Mustinka River

Watershed Restoration and Protection Strategy

Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities

Minnesota Pollution Control Agency

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Acronyms, abbreviations, and term definitions

AUID .... Assessment Unit (Identification Number) MPCA's a pre-determined stream segments used as units for stream/river assessment – each has a unique number
AWC .... MPCA's Altered Watercourse Project
BANCS .... Bank Assessment for Non-point source Consequences of Sediment
BEHI .... Bank Erosion Hazard Index
BOD_5 .... five-day biochemical oxygen demand
CR .... County Road
CSAH .... County State Aid Highway
DO .... Dissolved Oxygen
DS .... Downstream
EFC .... Environmental Flow Components
EPT .... Prime elimination of many of the sensitive taxa
EQuIS .... Environmental Quality Information System
GBT .... Gas Bubble Trauma
GIS .... Geographic Information System
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
IHA .... Indicators of Hydrologic Alteration
ISTS .... Individual Sewage Treatment Systems
IWM .... MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling
LWH/LWD .... Large Wood Habitat or Large Woody Debris
M .... The abbreviation for meter
mg/L .... Milligrams per liter
µg/L .... Micrograms per liter (1 milligram = 1000 micrograms)
Macrophyte .... Macro (= large), phyte (= plant). These are the large aquatic plants, such as Elodea and Coontail
MDA .... Minnesota Department of Agriculture
MDH .... Minnesota Department of Health
MDNR .... Minnesota Department of Natural Resources
MNDOT .... Minnesota Department of Transportation
MPCA .... Minnesota Pollution Control Agency
MSHA .... Minnesota Stream Habitat Assessment
M&A Report .... MPCA Monitoring and Assessment Report for the Mustinka River Watershed
MS4 .... Municipal Stormwater Plan, level 4
MRW .... Mustinka River Watershed
Macrophyte .... Macro (= large), phyte (= plant). These are the large aquatic plants, such as Elodea and Coontail
NH_3 .... Amonia/ unionized ammonia
NH_4 .... ammonium
NLCD .... National Land Cover Database
NPDES .... National Pollutant Discharge Elimination System
NO_2/NO_3 .... Nitrate

NRCS............................ Natural Resources Conservation Service
Natural background .. An amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors
P .... Phosphorus
TWP Rd .... Township Road
RRB............................. Red River Basin
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
SSTS............................ subsurface sewage treatment systems
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.
TDG .... Total Dissolved Gases / total gas saturation
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)
USEPA .... United States Environmental Protection Agency
WMA.......................... Wildlife Management Area (owned by MDNR)
WHAF......................... Watershed Health Assessment Framework
WRAPS....................... Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale
WWTP........................ Wastewater treatment plant
10X............................. Ten times (chemistry samples collected on 10 dates)
303(d) list................... The official, USEPA-accepted list of impaired waters of the state

Executive summary for the Mustinka River Watershed Stressor Identification Report

This report documents the efforts that were taken to identify the causes, and to some degree the source(s) of impairments to aquatic biological communities in the Mustinka River Watershed (MRW). Information on the Stressor Identification (SID) process can be found on the United States Environmental Protection Agency's (USEPA) website http://www.epa.gov/caddis/.

The MRW is situated at the southern extent of Glacial Lake Agassiz. As with other Red River Basin watersheds, the MRW can be divided geographically into the Glacial Moraine (rolling uplands), the Beach Ridge (the glacial lakeshore), and the Lake Plain (bottom of Lake Agassiz). Particularly in the Lake Plain, but also in some of the uplands, the soils and topography are very well-suited to agriculture. The vast percentage of land use in the MRW is rowcrop agriculture - corn, soybeans, sugar beets, and wheat. Very little of the MRW is used for livestock production. There is a relatively small amount of state-owned land in the MRW, with most being Wildlife Management Areas (WMA)s (16 total, most are smaller than 300 acres). The density of residential and urban land use is very low in the MRW. Stressors related to those land uses (excess runoff from stormwater, wastewater facility discharges, etc.) are not expected to be a large issue here; however, there are a handful of very small towns that have permitted municipal wastewater discharges. Given these landscape/land use attributes, the primary anthropogenic stressors in the MRW are most likely to be from intensive row crop agriculture. One stressor, which can occur anywhere roads are present, is barriers to fish migration caused by the structures used to place a road over a stream. Culverts, in particular, are commonly found to be at least partial barriers to fish passage. Landscapes with a high percentage of agricultural land, such as the MRW, have a greater likelihood of this issue, due to greater road density than in less-developed landscapes.

The *Red River Biotic Impairment Assessment Report* (EOR, 2009) investigated and discussed stressors across the whole of the Red River Basin (RRB). Due to the fact that geographical patterns, land use, and soils are very similar throughout much of the RRB, particularly watersheds that are more closely tied to the Red River Valley (the exception being the Red Lake Watershed), the stressors defined in that report are likely to occur in most of these RRB watersheds. The listed stressors included: "...instream sediment from field and gully erosion, intermittent stream flow, channelization, pesticides, low dissolved oxygen (DO), high temperature, and fish passage blockage" as being the most likely/influential stressors in the Red River Basin (see EOR 2009, Table 22, where relative rankings of each stressor were made based on stream drainage area categories).

Six Assessment Unit Identification (AUID) reaches on five streams were brought into the SID process because they were determined to have substandard biological communities via the 2010 Intensive Watershed Monitoring (IWM) and Assessment phase of this Watershed Restoration and Protection Strategy (WRAPS) project. Upon review of the data collected during the IWM and subsequent SID process, a number of the common Red River Basin stressors were identified as causing the impairments. Also, stream intermittency (the extent of human contribution not known) was identified as the stressor for two of the five streams.

- **Eighteenmile Creek** (AUID 09020102-508) - Low DO due to eutrophication.
- **Unnamed Tributary to Mustinka River** (AUID 09020102-538) - intermittency, lack of fish source area (due to DO impairment in mainstem, AUID 09020102-506).
- **Mustinka River** (AUID 09020102-580) - Barrier to fish migration (Pine Ridge Park Dam).

- **Twelvemile Creek** (AUID 09020102-514) - Upstream of the West Brach Twelvemile Creek confluence. Altered hydrology, flashiness, turbidity, DO.
- **Twelvemile Creek** (AUID 09020102-557) - Downstream of the West Brach Twelvemile Creek confluence. Altered hydrology, flashiness, turbidity, DO.
- **Unnamed Creek** (AUID 09020102-578) - Intermittency, barriers, lack of fish source area.

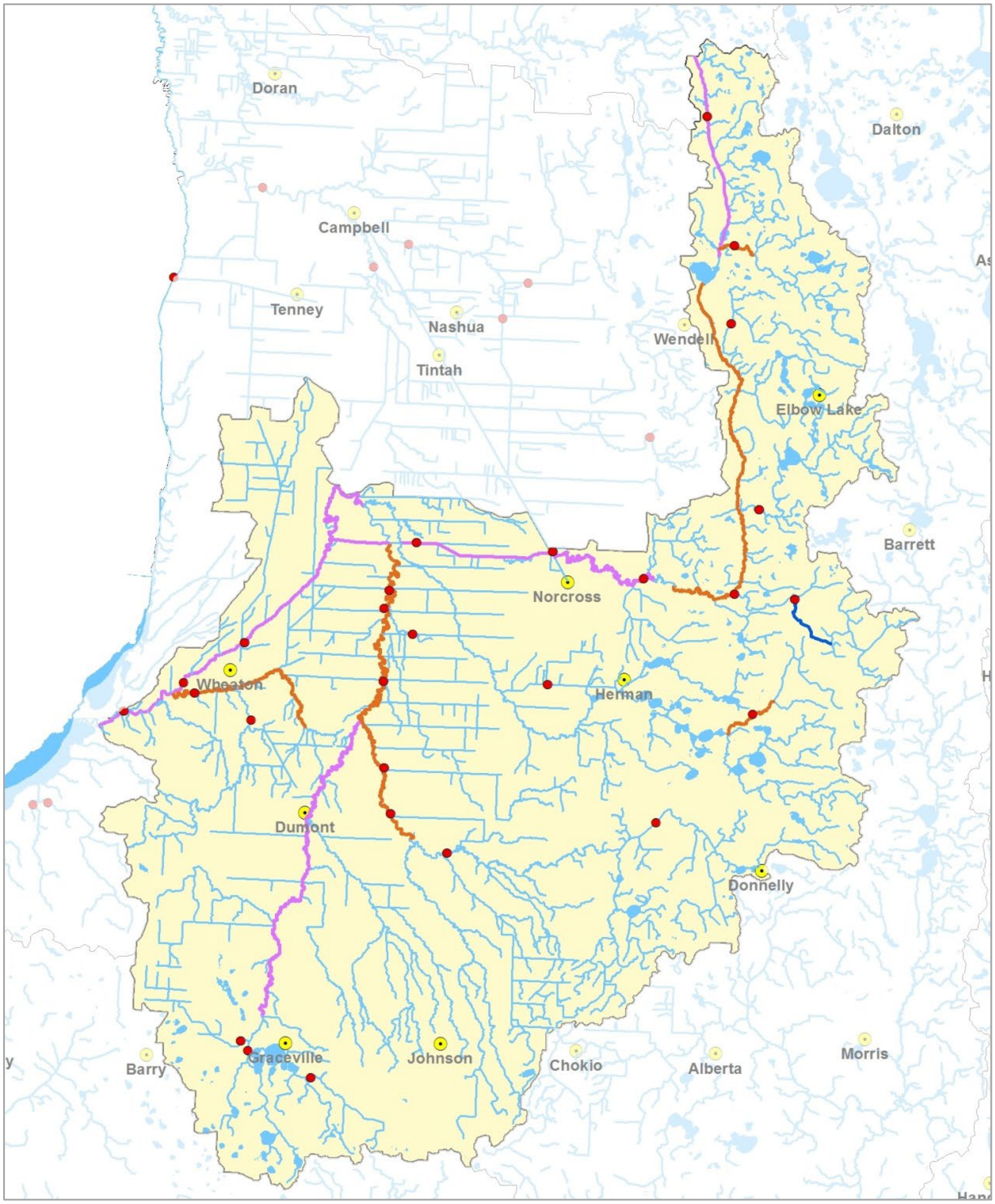


Figure 1. Reaches with Aquatic Life Use impairments. Orange reaches represent measured biological impairments. The dark blue reach is a biological impairment that is being deferred due to the extent of ditches in the AUID. The purple reaches have conventional chemistry parameter impairments, but not a measured biological impairment.

Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 81 Major Watersheds, known as Major Watershed Restoration and Protection Strategy (WRAPS). A WRAPS is comprised of several types of assessments. The MPCA conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2010 and 2011. The IWM assessed the aquatic biology and water chemistry of the MRW streams and rivers. The second assessment, known as the Stressor Identification Assessment (SID), builds on the results of the IWM. The MPCA conducted the SID assessment during the summers of 2012 and 2013. This document reports on the second step of a multi-part WRAPS for the Mustinka River watershed (MRW), located at the headwaters of the Red River Basin (RRB).

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 Mustinka River Watershed Monitoring and Assessment (M&A) Report. That document should be read together with this Stressor ID Report and can be found from a link on the MPCA's MRW webpage; http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/mustinka-river.html

Landscape of the MRW

An extensive description of various geographical and geological features of the landscape of the RRB is documented in a report by Emmons and Olivier, Inc. (EOR, 2009). Additionally, the MPCA's 2013 MPCA Monitoring and Assessment Report for the Mustinka River Watershed (M&A Report) provides similar descriptions and details specific to the MRW. Both reports contain information necessary for understanding the settings of the RRB watersheds, and how various landscape factors influence the hydrology within the Basin. The following information is intended to provide a basic description of the MRW landscape.

The natural landform of the MRW was created by glacial activity. As with other Red River Basin watersheds, the MRW can be geographically divided into the Glacial Moraine (rolling uplands, on the far eastern and southern portions of the MRW), the Beach Ridge (the glacial lakeshore), and the Lake Plain (bottom of Glacial Lake Agassiz, the flat terrain that is most intensively farmed – the valley/floodplain area). Each has distinct topography and soil types. The Lake Plain is extremely flat topographically with rich topsoil that has significant clay content and is poorly drained. The Beach Ridge soils contain much sand and gravel, as this area was the shoreline of Glacial Lake Agassiz. In the Glacial Moraine, there are several small lakes and large wetlands that were produced by glacial ice at the extent of the glacial advance. Glacial Moraine soils here are more well-drained and loamy than the Lake Plain soils. The Executive Summary above contains additional information regarding the MRW. The M&A Report also discusses landscape features in detail.

The original, pre-settlement landscape was almost exclusively prairie (Figure 2). The landscape of the MRW is decidedly devoted to agriculture, the primary focus of which is row crop production. Relative to the agricultural parts of central Minnesota, there is little animal agriculture in the MRW. Animal agriculture in the Red River Basin typically exists on the beach ridge lands where soils are not as conducive to row crop production. The percentages of various categories of land cover are presented in Table 1. Photo 1 shows the extent of land area that is cultivated in the Lake Plain area of the MRW.

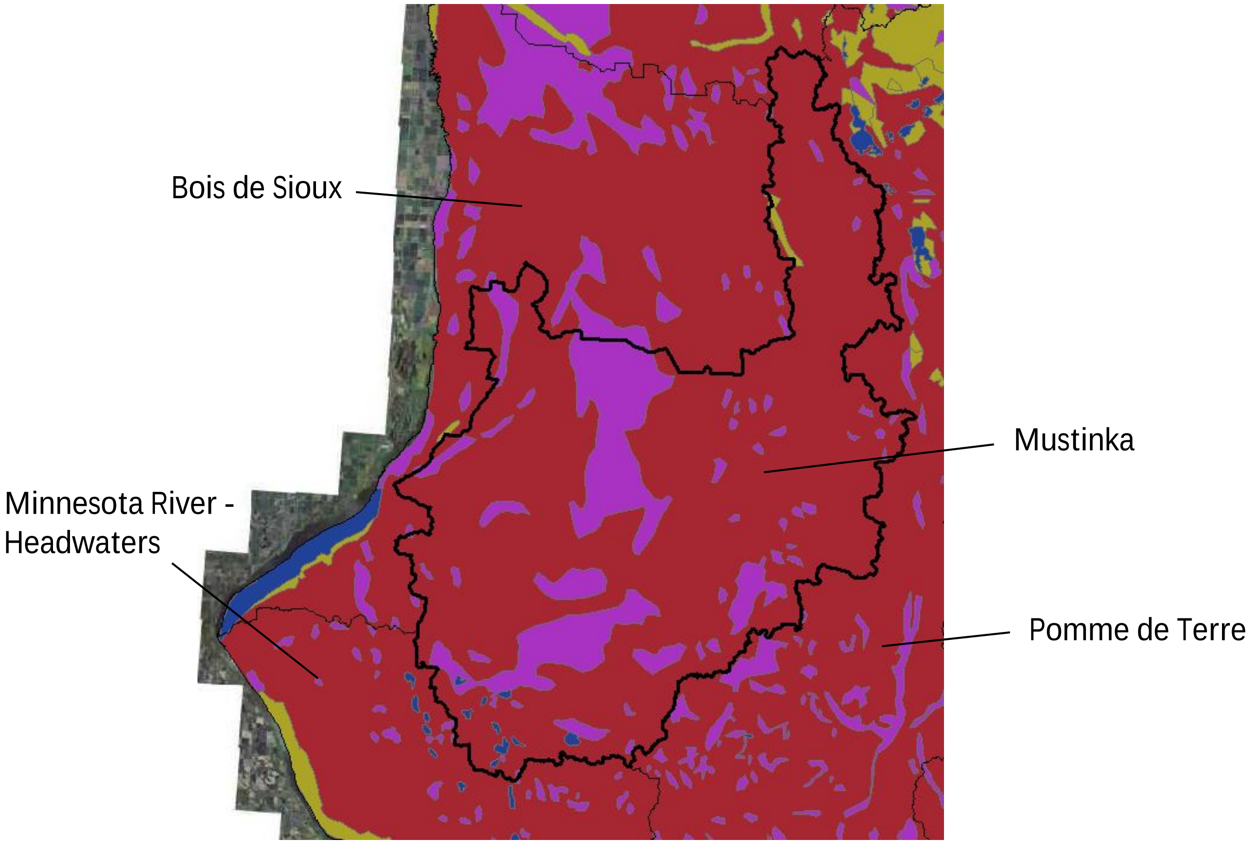


Figure 2. Original vegetation of the MRW and adjacent land, (Marchner, 1930). Red represents Grassland Prairie, purple represents Wet Prairie, blue represents Lakes, and gold represents River Bottom Forest.

Table 1. Percentages of the various land cover types from 2006 National Land Cover Database (NLCD) Geographic Information System (GIS) coverage (excludes open water).

Land cover type	Percent of Land Area
Developed (all intensities grouped)	5.27
Forest and Shrub	0.83
Grassland and Pasture	2.03
Cultivated Crops	87.19
Wetlands	4.65

Photo 1. Extent of agricultural land coverage in the MRW just east of Wheaton, Minnesota. The arrows point to the south-to-north running Twelvemile Creek.

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 USEPA provides a long list of stressors that have potential to lead to disturbance of the ecological health of rivers and streams (see USEPA'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. These 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 MRW for many years. The determination of candidate stressors used both the historical data and data collected during the 2010 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 of watershed health, which is shown in Figure 3. Given the high percentage of non-natural landscape in the MRW and the moderate level of municipal point-source pollution dischargers (no industrial dischargers), nonpoint source pollution is likely a relatively substantial threat to water quality in the MRW. Streams within the MRW are bordered by agricultural along most of their lengths. According to the Non-point Source Pollution Index, the MRW ranks a 24/25 (tied) out of the 81 (81^{st} has the least threat) watersheds in Minnesota. The WHAF also shows non-point pollution as being a greater threat in the MRW than in many of the other Red River Basin watersheds.

Another issue, which has very significant influence on the health of MRW water resources, is the alteration of the hydrologic patterns on the MRW landscape due to stream channelization, ditching, and wetland drainage. Water storage capacity in the MRW is very low, as is the case in most of the MRW subwatersheds (Figure 4). This low storage capacity reflects the human alterations to this landscape for the purpose of intensive agricultural production. Factors used to create the WHAF's Hydrologic Storage scoring protocol include the loss of storage basins (e.g. wetland drainage) and a stream straightening factor. A pre-1900 storage estimate is then compared to a current storage estimate to determine the score.

In addition to the metrics above, several other metrics were chosen from the MDNR WHAF that relate to either point or non-point source pollution. Using the data within the WHAF, the MRW's rank was computed to show its relative standing among Minnesota watersheds as a way to analyze which stressors may be particularly active in the MRW (Table 2). Though the Number of Point Sources metric

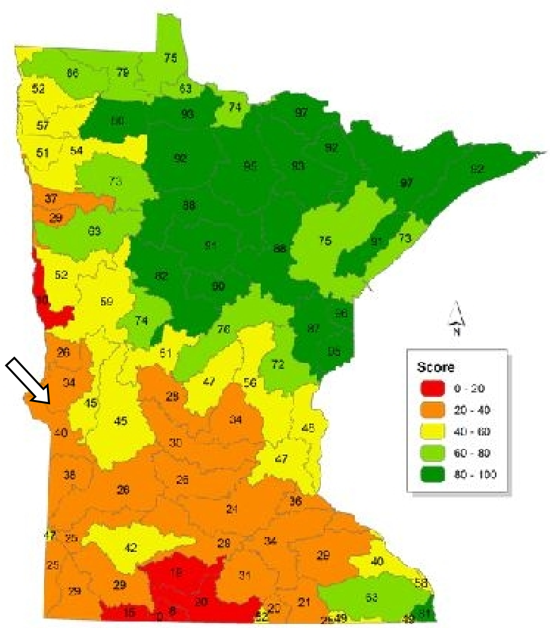


Figure 3. Scores and categorical ranking of the 81 Minnesota Major Watersheds for the MDNR Non-point Source Pollution Index.

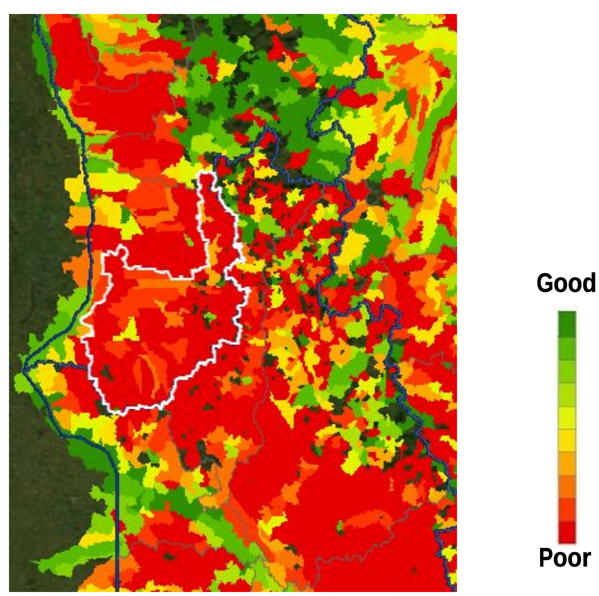


Figure 4. Hydrologic storage of subwatersheds in the MRW (white border) and surrounding area. The scoring is the degree of storage loss relative to all state of Minnesota subwatersheds.

Table 2. Ranking of several attributes of the MRW relative to Minnesota's other 81 watersheds. Rank is MRW standing within 81 watersheds. A high rank number is a positive; a low rank is a negative for water quality.

	Impervious Surface	Nonpoint Threat	Storage Loss	Perennial Cover	# of Point Sources	Ag. Chem. Use	Aquatic Connectivity
Rank	42	24/25	14	8	26	6	50

has the MRW ranked among the higher in the state, none are industrial, and most have small discharges due to the relatively small municipalities in the MRW. The Wheaton Wastewater Treatment Plant (WWTP) is by far the largest MRW discharger of phosphorus, though its discharge point occurs near the pour point of the MRW and does not therefore affect much of the MRW itself (MPCA, 2014 - http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=5e26e6c6756d4d0885da0ccadcb84737). The Wheaton discharge is, however, important to consider when the scope of analysis is larger than the MRW, because that phosphorus moves on into the Red River and points north. 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

EOR, Inc. - Red River Basin Report

In 2009, the MPCA contracted Emmons and Olivier, Inc. to determine and examine the likely, widespread stressors in the RRB (EOR, 2009, http://www.eorinc.com/BioticAssessment.php). Because geographical patterns, land use, and soils are very similar throughout the RRB, (the Red Lake Watershed being somewhat of an exception), the stressors defined in EOR's report, which mostly arise from the extensive and intensive agriculture conducted within the Red River Valley, are likely to occur in all of the RRB watersheds. The report listed: "...instream sediment from field and gully erosion, intermittent stream flow, channelization, pesticides, low DO, high temperature, and fish passage blockage" as being the most likely/influential stressors in the Red River Basin (see EOR 2009, Table 22, where relative rankings of each stressor were made based on stream drainage area categories). Also see Table 36 of the EOR report for a summary of where, among the handful of RRB geographical regions (e.g., Beach Ridge), these stressors are most active. The report helped form the basis of additional examination of candidate stressors that was conducted in this current Stressor Identification process.

Non-IWM MPCA Monitoring Programs

Aside from the IWM monitoring, MPCA has other programs that conduct various water monitoring efforts that can shed light on possible stressors. As established above, nutrients are a prominent stressor in agriculturally-oriented landscapes. MPCA's wastewater program compiles nutrient data apart from that collected in the IWM. Recent trend data for phosphorus originating from wastewater discharges is available for the major watersheds of Minnesota. The data for phosphorus in the MRW shows that from 2005-2013, wastewater phosphorus in streams has increased by 28%, whereas many other Red River Basin watersheds have shown a marked decrease in this parameter. http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=c53c280bb959419e891aaebfc1da9bb4 . The neighboring Bois de Sioux River watershed has also shown an increase. MPCA also provides water quality monitoring grants to local organizations, and this data, as well as all of the MPCA-collected data, is stored in the publically-available Environmental Quality Information System (EQuIS) database, at the following web page: http://www.pca.state.mn.us/index.php/data/environmental-data-access.html . Data from those programs is included in the water chemistry discussions of individual AUIDs that follow later in the report.

