Bois de Sioux River Watershed

Watershed Restoration and Protection Strategy

Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities

Minnesota Pollution Control Agency

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Author

Kevin Stroom (MPCA)

Contributors/acknowledgements

Kevin Biehn, Mike Majeski, Roger Hemphill (EOR, Inc.) - Geomorphology: field work, data analysis, and conclusions.

Julie Aadland (DNR), Dave Friedl (DNR), Jason Vinge (DNR) - Geomorphology field work assistance.

Gene Berger (Widseth Smith Nolting) - Geomorphology field work assistance.

Manuscript reviewers:

Julie Aadland (DNR)
Dave Dollinger (MPCA)
Cary Hernandez (MPCA)
Jeff Jasperson (MPCA)
Joe Magee (MPCA)

Editing and graphic design

Cover photo: Kevin Stroom - Bois de Sioux River at County Highway 6.

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Minnesota Pollution Control Agency

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

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

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Acronyms, 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

BdSW......................... Bois de Sioux River Watershed

BEHI.......................... Bank Erosion Hazard Index, a geomorphological measurement, per Rosgen protocols

CALM......................... Consolidated Assessment and Listing Methodology. The protocol used in MPCA's assessment of designated use attainment for surface waters

Chl-a.......................... Chlorophyll-a

cm.............................. Centimeter

CR.............................. County Road

CSAH......................... County State Aid Highway

DNR........................... Minnesota Department of Natural Resources

DO.............................. Dissolved Oxygen

DS.............................. Downstream

EPA.............................. United States Environmental Protection Agency

GIS.............................. Geographic Information System

HDS............................ Human Disturbance Score – a measurement of human disturbance at and upstream of a biological monitoring site

HUC.............................. Hydrologic Unit Code (a multi-level coding system of the US Geological Survey, with levels corresponding to scales of geographic region size, e.g., HUC-8)

HSPF.......................... The hydrologic and water quality model **H**ydrologic **S**imulation **P**rogram **F**ortran

IBI.............................. Index of Biological Integrity – a multi-metric index used to score the condition of a biological community

ISTS............................ Individual Sewage Treatment Systems

IWM........................... MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling

m................................ 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

MADRAS.................... Minnesota Agricultural Ditch Reach Assessment for Stability

MSHA............................ Minnesota Stream Habitat Assessment

M&A Report................. MPCA Monitoring and Assessment Report for the Bois de Sioux River Watershed

MS4............................... Municipal Stormwater Plan, level 4

NPDES............................ National Pollutant Discharge Elimination System

Natural background... An amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors

NBS........................... Near Bank Stress, a Rosgen geomorphology measurement quantifying the streamwater's frictional force against the bank material

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

SID............................. Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities

Sonde......................... A deployable, continuous-recording water quality instrument that collects temperature, pH, DO, and conductivity data and stores the values which can be transferred to a computer for analysis

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

Taxa............................ Plural form - refers to types of organisms; singular is taxon. May refer to any level of the classification hierarchy (species, genus, family, order, etc.). In order to understand the usage, one needs to know the level of biological classification being spoken of. For MPCA fish analyses, taxa/taxon usually refers to the species level, whereas for macroinvertebrates, it usually refers to genus level

TSS............................. Total Suspended Solids (i.e. all particulate material in the water column)

TSVS.......................... Total Suspended Volatile Solids (i.e. organic particles)

TP.................................... Total Phosphorus (measurement of all forms of phosphorus combined)

US.............................. Upstream

USGS......................... United States Geological Survey

WRAPS........................... Watershed Restoration and Protection Strategy, with watershed at the Hydrological Unit Code 8 scale

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

303(d) list..................... The official, EPA-accepted list of impaired waters of the state

Executive summary for the Bois de Sioux 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 Bois de Sioux River Watershed (BdSRW). Information on the Stressor Identification (SID) process can be found on the United States Environmental Protection Agency's (EPA) website http://www.epa.gov/caddis/.

The BdSW is situated at the southern extent of Glacial Lake Agassiz. As with other Red River Basin watersheds, the BdSRW 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 BdSRW is rowcrop agriculture – corn, soybeans, sugar beets, and wheat. Very little of the BdSRW is used for livestock production, with 28 registered feedlots. There is a relatively small amount of state-owned land in the BdSRW, with most being Wildlife Management Areas (16 separate parcels, most are between 100-200 acres in size). The density of residential and urban land use is very low in the BdSW. 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 BdSRW 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 BdSRW, 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 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, 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).

Five 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, notably low dissolved oxygen (DO) (via excess nutrients and flow alteration), excess sediment, and migration barriers (in bulleted list below, impairments follow AUID number, with identified stressors in the brackets).

- Bois de Sioux River (AUID 09020101-501) – Fish, DO, Turbidity [Low DO, TSS]
- Rabbit River (AUID 09020101-502) – Fish, macroinvertebrates, DO, Turbidity [Low DO, TSS]
- Rabbit River South Fork (AUID 09020101-512) – Fish, DO and Turbidity [Low DO, TSS]

- Unnamed Creek (AUID 09020101-535) **–** Fish [barrier to connectivity]
- County Ditch 52 (AUID 09020101-540) – Fish [Low DO, sediment and TSS, barrier]

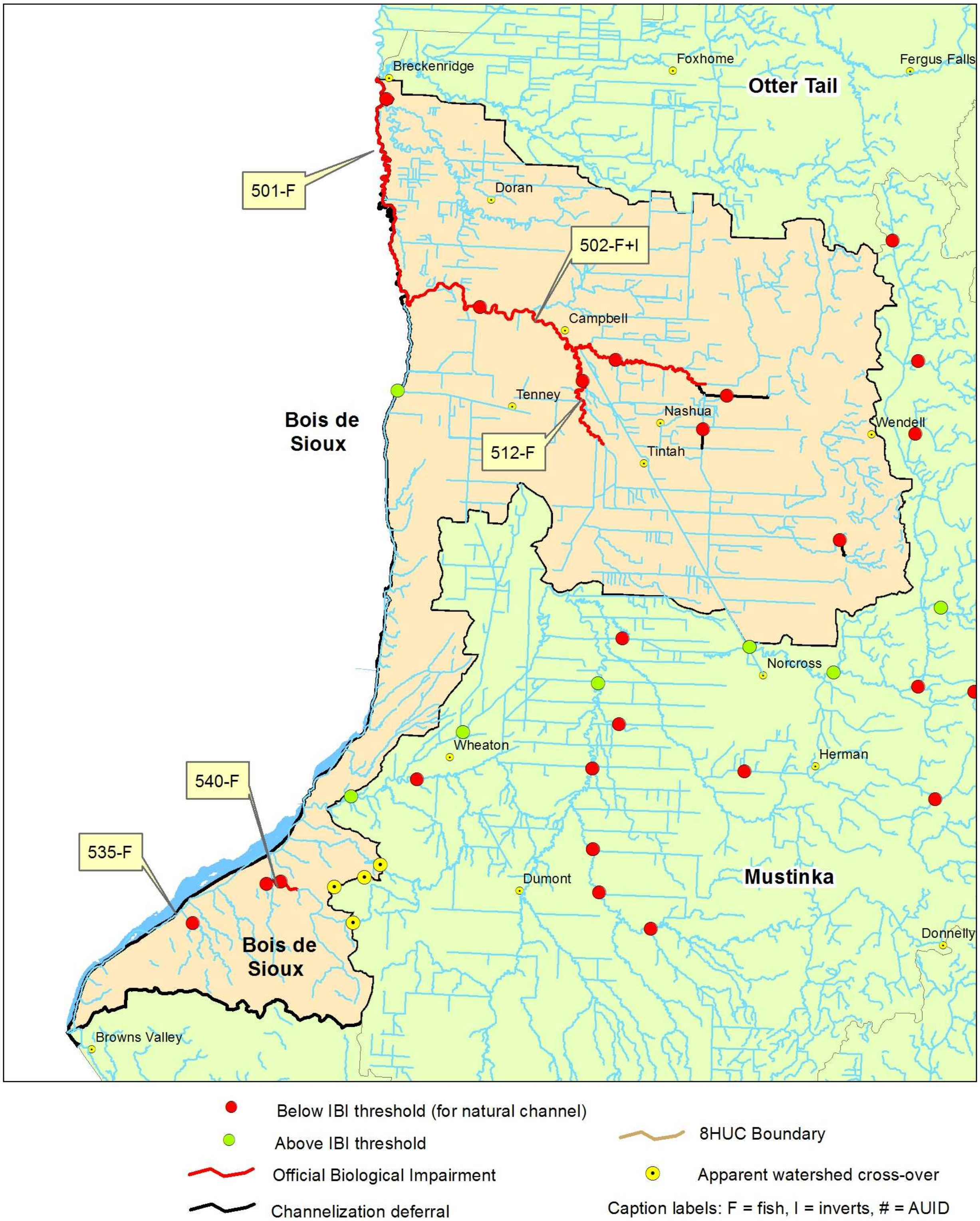


Figure 1. Stream reaches with aquatic life use impairments.

Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving the water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 major watersheds, known as the 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 BdSRW 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 the multi-part WRAPS for the Boise de Sioux River watershed (BdSRW), located at the headwaters of the Red River of the North Basin. Hereafter, the Red River of the North will be referred to as just the Red River.

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 BdSRW Monitoring and Assessment (M&A) Report. The M&A Report should be read together with this Stressor ID Report and can be found from a link on the MPCA's BdSRW webpage;
https://www.pca.state.mn.us/sites/default/files/wq-ws3-09020101b.pdf

Landscape of the BdSRW

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

The natural landform of the BdSRW was created by glacial activity. As with other Red River Basin watersheds, the BdSRW can be geographically divided into the Glacial Moraine (rolling uplands, on the far eastern and southern portions of the BdSRW), 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 region 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 are more well-drained and loamy than the Lake Plain soils. The Executive Summary above contains additional information regarding the BdSRW. 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 BdSRW today 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 BdSRW. 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. Figure 3 shows the extent of land area that is cultivated in the Lake Plain area of the BdSRW.

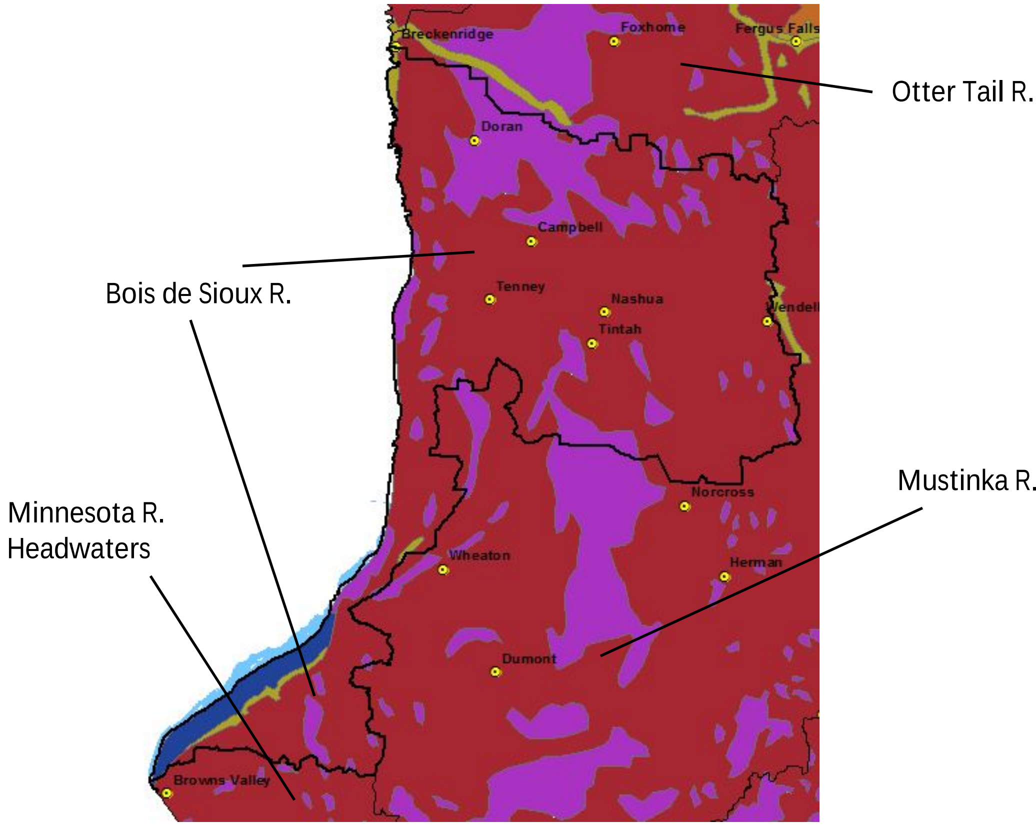


Figure 2. Original vegetation of the BdSRW and adjacent watersheds (Marchner, 1930). Red represents Grassland Prairie, purple represents Wet Prairie, blue represents Lakes, and yellow-green represents River Bottom Forest.

Table 1. Percentages of the various land cover types from 2011 NLCD GIS coverage (MPCA, 2013).

