Leech Lake River Watershed Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities

Minnesota Pollution Control Agency

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Cover photo: Kevin Stroom - Necktie River at CSAH 39 looking upstream.

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Acronyms, abbreviations, and term definitions

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

SID	Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.
Sonde	A deployable, continuous-recording water quality instrument that collects temperature, pH, DO, and conductivity data and stores the values which can be transferred to a computer for analysis
TALU	Tiered Aquatic Life Uses, a new process of setting standards for different categories of streams. MPCA plans to implement this approach around 2015.
Taxa	Plural form - refers to types of organisms; singular is taxon. May refer to any level of the classification hierarchy (species, genus, family, order, etc.). In order to understand the usage, one needs to know the level of biological classification being spoken of. For MPCA fish analyses, taxa/taxon usually refers to the species level, whereas for macroinvertebrates, it usually refers to genus level.
TSS	Total Suspended Solids (i.e. all particulate material in the water column)
TSVS	Total Suspended Volatile Solids (i.e. organic particles)
TP	Total Phosphorus (measurement of all forms of phosphorus combined)
US	Upstream
EPA	United States Environmental Protection Agency
WRAPS	Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.
10X	Ten times (chemistry samples collected on 10 dates)
303(d) list	The official, EPA-accepted list of impaired waters of the state.

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Executive summary

This report documents the efforts that were taken to identify the causes, and to some degree the source(s) of impairments to aquatic biological communities in the Leech Lake River Watershed (LLRW). 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 LLRW is situated mostly within a non-agricultural, forested region of north central Minnesota. Agricultural land usage is primarily in the northwestern part of the watershed. Most of the agriculture is animal rearing, with fields being used for hay. Major portions of the LLRW are within the Leech Lake Reservation, or the Chippewa National Forest. As such, development in much of the watershed is very low density. Another major landscape factor in LLRW is the extensive wetland acreage, much of it being the palustrine type.

Three Assessment Unit Identification (AUID) reaches on three streams were brought into the SID process because they were determined to have impaired biological communities via the 2012, Intensive Watershed Monitoring (IWM) and Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. Upon further investigation of these sites during the SID process, these streams were determined to be stressed by low dissolved oxygen (DO). The Spring Creek and unnamed creek impairments received a CALM categorization of 4D (impairment caused by natural conditions), where the stressor (DO) was determined to be natural. The Necktie River AUID DO impairment is being deferred due to the need for a different DO standard for low gradient, wetland dominated rivers.

- Spring Creek (AUID 07010102-610) - Macroinvertebrates
- Necktie River (AUID 07010102-502) - Fish
- Unnamed Creek (AUID 07010102-612) - Fish and Macroinvertebrates

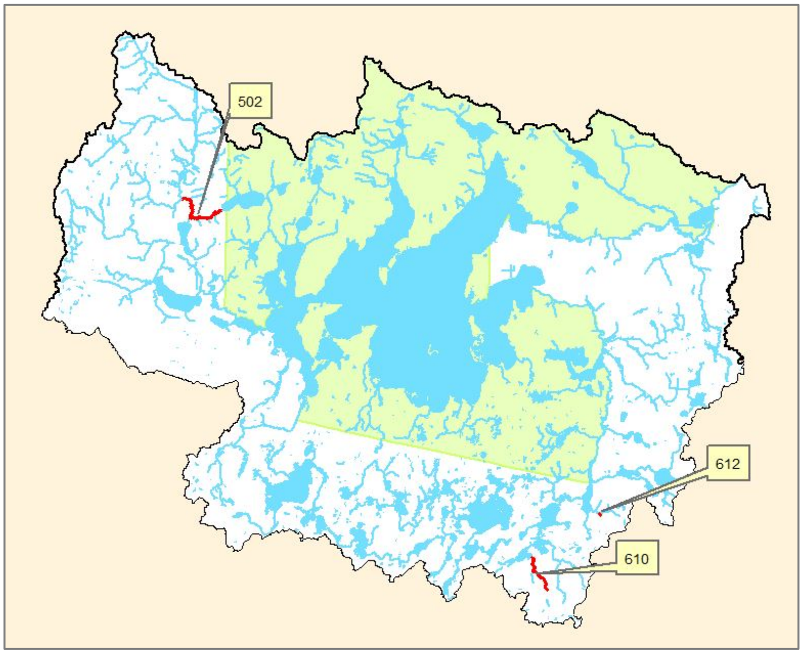

Figure 1. Stream reaches (in red) with Aquatic Life Use impairments. The green-shaded area denotes the Leech Lake Reservation within the Leech Lake Watershed.

Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed the Major Watershed Restoration and Protection Strategy (WRAPS) for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds. A WRAPS is comprised of several types of assessments. The MPCA conducted the Intensive Watershed Monitoring Assessment (IWM) part of the WRAPS during the summers of 2012 and 2013. The IWM assessed the aquatic biology and water chemistry of the LLRW streams and rivers. The Stressor Identification Assessment (SID) builds on the results of the IWM. The MPCA conducted the SID assessment during 2013 - 2015. This document reports on this second step of the multi-part WRAPS for the LLRW.

It is important to recognize that this report is part of a series, and thus not a stand-alone document. Information pertinent to understanding this report can be found in the Leech Lake River 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 LLRW webpage:
https://www.pca.state.mn.us/water/watersheds/leech-lake-river .

Landscape of the LLRW

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

The majority of the Leech Lake River Watershed is relatively flat terrain. As such, the streams and rivers that run throughout the watershed are primarily low gradient. This situation affects many other characteristics of the streams and aquatic biological communities. The streams and rivers flow slowly, and thus accumulate fine grained or organic particulate material as their primary substrate. Slow flows can influence the DO levels in the streams. Low gradient streams can also take on wetland characteristics. A large percentage of river miles within the LLRW have wetland riparian corridors, with either emergent wetland vegetation or palustrine wetlands (sedge meadows). watershed, and the agriculture occurring there is primarily hay and cattle production. The percentages of various categories of land cover are presented in Table 1. Figure 3 shows the extent of land area that is currently Palustrine wetland (16.1% of the LLRW).

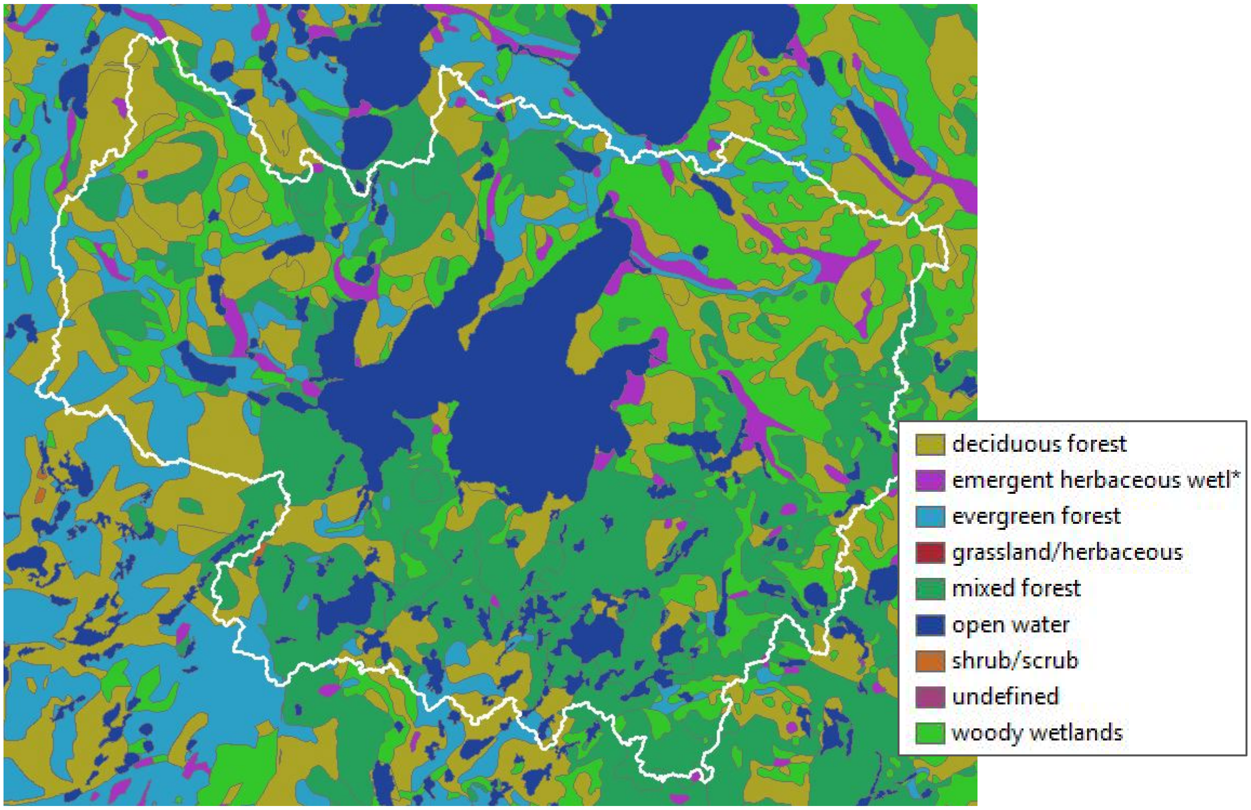

Figure 2. Original vegetation of the LLRW and adjacent watersheds, (Marchner, 1930). The white line is the LLRW boundary.

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

Land cover type	Percent of Land Area
Developed (all intensities grouped)	1.6
Cultivated Crops	0.6
Water, wetlands, and forest lands	93.4