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, substantial impervious surfaces, and stormwater runoff, which all increase with population density. According to the 2010 census data, the MRW is quite sparsely populated relative to the state as a whole. The MRW is composed of Traverse, Grant, Stevens, Big Stone, and Otter Tail counties with populations of 3558, 6018, 9726, and 5269 respectively (US Census Bureau, 2011). A large amount of the Stevens County population is in the city of Morris, which lies outside of the MRW. Graphs presented by the demography website show that population has continually declined since the 1960 census for three of the counties, and has remained nearly stationary in Stevens County.

There are no large towns in the MRW. The two biggest towns are Wheaton (pop. 1449) and Elbow Lake (pop. 1201). The remaining communities are all less than 500 persons - generally less than 250. None of these towns is large enough to require a Municipal Stormwater Plan, level 4 (MS4) (EOR 2009). Recent GIS-derived land use statistics showed that 5.1% of the watershed area is categorized as Residential/Commercial (NRCS, 2010). The MRW is about at the middle of the state's 81 watersheds for amount of impervious cover, ranking 42nd highest. Despite this rank, there is actually relatively little impervious cover, as the WHAF's raw score for the watershed is 94, with 100 being the maximum (and best) score. The predominant impervious surface in the watershed is roads. Wastewater discharges are a possible contributor to water quality impairments; four towns (Graceville, Dumont, Donnelly, and Herman) have treatment systems that seasonally discharge upstream of biologically-impaired locations of Twelvemile Creek. There are two other towns (Wendell and Elbow Lake) that discharge into the Mustinka River upstream of the biologically-impaired AUID-580. The census and urbanization information suggests that most stressors related to population density are likely only small contributors to the impairments found in the MRW. However, wastewater discharge may be having a significant impact, and as mentioned previously, wastewater phosphorus loading is increasing within the MRW.

One potential source of water resource stressors in rural areas is subsurface sewage treatment systems (SSTS), formerly known as individual sewage treatment systems (ISTS). Unsewered areas can have old septic systems that are either failing, or do not conform to current design standards. While there are no areas within the MRW that meet the MPCA criteria for the designation of "Unsewered Community", most rural homesteads in the MRW are not connected to a municipal sewer system, and thus have individual treatment systems. Rural areas can also have residences that discharge wastes directly to streams, though this is unlawful. These systems can contribute significant levels of nutrients and other chemicals to water bodies. Within the five MRW counties, there are between 5 and 25% of the individual treatment systems that are estimated to be "Imminent Public Health Threats" (i.e., direct discharge to stream), 2 to 26% "Failing", and 61 to 80% compliant systems. (MPCA 2012). Thus, there is reason to suspect that nutrient problems are due in part to non-compliant SSTSs. These can be difficult to detect unless counties have statues requiring inspection.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. While the MRW does have some industry, there are zero industrial NPDES permits within the MRW. Thus, industrial discharges should not be a source of pollutants (stressors) causing stream impairment in the MRW.

Forestry

Forest harvest can create stress on water resources. Land within the MRW is not used for timber production, nor is historical large-scale forest removal an issue in the watershed. Nearly all of the MRW was originally tall-grass or wet prairie (Marchner, 1930). Therefore, stressors related to forestry are not considered in this study.

Agricultural activities

The Red River Valley is well known for its extensive agricultural land use. Agricultural activities, particularly when operating over extensive areas of the landscape (Photo 1), are well established as being anthropogenic stressors of water quality. A large quantity of professional research articles 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). The desktop review of the MRW's land use, shown previously (Table 1) indicates that approximately 87% of the land cover is in cultivated crops. Therefore, it was reasonable to determine that an investigation into known agriculture-related stressors (e.g., nutrients, sediment, altered hydrology) as contributors to impairments in the MRW should be undertaken.

A common result of agricultural activity is altered hydrology. One agricultural activity that dominates the Red River Basin landscape is surface drainage. A large percentage of the watershed has had drainage enhancement via constructed ditches as well as either straightening or smoothing stream channels. The intent of drainage is to alter the hydrology of an area to benefit crop production, removing water that is in excess for optimum plant growth. In addition, the change in vegetation from native, perennial cover to annual crops will itself change an area's hydrologic patterns, particularly when the areal extent of that change is large.

A highly influential factor in the hydrological pattern of a watershed is the amount of precipitation that it receives. It has been noted that the period starting in about 1993 up to the time the MRW IWM monitoring occurred has been a "wet cycle". The MRW M&A report discussed precipitation patterns for the 20- and 100-year periods ending in 2010. No statistically-significant increasing (or decreasing) trend has occurred from 1990-2010. However, the 20-year period of 1990-2010 does appear to have higher precipitation than the period from 1970-1990. Some may suggest that many of the water quality problems seen at present can be attributed to this increased rainfall. A study done by the consulting firm EOR, Inc. (Lenhart et al., 2011) showed that the increase in regional stream flow measured in recent years cannot be explained by an increase in precipitation alone. In their paper examining hydrological changes in southern Minnesota streams, Schottler et al., (2013) showed that 1) artificial drainage of agricultural lands is a major factor of elevated streamflow volumes, and 2) streams in these watersheds exhibit widening channels. Because the increased stream flow cannot be explained solely by precipitation, anthropogenically-altered hydrology is considered a candidate stressor.

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). With the degree of agriculture occurring in the MRW, elevated nutrients must be investigated as a candidate stressor.

Pesticides

Given that the MRW is an intensely agricultural watershed, it is reasonable to also include pesticides as a potential stressor to aquatic life. Pesticides as stressors were considered more on a watershed-wide basis and will be discussed here only; not in the individual stream sections. Pesticide testing is very expensive, and monitoring for pesticides is difficult as applications are spotty, and occur irregularly. *The number of samples collected within this project, and the design of the sampling program, is not sufficient to determine whether or not pesticides are a stressor.*

In 2011, the MPCA collected a small number of stream samples (five) for pesticide analyses and were transferred to the Minnesota Department of Agriculture (MDA) for analysis in their pesticide lab. Sample sites are listed in Table 3. While some pesticide compounds were present in the samples, none were at levels that are currently known to individually cause damage to aquatic plants or organisms. Though the data cannot rule out past pesticide influences, it appears (with limited data) that there is not persistent, widespread presence of pesticides at levels thought to be individually harmful to the biological communities in the MRW. It is important to note that there is little scientific research on the cumulative impact of low level exposure to multiple pesticides on sensitive aquatic organisms. At this time there exists insufficient information to determine the role pesticides play on the health of aquatic biota across Minnesota's agricultural landscapes. More information on Minnesota's statewide pesticide sampling and results are available from the MDA at http://www.mda.state.mn.us/monitoring.

Table 3. Sites of MPCA water sample collections on August, 16 2011 for pesticide testing.

Stream	Bio. site #	EQuIS site #	Location Description
Mustinka R.	10RD037	S003-104	At CSAH-13, 6 mi NE of Herman
Twelvemile Cr.	10RD056	S004-197	At MN-27, 5.8 mi E of Wheaton
Eighteenmile Cr	10RD045	S005-143	At CSAH-7, 1.5 mi SW of Wheaton
Trib. to Mustinka R	10RD038	S006-895	At 230th Ave, 8 mi. SW of Elbow Lake
Unnamed stream	10RD042	S004-354	At CSAH-15, 4 mi NE of Wendell

Summary of candidate stressor review

Based on the review of human activity in the MRW, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the MRW, resulting in eight of the candidate causes moving forward for more detailed investigation.

Eliminated causes

- Industrial stressors (i.e., toxic chemical discharges)
- Mining stressors
- Forest management stressors
- Urban development stressors (altered hydrology, riparian degradation, high levels of impervious surfaces, residential chemical use). **Note**: The residential/urban areas within the watershed are possibly contributors to some of the candidate causes below, and need to be considered to the degree they contribute. The small size of all towns and overall low population density in the watershed suggest that urban development is not likely the primary source of the candidate stressors, however, such development is not fully eliminated as a contributor to impairments.

Modelling efforts, which follow this stressor identification effort, will determine the extent of contribution from urban/residential areas.

Inconclusive causes

- Pesticides - the relatively small amount of pesticide data collected specifically for this study by MPCA is not adequate to eliminate pesticides from contributing to impairments. The jurisdiction for the collection of pesticide data is the MDA. The MDA data provided to the MPCA for the MRW has not shown levels above Minnesota standards.

Candidate causes

- Low dissolved oxygen
- Excess sediment (both suspended and deposited)
- Altered hydrology
- Altered geomorphology
- Habitat loss
- Connectivity loss
- Elevated phosphorus
- Elevated nitrogen
  - Ammonia
  - Nitrate as nutrient
  - Nitrate as a toxicant

Mechanisms of candidate stressors and applicable standards

This section presents a brief overview of the pathway and effects of each candidate stressor. USEPA (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

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 was collected at many locations in the MRW 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 and are not completely representative of the DO regime at a given site.
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 (USEPA 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 (USEPA 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 (USEPA 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. Modelers at the MPCA have suggested that determining flow alteration in Red River Basin streams would be very difficult, due to the high degree of landscape and stream modification. The increased use of agricultural tile will generally tend to exacerbate the flashy hydrograph and the associated impacts to the stream's organisms. 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 (USEPA, 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.

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.

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.

Water quality standards

The previous water quality standard for suspended sediment was based on turbidity. Minnesota has nearly 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 National Pollutant Discharge Elimination System (NPDES) conditions resulting from the varied geology of the state and biological sensitivity. The new TSS standard for the MRW is 65 mg/L. A Secchi tube measurement of 10 cm of visual transparency is a surrogate for the TSS standard in the MRW. 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. Typically, fine mineral matter is more concerning and 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 visually 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} 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 phosphorus (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 4). The TP standard is a maximum concentration also requiring at least one of three related stressors above its threshold.

Table 4. River eutrophication criteria ranges by River Nutrient Region for Minnesota. The MRW is placed in the South Region.

Region	TP µg/L	Related Stressor		
		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

Water samples were collected from streams and rivers throughout the MRW. The most common data is for TP, though orthophosphorus samples were collected in some cases. 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 karst geology and heavily tiled watersheds) nitrate transport can become very significant. The soils and geology in the Red River Basin (RRB) are quite different from this situation, as is the extent of tile drainage (though this is becoming increasingly common in the RRB), so subsurface transport to waters will be less of a pathway here than some other prominent agricultural regions of Minnesota. However, given the amount of cultivated cropland in the MRW, it is feasible that fertilizer application could be a prominent source of nitrate in surface water and, with the increase in subsurface tiling, is likely to become more of a water quality issue in the RRB. 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 is actively developing an aquatic life standard for nitrate toxicity.

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) data for minimally-impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. Most of the MRW falls within the Red River Valley ecoregion, which has an ecoregion norm of 0.2 mg/L for Nitrate+Nitrite, N.

Types of nitrate data

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

Candidate cause: Physical habitat loss

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

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

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

Just like for terrestrial settings and those animals, aquatic population and community changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (USEPA, 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 MDNR 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/MDNR 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 dissolved oxygen, and water temperature also affects the toxicity of numerous chemicals in the aquatic environment. Algal blooms are often associated with temperature increases (EPA, 1986). Water temperature affects metabolism (and thus food and oxygen needs) and regulates the ability of organisms to survive and reproduce (EPA, 1986). Different organisms are adapted to and prefer different temperature ranges, and will thrive or decline based on the temperature ranges found in a stream. For more information on the causes and effects of elevated temperature, see EPA's CADDIS website: http://www.epa.gov/caddis/ssr_temp_int.html.

Water quality standards

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

Types of temperature data

Both point and continuous temperature data has been collected. Continuous data is measured at 15 minute intervals.

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 unionized ammonia (NH_3) concentration, which is toxic to aquatic organisms at certain concentrations. The fraction of 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 ammonia value is calculated from the ammonium, temperature, and pH at the time of collection.

Candidate cause: Specific conductance

Specific conductance refers to the collective amount of ions in the water. In general, the higher the level of dissolved minerals in water, the more electrical current can be conducted through that water. The presence of dissolved salts and minerals in surface waters does occur naturally, and biota are adapted to a natural range of ionic strengths. However, industry runoff and discharges, road salt, urban stormwater drainage, agricultural drainage, WWTP effluent, and other point sources can increase ions in downstream waters. Aquatic organisms maintain a careful water and ion balance, and can become stressed by an increase in ion concentrations (SETAC, 2004). Ions of many elements, such as calcium, sodium, and magnesium are necessary for aquatic health, but imbalances can be toxic (SETAC, 2004). There has not been much research into how specific ions, and at what level, can become toxic to individual species. Associations from research, between species and toxicity levels of ionic strength are limited, and so it may be difficult to confidently conclude that specific conductance is a stressor. The causes and potential sources for high ionic strength are modeled at: http://www.epa.gov/caddis/ssr_ion_int.html.

Water quality standards

Minnesota does not have an aquatic life standard for specific conductance.

Types of ionic strength data

Like DO, specific conductance readings can be collected by deployed devices at defined time intervals, or a single, instantaneous reading taken during a site visit.

Candidate cause: pH

Acidity is measured on a scale called pH, ranging from 0 to 14, with values of 0 to 6.99 being acidic, 7.0 neutral and above 7 being basic. Human effects on pH values can result from agricultural runoff, urbanization, and industrial discharges. Some geology produces naturally high hydrogen ions that can leach into surface water, but it would be rare for this to be the only cause when pH is a stressor. Photosynthesis from unnaturally-abundant plants or algae removes carbon dioxide from the water, causing a rise in pH. As pH increases, unionized ammonia (the toxic form of ammonia) increases, and may reach toxic concentrations (USEPA 2012a). Low pH values contribute to elevated ionic strength of water (more dissolved minerals). High or low pH effects on biology include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Values of pH outside the range of 6.5 - 9 or highly fluctuating values are stressful to aquatic life (USEPA 2012a). A conceptual model for pH as a stressor can be found on EPA's webpage: http://www.epa.gov/caddis/ssr_ph_int.html#highph.

Water quality standards

The pH standard for Class 2B (warmwater) streams is within the range of 6.5 as a daily minimum and 9 as a daily maximum (MN Statute 7050.0222 subp. 4).

Types of pH data

Like DO, pH readings can be collected by deployed devices at defined time intervals, or a single, instantaneous reading taken during a site visit.

Candidate cause: Pesticides

A pesticide is defined by the EPA as, "any substance intended for preventing, destroying, repelling or mitigating any pest." In this document, pesticides refer to fungicides, insecticides, and herbicides used to control various pests.

Herbicides are chemicals used to control undesirable vegetation. The most frequent application of herbicides occurs in row-crop farming, where they are most often applied to the crop during an early growth stage (often in June) to reduce the competition for water and nutrients from weeds. They may also be applied before crop emergence, a second time during the growing season, and pre-harvest. In suburban and urban areas, herbicides are applied to lawns, parks, golf courses, and other areas. Herbicides are also applied to water bodies to control aquatic weeds that impede irrigation withdrawals or interfere with recreational and industrial uses of water (Folmar et al., 1979).

Insecticides are chemicals used to control insects. Many insecticides act upon the nervous system of the insect, such as Cholinesterase inhibition, while others act as growth regulators. Insecticides are commonly used in agricultural, public health, and industrial applications, as well as household and commercial uses (e.g. control of roaches and termites). The U.S. Department of Agriculture (2001) reported that insecticides accounted for 12% of total pesticides applied to the surveyed crops. Corn and cotton account for the largest shares of insecticide use in the United States. To learn about insecticides and their applications, along with associated biological problems, refer to the EPA CADDIS website: http://www.epa.gov/caddis/ssr_ins_int.html.

Water quality standards

The MPCA has developed toxicity-based aquatic life standards for four herbicides and one insecticide; the chronic and maximum standards for these pesticides are shown in Table 5.

Table 5. Summary of MPCA surface water standards for pesticides (all units are µg/L).

Pesticide	Chronic Class 2A[1]	Chronic Class 2B	Maximum Standard 2A and 2B
Acetochlor	3.6	3.6	86
Alachlor	3.8	4.2	800
Atrazine	3.4	3.4	323
Chlorpyrifos	0.041	0.041	0.083
Metolachlor	23	23	271

[1] Chronic standards for aquatic organisms are protective for an exposure duration of four days

Types of pesticide data

Since 1985, MDA and Minnesota Department of Health (MDH) have been monitoring the concentrations of common pesticides in groundwater near areas of intensive agricultural land use. In 1991, these monitoring efforts were expanded to include surface water monitoring sites on select lakes and streams. The MDA annually collects samples from various surface water bodies throughout the state and analyzes those samples for the presence of pesticides and their degradates. The MDA attempts to capture the influence of different land uses on surface water resources. Out of the 100-plus pesticides this program routinely analyzes for, three have been named a "surface water pesticide of concern" in Minnesota - acetochlor, atrazine, and chlorpyrifos. When pesticides are detected at problematic levels, the MDA intensifies their monitoring in that area to locate the source and extent of the problem, so that it can be corrected. To learn more about the MDA pesticide monitoring plan and results, see the MDA web page: http://www.mda.state.mn.us/protecting/cleanwaterfund/pesticidemonitoring.aspx.

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 feature (i.e., 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). Due to the objectives of this study, vertical connectivity was not directly assessed.

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, though new design guidelines for culverts have been developed by Minnesota Department of Transportation 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 for unknown structures. Culverts are visited to determine their organism passage capability.

Investigations organized by impaired stream

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. Geomorphological analysis is discussed for each AUID, but a more thorough presentation of the geomorphological work and analysis from the whole watershed and broader region can be found in Appendix 1, which is a report written by project contractor Emmons and Olivier Resources, Inc.

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.

Unnamed Tributary to Mustinka River (AUID 09020102-538)

Impairment: The creek was assessed as impaired for not meeting fish and macroinvertebrate community expectations at 10RD042 (CSAH 15).

Initial data

Chemistry

The results of water chemistry monitoring from the IWM project are shown in Table 6. Though this is a very small data set, these particular results are good, with the exception that TP is essentially right at the new standard threshold of 0.150 mg/L.

Table 6. Water chemistry measurements collected during 2010 IWM. Values are in mg/L.

Date	DO	TP	Nitrate	Ammonia	Un-ionized Ammonia	pH	TSS	TSVS
June 7	8.34	0.148	0.111	0.114	0.008	8.18	22.4	< 4.0
August 9	8.14	--	--	--	--	7.98	--	--

Habitat

There was good flow during the fish and macroinvertebrate sampling visits in 2010. The MSHA score at 10RD042 was very good, receiving a score of 70.8, the second highest score of 30 sites in the MRW (Photo 2). The one instream component that was lacking was substrate complexity, as there was only fine particulate material present.

Photo 2. Photo from the August 9, 2010 macroinvertebrate visit. There is some good macroinvertebrate habitat here. Note that the water in the lower right is clear, and the left side is stirred up by the photographer showing the fine sediment that makes up the substrate. The circled area shows a good matrix of large, submerged wood in an area where there is significant water velocity - this is prime elimination of many of the sensitive taxa (EPT) habitat, as well as good fish habitat.

It is important when examining small, headwater streams to consider their connections to downstream areas that are seasonal sources of organisms for re-inhabiting these small streams during the growing season. In this case, the downstream source area is the adjacent section of the Mustinka River (AUID-506), which is bracketed by two small lakes; Stonybrook and Lightning. The "stream-like" habitat of this adjacent Mustinka River section where Unnamed Creek enters is only a short, approximately 350 meters long, reach that flows between Stonybrook and Lightning Lake. From aerial photos, it appears that habitat in this short reach is fairly good, with natural riparian conditions, and good sinuosity. However, the remainder of the habitat on both ends of this isolated Mustinka River reach is poor habitat for both fish and macroinvertebrates, having wetland-like characteristics (Photo 3). This Mustinka River AUID has very low DO, and water quality and game fish habitat is poor in Lightning and Stonybrook Lakes. Lightning Lake is listed as impaired for nutrients, while the smaller Stonybrook Lake has not been sampled. MDNR's LakeFinder webpage comment from June 2008 regarding Lightning Lake: "Maximum depth of this shallow basin is just 11.0 feet, which makes it prone to occasional winterkill. The last winterkill event occurred during the winter of 2007-2008. Consequently, fish community diversity and fishing opportunities are limited . . . 2008 survey results revealed the impact of the 2007-2008 winterkill event. . . . Non-game fishes tolerant of low DO levels comprised the most of the total capture sample". Downstream areas such as this more substantial river area and the two close-proximity lakes would normally be an important source and/or refuge area for fish, and to some degree, macroinvertebrates during times of flow intermittancy. However, this Mustinka River reach is likely not serving this ecological function very well due to the marginal and wetland-like condition of these areas. Implications of this situation will be discussed below.

Photo 3. Mustinka River looking upstream from the 320th Street. crossing - just downstream from the mouth of Unnamed Tributary to Mustinka River. The surface is completely covered by duck weed.

Biology

Even though there was hard substrate present and sampled, in the form of LWD, there were no EPT taxa collected in the sample. The sample consisted of gastropods, fingernail clams, amphipods, Diptera (mostly Chironomidae), Hemiptera, and Coleoptera. These are all taxa that do not require moving water as a habitat need and could survive in remnant pools when the flow stops during the intermittent periods. Such a pool occurred at the culvert of CSAH 15. In some streams, benthic macroinvertebrates are known to take refuge deeper into the substrate (the hyporheic zone) when flows stop. This phenomenon requires a substrate having interstitial spaces (small gaps between substrate particles), meaning gravel and/or coarse sand composition. This is logical because most benthic invertebrates are not adapted to burrowing in fine sediments, especially if the material is relatively compacted, such as clay. In such situations, several studies have found that the hyporheic zone is not a refuge for benthic macroinvertebrates (Wood et al., 2010). AUID-538 is a stream with a fine particle, mud-type substrate and little if any of this type of refuge habitat exists to support many of the important macroinvertebrate species.

Like the macroinvertebrates, the fish species collected at 10RD042 are also tolerant of low DO conditions, and able to live in wetland habitat (Table 7), such as is found within the adjacent Mustinka River reach. The two abundant species found at 10RD042 are thus able to take refuge in the downstream Mustinka River, and Lightning and Stonybrook Lakes when the stream goes dry. However, those downstream habitats are not suitable for many other fish species, especially in their impaired condition. These downstream habitats are not suitable for EPT macroinvertebrates either, even were they not impaired, and so this area does not serve as a source area for repopulating AUID-538 with EPT species during favorable flow conditions.

Table 7. Attributes of fish sampled at 10RD042.

		MPCA attribute			
Species	**Number**	**Tolerant**	**Very Tolerant**	**Wetland**	**Tolerant of Low-DO**
brook stickleback	226	x		x	x
fathead minnow	127		x	x	x
white sucker	1	x			

Targeted investigation and results

Chemistry

On August 1, 2013, water samples were collected for analysis of common chemistry parameters (Table 8) to augment the IWM chemistry data set. Water temperature was abnormally cool for this time of year and the measured DO levels may have been higher than typical for this date and time. The TP value was significantly under the MPCA draft standard, and ammonia levels were low. TSS was almost identical to the 2010 sample, and was well within the acceptable level for this region. Chl-a was significantly lower than the new standard for this region. A TP sample was also collected just downstream of the mouth of Unnamed Creek, in the Mustinka River (AUID-506) at the crossing of 320th Street. The result showed a high concentration of TP, at 0.251 mg/L.