Land cover type	Percent of land area
Developed (all intensities grouped)	5
Cultivated crops	86
Water, wetlands, natural lands	8

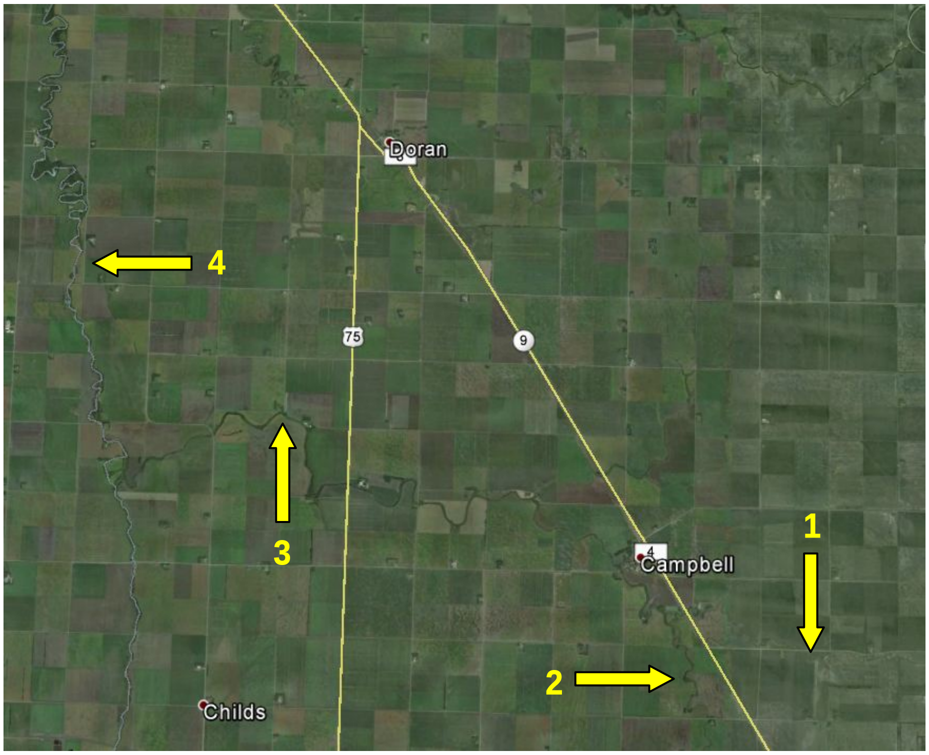


Figure 3. Extent of agricultural land coverage in the BdSRW along Highways 75 and 9. The arrows point to the more prominent rivers (1 and 3 Rabbit River, 2 South Fork Rabbit River, 4 Bois de Sioux River.)

Determination of candidate stressors

The process

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

In conjunction with the anthropological and geographical data, actual water quality, habitat, and biological data were analyzed to make further conclusions about the likelihood of certain stressors impacting the biological communities. Water chemistry and flow volume data has been collected within the BdSRW 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.

DNR watershed health assessment framework

DNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The WHAF includes an assessment of the nonpoint source pollution threat to water quality within the water quality component of watershed health, which is shown in Figure 4. This figure also shows non-point pollution as being a greater threat in the BdSRW than in many of the other Red River Basin watersheds. Given the high percentage of non-natural landscape in the BdSRW and only one (Campbell) municipal point-source pollution discharger (no industrial dischargers), it is nonpoint source pollution that is the primary threat to water quality in the BdSRW. Streams within the BdSRW are bordered by agricultural land along most of their lengths. According to the Non-point Source Pollution Index, the BdSRW ranks a 13-15 (tied) out of the 80 (80st has the least threat) watersheds in Minnesota. A major urban source of non-point pollution is runoff from impervious surfaces. This threat is very low in the BdSRW (Figure 5).

Another issue, which has very significant influence on the health of BdSRW water resources, is the alteration of the hydrologic patterns on the BdSRW landscape due to stream channelization, ditching, and wetland drainage. Water storage capacity in the BdSRW is quite poor (Figure 6). 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.

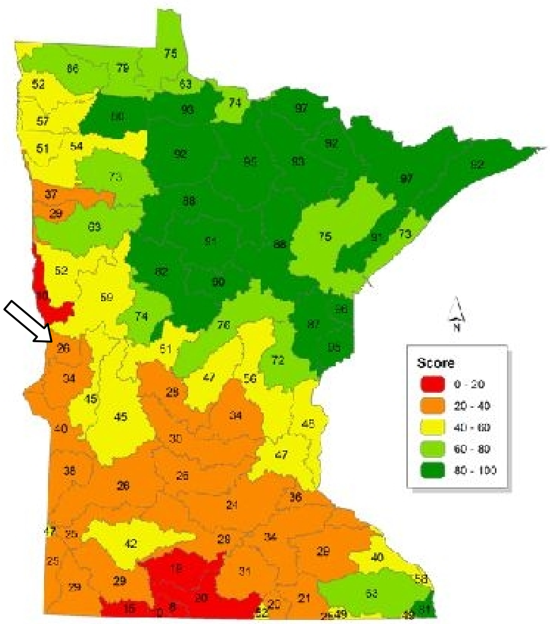


Figure 4. Scores and categorical ranking of the 80 Minnesota Major Watersheds for the DNR Non-point Source Pollution Index.

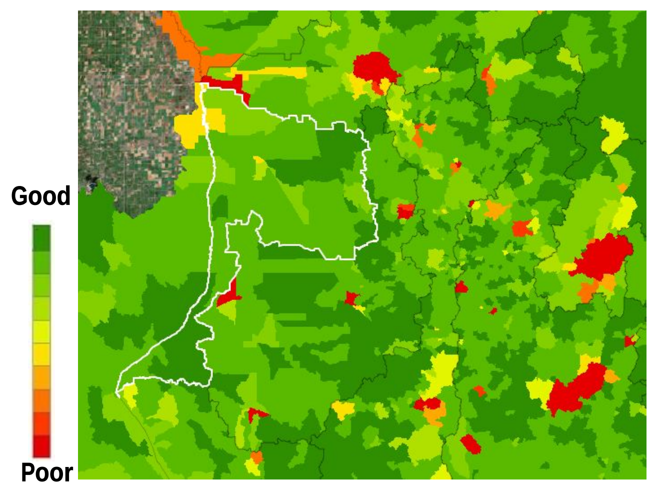


Figure 5. Impervious surface scores for the BdSRW (white boundary) and other subwatesheds in the area.

In addition to the metrics above, several other metrics were chosen from the DNR WHAF that relate to either point or non-point source pollution. Using the data within the WHAF, the BdSRW'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 BdSRW (Table 2). There is only one wastewater treatment discharge permit in the BdSRW, that being the Campbell Municipal Wastewater Treatment Plant (WWTP) (see MPCA, 2014 –

http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=5e26e6c6756d4d0885da0ccadcb84737). The Localized Pollutant Source Index in the WHAF shows very little influence in the BdSRW (Figure 7); the index score for the BdSRW was 99 out of 100. This index accounts for pollutant contributions from animal husbandry, hazardous waste and superfund sites, wastewater treatment effluent, mining, and septic systems. The overall WHAF scorecard, which includes many more metrics, can be found at: http://www.dnr.state.mn.us/whaf/about/report-cards.html.

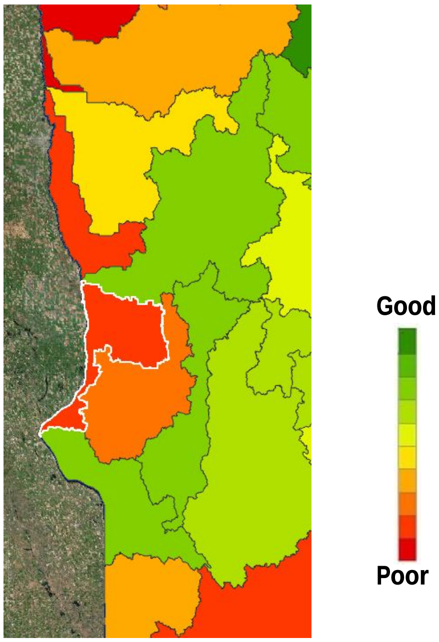


Figure 6. Hydrologic storage in the BdSRW (white border) and surrounding watersheds. The scoring is the degree of storage loss relative to all state of Minnesota watersheds.

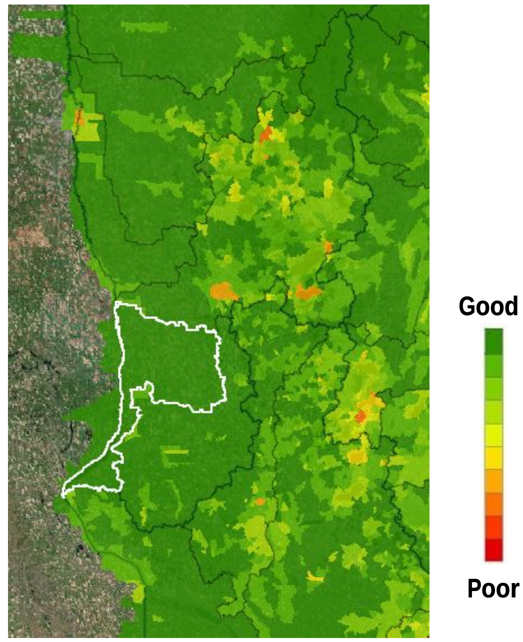


Figure 7. The sub-watershed scoring categories for the Localized Pollutant Source Index in the BdSRW and surrounding sub-watersheds.

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

	Impervious surface	Nonpoint threat	WWTP*	Storage loss	Perennial cover	Flow variability	Ag. chem. use	Aquatic connectivity
Rank	32-33 (t)	13-15 (t)	73	4	3-6 (t)	27-28 (t)	3	73

*WWTP = Wastewater Treatment Plant influence.
(t) = tied with other watersheds for these ranks.

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 to some degree. The report listed: "...instream sediment from field and gully erosion, intermittent stream flow, channelization, pesticides, low dissolved oxygen, 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 program monitoring, the MPCA has other programs that conduct various water monitoring efforts that can shed light on possible stressors. The MPCA's Major Watershed Pollutant Load Monitoring Network monitors pollutants, such as nutrients, at the pour point of HUC-8 watersheds. The 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 BdSRW shows that from 2005 to 2014, the wastewater phosphorus average has decreased by 38% (MPCA, 2015). Phosphorus loads from each of Minnesota's 8HUC watersheds are found on MPCA's webpage: http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=c53c280bb959419e891aaebfc1da9bb4. The MPCA provides water quality monitoring grants to local organizations, and this data, as well as all of the MPCA-collected data, are 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 are 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, impervious surface areas, and stormwater runoff, which all increase with population density. According to the 2010 census data, the BdSRW is quite sparsely populated relative to the state as a whole. The BdSRW is composed of Traverse, Grant, Wilkin, and a small portion of Otter Tail counties, with populations of 3558, 6018, and 6576, respectively, not including Otter Tail (US Census Bureau, 2011). There are no towns in the Otter Tail County portion of the BdSRW. Recent population trends show declines in each of these three counties from 1990-2010 US Census data (MSDC, 2015).

There are a number of small towns in the BdSRW: Campbell (population 158), Doran (54), Nashua (67), Tenney (5), Tintah (63), and Wendell (167). None of these towns are large enough to require a Municipal Stormwater Plan, level 4 (MS4) (EOR, Inc., 2009). Recent GIS-derived land use statistics showed that 5% of the watershed area is categorized as Residential/Commercial (MPCA, 2013). The BdSRW ranks at the 56.2 percentile of the state's 80 watersheds for the amount of impervious cover, tied with seven other watersheds at this position. Despite this rank, there is actually relatively little impervious cover, as the WHAF's raw score for the watershed is 86, with 100 being the maximum (and best) score. There are numerous watersheds in Minnesota that have relatively small amounts of impervious surface, which explains the "medium" percentile ranking of the BdSRW for impervious cover. The predominant impervious surface in the watershed is roads. Wastewater discharges are a possible contributor to water quality impairments, though only one town has a treatment system that seasonally discharges upstream of the biologically-impaired locations of the Rabbit River system. The town of Wendell discharges its effluent into the Mustinka River system. The census and urbanization information suggests that most stressors related to population density are likely only small contributors to the impairments found in the BdSRW. Wastewater discharge from Campbell is likely having some impact on nutrient-related stream impairments.

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 not conforming to current design standards. As of 2008, the following five areas within the BdSRW meet the MPCA "Unsewered Community" designation criteria: the towns of Doran, Nashua, Tenney, Tintah, and an area in Windsor Township along Lake Traverse. Most rural homesteads in the BdSW 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 three main BdSRW counties, there are between 4 and 10% of the individual treatment systems that are estimated to be "Imminent Public Health Threats" (i.e., direct discharge to stream), 26 to 51% "Failing", and 49 to 80% compliant systems (MPCA 2012). Thus, there is reason to suspect that nutrient problems are due, in part, to non-compliant SSTS. These can be difficult to detect unless counties have an inspection program.

Industrial activities

Industrial activities are another potential cause of water quality impairments within watersheds. The BdSRW has little non-agricultural industry and there are zero industrial NPDES permits within the BdSRW. A few industrial stormwater permits exist in the BdSRW. Thus, industrial discharges should not be a source of pollutants (stressors) causing stream impairment in the BdSRW.

Forestry

Forest harvest can create stress on water resources. Land within the BdSRW is not used for timber production, nor is historical large-scale forest removal an issue in the watershed. Nearly all of the BdSRW 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 (Figure 3), 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 BdSRW'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 BdSRW 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 BdSRW IWM occurred has been a "wet cycle". The BdSRW M&A Report discussed precipitation patterns for the 20-year periods ending in 2010. No statistically-significant increasing (or decreasing) trend has occurred from 1990-2010. However, the 100-year period ending in 2014 does show an increasing precipitation trend. 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 BdSRW, elevated nutrients must be investigated as a candidate stressor.

Pesticides

Given that the BdSRW 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 2012, the MPCA collected a small number of stream samples (four) for pesticide analyses. The samples 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 BdSRW. 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 July 26, 2012 for pesticide testing.

Stream	Bio. site #	EQuIS site #	Location description
Rabbit River	94RD002	S001-052	At CSAH 2 (480th St.)
Rabbit River, So. Fork	10RD012	S004-176	At CR-152.
Rabbit River	10RD005	S001-029	At US Highway 75.
Bois de Sioux River	NA	S000-553	At CSAH 6. (430th St.)