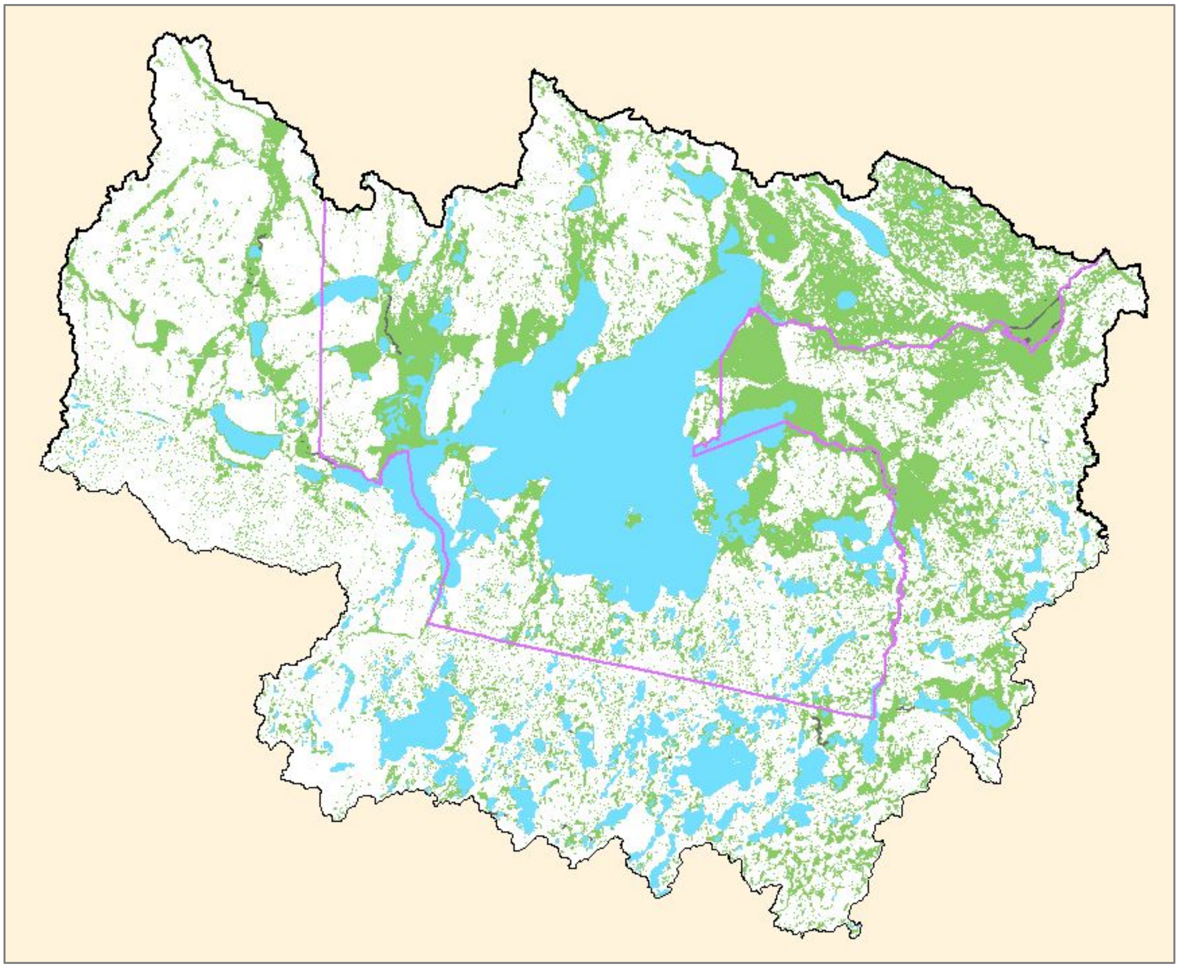

Figure 3. Wetland area as determined by the National Wetland Inventory. Blue is lakes, green is palustrine wetland, and dark blue (very limited) is riverine wetland. The purple line delineates the Leech Lake Reservation.

Determination of candidate stressors

The process

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

In conjunction with the anthropological and geographical data, actual water quality, habitat, and biological data were analyzed to make further conclusions about the likelihood of certain stressors impacting the biological communities. Water chemistry and flow volume data has been collected within the LLRW for many years. The determination of candidate stressors used both the historical data and data collected during the 2012, 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.

MDNR Watershed Health Assessment Framework

MDNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The WHAF includes an assessment of the nonpoint source pollution threat to water quality within the water quality component. The data shows non-point pollution, relative to other parts of the state, is not a widespread stressor in the LLRW Figure 4. According to the Non-point Source Pollution Index, the LLRW ranks as tied for 10th out of the 80 watersheds in Minnesota (where 1st is best, or has least threat). This equates to the 87.2 percentile. A major urban source of non-point pollution is runoff from impervious surfaces. Due to the small sizes of the cities/towns in the LLRW, this threat is very low (Figure 5). One can see from this figure that the poorer-scoring catchments are few and tend to be in the southern part of the LLRW. 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. Streams and rivers in the LLRW generally don’t have anywhere near the degree of shoreline development as area lakes, and thus this threat is particular to lakes. Neither of the two stream impairments has a town located near the stream channel.

The Localized Pollutant Source Index in the WHAF captures possible impact from point source and similar types of pollution sources, including pollutant contributions from animal husbandry, hazardous waste and superfund sites, wastewater treatment effluent, mining, and septic systems. Point source pollution is also not a significant source of stream stressors due to the very low numbers of point source dischargers. The WHAF map for the Localized Pollutant Source Index showed that all of the subwatersheds are among the green scale colors (in the good range) except for one small subwatershed containing the town of Hackensack. The index score for the LLRW was 92 out of 100. There are only three municipal wastewater dischargers, and these discharge to larger river reaches (e.g., the Longville WWTP discharges to the Boy River, and the Federal Dam and Army Corps Recreation Area discharge to the Leech Lake River), so smaller streams are not affected by point source effluent. There are some specific locations that have relatively high septic system densities per the WHAF tool output (Figure 6); however, these locations, mostly in the southern part of the watershed, coincide with locations having high lake densities and are likely septic systems from lakeshore properties (and thus not affecting streams). Additional statistics for several stressors are presented in Table 2.

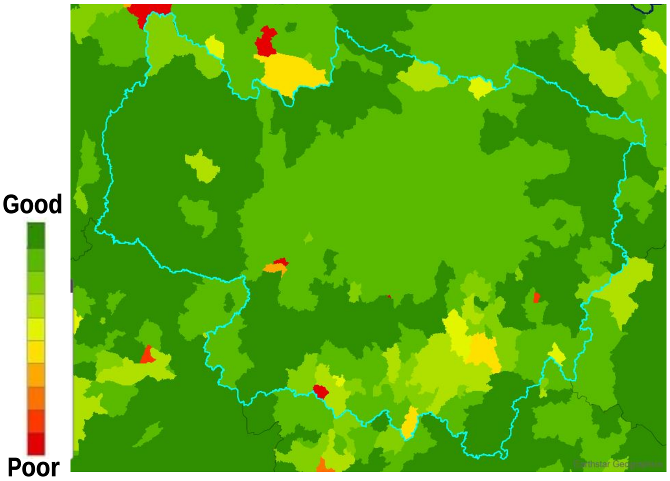

Figure 4. Catchment-scale impervious surface scores for the LRW (blue boundary) and surrounding catchments

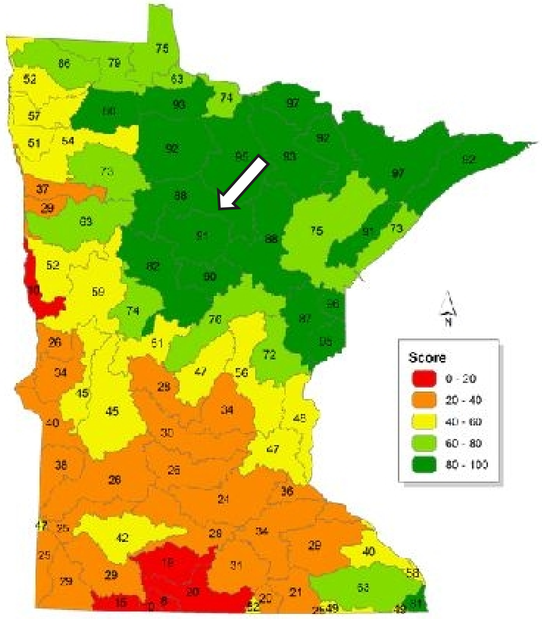

Figure 5. Scores and categorical ranking of the 80 Minnesota Major Watersheds for the DNR Non-point Source Pollution Index

The overall WHAF scorecard, which includes many more metrics, can be found at: http://files.dnr.state.mn.us/natural_resources/water/watersheds/tool/watersheds/scorews_all.pdf.

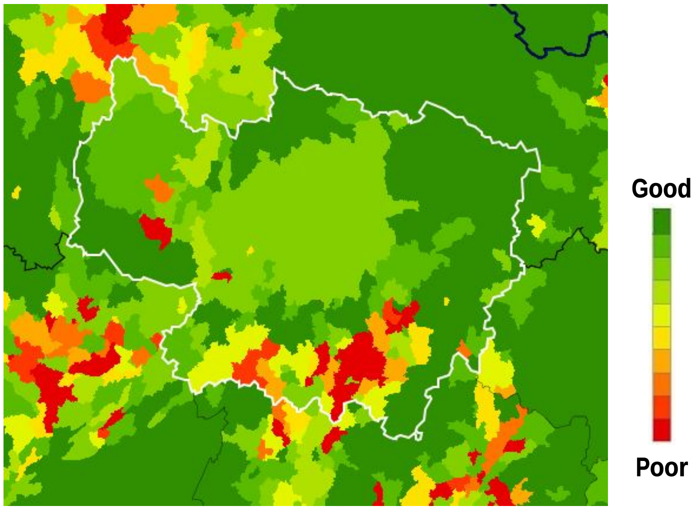

Figure 6. The WHAF Septic metric within the Nonpoint Source Index for the LLRW.

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

	Impervious Surface (2011)	Nonpoint Threat	Point Sources	Water Storage Loss	Perennial Cover	Phosphorus Risk	Aquatic Connectivity
Rank	21 (t)	11 (t)	33 (t)	16	10 (t)	13 (t)	19

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

Non-IWM MPCA monitoring programs

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

Desktop review

Urbanization /development/population density

Census data provides a way to look at human-induced stress or pressure on the water resources of a region. Stressor sources that are related to population density include: wastewater effluent, impervious surface areas, and stormwater runoff, which all increase with population density. According to the 2010 census data, the LLRW is quite sparsely populated relative to the state as a whole. A majority of the LLRW is located in Cass County, and the remainder in Hubbard County (with a very small piece in Beltrami County). Though relatively sparsely-populated relative to some parts of Minnesota, recent population trends show both of these two primary counties have experienced substantial population growth from 1990 - 2010 US Census data (MSDC, 2015). This likely means stress to the LLRW's waterbodies has and may continue to increase.

A relatively small number of towns are within the LLRW; with the exception of Walker (pop. 941), all are small communities. Other towns include Laporte (111), part of Akeley (432), Hackensack (313), Longville (156), Boy River (47), Federal Dam (110), and Bena (116) - population data from the 2010 US Federal Census. None of these towns are large enough to require an MS4 stormwater plan. Recent GIS-derived land use statistics showed that 1.8% of the watershed area is categorized as Residential/Commercial (MPCA, 2016). The LLRW rank tied for 21st (at the 71.2 percentile) with three other of the state's 80 watersheds for the amount of impervious cover. Despite this rank, there is actually relatively little impervious cover. There are numerous watersheds in Minnesota that have relatively small amounts of impervious surface, which explains the modestly above average percentile ranking of the LLRW for impervious cover. The census and urbanization information suggests that most stressors related to population density are likely only active at highly-localized areas (e.g., lakeshore development acting on a particular lake), if at all.

One potential source of water resource stressors in rural areas is subsurface sewage treatment systems (SSTS). Unsewered areas can have old septic systems that are either failing or not conforming to current design standards. Most rural homes/cabins in the LLRW are not connected to a municipal sewer system, and thus have individual treatment systems. Rural areas also have residences that discharge wastes directly to streams, though this is unlawful, and the numbers are declining. These systems can contribute significant levels of nutrients and other chemicals to water bodies. Recent septic system statistics for Cass County estimate 1% of the individual treatment systems to be "Imminent Public Health Threats" (i.e., direct discharge to stream), 9% "Failing", and 90% of systems in compliance (MPCA 2012).