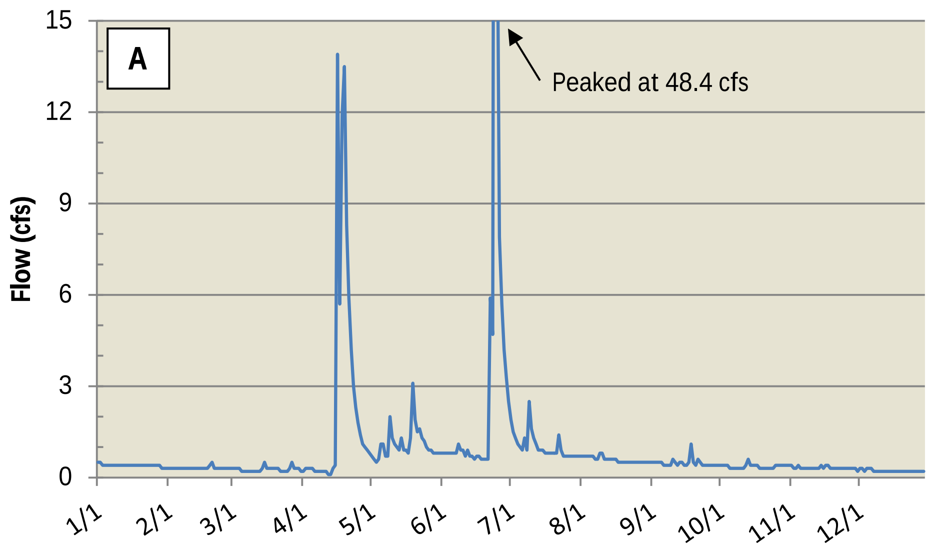
Table 8. Chemistry values collected on August 1, 2013 at S004-354 (=10RD042), in mg/L unless noted otherwise.

Time	Temp. ^{o}C	DO	TP	OP	Chl-a µg/L	Ammonia	TSS	TSVS	TSS-mineral
12:27 PM	18.8	7.41	0.085	0.065	9.51	0.08	23	5.2	18

A continuous-recording sonde is typically deployed in reaches that are biologically impaired, in order to better understand DO concentrations and patterns. Such a deployment was attempted in both late July 2012, and early August 2013. The stream had no flow during either attempt, though the deep pool at the culvert did hold water. Therefore, little additional information about DO levels is available.

Hydrology

As mentioned, the sonde deployment attempts in both years found a dry channel. There was still significant water pooled in the deep hole at the CSAH 15 culvert, but upstream and down, there was only damp mud in the channel. This experience suggests that the stream commonly goes dry in mid-late summer. To further explore this scenario, the modeling contractor (EOR, Inc.) ran the Hydrologic Simulation Program Fortran (HSPF) model for the years 2001-2006, which calculated daily flow volume (cubic feet per second). Modeling results (Figure 5) predicted frequent no-flow (i.e., dry) periods in August, and actually over fall and winter as well. Though the model output shows a very small amount of flow at all times, the modeler noted that HSPF tends to over-predict flows in small headwater streams such as this. Thus these very small predicted flow volumes may actually be periods of no flow. Though the actual size of the over-prediction is not known, it seems reasonable to suspect that with the known over-prediction, the days below one cubic foot per second may actually have had zero flow, and the creek may have been dry. The number of days during the July through September period with flows predicted as one cubic foot per second is shown in Table 9. Implications of this hydrologic pattern are discussed in the conclusion section following.



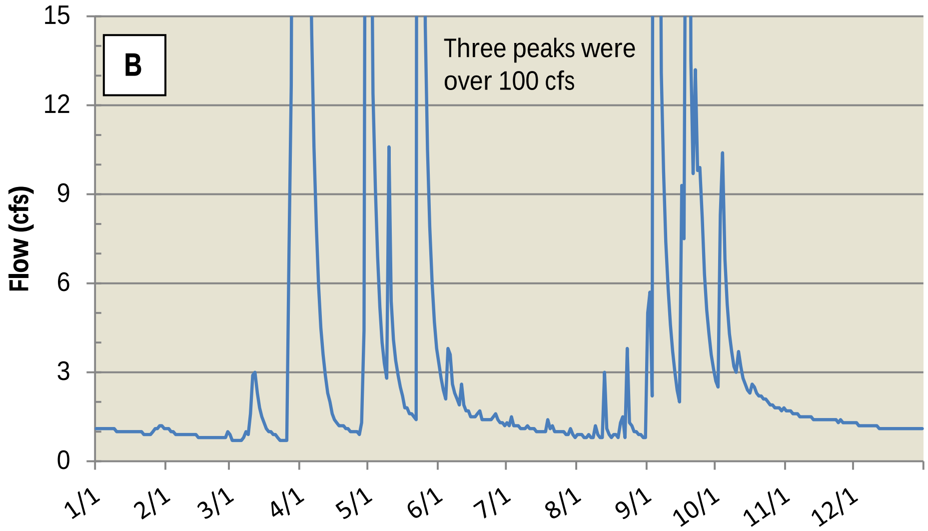


Figure 5. HSPF model flow output for site 10RD042 (CSAH 15). A. 2003 - a dry year, B. 2006 - a wetter year.

Table 9. Number of days from July 1 – September 30 with flow values less than or equal to one cubic foot per second, and average daily flow values for the same seasonal period at 10RD042. Data was from the model output.

Year	2001	2002	2003	2004	2005	2006
Days ≤ 1.0 cfs	0	60	81	50	0	37
Average cfs	1.99	2.86	0.70	5.41	2.97	5.92

Two visual ways to interpret the changes to hydrology in the subwatershed are to view the MPCA's Altered Watercourse Project GIS layer, and the National Wetlands Inventory Restorable Wetlands GIS layer. These layers are diagramed in Figure 6. As can be seen, there have been extensive changes to both channels and wetlands, but it is complex to determine how these changes have altered hydrology. Some of the original wetlands were likely not contributing to stream flow, at least by surface runoff, as many RRB wetlands were part of small, isolated basins (i.e. in depressions of the landscape that didn't have a surface outlet). A rigorous computer modelling exercise would be required to determine how all the various factors affect the current hydrological regime, and how it differs from the historical regime. At this time, such a modelling effort has not been completed.

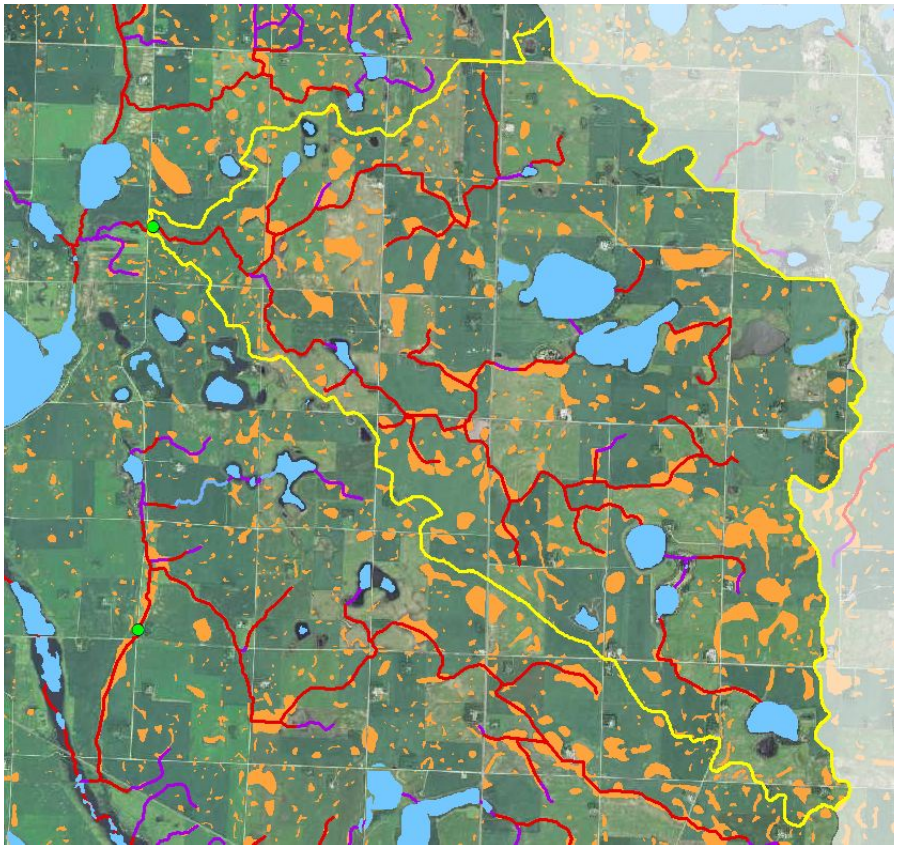


Figure 6. Altered hydrology in the subwatershed of 10RD042. The green dot is 10RD042, the yellow lines outline the contributing subwatershed, the red lines are either altered natural stream channels or constructed channels, purple lines are non-definable channels, and the orange shapes are locations where there were pre-settlement wetlands that are no longer wetlands (i.e., have been drained) or are partially drained.

Conclusions

The biological impairments in AUID-538 are most likely due to frequent intermittency in August and over the winter. The model predicted that no-flow periods in August would have occurred most years during the period from 2001-2006. The absence of refuge habitat for macroinvertebrates, due to the mud/clay natural substrate, means that macroinvertebrates would annually encounter a major setback in abundance, resulting in EPT. The lack of sensitive taxa represents the repeated occurrence of this no-flow phenomenon and a lack of opportunity for the macroinvertebrates to re-colonize the stream from nearby refuge habitat. The downstream-adjoining Mustinka River, being a wide, wetland-like flowage in the area where the AUID-538 enters, is also very unsuitable for EPT taxa. The importance of downstream, suitable refuge habitat was demonstrated by Griswold et al. (1982). The macroinvertebrates that would remain in pooled-up water within AUID-538 would be wetland-oriented taxa which can withstand warm, stagnant water due to their ability to breathe from the atmosphere (e.g., Corixidae, Dytiscidae, and Hydrophilidae). Again, this was found to be the case in the Griswold et al. study (1982). These same tolerant taxa would be found in the adjacent Mustinka River, which would also provide a repopulation source for the creek.

The fish community would also have a difficult time in this AUID, again due to the creek's intermittency. Though fish are much more mobile than macroinvertebrates, there is not a good source area downstream for fish to take refuge while the creek is in a dry condition, given the Mustinka River's wetland-like character in this area. Sensitive fish species would not survive in the Mustinka River's habitat, meaning Unnamed Creek is literally cut off from a source population of diverse fish species, and importantly the more sensitive fish species are not present to re-populate the creek when flow conditions are sufficient. The Griswold et al. study (1982) also stressed a need for suitable, downstream refugia for fish during drought.

The degree of hydrological alteration within this subwatershed due to agricultural land usage is significant as much of the upstream channel system (approx. 85%) is channelized or ditched. Channelization, along with the loss of wetland storage, laser-guided grading of farmed-through headwater streams, and tiling of the shallow groundwater has exacerbated of the effect of typical late-summer dry down conditions. Although the late-summer low-flow period occurs on a natural basis, impacts to stream hydrology from agriculture result in an increased frequency, areal extent, severity, and duration of these dry-down events, and has a significant impact on the biological communities. Hydrologic modelling of watershed conditions comparing the current situation of vegetation change, ditching, and wetland drainage to the natural pre-settlement condition would allow a better quantification of how this creek is being degraded by human activity. Such modeling would also provide insight into what actions could be taken to increase baseflow at critical times of the year.

Mustinka River (AUID 09020102-580)

Impairment: The river was assessed as impaired for not meeting fish community expectations at 10RD037, located at CSAH 13, approx. 6 mi. NE of Herman. Additionally, this AUID is impaired for aquatic life and on the 303d list for the parameters DO and turbidity.

Initial data

Chemistry

Dissolved oxygen

There are 87 instantaneous DO measurements in the EQuIS database for S003-104, which is located at near the downstream end of the AUID. This location is also the site of the biological sampling station 10RD037. The lowest reading was 2.3 mg/L, three other visits had concentrations below 3.0 mg/L, and 11 measurements total were below the standard of 5.0 mg/L. It should be noted that these 87 measurements were not necessarily the minimum DO values for those dates (which occurs around sunrise) and more of these dates may have had periods of substandard oxygen levels. The DO in this AUID was assessed as not meeting the state standard and a TMDL for DO is required.

Phosphorus

The June 16, 2010 water sample from the 10RD037 fish sampling visit found a TP concentration of 0.384 mg/L. TP data from this site from the period of 2002-2012 are shown in Figure 7. These data show problematic TP levels occurring over a broad period of the year, and over a number of years, highlighting this as a chronic issue. The newly-adopted TP standard was exceeded by 36 of the 44 samples (83.7%).

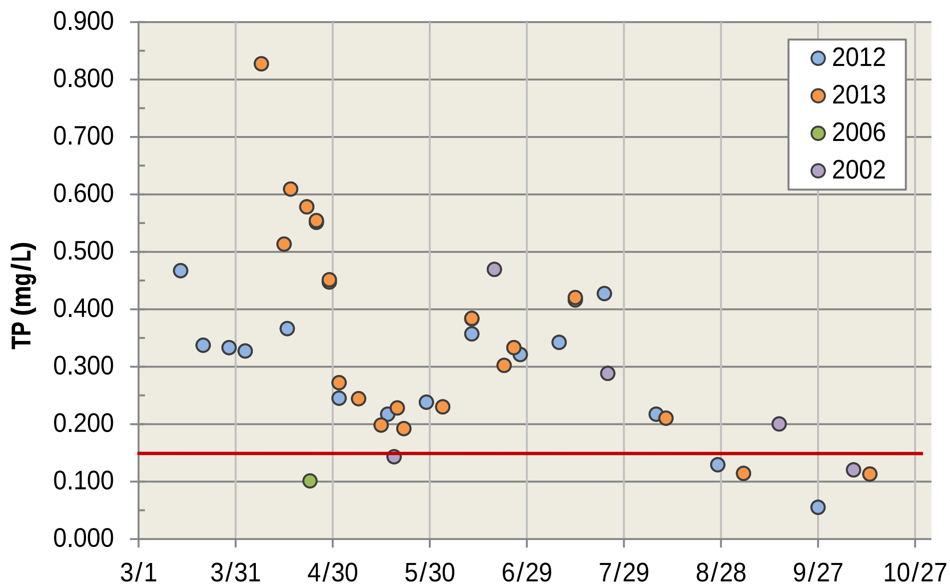


Figure 7. TP concentrations at S003-104 (= CSAH 13, = 10RD037). The red line is the newly-adopted Minnesota standard.

Nitrate

Nitrate concentrations are generally at fairly good (i.e., low) levels; however, there appears to be a seasonal aspect to the concentrations (Figure 8). Levels are significantly higher in April, during and just after snowmelt. This might be explained as a consequence of fall application of ammonia fertilizer to farm fields and the flushing of nitrates from the landscape during the spring runoff period. The concentrations at this time are approaching those considered to be toxic to aquatic organisms. The monitoring here is part of a long-term effort, and more data will be gathered each year, which will show whether this pattern is annually consistent or common, or was a one-time weather-related event.

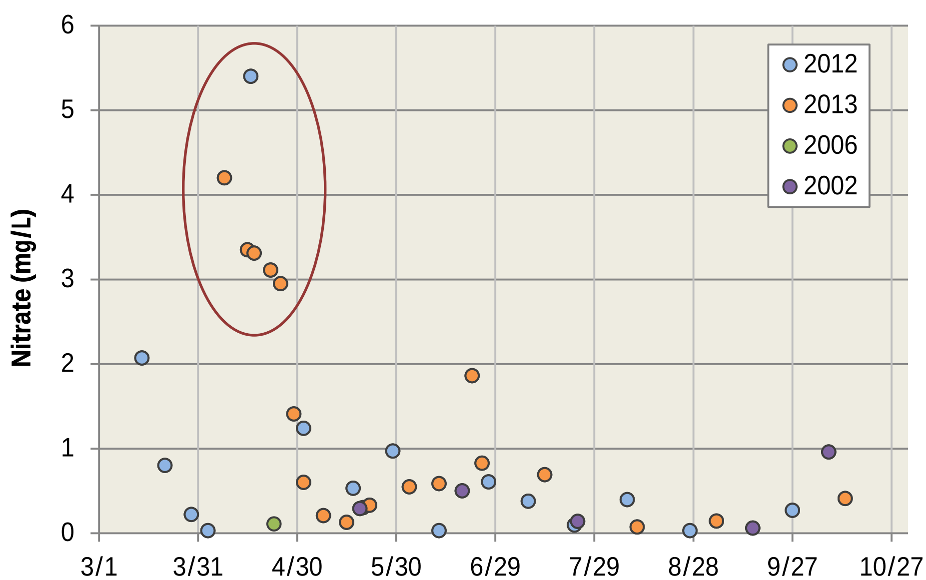


Figure 8. Nitrate concentrations at S003-104 (= CSAH 13, = 10RD037). The circled values are nearing the point where nitrate toxicity for aquatic organisms may occur.

Ammonia

While there was little ammonia data collected at S003-104, there is more ammonia data from further upstream within this AUID at S003-105 (CSAH 8). At S003-105, seven samples were collected throughout the 2009 growing season, and results ranged from less than the detection limit of 0.04 mg/L to 0.142 mg/L. The required pH and water temperature data were not co-collected with this ammonia data, so an exact concentration of un-ionized ammonia cannot be calculated. However, none of these concentrations should have an associated un-ionized ammonia concentration at levels toxic to aquatic life, based on the fact that un-ionized ammonia is generally < 5% of the ammonia levels.

Turbidity/TSS

Turbidity in this AUID does not meet the state standard and a TMDL for turbidity is required. The TSS measured during the fish sampling visit was high (82.4 mg/L) relative to the newly-adopted state standard of 65 for this region.

Habitat

This AUID is composed of alternating natural and ditched/channelized reaches. Site 10RD037 is at the lower portion of one of the natural reaches. The downstream boundary of the AUID is at the beginning of the Mustinka Flowage, the reservoir produced by the Pine Ridge Park dam. The following, from MDNR LakeFinder, describes habitat in this reservoir: "Sediment deposition has reduced maximum depth of the reservoir from approximately 18 feet to 8 feet. Dense algal blooms and suspended sediment limit water clarity. Secchi disk measurements generally do not exceed 2.0 feet. Rooted aquatic plants are limited by poor water clarity and thus sunfish densities are low."

The MSHA score of 41.2 for 10RD037 was below average for the MRW (49.45), and is categorized as poor. Of the five MSHA component parts, the poorest-scoring was substrate, which received a 7.2 of 27. What gravel substrate was present was rated as being severely embedded, meaning covered by fine-particle sediment. The presence of the dam at Pine Ridge Park has significantly reduced the upstream gradient, meaning the stream has less ability to move fine sediment, which is settling out and smothering important biological habitat. The presence of excess sediment in AUID-580 is also substantiated by the 303(d) impairment listing for turbidity. Although MSHA scores were not determined from any of the channelized reaches in this AUID, those reaches would likely score no better, given that the natural sites normally have better sinuosity, which is a positive factor in the MSHA score. Interestingly, it appears that some large-scale sinuosity was left in the channelized reaches in this AUID (i.e., the channels are not straight), because the channel pattern is nearly the same today as in the 1938 aerial photo (Photo 4).

Connectivity

The AUID starts at the outlet of Lightning Lake and ends at the beginning of the Mustinka Flowage. One obvious potential stressor is the dam at Pine Ridge Park, a complete fish barrier at all flow conditions, which prevents fish immigration into AUID-580 from the lower Mustinka River and Lake Traverse. There were biological sample sites located a short distance above and below the dam, which provided a good opportunity to see the effect of the dam on the fish community. The distance between these sites, 10RD037 and 10RD036, is approximately six river miles. No significant tributaries exist between the two sites to change the flow volumes or water chemistry. A comparison of the fish communities at the two sites are shown in Table 10. The site below the dam showed a healthy fish community. Six more species were collected below the dam than above it. The fish that are missing from the sample taken above the dam are larger species, and many of those are predators (piscivores); channel catfish, white bass, perch, walleye, crappie, and freshwater drum. Interestingly, perch, walleye, and crappie are found in the Mustinka Flowage (Pine Ridge Park Reservoir). Possibly related to this finding is the absence of fathead

Photo 4. Meander pattern has not changed much between 1938 (R) and 2013 (L).The MPCA has determined, with moderate confidence, that this reach has been historically altered.

Table 10. Fish communities sampled at 10RD036 (below dam) and 10RD037 (above dam). Red names are considered migratory species.

FieldNum	FishClass	FishClassName	VisitDate	VisitResult	ChanCon	CommonName	Number
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	northern pike	1
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	common carp	3
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	hornyhead chub	9
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	emerald shiner	12
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	sand shiner	11
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	fathead minnow	1
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	channel catfish	3
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	black bullhead	1
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	white bass	1
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	black crappie	2
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	yellow perch	7
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	freshwater drum	4
10RD036	2	Southern Streams	16-Jun-10	Reportable	NA	walleye	4
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	northern pike	1
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	common carp	12

FieldNum	FishClass	FishClassName	VisitDate	VisitResult	ChanCon	CommonName	Number
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	fathead minnow	18
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	black bullhead	2
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	brook stickleback	39
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	Iowa darter	1
10RD037	2	Southern Streams	16-Jun-10	Reportable	NA	white sucker	10

minnows and white suckers below the dam, though both exist above it. These are species that would be commonly eaten by predatory species such as walleye and perch. The fish community above the dam is more tolerant, suggesting that there may periodically exist conditions in the upstream AUID that are not acceptable to sensitive species. The dam also prevents those species from temporarily finding suitable habitat conditions downstream and returning again when conditions become favorable, meaning that those species are permanently lost to this AUID, unless stocked.

A secondary analysis was made regarding fish designated as “migratory”, as another way to assess the connectivity issue. That metric does not show a highly significant response, as each reach (above the dam versus below the dam) has two migratory species, though the species differ between reaches, and numbers of these species are low relative to the whole community in each reach. One difference is that the migratory species found below the dam are oriented to larger waterbodies, while the two species found above the dam are commonly found in smaller streams, thus showing the inability of fish to emigrate into the upstream AUID from the larger areas of the Mustinka River and Lake Traverse downstream.

A third analysis has been done by MDNR as part of a broader analysis of the effect of dams within the RRB (MDNR Stream Habitat group, personal communication). MDNR combined the MPCA samples in the MRW with other samples they collected in earlier years, and found that of the 31 fish species collected in the MRW, 15 were not present above the Pine Ridge Park dam.

Geomorphology

AUID-580 contained two EOR, Inc. geomorphology study locations, denoted EOR-114 and X-B (see Figure 34 in the appendix). At EOR-114, the channel appears to be over-widened, as the banks are eroding and raw, and have sloughing sod mats (Photo 5). A historical cross-section also confirms that there is some channel instability at this location; over the last decade, the channel cross-section has enlarged in both width and depth (Figure 9). Bank Erosion Hazard Index (BEHI) ratings were taken at seven locations in the EOR-114 reach (Table 11). Overall the erosion hazard rating is moderate, though one location was high. These geomorphic data suggest that a significant amount of the excess sediment and turbidity in AUID-580 is due to bank and bed erosion.

Photo 5. Geomorphology study site EOR-114, showing eroding and sloughing banks.

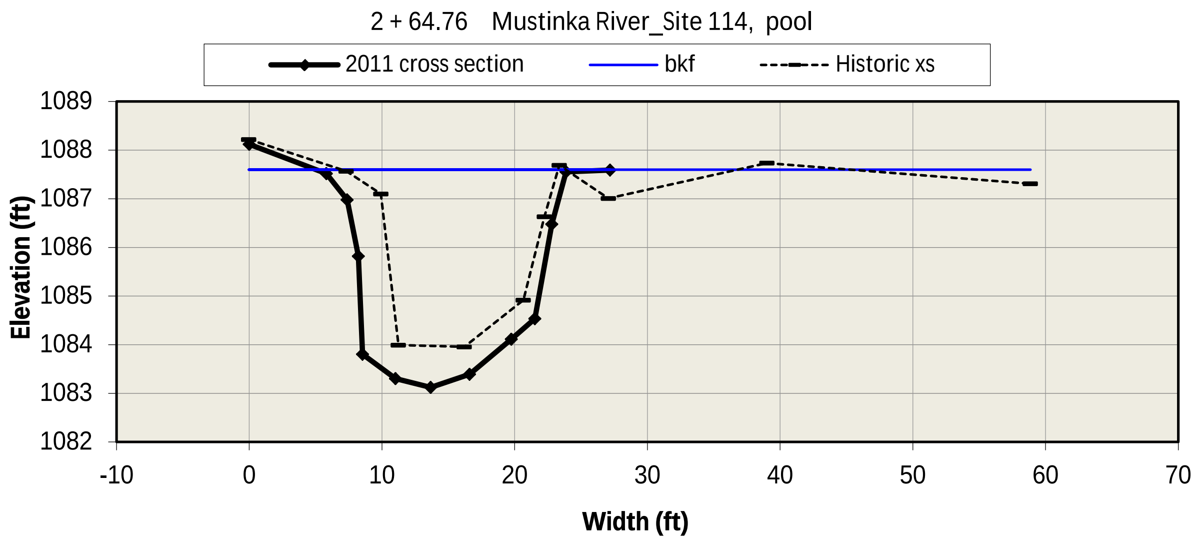


Figure 9. Comparative cross-section, surveyed in 2001 and 2011, showing channel enlargement.