Summary of candidate stressor review

Based on the review of human activity in the BdSRW, the initial list of candidate/potential causes was narrowed down to those stressors deemed most likely to occur in the BdSRW, 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 BdSRW 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. EPA (2012) 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 has been collected at numerous locations in the BdSRW 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. No longitudinal DO sampling was conducted in the BdSRW. An abrupt starting point (location) for low DO was not thought to be likely, given the homogeneous land use within most of the BdSRW AUIDs.

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. YSI loggers were placed in a few locations in the BdSRW during SID investigations.

Altered hydrology

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

Reduced flow

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

Increased flow

Increasing surface water runoff and seasonal variability in stream flow have the potential for both indirect and direct effects on fish populations (Schlosser, 1990). Indirect effects include alteration in habitat suitability, nutrient cycling, production processes, and food availability. Direct effects include decreased survival of early life stages and potentially lethal temperature and oxygen stress on adult fish (Bell, 2006). Increased flow volume increases channel shear stress, which results in increased scouring and bank destabilization. This subsequently has a negative impact on the fish and macroinvertebrate communities via loss of habitat, including habitat smothering by excess sediment. High flows and the associated increased flow velocities can cause displacement of fish and macroinvertebrates downstream, and mobilization and possible removal to the floodplain of habitat features such as woody debris, which are important as flow refugia for fish and living surfaces for clinging invertebrates. Macroinvertebrate types may shift from those species having long life-cycles to shorter ones; species that can complete their life history within the bounds of the recurrence interval of the elevated flow conditions (EPA 2012). 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 sub-watershed 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 (EPA, 2011). Recent studies in Minnesota have demonstrated that human activities on the landscape have dramatically increased the sediment entering our streams and rivers since European settlement (Triplett et al., 2009; Engstrom et al., 2009). Sediment can come from land surfaces (e.g., exposed soil), or from unstable stream banks (see geomorphology section for details). The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently-vegetated pastures. Human actions on the landscape, such as channelization of waterways, riparian land cover alteration, and increased impervious surface area can cause stream bank instability leading to sediment input from bank sloughing. Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can be detrimental to aquatic organisms.

Suspended sediment

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

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 recently completed the process of moving to a standard based on TSS. The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The new TSS standard for the BdSRW is 65 mg/L. A Secchi tube measurement of 10 cm of visual transparency is a surrogate for the TSS standard in the BdSRW. 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 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 removes oxygen from the water during the nighttime. Additionally, DO is lowered as bacterial decomposition occurs after the overly-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 dissolved oxygen 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 threshold concentration also requiring at least one of three response variables exceeding its threshold. Assessments are made with samples from June-September, using the mean concentration of at least 12 samples collected over a minimum of two years.

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

		Response variables		
Region	TP µg/L	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 have been collected from streams and rivers throughout the BdSRW, both prior to and as part of the IWM process. 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 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 BdSRW, 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, 2013b). These land applications can reach waterways through surface runoff, tile drainage, and leaching to groundwater, with tile drainage being the largest pathway (MPCA, 2013b). 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. Much of the BdSRW falls within the Lake Agassiz Plain (Red River Valley) ecoregion, which has an ecoregion norm of 0.2 mg/L for nitrate+nitrite, N. The area adjacent to Lake Traverse is in the Northern Glaciated Plains ecoregion, with an ecoregion norm of approximately 0.45 mg/L for nitrate+nitrite, N.

Types of nitrate data

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

Candidate cause: Physical habitat loss

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. The focus here will be on physical habitat. EPA's CADDIS website (2012) 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, dissolved oxygen) and so the reader is directed to other stressor sections for more detail.

Degraded physical habitat is a leading cause nationally of impairment in streams on state 303(d) lists. Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on the landscape by way of resource extraction, agriculture, forestry, urbanization, and industry. Channelizing streams leads to an overall more homogeneous habitat, with loss of important microhabitats needed by particular species (Lau et al., 2006).These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat, or reduced habitat quality, such as embedded gravel/cobble substrates. In the past, it was common to remove large woody debris (LWD) from stream channels for various reasons. It has now been shown (Gurnell et al., 1995, Cordova et al., 2006, and Magilligan et al., 2008) that LWD is very important in creating habitat (causes scour pools, provides cover for fish and creates pockets of protection from faster currents, and a living surface for macroinvertebrates that cling to hard objects).

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

Water quality standards

There are no state water quality standards for physical habitat.

Types of physical habitat data

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

Candidate cause: Elevated stream temperature

The factors that control streamwater temperature and the biological effects of elevated temperature are very complex. Stream temperature naturally varies due to air temperature, geological setting, shading, and the water inputs from tributaries and springs. Human activities can increase stream temperatures through altering riparian vegetation (loss of shading), urban runoff from warm impervious surfaces (e.g., parking lots), agricultural runoff, loss of landscape water storage and thus periods of reduced stream water volume, and direct discharges of warm wastewater to the stream. Warmer water holds less 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 in the BdSRW. 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 un-ionized ammonia (NH_3) concentration, which is toxic to aquatic organisms at certain concentrations. The fraction of unionized ammonia (NH_3) is not directly measured, but instead is calculated using measures of total ammonia, pH, temperature, and specific conductivity. Many human activities can contribute to elevated ammonia concentrations in streams. Sources of ammonia (NH_3) include human and animal waste, fertilizers, and natural chemical processes. Channel alteration can result in decreased natural conversion of ammonia to nitrate, and alteration or removal of riparian vegetation can reduce the interception of nitrogen compounds in runoff from the surrounding landscape. Channel alteration and water withdrawals can reduce ammonia volatilization by reducing the turbulence of the water. For a more detailed explanation of ammonia sources and causal pathways, see: http://www.epa.gov/caddis/ssr_amm4s.html .

Water quality standards

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

Types of ammonia data

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

Candidate cause: 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 (EPA 2012). 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 (EPA 2012). 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 degradants. 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).

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

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

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

Connectivity is defined as the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes within a river system (Annear 2004). Connectivity is thus the water-mediated transfer of energy, materials, and organisms across the hydrological landscape (Pringle 2003). The transport of these integral components within a river travel in four dimensions: longitudinal, upstream and downstream*; lateral, channel to floodplain; vertical, hyporheic to groundwater zones; and temporal, continuity of transport over time (Annear 2004). 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 DNR GIS coverage. Aerial photos are viewed to locate any undocumented structures. Culverts are visited to determine their organism passage capability.

Analysis of biological data

Biological data (the list of taxa sampled and the number of each) form the basis of the assessment of a stream's aquatic life use status. Various metrics can be calculated from the fish or macroinvertebrate sample data. An IBI, a collection of metrics that have been shown to respond to human disturbance, is used in the assessment process (https://www.pca.state.mn.us/water/index-biological-integrity). Similarly, metrics calculated from biological data can be useful in determining more specifically the cause(s) of a biological impairment. Numerous studies have been done to search for particular metrics that link a biological community's characteristics to specific stressors (e.g., Álvarez-Cabria et al., 2010, Angradi, 1999, Bond and Downes, 2003, Burdon et al., 2013, Houghton, 2004, Meador et al., 2008). This information can be used to inform situations encountered in impaired streams in Minnesota's WRAPS process. This is a relatively new science, and much is still being learned regarding the best metric/stressor linkages. Use of metrics gets more complicated if multiple stressors are acting in a stream (Statzner and Beche, 2010; Ormerod et. al., 2010, Piggott et. al., 2012).

Staff in MPCA's Standards, Biological Monitoring, and Stressor ID programs have worked to find metrics that link biological communities to stressors, and work continues toward this goal. Much work in this area was recently done to show the impact of nutrients (particularly phosphorus) on biological stream communities when Minnesota's River Nutrient Standards were developed (Heiskary et al., 2013). The Biological Monitoring Units of MPCA have worked to develop Tolerance Indicator Values for many water quality parameters and habitat features for species of fish, and genera of macroinvertebrates. This is a take-off on the well-known work of Hilsenhoff (1987, EPA, 2006). For each parameter, a relative score is given to each taxon regarding its sensitivity to that particular parameter by calculating the weighted average of a particular parameter's values collected during the biological sampling for all sampling visits in the MPCA biological monitoring database. Using those scores, a weighted average community score (a community index) can be calculated for each sample. Using logistical regression, the biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites to date. Such probabilities are only available for parameters that have developed standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

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

Investigations organized by impaired stream reach

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

Bois de Sioux River (AUID 09020101-501)

Impairment: The river was assessed as impaired for not meeting fish community expectations at 84RD005. This AUID also has documented dissolved oxygen and turbidity impairments. Records from the assessment meeting state that 54% of the samples for TSS, which did not have a standard at the time of the 2012 BdSRW assessments, exceeded the now-adopted standard. Near the completion date of this report, the MPCA completed assessments in early 2016 of a number of previously-assessed HUC-8 watersheds for the recently-adopted River Eutrophication Standard. AUID-501 was included in that assessment, was assessed as impaired for nutrients, and will be added to the proposed impaired waters for the draft 2016 303(d) list.

Initial data

Chemistry

The results of water chemistry monitoring at 84RD005 from the IWM project are shown in Table 6. As is commonly found throughout the southern watersheds of the Red River Basin, TP in AUID-501 is very elevated, while nitrate levels are quite low. TP is often substantially higher than the new Minnesota regional phosphorus standard of 0.150 mg/L, as seen in the 10X site chemistry data (Figure 8). Data is available here from as long ago as the early 1960's. Phosphorus levels have been high for decades (Figure 9). Nitrate was low, as is common for Red River Basin streams, and ammonia and unionized ammonia were at non-problematic levels also (Table 7).

Table 6. Water chemistry measurements collected at 84RD005 during the 2010 IWM. Values are in mg/L.

Date	Time	Water temp.	DO	TP	Nitrate	Ammonia	Un-ionized ammonia	pH	TSS	TSVS
August 16	18:52	23.6	7.94	0.372	0.184	0.11	0.010	8.2	78.8	25.3

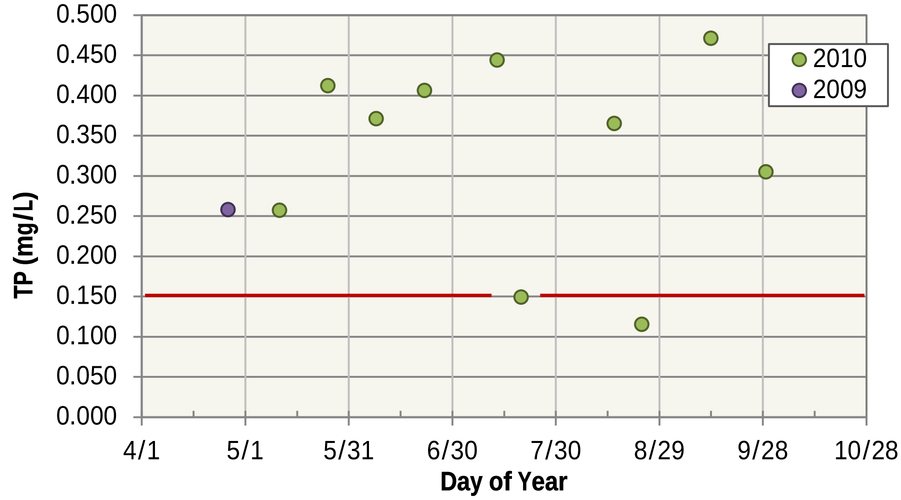


Figure 8. TP data for site S000-089, near the downstream end of AUID-501. Red line is the TP standard.

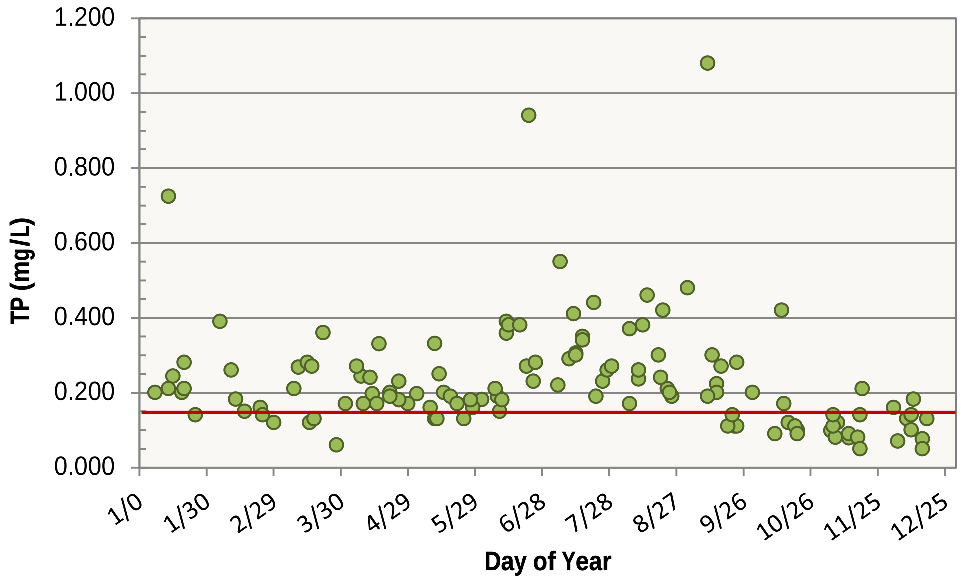


Figure 9. Historical TP data for site S000-089, from 1962-1977. The red line is the TP regional standard.

Table 7. Nitrate and ammonia at S000-089 from 2010 and one sample from 2009. Values in mg/L.

	# Samples	Average	High	Low
Nitrate	11	0.185	0.56	< 0.03**
Ammonia	11	0.097	0.298*	< 0.04**

*This value would yield an unionized ammonia concentration of 0.012, much less than the state standard.
**These values are below the lab detection limit.