These statistics are quite good relative to many of Minnesota's counties. Hubbard County statistics were not published. Given that a majority of these systems are on lakeshore properties, failing septic systems should not be a significant contributor to water quality problems in LLRW streams.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The LLRW has relatively little industry and there are zero industrial wastewater NPDES permits and three industrial stormwater permits within the LLRW. Thus, industrial discharges should not be a source of pollutants (stressors) causing stream impairment in the LLRW.

Forestry

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

Agricultural activities

The lands of the LLRW, as with those in much of north-central Minnesota, are not extensively used for row crop agricultural production. The area of the LLRW that has more than just sparse field agriculture is predominantly the Hubbard County portion of the LLRW (i.e., the northwestern part of the watershed). This is also the part of the watershed where pastures are located (Figure 7). The review of the LLRW's land use, shown previously (Table 1) indicates that approximately 0.6% of the land cover is in cultivated crops. It is reasonable to consider whether agricultural activities might be a possible contributor to water quality problems in the northwestern part of the watershed, though their contribution would be expected to be much less than in more southern and western parts of Minnesota. A large quantity of professional research exists with study results associating landscape changes from natural to agricultural land uses with water quality degradation and/or negative affects to biological communities (e.g., Fitzpatrick et al., 2001; Houghton and Holzenthal 2010; Diana et al., 2006; Sharpley et al., 2003, Blann et al., 2011, Riseng et al., 2011). Known agriculture-related stressors include nutrients, sediment, and altered hydrology.

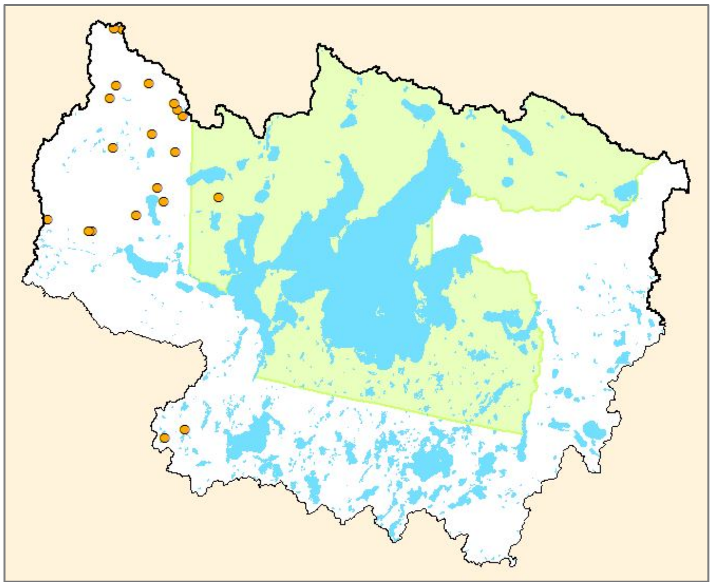

Figure 7. **Registered feedlot locations (≥ 50 animal units) in the LLRW.**

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

Pesticides

Pesticides as stressors were not given consideration in the few locations studied in this report, due to the prevailing non-agricultural land use patterns at those locations. Pesticide testing is very expensive, and monitoring for pesticides is difficult as applications are spotty, and occur irregularly. The Minnesota Department of Agriculture (MDA) conducts Minnesota pesticide monitoring, and no sampling has been done in the streams discussed below. More information about pesticide occurrence in Minnesota's environment continues to be gathered via Minnesota's statewide pesticide sampling program and results are available from the MDA at http://www.mda.state.mn.us/monitoring.

Summary of candidate stressor review

Based on the review of human activity in the LLRW in general, and then specifically in the two locations with biological impairment, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the LLRW, 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

  - Ammonia
  - Nitrate as nutrient
  - Nitrate as a toxicant

Inconclusive causes

- Forest management stressors - historical/legacy effects are difficult to determine. Impaired subwatersheds have had some recent current forest harvest, though understanding and quantifying the effects of forest harvest, and threshold levels for stress to occur to streams is not well known. There are current efforts underway or planned to better understand the effects of forest harvest impacts on streams.

Candidate causes

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

Mechanisms of candidate stressors and applicable standards

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

Dissolved oxygen

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

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

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

Minnesota DO standards

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

Types of dissolved oxygen data

1. Point measurements
   Instantaneous (one moment in time) DO data has been collected at numerous locations in the LLRW and used as an initial screening for low DO reaches. Because DO concentrations can vary significantly with changes in flow conditions and time of sampling, conclusions using instantaneous measurements need to be made with caution.
2. Longitudinal (Synoptic)
   This sampling method involves collecting simultaneous (or nearly so) readings of DO from several locations along a significant length of the stream path. It is best to perform this sampling in the early morning in order to capture the daily minimum DO readings.
3. Diurnal (Continuous)
   Short interval, long time period sampling using deployed YSIä water quality sondes (a submerged electronic sampling devise) provides a large number of measurements to reveal the magnitude and pattern of diurnal DO flux at a site. This sampling captures the daily minimum DO concentration, and when deployed during the peak summer water temperature period, also allows an assessment of the annual low DO levels in a stream system.

Altered hydrology

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

Reduced flow

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

Increased flow

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

Water quality standards

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

Types of flow alteration data

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

Increased sediment (suspended and deposited)

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

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

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

Deposited sediment
Whereas suspended sediment is a stressor operating in the water column, sediment is also deposited onto the stream bottom, and thus can have different effects on organisms oriented to living on or within the streambed substrate (this includes many of the macroinvertebrate taxa). Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refuge, and/or reproduction (Newcombe et al., 1991). Excessive deposition of fine sediment can degrade macroinvertebrate habitat quality, reducing productivity and altering the community composition (Rabeni et al., 2005, Burdon et al., 2013). Aquatic macroinvertebrates are affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance behavior, using current to seek a new suitable location) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and

other prey items (Pekarsky 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman, 1988); and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985; Gray and Ward, 1982). Fish species that are simple lithophilic spawners require clean, coarse substrate for reproduction. These fish do not construct nests for depositing eggs, but rather broadcast them over the substrate. Eggs often find their way into interstitial spaces among gravel and other coarse particles in the stream bed. Increased sedimentation can reduce reproductive success for simple lithophilic spawning fish, as eggs become smothered by sediment and become oxygen deprived.

Water quality standards

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

Types of sediment data

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

Elevated nutrients (phosphorus)

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

Water quality standards

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

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

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

Types of phosphorus data

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

Elevated nutrients (nitrate nitrogen)

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

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

Water quality standards

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

Ecoregion information

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

Types of nitrate data

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

Candidate cause: Physical habitat loss

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

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

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

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

Water quality standards

There are no state water quality standards for physical habitat.

Types of physical habitat data

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

Candidate cause: Elevated stream temperature

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

Water quality standards

The standard for Class 2B (warmwater) waters of the state is not to exceed 5 degrees Fahrenheit above natural, based on a monthly average of maximum daily temperature. The maximum allowable average is 86 degrees Fahrenheit (30 degrees Celsius).

Types of temperature data

Only point (instantaneous) temperature data has been collected in the LLRW.

Candidate cause: Ammonia (NH_3)

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

Water quality standards

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

Types of ammonia data

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

Candidate cause: Connectivity

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

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

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

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

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

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

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

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

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

Water quality standards

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

Types of physical connectivity data

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

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 Tolerance Indicator Values for many water quality parameters and habitat features for species of fish, and genera of macroinvertebrates. This is a take-off on the well-known work of Hilsenhoff (1987, EPA, 2006). For each parameter, a relative score is given to each taxon regarding its sensitivity to that particular parameter by calculating the weighted average of a particular parameter's values collected during the biological sampling for all sampling visits in the MPCA biological monitoring database. Using those scores, a weighted average community score (a community index) can be calculated for each sample. Using logistical regression, the biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites to date. Such probabilities are only available for parameters that have developed standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

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

Analysis of chemical data

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

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.

Necktie River (AUID 07010102-502)

Impairment: The river was initially being considered as impaired for not meeting fish community expectations at station 12UM088. The river is non-wadeable, which prevented sampling for macroinvertebrates. Subsequent discussion determined that the fish community should not be assessed at this time, due to MPCA not having an appropriate FIBI for low gradient streams with drainage areas larger than 50 square miles. This stream type also is being deferred for DO assessment. Stressor ID work was conducted in the intervening period between these decisions, and is presented here to record the findings as a means to better understand the characteristics and functioning of streams in the LLRW and adjacent watersheds.

Data and analyses

Chemistry

The results of water chemistry monitoring at 12UM088 from the IWM fish sample visit are shown in Table 4. TP in AUID-502 was elevated relative to the region's river nutrient standard of 0.050 mg/L. Nitrate was low, as is common for LLRW streams, and ammonia and unionized ammonia were at non-problematic levels also. This site was also a 2012 10X chemistry site, and data has also been collected here in 2010-2011 by the Cass County Citizen Monitoring program. These two data sets' measurements are averaged and presented in Table 5. Average values of all parameters listed were quite low, with the exception of TP. The average TP concentration is above this region's river nutrient standard.

The chemistry data shows that numerous DO measurements were below the DO standard (Figure 8), and the regression line shows that DO concentrations go below the standard from about early July through late September. The TP concentration was often above the standard of 0.050 mg/L for this region (Figures 8 and 9). Oxygen levels control the solubility of phosphorus, with lower levels of DO resulting in greater phosphorus solubility. At higher oxygen levels, phosphorus adsorbs to iron found commonly in soil. The levels of DO and TP are quite inversely related (Figure 8). Conversely, un-natural levels of phosphorus (from human activities) can cause periods of low DO via the process of eutrophication. In this second case, large amounts of either filamentous or water-column algae would be present. However, abundant algae were never observed during the many visits the author made to the river. The water was always very clear, and aquatic plants were very clean of attached filamentous algae. It is also of note that the TP levels in 2015, were lower in summer than were levels in other recent years (Figure 9). The lower TP levels were probably related to the overall dry spring, summer, and early fall in 2015. This dry condition would have resulted in less stream flow volume being contributed from wetlands, and thus less soluble phosphorus leaching from wetland soils into the river.

Table 4. Water chemistry measurements collected at 12UM088 during the 2012 IWM. Values in mg/L.

Date	Time	Water Temp.	DO	TP	Nitrate	Ammonia	Un-ionized Ammonia	pH	TSS	TSVS
Aug. 29, 2012	14:43	23.6	3.09	0.086	0.20	0.10	0.001	7.17	< 4	< 4

Table 5. Chemistry measurements at S006-256 (12UM088) from 2010-2012. Values in mg/L.

	# Samples	Average	High	Low
Nitrate	30	< 0.03	0.03	< 0.03*
Ammonia	10	0.0451	0.091	< 0.04*
Total Phosphorus	30	0.068	0.174	0.030
TSS	38	< 5.2	26	1

* These values are below the lab detection limit.