Table 11. BEHI ratings for seven locations at EOR-114. "Very Low" is the best bank condition.

BEHI Rating	Very Low	Low	Moderate	High	Very High
# of locations	1	1	4	1	0

Biological response

In addition to the biological differences between upstream and downstream of the dam, the fish community at 10RD037 also shows a response to the low DO concentrations sometimes found there. Of the seven species collected in the MPCA fish sample at 10RD037, the three most abundant species (brook stickleback, fathead minnow, and common carp), which made up 83% of the individuals caught, are all very tolerant of low DO. Two of the other species present are also very tolerant to low DO (black bullhead and northern pike).

The reservoir at Pine Ridge Park would seem to be a source area for fish to populate AUID-580. MDNR last surveyed fish (game or other larger species) in the Mustinka Flowage in 2008 (Table 12). According to MDNR LakeFinder, "Mustinka Lake is prone to occasional winterkill." The local MDNR fisheries supervisor was consulted regarding winterkill occurrences in the years immediately preceding the MPCA fish sampling (2010), and he had no knowledge of any winterkills (at least significant ones) occurring within at least six years prior to their last sampling effort in 2008. MDNR is not aware of public reports of fish kills between 2008 and the summer of 2010. Although several of the species collected in the Mustinka Flowage (e.g., bluegill, walleye, yellow perch) can be found in streams the size of the Mustinka River above the reservoir, none of these were caught in the 10RD037 sampling. Two plausible explanations for this are: 1) that they are not present because of the low DO conditions in AUID-580, and 2) as the MDNR description of the Mustinka Flowage suggests, its poor health precludes it from being a significant source for population supplementation. It is possible that previous winterkills have reduced the viability of certain species in this AUID, since the dam prevents re-population from refuge areas farther downstream of the flowage.

Table 12. 2008 MDNR fish survey of the Mustinka flowage.

Species	Number caught
black bullhead	690
black crappie	192
bluegill	3
common carp	64
largemouth bass	1
northern pike	26
walleye	28
white sucker	12
yellow bullhead	9
yellow perch	4

Targeted investigation and results

Because there were two existing conventional parameter aquatic life use impairments for this AUID (DO and turbidity), as well as the clear issue of the dam being a barrier to fish movement into and out of AUID-580, little additional investigation was conducted in this AUID, other than the deployment of a sonde to explore the daily minimum DO readings and assist the modelling effort.

Chemistry

Dissolved oxygen

A sonde was deployed for six days, from July 24 - 31, 2012 at 10RD037 (= CSAH 13). During this period, there were two days with periods in which the DO concentration fell below the standard (Figure 10). The daily minimum for those two days was about 4.0 mg/L. There was a prolonged rain event over these days, and the overcast skies would have reduced photosynthesis. Some flushing of wetlands may also have contributed to the reduced DO, although there was actually a nocturnal increase in DO just after the rain started. When the weather returned to a partly sunny condition over the next several days, the typical symmetrical “sine wave” daily fluctuation pattern returned and the DO levels were better. Part of the improvement in DO may have been increased flow volume in the river. The observed DO pattern over these days may suggest that DO is particularly a problem at lower flow conditions. Additional sonde deployments in this AUID would help define the conditions when DO is at problematic concentrations.

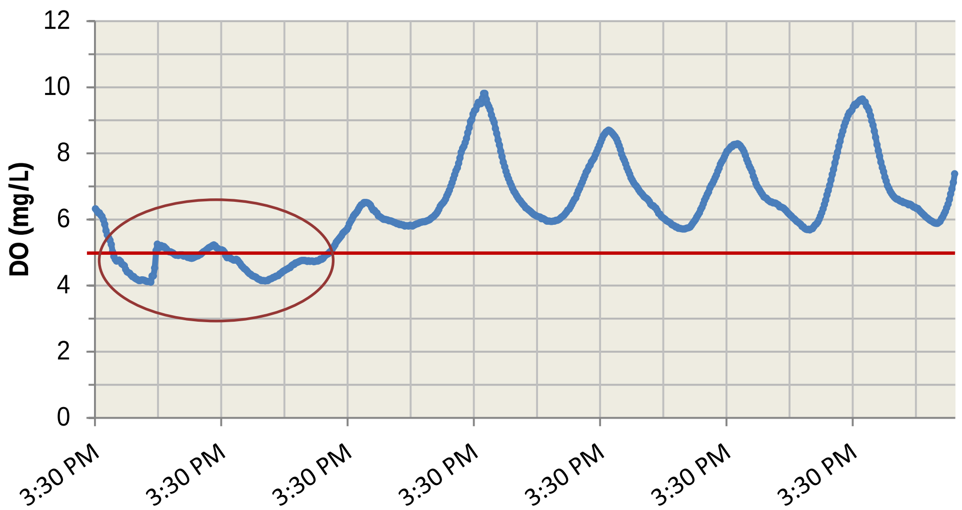


Figure 10. Sonde DO data for July 24 - 31, 2012, at 10RD037 (CSAH 13). The weather for the period covering the circled area was likely overcast during the day, and thus less photosynthesis occurred in the river. The red line represents the Minnesota standard.

Conclusions

The fish community in AUID-580 is suffering due to a number of factors. The two conventional parameter impairments (DO and turbidity) are causing much of the habitat degradation. Besides causing turbidity, excess sediment is smothering important hard-substrate habitat. High phosphorus concentration (i.e., nutrient loading) is likely a major factor contributing to the depressed DO and the excess turbidity is likely exacerbating low DO due to elevated water temperature from the increased solar absorbance of the darker, turbid water.

In addition to nutrient loading, another primary cause of the biological stressor is altered hydrology, both from land drainage, as well as the Pine Ridge Park Dam, the latter having reduced the stream gradient. There are clear signs of channel instability along this AUID. An unstable channel results in excess sediment, habitat degradation, turbidity, temperature elevation, and a decreased level of oxygen. Altered hydrology leads to unstable channels and reduced baseflow, which then results in numerous follow-on effects.

The third root cause of the fish community impairment is blockage of migration to and from downstream reaches. Removal of the dam at Pine Ridge Park would likely help the biological community in several ways: 1) by allowing fish immigration from further downstream; 2) by increasing gradient which would provide cleaner hard substrate and probably improve DO readings by allowing less algal growth in the swifter waters; and 3) by allowing for a more complex habitat to develop via creation of riffle-pool sequences as flow velocity improves. Removal of the dam, possibly with the placement of a rock rapids to aid migration, should be evaluated as these projects often result in immediate and significant improvement to aquatic communities. Benefits of dam removal would have to be evaluated related to costs. Among these are loss of a recreational amenity, possible reductions in stream volumes during baseflow conditions, and a loss of storage for flood control purposes. Hydrologic modeling, followed by technical evaluation by fisheries staff trained in river restoration, should be retained to inform any dam removal/alteration decision.

Regardless of the decision on the dam, nutrient and sediment inputs need to be reduced to improve habitat conditions. This will mean lessening the effects of altered hydrology and a reduction of nutrient inputs to the river. Those issues will likely be addressed within the conventional parameter TMDLs for DO and turbidity.

Unnamed Creek, tributary to Fivemile Creek (AUID 09020102-578)

Impairment: The creek was assessed as impaired for not meeting the fish community threshold at site 10RD054 located at CSAH 13, 5.75 miles East of Herman. The site did not have sufficient water during the macroinvertebrate sampling period, so fish is the only biological community sampled at this location.

Initial data

Chemistry

The only chemistry data available within this AUID was that collected at the fish sampling visit on June 9, 2010. The results of that sampling were: DO was 7.02 mg/L, TP was 0.065 mg/L, nitrate was 2.13 mg/L, ammonia was 0.1 mg/L, TSS was 6 mg/L, and the transparency tube reading was greater than 100 cm. From this data, the only parameter of concern was nitrate, which was elevated, though not to levels causing toxicity to aquatic organisms.

Biology

Only two species of fish were captured at 10RD054. One was a pioneering species (fathead minnow), suggesting there is an unstable flow and related habitat instability in this small creek. AUID-578 likely has little if any water in drier years or later in summer, as was the case on August 10, 2010, the attempted macroinvertebrate-sampling visit. Some landscape characteristics and related anthropogenic influences downstream of the site pose a likely problem for fish recolonization in years following a creek dry-up.

Targeted investigation and results

Additional analysis was conducted to further investigate connectivity and flow volumes.

Connectivity

The immediate area where the fish were sampled has a high gradient, due to the steep-sided and deep valley the stream flows through. The road surface of 120th Street is very high at the crossing due to the depth of the channel valley relative to the surrounding land, resulting in a very wide fill area at the culvert elevation. This wide road base requires an extra-long culvert, approximately 140 feet. Culvert length can affect fish passability, since the velocity is continuous throughout the culvert. Small fish species have difficulty making the sustained surge required to pass through long stretches without features that provide velocity breaks. The culvert outfall area was repaired in 2011, and shored up with rock to protect the channel from erosion. This significant rip-rap effort suggests that there is a fair amount of gradient and velocity within the culvert that makes this a fish passage barrier, at least at times of higher flow.

A very short distance downstream of 10RD054, the creek is crossed by County Road (CR) 33, which also has a new set of box culverts and rip-rap (Photo 6). These culverts appear to be a migration barrier as well. At the August 22, 2013 visit, the culverts were passing no water (were dry), though small amounts of water were present above and below this crossing. The downstream side has significant gradient. At high flows, there would be significant turbulence and velocity here; conversely at low flows, there would just be small trickles through the rock rip rap. Both conditions would appear to preclude fish passage.

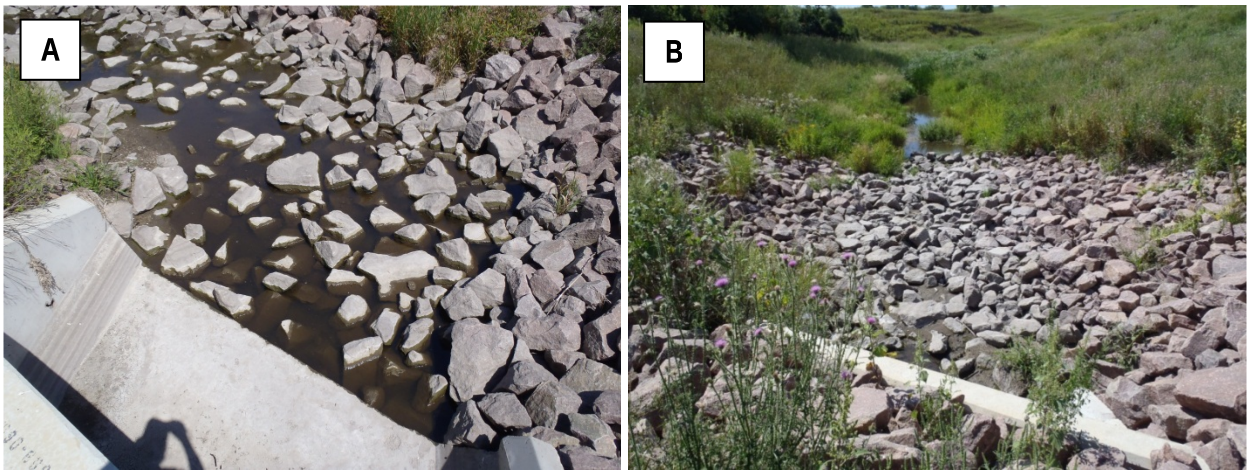


Photo 6. The channel a short distance below the biological site. A) On the upstream side of CR 33. There was only a minimal amount of standing water in the channel. B) On the downstream side, there is high gradient within the new, rip-rapped stream bed.

An additional, and apparently natural, landscape barrier to migration into AUID-578 is the area about a half mile downstream of 120th Street. The creek flows into a large wetland, and it appears from aerial photos (Figure 11) that the water is dispersed and dissipated within this wetland and the channel is absent. A channel re-appears near the outlet of the wetland, and flows into the Niemaki chain of lakes. This seemingly discontinuous channel appears to be a break in connectivity between reaches within AUID-578.

The Niemaki Chain may itself be a natural barrier. Aerial photography, which shows very different algal quantities among these lakes (Figure 12), suggests that the fish communities are different between them, and that some appear to be fishless. The indirect regulation of algae by fish is known as the trophic cascade. When few or no planktivorous fish are present, zooplankton will flourish. Since zooplankton feed on free-floating algae (phytoplankton), the water will be clearer when they are abundant. The same result will occur if predatory fish are present, because they feed on the planktivorous fish, meaning more zooplankton survive to eat algae. The first lake (unnamed) downstream of the wetland is clear, with aquatic plant life well into the middle of the lake. The bottom of the lake is also visible throughout the lake, meaning it is shallow, and probably winterkills frequently. Thus, there is probably a frequent extermination of the fish community, which would otherwise be the supply of fish that could immigrate upstream into AUID-578. No water quality data were found for this lake, and no information on fish was found in MDNR's Lakefinder.

Figure 11. Wetland downstream of 10RD054. The channel seems to disappear within the circled area.

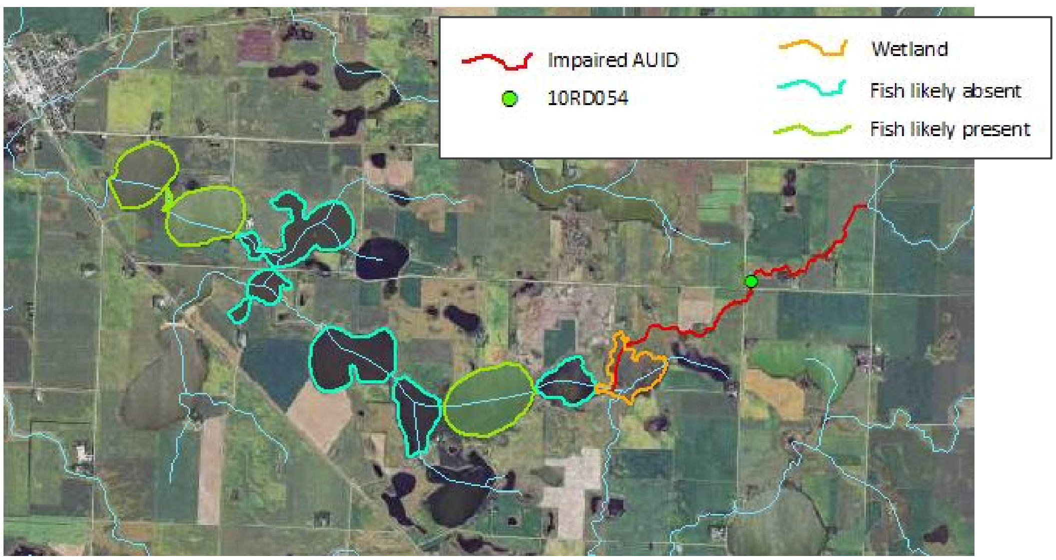
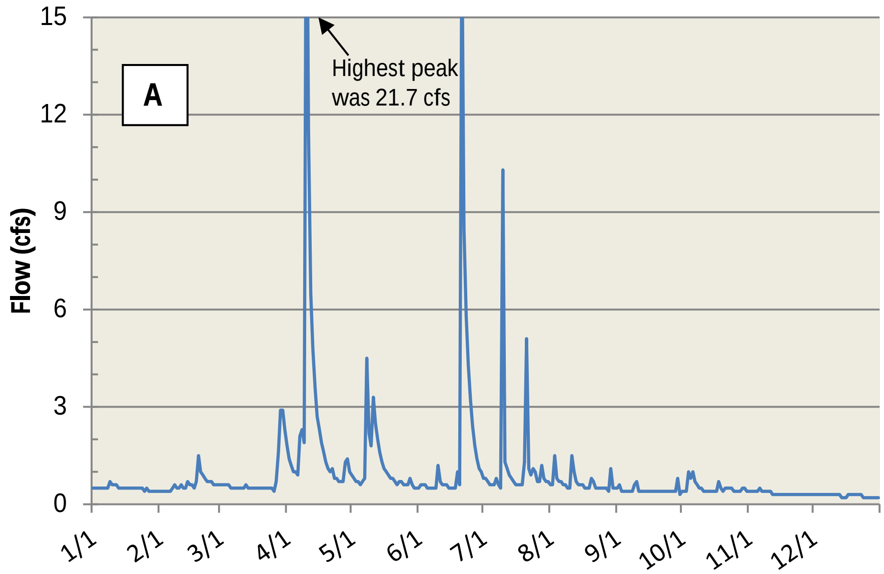


Figure 12. Chain of lakes below 10RD054 with varying levels of algal growth. The red channel is AUID-578.

Hydrology

EOR, Inc. ran the HSPF model to estimate flow volumes within AUID-578 for 2001-2006. The predicted flow volumes during later summer are extremely low (Figure 13). The flow volume over a large portion of the year is less than one cfs. In drier years (e.g., 2002), the majority of the year had flow volumes of 0.5 cfs or less. As previously mentioned, HSPF tends to overestimate flow in small streams, so much of the time the creek likely had no flow. This no-flow condition was witnessed during a site visit on August 22, 2013 (Photo 7).



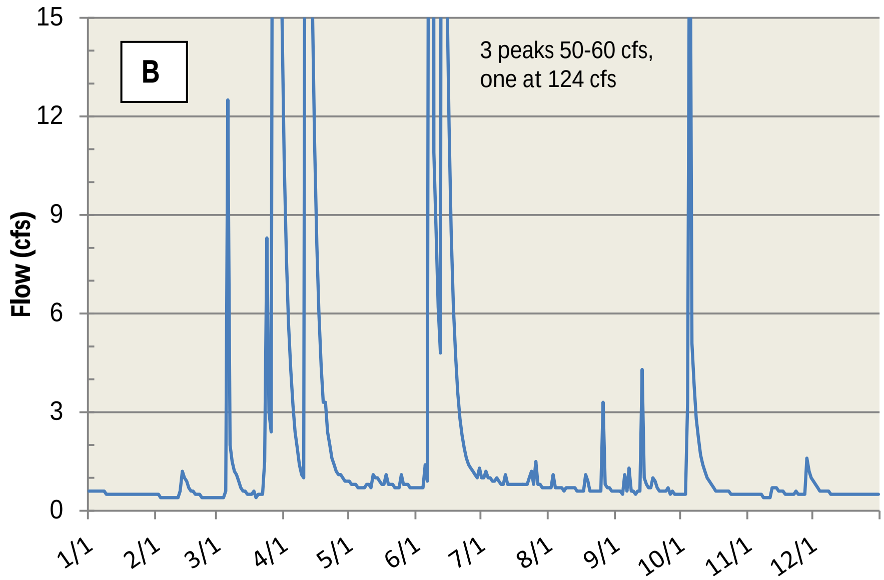


Figure 13. HSPF model flow output for Unnamed Creek site 10RD054 (CSAH 15). A. 2002 - a dry year, B. 2005 - a wetter year.

Photo 7. The channel within the 10RD054 biological reach on August 22, 2013.

Conclusions

AUID-578 is a very small stream that likely has intermittent flow in mid- to late-summer of most years. This was directly observed in 2010 and 2013, and was also predicted by a model run that showed dry periods at numerous points in 2001-2006. Small, very tolerant fish species may be able to survive these periods in pools that retain some water; however, this scenario would not support a diverse fish community and sensitive species would not persist. The two fish species collected were indeed tolerant ones; brook stickleback is designated by MPCA as "tolerant" and fathead minnow as "very tolerant".

There appears to be three potential connectivity features that prevent an abundant fish community from thriving in AUID-578. None of the features are reasonably fixable, and again, some may in fact be natural. Due to the large amount of excavating that would be required to change the culvert characteristics at CSAH 13 and 120th Street, it is probably not financially feasible to consider that option. This is especially so considering the limited habitat present downstream which could prevent any significant improvement in the fish community. More study on the AUID's biological potential would need to be conducted to justify considerable structural fixes at the crossings. It is not likely that this AUID would have a robust fish community even without those barriers, due to its small size, intermittency, and lack of a fish source area downstream for repopulation of the stream after a drought or hard winter.

As in most agricultural areas of the RRB, there have been extensive landuse and drainage changes relative to pre-settlement conditions in the subwatershed containing AUID-578. The role of agricultural drainage in the intermittent or very low late-summer flows is not known, though the hydrological regime has changed in some direction and degree (that is the purpose of the drainage alterations). Determining the effect of artificial drainage on the streamflow pattern in a creek or river is complex, and dependent on numerous factors (Rahman and Lin, 2013). It would require the use of a hydrologic model to determine whether or not the alterations to drainage have exacerbated the late-season low flow conditions in this subwatershed, and to quantify that effect. If human activity has exacerbated the low flows, it would be advisable to work on that stressor first. Without restoration of a permanent flow regime, other restoration work is probably not cost-effective in AUID-578. Additionally, it would be advisable to consult fisheries professionals to determine if the AUID has sufficient overwintering habitat capacity to sustain a significant fish community year-round, given the seemingly natural lack of access to refuge areas farther downstream. Only when these items are known should work be done at the road crossings to improve fish passage.

Twelvemile Creek (AUID 09020102-514)

Impairment: The creek was assessed in 2012 as impaired for not meeting fish and macroinvertebrate community IBI thresholds. This AUID was at that time considered to have a natural channel. The subsequent Altered Watercourse Project, completed in late 2013 determined that this AUID's channel was historically altered. Biological stations included 10RD059, located at CSAH 6 and 10RD057, located at CSAH 13. Additionally, this reach is impaired for aquatic life and on the 303(d) list for the parameters DO and turbidity.

Review of the subwatershed

The land comprising the subwatershed of AUID-514 is heavily devoted to row crop agriculture. There is one small town (Donnelly) that sits at the far upstream edge of the subwatershed and consequently may contribute to water quality issues in Twelvemile Creek. The headwaters AUID upstream of AUID-514 has a use class designation of Class 7, which has reduced standards due to receiving of permitted wastewater discharges.

Initial data

Chemistry

This AUID contains an IWM 10X site (S006-152, co-located with 10RD057), and was also visited five times in 2010 for biological sampling. Fish sampling with associated water quality grab sampling occurred on two different dates at 10RD057, and one visit at 10RD059.

Dissolved oxygen

As a result of the analysis of data collected during the 10X monitoring and by local partners at an upstream site (S003-114, co-located with 10RD059), it was determined that DO does not meet the state standard, and an assessment of aquatic life use impairment was made for this AUID. Low DO can be considered a stressor without further exploration due to this impairment.

Phosphorus

TP concentrations are substantially above the newly adopted state standard for the Red River area at all sample sites in this AUID, with none meeting that standard (Figure 14). The town of Donnelly is located upstream of AUID-514 and discharges treated municipal wastewater into the headwater reach of Twelvemile Creek. The actual discharge is shallow groundwater from beneath the community mound system, which is discharged into Joe Peterson Slough, just to the east of Donnelly. Phosphorus contributions from this particular system may be fairly small, since phosphorus binds to soil, and is not typically found in groundwater in significant concentrations. However, formal sampling would need to be conducted to assess the treatment effectiveness of the system.