Temperature

The highest temperature recorded among 14 samples, collected during the June – August periods of 2010 and 2011, was 27.6°C (81.7°F). Warmwater fishes begin to experience temperature stress at about 30°C (86°F).

Habitat

The MSHA score at 84RD005 was in the "Poor" category, receiving a score of 38. The "Substrate" and "Cover" subcategories were particularly low-scoring. There was no coarse substrate: 100% of the channel was lined with clay or silt. Macrophytes were not present, and instream fish cover was in the "Sparse" category. There was a small amount of woody debris present.

Biology

Fish

The fish community collected at 84RD005 is very tolerant of low DO and high TSS conditions based on the very low percentiles of the Community DO and TSS Index scores among Fish Stream Class 1 sites (Table 8). Of the 60 individuals captured in the sample, 40 were common carp. The high relative abundance of carp was a major factor contributing to the substandard F-IBI score. The species collected included some positive, large river ones, including freshwater drum, bigmouth buffalo, emerald shiner, white bass, channel catfish, goldeye, quillback, silver redhorse, and walleye, but most of these were represented by only 1-2 individuals.

Table 8. Community Tolerance Index scores at 84RD005 for fish and macroinvertebrates for DO and TSS. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within Fish Class 1 streams. "Prob." is the probability, expressed as a percent, a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined.

Biology type	Stream class	DO TIV index	Class avg.	Percentile	Prob. as %	TSS TIV index	Class avg.	Percentile	Prob. as %
Fish	F - 1	6.81	7.49	8	38.8	39.78	30.97	7	0.4
M-Invert	MI - 2	5.84	7.00	5	NA*	22.06	18.89	17	NA*

* This analysis has not been completed for MPCA macroinvertebrate data.

Macroinvertebrates

Though the macroinvertebrate community passed the M-IBI, a review of the list of taxa in the sample showed many "wetland-oriented" ones, including the most abundant taxon, the damselfly genus *Enallagma*. Wetland taxa are generally tolerant of low DO conditions. Others included four Hemipteran taxa (air breathers), and a dytiscid beetle, *Liodessus*. The two more-abundant mayfly taxa that were collected (*Caenis* and *Tricorythodes*) are tolerant of fine sediment, unlike most other mayflies. The low DO TIV index score and percentile rank within MI-Class 2 rivers (Table 8) confirms that the macroinvertebrate community found here is tolerant of low DO.

Targeted investigation and results

Chemistry

Because significant amounts of water quality sampling have been conducted for a number of years prior to the SID effort, relatively few additional lab chemistry samples were collected for analysis of common chemistry parameters. Field-measured chemistry data were collected on several reconnaissance trips (Table 9). During the 2014 visits, water levels in the reach were high, though not so in other locations of the watershed, possibly the result of discharges from the reservoirs upstream. The one location where some additional sampling occurred was at the CSAH 6 crossing.

A continuous-recording sonde is typically deployed in reaches that are biologically impaired, in order to better understand DO concentrations and patterns. Two locations in AUID-501 were studied using sondes. The first deployment occurred in 2013 (Figure 10), just south of Breckenridge. A second deployment was done the following summer (Figure 11), a bit farther upstream, at CSAH-6, from August, 7 - 21, 2014. A third deployment was done over July 7 - July 21, 2015 (Figure 13), again at the CSAH-6 location. Flow conditions during the 2014 deployment period are shown in Figure 12 and for the 2015 deployment in Figure 13.

Table 9. Field chemistry data from Bois de Sioux River, CSAH 6.

Date	Time	Temp. ^{o}C	DO	DO percent saturation	Conductivity	pH
July 17, 2014*	15:00	23.39	6.16	72.5	1366	8.03
August 21, 2014	12:20	23.79	6.23	74.5	1169	8.39
July 7, 2015	13:22	21.99	8.64	99.2	1771	8.62
July 21, 2015	12:05	22.83	11.02	128.9	1926	8.67
July 21, 2015	12:28	23.40	11.67	138.0	1929	8.70

*Water level was very high this day.

During the 2013 deployment, DO levels typically dipped to the 4.5 mg/L range, though minimum levels on some nights were slightly above 5 mg/L. The minimum level recorded for this period was 2.12 mg/L, certainly a stressful concentration for fish and other aquatic organisms. The DO conditions were better (comparing almost the same dates of the year) in 2014, where the DO minimums in early August were always above 6 mg/L. However, the DO flux on most days was approximately 5-6 mg/L, a level that has been shown to correlate with impaired Minnesota biological communities (Heiskary et al., 2013). The dissolved oxygen saturation levels were also significantly above 100%, meaning there was excessive algal abundance (almost no macrophytes exist in AUID-501) pumping in large amounts of oxygen during sunlight hours. The maximum DO saturation level was approximately 200%, a potentially-problematic level for aquatic organisms (Marking, 1987, Weitkamp and Katz, 1980). In 2015, the DO levels generally stayed above 5.0 mg/L, though on two days the minimums dropped below 4, with one of them as low as 1.72 mg/L. The DO flux was more problematic. On four days, the DO flux was about 8 mg/L. These high-flux days were associated with the lowest flows that occurred during this deployment period. These same days experienced the highest DO concentrations. Many of the days experienced peak DO percent saturation levels of 130% or higher, and several exceeded 160, with the maximum reading of 201.9% occurring on July 19 at 7:00pm.

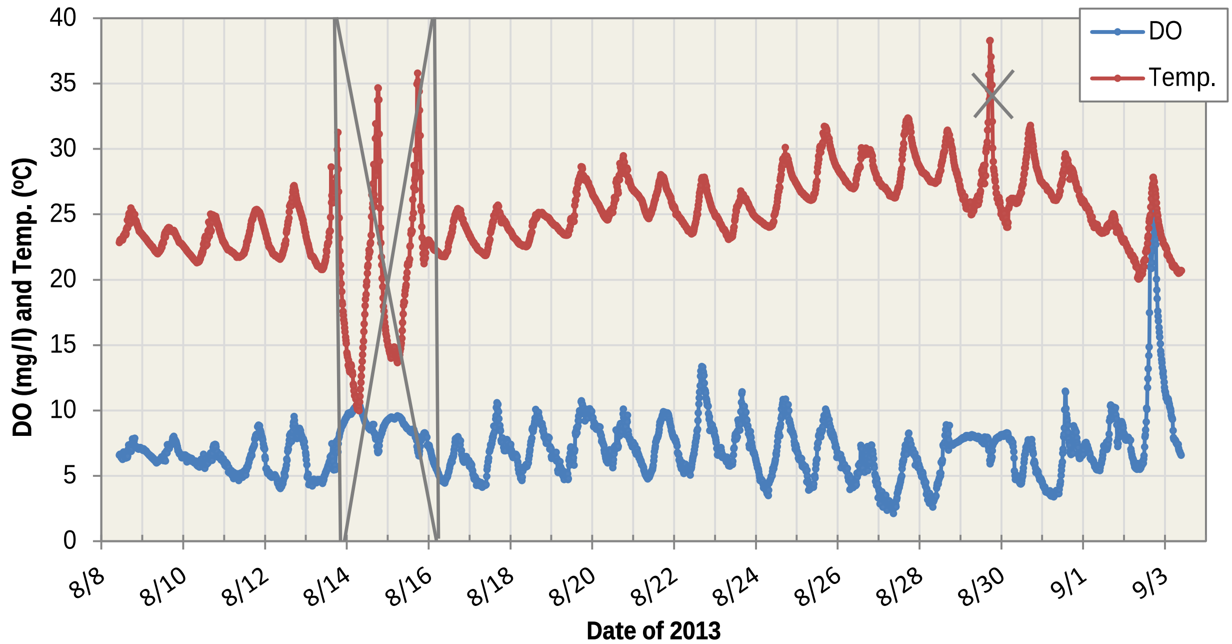


Figure 10. Sonde readings during the August 8 - September 3, 2013 deployment in the Bois de Sioux River near Breckenridge. The periods crossed out are suspected to be incorrect readings, perhaps due to vegetation caught on the sonde's probes.

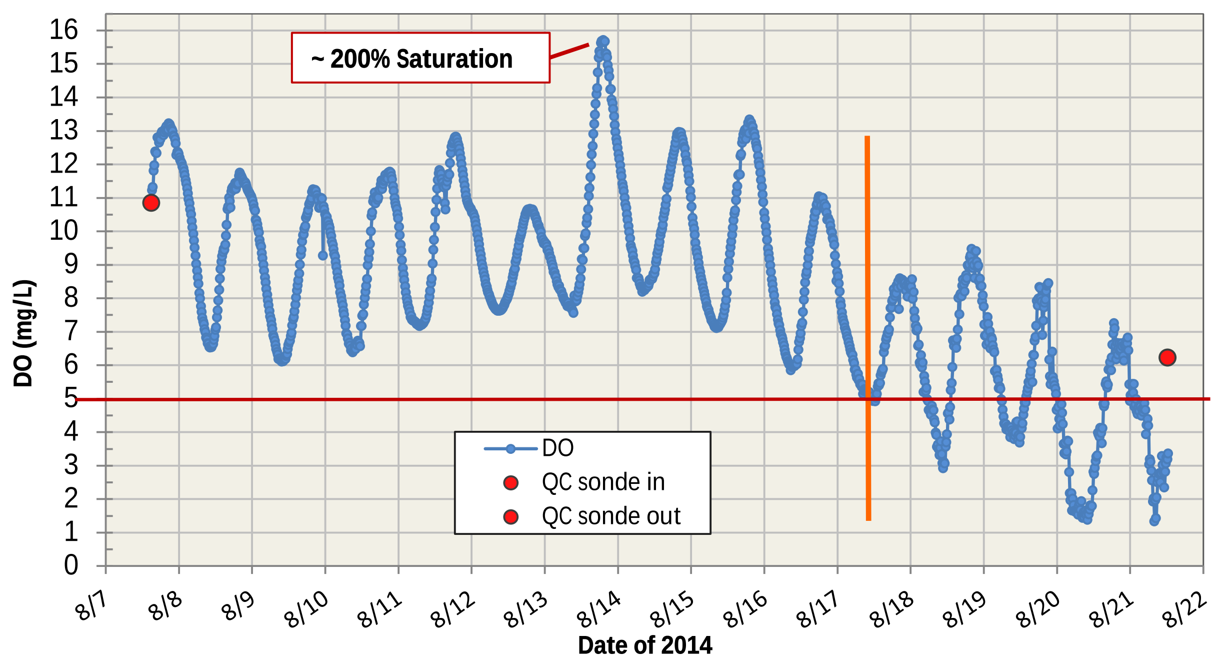


Figure 11. Sonde deployment during August 7 - August 22, 2014 in the Bois de Sioux River at CSAH-6. Data to the right of the orange bar appears to be compromised (calibration drift of instrument).

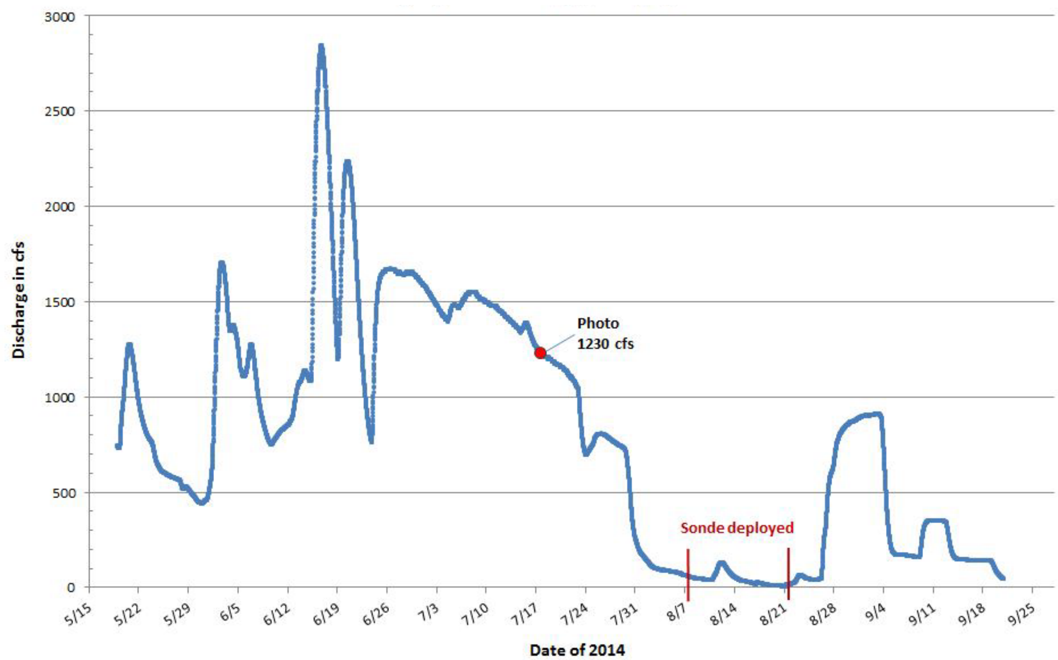


Figure 12. Flow conditions at the 2014 CSAH-6 sonde deployment station. This site is also a USGS gaging station site.