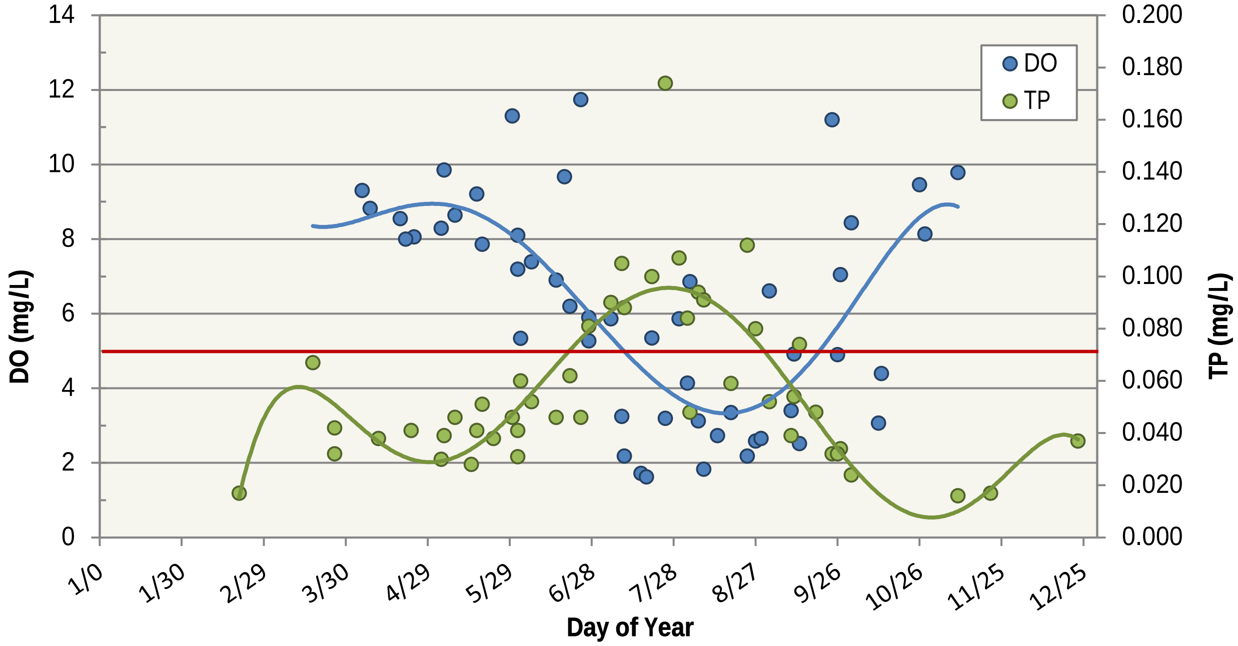

Figure 8. Historical, 10X, and SID project DO and TP data for site S006-256, 2010-2012 and 2015. The blue line is a 5th order polynomial regression line for DO, having an R^2 value of 0.5259. The green line is a 6th order polynomial regression line for TP, with an R^2 value of 0.6624. The red line is the DO standard.

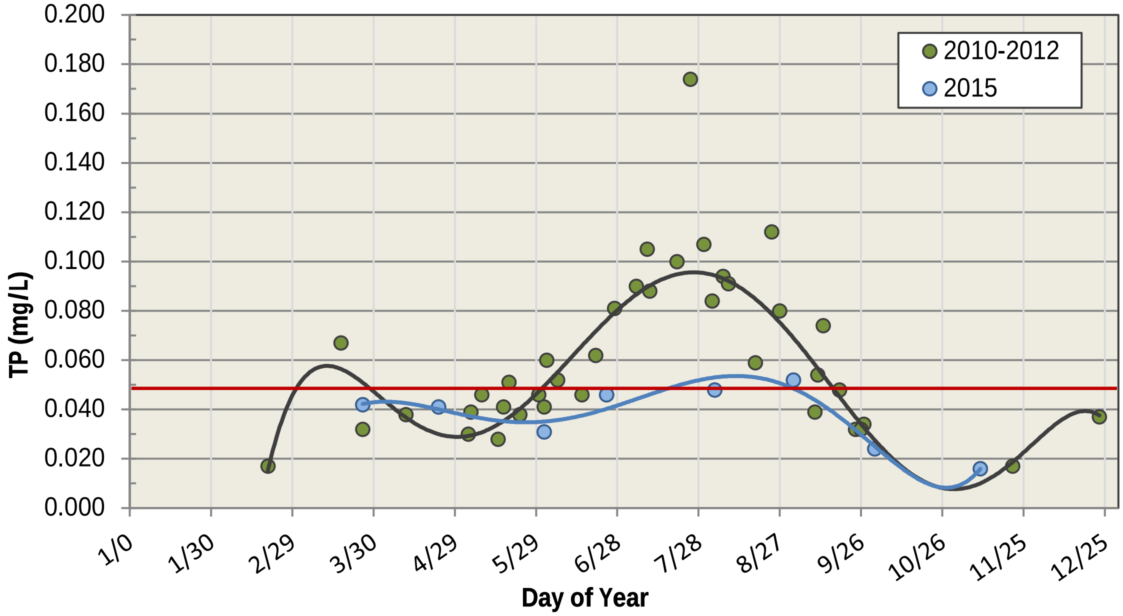

Figure 9. Historical, 10X, and SID project TP data for site S006-256, 2010-2012 (and one 2016 spring sample) and 2015. The blue line is a 6th order polynomial regression line of only 2015 data, having an R^2 value of 0.9196. The black line is a 6th order polynomial regression line of all data, having an R^2 value of 0.6624. The red line is the TP threshold for this region's river nutrient standard.

Temperature

The Necktie River at this location is a warmwater stream (it is coldwater further upstream). Water temperature at S006-256 peaks during late June/early July (Figure 10). Warmwater fishes experience temperature stress when temperatures are at about 30°C (86°F) for extended periods of time per Minnesota's water temperature standard. Water temperature is not a stressor to fish in AUID-502.

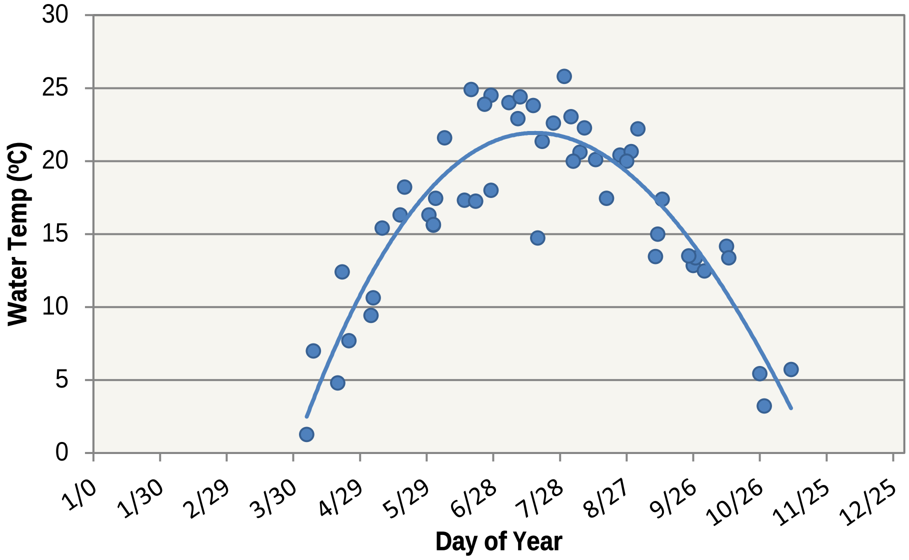

Figure 10. Water temperature readings at S006-256 during 2010-2012 and 2015. The curved line is a 3rd order polynomial regression line with an R^2 of 0.8245.

Habitat

The MSHA protocol was not conducted at 12UM088 due to its non-wadeable character. The substrate is sand in the center of the channel, and detritus in the lateral parts of the channel. Macrophytes are very abundant, but not choking the water column. Fish have good amounts of cover. Large woody material appears to be minimal, likely due to the wide, wetland corridor the river flows through. Trees do not grow close enough to the channel to fall into the river. There is no evidence that habitat degradation has occurred here, and loss of habitat is not a stressor.

Geomorphology

No geomorphology fieldwork was done on AUID-501 due to its non-wadeable channel. Observations by the author have consistently found excellent water clarity, one factor suggesting erosion and bank instability are not problems happening here. A very isolated patch of bank erosion is occurring on one side of the river where cattle access the river to drink. No signs of unusual sediment movement or deposition were seen by observing the stream channel from the CSAH-45 crossing nor the slightly farther upstream crossing of CSAH-39. The low gradient nature of the channel and its wetland periphery make this channel quite protected against instability. Channel instability and its accompanying sediment and habitat loss problems are not occurring in AUID-502.

Hydrology

Field and aerial photography observations do not reveal significant amounts of landscape alterations (forest removal, row crop agriculture, land drainage systems) that would suggest hydrological alteration to the river's flow patterns are occurring. The observations of the healthy channel geomorphology affirm this conclusion.

Connectivity

There are two road crossings downstream of the sample reach on AUID-502, at CSAH-45 and CSAH-39. Both are bridges and are not impeding fish migration from downstream. There are no road crossings upstream between the sample reach and Hart Lake. Upstream of Hart Lake is another bridge at CSAH-16, which again fully allows fish passage. Fish can readily move between the river and an upstream and downstream lake. Thus, connectivity restrictions are not causing any problems for the fish community in AUID-502.

Biological response

Fish

The fish community collected at 12UM088 was dominated by yellow perch. Smaller numbers of seven other species were also collected. No small riverine species, such as shiners, minnows, dace, or darter species were collected, some or all of which commonly inhabit streams in the Upper Mississippi Basin. The sampled community is quite tolerant of low DO based on the low score and percentile of the Community DO Index for Class 5 streams (Table 6). Other individual metrics show the community as very skewed to low-DO tolerant species (Table 7). The absence of the small riverine species is unexplained, because as a group, they wouldn't be classified as intolerant to low DO. The community is quite intolerant of high TSS conditions based on the low (good) score and high percentile for the TSS Index (Table 6). The probability of the sampled fish community coming from a reach with DO meeting the standard is low, while the probability of coming from a reach with meeting its TSS standard is high. This information confirms that low DO is the likely reason for the substandard fish community in AUID-502.

Table 6. Fish Community Tolerance Index scores at 12UM088 for DO and TSS. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within Fish Class 5 streams. "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 June 2016 version of this tool was used.

Stream Class	DO TIV Index	Class avg./median	Percentile	Prob. as %	TSS TIV Index	Class avg./median	Percentile	Prob.
5	6.44	6.97/7.09	14	24.8	11.53	13.99/13.06	83	87.4

Table 7. Fish metrics related to dissolved oxygen. Metric values are calculated from the May 2016 version of MPCA's fish data set.

# Low-DO Intolerant Taxa	% Low-DO Intolerant Individuals	# Low-DO Tolerant Taxa	% Low-DO Tolerant Individuals	# Low-DO Very Tolerant Taxa	% Low-DO Very Tolerant Taxa
0	0	6	86.7	3	14.3

Upstream influences on phosphorus levels in AUID-502

Landscape sources

Low DO problems often are caused by excess nutrients (particularly phosphorus), and TP has been shown to be above the North Region River Nutrient Standard in AUID-502, so it was prudent to investigate conditions in the Necktie River subwatershed above 12UM088 (Figure 11 and 12), exploring possible phosphorus sources to AUID-502.