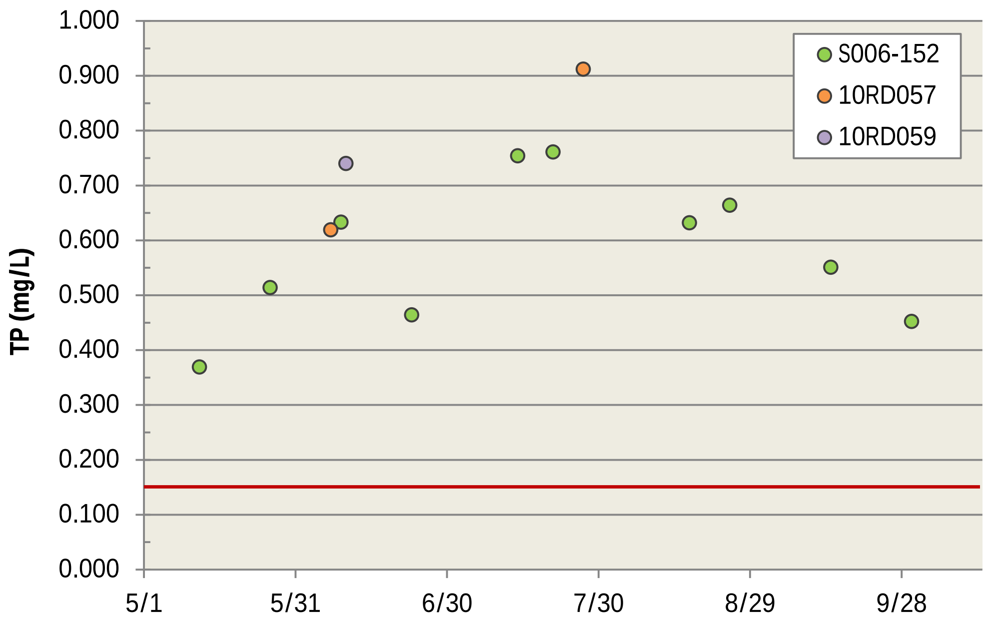


Figure 14. TP samples from 10RD057 (= S006-152) with one sample from 10RD059. The red line is Minnesota's newly adopted TP standard for this area of the state.

Nitrate

Nitrate concentrations from the 2010 samples at S006-152 were mostly at very low levels, with concentrations generally below or slightly above the laboratory detection limit. Three samples were slightly over 1.0 mg/L, much higher relative to the other seven samples, but still relatively low compared to other agricultural parts of the state. However, increases in subsurface tiling may raise stream nitrate to levels comparable to these other agricultural regions. The higher readings were sporadic, without an apparent pattern or seasonality. These nitrate concentrations are much lower than levels considered toxic to aquatic organisms.

Ammonia

Samples from the 10X set were low in ammonia, ranging from 0.04-0.138. The toxic unionized form of ammonia is generally < 5% of the ammonia level, which for these samples would be well below the Minnesota toxicity standard of 0.04 mg/L.

Habitat

Habitat diversity for macroinvertebrates was poor at 10RD059. Only one of the four target macroinvertebrates habitats was significantly present (undercut banks). The habitat at 10RD057 was also not diverse, though an important macroinvertebrate habitat feature, hard substrate, was present in the form of wood. This difference in habitat between the two sites can be attributed to the riparian vegetation differences. At 10RD057, mature trees line the riparian corridor, whereas at 10RD059, there is little woody vegetation along the channel (Figures 15 and 16).

Figure 15. 1938 (L) and 2013 (R) aerial photos of 10RD057. The channel appears to have been smoothed all along this AUID. The forested patch that exists along the sampled reach presently was just beginning to grow up in 1938, likely the result of this early homestead adjacent to the young trees. The red dot denotes the center of the biological reach.

Figure 16. 1938 (L) and 2013 (R) aerial photos of site 10RD059. Note that unlike 10RD057, there are still few trees along the channel here. The red dot denotes the center of the biological reach.

The MSHA scores, which are somewhat more oriented to the fish community, were 50.3 and 48.1 at 10RD057 and 10RD059, respectively. These scores rank in the lower end of the “fair” category. The scoring breakdown for the individual MSHA components for these sites is found in Table 15, p. 44 of the M&A Report (MPCA, 2013). The most problematic component for 10RD057 was “Channel Morphology”, which received only 31% of the possible score. For 10RD059, the “Substrate” component received only 24% of the possible points. Here, the substrate was almost all fine material, silt or clay, and the observers noted that there was “severe” embeddedness of the larger gravels. This information is consistent with the finding of turbidity impairment for this AUID. The MPCA’s Altered Watercourse

(AWC) project determined with medium confidence, that there has been historical channel alteration of this AUID, and the poor channel development at 10RD057 may be a legacy effect of that alteration. The AUID does have much more sinuosity than a ditch (i.e., the channel is not straight).

Riparian (streamside) vegetation and habitat is critically important for a stream's water quality and biological communities (Gregory et al., 1991), in part because of protection of the stream from sediment inputs (Osborne and Kovacik, 1993). In the area upstream of AUID-514, where Twelvemile Creek is County Ditch 1, there is extreme field encroachment on the creek and smaller tributary ditches in numerous areas (photo 8). It appears that many locations do not comply with Minnesota statutes regarding ditch buffer widths.

Photo 8. Photo of Twelvemile Creek upstream of AUID-514, showing lack of a riparian buffer.

Hydrologic alteration

Upstream of AUID-514, there is an extensive network of reaches that have been channelized, or ditched, allowing for an increase in the speed of water moving off the landscape. Channelization generally removes at least some of the sinuosity of the stream channel, which increases the gradient of the new channel, because there is a shorter channel length between given upstream and downstream points on the landscape. An example from Twelvemile Creek (a.k.a Co. Ditch 1) upstream of AUID-514 is shown in Figure 17. Peak flows are also increased by channelization. The combination of peak flow increase and gradient increase causes the sheer stress on the bank soils and bed to increase, which means increased erosion will occur, resulting in channel destabilization (Photo 9). Such bank destabilization contributes to turbidity and sediment issues in the creek.

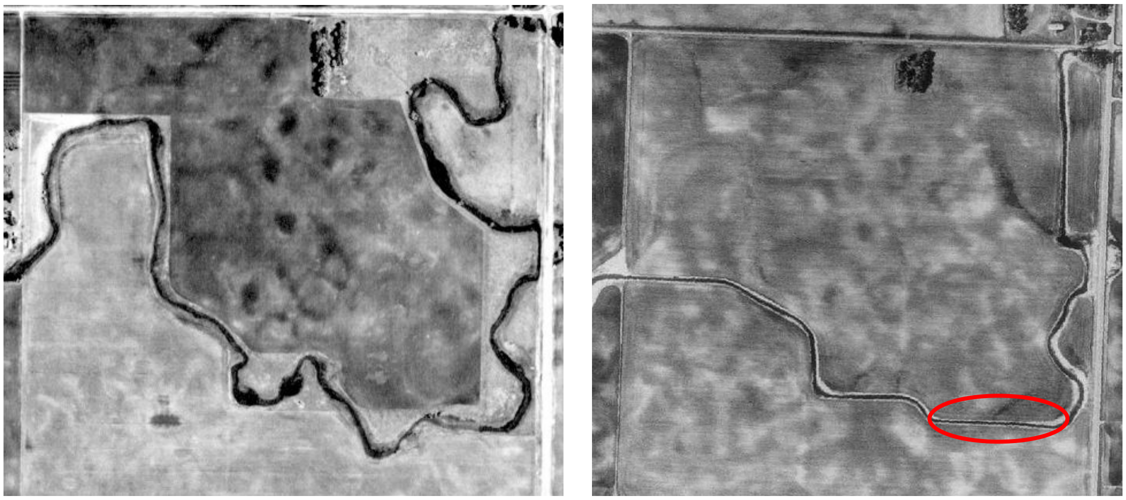


Figure 17. Channel alteration upstream of AUID-514. At left is the 1951 aerial photo, and at right, the 1991 photo. The red circled area is the EOR-51 geomorphology study site.

Photo 9. Bank destabilization within study reach EOR-51. Arrows point to formation of fissures, which will likely lead to a sizeable section of bank collapsing into the creek, as happened between the arrows. The roots of the short grasses here are insufficient to structurally hold the sharply-angled bank.

Biological response

Macroinvertebrates

10RD057 The macroinvertebrate sample scored above the impairment threshold. The notable habitat difference was the presence of a fair amount of woody debris, which was the only target habitat found to sample. The stream here is somewhat unique in that it flows through a mature riparian forest. Though the flow volume was very low when the sample was collected, it appeared based on the exposed bottom topography that at somewhat higher baseflow conditions, there would probably be some "run" habitat, where flows are swifter. Combined with hard substrate (the wood), such velocity adds to the diversity of microhabitats in a reach and the stream will support additional species, especially the more-sensitive taxa. This was seen in the number of EPT taxa present (10) relative to site

10RD059. Notably there was a stonefly captured here (a Perlidae). Despite a passing score, there were still signs of problems; in particular, the high number (82) of Physa snails, which commonly become abundant in degraded streams.

10RD059 The macroinvertebrate sample almost exclusively contained taxa that are common to wetlands. Only two genera (a single specimen of each) of the EPT taxa were collected; one mayfly (*Caenis*) and one caddisfly (*Nectopsyche*). Unlike most other mayflies, *Caenis* is fairly tolerant to pollution and silt, and can be found in wetlands as well as streams (Edmunds et al., 1976). This is arguably the most tolerant mayfly genus in Minnesota. The caddisfly taxon *Nectopsyche* is also a flexible lentic or lotic genus, and when lotic, lives in slow-flowing areas (Wiggins, 1996).

Fish

10RD057 The community here was exceptionally poor. Only seven individuals were collected, representing five species. The only species with more than one individual was black bullhead. No sensitive species were collected here. Three of the species present are tolerant of low DO (black bullhead, fathead minnow, and northern pike).

10RD059 While more fish were collected here (42 individuals) than at 10RD057, this is still very few for a creek this size. As expected from a reach with a known DO impairment, the fish community also shows evidence of the poor DO found here. The three species that made up 95% of the individuals are ones that are known to be tolerant to low DO; northern pike, black bullhead, and yellow bullhead. These three species are classified as wetland tolerant (able to live in wetlands). One white sucker was captured, which has a "tolerant" designation. The lone individual sampled that is designated as a "sensitive" as well as "riverine" species was a hornyhead chub.

MPCA biologists have determined tolerance values for fish species for both DO and TSS (manuscript in development). Using those values, a weighted average community score 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. The results are presented for the two sites in this AUID in Table 13. The calculated percentages suggest that the bigger problem here is the low DO concentrations.

Table 13. Percent likelihood that the sampled community would meet the TSS or DO standard. A similar model for macroinvertebrates has not been developed.

Site	Community	TSS	DO
10RD057	Fish	53.3	14.2
10RD059	Fish	70.8	0.1

Targeted investigation and results

Chemistry

Dissolved oxygen

In order to add further insight into the DO regime, a sonde was deployed from July 24 - 31, 2012 to determine the daily minimum values as well as the daily DO flux (Figure 18). Some of the daily minimum DO values were below the 5.0 mg/L standard, but none went below 4.0 mg/L. The daily DO flux was fairly good, being about 3-4 mg/L.

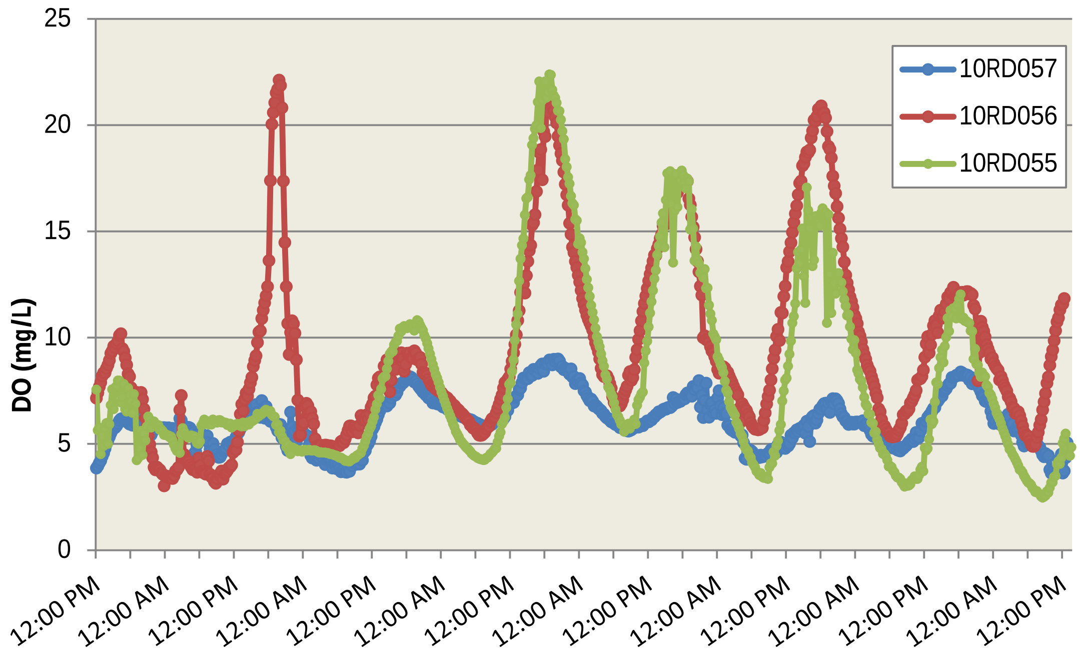


Figure 18. Sonde DO data from 10RD057, 10RD056, and 10RD055, July 24-31, 2012. The latter two locations are in the Twelvemile Creek AUID directly downstream of AUID-514.

Geomorphology

The Altered Watercourse Project determined that the channel within this AUID is altered. One geomorphology study site (EOR-67) was located in this AUID, just downstream of biological site 10RD057. There were obvious signs of channel instability, such as eroding banks (Photo 10). The geomorphological measurements provide evidence of this channel's historical alteration. The entrenchment (vertical containment) of the creek here is in the "moderately-entrenched" category (entrenchment ratio = 2.06) which would put this stream reach in the Rosgen B stream type. This stream type does not occur naturally within this landscape topography, providing evidence of alteration. The calculated sinuosity here is also low, at 1.15.

This entrenchment level means there is fair, but not good connectivity to the floodplain during higher flow events, resulting in higher sheer stress acting on the channel bed and banks, leading to accelerated erosion within the channel. This is contributing to the sediment issues causing turbidity and fine material smothering of bed materials.

Photo 10. Bank erosion within the geomorphology study reach. The banks are a significant source of sediment to the channel with the current hydrological regime. Riparian vegetation roots are inadequate to hold the streambank soil. The granular soil material (sand and small gravel) below the 12-inch topsoil layer is relatively susceptible to erosion by stream currents.

The EOR-67 reach contains a historical, surveyed channel cross section location from 2002, measured by the Bois de Sioux Watershed District. This cross section was re-surveyed in 2012 to gain insight into the rate of change of the channel dimension. This cross section shows channel degradation (down-cutting) and widening (Figure 19). The bed elevation has dropped approximately one foot, and the channel width has increased approximately 6-7 feet. This is not simply a lateral movement of the channel, because there is channel expansion on both sides of the historical cross section. Precipitation change (MPCA 2013) does not seem to explain this channel enlargement. Increased annual discharge due to the proliferation of drain tile installation within this time period (MPCA 2013) may better serve to explain these changes.

The BEHI score was determined in multiple locations in the MRW. One BEHI location was examined within this AUID, in reach EOR-67 (see map in appendix), and it was ranked as "Very High". This location was also rated as having high near bank stress (due to the water's primary path, the thalweg, being up against the bank), indicating this site is contributing significant sediment.

A few geomorphologic alterations that may be contributing to turbidity and/or DO problems, but not related to historical channelization, are also found in this AUID. One location appears to be an old farm crossing which holds back some water (channel is wider upstream of the constriction for a significant distance), and at the downstream side causes a large scour pool. The reduced gradient caused by the constriction slows flow, exposing the water to increased solar radiation, which reduces the oxygen-holding capacity of the water. One might think that pooling areas like this provide storage for better baseflow levels, but due to the sediment issues in this AUID, this pooled area likely contains much deposited sediment, and storage capacity is likely less that it might seem. Though there is not as much animal agriculture in the MRW as some other parts of the state, there is an area of over-widened channel with eroding banks due to cattle access to the creek on this AUID (Figure 20). There are also field gullies that are tributaries to the creek (Figure 21).

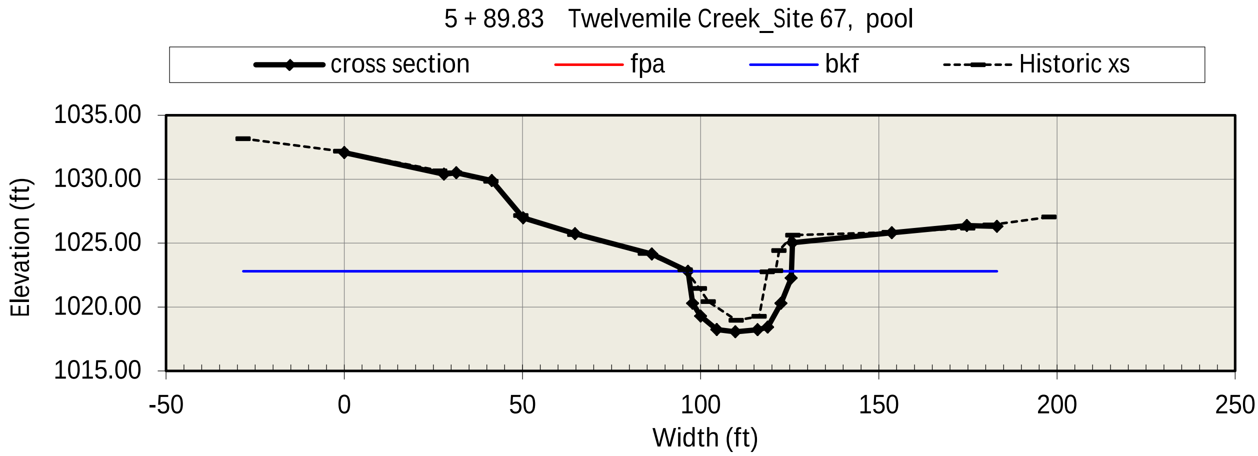


Figure 19. 2002 and 2012 surveyed cross sections at the identical location (site EOR-67).

Figure 20. A site location within AUID-514. Photo A: The channel here is within a pasture. B: The channel just downstream of the pasture. Red lines denote channel widths measured by a computer tool. 1 = 37.6 ft., 2 = 54.3 ft., 3 = 16.6 ft., and 4 = 17.7 ft.

Figure 21. Field gully along the creek bank. The white arrow points to the nick point which is migrating away from the creek.

Connectivity

There are six culvert crossings and one bridge in the AUID counting from the downstream end to the upper biological site. Downstream crossings do not appear to be causing connectivity or migration barrier issues for fish. Bridge crossings do not generally form a barrier, and the reach immediately downstream of AUID-514 (AUID-557) has mostly bridge crossings (just one culvert). Therefore, movement to and from refuge areas downstream is not restricted, and thus blockage to migration is not a likely explanation of the impaired fish community.

Conclusions

Though this AUID does not have the look of a wetland stream (i.e., has defined, non-saturated banks, and minimal emergent or submergent aquatic macrophytes), the biological communities, both fish and invertebrates, have a definite wetland signature, as a high percentage of the individuals are commonly found in wetland habitat. Because of the accumulation of organic material, wetlands typically have lower DO concentrations than healthy streams. Organisms that can live in wetlands typically are tolerant of low DO conditions. The predominance of wetland-oriented fish and macroinvertebrate taxa agrees with the findings of frequent low DO in both the instantaneous measurements and the continuous sonde recordings of DO and meshes well with the determination of a DO impairment in this AUID.

The biological species present, both among the fish and the invertebrates, are also predominantly habitat and or feeding generalists. This coincides well with the habitat data found in biological sampling visits, as macroinvertebrate habitat diversity was poor (only one of the four target habitats were found at each site), and overall MSHA habitat scores were only in the lower part of the "fair" category, also suggesting that habitat diversity is lacking. This habitat condition is likely due, in part, to the channel alterations in the fairly early years of settlement. This AUID probably would have originally been a Rosgen Type E channel, having a narrow width/depth ratio, with high sinuosity, as E channels are the typical stream form found in low gradient, grassland areas (Rosgen, 1996).

There are clearly channel stability problems in this AUID, in part because of channelization, the increased stream gradient due to channelization, and increased flow volumes (hydrologic alteration) from land drainage. These anthropogenic factors all combine to increase erosive forces against the stream channel, and cause within-channel sediment import to the stream as the channel bed is cut deeper, and subsequently as banks become raw and slough down into the stream. These factors contribute to the sediment load responsible for the elevated TSS and embedded gravel substrate. A local resident reported that the stream rapidly increases in volume following rain events, much quicker than occurred years ago. Though riparian buffers are quite good in this AUID, further upstream, some areas have very minimal buffering, often much lower than required by state statute. Such situations generally mean more field soil enters the stream.

The above stressors (nutrient addition leading to decreased oxygen content, excess fine sediment/ turbidity, altered hydrology, and altered geomorphology) combine to result in a habitat condition that is not conducive to healthy populations and diverse communities of aquatic organisms.

Twelvemile Creek (AUID 09020102-557)

Impairment: The creek was assessed as impaired for not meeting either fish or macroinvertebrate community health thresholds. Biological stations included 10RD056, located at State Hwy 27 and 10RD055, located at CSAH 14. Additionally, this reach is impaired for aquatic life and on the 303(d) list for turbidity.

Review of the subwatershed

This subwatershed's land is heavily devoted to row crop agriculture. There are three small towns (Donnelly, Graceville, and Dumont) that are within this subwatershed and these may contribute to water quality issues in Twelvemile Creek. The upstream end of AUID-557 is at the confluence of Twelvemile Creek (AUID-514) and West Branch Twelvemile Creek (AUID-511), both of which have aquatic life impairments, meaning the quality of water entering AUID-557 is already compromised. Water from Fivemile Creek gets diverted into the mid-portion of AUID-557 via a lateral ditch that crosses the natural topographical divide between Fivemile and Twelvemile Creeks and runs along CR 82. Fivemile Creek also has problematic phosphorus levels, and contributes to the phosphorus loading of AUID-557.

Initial data

Chemistry

Dissolved oxygen

A large number of instantaneous readings have been collected at S003-124 (co-located with 10RD055), with only 1 of 68 samples (1.5%) collected over a broad time period (May - Sept., 2002- 2013) being below the state standard. However, these readings were not taken at the time when daily minimum DO concentrations occur (i.e., sunrise), so they do not necessarily exonerate low DO as being a stressor. It was determined that a sonde should be deployed to collect daily minimum readings and determine the daily DO flux. That data is shown below.

Phosphorus

As with DO, a large amount of TP data exists from S003-124 (co-located with 10RD055). Additionally, a smaller set of orthophosphorus data had been collected from this site. The TP values are consistently very high (Table 14 and Figure 22) with respect to the newly adopted TP standard. Orthophosphorus was typically at least half of the TP on any particular date, meaning there is much plant-available phosphorus, though it varied by year. In 2011, orthophosphorus was a high percentage of TP on nearly every sample date. In 2012, samples were collected over a broader range of dates, which revealed that orthophosphorus is a much lesser percentage of TP in spring and fall. There are two towns that discharge treated, municipal wastewater to the West Branch of Twelvemile Creek (Dumont and Graceville), which is upstream of AUID-557. The treatment ponds are discharged in June and September. The discharged wastewater is likely a contributor to these high phosphorus readings. The modelling phase of the TMDL study will help quantify the wastewater contribution to the phosphorus levels.

Table 14. Grab samples of TP from biological visits in 2010, in mg/L.