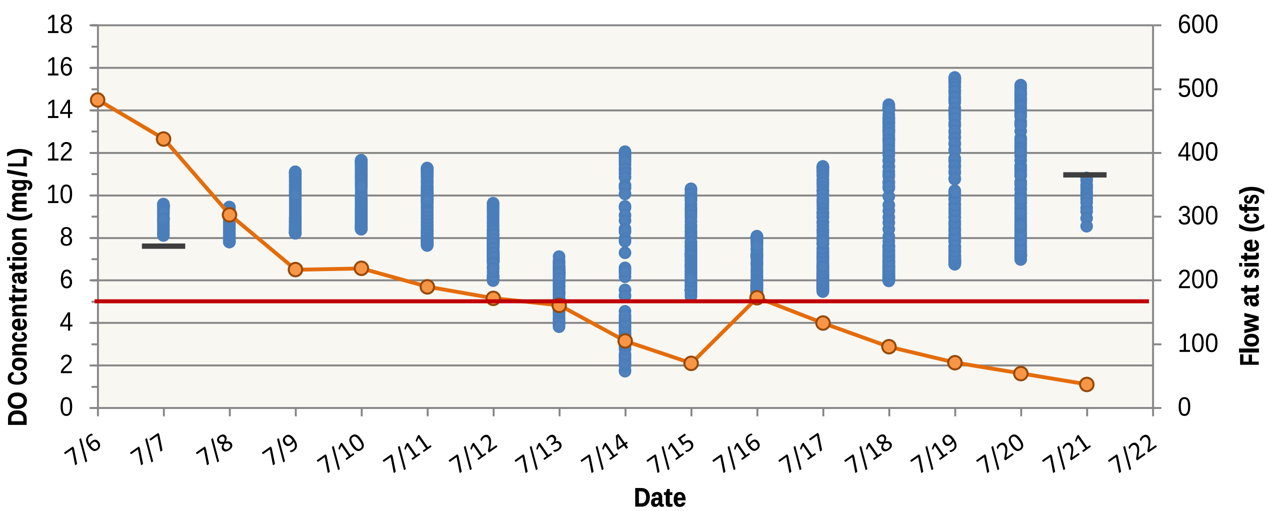


Figure 13. Sonde deployment during August 7 - August 21, 2015 in the Bois de Sioux River at CSAH-6. Blue dots are DO measurements, while orange dots are flow measurements.

Nutrients and Chl-a

A rather extensive data set has been collected at the CSAH-6 crossing (S000-553), including much data by MPCA grantees subsequent to the 2010 IWM effort. TP data for the years 2009-2014 is shown in Figure 14. The author also collected some nutrient and Chl-a samples to assist in interpreting DO levels (Table 10). As the previous sampling showed, phosphorus again was well above the state standard, and Chl-a was well above the threshold for a phosphorus response variable. Though more Chl-a data would be required to determine an official impairment for nutrients (see page 16), one sample was near the impairment threshold, and the other two samples were significantly above the standard.

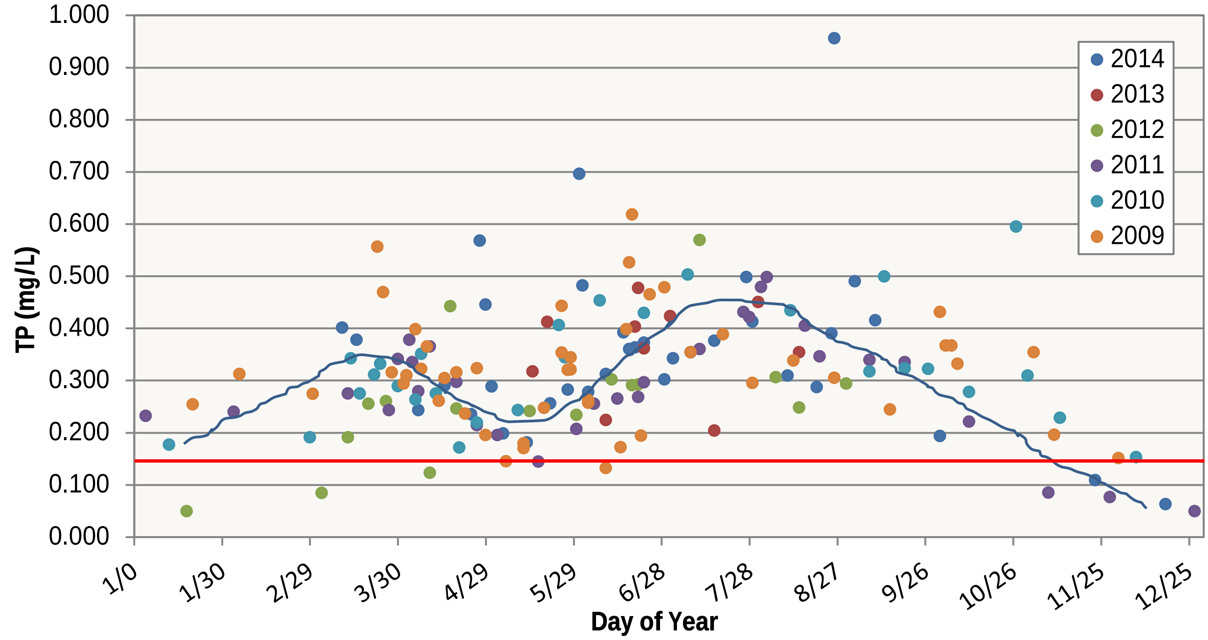


Figure 14. Total phosphorus data from S000-553 (CSAH-6), downstream of the confluence with the Rabbit River. The line is a hand-drawn estimate by the author of the general pattern of data points. Similar patterns have been seen in Central Minnesota streams – particularly the mid-summer peak around the end of July. The red line is the new regional TP river standard for this area.

Table 10. Grab sample data from the Bois de Sioux River, CSAH 6 (S000-553). Data in mg/L.

Date	Time	TP	Nitrate	Ammonia	Chl-a
August 21, 2014	12:20	0.287	< 0.05	< 0.05	44.1
July 7, 2015	13:22	0.187	--	--	31.5
July 21, 2015	12:20	0.215	--	--	71.1

A handful of other Chl-a samples have been collected here in prior years (Figure 15). Again there are samples that were below and above the regional Chl-a river standard. Though the data points for a given year aren't very dense, it appears that different summers produce different Chl-a levels.

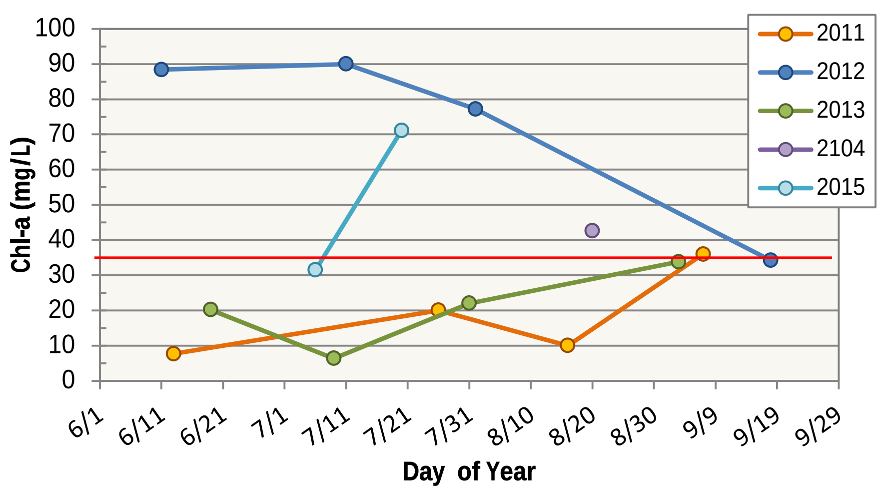


Figure 15. Chl-a concentrations at S000-553 (CSAH 6), Bois de Sioux River. Red line is the regional Chl-a threshold of the River Nutrient statute.

Hydrology

In addition to hydrological alterations stemming from extensive land drainage, a further alteration of natural flow conditions in the river is the damming of Lake Traverse and reservoir releases. These releases complicate the analysis of water quality parameters, since pulses of lake (reservoir) water are periodically flushed through the river. Flow levels in the Bois de Sioux River change rapidly and strongly. The conductivity data recorded during the 2014 sonde deployment captured the effect on water quality during one such rapid fluctuation. At about 17:45 on August 10, 2014, flow volumes rapidly rose, tripling the flow volume in about 30 hours (Figure 16). Then, from the peak flow, volumes decreased to the pre-peak flow over four days. There does not appear to be a precipitation event that explains this flow change (Table 11).

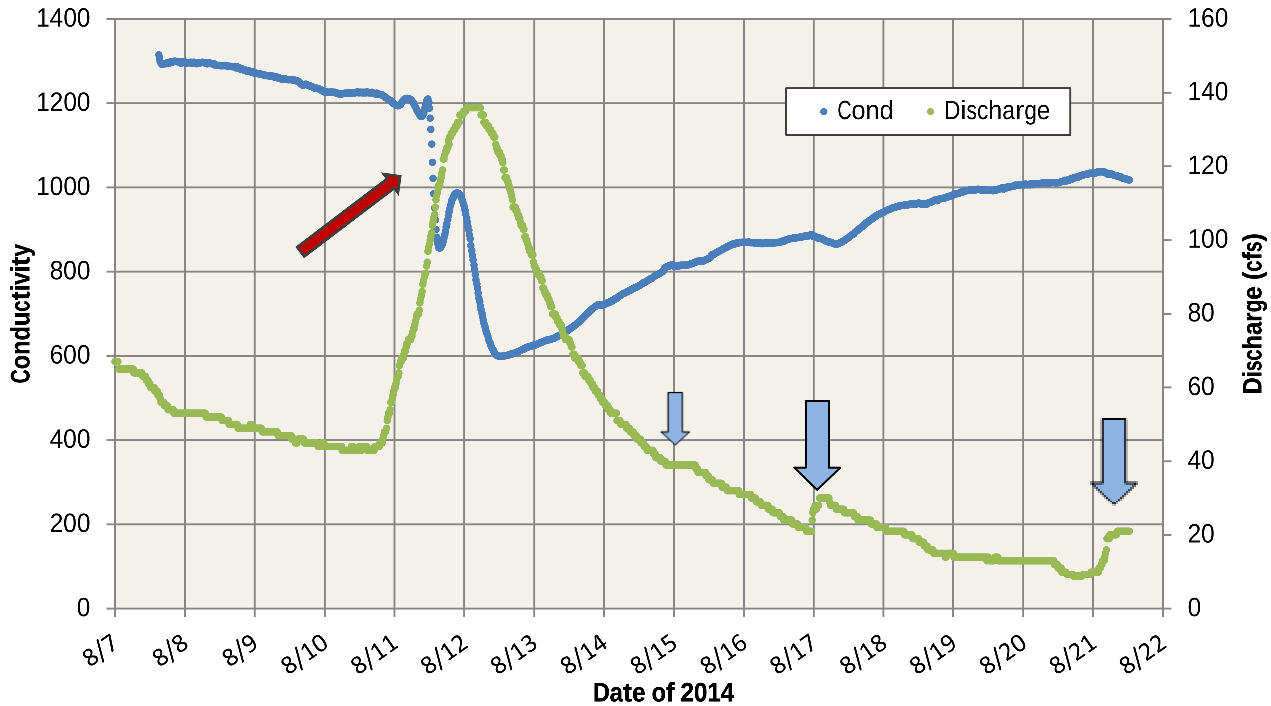


Figure 16. Conductivity and USGS flow data at CSAH 6 gaging station during sonde deployment. Red arrow points to quick drop in conductivity, and blue arrows denote rain events which increase flow. There were no significant rain events the days surrounding the August 11 - 12, 2014 abrupt changes in conductivity and flow.

Table 11. Weather data from two weather underground stations near or in the AUID-501 sub-watershed during the 2014 sonde deployment. Precipitation in inches, temperature in ^{o}F. Significant rains are highlighted in red, and their effects can be seen in the hydrograph in Figure 12.

Date	Wetherbee Farm, ND (nr. Tenney)	Wheaton airport	Wheaton AP max temp	Wheaton AP min temp
August 8	0.00	0.00	73	53
August 9	0.06	0.00	73	62
August 10	0.00	0.01	75	59
August 11	0.00	0.00	71	53
August 12	0.00	0.00	71	48
August 13	0.00	0.00	80	57
August 14	0.06	0.21	75	57

Date	Wetherbee Farm, ND (nr. Tenney)	Wheaton airport	Wheaton AP max temp	Wheaton AP min temp
August 15	0.04	0.11	77	62
August 16	0.98	0.00	80	62
August 17	0.00	0.50	75	64
August 18	0.00	0.00	78	60
August 19	0.00	0.05	78	60
August 20	0.00	0.00	78	57
August 21	0.00	0.54	78	64

Two visual ways to interpret the changes to hydrology in AUID-501 and its sub-watershed 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 17. 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 did not 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.

