R2 value of 0.6988. The red line is the regional state standard.

A SID visit was made to AUID-508 on August 3, 2016. The stream was flowing nicely, and in the range of its normal baseflow. Water clarity, by visual observation, appeared to be somewhat less at the downstream site (S004-832 at CSAH-23, 14RD112) than upstream at S009-251, CSAH-32 (Photo 5). In order to explore if there was a significant difference between these two sites during a higher flow event, samples were collected on September 8, 2016, the morning following an afternoon/evening rain event of about 1 inch. The Secchi tube measurements from that day were >100 cm at S009-251, and 69 cm at S004-832, confirming the August 3 observation of more suspended solids at the biological station than farther upstream on AUID-508.

Photo 5. Darrigan's Creek. Upstream site (L) and downstream site (R).

Land use differences are the likely contributor to the TSS differences between the two sites. The riparian corridor between the two sample sites appears from aerial photos to be pasture, with cattle having access to the channel for the whole distance. It should be noted that there is also riparian pasturing upstream of S009-251, but for a significantly less distance along the channel. Recent aerial photography found on Google Earth, from May 2015, shows many areas where cattle trampling of the banks has formed raw areas of soil on the sloped banks (a common occurrence in pastured riparian areas found all across the state); Photos 6 and 7. Such unprotected soil is readily available to be eroded by both raindrops and stream flow. Ground observations did note significant sediment entering the stream at cattle access areas. No other logical explanations are apparent to explain the source of the greater suspended sediment at the downstream site. On-the-ground observations of the banks where cattle did not have access found them to be in very healthy condition.

TSS can be composed of either mineral particles, algae, or bits of decaying organic matter. Separating out which type it is can help determine the source of the particles. The September 8, 2016, sampling of the upstream and downstream sites included samples of TSS and Total Suspended Volatile Solids (TSVS). Taking the difference of the two provides the mineral component of the solids. The TSVS at the two sites was quite similar, while the TSS was 2.5 times higher downstream, meaning the proportion of the TSS that is mineral (i.e., soil) is greater downstream than upstream, which also points to soil erosion as being the primary source of the TSS in Darrigan's Creek.

Photo 6. Cattle trampling along Darrigan's Creek, showing the well-documented channel changes of becoming wider and shallower where cattle traverse the banks. Note also the many gullies on the bank from cattle hooves and subsequent erosion.

The elevated TP may be coming from two sources, one being manure deposited near or in the channel by the cattle, or from the soil particles eroding from the stream banks. Phosphorus binds to soil particles and a correlation of the TP and TSS concentrations from same-day visits showed a moderately good relationship (Figure 25), suggesting some of the phosphorus is particle bound and likely from near-channel soil that has eroded into the stream (

Photo 7. Close up of bank erosion on Darrigan's Creek caused by cattle accessing the creek.

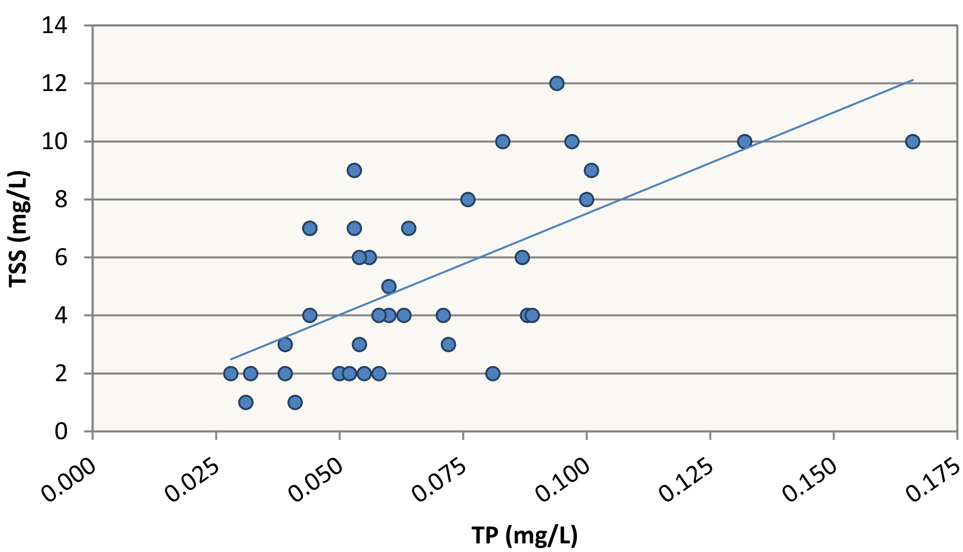

Figure 25. Correlation of TSS and TP at Darrigan's Creek, 14RD112. The regression line has an R^2 value of 0.4223.

Biology

Macroinvertebrates

Two samples were collected at site 14RD112, one in 2014 and one in 2016, and both fell short of meeting the MIBI threshold. In the 2014 sample, the macroinvertebrate community was dominated by four taxa, the caddisflies *Helicopsyche borealis* and *Cheumatopsyche*, the elmid beetle *Dubiraphia*, and the mayfly, *Maccaffertium* (here listed in order of abundance). In the 2016 sample, the most abundant taxa was the midge *Cricotopus*, rather than the caddisfly *Helicopsyche*, a sensitive taxon that was less abundant in 2016. However, the cranefly *Tipula*, another positive taxon, was much more abundant in the 2016 sample, and a second cranefly genus *Limonia*, also was present, with a single individual.

Neither of the samples contained any stoneflies, a very sensitive order of aquatic insect that should be found in a healthy riffle/run stream containing cobble substrate. Table 23shows DO-related metric scores for the macroinvertebrate community at 14RD112. The within-class percentile of the Community DO Index is well above the median, and a comparison of the number of taxa that are low-DO intolerant versus low-DO tolerant is very skewed toward intolerant taxa in both samples. These results suggest that low-DO is not a factor that is negatively influencing the macroinvertebrate community to a significant degree.

Table 23. Macroinvertebrate metrics related to DO for 14RD112 utilizing MPCA tolerance values (2016 version of the index 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	Probability (%) of meeting the standard
3 (2014)	6	0	18.9	0	7.27	67	80
3 (2016)	8	3	10.6	4.2	7.19	64	75

Table 24 shows TSS-related metric scores for the macroinvertebrate community. The TSS community index scored very poorly among Class 3 streams for both samples, at just the 9th and 3rd percentiles. Additionally, there were more than twice as many TSS tolerant taxa as there were TSS intolerant taxa in 2014, and more than four times as many in 2016. The percentage of TSS-tolerant individuals was also more than twice that of TSS-intolerant ones in 2014 and about four times more in 2016. These metrics, taken together, strongly suggest that elevated TSS (or perhaps the correlated bedded sandy sediment) is a stressor to the macroinvertebrate community. The probability calculations of the samples coming from a TSS-passing site are somewhat good, but this metric is less informative simply because it combines all stream classes, which do differ in their DO regimes. Interestingly, the quite intolerant caddisfly *Helicopsyche borealis* was common here. This species can still be present with moderate siltation (i.e., that fills interstitial spaces in coarse substrate, but doesn't completely bury the stones) because they live on the top surfaces of rocks, where they cling on and feed. They are not geared for tight crevices due to the snail-like pebble case they make for themselves. Upper surfaces of rocks were available in Darrigan's Creek.

Table 24. Macroinvertebrate metrics related to TSS at 14RD112 utilizing MPCA tolerance values (2016 version of the index 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	Probability (%) of meeting the standard
3 (2014)	4	9	17.6	39.3	15.79	9	67
3 (2016)	3	13	6.13	28.1	15.26	3	72

Fish

The fish community passed the FIBI, but is analyzed here to possibly add insight into what may be stressing the macroinvertebrates. Based on the DO and TSS Community indices and scores relative to the class averages (Table 25), the fish community does not seem to be affected by either a low DO or TSS problem here.

Table 25. Fish Community DO and TSS Tolerance Index scores at 14RD112 (2016 version). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined.

Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
14RD112	6	7.48	6.51/6.56	96	68.4	12.12	14.08/13.30	80	85.6

Neither the macroinvertebrates nor the fish community show a significant influence of insufficient levels of DO, which is confirmed by the actual DO measurements. The macroinvertebrate community does show a strong negative influence from TSS, while the fish do not. This AUID has gravel and scattered cobble and boulder substrate (good for fish and macroinvertebrates) but had significant amounts of fine particulate substrate where cattle have access to the stream, and what may be happening here is that infrequent high TSS, from eroding banks and re-suspension of deposited fine sediments during higher flow events, may be abrasive to delicate macroinvertebrates, and therefore a stressor to that community. It could also be that the sand has filled in the important interstitial spaces between the gravel/cobble substrate, eliminating very important macroinvertebrate habitat, while enough exposed rock exists for the fish community's habitat needs. This is not to say that the fish community is unaffected here. Were the stream in its natural state, it is likely the fish community would be healthier than it is, even though it still does pass the assessment threshold.

Habitat

The MSHA score for site 14RD112 was 62.5 in 2014 and 65.5 in 2015. These scores are in the "Good" category. The poorest-scoring subcategory score, from a percentage of its possible score, was riparian land use, which here is cattle pasture. The biological staff sampling fish measured the substrate embeddedness at "Light" (25-50% embedded). With the TSS community index score being at such a low percentile, the very high TSS reading found at one visit, and the long reach of pastured land at and upstream of the site (with bank erosion evident in the aerial photos there may be greater embeddedness at other locations in the AUID than at the specific location the biological staff observed. Overwidened areas with corresponding bank erosion, both caused by cattle trampling, typically will have more embeddedness as there is an immediately adjacent sediment source, and less sheer stress on the stream bed due to the wider channel. Such areas can be seen in numerous places in the recent aerial photography.

Geomorphology

Almost the entire riparian corridor is pastured above site 14RD112. From aerial photography review, there are areas of bank erosion caused by cattle trampling and shallow-rooted riparian vegetation due to cattle foraging. Water quality sampling following a moderate rain event in September 2016 showed that suspended mineral material increased along this pastured reach, as the site upstream had significantly less suspended mineral material than the site just downstream of the long, pastured reach, while the suspended organic material was quite similar at the two sites (Table 22).

Conclusions

The macroinvertebrate impairment in Darrigan's Creek is caused by excess fine particulate sediment. The primary source of this sediment is bank erosion caused by cattle trampling of the stream banks. A long distance along the stream is currently, or has a history of being pasture, with cattle having full access to the creek. A review of public domain aerial photography revealed that many areas of bank erosion are evident along the creek. Continual grazing of cattle in riparian areas of streams (as opposed to flash grazing) nearly always results in degraded and eroding banks, as well as a widening and shallowing of the stream channel (Kauffman and Krueger, 1984). This is happening at Darrigan's Creek. When banks are not protected by vegetation, erosion and habitat degradation is inevitable (Waters, 1995). Allowing a natural buffer to grow along the creek will also reduce nutrient input to the stream from adjacent pasture area (Osborne and Kovacik, 1993). If deep-rooted grasses and woody vegetation, as originally found here, were allowed to re-colonize the banks, erosion would be greatly reduced. Excluding cattle from the riparian corridor is the best solution to the bank instability occurring on Darrigan's Creek. That solution would also go a long way to solving the bacteria impairment on this same reach.

The creek appears to have strong potential to have a very good macroinvertebrate community. There are larger hard substrates present here (cobble and gravel), that were they clean of fine sediment, would provide stellar habitat. Very clear stream flow was observed by the author at CSAH 32 (Nebish Road). The channel was also narrow and deep at that location, with healthy amounts of macrophyte growth, and the general reach has gradient that produces flow velocities that would provide for varying microhabitats, all of which are positive habitat features.

Reducing or eliminating cattle access to the stream is the standard method for correcting this common problem of sedimentation by animal trampling/bank soil exposure.

Lost River (AUID 09020302-602)

Impairment: The river was assessed as impaired for not meeting the fish community IBI threshold at site 14RD148, located at Balsiger Road, 6 miles east of Waskish. It should be noted that the adjacent downstream AUID (on the Tamarac River) also has a fish impairment. This site also served as a 10X water chemistry site in the IWM, site S007-886.

Subwatershed characteristics

The Lost River starts in a large bog, flows through an upland stretch, and then flows back into another large bog. Shortly after it enters the second bog, the channel disappears and the water dissipates into the bog soil/vegetation. It re-emerges in several locations as small channels, which coalesce into a single channel again, where the biological sample was collected in AUID-602 (orange arrow in Figure 26). Thus, there is a discontinuity in the channel such that fish cannot move from the lower portions of AUID-602 and the upper parts of AUID-602, and vice-versa. The great majority of the subwatershed is in natural condition, with a relatively small number of small clearcut patches near the upstream end of AUID-602. The biological site 14RD142, at the end of the adjacent upstream AUID-603 scored very good for both fish and macroinvertebrates. Because there is little human activity on the landscape that contributes to the upper part of AUID-602, and because AUID-603 is in very good biological condition, the upper part of AUID-602 is presumably in good condition biologically and water quality wise.

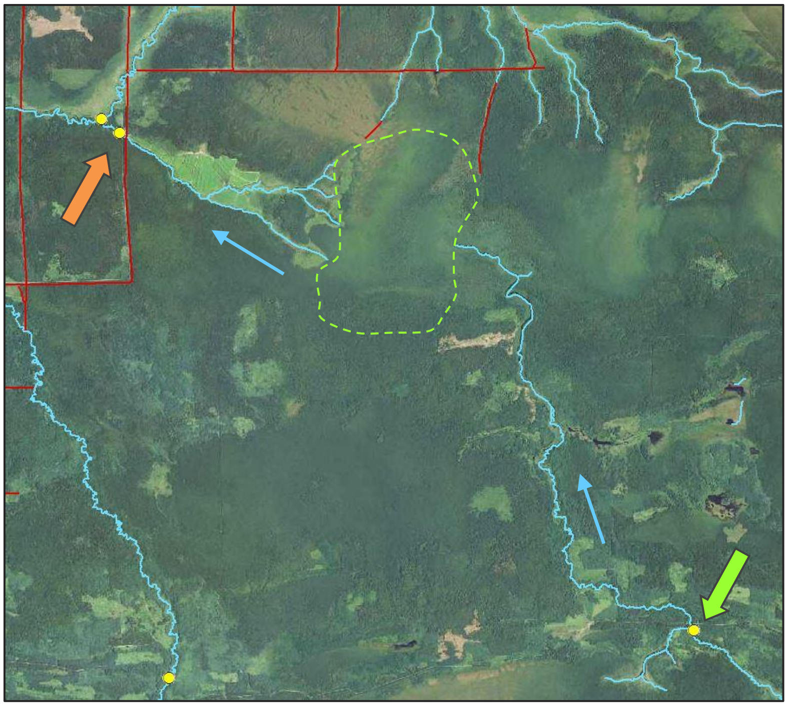

Figure 26. AUID-602, showing its landscape features and flow path (blue arrows). Yellow dots are biological sampling sites. The green arrow points to a biological site located at the downstream end of Lost River AUID-603. The dotted shape is the area within the bog where the river disappears to become shallow groundwater (no channel here), and then reappears as surface flow. The orange arrow points to the sample site for AUID-602 (14RD148).

Data and analyses

Chemistry

The biological sampling visit chemistry measurements are shown in Table 26. Additional chemistry data from the 10X chemistry monitoring is shown in figures that follow.