Land use in the watershed contributing to site 12UM088 is a mix of forest, wetlands, and agriculture. Though small amounts of row crops are grown in this area, the predominant agricultural endeavors are raising cattle. As such, there are many pastures and hay fields on the landscape. The author tried to quantify pastured area via review of publically-available high resolution aerial photography and delineation of these areas via a GIS. A map of the results is shown in Figure 10. Generally, the pastures were set back a good distance from the Necktie River as well as the two main tributaries Bungashing and Pokety Creeks.

As mentioned above, wetlands are a significant landscape feature in the watershed contributing to 12UM088. These are predominantly riparian wetlands, and are prominent along the whole length of the

Necktie River, as well as the tributary Bungashing Creek (Figure 11). These wetlands are areas with peat soils which are often saturated with groundwater and are too wet to grow trees. Peat soils are known to be sources of phosphorus, being produced from the breakdown of these organic soils (Banaszuk et al., 2005, Dillon and Molot, 1997, Dupas et al., 2015). This phosphorus can then be transported to the stream as the groundwater moves to the stream channel. Because these riparian wetlands are extensive, and are more intimately connected to the Necktie River and its tributaries, it is likely that much of the phosphorus measured in the Necktie River, Bungashing Creek, and Pokety Creek is coming from these riparian wetlands. Cattle agriculture likely also contributes some phosphorus. The relative quantities from these two sources are not known. Data from Bungashing and Pokety Creeks are presented in separate sections of this report.

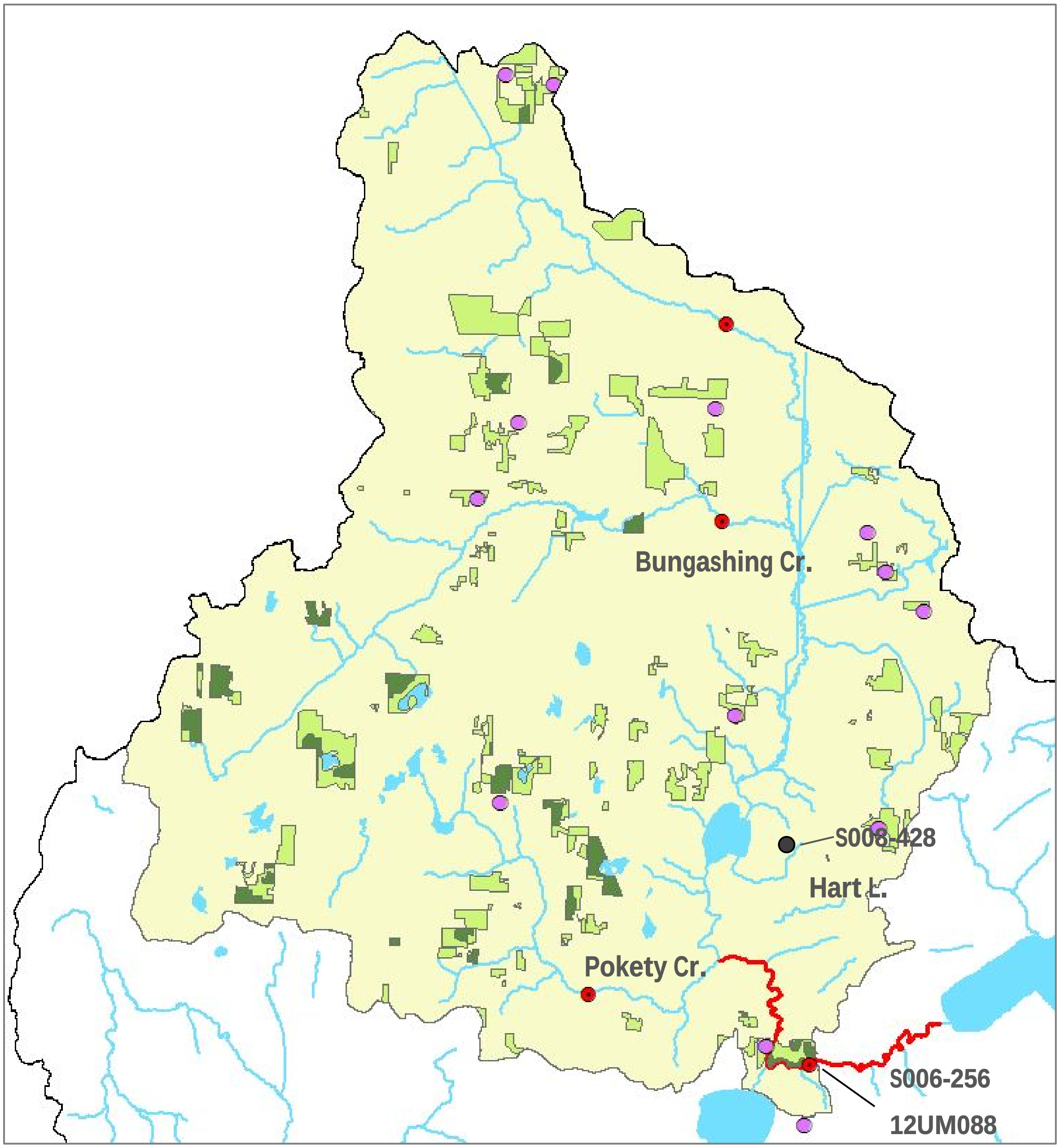

Figure 11. Map of the Necktie River subwatershed contributing to the water flow at S006-256 (biological station 12UM088). Light green represents pastured acreage, dark green represents forested pasture, purple dots are registered feedlots (≥ 50 animal units), and the red dots are biological sampling locations. The red line is AUID-502, the lower Necktie River.

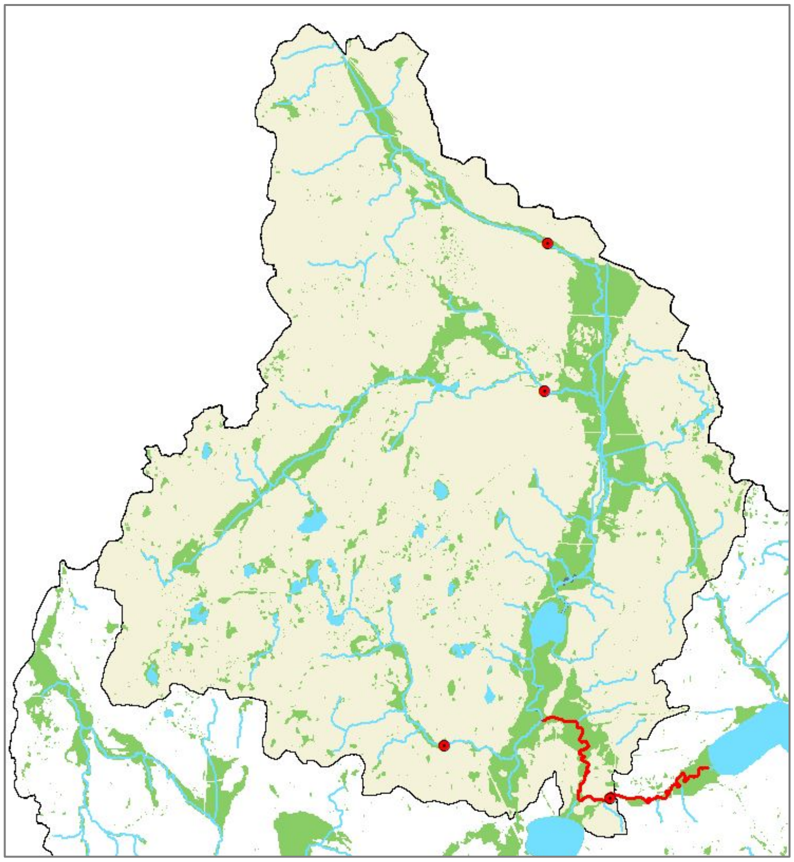

Figure 12. Map of the Necktie River subwatershed contributing to the water flow at S006-256 (biological station 12UM088). The green area is palustrine wetland from the National Wetland Inventory dataset.

Hart Lake

The Necktie River flows into and out of Hart Lake, with Hart Lake located at the upstream end of AUID-502. The lake has been assessed as not meeting recreational standards for phosphorus. The assessment deliberations on AUID-502 questioned how Hart Lake might be influencing AUID-502. In order to provide some insight into this question, the author began collecting TP samples from the Necktie River just upstream from where it enters Hart Lake CSAH 16 (S008-428), and simultaneous samples from AUID-502 (downstream of Hart Lake) at CSAH 45 (S006-256, 12UM088). Results are presented in Figure 13. As the graph shows, with the exception of early springtime (during snowmelt and the spring rainy period), when TP concentrations are nearly identical above and below Hart Lake, the TP concentration in the Necktie River is significantly lower downstream of Hart Lake, in AUID-502, suggesting Hart Lake is not negatively influencing AUID-502.

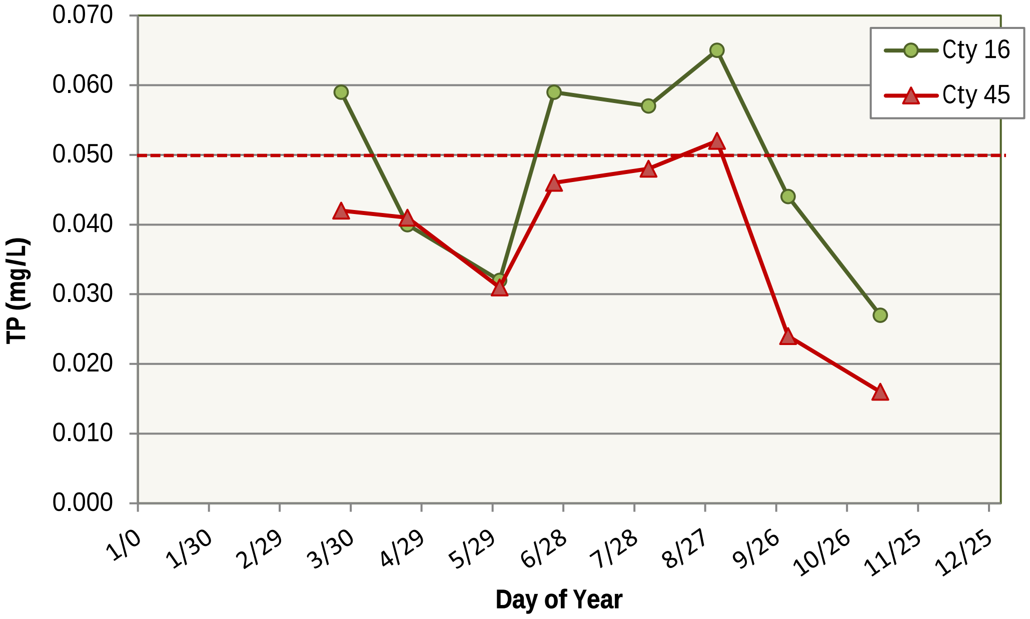

Figure 13. Total Phosphorus levels above and below Hart Lake in 2015-2016. The red dashed line is the region's river nutrient standard for TP.

Upstream tributaries

Two tributaries, Bungashing and Pokety Creeks, enter the Necktie River in the adjacent upstream AUID-503. Bungashing Cr. is upstream of Hart Lake, while Pokety enters the Necktie R. between Hart Lake and biological site 12UM088 (Figure 11). Both creeks are designated trout streams, which typically have fine water quality. The IWM monitoring result showed each of these smaller streams to have unexpectedly high TP concentrations. Thus, further sampling was conducted as part of the SID process.