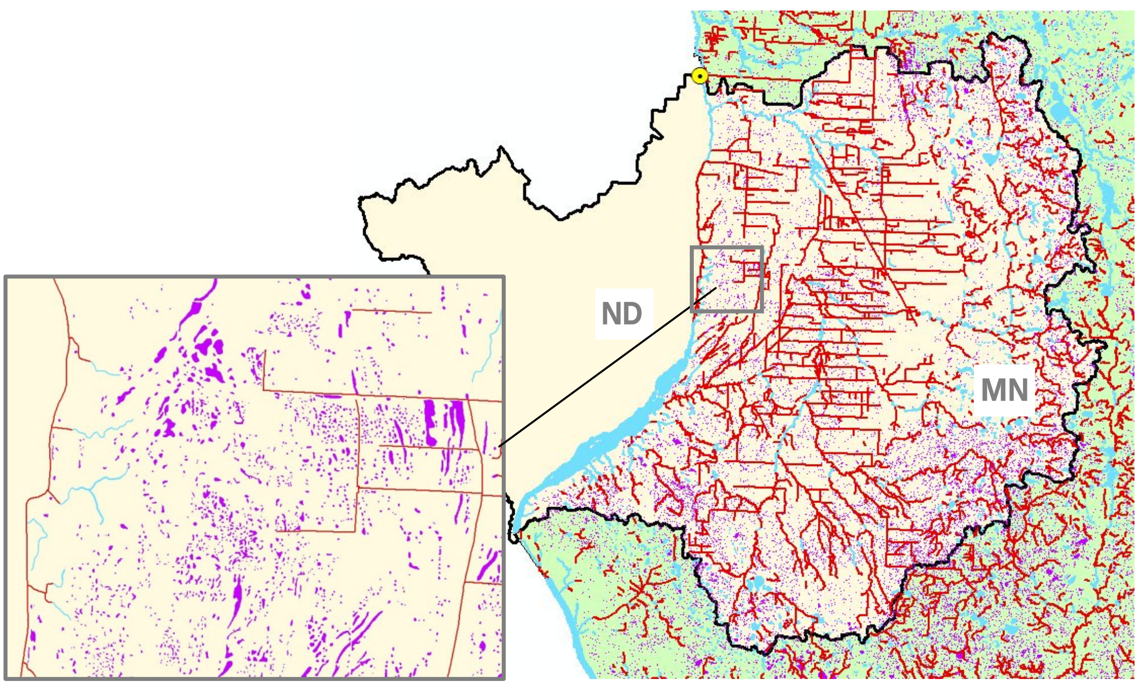


Figure 17. Altered hydrology in the sub-watershed of AUID-501. The black outline is the contributing sub-watershed to the river point at CSAH 6 (yellow dot), the red lines are either altered natural stream channels or constructed channels, and the purple shapes are locations where there were pre-settlement wetlands that are no longer wetlands (i.e., have been drained) or are partially drained. The inset box is enlarged to better show these former wetland areas.

Temperature

During the 2013 sonde deployment, there was a stretch of eight days (August 24 - August 31) where the water temperature was quite elevated, reaching peaks of about 86-90.5°F (30-32.5°C, Figure 10). It is not common for Minnesota stream temperatures to reach these levels, which are stressful for fish. It is difficult to express quantitatively how stressful these temperatures would be (depends on exposure duration, the species, etc.), but for comparison, Minnesota's temperature standard is a monthly maximum average daily high of 30°C.

During the 2014 sonde deployment, water temperatures were always below 29°C (Figure 18). Air temperatures in the 2014 deployment were cooler than normal, especially for the first six days. During the overall deployment period, the daily high air temperatures were between 5-12°F below normal. This would raise the daily DO minimums above normal as cooler water holds more oxygen. During the 2015 sonde deployment, a temperature over 30°C was reached on one day of the 14-day period (Figure 19). In general, stream temperatures will be influenced by a number of factors, including: water flow volumes, air temperature, solar radiation, and turbidity of the water. Flow volume can be seen as a factor in the 2015 date in Figure 19, where for the first ¾ of the period, temperature and flow were trending inversely.

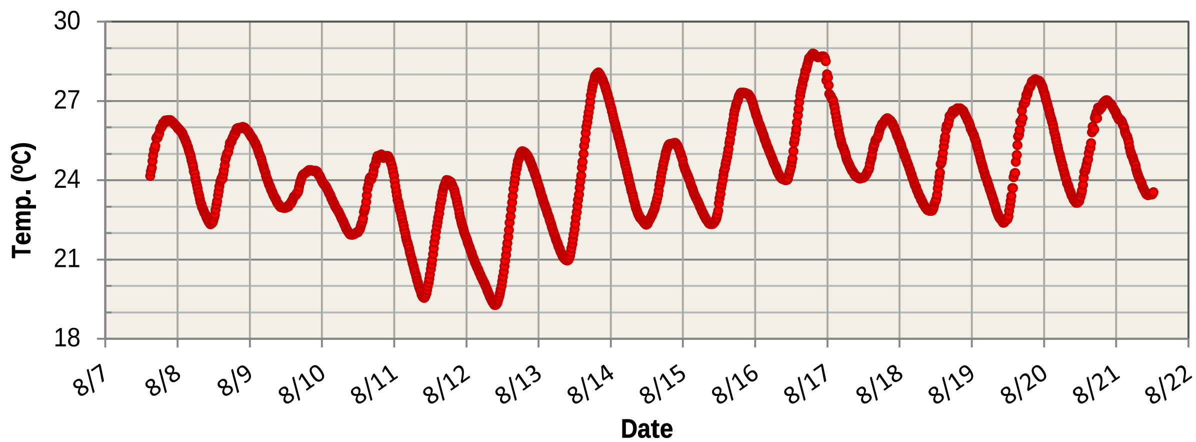


Figure 18. Water temperature readings from 2014 sonde deployment at S000-553 (CSAH-6).

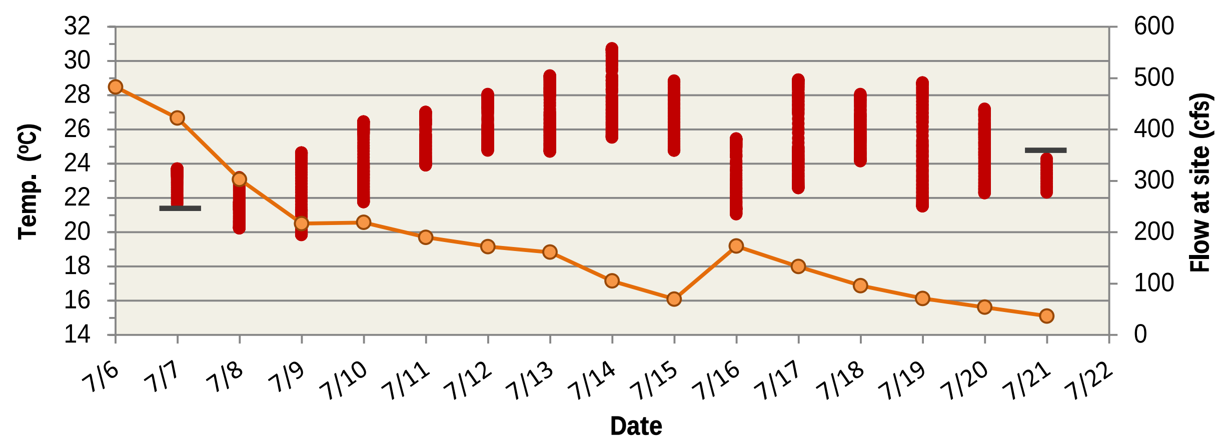


Figure 19. Water temperature readings (in red) and flow volumes (in orange) from 2015 sonde deployment at S000-553 (CSAH-6).

Geomorphology

No geomorphology fieldwork was done by EOR, Inc. on AUID-501. Observations by the author at the CSAH-6 water quality sample site found some significant bank instability/erosion (Photo 1). Eroding banks can be easily seen from aerial photography (Photo 2). In addition, the channel has been altered by removing meanders to facilitate quicker downstream transport of water (Photo 3).

Photo 1. Looking downstream from the CSAH-6 bridge. The arrow points to a large piece of bank material caving into the channel.

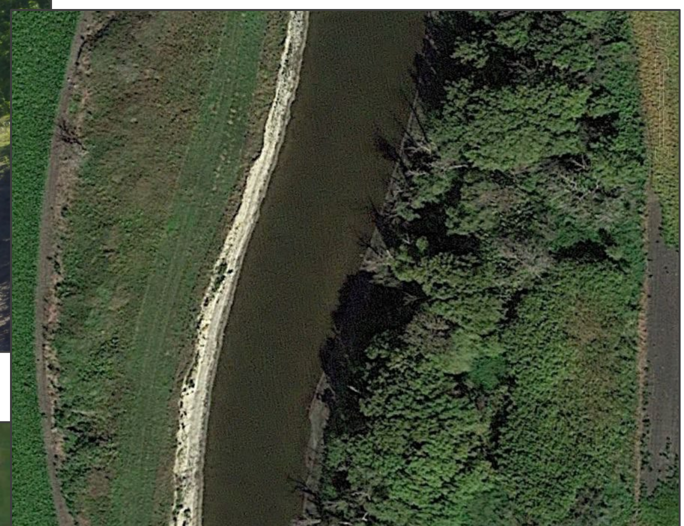


Photo 2. High, steep eroding bank on left side of channel along AUID-501.

Photo 3. Channelization to remove meanders from the river's pathway. The yellow line traces the current altered channel path.

Conclusions

The AUID-501 reach of the Bois de Sioux River has conventional impairments for DO and Turbidity. It would likely have been assessed as impaired for TSS, had there been a standard in place in 2012, when the assessment process occurred for the BdSRW. These are aquatic life parameters, and the standards are set where stress is known to occur for biological organisms. The community index analysis of the fish community also shows that it is strongly weighted to fish that are very tolerant to low DO and high TSS. Wide swings in flow volumes are likely partially to blame for the high TSS occurring in this AUID.

The landscape of the BdSRW has been highly drained, leading to quick runoff into the Bois de Sioux River. Additionally, releases from Lake Traverse (a reservoir) via the White Rock Dam, may be an additional factor in these wide swings of water volume moving through the river. The high levels of phosphorus, in combination with the wide diurnal flux of DO and supersaturation of the DO levels in mid-afternoon, as well as the high Chl-a measurements, strongly implicate a river experiencing eutrophication. The low DO during nighttime hours and supersaturated DO in mid-day periods are both at levels that create stress to aquatic organisms. The excess turbidity is also causing water temperatures to rise more than if the water were clear, exacerbating the decline of DO during parts of each day.

Future studies here should include a further analysis of TSS, as to whether the primary component is mineral or organic (which includes suspended algae). This will allow a more complete understanding of the process which is creating the suspended material problem. From general knowledge and observations of the RRB streams and rivers, at high water, TSS is likely dominated by mineral particles, while during lower water conditions, TSS likely is increasingly due to algal particles.

The channel of the Bois de Sioux River has been altered in many places, by cutting new channels across the meanders to straighten the river. Straight channels form uniform channel depths of uniform bed material. This homogenization of habitat removes the heterogeneous habitat found in natural rivers (variable depths, pools, riffles, patches of different types of bed materials), drastically reducing or eliminating specialized habitats required by many species.

The degree of hydrologic alteration within this sub-watershed due to agricultural land usage is significant as most of the upstream channel system which feeds AUID-501 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 naturally, 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 the river is being degraded by the changed hydrology. Such modeling would also provide insight into what actions could be taken to increase baseflow at critical times of the year.

The additional work done in this stressor ID effort confirms that DO and TSS are biological stressors in this AUID, and that elevated nutrients and altered hydrology are involved in causing those parameters to be problematic. Poor habitat is also a stressor here. Altered hydrology and its influence on increasing TSS levels plays a role in the poor habitat. Channel straightening (reducing sinuosity) plays another role in degrading habitat as higher sinuosity creates more heterogeneous habitat features (e.g., depth, flow velocity, and substrate variability). See summary Table 24.

Rabbit River (AUID 09020101-502)

Impairment: The river was assessed as impaired for not meeting fish or macroinvertebrate community expectations based on biological samples from 10RD005, at US Highway 75, about four miles west of Campbell, and 94RD002, at CSAH 2 (480th St), about 2.5 miles southeast of Campbell. Additionally, this AUID is impaired for aquatic life and on the 303(d) list for the parameters DO and turbidity. The 2012 assessment process records also noted that "TSS data would exceed the proposed TSS criteria." The TSS criteria were officially adopted subsequent to the time of the 2012 assessments.

Initial data

Chemistry

There is a very large water chemistry dataset from the Rabbit River at US Highway 75. This location is assigned EQuIS number S001-029. Less-comprehensive data (much of it focused on DO and turbidity) are available from other locations on this AUID, primarily at S002-002 (at Campbell), and further upstream at S001-053. Unless noted otherwise, data presented in this chemistry section are from S001-029.

Dissolved oxygen

This AUID has been assessed as impaired for low DO based on oxygen measurements, and placed on the 303(d) list. From 46 measurements of DO saturation collected in the late 1980's and early 2000's, six readings were above 120% of saturation, the highest of which was 175.4%, suggesting eutrophication. Nine samples were also below 60% saturation, with one as low as 24.0%.

Phosphorus

TP samples from the fish sampling visits of June 15, 2010 at 10RD005, and June 16, 2010 at 94RD002 found concentrations of 0.383 and 0.358 mg/L respectively. TP data collected from S001-029 (10RD005) over the period of 1985-2014 are shown in Figure 20. These data show problematic TP levels occurring over a broad period of the year, and over many years, highlighting this as a chronic issue. Minnesota's new river TP standard was exceeded by 167 of the 175 samples (95.4%).

A large number of orthophosphorus data has also been collected from S001-029. Concentrations can vary dramatically for similar dates during the period of mid-March through late September (Figure 21). The majority of these values are very high relative to natural levels of orthophosphorus in stream waters. Orthophosphorus is a sub-component of TP, and yet the majority of these results are higher than the TP standard.