Table 26. Chemistry measurements from IWM biological sampling visits at 14RD148.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	T-tube (cm)	TP	Nitrate	Amm.	TSS	TSVS
Aug. 26, 2014	9:44	14.6	6.09	62	7.07	233	94	--	--	--	--	--
July 27, 2015	18:40	25.7	6.92	90	7.05	163	90	0.032	< 0.05	0.152	< 4	< 4
Aug. 19, 2014	18:50	20.1	5.56	68	7.17	209.2	> 100	--	--	--	--	--

Nutrients

As is common with smaller northern Minnesota streams, there was a mid-summer peak in TP concentrations (Figure 27), some of which were above the north region river nutrient standard. Nitrate concentrations were extremely low, until a sudden jump in late August, which had largely returned to low concentration levels by late September (Figure 27). This signal may correspond to dewatering of wild rice beds adjacent to the stream site. Even though nitrate levels spiked for a relatively short period, the peak nitrate concentration was still quite low relative to agricultural streams in other parts of the state, and still far below the levels that can become toxic to fish or macroinvertebrates. Ammonia values showed a fairly similar pattern to nitrate, with a similar spike. The high value of 0.29 mg/L ammonia would still have an associated un-ionized ammonia level of 0.001 mg/L, much less than the aquatic life standard.

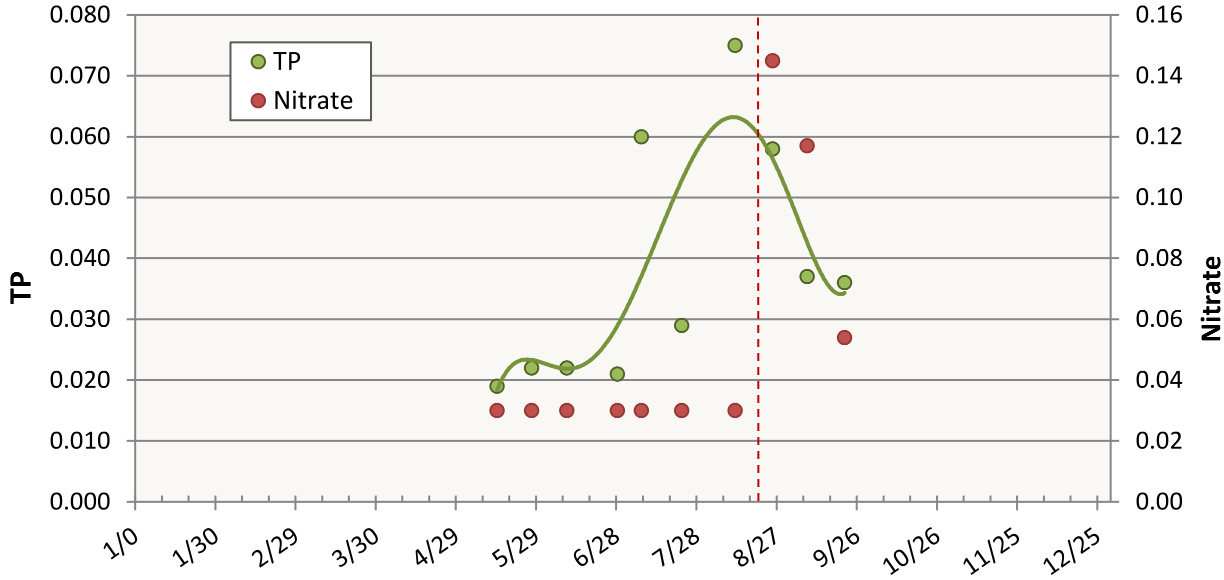

Figure 27. Lost River TP and Nitrate concentrations at S007-886 (14RD148), collected in 2014 with a couple samples from 2015. The green line is a polynomial regression line for TP with an $R^2 = 0.6201$. The dashed red vertical line highlights the approximate date of abrupt increase in nitrate concentration.

Dissolved oxygen

DO levels were quite different in 2014 than 2015, with numerous 2014 samples being at or under the water quality standard, while only one was below in 2015 (Figure 28). The difference in the years may have been due to flow levels. The summer of 2014 was a wetter one than 2015 in this area (Figure 29), meaning there may have been more contribution of wetland-sourced water inputs to the stream, which generally will decrease the DO concentration in the stream. In order to learn more about suspected DO issues in the Lost River, Red Lake DNR deployed a continuous DO monitoring device over the second part of the summer of 2017 (Figure 30). DO was below the standard for a majority of this period, and a number of days never reached a maximum concentration above 5 mg/L.

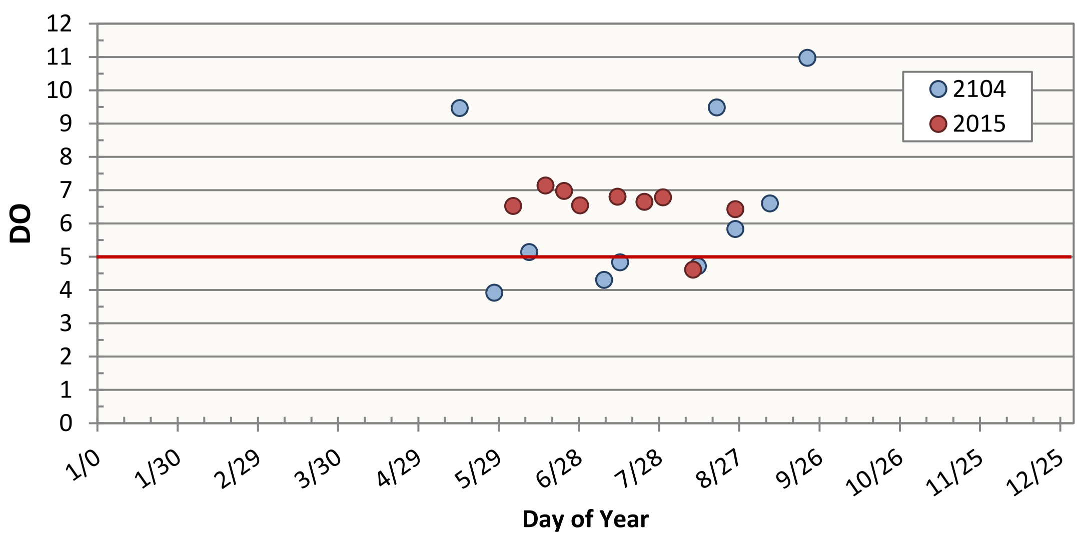

Figure 28. DO data for the Lost River at S007-886 (14RD148), for 2014 and 2015 seasons. The red line is Minnesota's DO standard for warmwater streams.

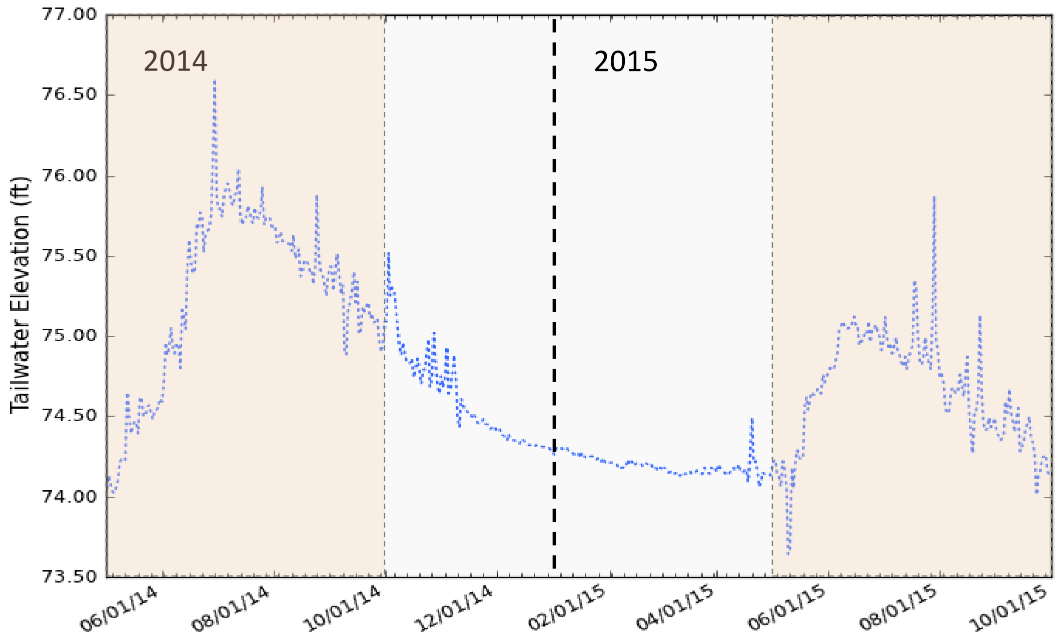

Figure 29. Stage data at the mouth of the Tamarac River (Gage # 04003501) for June 1, 2014 - Sept. 30, 2015. The light orange-shaded regions are the overlapping time periods (May - October) for comparison of the two years.

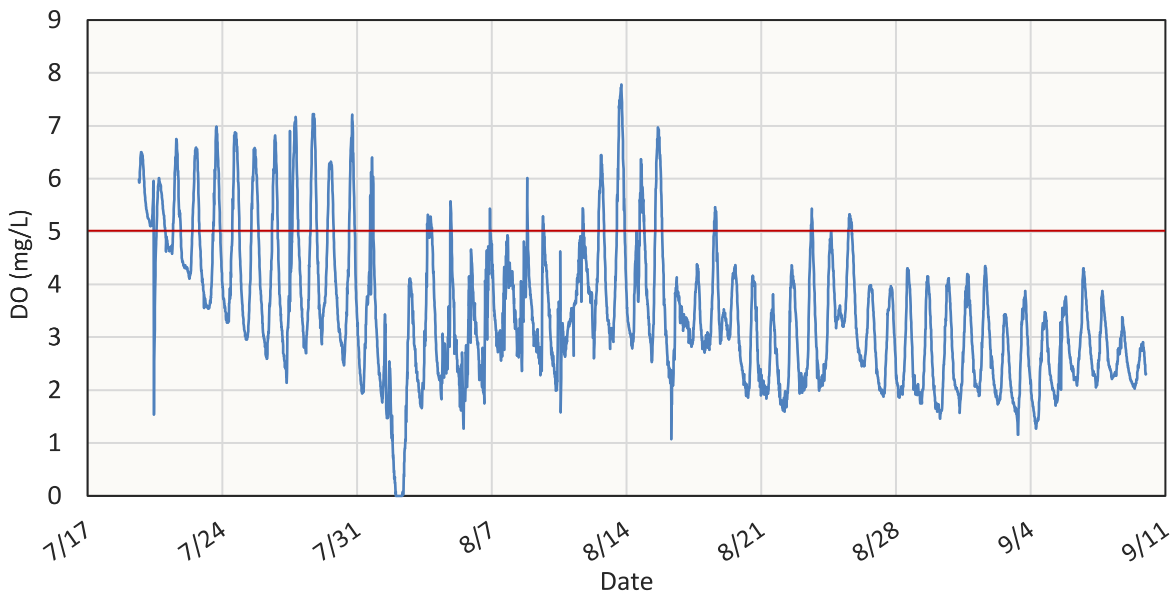

Figure 30. Continuous DO data for Lost River at site S007-886 during the period of July 19 - September 9, 2017. The red line is the DO standard.

The parameter assessment for DO is being deferred due to the heavy influence of wetlands in this subwatershed. However, naturally-occurring low DO may explain the poor-scoring fish community.

TSS and TSVS

TSS and TSVS were very low during the one of the fish sampling visits (not collected at the other biological visits, since this was a 10X site), with both parameters being below the lab's detection limit. All of the 10X samples (collected at set intervals from mid-May - September 2014, and one June and July sample from 2015) were extremely low for both TSS and TSVS, with the highest TSS value being 3 mg/L, and the majority being below the 1 mg/L lab detection limit.

Biology

Fish

The fish community collected in 2014 consisted of only three species, being dominated by central mudminnow, with a fair number of small northern pike, and just three white suckers. These are ubiquitous taxa, found in a wide range of habitats, and can tolerate low DO. There were no sensitive species. The 2015 sample was quite similar in composition to the 2014 sample, with central mudminnow dominant. Again very small numbers of northern pike and white sucker were collected, in addition to a larger number of brook stickleback, not found in the 2014 sample. Again in 2015, only very- ubiquitous species were captured. Metrics related to DO and TSS are shown in Table 27. As shown, this community has little chance of coming from a stream with standard-meeting DO. The TSS TIV scores are below average for this class of streams, though on the whole, the community has a high chance of coming from a stream with standard-meeting TSS.

Table 27. Fish Community DO and TSS Tolerance Index scores in AUID-602 at 14RD148 (2016 version of the index metrics). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined.

Year	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2014	5	5.53	6.97/7.09	1	6.0	12.39	13.99/13.06	67	84.7
2015	5	5.39	6.97/7.09	1	4.7	12.39	13.99/13.06	67	84.7

Macroinvertebrates

The macroinvertebrate community was assessed as meeting the standard in Lost Creek. Even so, macroinvertebrate metrics were calculated to see if there might be some signal in the community to confirm that low DO is, and TSS is not, a stressor (Table 28). These metrics for macroinvertebrates somewhat contradict the conclusion from the same metrics for fish. The DO TIV Index scored much higher than its class average for both samples, opposite the fish community. For the TSS TIV Index, the 2014 sample scored better than its class average (as did both fish samples), while the 2015 sample scored notably worse. One taxon, the black fly *Simulium*, was responsible for the widely-varying macroinvertebrate IBI scores between 2014 and 2015, due to its extreme abundance (249 individuals) in the 2014 sample. They require good current (they are filter feeders that strain food from the passing water), and streams with that habitat often have good DO, meaning *Simulium* have a fairly high DO TIV assigned to them, which inflated the DO TIV Index score in 2014. *Simulium* is present for a relatively short period of time, and the 2015 sample, collected about three weeks earlier in the year, collected only five individuals. Without containing the short-term burst of *Simulium*, the 2015 sample is more reliable as an indicator of conditions, and was the sample used for assessment.

Table 28. Macroinvertebrate Community DO and TSS Tolerance Index scores (2016 version) in AUID-602 at 14RD148. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined.

Year	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
2014	4	7.34	6.26/6.43	96	76	13.05	13.58/13.69	66	87
2015	4	6.77	6.26/6.43	72	66	14.82	13.58/13.69	23	76

There were quite a few taxa in the 2015 sample that are wetland- or sluggish water-oriented, including five snail genera, several aquatic beetle taxa, the fingernail clam Pisidiidae, many *Caenis* mayfly individuals, and the Hemipteran *Sigara* (a "water boatman"). Such taxa are common in lower DO environments. Therefore, there is some signal of a low-DO tolerant community, even though the community isn't strongly skewed that way.

Taking the full above discussion into account, the biological data point to DO being a stressor, with TSS potentially being a minor stressor, though actual TSS samples suggest TSS is not a problem.

Temperature

Water temperature was not problematic for fish at any of the three dates with temperature measurements (Table 29). These dates fall within or near the warmest part of the summer, and thus represent the upper end of the likely temperature range the stream experiences. However, more data points would certainly better reveal the seasonal water temperature pattern and maximum that the stream experiences.

Table 29. Water temperature readings at biological sampling visits, in degrees Celsius.

Date Year	Time	Water Temp.
Aug. 19, 2014	6:50 pm	20.1
Aug. 26, 2014	9:44 am	14.6
July 27, 2015	6:40 pm	25.7

Habitat

The MSHA protocol was conducted at three biological sampling visits, with scores of 63, 61, and 53.9, with an average of 59.3, which is toward the upper end of the "Fair" habitat range. The five subcomponent scores were averaged for the three visits, and the percentage of points possible for each subcomponent was calculated. "Channel Morphology" scored the lowest percentage, followed by "Substrate", attaining 46 and 55% of the points, respectively. The two landscape-oriented subcategories scored very well.