Site	Date	TP
10RD055	July 26	0.308
10RD056	June 17	0.883
10RD056	July 27	0.668

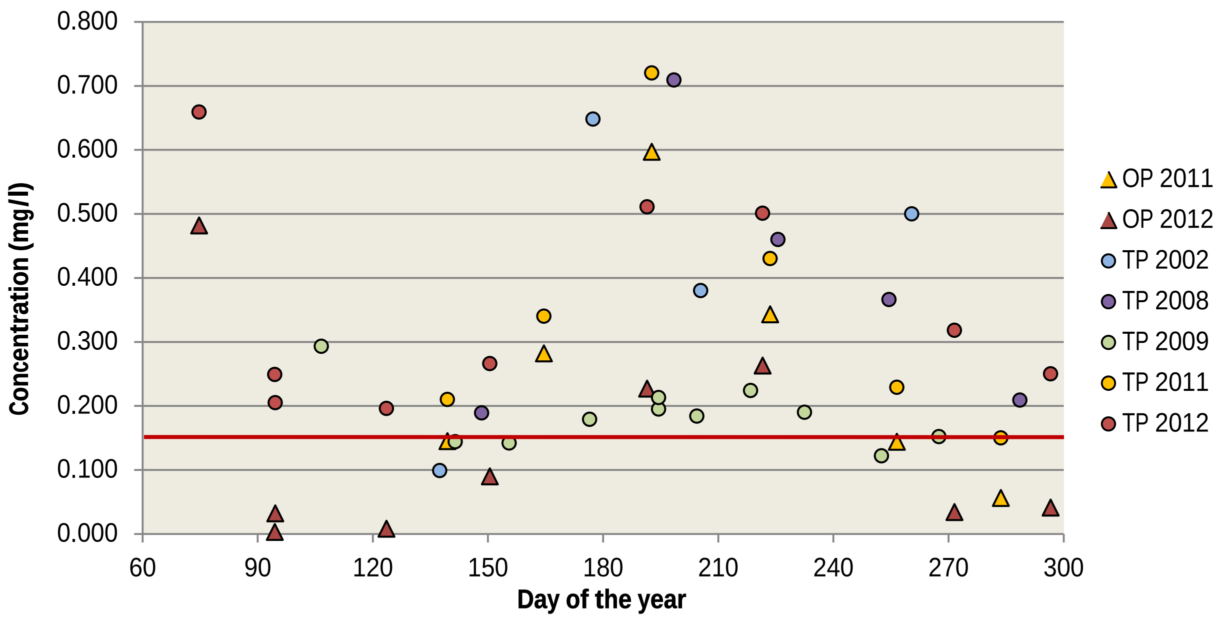


Figure 22. United States Environmental Protection Agency and orthophosphorus concentrations at S003-124 (co-located with 10RD055). Note that 2009 TP concentrations were much lower than in the other years. The red line is Minnesota's newly - adopted river phosphorus (TP) standard.

Nitrate/Ammonia

Nitrogen nutrient values were generally very low (Table 15). Within the normal ranges of pH and water temperature, unionized ammonia is only a very small percentage of the ammonia (< 5%), meaning that even at the highest value measured here, the unionized ammonia would be far below the Minnesota standard for ammonia toxicity.

Table 15. Nitrate and Ammonia concentrations in mg/L at S003-124 (10RD055).

	Nitrate	Ammonia
Number of samples	37	8
Number < detection limit	17	5
Highest value	2.35	0.06
Lowest value	< 0.02	< 0.03
Average value	0.219	0.040
Median value	0.03	0.018

Chlorophyll-a

Chlorophyll-a concentrations generally fluctuated between 5 - 20 µg/L except for times in late summer when the chlorophyll-a concentrations spiked between 50 - 60 µg/L (Figure 23). Somewhat oddly, the TP concentrations on those two dates were among the lowest of 34 samples in the EQuIS record for this site, although both were above the newly-adopted Chl-a portion of the river TP standard - one just barely, and the other moderately. Those lower results may be due to the uptake of phosphorus by the more-abundant algae.

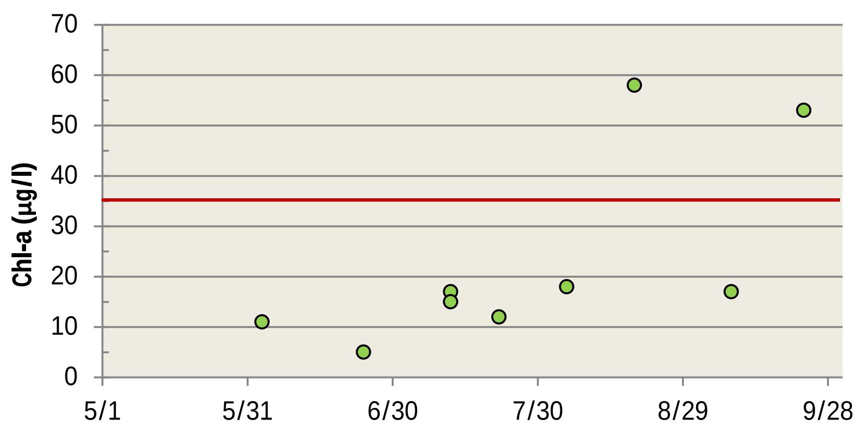


Figure 23. Chl-a concentrations (corrected for pheophytin) at S004-127 (10RD055) during summer 2009. The red line is the Chl-a component threshold of the newly-adopted river nutrient standard.

TSS/turbidity/sediment

This AUID was previously assessed as impaired for turbidity (see M&A report) so less work investigating TSS/turbidity/sediment was needed. Much sediment is brought into the lower half of AUID-557 with the water from Fivemile Creek (Figure 24). Sediment issues pertaining to habitat are discussed in the following paragraph.

Figure 24. The confluence of Fivemile Creek (on right) with Twelvemile Creek. Note the turbid water (color difference) coming in from Fivemile Creek, which can be seen mixing with the water in Twelvemile Creek.

Habitat

Habitat assessments for the two biological sites were both within the “fair” range. Some sub-component scores differed quite a bit, so there were different positive and negative habitat features between sites (Table 16). Related to the turbidity impairment in this AUID, excess sediment was more problematic at 10RD056, which is four straight-line miles upstream of 10RD055. Embeddedness was categorized as light at 10RD055, while “moderate” at 10RD056. This may just be a local effect, but also could be due to the location of 10RD056, which is closer to the upstream AUID-514 where the BANCS model showed the most bank erosion in all of Twelvemile Creek (Appendix 1). A major habitat deficiency at 10RD056 was poor variability in streambed topography. Bed irregularity adds to habitat complexity, and promotes biological diversity. Neither site had diverse habitat as reflected in the number of target macroinvertebrate sampling habitats found, with each having two of the four target habitats present. Riffle habitat was sampled at 10RD055, but there was insignificant flow velocity over the stones, greatly reducing the quality of this habitat.

Table 16. MSHA scores for biological sample sites on AUID-557. Heading numbers in parentheses are points possible.

Bio. site	Land Use (5)	Riparian (15)	Substrate (27)	Cover (17)	Channel Morphology (36)	Total (81)
10RD055	0	9.5	20	7	13	49.5
10RD056	0	8	14.2	15	22	59.2

Channelization/Ditching

Physical habitat in the Twelvemile Creek system is altered on a large scale. The MPCA recently undertook a large project to assess the state’s stream channels for past alteration. The majority of the tributaries, as well as much of the main stem of Twelvemile Creek, were found to be altered (Figure 25). Smoothing and/or straightening stream channels typically results in a homogenization of habitat. One positive is that many of these altered reaches have retained a fair amount of the sinuosity of the channel, which is good because this will help contribute to variability in habitat (creates pools and riffles, and variability in flow velocities). In addition, there is a large network of lateral ditches intersecting AUID-557. These ditches are delivering sediment to the main channel.

Altered hydrology

AUID-557 receives water from an area in which much channel smoothing, ditching, and drainage has occurred (Figure 25). In addition, Fivemile Creek has been re-routed to enter Twelvemile Creek (within AUID-557) about six miles upstream from where it naturally entered Twelvemile Creek (near the downstream end of AUID-557, which is also very near the confluence of Twelvemile Creek with the Mustinka River). Numerous other lateral ditches from the Fivemile Creek subwatershed enter AUID-557 in its lower half. This rerouting of hydrology significantly increased the watershed area draining to Twelvemile Creek in the downstream half of AUID-557, meaning that this portion of AUID is carrying more water than the channel naturally formed to handle. The highly-altered upstream area also speeds water drainage to AUID-557. Such a situation is likely to result in channel instability; incision, channel widening, bank instability, increased bank-derived sediment, turbidity, and sediment deposition on important habitat features.

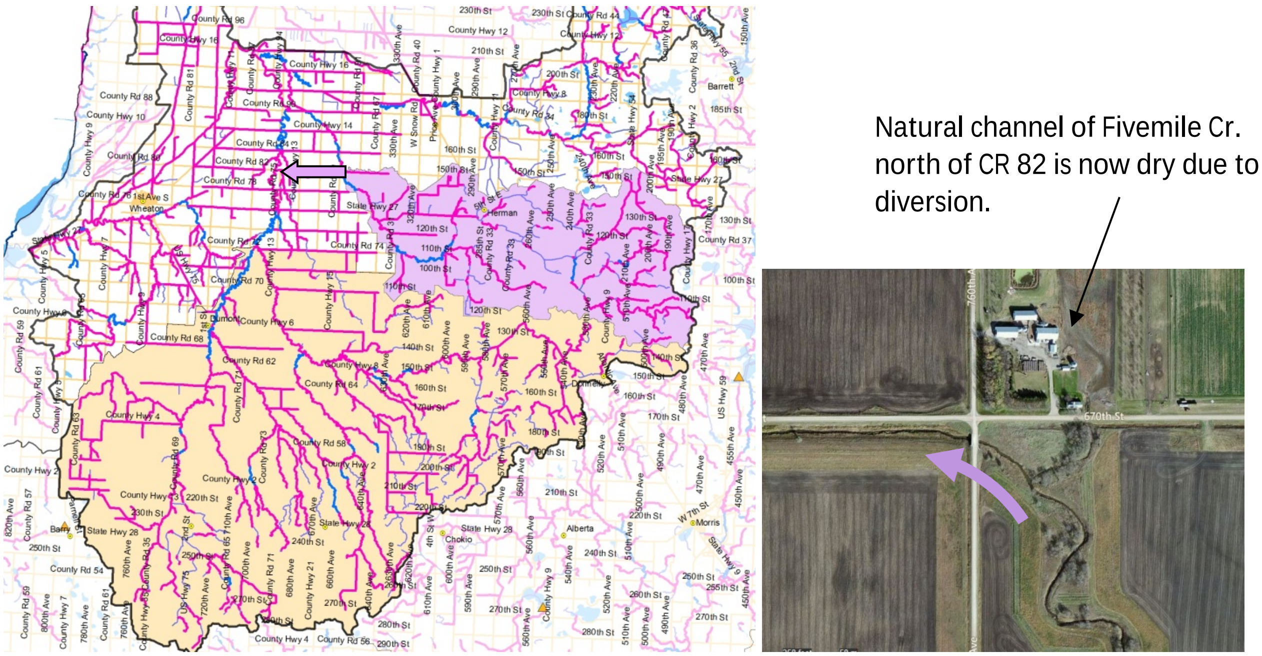


Figure 25. Map of the contributing area to the upstream end of AUID-557 (tan) and the area of the Fivemile Creek subwatershed that is diverted into Twelvemile Creek (purple). The purple arrow on left side follows the ditch that delivers the water from the Fivemile Creek subwatershed into Twelvemile Creek. The close-up photo on the right side shows the start of the diversion. The pink channels are those determined to have been modified to some degree in the past based on the MPCA Altered Watercourse Project. The blue channels are natural.

Biological response

The use of MPCA-developed taxon-specific tolerance values can be informative in linking the observed biological community at a site to stressors. The MPCA has developed tolerance values for low DO and elevated TSS. These are available for both fish and macroinvertebrate taxa. Several metrics were calculated for macroinvertebrates using these DO and TSS tolerance values (Tables 17 and 18) to provide insight into the influence of these two stressors. As is seen in the tables, the macroinvertebrate communities at the two sampled locations are missing intolerant taxa, and are heavily skewed to both low DO- and elevated TSS-tolerant organisms. The Community Index scores for DO and TSS were compared to all other scores in MPCA's dataset from within the appropriate stream class to calculate the percentile each site falls into for DO and TSS Community Index scores. The result of these comparisons show that both sites have much lower percentiles for DO than TSS, suggesting that DO is a more influential stressor than TSS. Because a lower TSS Community Index score is better, both sites in AUID-557 were actually better than the median score for all class seven streams in MPCA's dataset: better than 52 and 60% for 10RD055 and 10RD056 respectively.

Tables 19 and 20 show similar analyses for the fish communities at these sites, though the method of developing the analysis was different for fish. As with macroinvertebrates, both DO and TSS concentrations are problematic, as there are relatively low probabilities that the fish communities found at either site would appear at a site meeting the DO or new TSS standards. Regarding DO, both sites 10RD055 and 10RD056 rank near the bottom of the poor end among all sampled "Southern Rivers" stream class sites in Minnesota for low-DO-tolerant fish community, while in general, they showed better rankings for Southern Rivers for TSS, and the probabilities of meeting the parameter standards follow. It would then follow that the fish community suggests that low DO is a greater stressor than elevated TSS in this AUID.

Table 17. Macroinvertebrate metrics related to DO utilizing MPCA tolerance values. The percentile rank is based on the Community DO Score metric (high score and high percentile is better).

Biological Site (Class)	# Low-DO Intolerant Taxa	% Low-DO Tolerant	Community DO Score	Ranking within stream class (percentile)
10RD055 (2)	1	23.1	6.28	6th
10RD056 (7)	0	60.3	5.99	18th

Table 18. Macroinvertebrate metrics related to TSS utilizing MPCA tolerance values. The percentile rank is based on the Community TSS Score metric (low score and low percentile is better).

Biological Site (Class)	# TSS Intolerant Taxa	# TSS tolerant Taxa	# TSS very tolerant Taxa	% TSS Tolerant	% TSS Very Tolerant	Community TSS Score	Ranking within stream class (percentile)
10RD055 (2)	1	10	4	54.0	36.1	20.2	48th
10RD056 (7)	0	11	6	20.2	8.6	16.6	40th

Table 19. Fish metrics related to DO, and the community DO index score (high score and high percentile is better). Note there were two visits to 10RD056.

Biological Site (Class)	Community DO Score	Percentile within stream class	Probability (%) of meeting DO standard
10RD055 (1)	6.47	6.4	25.9
10RD056 (1)	6.36 & 6.44	4.5 & 5.7	22.4 & 24.9

Table 20. Fish metrics related to TSS, and the community TSS index score (low score and low percentile is better). Note there were two visits to 10RD056.

Biological Site (Class)	Community TSS Score	Percentile within stream class	Probability (%) of meeting TSS standard
10RD055 (1)	20.14	12.2	38.9
10RD056 (1)	23.77 & 16.57	25.7 & 2.5	20.2 & 61.3

Targeted investigation and results

Chemistry

Dissolved oxygen

Sondes were placed at two locations in AUID-557 in 2012, from July 24 - 31, 2012. The sites were at 10RD056 (co-located with S004-197) and 10RD055 (co-located with S003-124). Both sites had DO levels drop below the standard on several successive days during the deployment, with 10RD055 typically having slightly lower readings (Figure 18 - found in the Twelvemile Cr. AUID-514 section).

Aside from the drops below the minimum DO standard, the daily high DO readings were remarkably elevated. There were three days in the 2012 sonde deployment at 10RD056 where the peak DO was approximately 22 mg/L. Further downstream, 10RD055 had one day at this 22 mg/L level. Discussion with other MPCA staff confirmed that these are very rare readings. The highest DO saturation percentages at the two sites during these high DO readings were 291.5 and 289.2%, respectively. It is uncommon to record DO levels above about 14 mg/L even in streams experiencing eutrophication. Quality control checks of the sondes, including independent measurements at deployment and retrieval, verified that the sondes were working properly. The DO flux on these days was 18- 19 mg/L, which is extremely high, and likely very stressful on aquatic organisms (Heiskary et al., 2013). Additionally, DO levels that get this high might be harmful and potentially lethal to aquatic organisms (Fidler and Miller, 1994), and can occur due to algae blooms (Meyer and Barclay, 1990). The lack of certainty of harmful levels of DO is due to a lack of scientific study; studies have focused mostly on nitrogen. Suspicion of high DO harm has been inferred from some historical fish kills, based on other evidence gathered in those situations.

The effect of very high concentrations of dissolved gases on aquatic organisms is called “Gas Bubble Trauma” (GBT). It is important to note that the parameter Total Dissolved Gases (TDG) includes both oxygen and nitrogen gases (and the minor contribution of argon gas). Nitrogen gas supersaturation is more problematic than oxygen, and occurs where there is extreme turbulence in waters, usually in situations associated with dam outfalls. When photosynthesis is the cause of gas supersaturation (as is the case here) only oxygen is involved. The EPA has recommended a threshold for total gas saturation (TDG) of 110%. No criterion has been set for situations where the only supersaturated gas is oxygen. However, some studies have found that oxygen supersaturation at levels around 300% can cause GBT (Weitkamp and Katz, 1980). In 2012, the recorded percentages in this AUID were almost to 300%.

Because of this very abnormal DO pattern, sondes were again deployed at these two sites for an extended duration lasting from August 6 to September 9, 2013. Interestingly, a similar pattern was recorded, though somewhat more muted at 10RD055 (Figures 26 and 27). A striking DO flux pattern change occurred during the sonde deployment. At 10RD056, the early morning DO concentrations fell to essentially zero for a 6-day period. The patterns of suddenly increasing DO flux, with both higher maximums and lower minimums than the preceding days, seems best explained by a rapid algal (and/or diatom) bloom, which produces oxygen during daylight hours, but consumes oxygen at night. The daily DO minimums at 10RD056 (Figure 26) were either right at or slightly below the standard in the days leading to when the algal bloom occurred. At 10RD055, DO minimums in the days prior to the bloom were above the standard; during the less intense bloom here, the minimum concentrations below the standard occurred on about a third of the days, and the minimums were not nearly as low as those upstream at 10RD056. The highest DO saturation percentages were not as high as in 2012, but were still very elevated. The maximum saturation percentages were 235 and 186 at 10RD056 and 10RD055 respectively.

Chl-a samples were collected on August 22, 2013. At site 10RD056, the Chl-a concentration was 33.1 µg/L, while at 10RD055, Chl-a was 5.36 µg/L. Because the diurnal flux increased at 10RD056 in the days after the sample was taken (Figure 26), it is likely that the Chl-a concentration increased above the August 22, 2013 measurement in the succeeding days. The sonde at 10RD055 (Figure 27) showed an interesting pattern change, where the influence of algae suddenly disappeared between August 31 and September 1, 2013. This could be explained by a flushing event where streamflow volumes rose and sent the algae from the previously quite stagnant water downstream. This hypothesis is supported by precipitation records of 1.46" and 0.77" inches of rain at two recording stations near Wheaton, seven miles west of this reach of the creek, on August 31, 2013 at about four pm. The rain came down over a period of approximately one hour, making it an intense event. This change in daily pattern, coincident with an elevated stream flow (flushing) event, further supports the theory that this temporary expansion of the DO flux, and crashing of nighttime DO concentrations, was caused by an algal bloom. Note that after that flushing event, the DO concentrations and minimums were quite good.

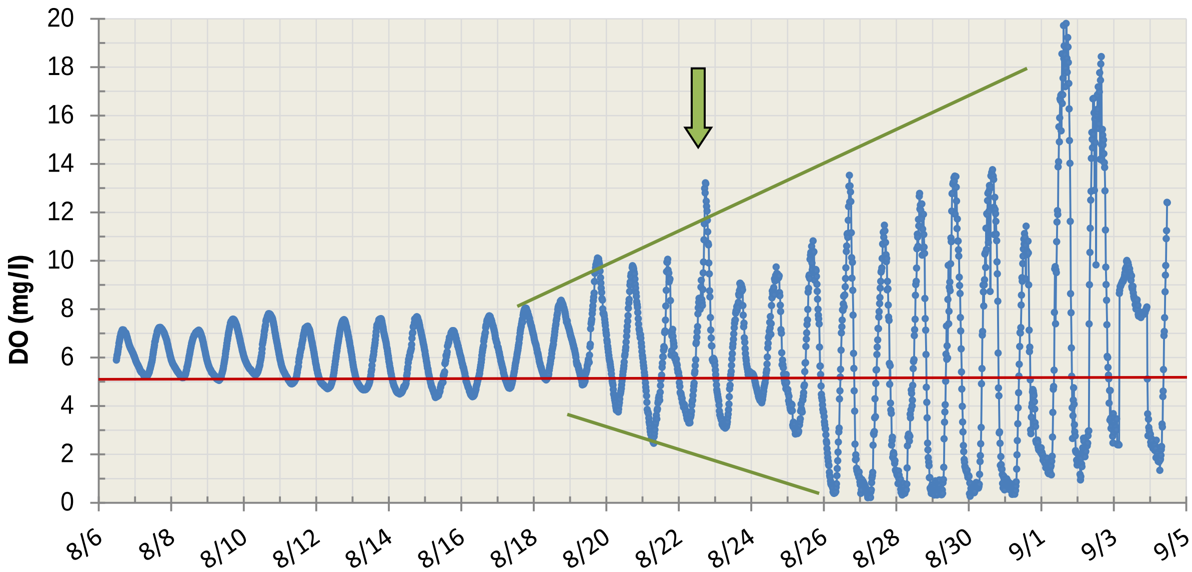


Figure 26. DO sonde record at 10RD056 for the period August 6 - September 9, 2013. The arrow indicates when the Chl-a sample was collected, the green lines are emphasizing the change in DO pattern, and the red line is the Minnesota DO standard.

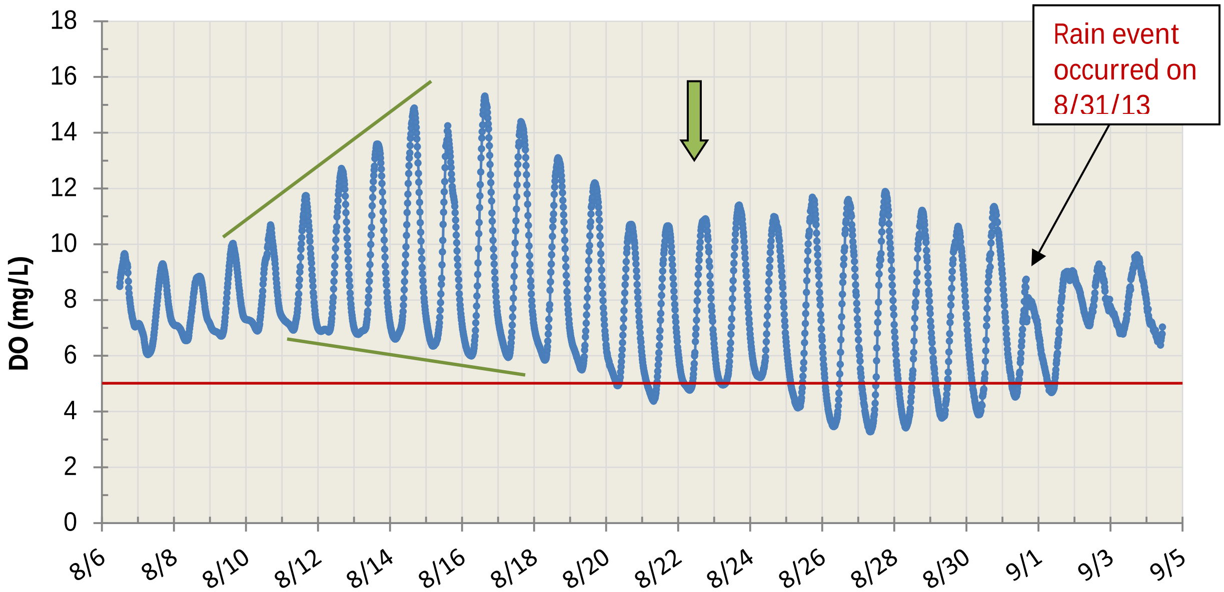


Figure 27. DO sonde record at 10RD055 for the period August 6 - September 9, 2013. The arrow indicates when the Chl-a sample was collected, the green lines are emphasizing the change in DO pattern, and the red line is the Minnesota DO standard.

TSS/TSVS

Suspended solids samples were collected on August 1, 2013 at 10RD056. The TSS value was 38 mg/L, while the TSVS value was 7.2 mg/L. The difference in these values is the mineral (inorganic) particle component of TSS, which was 31 mg/L. These results show that most of the turbidity on this date was due to clay particles, and not algae or organic particles, which implicates soil erosion as being the primary cause of the turbidity.

Geomorphology

Two geomorphology study sites (EOR-65 and EOR-76) were located in this AUID, at the very upstream end and near the downstream end, respectively, and about 12 river-miles apart. EOR-65 has a historical cross-section survey from 2002. The entrenchment ratio here is 3.61, which in the Rosgen system is classified as "not entrenched". There are clear signs of the widespread damage that altered hydrology is causing to the channel. There is active bank erosion occurring at both geomorphology sites (Photos 11, 12, and 13). Evidence of the high elevation of flows that occur here can be seen in the debris caught on tree branches (Photo 14). As with the upstream cross-section in AUID-514, the bankfull channel cross-sectional area has expanded (Figure 28). Two BEHI evaluations were done in EOR-65 and EOR-76. All four of these had a "high" rating for erosion hazard.