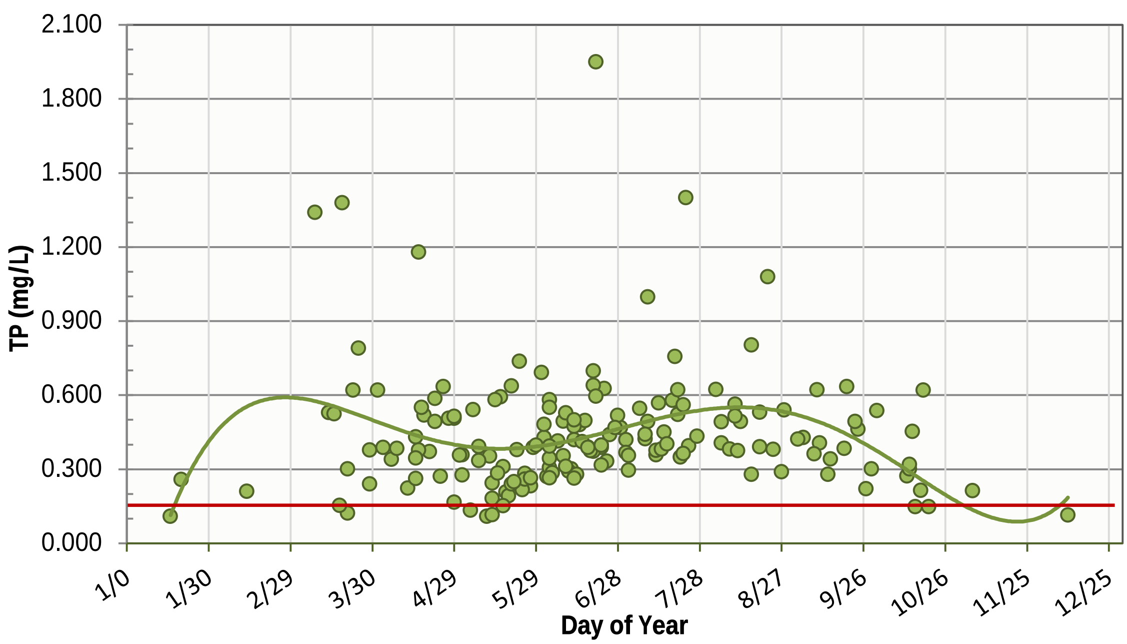


Figure 20. _Total phosphorus concentrations at S001-029 (US Highway 75, 10RD005). Data are from the periods 1985 - 1989, and November 2001 - October 2014. The red line is the Minnesota standard for TP, of which OP is just a fraction. The green line is a 5th order polynomial regression line, with an R^2 value of 0.1122.

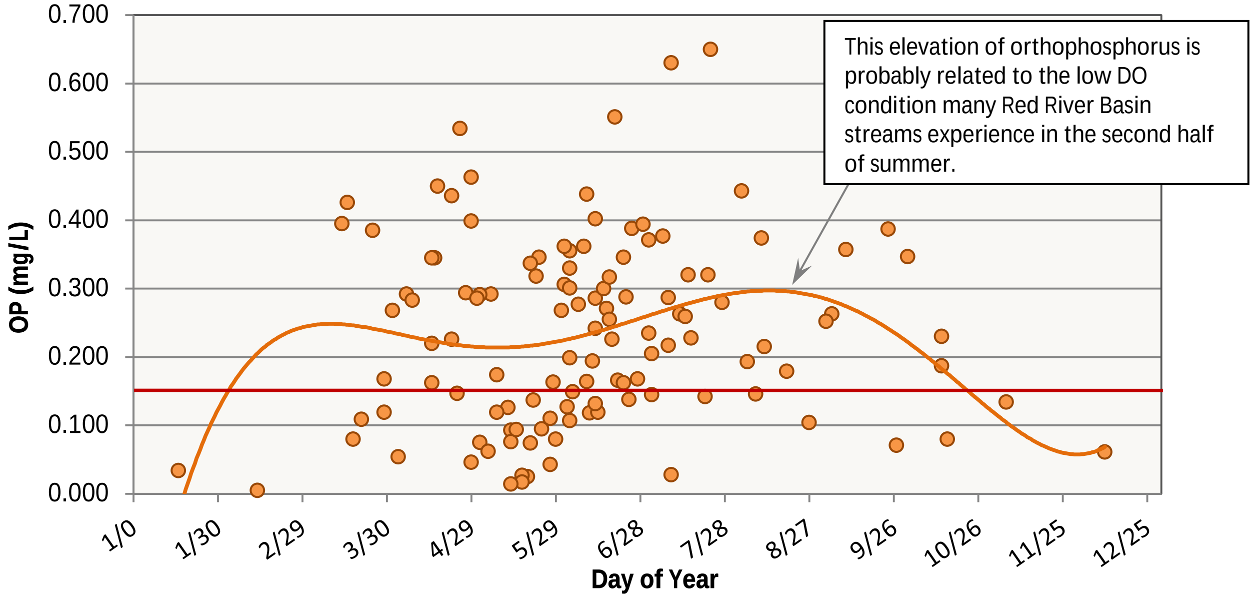


Figure 21. Orthophosphorus concentrations at S001-029 (US Highway 75, 10RD005). Data were collected over the period of November 2001 – October 2014. The red line is the regional standard for TP. The orange line is a 5th order polynomial regression line, with an R^2 value of 0.0895.

Nitrate

Nitrate concentrations show a dramatic seasonal aspect to the concentrations (Figure 22). Levels are significantly higher in April, May, and June, during snowmelt and until crops are getting larger and soil cover is better. An uptick again occurs in October. This is likely 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 in spring are approaching those considered to be toxic to aquatic macroinvertebrates (fish tend to be less affected at these levels). Summer nitrate concentrations are very, very low, with many of the samples being less than the lab detection limit.

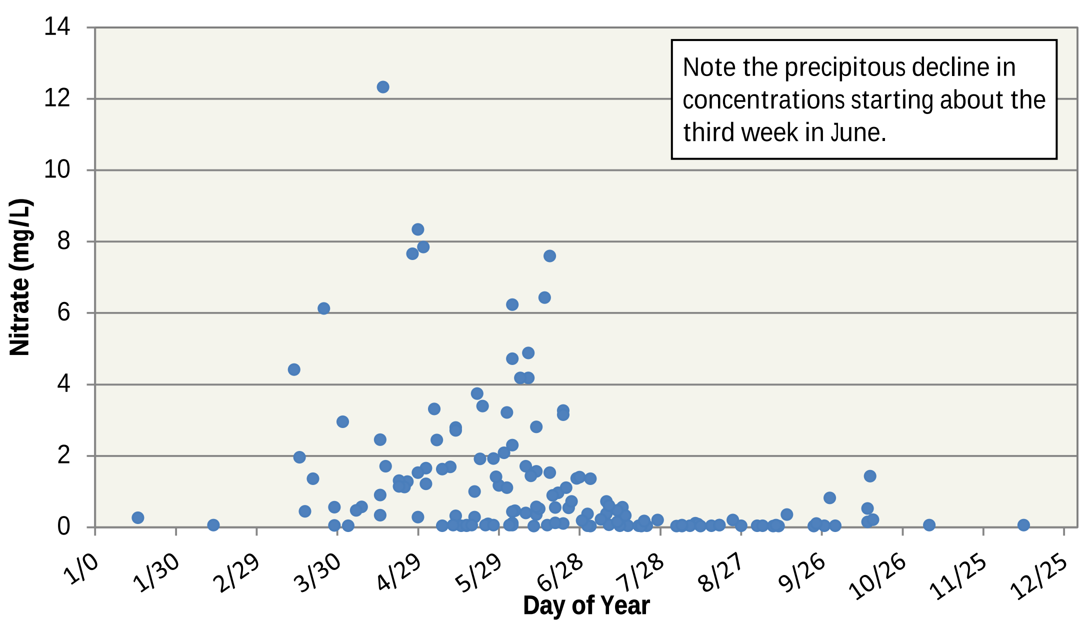


Figure 22. Nitrate concentrations at S001-029 (US Highway 75, 10RD005) over the period of November 2001 – October 2014.

Ammonia

Ammonia shows a similar pattern to nitrate of being highest in early spring, and dropping off in early June (Figure 23). None of the post-2000 ammonia samples had associated un-ionized ammonia concentrations above the standard. There were two samples from the late 1980's data that had unionized ammonia standard exceedances, in the 0.70-0.95 mg/L range. Due to the time of year they occurred (late winter and late October), they may have been associated with fall application of ammonia as agricultural fertilizer. The pH levels, which are strong drivers of the un-ionized fraction of ammonia (higher pH increases un-ionized concentration), appear to have been generally higher in the late 1980's than they have been in recent years.

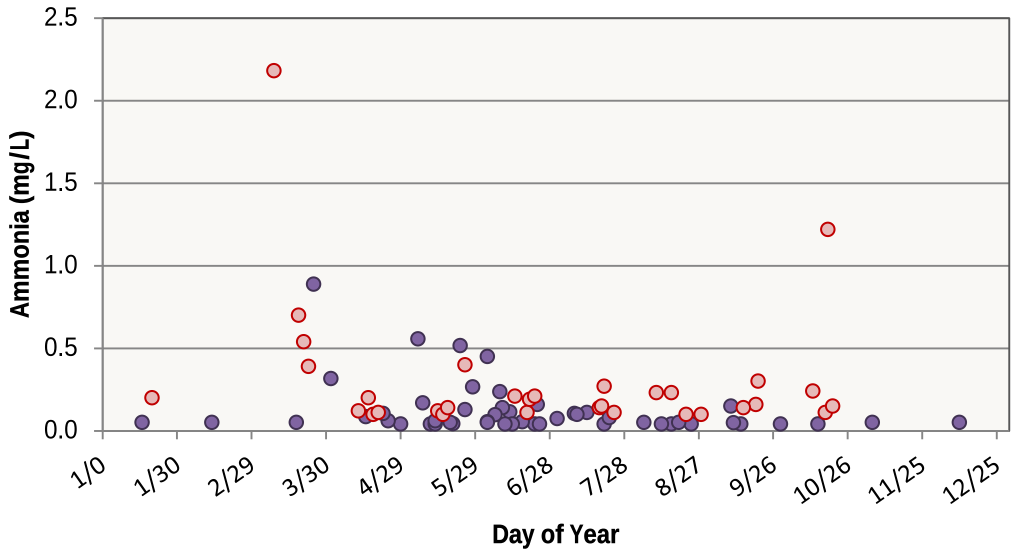


Figure 23. Ammonia concentrations from the late 1980s (light red points) and 2001-2010 (purple points) at S001-029 (US Highway 75, 10RD005).

Turbidity/TSS

Turbidity in this AUID does not meet the state standard and the reach has been placed on the 303(d) list. The TSS measured during the fish sampling visit was high (74.4 mg/L) relative to the newly-adopted state standard of 65 for this region. There are 123 samples in EQuIS later than 2000. The average TSS concentration is 85.1 mg/L, and 43.1% of these samples were above the new TSS standard.

Habitat

AUID-502 is composed predominantly of natural channel, the exception being a mile-long stretch along 480th Street, between 310th and 320th Avenues, where the channel has been straightened. However, the incoming waters from upstream of the AUID are predominantly ditches.

The MSHA score of 22.0 for 94RD002 is in the poor range. Each of the five subcomponent scores was poor, with "Land Use", "Substrate", and "Channel Morphology" scores performing especially poorly. Substrate was all fine-grained material, though some coarser material was present, it was buried by fine sediment – embeddedness was rated at 75-100%. Depth variability and sinuosity were poor, and no riffles were present. The MSHA score at 10RD005 was even worse than at 94RD002. The "Land Use", "Substrate", and "Cover" subcomponent scores were particularly bad. Only silt was found as a substrate, and again, embeddedness was 75-100%. No macrophytes were found in this reach. Depth variability was again poor, and again, no riffles were present. The author found deep silt on the stream bed well out into the mid channel area during the sonde deployment.

Connectivity

There are no dams in the BdSRW. This reduces the possibility of significant migration barriers as a stressor, however culverts remain a possibility to blocking of fish movement. For the 10RD005 site, at US Highway 75, there are no apparent barriers down to the confluence with the Bois de Sioux River. There are two fording locations, but they are likely not barriers at normal flow levels. There are just two road crossings, both with bridges. Examining the recent aerial photography, there appears to be only one infrastructure-related barrier along all of AUID-502, which is upstream of both biological sites. This is an undersized culvert at -96.332969, 46.078423 (decimal degrees) along CSAH-2. The extremely large scour pool indicates very high velocity through the culvert when flows are elevated. There are also a few low beaver dams between the biological sites, but they are not holding a great deal of water back (thus probably low dams), so at higher flows, they probably are passable.

At both sites, there were migratory fish species present. At the upstream site (94RD002), these included shorthead redhorse, quillback, and white sucker, while at the downstream site (10RD005), these species included quillback, walleye, Iowa darter, silver redhorse, and white sucker. At 10RD005, there were also a large number of emerald shiners, a species which inhabits larger rivers, and which suggests that there is connectivity to the Bois de Sioux River downstream.

Geomorphology

AUID-502 contained four EOR, Inc. geomorphology study sites, two above and two below the confluence of the South Fork Rabbit River. Of the two sites above the confluence, site 8 is in a reach that is difficult to determine whether historical channelization has occurred, whereas site 9 is definitely in a short, channelized section. The MADRAS ditch stability protocol (Magner et al., 2010) was used (EOR, 2014) at sites 8 and 9, scoring 37 and 32 respectively (on a zero to 60 scale, with low scores being better). These scores rank as "fairly stable". BEHI and NBS scores for all four sites are presented in Table 12. An overall rating averaging the four sites would be moderate BEHI and moderate NBS. These ratings suggest that there is more bank erosion happening at the more-downstream sites 4 and 6, which are located below the confluence of the South Fork Rabbit River, and hence carry more water. At sites 4 and 6, field staff noted that stream bottom elevation variability was very poor, meaning a homogeneous depth with no pools.

Historical cross-sections were available at two locations in AUID-502 (sites 6 and 9). Over the last decade, the channel cross-section has enlarged in both width and depth at site 6, while the farther-upstream site 9 showed almost no change in the channel cross-section (Figure 24). These historical cross sections confirm that more bank erosion is occurring in the lower half of AUID-502 (downstream of the confluence of the South Fork Rabbit River. These geomorphic data suggest that some amount of the excess sediment and turbidity in AUID-502 is due to bank and bed erosion, though not extreme amounts, probably due to the relative cohesiveness of the soils, particularly in the Lake Plain regions of the watershed.