Within the two poorest scoring subcomponents, individual metrics were reviewed, and for "Channel Morphology", the metrics most responsible for the low score were "Channel Stability" and "Channel Development" (i.e., the presence of distinct riffles, runs, and pools). For "Substrate", the score was relatively poor due to the predominance of fine sediment types (sand and silt). Small amounts of gravel were present. The larger forms of habitat relating to the channel and substrate were relatively homogeneous, however smaller habitat features such as macrophytes, woody debris, occasional boulders, and deeper pools were present, all of which are positive features that provide habitat complexity. Habitat should be sufficient to provide for a fish community that passes the IBI.

Hydrology

Hydrology was investigated to determine if there are periods of intermittency. No gaging station has been set up on this lower end of the Lost River. However, the HSPF model flow data can be used to construct flows for all dates from 2006 - 2014. In order to determine how flow levels may effect chemistry data and biological life in the river, summary data were reviewed from HSPF output. In order to look at seasonal trends, as well as general levels, flow data from July 1, August 1, and September 1 were compared across 1996-2014 (Figure 31). There are wet years and dry years that can be seen in this 19-year prediction record. The years 2006 – 2012 were an extended period of relatively low flow. The July 1 and August 1 flow volumes were relatively high, but had dropped to more common levels for September 1. It can also be seen that in general, flow decreases from July 1 to August 1 to September 1.

Also, early July flow volumes can be much higher than levels in early August and early September. Lastly, the model does not predict flow from any of these three dates spanning much of the summer to drop to near zero, though quite often by September 1, flow is down to around 6-10 cfs.

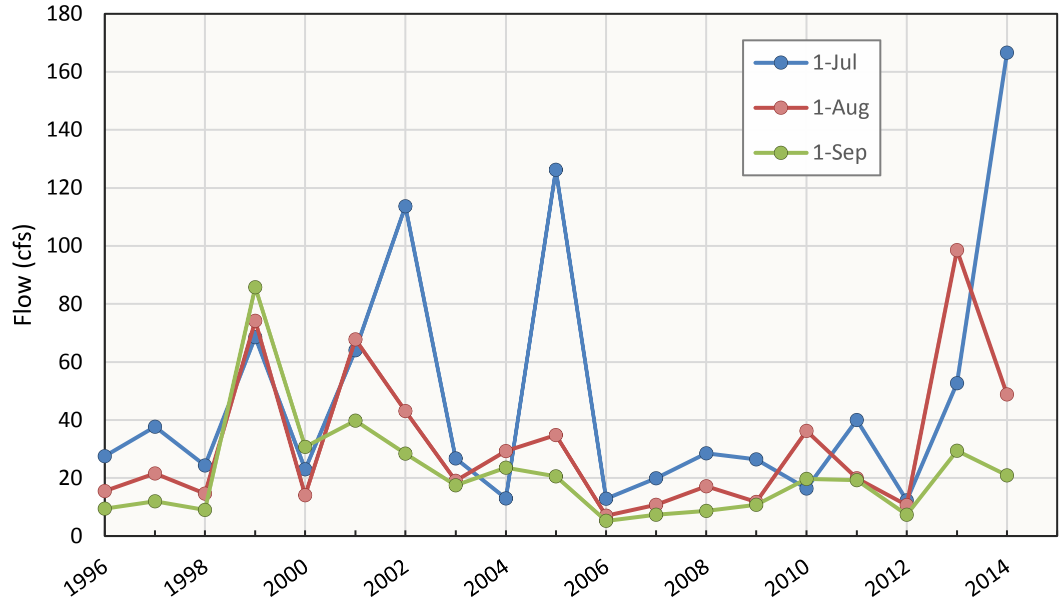

Figure 31. HSPF predicted flow volumes on July 1, August 1, and September 1 of each year of the 2009 - 2014 period. HSPF output beyond 2015 is not currently available.

Connectivity

It does not appear, from a review of pertinent aerial photography, that there are any connectivity issues preventing fish from entering AUID-602. It is true that there is a connectivity block upstream, where the channel disappears in the bog, but connectivity downstream is the more important direction, since fish take winter refuge in larger streams, which will be downstream. There are no barriers in the short distance between the monitored site on AUID-602 and the Tamarac River, and no barriers are present on the Tamarac River (see page 17), upstream to the confluence with Lost River.

Geomorphology

DNR geomorphology specialists conducted a Pfankuch assessment at 14RD148 (score = 92) and a Rosgen level II study. The channel classified as an E5 stream type (low width-to-depth ratio, sand bed stream), making the Pfankuch rating “moderately unstable”. It was noted that this rating was related to the sandy nature of the geology here, but the sandy substrate was consolidated (i.e., packed), meaning it is not shifting in an unstable state. The channel bottom did not have much irregularity (i.e., the pools were not very deep relative to the riffles, which can mean excess fine sediments are filling in the pools. There are some hints that some channel instability and channel incision exists in the AUID upstream of the biological site, along the rice fields. Erosion from that area, where the gradient has been steepened by channelization, may have led to some deposition of fine sediment in the part of the reach sampled for fish (because gradient lessens there due to a return to natural sinuosity downstream of the road. This scenario may have harmed the habitat to a degree, but the effects of channel instability appear relatively minor. Depth variability is a significant habitat feature for fish that is lacking here. It remains a possibility that a natural lack of habitat for fish exists here. A return of the natural sinuosity in this AUID upstream of Balsiger Road (FR-98), along the rice fields, would add habitat versus the straight, dug channel that exists in places there now.

Conclusions

The cause of the poor fish community in the Lost River most likely is periods of low DO. This is shown by analysis of DO-related metrics, as well as by measurements of DO taken over several years. Levels of nutrients are not problematic, and land use in the Lost Creek subwatershed is overall very natural. Though there is a set of rice fields immediately adjacent to the impairment, it is not immediately clear how it would be contributing stress, because it is hydrologically walled off from the stream in order to keep the rice plants inundated, except for a short time at harvest when fields are drained. Parts of the stream however, have been straightened adjacent to the rice fields and may be contributing to some habitat loss downstream, where the fish were sampled. The timing of the fish sampling occurred prior to the time when rice field drainage would be occurring, so that does not seem to be an explanation.

Reasons for the low DO in Lost Creek appear to be due to natural landscape factors. Seepage from a very large bog a short distance upstream from 14RD148 is the main source of water in this lower part of the Lost River. In fact, the upper part of the Lost River completely disappears into this bog for some distance, before re-emerging from several seepage outlets at the downstream edge of the bog. This river water turned to shallow groundwater moves through peat (hydric) soils, where bacterial breakdown of the organic matter saps the water of oxygen. It is also likely that the poor fish community in the adjacent area of the Tamarac River means that there is some lack of a source area from which fish would migrate into AUID-602. Restoring flow to the natural channel along the rice fields would increase habitat diversity in the lower part of the AUID and possibly improve the fish community, though perhaps still not to a passing IBI score, due to the low DO caused by the bog influence.

Perry Creek (AUID 09020302-605)

Impairment: The creek was assessed as impaired for not meeting the fish community IBI threshold at site 14RD116 located at the end of unnamed road, south of Highway 1, 2.5 miles southeast of Quiring. No macroinvertebrate sample was collected here due to a beaver impoundment in 2014 and dry conditions in 2015.

Subwatershed characteristics

The headwaters area of this subwatershed has numerous cattle operations with hay pasturing along or through a number of small, intermittent tributaries. These are all at least 3 miles upstream of site 14RD116. The landscape and riparian corridor in between is mostly natural, with forested and wetland land cover.

Data and analyses

Chemistry

This site only had IWM 1X chemistry monitoring (Table 30). However, Red Lake DNR monitored the AUID at a slightly different location (upstream) in 2015 and 2016 (Table 31). The results are quite good, with the exception that TP is quite high relative to the regional river nutrient standard of 0.050 mg/L.

Table 30. Chemistry measurements collected at the fish sampling visits from 14RD116, values in mg/L.

Date	Time	Temp.	DO	DO % Sat.	pH	Cond.	TP	Nitrate	Ammonia	TSS	T-tube (cm)
June 10, 2014	8:22	16.7	7.21	77	7.65	260	0.161	< 0.05	< 0.1	4.8	70
Sept. 3, 2014	11:51	18.5	8.60	97	7.77	410	--	--	--	--	> 100
July 21, 2015	14:41	22.7	7.86	95	7.73	340	0.148	< 0.05	< 0.1	4.4	95

Table 31. Chemistry measurements collected about 0.75 miles upstream of 14RD116, at the Buckeye Road crossing. Sampling was conducted by Red Lake DNR staff. Values in mg/L.

Date	Time	Temp.	DO	pH	Cond.	TP	Nitrate	Ammonia	TSS	T-tube (cm)
July 21, 2015	15:20	23.9	7.57	8.12	127	0.112	*	*	2	> 100
Aug. 13, 2015	15:17	20.0	9.88	7.86	460	0.166	*	*	--	> 100
Aug. 26, 2015	15:08	15.4	12.13	8.04	385	0.094	*	*	8	> 100
May 23, 2016	15:17	21.4	8.44	7.78	338	--	--	--	--	> 100
June 7, 2016	15:17	19.5	10.68	7.88	352	0.104	--	0.042	2	> 100
June 22, 2016	14:52	18.6	6.56	7.68	378	--	--	--	--	> 100
July 12, 2016	14:53	21.3	6.28	7.74	408	0.116	--	--	--	61
Sept. 6, 2016	13:02	18.8	5.43	7.40	424	0.122	--	--	8	> 100
Sept. 12, 2016	11:13	15.6	6.68	6.94	302	--	--	--	2	> 100
Sept. 19, 2016	11:49	13.5	7.67	7.53	404	0.088	--	--	--	> 100

*below the laboratory detection limit.

Dissolved oxygen

All instantaneous DO measurements were above the standard, though no pre-9 a.m. samples were collected. Without early morning samples, which reveal the daily minimum DO concentrations, these data cannot determine that the stream is meeting the DO standard. They do however show that there are good DO levels during the day. Samples taken in mid-afternoon during summer did show a high DO reading (August 26, 2015), which can signal eutrophication (much photosynthesis-produced oxygen). The sample from September 6, 2016, though above the standard, was not much above 5.0, and this concentration after many hours of daylight, probably means that the daily low, at sunrise, was below the standard. DO percent-saturation measurements (only available for IWM data - Table 30) did not signal eutrophication (all were <100%). Taken together, the DO measurements do occasionally show some signal of possible eutrophication-caused low DO. More measurements at early morning or deployment of a continuously monitoring sonde would be helpful to sort out whether low-DO occurs at a problematic frequency.

Phosphorus

As mentioned above, TP levels were routinely relatively high. Notes from the visit on June 10, 2014, said that the water was darkly stained (tea-colored). This is a sign of abundant wetland-sourced water, which can contain significant phosphorus due to plant material breakdown.

Nitrogen

Both the nitrate and ammonia samples were consistently very low in concentration, and usually below the lab's detection limit. Low levels of nitrate are helpful in preventing eutrophication, as algae require both N and P as nutrients, particularly here where the TP is elevated.

Total suspended solids

Secchi-tube readings were almost always >100 cm. One notable exception was a measurement of 61 cm. TSS samples were always below the appropriate standard for the north region.

Biology

Fish

The first visit on June 10, 2014, produced only four fish, and four species; one each of black bullhead, blacknose dace, brown bullhead, and creek chub. It was felt that the electrofishing equipment was not functioning properly, so this sample is not considered an official sample. The sample collected on July 21, 2015, obtained more fish (100), and six species. The sample was dominated by two species, central mudminnow and white sucker; less abundant were creek chub, pearl dace, common shiner, and johnny darter.

Metrics pertaining to DO and TSS are shown in Table 32. The Index scores were fairly average for both parameters within this stream class; however, based on the low probability of this community coming from a site that meets the DO standard, low DO could be a stressor. An analysis of Tolerant vs Intolerant species (Table 33) shows that the community is indeed biased toward species that are tolerant to low DO, and one-third of the individuals were Low-DO Tolerant, while no individuals were Low-DO Intolerant. TSS showed no bias towards either TSS-Tolerant or TSS-Intolerant taxa. These metrics suggest that low DO levels are a stressor in Perry Creek.

Table 32. Fish Community DO and TSS Tolerance Index scores in AUID-605 (using the 2016 version of the index metrics). For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class. "Prob." is the probability a community with this score would come from a stream reach with DO or TSS that meet the standards, based on all stream classes combined.

Site	Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob. as %
14RD116	6	6.42	6.51/6.56	43	24.2	13.70	14.08/13.30	40	79.6

Table 33. Fish Tolerance metrics (Class 6) for DO and TSS at 14RD116 in 2015. "Very Intolerant" is included in "Tolerant" values.

Parameter	# Intolerant Taxa*	# Very Intolerant Taxa	# Tolerant Taxa	# Very Tolerant Taxa	% Intolerant Individuals	% Tolerant Individuals
DO	0	0	2	1	0	33.3
TSS	0	0	0	0	0	0

Habitat

The fish sampling crew recorded a general observation that habitat looked excellent, and the MSHA score at 14RD116 backed that general observation, receiving a score of 79.5, well up into the "Good" scoring range. The instream subcomponent scores were particularly good. These habitat features need to have adequate water. This is discussed next in the Hydrology section.

Hydrology

Aerial photos indicate that the stream has significant flow in early summer. The flow volume becomes very reduced in mid to late summer, however. The stream was quite low in the late summer period of 2014, and was low again in 2015 (on July 21 and August 5). The 14RD116 site appears to be the approximate location at which the stream transitions to becoming intermittent. It is difficult to find the stream channel network in 2015 aerial photos upstream of 14RD116. These channels appear to be intermittent in flow, looking like dry swales at the time the aerial photos were taken. The September 9, 2011 aerial photos also show the stream to be barely flowing, if at all. It appears that water in the channel was isolated in pools. The Red Lake DNR stopped collecting water chemistry data in both 2015 and 2016 during August, because the stream was not flowing. Only shallow, unconnected pools remained in the channel. The author visited the Buckeye Road crossing on August 3, 2016, and found this same condition (Photo 8), estimating flow of much less than 1 cfs.

The HSPF model created for the WRAPS/TMDL process is a tool that can be used to look at estimates of flow at the end point of any stream channel in the watershed. Figure 32 shows the mean daily flow output of Perry Creek where it meets the South Cormorant River on August 1 and September 1, of years 1996 - 2014, the last year that model inputs are available. Though 2015 (one of the biological sampling years) is not modeled, these data do show that summer flows do become quite low in many years, often declining to the 3-4 cfs range, and in some years (e.g., 2006) even less. These estimated flows are likely higher than the flows were at the biological station, for two reasons: 1) model output is for the mouth of Perry Creek, and the biological site is about 1.6 stream-valley miles upstream, and 2) HSPF tends to over-predict flow at very low flow volumes. Also, 2015 and 2016 were dry years in this region of the state, and so flows those years were almost certainly lower than most of the years shown in Figure 32.