Bungashing Creek

Additional water chemistry monitoring was done at the biological sampling location (S008-427, 12UM096) in 2015-2016 for TP (Figure 14). It should be noted that Bungashing Creek was assessed as meeting the exceptional use criterion, and thus is in outstanding health. The high TP value of 0.183 collected in 2012 was much higher than any of the samples from 2015-2016, though a number of samples did exceed the North Region River Nutrient standard of 0.050 mg/L, particularly in the pre-July period. It should be noted that sampling from other streams in this general area also seemed to have lower TP levels in 2015, than in previous years (as mentioned above for the Necktie River - AUID-502), possibly because the water table was lower in 2015, based on the author's observations of extremely low snowmelt flow levels in area streams, and the dry depressional wetlands in spring and summer of 2015. Bungashing Creek has extensive riparian wetlands which are hydrologically connected to the creek (Figure 12), both surficially, and especially via subsurface flow from the wetlands to the creek.

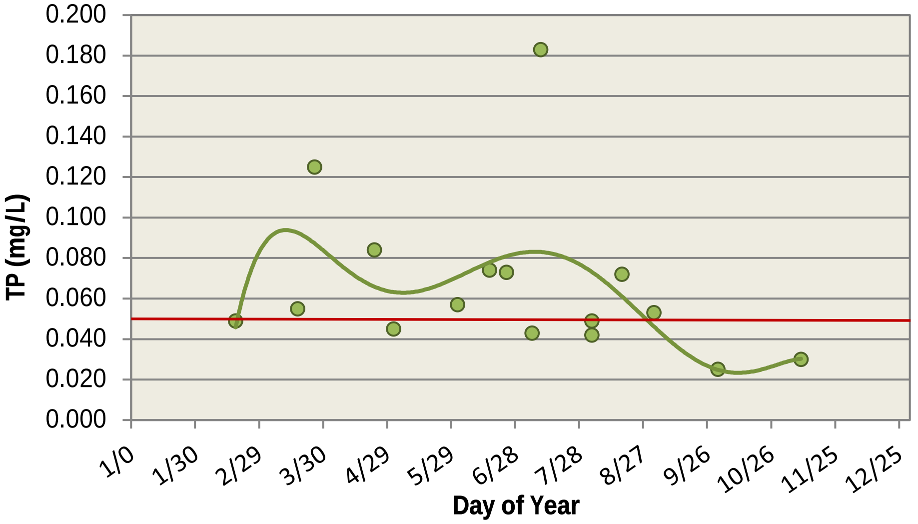

Figure 14. Total Phosphorus in Bungashing Creek at S007-427, 2012 and 2015-2016. The green line is a 6th order polynomial regression line with an R^2 value of 0.2607. The red line is the North Region River Nutrient Standard threshold for TP.

Pokety Creek

Pokety Creek enters the Necktie River downstream of both the mouth of Bungashing Creek and Hart Lake. Additional water chemistry monitoring was done at the biological sampling location (S007-966, 12UM097) in 2015-2016 for TP (Figure 15). A large beaver pond is found a short distance upstream of the sampling site. A new beaver dam was constructed in 2013 or 2014, which impounded the sampling location at the road crossing. However, slow flow was still observed at sampling visits and thus samples were not being collected from stagnant water. Also, the county occasionally breaches this downstream dam, and at some visits, the dam was only impounding water very minimally.

There is clearly an inverse relationship at this site between TP and DO (Figure 15). One explanation for this is a redox-controlled dynamic of phosphorus entering the stream from wetlands hydrologically connected to the stream. A well-known relationship exists between oxygen and inorganic phosphorus, where in aerobic conditions, phosphorus binds to iron in soils, while in anaerobic conditions, phosphorus unbinds from iron and becomes soluble and able to move through hydrological pathways into the stream. The DO levels in Pokety Creek get very low in mid-summer (Figure 15), meaning that the wetland/stream system is quite anoxic at that time, and that phosphorus becomes soluble in the peat soils adjacent to the stream, where groundwater then moves it into the channel. Note that conductivity is also inversely proportional to DO (compare the blue lines in Figures 15 and 16). This makes good sense, as higher conductivity measurements occur when more of the stream water originates from groundwater inputs, and groundwater is generally low in DO. Additional evidence that natural landscape factors play a large role in the phosphorus concentrations in Pokety Creek's water is that TP values are lowest when conductivity is lowest (which occurs when there is a greater proportion of surface water runoff contributing to streamflow - Figure 17) or when at the highest levels, probably meaning that proportionally more of the groundwater is deep groundwater (during dry conditions), which has little phosphorus content. If the high phosphorus were originating from phosphorus-contaminated surface runoff, it would be expected that TP values would be higher at low conductivity periods, the opposite of what is seen here.

Further evidence of a lack of human-caused nutrient problems in Pokety Creek are five nitrate samples collected at various times of the spring/summer, all of which were below the lab reporting limit of 0.05 mg/L.

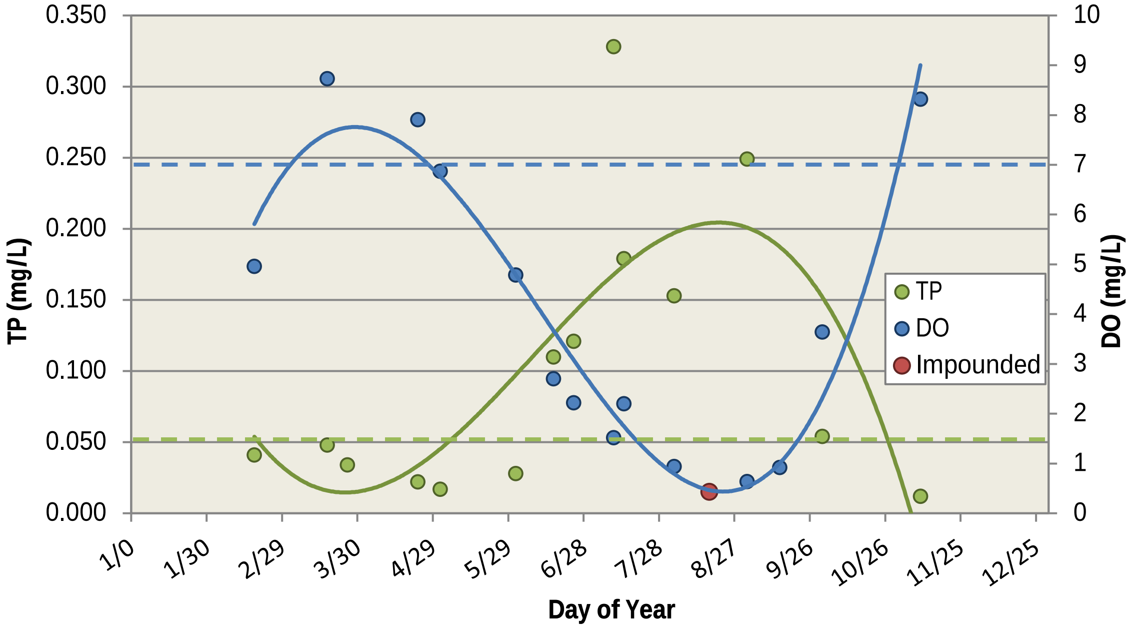

Figure 15. Pokety Creek TP and mid-day DO measurements at the biological monitoring station (S007-966, 12UM089) in 2015-2016. The blue line is a 3rd order polynomial regression line of DO, with an R^2 value of 0.9443. The blue dashed line is the DO standard for coldwater streams. The green line is a 3rd order polynomial regression line for TP, with an R^2 value of 0.6026. The dashed green line is the regional river phosphorus standard.

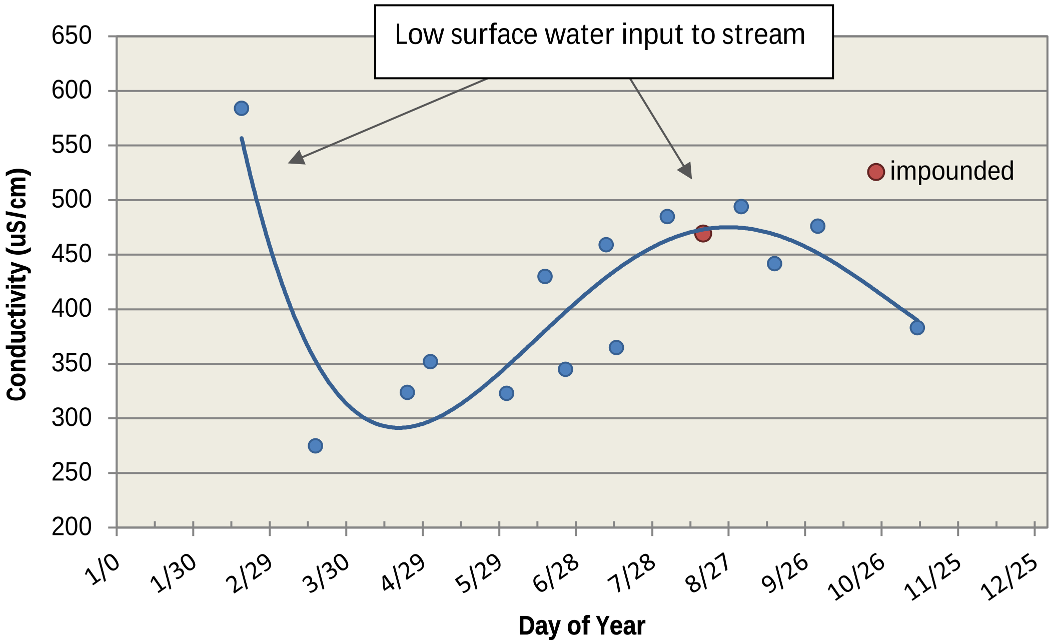

Figure 16. Pokety Creek's seasonal pattern of conductivity. The blue line is a 4th order polynomial regression line with an R^2 value of 0.7384.

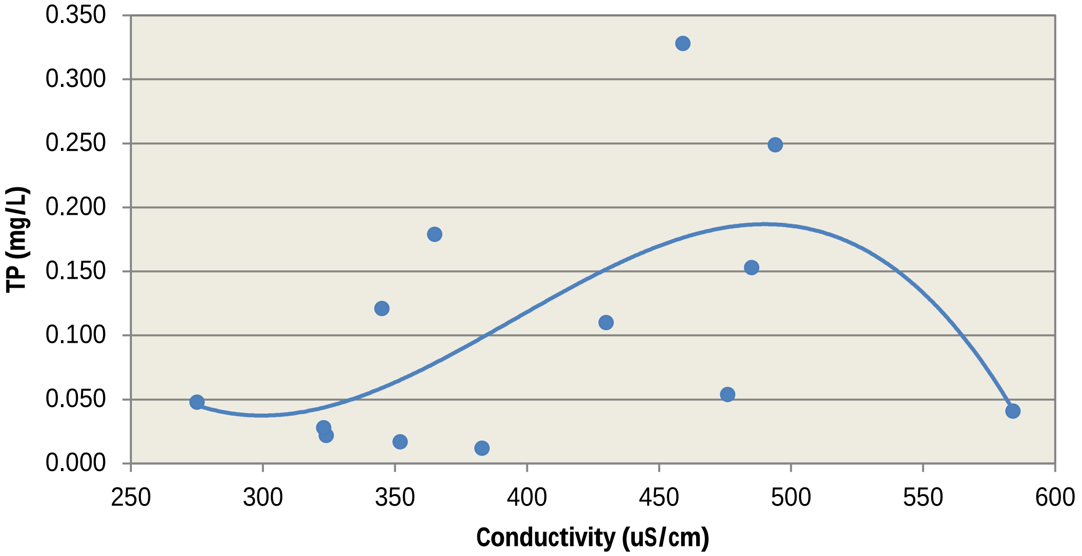

Figure 17. Pokety Creek Conductivity vs. TP correlation. The blue line is a 3rd order polynomial regression line with an R^2 value of 0.3937.