In addition to the ubiquitous general bank erosion along this AUID, there are also spot locations where geomorphology has been altered, leading to unstable banks and sediment input to the creek, such as the culvert on Twp 105. This culvert is undersized, leading to increased flow velocity within the culvert, meaning more-erosive water exiting the culvert (Figure 29). Significant bank erosion is occurring as a consequence of this faster water. Most of the road crossings in this AUID are bridges, with only one crossing being a culvert. Bridges are much less likely to cause localized geomorphology problems than culverts. However, the upstream AUIDs that feed AUID-557 do have many culvert crossings. An unknown structure (riffle) was discovered near the downstream end of the AUID (Figure 30), which may be a barrier to migration. It is high enough that it ponds water upstream of it. A site upstream of the

AUID, on the West Branch Twelvemile Creek, has an overwidened section a due to animal trampling in a pasture (Figure 31). Overwidening (increased width-to-depth ratio) is a common consequence of animal access to stream channels (Kauffman and Krueger, 1984).

Photo 11. Raw bank with sloughing sod mats (mass wasting) in reach EOR-65.

Photo 12. Widespread raw, eroding banks along the EOR-76 reach. The channel is overwidened here.

Photo 13. Bank erosion on both sides of river at a bend signals downcutting (incision) of the channel. The erosion of banks are contributing to the turbidity and bedded sediment problems.

Photo 14. Vegetative debris caught in tree branches during a high water event.

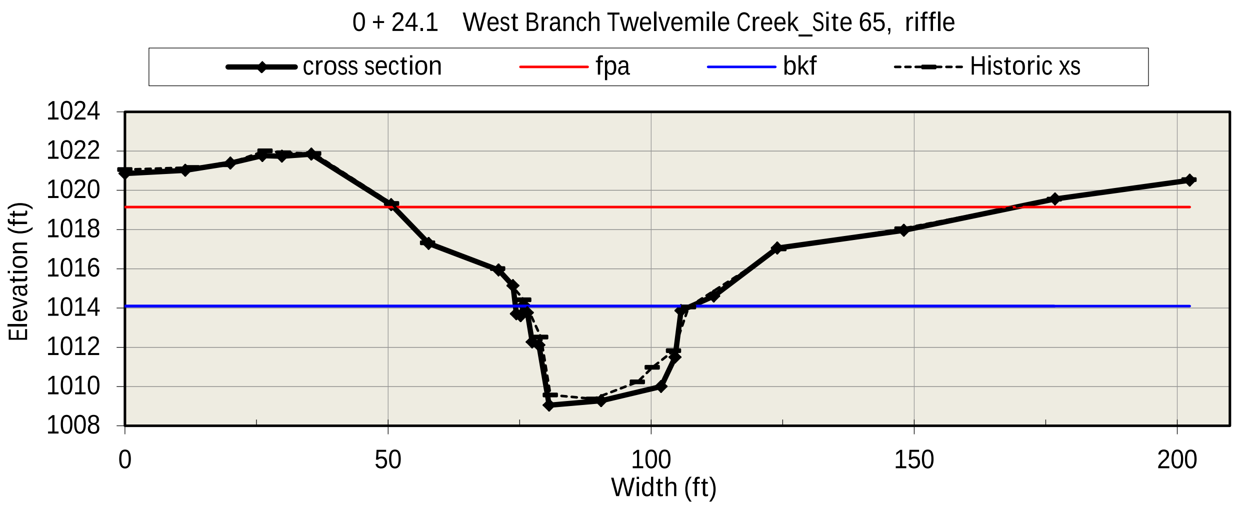


Figure 28. 2012 cross-section of EOR-65, with 2002 historical cross-section superimposed.

Figure 29. Culvert on Twp. Rd 105. The culvert is undersized, creating an increase in water velocity (note the water turbulence on the downstream (left) side of the culvert), and the associated eroding banks, especially the west bank. Note that the field access road will soon be impacted. The yellow lines show the culvert width, which is much narrower than the channel width.

Figure 30. An apparently-created structure (trail leads to it), which may be a barrier to fish migration. Note the much wider channel on the upstream side, meaning the structure is ponding water. The convex shape of the structure is also diverting part of the flow into the south bank and causing erosion.

Figure 31. Altered channel morphology due to animal grazing. The orange rectangle contains a pastured area along the creek upstream of AUID-557, on the West Branch of Twelvemile Creek. Note how much wider the channel is within the pasture, relative to the upstream and downstream channel widths.

Conclusions

The existing turbidity impairment in AUID-557 is likely a direct contributor to the biological impairment, and is a parameter that suggests that bedded sediment is also a problem (these often occur together as they both involve sediment). One of the two biological sites did have an MSHA observation of “moderate” embeddedness of gravel by fine sediments. Analyses of the biological communities strongly suggest that both turbidity/TSS and low DO are stressors acting to degrade these communities.

Though the 10X monitoring station did not capture measurements of low DO, the SID project deployment of sondes at State Hwy 27 and CSAH 14 did record periods where the DO concentration dropped below the state standard. This appears to be linked to sudden algal blooms that occurred during deployments in both 2012 and 2013, where DO concentrations spiked to unusually high levels during the mid-day hours and then to very low levels at night. This pattern is consistent with a plant-driven DO regime. During the 2013 deployment, a water sample tested for Chl-a was high, suggesting algae and/or diatoms were driving the unusual DO patterns during this period. A review of the 10X data at CSAH 14 (S004-197) from 2009 showed two high Chl-a values at a similar time of year (later summer). It appears there is a common pattern likely involving low stream flow (very slow water movement) and high water temperature that results in prime conditions for a strong algal bloom, resulting in problematic DO levels both in terms of the low nocturnal DO concentration due to plant respiration, as well as the mid-day levels that become extremely high (and toxic) from oxygen production during photosynthesis. However, this late-summer phenomenon is probably not the only cause of biological impairment, because an impaired fish community was found in mid-June at 10RD056.

Besides certain flow levels and temperatures, another critical factor that is required for a significant algal bloom is sufficient nutrients in the water. Phosphorus levels are very high as evidenced by 86% of the samples being above the newly-adopted river phosphorus standard. These levels of phosphorus normally result in eutrophication (excessive plant growth). The adopted standard is based on the phosphorus concentration threshold plus a secondary requirement of exceedance of a response variable, either elevated Chl-a, BOD_5 or high diurnal DO flux. During the summer period (June 1 - September), all phosphorus measurements from numerous years exceed the region's threshold of 150 mg/L. The DO flux threshold for the region is ≤ 4.5 mg/L, which was far exceeded in parts of both 2012 and 2013 sonde deployment periods. Additionally, Chl-a (regional standard of ≤ 35 µg/l) was exceeded in 2009 and at one site (Hwy 27) in 2013, the Chl-a was 33 µg/L, just below the threshold. As shown above, Chl-a levels at Hwy 27 were likely higher in the days following the sample date. The 2009 data from CSAH 14 (S004-197) and the single samples collected during the SID process are the only Chl-a measurements in AUID-557. Given these data, this AUID may qualify to be assessed as nutrient-impaired using the adopted river standard thresholds. Some additional Chl-a or DO-flux data may be required to fully apply the standard.

Altered hydrology is another primary stressor acting in several ways in AUID-557. It appears to be the direct cause of much of the turbidity and sediment issues, as well as a contributor to habitat loss, increased stream temperature and low DO levels. Dark-colored streams absorb more solar radiation as do streams with a higher width to depth ratio. Increased peak flows contribute to turbidity, bank erosion, and channel widening, making it a root cause for these other stressors. Low flows during dry periods are exacerbated due to loss of water storage upstream. Such reduced flow, making the water more stagnant, may be contributing to the algal blooms happening in this reach.

Addressing the DO and turbidity impairments in upstream AUID-514, and the DO impairment in upstream AUID-511 should improve these parameters in AUID-557 as well, since these waters compose much of the flow of AUID-557. As a TMDL for Twelvemile Creek will also include curbing turbidity from sources adjacent to AUID-557, these combined efforts should improve ecological conditions in AUID-557. The problems of excess nutrients and altered hydrology will need to be addressed in mitigating the turbidity and DO impairments.

Eighteenmile Creek (AUID 09020102-508)

Impairment: The creek was assessed as impaired for not meeting fish and macroinvertebrate community IBI thresholds at biological station 10RD045, located at CSAH 7. Additionally, this reach is impaired for aquatic life and on the 303(d) list for DO.

Initial data

Chemistry

The primary site from which chemistry data is available is at CSAH 7 in the lower part of Eighteenmile Creek. This site is EQuIS number S005-143, as well as the biological station 10RD045. There is a significant amount of data from 2008, 2009, 2010, and 2011.

Dissolved oxygen

Site S005-143 was a 10X IWM chemistry site, and as a result of that monitoring and additional local monitoring efforts, the DO was determined to not meet state standards. Based on this data, AUID-508 was assessed as impaired for aquatic life use. DO was generally at or below the 5.0 standard, even though most of the readings were after 12pm.

Phosphorus

The TP grab sample collected on June 7, 2010 was 0.435 mg/L. Numerous other TP samples were collected at site S005-143 between 2008 and 2010 (Figure 32). Most of the samples are at least two times the newly-adopted River Nutrient Standards for TP for this region, and many are significantly higher than that.

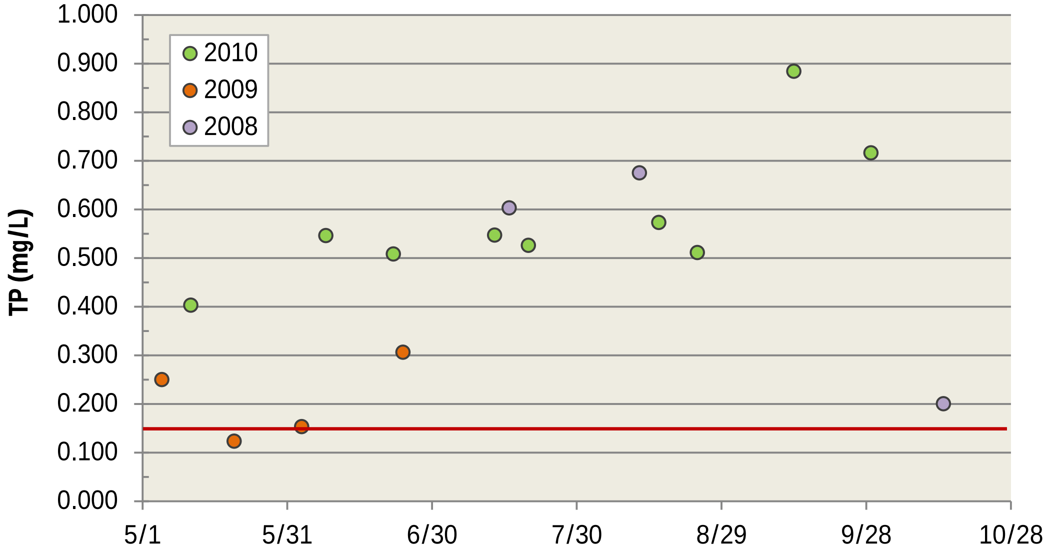


Figure 32. TP concentrations from 2008-2010. The red line is the newly-adopted TP standard for this area.

Nitrate

Nitrate concentrations taken on the same dates as the 2008 - 2010 TP samples showed very low levels of nitrate, with concentrations most often below the laboratory detection limit, and the highest readings at only about 0.25 mg/L, which is far less than other agricultural areas of the state. It is not uncommon in other agricultural areas to have concentrations 10 or more times this level.

TSS/Turbidity

TSS and turbidity are fairly low over many measurements during 2008 - 2010. Typical TSS values are less than 14, and most often between 3-6 mg/L. T-tube readings were generally very good in 2009 - 2010 Table 21. Even the maximum TSS measurement is well below the newly-adopted TSS standard.

Table 21. Statistics for 2008-2010 TSS and 2008-2011 transparency measurements at S005-143.

Parameter	n	Min.	Max.	Avg.	Median	25th percentile	75th percentile
TSS (mg/L)	30	1	21	5.4	4	3	5
T-Tube (cm)	40	14	> 100	74.1	94	42	> 100

Habitat

AUID-508 scored in the lower half of the "Fair" category. The surveyed reach has some positive habitat features. Very little bank erosion was noted, and there is a fairly good riparian buffer in place here. Viewing the channel on aerial photography shows it to have nice sinuosity, and the sinuosity measured in the MSHA effort was categorized as "excellent". There was also a good variety of substrate materials present, all the way up in size to the boulder category. A negative regarding substrate was that there was "moderate" embeddedness occurring within this good substrate mix, and no riffles were found here. Another missing positive habitat feature was shade, as there is almost zero near-channel tree or brush growth.

Biological response

The fish community was extremely poor, and consisted of five black bullheads, which are very tolerant of low DO and are habitat generalists.

Though there was water throughout the channel at the macroinvertebrate sampling visit, flow was not detectible by sight. The macroinvertebrate community was dominated by taxa that favor wetland-like habitat, and the stream-dwelling EPT taxa are completely missing, despite the good amount of gravel and cobble in the channel, which is the habitat preferred by many of the EPT species. Even the tolerant mayfly *Caenis* is not present. The gradient in this AUID is higher than generally found in the Lake Plain, which should also be a positive habitat feature for macroinvertebrates. The sample here contained numerous gastropod (snail) taxa, numerous taxa from the order Hemiptera (which are air breathers), chironomid midges, and the order Coleoptera (beetles, which also breathe air). These groups are commonly found in wetlands, and they do not need to have significant DO in the water in which they live. Of the 30 taxa present, 86% are considered tolerant taxa, and no taxa considered sensitive are present.

Targeted investigation and results

Chemistry

Because this reach had a 10x site co-located with the biological site (10RD045), no additional chemistry data were collected during the SID effort. It was very clear that there are nutrient and DO issues here.

Dissolved oxygen

In order to add further insight into the DO regime, a sonde was deployed from July 23 - 31, 2012 to determine the daily minimum values as well as the daily DO flux. Each day the DO dipped to 3 mg/L or lower, with two days reaching 1 mg/L. The abundant macrophyte community (Photo 15) is the primary cause of the low nightly DO, as well as high afternoon levels (as on July 25 in Figure 33).

Photo 15. Excessive macrophyte and algae growth, resulting in DO issues and habitat smothering.

Connectivity

The only culvert separating the biological site from the Mustinka River is at the downstream end of the biological reach at CSAH 7. Those culverts (Photo 16) are exceptional in design, a textbook example of how to provide fish passage and avoid altering the geomorphology of the channel, by proper sizing of the main culvert, and providing additional high water capacity with a floodplain-level second culvert.

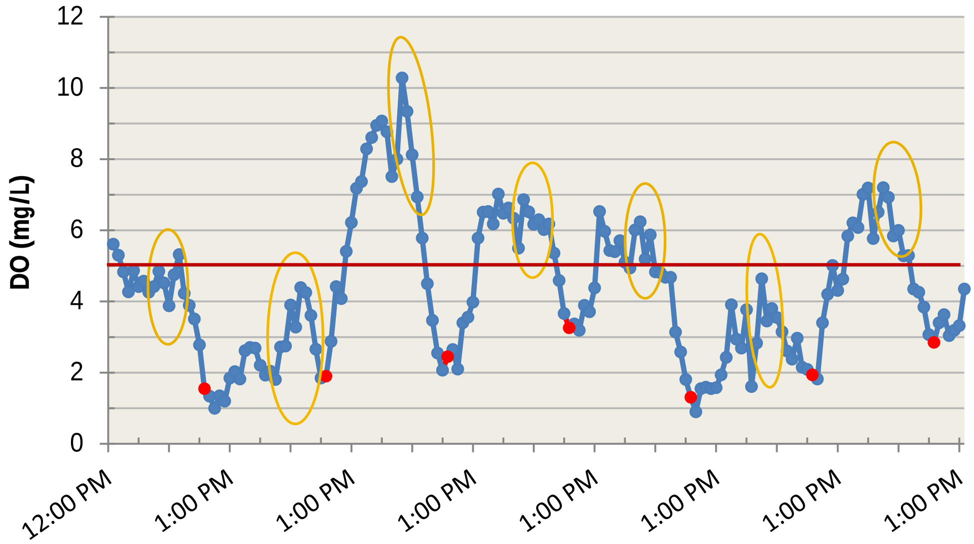


Figure 33. DO concentration at 10RD045 from July 23 - 31, 2012. The red line is the Minnesota DO standard. Orange circles denote an odd daily pattern of DO increase starting at dusk and lasting for a few hours, followed by the normal nocturnal decline with minimum shortly after dawn. The red-highlighted points are the 8 am data points.

Photo 16. CSAH 7 culverts are very well-designed for fish passage (one culvert carries baseflow, and one culvert set at the floodplain elevation). This design maintains proper stream geomorphology, and reduces erosion of the streambed and banks.

Conclusions

Dissolved oxygen has been shown by both the instantaneous measurements, as well as the sonde data, to be a stressor to both the fish and macroinvertebrate communities in this AUID. Daily minimums in late July were as low as 0.90 mg/L. Based on nutrient sampling, the cause of the low DO is excess phosphorus, which was higher than the new river standard in 100% (12 of 12) of the June 1 - Sept 30 samples. Three of four samples outside that time frame also exceeded the standard. The elevated phosphorus is causing eutrophication, based on the dense macrophyte growth observed by the author, who collected the macroinvertebrate sample at site 10RD045. The DO TMDL should focus on a reduction of phosphorus to significantly lower its concentrations, reducing eutrophication and its resulting nocturnal DO decline.

Overall conclusions

The Stressor Identification process identified several stressors for the six biologically-impaired stream reaches (Table 22). These stressors are among those determined to be widespread in the RRB (EOR, 2009), including excess nutrients and sediment, channel alteration, connectivity loss, low DO concentrations, and altered hydrology. In a few cases, almost all of these stressors are at play, while in others, only one or two were found to be problems. Some stressors are a “root cause” of impairment, though they do not in and of themselves cause the stress. Phosphorus, which does not have a toxic effect, is an example. Elevated phosphorus, however, leads to eutrophication, which results in reduced oxygen concentrations. Since insufficient oxygen is what actually harms the organisms, low DO is the “direct cause” or “direct stressor”. In order to correct the direct stressor, the root stressor must be corrected.

Table 22. Summary of stressors causing biological impairment in MRW streams by location (AUID).

Stream	AUID Last 3 digits	Reach Description	Biological Impairment	Impairment Category	Stressor: Dissolved Oxygen	Stressor: Phosphorus	Stressor: Sediment/Turbidity	Stressor: Connectivity	Stressor: Altered Hydrology*	Stressor: Channel alteration	Stressor: Pesticides
Unnamed Trib. to Mustinka R.	538	Unnamed Creek to Mustinka River	Fish and MI	5					◦		
Mustinka River	580	Lightning Lake to Mustinka River Flowage	Fish and MI	5	•	¨	•	•	◦	•	?
Unnamed Trib. to Fivemile Cr.	578	Unnamed Creek to Unnamed Creek	Fish	5				◦	◦		
Twelvemile Cr.	514	T126 R45W S21, south line to W Br Twelvemile Cr	MI	5	•	¨	•		¨	•	?
Twelvemile Cr.	557	W Br Twelvemile Cr to Mustinka River Ditch	MI	5	•	¨ ,+	•		¨	•	?
Eighteenmile Cr.	508	Unnamed Creek to Mustinka River	Fish	5	•	¨			◦		?

*Includes intermittency and/or geomorphology/physical channel issues

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

• Determined to be a direct stressor

o A stressor, but anthropogenic contribution not quantified

+ Based on new (2014) nutrient standards, but not officially assessed and listed for this parameter

? Inconclusive - not enough is known to make a conclusion either way

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Appendix 1

Geomorphological Assessment of the Mustinka River Watershed

Fieldwork and analysis lead by Emmons and Olivier Resources, Inc.

Date |	March 2, 2012	
To |	Kevin Stroom – MPCA	Jon Roeschlein – BDSWD
cc |	Jack Frederick – MPCA Charlie Anderson – WSN David Friedl – MNDNR	Jason Naber – EOR Andrea Plevan – EOR
From |	Kevin Biehn – EOR	Chris Lenhart – EOR
Regarding |	Mustinka TMDL – Stream Deliverables	

The intent of this memo is to provide a summary of the geomorphic data and analysis completed for the Mustinka TMDL delivered as part of this package. A brief perspective of the deliverables provided is included along with hydrologic research on streamflow trends in west central Minnesota and consequences for channel stability.

Complete to date

During the week of October 24, 2011, twenty-two separate reaches (see Figure 34) were surveyed across the Mustinka Watershed by two crews of three people. The reaches were previously selected by BDSWD, WSN, MNDR and EOR staff to reflect a representative cross-section of the Mustinka River and its tributaries. Data necessary for a Level III Rosgen Assessment was collected.

Deliverables included (on CD)

- A summary report discussing the Indicators of Hydrologic Alteration Analysis and Bank Erosion Prediction using BEHI and NBS scores
- Shapefile of survey reaches - GIS files showing the location of each stream reach and associated stream profiles and cross sections
- Estimation of Bankfull Stage
  - Field Indicators
  - Regional curves
  - Recurrence interval discharges
- Stream morphology data from the 22 reaches utilizing the Reference Reach Spreadsheet for channel survey data management. The worksheets include the following:
  - Reach location and context, including drainage area
  - Channel cross-section dimension
  - Meander pattern
  - Longitudinal slope profile
  - Channel material
  - Rosgen dimensionless ratios
- Site photographs - site images of each stream reach surveyed.
  - Raw Survey data - data collected by EOR is in the Minnesota Central State Plane coordinate system, elevations in NAVD 88 datum. Data collected by the BdSWD is in the Traverse

County coordinate system, elevations in NAVD 88 datum. The origin of the survey data used in the Mecklenburg Spreadsheets is stated in the summary tab for each spreadsheet.

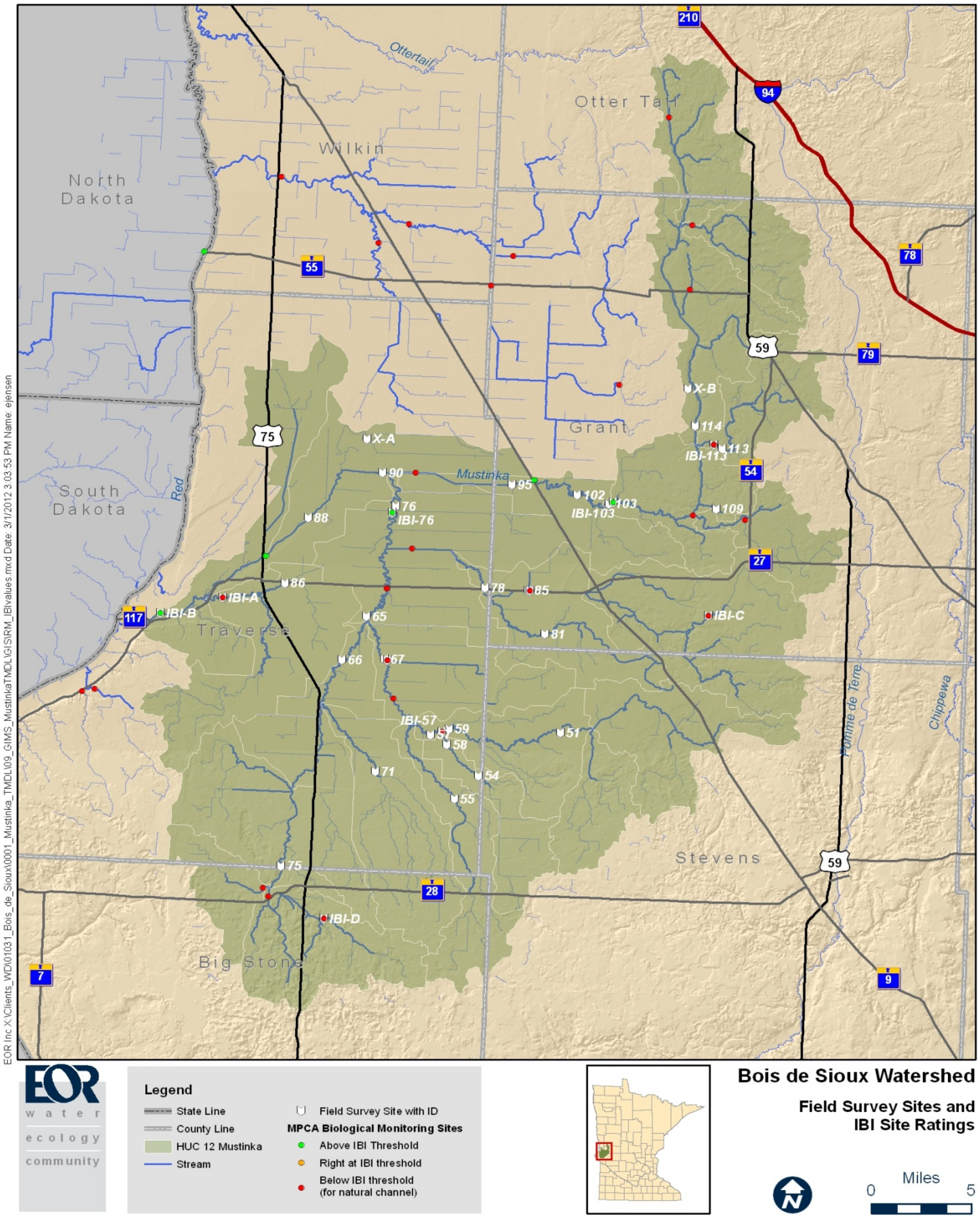

Figure 34. Survey Reaches and IBI Scores within the Mustinka Watershed.