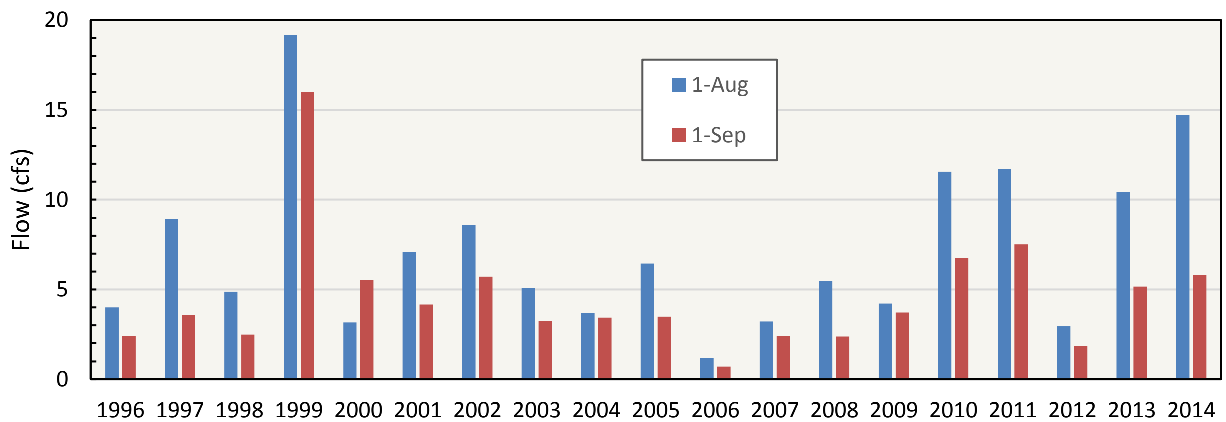

Figure 32. HSPF modeled flow (average daily flow) at the mouth of Perry Creek on August 1 and September 1 of each year, 1996 - 2014.

 

Photo 8. Perry Creek at Buckeye Road, August 3, 2016, looking downstream. Of the paired culverts at this crossing, the left photo is the culvert that carries more of the low flow. The right photo (and right culvert) is a bit out of the channel/thalweg and has accumulated some sediment below the outfall. Emergent aquatic vegetation is growing inside the culvert (very rarely observed), suggesting frequent low flow volumes or stagnant conditions (as it was here).

Connectivity

Beavers and their dams are common in the ULRLW landscape. Beaver dams can be barriers to fish migration. In smaller streams like Perry Creek, where overwintering conditions are inhospitable, fish move downstream to larger waters in the winter and travel up smaller streams to repopulate them in summer. Beaver dams can prevent this springtime migration. There was a beaver dam located between the larger South Cormorant River, and the biological site on Perry Creek (Photo 9). This may have reduced the number of fish that were able to travel up into Perry Creek in 2015 (and possibly other years). Another beaver dam was observed within 50 feet (downstream) of the private road crossing at the downstream end of the biological reach when fish were sampled in 2014. A return visit later in 2014 found that this dam had created a reservoir up into the biological sampling reach and a fish sample was therefore not collected at that date. This dam was not present, or at least had been breached, during the fish-sampling visit in 2015; the biological reach was not impounded.

The culvert of a private field-access road may be an occasional barrier to fish migration. This culvert is immediately downstream of the biological reach. An observation in August, 2016, found woody debris caught at the front (upstream) end of the culvert, and it appeared that fish may have a difficult time crossing that debris jam (Photo 10A). There is more water in the upstream end of the culvert than in the downstream end, meaning the culvert’s slope is opposite of the channel slope. At low flow, as in the photos, the culvert bottom is essentially at the water elevation (Photo 10B). The bottom of the culvert at the downstream end is about 0.8 feet above the streambed in the thalweg. Culverts function best for organism passage when the bottom of the culvert is below the streambed.

DNR staff also observed some rock riffles that they felt looked as if they were human-placed, and noted that at the low flow volumes that were occurring in 2015, these may be barriers to fish movement.

Photo 9. Perry Creek. A beaver dam exists between possible overwintering habitat in the South Cormorant River and the IWM biological monitoring site in this photo dated May 20, 2015.

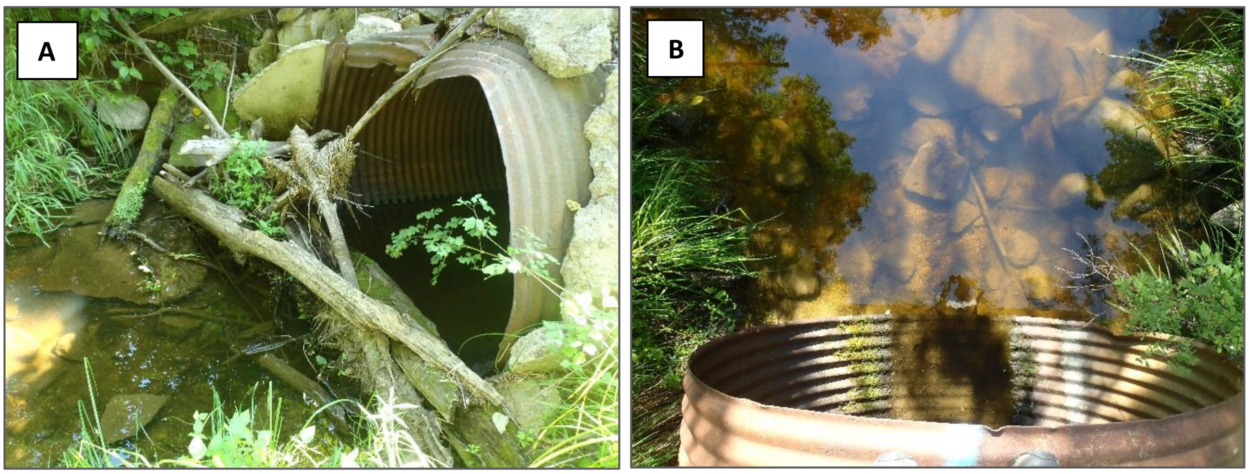

Photo 10. August 3, 2016. A. Upstream end of culvert on private field-access road, showing debris accumulation, B. Downstream end of culvert showing a nearly-perched condition.

Geomorphology

DNR geomorphology specialists studied the biological site in 2016 and conducted a Pfankuch assessment (score = 72) and a Rosgen level I study. The stream classified as an E4 stream type, and the associated Pfankuch score classified the stream channel as stable, though DNR staff noted a bit of incision. DNR staff noted a nice variety of substrates, including a general gravel bed, with cobble, boulders, and areas of fine sediment present. Therefore, the physical channel is in fairly good condition The hydrology of the subwatershed has been altered somewhat from the stream's natural state, just given the clearing of some land in its subwatershed, but effects on the stream are not large.

Conclusions

No clear human-caused stressor was found for Perry Creek. The stream channel and habitat are in good condition. Among the water chemistry parameters, all were good except phosphorus, which is significantly elevated above the river nutrient standard. It is not certain that this is a human-caused elevation of phosphorus. Abundant wetlands occur in the headwaters and may be the source of much of the phosphorus. The fish data suggested there may be periods of low DO in the stream, as the community was somewhat biased toward those species tolerant to low DO conditions. Another likely contributing cause of the poor fish community is barriers to migration from farther downstream. In this case, it is mostly a natural situation, as beaver are quite prevalent and active in this AUID downstream, at, and upstream of the sample site. It also appears that Perry Creek in this area can go dry or experience very low flow volumes in the latter parts of summer. Red Lake DNR staff have noted this where they have been sampling a short distance upstream of 14RD116. Late summer flow volumes were quite low again in 2015 and 2016. No human cause of the low flows were found. This also means that overwintering locations in AUID-605 are minimal, making the barriers to spring migration back into Perry Creek from the South Cormorant River a more significant issue for fish usage of Perry Creek. It appears that a number of factors are combining to contribute to the impaired fish community, none of which are obvious as being human-caused. Future investigation should target more DO sampling, particularly continuous monitoring to catch morning lows. Longitudinal monitoring for TP and DO may help by determining whether there is a location where these parameters change significantly. This would help determine whether human activity may be responsible for contributing stressors.

Other stream investigations

North Cormorant River **(AUID 09020302-506)**

Overall, the biological communities passed the IBI thresholds, and this reach was not assessed to be impaired biologically, but this is a nearly 40 mile long AUID and the farthest downstream site did fail for both fish and macroinvertebrate communities. The high flows prevalent in 2014, the year that sampling was conducted, potentially confound the IBI results at the downstream site, making it uncertain as to whether habitat or water quality conditions are degraded in the downstream portion of AUID-506 or whether the high flows contributed to a not-fully-efficient sampling procedure, or caused many organisms to seek shelter elsewhere. Biologists did note that signs of channel instability (which typically reduces habitat quality) were present at this downstream site. Those will be discussed here in order to bring attention to projects that may be beneficial to pursue in this part of the river.

MSHA scoring was conducted at the two 2014 fish visits, and the two scores were quite different. The July 14 total score was 50, while the August 19 score was higher, at 61. One of the notable differences between the sub-scores was for substrate. The July score (9) was quite a bit lower than the August score (16.2). One difference was that gravel was noted as an observed substrate in riffles, while in July, riffle habitat was not noted, and only sand and clay were observed as substrate types. Also, embeddedness was rated as “severe” in July, while rated “moderate” in August. There may have been a flow event between the two visits that scoured some fine sediment off of larger substrates. These two observation dates suggest that there may be issues of excess fine sediment in the lower parts of the river.

There are signs of channel instability along the North Cormorant River. These signs include trees leaning into or toppling into the channel, mid-channel fine sediment bars, steeply-graded banks on the inner banks of bends, and terrace formation (Photo 11). High flow marks are evident as well, such as the vegetative debris quite high up in overhanging woody material (Photo 12). These signs are evidence of the effects of hydrologic alteration (more water flowing than the channel developed to carry). Ditching has occurred in the North Cormorant system upstream of 14RD124, the lower biological monitoring station (Figure 33). This subwatershed also has the most intensively farmed area of the ULRLW, and the change in land use from forest to open field has altered hydrology as well.

Photo 11. North Cormorant River, with signs of channel instability as noted in the text.

Photo 12. North Cormorant River, with signs of terrace formation (yellow line showing ground surface) and high flow indicators (arrows pointing to caught debris).

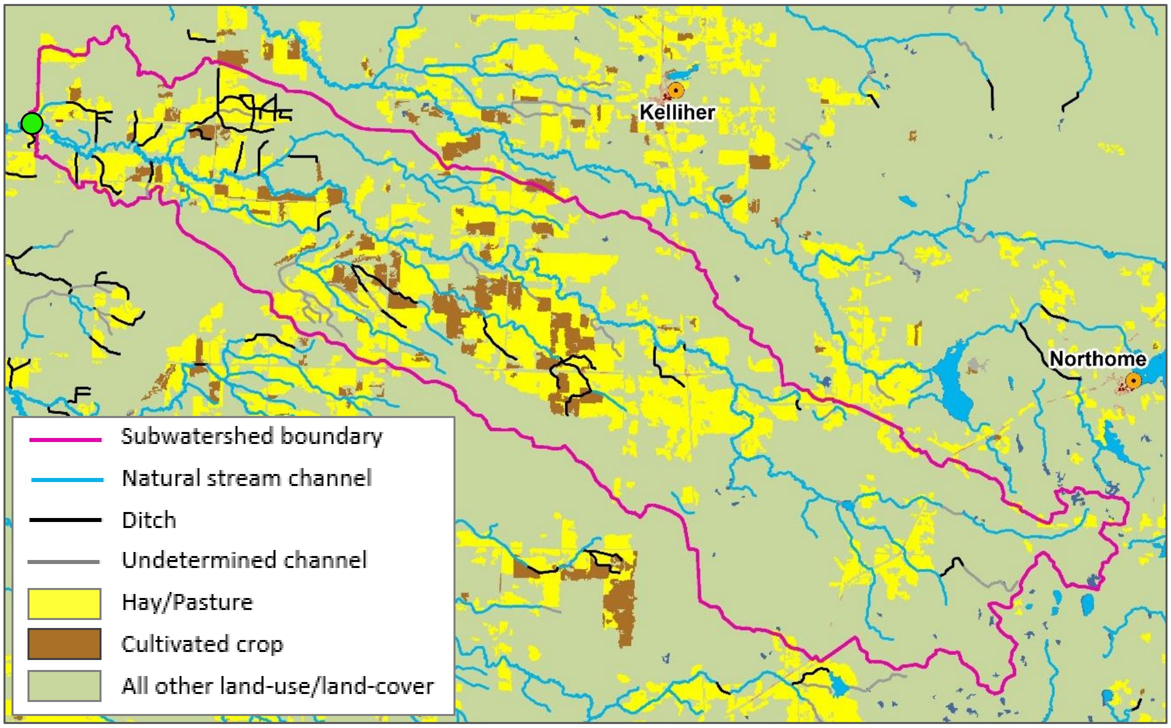

Figure 33. Land use in the North Cormorant River subwatershed for biological site 14RD124 (green dot). Stream flow direction is from bottom right to upper left.

Other ongoing stressor ID work

Red Lake River DNR - The Red Lake River DNR is continuing to monitor a number of sites in the ULRLW. Of particular note at the writing of this document, a culvert assessment for fish passage was conducted in 2015-16, primarily on streams in the part of the ULRLW south of Lower Red Lake. This project may be extended in the future to other parts of the ULRLW. Contact the Red Lake DNR for more information and reports.

Red Lake Watershed District - The Red Lake Watershed District is participating in TMDL work, as well as doing long term monitoring at a number of sites. See their webpage for updates - http://www.redlakewatershed.org/.

Overall conclusions for ULRLW streams and rivers

Most stressors in the ULRLW (Table 34) are fairly local, and have local effects. Anthropogenic stressors include:

- Pasturing cattle in riparian areas and allowing cattle to access stream channels
- Field ditches and legacy peatland ditches
- Road crossings where culverts are not installed in a manner that allows for fish passage.

The exception to local stressors is the extensive bog/fen ditching that occurred about a century ago, primarily in the upper half of the ULRLW. This ditching has altered hydrology and caused channel, habitat, and water quality impacts in downstream locations.

Other stressors appear to be due to natural situations, including:

- Low DO when source water comes from bogs or other wetlands
- Beaver activity (dams) that can block fish passage to upstream locations
- Low flows in later parts of summer, which have more of a tendency to occur in western parts of Minnesota due to the lesser amounts of rain that fall there relative to eastern Minnesota

Returning the hydrological regime of streams with headwaters ditching to more closely match the original, unmodified hydrological patterns will provide benefit to the streams in the upper half of the watershed. As mentioned in the body of the report above, restoring drained-bog hydrology is complex, and requires the guidance of professionals with strong knowledge of soils, hydrology, and hydrogeology. Repairing local stressors, such as excluding cattle from stream channels and near-channel banks, and replacing culverts using designs that allow fish passage, will allow biological communities to improve in places affected by those situations. Restoring a more natural flow regime in the southern half of the watershed, where hydrological alteration from field ditching has harmed the channel, will improve habitat for biological organisms in the southern parts of the ULRLW.

Table 34. Summary of stressors causing biological impairment in ULRLW streams by location (AUID).

				Stressor						
Stream	**AUID Last 3 digits**	**Reach Description**	**Biological Impairment**	**Dissolved Oxygen**	**Phosphorus**	**Sediment/TSS**	**Connectivity**	**Altered Hydrology**	**Channel alteration**	**Habitat**
Tamarac River	501		Fish	•				♦		
Shotley Brook	502		MI			•		♦	•	•
N. Br. Battle R.	503		Fish	•			•	◊		
Darrigan's Creek	508		MI			•			♦	
Lost River	602		Fish	•		?			?	?
Perry Creek	605		Fish				o	o		
North Cormorant R.	506		(Fish and MI)			•		♦	•	•

♦ 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 anthropogenic contribution, if any, not quantified. Includes beaver dams as a natural stressor.
\+ Based on river nutrient concentration threshold (though necessary response variable thresholds were not collected), but not officially assessed and listed for this parameter.
? Inconclusive

Monitoring and assessment of lakes

Overview of Upper/Lower Red Lake Watershed lake monitoring

The approach used to identify biological impairments includes the assessment of fish communities of lakes throughout a major watershed. The Fish-based lake Index of Biological Integrity (FIBI) utilizes data from trap net and gill net gamefish surveys, as well as nearshore surveys that focus on sampling the nongame fish-community utilizing beach seines and backpack electrofishing. From this data, a FIBI score can be calculated for each lake that provides a measure of overall fish community health. DNR developed four FIBI tools to assess different types of lakes throughout the state (Table 35). Thresholds for the two tools used in ULRLW lakes are shown in Table 36. More information on the FIBI tools and assessments based on the FIBI can be found at the DNR website. Although an FIBI score may indicate that a lake fish community is impaired, that alone is not sufficient to assess a lake as impaired for Aquatic Life Use. A weight of evidence approach is used during the assessment process which factors in considerations such as sampling effort, sampling efficiency, tool applicability, location in the watershed, and any other unique circumstances to validate the FIBI score.