Upstream reaches of the Necktie River

The Necktie River upstream of the biological monitoring site (12UM088) is highly connected to extensive riparian wetlands (Figure 12). A significant length of the river above Hart Lake was modified in the early 1900's by cutting a new, straight channel through the riparian wetland. At some points, the channel is in a completely new location while at other points the dug channel cuts through the original meandering Necktie River. It is possible that the trenching through this miles-long wetland increased the phosphorus export from the wetlands into the Necktie River/Hart Lake, though it would be very hard to quantify because of the length of time that has passed since construction and since no water chemistry data exists from that historical period. Analysis of a lake sediment core (soil strata dating and buried diatom identification) from Hart Lake would be the most informative way to answer that question.

To investigate whether the forested pasture (typical cattle numbers not known) that is located on the northeastern bank of the biological monitoring reach could be causing an issue, an upstream/downstream simultaneous comparison of DO concentrations was collected on July 14, 2014. The downstream sample was collected at CSAH-45, immediately downstream of the pastured acreage, while the upstream sample was collected at CSAH-39, which is at the northern boundary of the pasture. The DO concentration was 4.28 mg/L at the downstream site (10:15 am), and 3.87 mg/L at the upstream site (10:30 am), so the DO actually improved going through the reach adjacent to the pasture.

Conclusions

The fish community shows definite signs of being limited by low DO. A high percentage of the fish community captured were those capable of living in lower-DO environments. It is believed that this low-DO condition and the accompanying impaired fish community are due to natural causes.

Elevated levels of phosphorus (often due to human activities) is a primary reason for reduced oxygen in water bodies. There are plausible, scientifically-based explanations as to why the "elevated" phosphorus, even the great majority of it, found in the Necktie River system could be the result of natural landscape features and associated hydrological pathways. These findings do not necessarily mean there is absolutely no phosphorus contribution from anthropogenic activity in various parts of these subwatersheds. There is a fair amount of cattle pasturing that occurs in the Necktie River subwatershed. Runoff from these pastures could be contributing phosphorus to the Pokety and Bungashing Creeks, as well as the Necktie River; however, the wetlands in the subwatershed are much more closely located to the stream channels than are the pastures in general.

Evidence that the low DO found in this reach is due to natural factors (both wetland and groundwater inputs to the stream) are that: 1) water clarity was high at all visits (very little if any suspended algae present), 2) there were no observations of filamentous algae, and 3) mid-day DO readings were low - where eutrophication is occurring, mid-day DO readings generally get very high (low to mid-teens in mg/L). Aquatic macrophytes are abundant due to a combination of natural factors: the silty substrate, low gradient channel, clear water, and abundant sun exposure due to lack of tree growth near the channel.

The following discussion on Spring Creek will also shed light on the possibility of the "elevated" TP concentrations being the result of natural phenomena.

Spring Creek (AUID 07010102-610)

Impairment: The creek was initially assessed as impaired for not meeting the macroinvertebrate community threshold at site 12UM106 located at CSAH-47, 2.5 miles SW of Wabedo. After further investigation by the SID effort, the creek was brought forward to the Natural Background Committee for review to consider placing AUID-610 into CALM category 4D (impaired due to natural conditions). It was determined that 4D is the proper categorization for AUID-610.

Chemistry

The chemistry data that was collected at the three fish and/or macroinvertebrate sampling visits in 2012 and an SID visit is shown in Table 8. The parameter of potential concern from these results was phosphorus and DO, which were significantly elevated and reduced respectively. Nitrate was extremely low. From the suspended solid data, about half of the material is mineral, and half is organic material. The Sept. 4th TSS data seems very high for a small, low gradient stream in a natural setting, particularly when the T-tube reading was > 100 cm, which is very clear water.

Table 8. Chemistry data from IWM and SID sampling at 12UM106 (S007-949).

Date	Time	Temp.	DO	DO % Sat.	pH	TP	Nitrate	TSS	TSVS	T-tube (cm)
June 12, 2012	18:16	20.0	3.63	42	7.23	0.132	0.05	10.4	5.6	> 100
Aug. 13, 2012	17:40	20.0	4.39	51	7.35	NA	NA	NA	NA	> 100
Sept. 4, 2012	17:42	19.3	3.71	45	7.52	0.376	0.20	38.8	16	> 100
July 9, 2014	10:15	19.31	1.98	NA	7.43	0.152	NA	NA	NA	Est. > 100

Some additional chemistry parameters were collected at the SID visit to investigate the elevated phosphorus situation seen in the IWM data. These included sampling for orthophosphorus and two other fractions of phosphorus, those passing through 1.0 and 0.2 mm filters (which bracket the sizes of particles considered to be colloidal (small enough to be permanently suspended). This sampling of various partitions of phosphorus was done to potentially aid in understanding the phosphorus sources and dynamics in the stream. Similar sampling is being done by the author in the adjacent Crow Wing River watershed at several small streams with high TP to see if a regional pattern exists, and might help provide understanding of phosphorus dynamics in this region of Minnesota. The results are shown in

Table 9. A more complete analysis will be completed in the future, when sampling of this and several other north central Minnesota streams is completed.

Table 9. Additional chemistry data from the SID visit to S007-949 on July 9, 2014. Values are in mg/L.

DOC	Ortho-P	P < 1.0 µm	P < 0.20 µm	% Ortho-P	% Colloidal P	% Particulate P	Total Iron	Diss. Iron
18.2	0.094	0.127	0.100	61.8	17.8	16.4	908	422

Landscape factors were considered to help explain the low DO and high TP measurements found in Spring Creek. Wetlands can have an influence on these parameters since they are places of relatively slow-moving water and a place where substantial plant material grows and then decays. Bacterial decay of the plant material utilizes DO from the water, thus reducing the DO concentration. Also, breakdown of plant material releases phosphorus, which is a component of plant tissue. The National Wetlands Inventory GIS layer shows substantial wetland area hydrologically connected to the stream (most of the riparian corridor is wetland - Figure 18). Beaver activity has exacerbated the wetlands by the impoundments created by their dams. Figure 18 also shows the extent of beaver activity upstream of CSAH-47. A ground-level view of the flooded, wetland corridor is shown in photo 1.

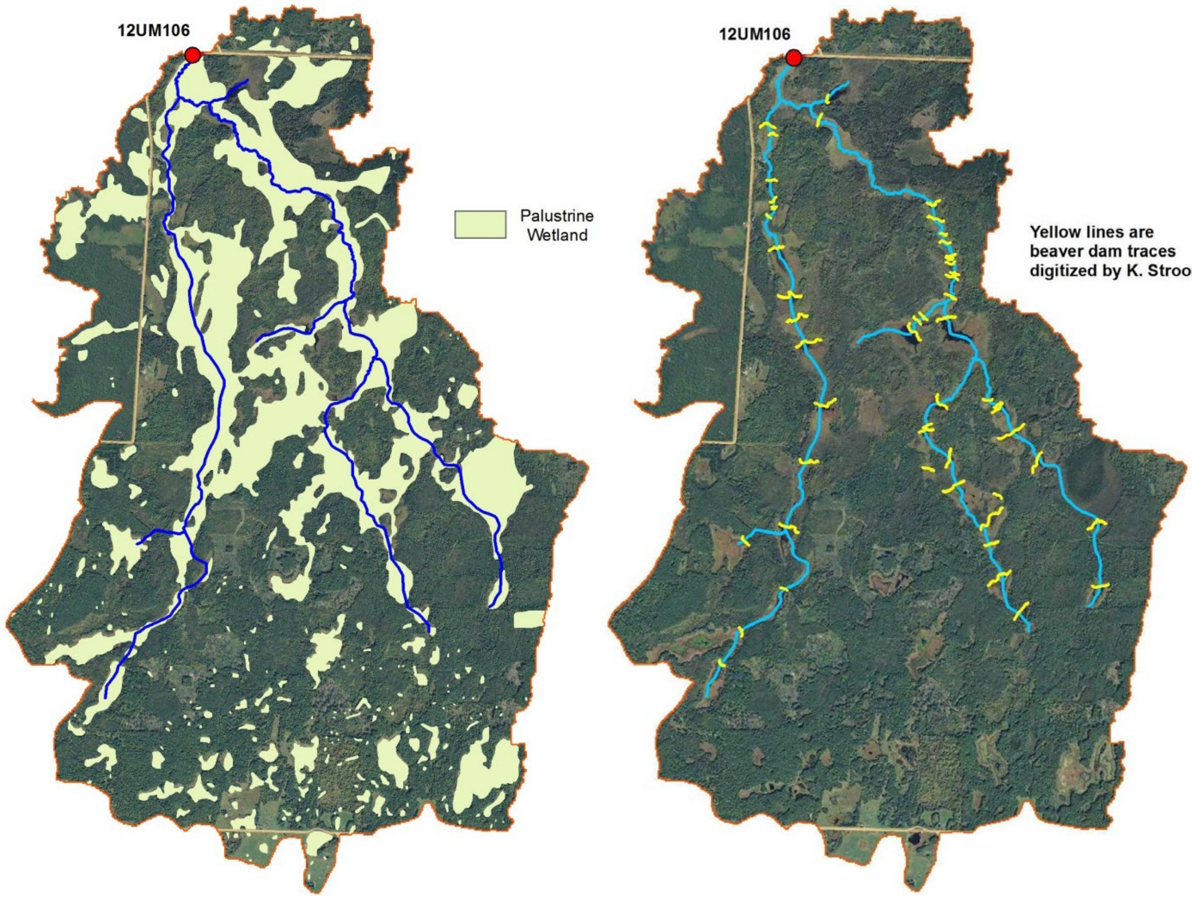

Figure 18. Left - Palustrine wetland area in the Spring Creek subwatershed upstream of 12UM106. Right - existing or breached beaver dams in the Spring Creek subwatershed upstream of biological site 12UM106.

Photo 1. A flooded riparian area due to a beaver dam just above the culvert on CSAH-47, July 9, 2014.

Temperature

Water temperatures were quite cool at all four visits (ranged from 19.3 to 20.0°C) and were not close to levels considered to be stressful to fish.