Hydrologic Analysis of Streamflow Trends and Flood Frequency

The Indicators of Hydrologic Alteration (IHA) software was used to examine recent changes in streamflow in west central Minnesota and its consequences for channel instability (Richter et al. 1996). There has been significant streamflow increases in most western Minnesota streams in the past 30 years. This has likely contributed to increased rates of channel erosion in many watersheds (Lenhart et al. 2011a). Potential geomorphic adjustments are discussed in this section, using the Lac qui Parle research as a regional example. The Christner (2009) study of Lac qui Parle was one of the most detailed studies of channel evolution done in this region.

Methods

The IHA is designed to identify changes in hydrologic regime that may be important for aquatic ecology, water quality and sediment transport beyond simple measures of peak flow that are often the focus of hydrologic studies. The IHA calculates a total of 67 statistical parameters which are subdivided into two groups, the IHA parameters and Environmental Flow Components (EFC). The IHA parameters include metrics of streamflow magnitude, duration, frequency, timing and rate of change. The EFC are of particular ecological importance and include metrics on low flows, extreme low flows, high flow pulses, small floods, and large floods. IHA parameters were calculated using non-parametric (percentile) statistics because hydrologic datasets tend to be skewed and thus do not meet the normality requirements of parametric statistics. The coefficient of variation (c.v) (which is the standard deviation of the daily mean flows divided by the annual mean) was also calculated as a measure of streamflow variability.

This suite of hydrologic statistics is used to compare changes to the above metrics before and after a given time period. The time periods 1940-1979 and 1980-2009 were compared in this study for three study watersheds in close proximity to the Mustinka River (Yellow Bank, Bois de Sioux and Buffalo) beginning from 1940-1945 continuing through the present. The Mustinka was not used for this analysis because 1959-1984 data was missing completely and only peak flows were collected after 1984). The year 1980 was chosen as the dividing point to compare pre-impact to post-impact hydrology. The year 1980 was selected because the indicators of climate change began appearing at that time and subsurface tile drainage began expanding rapidly in Minnesota around that time. Significance testing was done by re-shuffling the existing data to obtain a larger sample size, similar to a boot-strapping procedure.

Flood frequency data was calculated for the Mustinka River at Wheaton and annual peak flows were examined since there was a high-flow gauge operated at the river from 1985-2005. The site did not have a continuous flow record, with no data recorded from 1959-1984 (Table 23).

Changes in the discharge to precipitation (Q:P) ratio were also examined in the Buffalo watershed as a regional indicator of changes in land-use or changes in climate. The increased Q:P ratio is thought to be caused by expansion of subsurface drainage for agriculture, increased row crop coverage in place of hay and pasture and/or increased rainfall (Christner 2009; Lenhart et al. 2011a and 2011b). All of these factors may contribute to greater streamflow per unit of rainfall. Q:P ratios were calculated for the Buffalo watershed using monthly, seasonal and annual data. Discharge data, which is a combination of both groundwater discharge and surface water runoff, was obtained through the USGS Surface Data for Minnesota website (USGS, 2010). Precipitation data for the NOAA climate division (west central Minnesota) was obtained from the Western Region Climatic Center (WRCC, 2010). To address those watersheds which overlapped several climate divisions, mean monthly and annual precipitation was calculated using the Thiessen polygon method. To obtain a dimensionless ratio, precipitation was then converted to a volume by using the area of each watershed. Significance was tested for using the Mann-

Whitney test. The Mann-Whitney test is the non-parametric alternative to the unpaired student t-test and will identify whether the two time periods have the same distribution of Q:P ratios.

Table 23. Watershed characteristics for USGS gauge sites in west central Minnesota used in IHA analysis.

Watershed Name	Station	Period of record at USGS gauge	Watershed Area (mi^2) at USGS gauge	Mean annual flow since 1980 (cfs)
South Branch Buffalo	Hawley	1945-present	325	112
Yellow Bank	Odessa	1940-present	459	160
Bois de Sioux	White Rock	1942-Present	1160	192
Mustinka	Wheaton	1916-1958, 1985-present*	810	71* (1916-1958, 2007)

*Mustinka period of record was 1915 to 1924 and 1930 to 1958, (continuous-record station); 1985 to 2006, (high-flow partial-record station); October 2006 to September 2007, (continuous-record station); October 2007 to current year. The Mustinka was not used in the IHA due to lack of daily flow data.

Results

The largest increases in streamflow in the Bois de Sioux region have been in the low to moderately high flow (<bankfull) levels. These three watersheds did not have a significant increases in the magnitude of small or large floods (2 yr and >10 yr recurrence interval flows) since 1980. However the changes in the low flows, mean flows and moderately high flows have been substantial. For example, the Yellow Bank River had a mean annual flow that approximately tripled from 58 cfs to 160 cfs since 1980, while the Bois de Sioux more than doubled, increasing from 82 to 192 cfs. Moderately high flows (defined as 75 – 90% flows) have increased substantially in all three watersheds.

The timing of the large floods (>10 yr recurrence interval) did not change significantly at these sites using the IHA statistical test of significance. However the timing of the small (< 2 yr floods) changed from early to late April in the Buffalo River and from early April to mid-October in the Bois de Sioux River when comparing the pre-1980 to post- 1980 time periods. The occurrence of fall flooding in addition to spring floods could increase channel erosion rates in the region.

The duration of floods did change in some of the watersheds. Large flood duration increased significantly in the Buffalo River and Yellow Bank River from 64 and 67 days to 152 and 118 days respectively, although not in the Bois de Sioux. Longer duration of high flow levels is important because of the increased cumulative shear force acting on the stream channels, leading to more channel erosion.

Low flows increased significantly by many metrics in all three watersheds. The 1-day, 3-day, 7-day, 30-day, and 90-day minimums increased at the Yellow Bank, Bois de Sioux and Buffalo Rivers. Monthly low flows increased in many of the months particularly in fall and winter (the typical low-flow season in the region). Although low flow increases do not generally increase sediment transport or channel stability substantially, they may have ecological consequences for aquatic plant and animal life cycles.

The variability of streamflow decreased slightly as measured by the coefficient of variation (c.v). The c.v. dropped from 2.84 to 2.31 in the Bois de Sioux, from 1.81 to 1.69 in the Buffalo and from 3.57 to 3.44 in the Yellow Bank at Odessa. The reason for this is that the low and median flows increased much more than the flood peaks, thus decreasing the standard deviation of the daily flows. However the *range* of flow levels (difference between the minimum and maximum stage) may appear greater as there are more frequent high flows.

Flood frequency statistics for the Mustinka River at Wheaton USGS gauge

Although large floods were not shown to increase significantly using the IHA tests, there is some evidence that large floods are increasing in frequency in the region. There have been ten annual peaks over 4000 cfs between 1985 and 2010 and only one during the 1916-1958 time period (flow data was not recorded from 1959-1985, Figure 35). Based on annual peak data, the 1.5 year recurrence interval flow at the Wheaton USGS gauge was calculated to be 610 cfs.

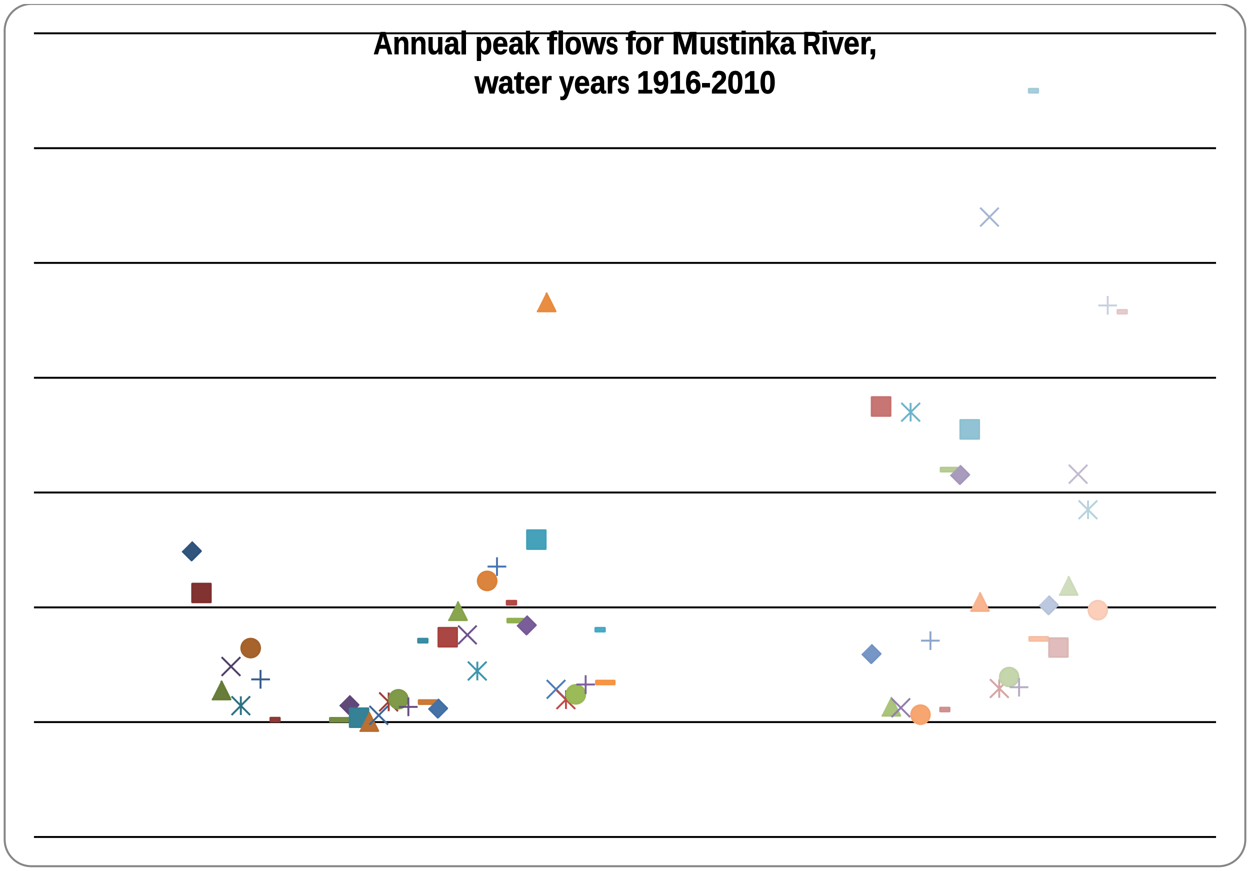

Figure 35. Annual peak flows in the Mustinka River (streamflow data was not collected from 1959-1984). Numerous large peak flows have occurred since 1985.

Bankfull discharge was estimated by the 1.5 year recurrence using the StreamStats program (Figure 36). At the Wheaton gauge (810 mi^2) the 1.5 year discharge was estimated to be about 500 cfs. Field estimates of bankfull discharge made by EOR staff in September and fall within the range of flows in Figure 3. Bankfull discharge estimates based on field indicators could not determine the channel's water surface slope very accurately as there was very little water in the Mustinka River and tributaries in the fall of 2011. Slopes obtained from *StreamStats* over the stream's local vicinity were typically about 0.05 percent to 0.1% for the Mustinka basin.

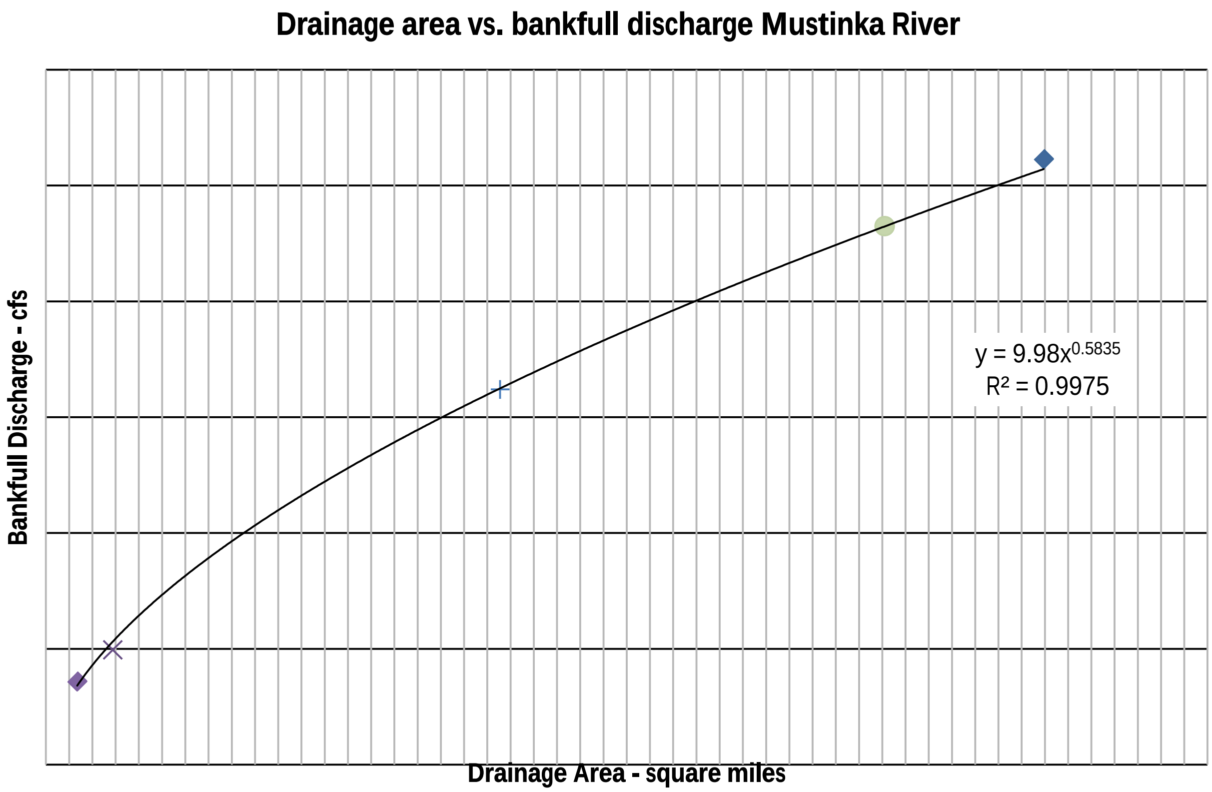

Figure 36. Regional curve for Mustinka River bankfull discharge generated using data from the USGS StreamStats program. The 1.5 year recurrence intervals were calculated from regional regression equations at points across the watershed.

Streamflow: Precipitation ratio

The Q:P ratio, an indicator of hydrologic change, increased from 14.0% to 18.3% in the Buffalo watershed during the past three decades (1980-2009) compared to the pre-1980 time period (Figure 37). In the Bois de Sioux the ratio doubled from 4% to 8%. This represents a 31% to 100% increase in streamflow per unit of rainfall for these watersheds. Overall for the northern Glaciated Plains ecoregion, there was an increase in the Q:P ratio from 11% to 15% (Figure 4). Lenhart et al (2011a and 2011b) found that this increase was from increased subsurface tile drainage, with increasing annual row crops contributing as well. During this time period, annual rainfall increased by about 10%, contributing to increased flow as well. However the volume of water produced by a 10% rainfall increase, given that only 4-18% of the rainfall in this region ends up as streamflow could not account for the degree of streamflow increase (50-100% increase) in mean flow observed in the region.

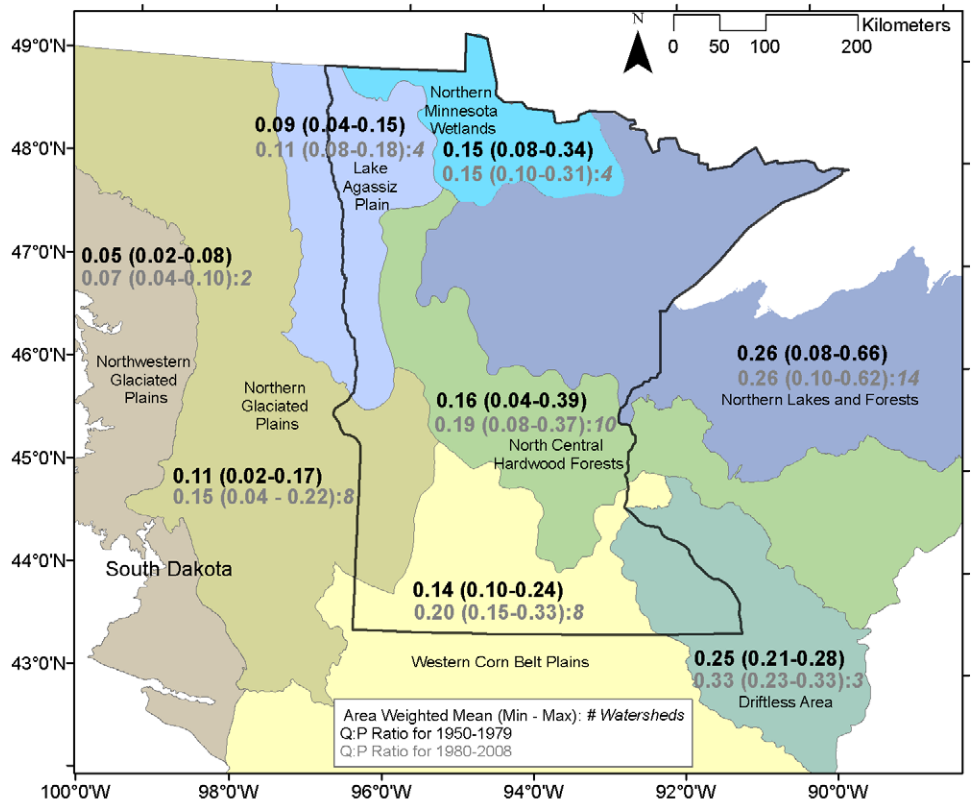

Figure 37. Change in the Q:P ratio for Minnesota (from Lenhart et al. 2011b). The values represent the average Q:P for several watersheds examined in the region from 1950-1979 (top number) and 1980-2009 (bottom number).

Geomorphic field data and related research in the region

Channel dimensions have likely responded to increased streamflow in the region by enlarging. With increased flows (with the greatest percentage changes to the less-than-bankfull flows) there is greater cumulative stream power acting on stream channels. While bankfull discharge (the frequently occurring 1-2 yr peak flows) are thought to do the most work in shaping channels over time, increased high flows below the bankfull level that have high shear stress can cause considerable channel erosion as well. Over many years increased duration of moderately high flows could cumulatively cause as much channel erosion as increased 1-2 year recurrence interval flows.

In fact, some cross sections in the Mustinka showed slight cross sectional area increases over a time scale of about 10 years. BANCS scores predict low rates of stream bank erosion for the Mustinka basin, with a median of 0.1 ft/year. However a more detailed examination of channel change over time is needed to understand the channel evolutionary trends in different parts of the watershed. Christner (2009) examined channel change on the adjacent Lac qui Parle watershed and showed that channel cross sectional areas enlarged from 1965-1966 to 2002-2003 by 2 - 30% due to channelization, increased flows and resultant channel evolution. Over 2/3 of the channel sites surveyed had increased in maximum channel depth, while changes in width were more variable with about half undergoing widening and half narrowing. Although it is unknown how the Mustinka has responded to increase flows, it is in a similar geologic and climatic setting so the response may be similar. More research is needed into channel change trends.

Geomorphic alteration via channelization has also impacted channel stability and biotic integrity as channelization led to a permanent decrease in sinuosity and subsequently more erosive flows contained within the channel. In the region, Christner (2009) found a moderate sinuosity in the Lac qui Parle of 1.5.

The Mustinka River does appear to have low sinuosity in many reaches due to historic channelization and ongoing ditch maintenance, with a median sinuosity of 1.1 measured at 19 river reaches (Figure 1). Some un-channelized reaches still have very high sinuosity, up to 2.3. The channel cutoff on the northern end of the Mustinka River done in the mid 1900s reduced river length by about 7.5 miles, potentially causing head-cutting and entrenchment upstream of the channelization project (near Site 90 in Figure 1).

Bank erosion prediction

The BANCS data collected had 78% very low-low NBS ratings, with occasionally high-very high values (Table 2). The BEHI scores in contrast had 49% high-very high ratings, with 36% moderate and 13 low-very low. Low NBS and moderately high BEHI is typical of a highly channelized river system, as straightening reduces radius of curvature and NBS, while ditch maintenance and moderately cohesive banks promote steep bank angles and moderate-high BEHI.

Table 24. Distribution of BANCS scores for Mustinka basin by % in categories

Sample # (n)	55	46
BANCS category	BEHI	NBS
Rating description	% with BEHI rating	% with NBS rating
Very low to low	13	78
Moderate	36	2
High – very high	49	17
Extreme	0	2

Erosion rates predicted by the BANCS equations produced the data in Table 3. Although 46 erosion rates were obtained, 20 of these were collected at two river reaches, Site IBI-D and Site 103 so the summary statistics in Table 3 might not be representative of the entire basin. The median rate of 0.10 ft/year is a fairly low rate, suggesting that channel loading of sediment may be small compared to field/gully sources, although more complete sediment loading data would be required to make this determination.

Table 25. Erosion rates predicted by BANCS data in the Mustinka Basin*

Statistic	Predicted bank erosion rate in ft/year
Sample size	46
average	0.22
median	0.10
st. deviation	0.28
95 % confidence Interval for median	0.02< x < 0.18

**erosion rates obtained used Colorado graph of NBS and BEHI*

Some of highest predicted erosion rates by BANCS of 0.7 – 1.3 ft/yr were located on Twelve-Mile Creek at 58-107 square miles of drainage area, in the southeastern headwaters of the Mustinka watershed (Sites 51 and 57) (Figure 1). Site 103 in the eastern headwaters of the Mustinka watershed (171 sq. miles drainage area) also had a high predicted rate of erosion at 0.88 ft/yr.

Future data analysis needs

The data collected for this study was to provide government agency staff with the information needed to do a more thorough investigation of channel-sediment loading and consequences for biotic and turbidity impairments. Based on our preliminary review of the data we suggest the following topics for further analysis:

- Further analysis of bankfull flow elevation at cross sections from field indicators
- Calculation of total sediment load from channel erosion via BANCS calculations; estimation of sediment delivery rates and/or deposition in the stream valley(s)
- Channel evolution stage determinations to identify the current stage of channel evolution at each survey site
- Determine geomorphic and ecological consequences of increased low flows in western Minnesota streams? Increased high flows have direct consequences for sediment transport, but it is harder to predict the impacts of increased low flows on stream ecology and riparian vegetation.
- Determine exact causes of increased flows in the past 30 years from crop cover change, expanded drainage and increased rainfall
- Management recommendations should be developed based on geomorphic and hydrologic research.

References

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