Table 35. Summary of lake characteristics and metrics for current FIBI tools.

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

A common misconception is that if a lake is a good fishing lake, or produces high numbers of large gamefish, that it is a healthy lake. This is not necessarily true. The smaller nongame fishes are ecologically important and are often the most sensitive to differences in human-induced stress. Even though Walleye and Northern Pike are highly sought gamefish species, their numbers and average size will not disproportionately affect the FIBI score due to each metric having equal weight.

The FIBI was used to assess six lakes in the Upper/Lower Red Lake Watershed (Figure 34 and Table 37). Two lakes, Blackduck (DOW 04-0069-00), and Sandy (DOW 04-0307-00) had repeated nearshore surveys. Five lakes had FIBI scores at or above the impairment threshold. Blackduck Lake (DOW 04-0069-00) had FIBI scores below the threshold, but insufficient information for an assessment of Aquatic Life Use. Both surveys on this lake had FIBI scores which fell below and very near the impairment threshold. This data suggests it is vulnerable to future Aquatic Life Use impairment (Table 38). Dellwater (DOW 04-0331-00) and Dark Lake (DOW 36-0014-00) were sampled but not assessed for various reasons. The fish community in Dellwater Lake is heavily influenced by recent winterkills. Dark Lake was not assessed due to an insufficient nearshore sampling effort – a lack of backpack electrofishing. This report will examine potential stressors to the fish community in Blackduck Lake (DOW 04-0069-00).

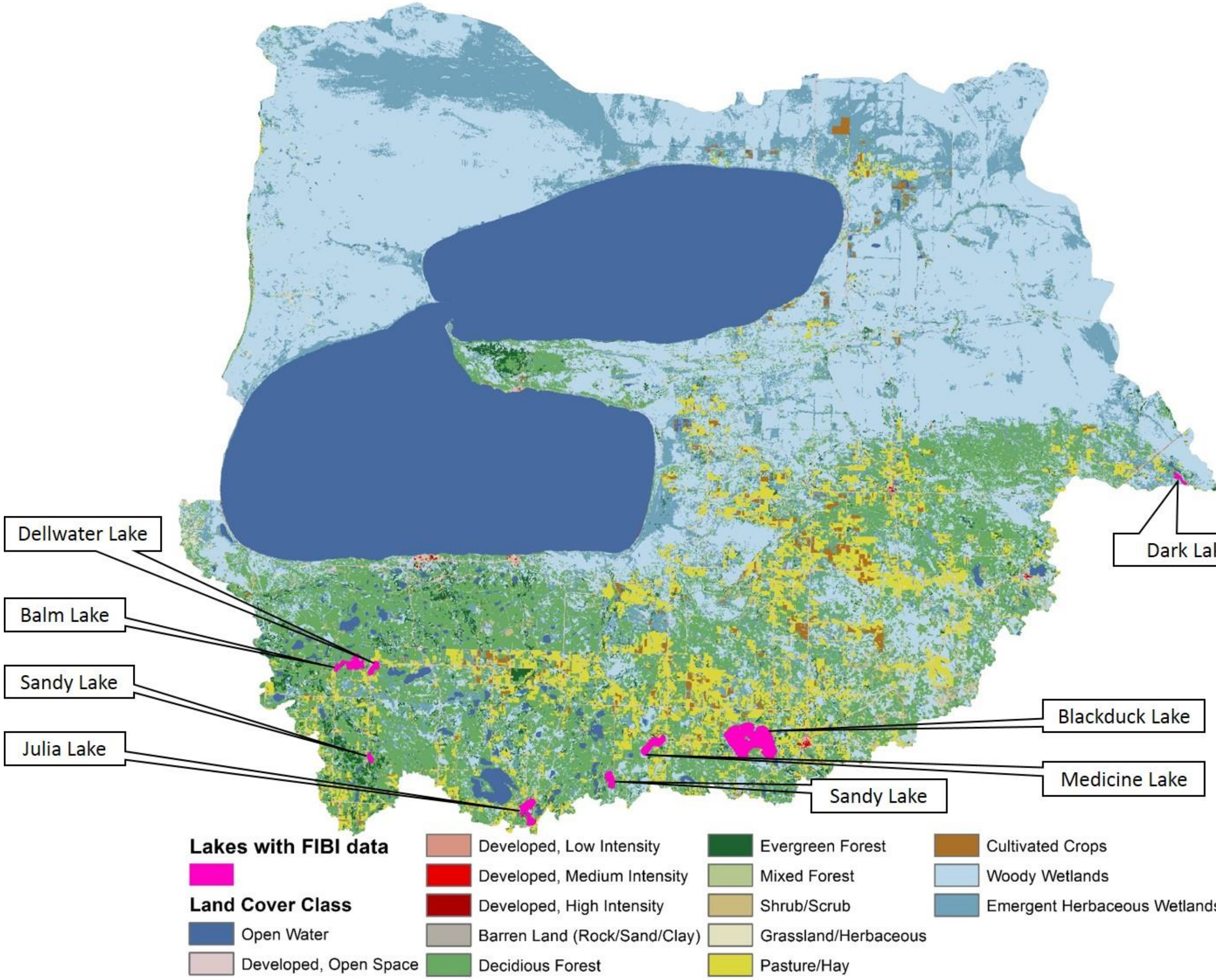

Figure 34. Upper/Lower Red Lake Watershed and land cover classes with the lakes sampled with the FIBI protocols labelled and color fuchsia.

Table 36. Lake FIBI Tools with respective FIBI thresholds and upper/lower confidence limits (CL) found in the Upper/Lower Red Lake Watershed.

Lake FIBI Tool	FIBI Threshold	Upper CL	Lower CL
Tool 2	45	54	36
Tool 4	38	46	30

Table 37. Summary of lakes in the Upper/Lower Red Lake Watershed assessed with FIBI Tools. The shaded row is the lake discussed further in this document. The % littoral is the % of the lake that is less than 15 feet deep calculated using the DNR GIS data. Color coding is described at the bottom.

DOW	Lake Name	County	Nearshore Survey Year(s)	Notes	DNR GIS Acres	FIBI Tool	% Littoral	FIBI Score(s)	Below Impairment Threshold	Within 90% CI of Impairment Threshold
04-0069-00	Blackduck	Beltrami	2013, 2015		2686	2	51	43, 44	Yes, Yes	Yes
04-0122-00	Medicine	Beltrami	2013	Repeated within year (July, August)	461	4	67	44, 49	No, No	Yes, No
04-0124-00	Sandy	Beltrami	2014		261	4	77	59	No	No
04-0166-00	Julia	Beltrami	2013		511	4	33	66	No	No
04-0307-00	Sandy	Beltrami	7/2010, 8/2010, 2015	Low effort – 1, 2, or 3 stations seined	103	4	11	75, 72, 77	No	No
04-0329-00	Balm	Beltrami	2013		537	2	52	77	No	No
04-0331-00	Dellwater	Beltrami	2010	Not assessable – recent winterkills	199	4	82	53	No	No
36-0014-00	Dark	Koochiching	2010	Not assessable – no electrofishing	120	4	59	29	Yes	No

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

Summary of biological impairments of lakes

The majority of the lake fish communities assessed had FIBI scores above the thresholds (Table 37). Many were near, if not above, the upper bound of the confidence interval.

One lake within the watershed, Blackduck Lake, had a FIBI score indicative of an impaired fish community because it did not meet the expected aquatic life scores in the respective FIBI. Utilizing a weight of evidence approach though, there is insufficient information to assess the lake. The information we have suggests Blackduck Lake is vulnerable to future impairment if stressors are not mitigated.

Table 38. Lakes that are vulnerable to future Aquatic Life Use impairment in the Upper/Lower Red Lake Watershed.

Lake name	DOW #	Location description	Impairments
Blackduck	04-0069-00	Approx. 1.5 miles west of the city of Blackduck	Aquatic Recreation (2009)

Possible stressors to fish communities in lakes

Candidate causes

Several human induced changes have been shown to impact the community of fish inhabiting a lake. A comprehensive list of stressors that can potentially cause biological impairment can be found at: Stressors that Can Potentially Cause Biological Impairment. A list of possible stressors was selected for consideration for lakes with FIBI data and within in the Upper/Lower Red Lake Watershed:

- Toxic chemicals
- Watershed alteration
  - Excess nutrients
  - Loss of connectivity
- Aquatic invasive species
- Gamefish management
- Habitat alteration
  - Aquatic plant control
  - Riparian lakeshore development
  - Sedimentation/change in substrate
  - Water level management

Eliminated causes

Toxic chemicals

A number of toxic chemicals exist which impact aquatic life and can enter the aquatic environment through a variety of pathways. Impacts to fish communities range from direct lethal effects on individuals, altered food web from impacts to forage organisms, and reduced fitness from chronic exposure.

Hazardous chemicals such as herbicides, pesticides, fertilizers, and petroleum based products typically enter the aquatic environment as a result of an unintentional discharge or spill. A desktop review of MDA incident reports indicated no agricultural chemical contamination in the quantity and proximity to any lake assessed to impact the fish communities present (MDA, 2016). The MDA also conducts sampling to monitor surface waters for pesticides. A summary of monitoring data from the 2012 National Lakes Assessment concluded that pesticide levels detected in lakes were well below applicable water quality standards and reference values (Tollefson et al., 2014). A review of publicly accessible MPCA data also indicated hazardous chemicals were not likely a significant stressor to the fish community (MPCA, 2017c). Direct application of chemicals to lakes for management purposes will be discussed in following sections.

Mercury is another naturally occurring chemical that can be toxic to fish and other aquatic life. Currently, mercury levels in fish tissue are used to assess lakes for Aquatic Consumption Use. The Upper/Lower Red Lake Watershed (ULRLW) has several lakes that have been identified as impaired based on mercury levels. MPCA and local partners have developed a statewide mercury reduction plan approved by EPA to address these impairments (MPCA, 2007). Mercury concentrations that are toxic to fish and other aquatic organisms would need to far exceed the current aquatic consumption standards. Therefore, current standards and actions intended to address aquatic consumption impairment should provide adequate protection to eliminate mercury as a likely candidate cause for the impaired fish community.

Based on the information presented above toxic chemicals were eliminated as a candidate cause of FIBI scores below threshold.

Non-native aquatic species

Fish communities may experience stress caused by direct competition from newly arrived organisms, or non-native species. A few examples of newly arrives organisms that directly compete with native fish species for resources are rainbow smelt and alewife. These species have led to changes in the forage base of the Great Lakes including Lake Superior. More often, new species arrivals indirectly alter fish habitat and food web dynamics due to specific life history and behavioral processes.

Some non-native species have multiple mechanisms for impacting the aquatic environment. Common Carp, for example, compete with native fish species for resources and reduce aquatic plant habitat through their feeding behavior. Invertebrate species such as Spiny Waterflea, Zebra Mussels, and Faucet Snails are examples of non-native species that alter lake ecology by changing the food web that structures the fish community. Non-native aquatic plants may compete with native species, which can alter the aquatic plant community and change the character and quality of fish habitat.

Biotic and abiotic characteristics can also impact the extent to which a newly arrived species will ultimately impact each lake. Lake morphology may limit the potential impacts of certain species and favor others based on the amount of available resources in each lake. Regardless of abiotic factors, lakes that maintain high biological diversity are generally more resilient to changes caused by non-native species. Research continues to develop and improve techniques to quantify the impact of non-native species to aquatic ecosystem function. There are not any records of non-native species in lakes in the Upper/Lower Red Lake Watershed that have been sampled according to FIBI protocols. Therefore, non-native aquatic species are excluded from further consideration as a stressor to lakes in the Upper/Lower Red Lake Watershed.

Inconclusive causes

Connectivity

The ability of fish to move upstream and downstream is important to the natural population and community dynamics of some fish species. The impact of connectivity is more widely studied in flowing water systems although there has been increased interest in understanding the importance of connectedness to lake fish diversity. Aquatic connectivity can be an important factor in explaining some of the natural variability of species richness in some gamefish lakes (Tonn & Magnuson, 1982), but other geologic and hydrologic variables best explain variation in species richness (Hrabik et al., 2005).

Connectivity influences the number of species available to inhabit lakes and can impact the abundance of certain species (Bouvier et al., 2009). Connectivity affects the recovery or recolonization of a lake by potentially limiting the species pool. A review of available data (DNR, 2017) found 52 fish species collected from the Upper/Lower Red Lake Watershed overall and 30 species from the lakes assessed with the FIBI. Most of the species absent from the lakes assessed were predominantly riverine species. Eleven fish species found in lakes and intolerant of disturbance have been recorded from lakes in the watershed. Seven species have vouchered specimens and 4 species lack voucher specimens. Eight of these 11 historically reported intolerant species in the watershed were sampled from lakes during this assessment cycle. The other 3 species are uncommonly found in the types of lakes that were assessed. This indicates there may not have been any loss of species from the lakes in the watershed as a whole, but within any individual lake, species losses cannot be ruled out; this will be discussed further in latter sections.

It is important to understand the limitation of the available data that includes information collected over a long time period, by many organizations using a variety of methods, and for different purposes. Availability of confirmable historic species lists is also limited and makes substantiating claims of loss of species in an individual lake difficult. Protocols for collecting data that is used for FIBI aquatic life use assessments of lakes were adopted in 2012 and make historic comparisons impossible. The goal of the protocols is to capture a representative sample of the fish community and 90% or more of the warm-water species in a lake. The data used during this assessment will allow for comparisons over time going forward.

It is also important to consider how connectivity can influence species diversity differently at short and long-term time frames. Connection to other surface waters may be important to determine the number of species available to inhabit a given lake, but once established these species should persist if the lake has enough appropriate habitat. Therefore, the loss of connectivity is not likely the mechanism for loss of species in lakes but may limit the potential for recolonization once a species is lost. The effects connectivity has on the FIBI score are unknown.

Gamefish management

Fisheries management includes a wide range of activities ranging from protecting fish habitat, regulating harvest of species to improve quality, stocking fish to provide additional opportunities, removing fish to restructure the community, and many others. Some of these activities have the potential to be stressors to the fish community in a lake.

In Minnesota, regulating fish harvest is typically pursued to preserve or enhance the quality of predator fish populations such as Largemouth Bass, Northern Pike, or Walleye. It is generally regarded that regulations do not significantly affect biological integrity although no research has been completed in Minnesota to evaluate the impact of fish regulations on the FIBI score. Predator size may influence the relative abundance of different forage species in a lake, but is not likely to result in lower species richness. Since the fish community within a lake is determined over a long time and by many forces, lake fish communities have a natural adaptive capacity or resilience.