Biological response

Fish

Both fish samples scored above (passed) the IBI threshold, but DO and TSS metrics were explored to add insight into possible stressors. The fish community at 12UM106 in the July visit had relatively few fish collected (44) and the two dominant species were yellow perch and northern redbelly dace. The September visit had more fish (156) but fewer species and was dominated by yellow perch and secondarily by central Mudminnow; redbelly dace and pearl dace were absent in September. The fish community scores were very low (poor) and mid-range for the DO TIV Index and quite low (good for this metric) for the TSS TIV Index (Table 10). The probabilities of this fish community coming from a stream reach with standard-meeting levels of DO are low, and for TSS are very high (Table 10). This suggests the fish community here is limited to species that are low-DO tolerant and the very good TSS TIV score suggests that the community is not limited to TSS tolerant species. Thus, low DO seem to be the limiting factor for the fish community, though it did pass the IBI standard.

Table 10. Fish Community Tolerance Index scores at 12UM106 for DO and TSS. "Percentile" is the rank of the index score within the fish class 7 streams. "Prob." is the probability a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined. The April 2015 version of this tool was used.

Date	DO TIV Index	Class avg.	Percentile w/in class	Prob. as %	TSS TIV Index	Class avg.	Percentile w/in class	Prob. as %
June 12, 2012	5.610	6.20	18	6.9	11.06	15.45	98	88.7
Sept. 4, 2012	6.275	6.20	57	19.7	11.54	15.45	96	87.4

Macroinvertebrates

The macroinvertebrate community was dominated by a midge (*Rheotanytarsus*) followed by a mayfly (*Caenis*) and the amphipod *Hyalella*. 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 11 shows DO-related metric scores for the macroinvertebrate community at site 10RD019. Though the within-class percentile of the Community DO Index is relatively high, the number of taxa and the percent of the individuals composing the community which are tolerant of low DO reveal that the community is skewed toward low-DO tolerant taxa and individuals. Table 12 shows TSS-related metric scores for the macroinvertebrate community, which reveal a similar pattern to the DO tolerance metrics, except that the percent of individuals tolerant to elevated TSS is very low. Taken together, these data would suggest that DO is a stressor, and that TSS being a stressor is inconclusive.

Table 11. Macroinvertebrate metrics related to DO for 12UM106 utilizing MPCA tolerance values (using the 2015 version of the metrics). The percentile rank is based on the Community DO Index score (2015 version).

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
4	0	7	0	28.2	6.70	73

Table 12. Macroinvertebrate metrics related to TSS for 12UM106 utilizing MPCA tolerance values (using the 2015 version of the metrics). The percentile rank is based on the Community TSS Index score (2015 version).

M-Invert Class	# TSS Intolerant Taxa	# TSS Tolerant Taxa	% TSS Intolerant Individuals	% TSS Tolerant Individuals	Community TSS Index score	Percentile within stream class
4	0	4	0	2.5	12.88	59

Connectivity

Fish in smaller creeks migrate downstream in fall to find deeper overwintering habitat, and then in spring, migrate back up from the larger streams or lakes where they overwintered. If a barrier exists in the stream between the overwintering area and the smaller streams (such as Spring Creek), those smaller streams will be deprived of fish.

Dams or improperly sized or installed culverts are common forms of connectivity barriers. There are no dams or culverts between Wabedo Lake (mouth of Spring Creek) and the sample site on Spring Creek. Beaver dams also can be a natural barrier to fish passage. There is beaver activity (at least occasionally) in the creek below the biological site at CSAH-47, which may have impeded fish movement to the biological site in summer 2014, (no aerial photo from 2014, is available - see figure 19). Therefore, connectivity (due to beavers, and thus natural) may in some years be a problem for upstream fish colonization.

Though it wouldn’t have influenced the fish community at the sample site since it is not located between the lake and the biological reach, the culvert on CSAH-47 (Photo 2) is a human-caused barrier starting just upstream of the biological sample reach, preventing fish from getting upstream farther than where the fish were sampled. The culvert is placed at too high an elevation and is perched on the downstream end, causing a vertical discontinuity in the channel, over which fish cannot leap to continue their movement upstream.

Figure 19. Spring Creek at CSAH-47. Left photo is spring 2013, right photo is fall 2015. Beaver dams at the road crossing and downstream in 2013 are breached and not holding back significant water in 2015.

Photo 2. The downstream end of the CSAH-47 culvert. The lip of the culvert is elevated several inches above the water level in the downstream channel.

Hydrology and geomorphology

Because there is very little human activity in the Spring Creek subwatershed, it is unlikely that there is any human-caused alteration in the flow patterns of Spring Creek, and thus altered hydrology is not considered a stressor here. Without hydrological alteration, the geomorphology of the stream channel should be in a stable condition.

Conclusions

The fish community at 12UM106 is impaired by low DO concentrations. Spring Creek's watershed is in a very natural condition, with almost no human activity occurring within it. Beaver activity (dam building and the resulting impoundments) likely contributes to depressing the DO, due to their impoundments slowing and warming the water, and flooding organic riparian soils, where bacteria utilize DO from the water as they break down the organic soils. Beavers also likely play a part in limiting the fish community by causing migration barriers. Beaver dams are very numerous on Spring Creek. These dams come and go, either due to human breaching or from beaver predation and the subsequent lack of maintenance, so the exact location of beaver-caused barriers can move back and forth over the years. The MPCA natural background review committee met to consider the proper impairment category for Spring Creek, and it was determined that the impairment is due to natural factors, and thus a TMDL will not be prepared for the Creek.

The culvert barrier issue on CSAH-47 may not be a high priority in terms of spending on culvert improvements. The cost of replacement may not be worth the benefit to the fish community here, due to the extensive beaver activity on this creek. Even if the fish could pass the culvert, they would encounter other beaver dams a short distance upstream that likely would block their passage. Before replacement is considered for the fish passage issue, MDNR fisheries staff should be consulted to determine how beneficial the replacement would be. When the time comes for replacing the culvert for other reasons, re-installing the new culvert should be done at the proper elevation level and with a proper sizing to allow fish passage. MNDOT has new design guidelines for such considerations.

Unnamed Creek (AUID 07010102-612)

Impairment: The creek was assessed as impaired for not meeting both the macroinvertebrate and fish community thresholds at site 12UM107 located at South Inguadona Drive (upstream side), five miles SE of Longville. Because of the remote setting and beaver influence, the creek was brought forward to the Natural Background Committee for review to consider placing AUID-612 into CALM category 4D (impaired due to natural conditions). It was determined that 4D is the proper categorization for AUID-612.

Chemistry

The only chemistry data for AUID-612 is that collected at the fish and macroinvertebrate sampling visit. DO was well below the standard, particularly notable due to the cold temperature of the water. All other parameters showed good water quality, except that TP was elevated above the regional standard. The landscape of this small subwatershed is largely wetland: the elevated TP from wetland-influence is similar here as with the Necktie River, Bungashing Creek, and Pokety Creek.

This short AUID has a very large beaver dam located directly above the biological sample reach, which is impounding a large amount of water. The flooding of the organic soils within the impoundment likely contributes significantly to the low DO found below the beaver dam. This situation is also likely responsible for the elevated TP concentration measured at the biological station. See above text in the Necktie River and Spring Creek sections for more discussion on the relationship between wetlands, organic soils, DO, and phosphorus.

Table 13. Chemistry results collected at 12UM107 (in mg/L).

Date	Time	Temp.	DO	DO % Sat.	pH	TP	Nitrate	TSS	TSVS	T-tube (cm)
8/21/2012	12:00	14.7	3.29	36	6.84	0.081	< 0.05	< 4	< 4	> 100

Connectivity

The culvert on South Iguadona Road is properly set such that it does not cause a barrier to fish movement into the biological sample reach from Lake Iguadona or lower reaches of Northby Creek.

There are two large beaver dams between Lake Iguadona and the biological reach, which are likely barriers to fish migration into this small unnamed creek, where no overwintering habitat likely exists.

Biological response

Fish

Only two species of fish were caught in the sample; central mudminnow (109) and brook stickleback (1). These species are ubiquitous in central and northern Minnesota streams and are broadly tolerant to a wide variety of habitat and DO concentrations.

Macroinvertebrates

The macroinvertebrate community was highly dominated by the chironomid (midge) genus *Chironomus*. This genus is notable for its ability to live in low DO waters. The next three most abundant taxa are also low-DO tolerant, these being Oligochaeta (worms), the snail genus *Physa*, and another chironomid genus, *Glyptotendipes*. Numerous wetland-oriented taxa (generally these are tolerant of low DO with some breathing from the atmosphere) were found in the sample including the snail genus *Physa*, the snail families Planorbidae and Lymnaeidae, the fingernail clam Pisidiidae, coleopteran (beetle) taxa *Haliplus*, Dytiscidae, *Gyrinus*, *Hygrotus*, and *Limnophyes*, the hemipterans Corixidae and *Ranatra,* a culicid mosquito larva and the pond-dwelling caddisfly species *Glyphopsyche irrorata*. No taxa requiring good DO levels (i.e., Ephemeroptera [mayflies], Plecoptera [stoneflies], or Trichoptera [caddisflies]) were collected from this site. The taxa collected in this sample are highly skewed toward those tolerant to low-DO, or those not requiring aquatic DO (air-breathers).

Conclusions

Unnamed Creek (tributary to Northby Creek) is a very small creek (0.17 miles long). Its watershed is a wetland dominated, forested landscape with no development. Its setting suggests that anthropogenic stressors are unlikely, whereas there are natural features that are known to cause water quality issues observed in samples collected here. Wetlands are likely responsible for the low DO found in the stream, and natural beaver dams block the ability of fish overwintering in Lake Iguadona from spring migration into Unnamed Creek. The MPCA Natural Background Committee met and determined that natural factors are highly likely to be causing the impaired condition of the fish and macroinvertebrate communities found in AUID-612, and the Creek was placed into CALM category 4D.

Overall conclusions for the LLRW

The Stressor Identification process identified one stressor (low DO) for the three biologically-impaired stream reaches (Table 14). For Spring and Unnamed Creeks, the natural background review committee met and determined that the low DO concentrations (and thus also the poor fish community) are due to natural causes, in this case, enhanced wetlands due to high numbers of upstream beaver impoundments. Beaver dams are also likely acting as migration barriers for fish. The fish community in the lower Necktie River (AUID-502) is also influenced (or limited) by low DO levels. The low DO impairment for the Necktie River is being deferred currently. It has been recognized by MPCA that a special DO standard is needed for north central and northeastern Minnesota low gradient streams that are highly influenced by abundant natural wetlands. Thus, there are no biological stream impairments at this time that require a TMDL.

Table 14. Summary of stressors causing biological impairment in LLRW streams by location (AUID).

Stream	AUID Last 3 digits	Reach Description	Biological Impairment	Impairment Category	Stressor					
					Dissolved Oxygen	Phosphorus	Sediment/Turbidity	Connectivity	Altered Hydrology*	Channel alteration
Necktie River	502		Fish	Deferred assessment	•					
Spring Creek	610		MI	4D	o					
Unnamed Creek	612		Fish and MI	4D	o					

*Includes intermittency and/or geomorphology/physical channel issues

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

◊ Possible contributing root cause.

• Determined to be a direct stressor.

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

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

? Inconclusive

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