Fish stocking is another common technique managers use to preserve or enhance opportunities for anglers. Historically, authorized stocking has focused on adding an additional top carnivore species to a fish community that was not naturally present in the lake. There are instances where forage species and non-top carnivore species have been added to the fish community through either authorized or unauthorized stocking efforts. Introduced predators can influence the community by replacing an existing predator, adding to total predator density, or providing a predator in a completely new niche for the system (MacRae & Jackson, 2001). Therefore, stocking has more potential influence the fish community (and FIBI score) than the regulation of harvest. However, unless the prior fish community was predator free, the fish community structure in a lake is influenced more by its location and the amount/diversity of habitat than by the introduction of a predator species (Trumpikas et al., 2011).

There are specific case studies that demonstrate the potential for negative consequences of fish stocking in the United States. Some examples include the introduction of Lake Trout to the Greater Yellowstone Ecosystem and the introduction of Northern Pike to river systems in California, which have changed these systems dramatically. In addition, current stocking practices typically involve ongoing efforts at regular intervals that maintain target species above their natural levels. This higher predator density can affect the composition of the community, but probably not the overall richness of species. Stocking often results in changes to the flow of nutrient and energy through the food web through direct competition and indirectly by affecting forage fish or zooplankton density and composition (MacRae & Jackson, 2001; Eby et al., 2006).

Predator stocking remains a commonly used tool for fish managers in Minnesota. Limited research in the region has focused on the impact of predator stocking to other gamefish populations (Fayram et al., 2005; Knapp et al., 2008). Studies have shown a negative relationship between predator stocking and Yellow Perch abundance, an important forage fish in many Minnesota lakes (Anderson & Schupp, 1986; Pierce et al., 2006). Strong Yellow Perch year-classes are thought to buffer small bodied fishes like minnows and darters to the impact of Walleye predation (Forney, 1974; Lyons & Magnuson, 1987). Statewide analysis found a significant negative trend in Yellow Perch catches in Minnesota from 1970 to 2013 (Bethke & Staples, 2015) which may indicate a reduced ability of lake fish communities to adapt to stressors.

While some gamefish management activities can result in significant changes to the fish community of a lake, in general, there is an overall lack of conclusive evidence linking these changes to FIBI scores. Therefore, gamefish management activities are not considered further as a potential stressor to the fish community because the effects of gamefish management on the FIBI score are unknown.

Aquatic plant management

Healthy aquatic plant communities provide important benefits to fish communities including providing spawning habitat for some species, protection or refuge areas for juvenile fish, and foraging opportunities. Because aquatic plants growing in public waters in Minnesota are owned by the state, control activities are regulated by the DNR Fisheries, Aquatic Plant Management (APM) permit program.

APM program rules limit the amount of control on a given lake based on the type of plant and control method in order to protect fish habitat and allow lakeshore owners reasonable access. Activities that have the potential to cause damage to fish, such as herbicide applications, or to important fish habitat, such as removal of emergent vegetation, require an APM permit. Other activities, such as the removal of some submersed vegetation or a small amount of floating-leaf plants which are not likely to significantly alter fish habitat on a lakewide scale, do not require a permit but are covered under program rules.

Current APM rules that limit the total lakewide removal of vegetation are designed to prevent impact to the fish community, but lower amounts of removal still constitute a loss of habitat (Radomski & Goeman, 2001; Valley et al., 2004).

In addition to regulated control activities, aquatic plants are sometimes destroyed through illegal activities that can be difficult to identify. The cumulative impact of illegal activities is also difficult to quantify since incremental habitat loss can occur over a long period of time. High quality aquatic plant survey data which would provide a baseline for comparison to quantify the amount of habitat loss is often limited or completely absent. Lack of this type of data is a problem for statewide analysis although some organizations do have quantitative data in various formats.

Aquatic plant control activities are not likely a candidate cause for the vulnerable assessment, but the effects of APM activities on the FIBI score are unknown due to lack of quality data.

Sedimentation

Diverse quality habitats are required to sustain healthy robust fish communities in lakes. Sedimentation can be caused by a variety of activities. Human development along lakeshores can result in significant changes to the sediment characteristics in a lake (Francis et al., 2007). Destruction of nearshore aquatic vegetation and removal of woody material, both of which help to stabilize substrates, can lead to resuspension and redistribution of sediments. Non-native Common Carp also contribute to the loss of aquatic vegetation by dislodging plants, which leads to the resuspension of bottom sediments (Bruekelaar et al., 1994).

The effects of sedimentation could alter a fish community in many ways. The filling in of interstitial spaces in spawning substrates can smother entire year classes and reduce the potential for future spawning events. This filling could continue and affect the frequency of winterkill due to the gradually reduced depth/volume of water, and ultimately fill the entire basin of some lakes.

Minimal quantitative data were collected historically to document the condition of lake substrates in Minnesota, although some DNR Fisheries surveys do include a qualitative evaluation. DNR Fisheries researchers are currently investigating the spatial relationship between a variety of habitat measurements and their associated fish communities. Completion of this study is pending and may provide a more clear understanding of the importance of different habitats to the overall fish community living within a lake.

Although it is possible that sedimentation may be contributing to lower than expected FIBI scores of some lakes, the lack of high quality quantitative data and scientific research makes it impossible to say conclusively. Therefore, sedimentation is not considered further as a candidate cause for the vulnerable assessment but cannot be eliminated as affecting the FIBI score.

Water level management

Historically, managing water levels in lakes has been undertaken in response to perceived problems that humans have with the quantity of water within a lake basin at a given time. Lake water level control structures were often built to allow manipulation of the natural hydrology of a lake. Oftentimes this resulted in maintaining a more consistent water level with elevations set to reduce low water conditions in late summer. Little or no consideration was given to the impact of these water level manipulations on the quantity and quality of the aquatic habitat for fish.

However, research has shown that water level fluctuations are important for maintaining diverse aquatic plant communities and providing complex habitat that benefits several organisms (White et al., 2008). Most studies focus on the impact to aquatic plant communities while few studies evaluate the impact to fish communities directly (Leira & Cantonati, 2008). Natural water level fluctuations promote more structurally diverse plant communities than artificially regulated water levels (Wilcox & Meeker, 1991). More diverse plant communities provide better fish habitat. Additionally, these plants may perform secondary functions that benefit the fish community such as stabilizing lake sediments or harboring forage organisms for fish. Submersed plant coverage may also be altered due to changes in light penetration that are caused by high water levels. Emergent and shoreline plant coverage could also be affected due to life cycle requirements and optimum conditions not being met.

In addition to direct manipulation using control structures, water levels are impacted by the timing and quantity of water entering the lake basin. These factors are affected by land use in the immediate and contributing watershed and can be caused by human activities such as draining wetlands and increasing impervious surface coverage. These alterations influence the rate at which lake levels rise after a rainfall and the extent of peak lake levels. Sophisticated and time-consuming modeling would be needed to quantify the impact of this change to the quality of the existing aquatic habitat. In addition, limited research is available to suggest the appropriate range of lake level fluctuations for optimum fish habitat.

Minimal quantitative data is available describing fish habitat conditions prior to engaging in long-term water level management on lakes within the watershed and the effects of water level management on the FIBI score are unknown. Therefore, hydrologic regime alteration is an inconclusive stressor due to a lack of data to draw conclusions.

Candidate causes selected for investigation in the Upper/Lower Red Lake Watershed (Blackduck Lake)

The preliminary list of candidate/potential causes was narrowed down after the initial data evaluation/data analysis to two candidate causes of the FIBI score that suggests Blackduck Lake is vulnerable to future Aquatic Life Use impairment (Table 37 and Table 38).

Candidate cause: excess nutrients – eutrophication (phosphorus)

Primary production in lakes is driven by phosphorus (P). In pristine lakes and watersheds, the P comes from resuspension and regeneration in lake sediments. Additional P is associated with increases in algal growth that results in reductions in water clarity, oxygen levels, and submersed vegetation as well as increases in abundance of tolerant fish species such as Common Carp and Black Bullhead (DNR, 2013); Common Carp have not been sampled within the ULRLW.

The addition of excess P is the primary cause of eutrophication in lakes and accounts for about a third of the impairment listings for lakes in Minnesota (Draft 2016 Inventory of All Impaired Waters). Research has shown that elevated P levels significantly affect fish community structure and function in Minnesota lakes (Schupp & Wilson, 1993; Heiskary & Wilson, 2008). Negative effects of eutrophication include altered plant growth, shifts in phytoplankton and zooplankton composition, and decreases in water transparency that lead to changes in the fish community that are detected by FIBI tools.

There are several mechanisms by which eutrophication contributes to impaired fish communities. Excess nutrients affect plankton communities, which make up the foundation of aquatic food webs. Increased primary production leads to more phytoplankton, reduced light penetration, and fewer rooted aquatic macrophytes. Loss of aquatic plants represents a physical alteration to available habitat which can alter fish community composition over time. Reduced plant cover can impact the success of vegetation dwelling species from a variety of feeding guilds. Decreased light penetration can also reduce the efficiency of sight-feeding predators that are not adapted to turbid conditions, like Largemouth Bass and Northern Pike, and result in lower biomass of top carnivores in the community.

Increased phytoplankton can also lead to an unbalanced community with few large bodied zooplankton that are the preferred food for forage fish and important to the diet of many young game fish. These conditions favor undesirable plankton eating fish species over game fish. In turn, some planktivorous/benthivorous fish like Common Carp and Black Bullhead increase internal loading of nutrients in shallow lakes through feeding behaviors (Matsuzaki et al., 2007; Chumchal & Drenner, 2004).

Because of the potential impact of eutrophication to aquatic environments, the MPCA has developed nutrient water quality standards to assess lakes using measurements of total phosphorus (TP), chlorophyll-a, and transparency. Data for TP and either of the other two variables is needed to determine whether a lake meets the standard. Available data will be evaluated later in this report.

Candidate cause: riparian lakeshore development

Residential development adjacent to lakes is known to have negative effects upon riparian habitat (Jennings et al., 2003) and result in changes to fish community composition (Radomski & Goeman, 2001; Jennings et al., 1999). Among five lakes in northern Wisconsin, several fish species were linked to specific nearshore habitats during spring, summer, and fall, and residential development altered spatial distribution patterns of fishes in Washington lakes (Hatzenbeler et al., 2000; Scheuerell & Schindler, 2004). Human development of lakeshores oftentimes results in clearing of riparian vegetation for lawns and views, addition of sand blankets for swimming beaches, rip-rap for erosion control, destruction of aquatic vegetation, and placement of docks for recreation. An analysis of lakeshore development found that up to half of the shoreline and 14% of the littoral zone habitat in some Minnesota lakes may be lost with full build out on lakes with current shoreland development standards (Radomski et al., 2010).

These activities affect fish communities through a variety of indirect pathways and to different extents. For example, destruction of aquatic vegetation reduces available fish habitat that influences the reproduction, survival, and abundance of some species. Whereas the clearing of riparian vegetation can increase sedimentation, which affects habitat and nutrient inputs that influence ecological processes at the base of the food web. About two-thirds of nearshore emergent and floating-leaf vegetation was lost due to development in a subset of Minnesota lakes (Radomski & Goeman, 2001). Clearing of dead trees from the shoreline can also reduce habitat complexity, which is important for supporting a biologically diverse and resilient aquatic ecosystem. Density of coarse woody habitat, emergent vegetation, and floating vegetation increased as shoreline development decreased among Wisconsin lakes (Christensen et al., 1996; Jennings et al., 2003).

Fish communities are influenced by the cumulative effects of modifications to several components of riparian habitat that occur incrementally over many years, making it difficult to separate the impact of individual components (Jennings et al., 1999). In addition, there is a lag time between the loss of habitat and fish community response that occurs over several generations of fish. Therefore, the status of the current fish community is a reflection of the impact of the collective activities that have resulted in the loss of riparian habitat over several decades.

Attempts to assess the extent of riparian habitat loss have ranged from direct measurements of physical conditions to indirect quantification of human structures that are related to decreases in available habitat. Direct measurements of physical habitat are expensive, require large amounts of time, and have lacked professionally accepted standard protocols. To address some of these limitations, DNR-EWR developed “Score the Shore” survey protocols (Perleberg et al., 2016) in 2013 to assess riparian lake habitat. These protocols have subsequently been adopted for use by DNR Fisheries beginning with the 2015 field season. A review of Score the Shore (StS) surveys completed on lakes within the ULRLW indicate that development of riparian habitat is evident, and could be affecting the fish community in some lakes. Similarly, an inventory of residential docks has been used as a surrogate to measure the impact of human development to riparian areas (Radomski et al., 2010). DNR Fisheries research indicates a dock density greater than 10 docks per kilometer of shoreline results in a noticeable change in fish community; at this breakpoint there is a lower likelihood of sampling sensitive nearshore fish species (DNR; Bacigalupi J., 2016; personal communication). The assessed lakes in the ULRLW had dock densities below where we expect to detect changes in the fish community.

Although quantifying the status of riparian habitat is difficult, some measures have been developed. Based on available data from the ULRLW, the alteration of fish habitat by riparian lakeshore development may be contributing to low FIBI scores and will be discussed further.

Evaluation of stressors for Blackduck Lake (DOW# 04-0069-00)

Excess nutrients and riparian lakeshore development have been identified as likely stressors to aquatic life use in Blackduck Lake (DOW# 04-0069-00) and will be evaluated further. A description of available data and current understanding of levels believed to affect the fish communities will be discussed for each candidate.

Blackduck Lake is 2,686 acres in size and has a maximum depth of 28 feet. The littoral zone of Blackduck Lake covers approximately 50% of the lake area. Blackduck Lake is scored with FIBI Tool 2. The lakes scored with this tool are characterized as generally deep with complex shorelines, less than 80% littoral area, and high species richness.

Biological community

Blackduck Lake was assessed as having insufficient information for an assessment at this time, but very near the impairment threshold and vulnerable to future impairment based on data from multiple nearshore surveys (N = 2; 2013, 2015) and trap net and gill net data from a 2012 survey. Both surveys resulted in FIBI scores (44 using 2013 data, 43 using 2015 data) below the threshold (45) and within the 90% confidence interval (36-54). Due to some sampling issues, the data quality is medium: seining was difficult due to abundant emergent vegetation, trap nets did not fish well due to the shoreline slope and vegetation, and staff did not measure or weigh all individuals in the trap net catches.

The FIBI score is negatively influenced by low species richness for a lake of this size across several metrics (numbers of native, intolerant, insectivorous, cyprinid, small benthic-dwelling, and vegetative-dwelling species), the relatively low proportion of the nearshore catch as intolerant species, and the proportionally low biomass of top carnivores in the gill nets (52%). These top carnivores, Northern Pike (33%) and Walleye (19%), along with insectivorous Freshwater Drum (26%), were the most abundant species by biomass in the gill nets. The low proportion of the gill net catch as top predators is attributable to a relatively high biomass of Freshwater Drum (*Aplodinotus grunniens*), which are known to benefit from the habitat that results from eutrophication (Welch, 1978). Lake Whitefish, a species intolerant of disturbance and sampled in fewer than 200 lakes in Minnesota, were also captured in the gill nets. Northern Pike (51%) and Walleye (17%) were the most abundant by biomass in the trap nets. Nearshore sampling captured 16 and 18 species including four intolerant species (Banded Killifish, Burbot, Iowa Darter, and Rock Bass). Yellow Perch were the most abundant species in the nearshore surveys making up 61% and 80% of the individuals captured in 2013 and 2015 respectively.

Walleye have been present in every fish assessment of Blackduck Lake and are considered a natural part of the lake ecosystem. Supplemental stocking of Walleye fry two out of every three years is ongoing as described in the current Blackduck Lake management plan (DNR, 2016). An evaluation of FIBI Tool 2 has shown stocking density to not be correlated to FIBI score, but there was a statistically significant difference between non-stocked and stocked lakes in metric, with a higher number of tolerant species sampled in non-stocked lakes (DNR; Bacigalupi J., 2016; personal communication). Furthermore, it is especially difficult to relate Walleye stocking to FIBI score because many Tool 2 lakes are, or have been, stocked with Walleye (DNR; Bacigalupi J., 2016; personal communication).

The Walleye stocking rate and frequency have not changed much since stocking was resumed in 1978. Any changes observed in the fish community cannot be directly linked to the stocking of Walleye. Since 1986, the Yellow Perch gill net catch per unit effort (CPUE) has remained fairly stable (about 60 per gill net) aside from 2012 (about 27 per gill net). This decrease in Yellow Perch CPUE could be related to many confounding factors such as an increase in young (two – four year old) Northern Pike CPUE in 2012 or the fluctuating sunfish and Black Crappie CPUE since 2001. Thus, there are too many other fish population changes to be able to definitively state that Walleye stocking is having an effect on the fish community of Blackduck Lake that is substantial enough to be reflected in the FIBI score.

There are several historic surveys in which other species of fish were recorded, although no vouchers were taken, so it is not possible to confirm changes in species assemblage. A survey conducted in 1940 identified 12 species not commonly identified during lake game fish surveys: Banded Killifish, Blacknose Shiner, Bowfin, Burbot, Fathead Minnow, Finescale Dace, Golden Shiner, Hornyhead Chub, Iowa Darter, Johnny Darter, Lake Whitefish, and Spottail Shiner. Of these 12 species, only 6 (2013) and 7 (2015) were sampled during these assessment surveys. Other species that have been infrequently sampled from Blackduck Lake include: Brassy Minnow (last sampled in 1984), Central Mudminnow, Common Shiner, Emerald Shiner (only sampled in 1985), Mimic Shiner (last sampled in 1990), Northern Redbelly Dace, Shorthead Redhorse (only sampled in 2006), Tadpole Madtom, and Weed Shiner (last sampled in 1979). Throughout the history of surveys on Blackduck Lake, DNR Fisheries personnel have identified a total of 36 different species. Some of these species are represented by only one or two occurrences and identification confirmation cannot occur due to the lack of vouchered specimens. This is the first time utilizing the FIBI protocols in the lake assessment process, and as such, we do not have any historical surveys of similar rigor to be able to compare fish species assemblages through time. Although, we hope to be able to make these comparisons in future iterations.

Information about select inconclusive causes

Connectivity

The effects connectivity has on the FIBI score are inconclusive, but it is still important to investigate how it may affect fish community changes in lakes. Connectivity may play a role in the recovery of a lake by limiting species reestablishment where they have been locally extirpated.

Blackduck Lake is the source of the Blackduck River and is about 33.2 river miles from the mouth at Lower Red Lake. On this circuitous route from Blackduck Lake to Lower Red Lake there is a wetland complex, eight road crossings, four private small bridges, many beaver dams, the lake outlet weir and associated cattail fringe in the lake that could act a seasonal impediments, but rarely a barrier, to fish migrating upstream and into the lake. The two biggest connectivity concerns for the area risheries office are the lake outlet structure (Figure 35) and the preponderance of beaver dams. The multiple beaver dams are perceived to be more of an impediment to fish migration than anything else during low flows. Although there may be dams on the inlet streams to Blackduck Lake, the FIBI is not particularly sensitive to fish species that require access to streams for certain life history processes. The FIBI places importance on the smaller bodied nongame fishes, many of which can sustain populations in lakes with or without inlet streams. Furthermore, the FIBI was developed utilizing a statewide data set and may not be sensitive to nuances of lakes with very unique circumstances.

The ability for smaller bodied fishes to traverse the impediments found along the river to inhabit Blackduck Lake is not well known. There is a 7.94-mile stretch of the Blackduck River (between South Cormorant River and North Cormorant River) that is impaired for aquatic life by not meeting the dissolved oxygen standard. This impaired stream stretch and other potential barriers do not apparently impede the travel of larger bodied fishes like Northern Pike, Walleye, and Lake Whitefish. The DNR Fisheries Area has reported aggregations of these species staging below the water level control structure, seasonally, most years. In some years, their numbers have been in the thousands.

This seasonal concentration of fishes at the lake outlet structure indicates that the weir is currently functioning as a seasonal impediment to fish movement. A fish passage structure was created in 2002, and has since degraded to a current condition of limiting fish passage. There are records of Walleye successfully traversing all of the potential barriers to inhabit Blackduck Lake. A water level control structure improvement project incorporating a more permanent fish passage structure is anticipated to be completed in the fall of 2017. The efficacy and longevity of the fish passage structure should be monitored with an emphasis on the potential effects of connectivity for the generally understudied small bodied nongame fishes.

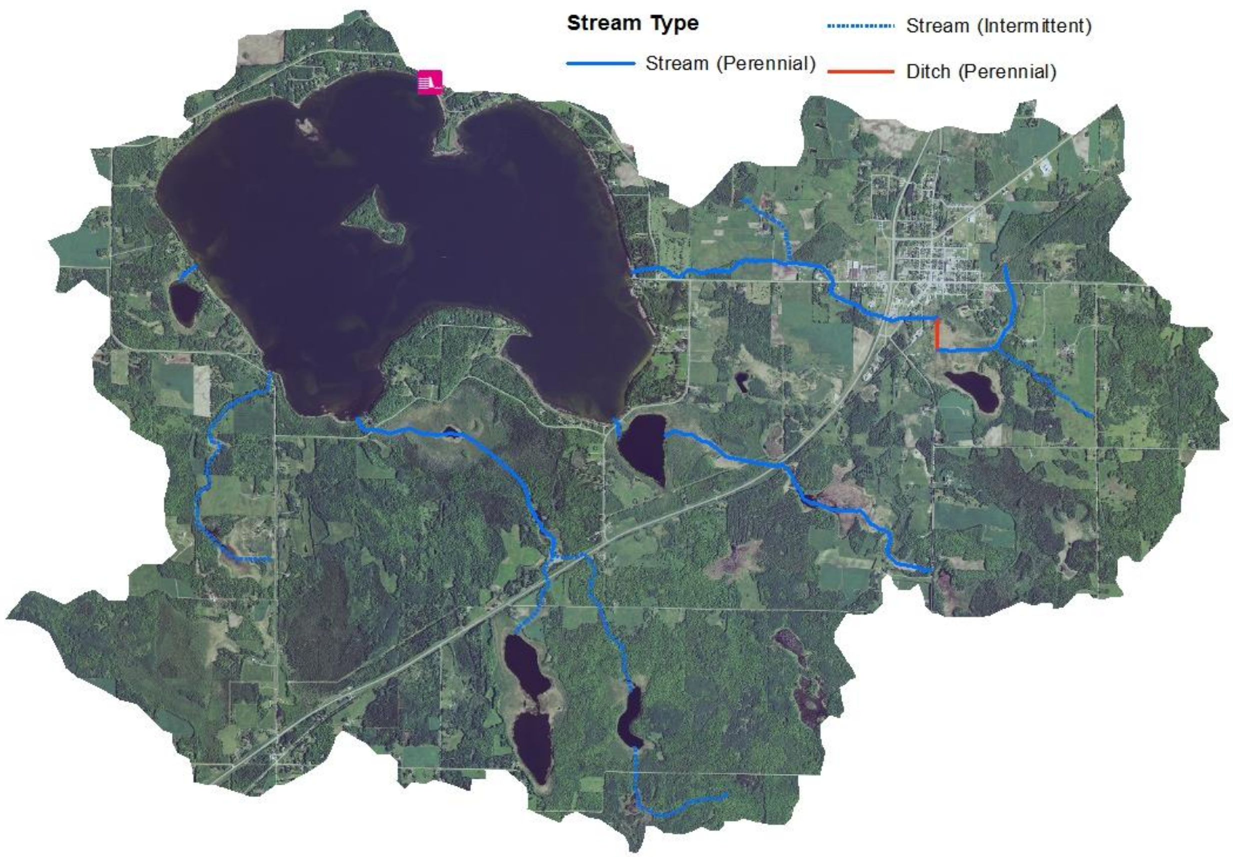

Figure 35. Aerial photograph (FSA 2013) of Blackduck Lake (DOW 04-0069-00) and the contributing watershed. Note the location of the water level control structure on the northern shore.

Blackduck Lake has five inlet creeks, as reported by DNR Fisheries (DNR, 2016). The most recent survey of flow from these inlets was in 1978. Coburn Creek flows near the City of Blackduck and the other four unnamed creek inlets flow from wetland complexes and smaller lakes. The utility of these for game fishes and smaller bodied nongame fishes and the potential effects on FIBI scores are unknown. None of the inlet creeks have been assessed for any use categories.

There is and has been seasonal connectivity between Lower Red Lake and Blackduck Lake, which could allow for recolonization of species in Blackduck Lake. Connectivity is an inconclusive candidate cause of the condition of the fish community of Blackduck Lake.

Aquatic plant management

The removal of aquatic plants, permitted or not, is still an alteration to the habitat of a lake and could affect the fish community. Few APM permits have been issued for the control of aquatic plants on Blackduck Lake. Annually, less than 10 permits are issued, the total permitted area is less than one acre, and the permitted frontage was less than 15% of the combined shoreline owned by these permittees. These levels of permitted aquatic plant control are not likely to be affecting the fish community, but the effects it has on the FIBI score are unknown.

Data analysis/evaluation for each candidate cause

Riparian disturbance

There is development along the shoreline of Blackduck Lake. Currently, there are 184 land parcels adjacent to Blackduck Lake that are not a part of the regional park or other public land. These lots do not have equal shares of shoreline, and some of the longer stretches of undeveloped shoreline are single larger parcels. There are about 97 docks along the shoreline of Blackduck Lake or approximately 5 per km of shoreline (counted from aerial imagery in Google Earth Pro version 7.1.5.1557). The publically owned parcels contain approximately 4.8 km of the entire shoreline, or about 24%.

Minnesota DNR Fisheries IBI program staff conducted an assessment of lakeshore habitat on Blackduck Lake in May 2015, following StS survey protocols. The assessment consisted of 106 survey sites evenly spaced every 200 meters around the lake. Assessments were made in three habitat zones: Shoreline Zone (the shore-water interface to the top of the natural bank), Shoreland Zone (landward from shoreline to development structure or 100 feet), and Aquatic Zone (lake-ward from the shoreline 50 feet). Table 39 depicts the scores calculated from the StS survey efforts. The average lakewide habitat score was 78.0 (± 2.3) out of 100 possible; this is above the average score (73.6) of StS surveyed lakes to date (end of 2016). Approximately 51% of the sites were developed with a mean score of 63.4 (± 3.3), while undeveloped sites had a mean score of 93.9 (± 1.0). During the StS survey, 40% of sites had visible woody habitat and 95% had at least some emergent vegetation in the aquatic zone. These results, along with observations during field surveys and review of aerial imagery, indicate that portions of the shoreline of Blackduck Lake are substantially altered but not at a level where the effects are detectable with the FIBI. Research continues to develop and improve techniques to quantify the impact of riparian disturbance to FIBI scores.

Table 39. Breakdown of how Blackduck Lake (DOW 04-0069-00) scored utilizing the Score the Shore survey separated out by lakewide, undeveloped and developed land use and each of the three zones (Shoreland, Shoreline, Aquatic).

Category	Survey Sites	Shoreland Score (33)	Shoreline Score (33)	Aquatic Score (33)	Mean Score Std Error	Mean Score (100)
Lakewide	**106**	**27.0**	**27.2**	**24.5**	**2.3**	**78.0**

Category	Survey Sites	Shoreland Score (33)	Shoreline Score (33)	Aquatic Score (33)	Mean Score Std Error	Mean Score (100)
Undeveloped Total	**51**	**33.3**	**31.9**	**29.2**	**1.0**	**93.9**
Undeveloped Non-wetland	37	33.3	32.8	30.3	0.9	95.7
Undeveloped Wetland	14	33.3	29.5	26.2	2.3	89.0
Developed Total	**55**	**21.1**	**22.8**	**20.1**	**3.3**	**63.4**
Boat Access	1	5.0	26.7	13.3	0.0	45.0
Campsite	3	29.4	33.3	28.9	1.0	91.7
Multiple Dwelling Development	3	27.8	28.9	15.6	12.8	72.2
Public Park	1	33.3	33.3	16.7	0.0	83.3
Resort or Commercial Campground	8	11.0	11.7	15.0	6.5	37.7
Roadway	6	19.4	29.4	30.0	5.6	76.7
Several Single-Family Residential Lots	9	23.0	18.1	18.9	7.4	60.0
Single-Family Residential	24	22.4	24.0	19.7	5.2	65.1

Fisheries Lake IBI program staff mapped emergent and floating-leaf aquatic plant stands on Blackduck Lake (2686 acres) in September 2015 (Figure 37). Most of the shoreline was bordered with emergent vegetation. Stands with an emergent plant recorded as the primary species covered 331.1 acres (74 stands) while floating-leaf plant stands covered 11.9 acres (9 stands). Mixed stands of emergent and floating-leaf vegetation covered 97.3 acres (9 stands). Bulrush species were the most common and abundant emergent plant stands and included 37 stands that covered 259.2 acres (Table 40). Although emergent mapping indicates that there are vast expanses of emergent vegetation, some are broken up by human made channels. There is a possibility that the vast expanses of emergent vegetation could be buffering the lake from anthropogenic nearshore activity. Conversely, this extensive vegetation could potentially hinder nearshore sampling efforts resulting in lower species richness metrics, and an incomplete representation of the current fish population. Although, further research is needed to better understand both of these scenarios.

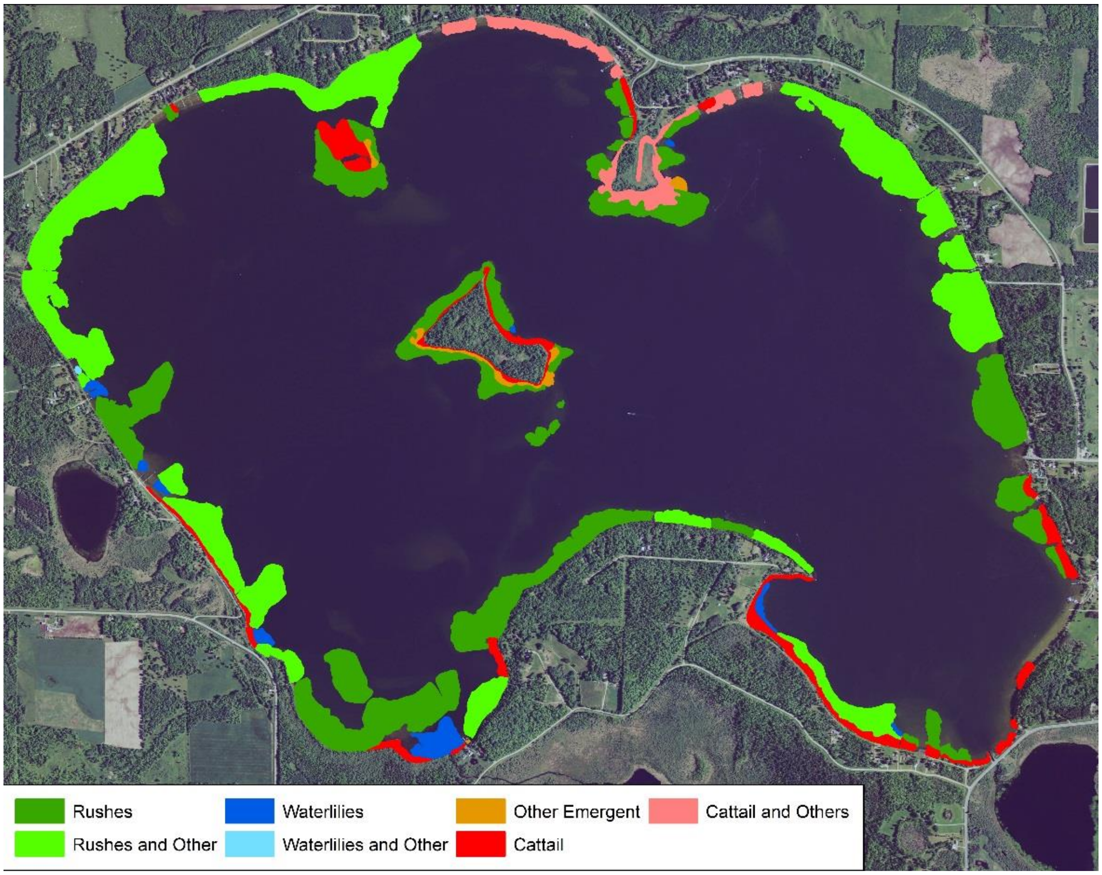

Figure 36. Emergent Vegetation map of Blackduck Lake (DOW 04-0069-00) from 2015 data overlaid on an aerial image of the lake. Source: Minnesota Department of Natural Resources, Floating-leaf and Emergent Vegetation Summary Report, 2015.

The riparian area has been altered by human activities as indicated by the StS results and APM information. However, a large portion of the shoreline has adjacent emergent and floating-leaf vegetation (Table 40). Development has an effect on the riparian habitat of Blackduck Lake; StS scores for developed sites (63.4) are 30 points lower than undeveloped sites (93.9). The lakewide StS score of 78.0 is above the statewide average for lakes surveyed to date. The amount of in-lake habitat permitted to be destroyed has increased in the last few years. The level of permitted destruction of the littoral area is minimal with a range of 0.009% in 2010 to 0.060% in 2015. The effects of riparian habitat alteration on the FIBI score are unknown. Considering this information, shoreline development practices may be a stressor on the fish community of Blackduck Lake but no conclusions can be drawn. Local, county and state shoreland ordinances should be reviewed with a focus on improving water quality and nearshore habitat, specifically focusing on reducing nutrients from entering the lake.

Table 40. Number of stands and area covered (Acres) broken out by stand type and primary species in that stand as determined by the emergent and floating-leaf vegetation mapping efforts.

Stand Type and Primary Species	# of Stands	Total Acres	Mean Acres (1 SE)
Grand Total	**92**	**440.3**	4.8 (+/-0.8)
Emergent	**82**	**428.3**	**5.2 (+/-0.9)**
Cattail	24	39.6	1.7 (+/-0.5)
Cattail and Others	6	23.3	3.9 (+/-1.8)
Other Emergent	6	5.0	0.8 (+/-0.3)
Rushes	29	168.4	5.8 (+/-1.5)

Stand Type and Primary Species	# of Stands	Total Acres	Mean Acres (1 SE)
Rushes and Others	17	192.0	11.3 (+/-2.6)
Floating	**10**	**12.0**	**1.2 (+/-0.6)**
Waterlilies	9	11.9	1.3 (+/-0.7)
Waterlilies and Others	1	0.2	0.2 (+/-0.0)

Excess nutrients

MPCA has developed water quality standards to assess nutrient impairment for lakes using measurements of TP, chlorophyll-a, and transparency. Data for TP and either (or both) of transparency and chlorophyll-a are needed to determine whether a lake meets the standard. Blackduck Lake was assessed as not supporting for Aquatic Recreation due to excess nutrients; the data is presented below.

Previously mentioned, Coburn Creek flows near the city of Blackduck, past a golf course, and likely receives stormwater drainage. It has not been monitored recently, but historically had high TP and low DO as sampled by the MPCA Lake Monitoring Program Project in the late 1970s and early 1980s. It was the conduit for the wastewater treatment facility effluent from 1913 until the current wastewater treatment facility was constructed in 1989. For 76 years, Blackduck Lake was the "final disposal" site after treatment. The legacy effects of this long-term use of Blackduck Lake as the final disposal site for sewage are difficult to quantify. The city of Blackduck was contributing an estimated 42% of the TP load to Blackduck Lake in 1972 (EPA, 1974). Blackduck Lake, an intermittently stratified lake, has periods of thermal stratification throughout the summer resulting in anoxic hypolimnion conditions. Anoxic conditions increase the release of TP from lake sediments (Larsen et al., 1981). The internal P loading can occur in both oxic and anoxic sediments, but substantially more TP is derived from anoxic sediments (James et al., 1995). Although motor boat activity has been shown to release phosphorus bound in the sediments of shallow lakes (Nedohin & Elefsiniotis, 1997), the quantity of motor boat activity is unknown and the polymictic nature of Blackduck Lake results in a situation where the cause and effect cannot be separated out with current data. When weather conditions provide enough wind energy, the lake destratifies, mixes, and brings this nutrient rich water into the epilimnion where it fosters increased algae growth. This cycle may repeat many times throughout the spring, summer, and fall (MPCA, 2009). The TP load in Blackduck Lake is the most likely stressor to the FIBI score.

Another tool to evaluate the potential impact of excess nutrients to fish communities is to summarize the land use within the immediate watershed. Modeling of Minnesota lakes suggests TP 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 & Jacobson, 2013).

Urban and agricultural land use disturbances affect specific lakes differently due to unique non-stressor variables such as watershed area and lake size and depth that help to modify their impact on aquatic communities. Characterizing land use disturbances at the watershed scale are the best predictors of differences in fish and wetland plant communities although smaller scales may be useful to explain specific responses of particular components of these communities (Brazner et al., 2007). Data used to develop the FIBI Tools showed a significant relationship between watershed land use and most FIBI metrics and the FIBI score.

The contributing watershed of Blackduck Lake is 15,548 acres. The ratio of lake size (2,686 acres) to contributing watershed size is roughly 1:6. There are several wetland complexes within the contributing watershed ranging in size from 44 – 429 acres plus many smaller wetlands and those associated with flowing waters. These have the potential of utilizing and binding excess nutrients before they reach Blackduck Lake. An overall GIS quantification of land use types based on the National Land Cover

Database (NLCD) 2011 (Homer et al., 2015) showed 23% of contributing watershed area covered by unnatural land uses (17% cultivated and 6% developed; Figure 37). The rest of the contributing watershed is covered by water or wetlands (36% combined) and forests (41%; Figure 37). Minor changes in land use have occurred since 2001 based on a review of the NLCD coverage. This change is primarily pasture/hay fields being developed due to expansion of development around the city of Blackduck, which is 1.5 miles east of the lake.

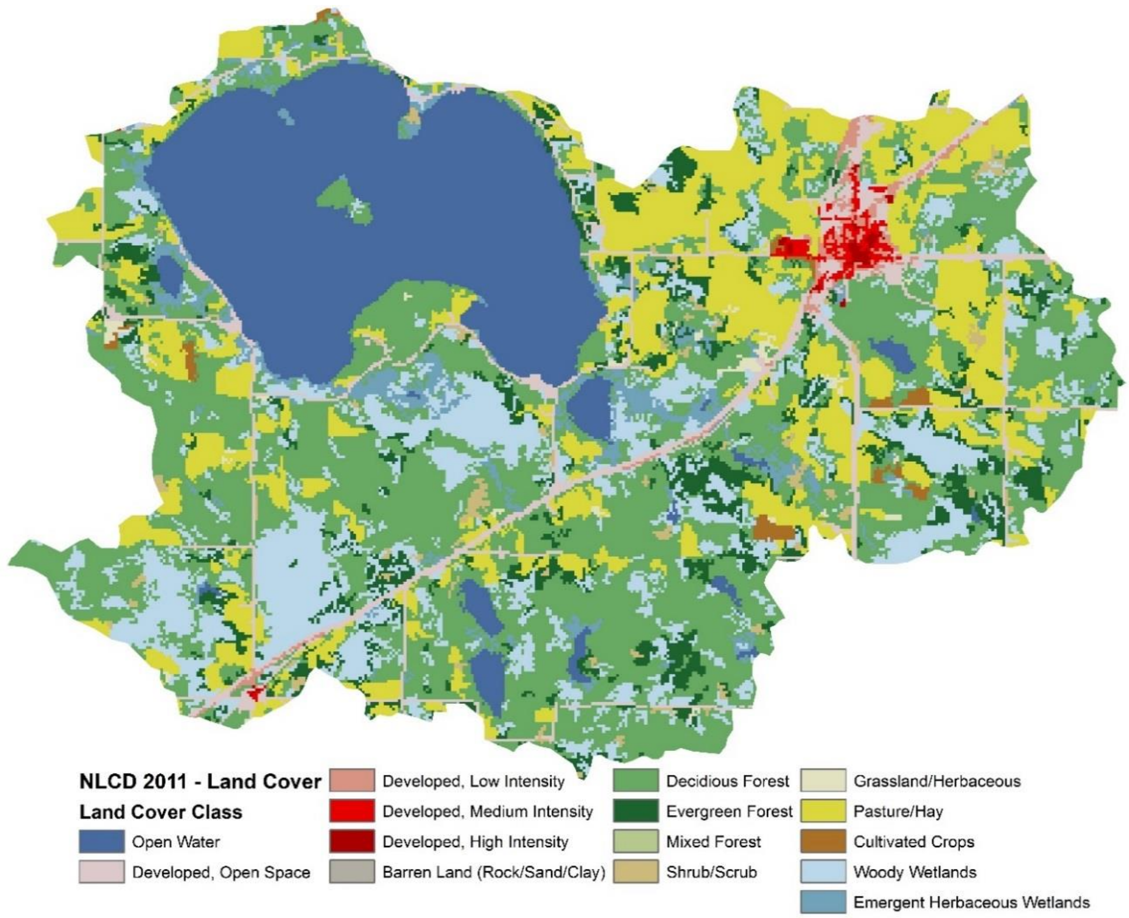

Figure 37. Land use (NLCD 2011) in Blackduck Lake (DOW 04-0069-00) contributing watershed.

Water quality data for Blackduck Lake has been collected by MPCA and other partners since 1975. Average water quality parameters based on the last 10 years of data (2005 – 2014) include: chlorophyll-a level of 24 µg/L, TP level of 0.036 mg/L, secchi disk reading of 2 meters (MPCA, 2015 data, J. Donatell; personal communication). Measurements of TP and chlorophyll-a are exceeding the eutrophication standards; transparency is meeting the standard. From this assessment cycle, Blackduck Lake is proposed to be listed as impaired for Aquatic Recreation – nutrients. This water quality data results in Blackduck Lake being considered eutrophic.

Transparency has been trending higher from 1975 to 2011. The transparency had a significant increase based on 12 years of data within this timeframe. This transparency improvement was credited to improved wastewater treatment by the city of Blackduck (Heiskary, 1997). This may indicate that Blackduck Lake is recovering from over 75 years of wastewater effluent disposal.

Poor water quality is a significant stressor on the fish community. This is concluded because the FIBI score is near the impairment threshold and the water quality is not meeting standards. Only 23% of the land cover in the contributing watershed is classified as disturbed. This amount of disturbance is less than what has been identified to have detectable effects on the FIBI score. The density of docks is below where detectable effects on the FIBI score occur. This information indicates that eutrophication is likely the greatest stressor affecting the fish community of Blackduck Lake resulting in an FIBI score indicating a fish community that is vulnerable to future impairment for Aquatic Life Use.

Conclusions and recommendations

Conclusions

There was only one lake in the ULRLW which had an FIBI score that suggested an impaired fish community (Table 41), but there was insufficient information to list the lake as impaired for Aquatic Life Use. The fish community of Blackduck Lake is vulnerable to future impairment for Aquatic Life Use based on the FIBI. Many potential stressors were considered as affecting the fish community in Blackduck Lake (Table 42). The main stressor that stands out as a major contributor to the condition of the fish community, as measured with the FIBI, is excess nutrients. The percent of the watershed that is a disturbed land class is below levels where effects are detected in the FIBI. The shoreline habitat has undergone some development as described by the StS score and dock counts, but is not at a level where the effects are detectable with the FIBI. The effects of connectivity and water level control on the FIBI are inconclusive.

Table 41. Summary of the lakes that are vulnerable to Aquatic Life Use impairment in the Upper/Lower Red Lake Watershed. The most recent FIBI score is listed last. Score the Shore (StS), a rapid assessment of lakeshore habitat condition with lake-wide scores ranging from 0 – 100. Plant assessment reported as the relation to the threshold determined for plants. Aquatic recreation impairment reported as the lake status as impaired or a candidate for impairment for aquatic recreation.

DOW	Lake Name	FIBI Score(s)	% disturbance in contributing watershed	StS Score	# of docks per km of shoreline	Plant Assessment	Aquatic Recreation Impairment?
04006900	Blackduck	43, 44	23	78.0	5	Above	Yes

Table 42. Summary of stressors determined to be most likely causing Blackduck Lake (DOW 04-0069-00) to be vulnerable to future Aquatic Life Use impairment.

Stressor	Conclusion
% disturbance in watershed	An anthropogenic stressor, but at a level where effects on the FIBI are undetectable
Shoreline habitat	Inconclusive
Excess nutrients – eutrophication	A “root cause” stressor, which causes other consequences that become the direct stressors
Water levels impacting spawning or other habitat	Inconclusive

Recommendations

Efforts to reduce nutrients entering the lake and to determine the within lake dynamics of nutrients should be supported. Future projects that mitigate the presence of excess nutrients in Blackduck Lake will benefit human (Aquatic Recreation Use) and the aquatic ecosystem (Aquatic Life Use) health. Nitrogen was identified as limiting algal production in Blackduck Lake in 1972 (EPA, 1974). Recent research (Schindler et al., 2008) indicates that controlling P should be the focus of management to reduce eutrophication even in apparently N-limited systems. Furthermore, a full response of lake ecology may take decades after external nutrient loads are reduced (Schindler, 2006). Investigations into septic systems and their potential roles in the nutrient dynamics of Blackduck Lake should be considered.

An evaluation of inlet streams to Blackduck Lake should be undertaken to better understand their role in the nutrient dynamics of the lake. If prioritization is needed, focus on the most permanent of these streams and Coborn Creek, as it flows through the city of Blackduck. Walleye and Northern Pike might be able to better propagate if access was improved to inlet streams, but further information regarding the potential for increasing recruitment to the lake population in addition to the potential for increased nutrient loading from better flushing of these inlet creeks is needed prior to recommending wholescale removal of migration barriers.

Projects and policies that restore or enhance riparian lakeshore habitat complexity should be promoted. Lakeshore restoration should include trees, shrubs, and natural ground cover in an attempt to reestablish the habitat complexity around the perimeter of the lake. Lakeshore buffers would also have the added benefit of reducing external nutrient loading and sedimentation associated with riparian development. Removal of woody habitat from the lake should be discouraged because natural woody structures add to the nearshore habitat complexity important to a variety of organisms including fish. Trees that provide habitat for wildlife while living can provide habitat in aquatic environments for a much greater period of time because submerged wood decomposes slowly. Removing dead trees from the water has the effect of reducing overall aquatic habitat in a lake for decades or longer. Efforts, projects and ordinances that focus on protecting, enhancing and/or maintaining the emergent aquatic vegetation should be promoted.

The efficacy and longevity of the fish passage structure should be monitored with a focus on the use by smaller bodied and nongame fish species. Projects that investigate this and the effects on the FIBI should be supported.

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