Table 12. Channel bank stability ratings using Rosgen's (2006) BEHI and NBS rating systems. US = upstream, DS = downstream.

EOR site #	Relative to AUID-512 confluence	BEHI rating	NBS rating
4	DS	Moderate/High	Moderate
6	DS	Moderate	High
8	US	Moderate	Low
9	US	Moderate	Low

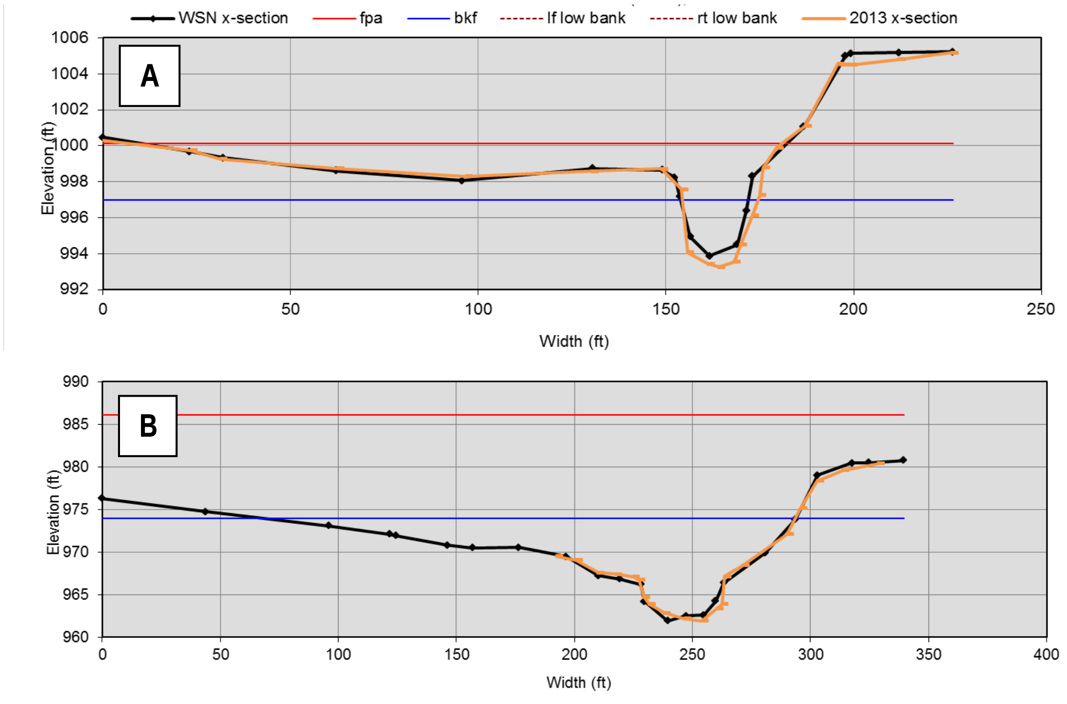


Figure 24. Historical (2001) and 2013 cross-sectional surveys of sites 4 (A) and 6 (B).

Biological response

Fish

The fish community at 10RD005 was dominated by emerald shiners and fathead minnows, each comprising 31.7% of the total individuals. At site 94RD002, farther upstream, neither of these species was present, but the community was instead dominated by white suckers, comprising 81.3% of the individuals. The two sites differ in their stream classifications, so there is an expectation that their fish communities would have some differences. Values for the metrics Community DO TIV Index and Community TSS TIV Index were calculated for the fish communities of the two sites. At both locations, the DO Index scored below the average for the appropriate fish class, and the scores were very low as percentiles within those fish classes (Table 13). For the TSS Index, the values were above the appropriate class average (for TSS, higher scores are a negative, so being above the average score is a negative). Both sites were below the 50th percentile (corrected so that a low percentile is a negative), particularly at 94RD002, which scored at the 14th percentile. These values confirm that these parameters (low DO and high TSS) are negatively influencing the fish community.

Table 13. Community Tolerance Index scores at 10RD005 and 94RD002 for fish and macroinvertebrates for DO and TSS. "Percentile" is the rank of the index score within streams of the appropriate stream class. "Prob." is the probability, expressed as a percent, a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined.

Site	Biology type	Stream class	DO TIV index	Class avg.	Percentile w/in class	Prob. as %	TSS TIV index	Class avg.	Percentile w/in class	Prob. as %
10RD005	Fish	F - 1	6.94	7.49	11	44.8	32.50	30.97	43	2.5
10RD005	M-Invert	MI - 7	5.95	6.11	33	NA*	25.18	16.26	2	NA*
94RD002	Fish	F - 2	6.41	6.99	16	23.8	26.60	20.19	14	11.0
94RD002	M-Invert	MI - 7	6.55	6.11	66	NA*	19.79	16.26	12	NA*

*This analysis has not been completed for MPCA macroinvertebrate data.

Macroinvertebrates

The macroinvertebrate community shows a very strong negative influence of TSS. The farther-downstream site (10RD005) scores as being more negatively affected than the upstream site. The downstream site's score is only at the 2nd percentile of all the Minnesota Class 7 streams. The community shows a somewhat varied signal of impact by low DO, with one site score being a fair amount higher than average, while the other is below the class average. Again, the index score and percentile are quite a bit lower downstream.

The community collected had a wetland-oriented taxa list at both sampling sites. Among these taxa at 94RD002 are Coenagrionidae (damselflies), the hemipterans *Sigara*, *Neoplea*, *Belostoma*, the Trichopteran *Nectopsyche*, and the two mayflies *Trichorythodes* and *Caenis*. Only one individual of the more stream-oriented EPT taxa was collected, a *Pseudocloeon* mayfly. Additionally, a relatively high number of *Physa* snails were collected, which are often abundant in streams experiencing eutrophication. At site 10RD005, similar wetland-oriented taxa were found, including some additional ones: *Callibaetis* mayflies, two additional Corixidae (*Trichocorixa* and *Palmacorixa*), another hemipteran *Rheumobates*, the beetle *Haliplus*, and a much greater fraction of the midge *Glyptotendipes*. Again there were abundant *Physa* and Coenagrionidae.

Taking into account both sites, and based on the within-class percentiles, it appears that TSS is relatively more of an issue for the macroinvertebrate community than is low DO, and that both of these issues become more problematic moving from upstream to downstream within the reach.

Targeted investigation and results

Because there were two existing conventional parameter aquatic life use impairments for AUID-502 (DO and turbidity) and a solid chemistry dataset, little additional chemistry monitoring was conducted, other than the deployment of a sonde to explore the daily minimum DO readings and assist the modelling effort, and collection of some Chl-a samples with matching TP samples.

Chemistry

Dissolved oxygen

A sonde was deployed for 25 days, from August 8 - September 3, 2013 at 10RD005 (US Highway 75). For about the first week of this period, the DO minimum concentrations ranged from about 5 - 5.5 mg/L. In the latter 2/3 of the deployment, daily minimum DO levels declined, and were always below 5 mg/L, often substantially lower, down to approximately 2.0 mg/L. (Figure 25). Besides the daily minimum concentrations, the daily flux in concentration has also been determined to be important (Heiskary et al., 2013). The daily flux for many of the days surpassed the threshold determined to be impactful to aquatic organisms in this region (4.5 mg/L flux). Statistics on the flux during this period are presented in Table 14.

A second sonde deployment was done the next summer, from July 17 - August 7, 2014. Some of the days had high DO flux similar to the 2013 monitoring, while other days the flux was much lower, at approximately 3 mg/L, and below the level of concern (Figure 26 and Table 14). The quality control sonde measurement at the end of the deployment was significantly different than the deployed sonde. It is believed the quality control sonde measurement was not taken at the exact location as the deployed sonde. Since the flow here is slow and non-turbulent, the water is not thoroughly mixed, and DO readings a short distance apart can be quite different for some parameters, such as DO. However, the absolute DO readings nearer the end of the deployment may be off from what is shown. Flux measurements will be unaffected.

Additional monitoring visits were made in 2015, and DO levels attributable to high biological productivity were again found (Table 15). On July 7, 2015, the DO concentration was very high, and the percent saturation was over 200%, which can only happen in this setting if algae are thriving.

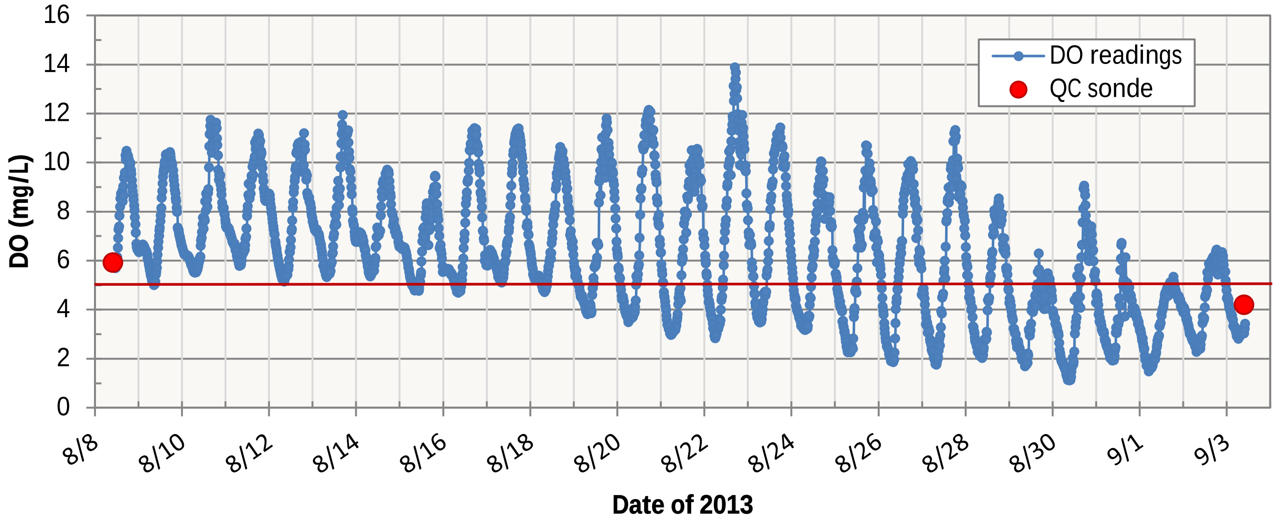


Figure 25. Sonde DO statistics for the August 8 - September 3, 2013 deployment at 10RD005 (State Highway 75). The red line represents the Minnesota standard.

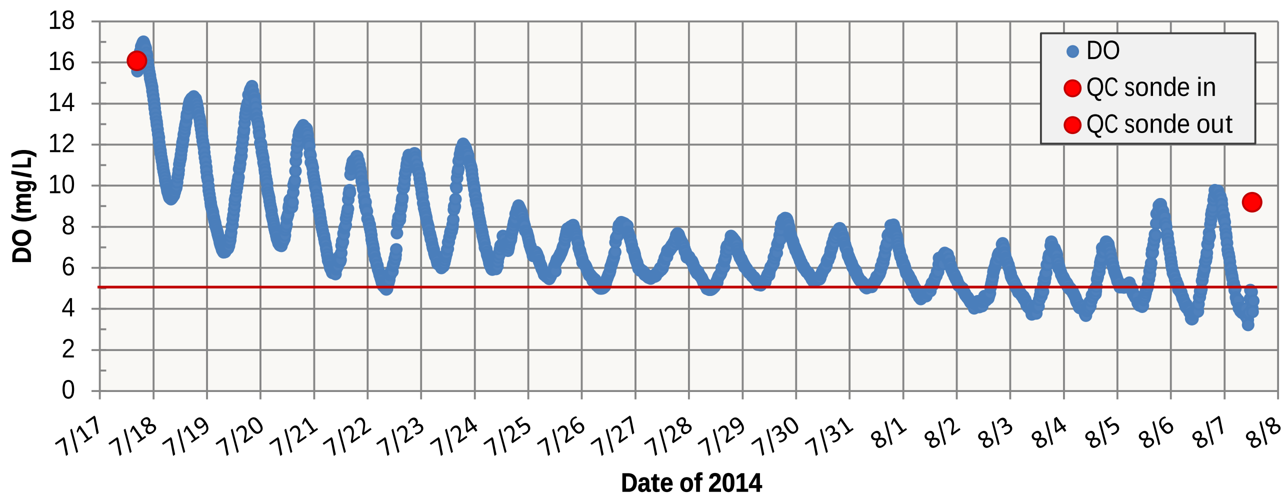


Figure 26. Sonde DO statistics for the July 17 - August 7, 2014 deployment at 10RD005 (State Highway 75). The red line represents the Minnesota standard.

Table 14. DO Flux statistics for the August 2013 and July/August 2014 sonde deployments at 10RD005.

Year	Count	Avg. flux	Min. flux	Max. flux	Lowest min. DO	Highest max. DO
2013	25	6.62	3.87	11.05	1.10	13.87
2014	21	4.76	2.63	8.09	3.19*	17.00

*This reading was late in the deployment and may not be accurate.

Nutrients and Chl-a

Additional samples were collected for TP and Chl-a at two locations on AUID-502 in 2015 (Table 15). One site was above the confluence with the South Fork Rabbit River, and one below the confluence. The July 7 samples had lower TP concentrations at both sites, and these were below the river eutrophication standard. Chl-a concentrations, however, were higher at both sites on July 7, and both were substantially above the eutrophication standard. The TP levels on July 21 were well above the river eutrophication standard. A tributary to AUID-502, Judicial Ditch 12, was sampled on July 7 (S008-700) because it was carrying a significant volume of water (Photo 4). It enters AUID-502 a short distance upstream of the mouth of South Fork Rabbit River. It too had TP levels below the standard, but Chl-a levels substantially higher than the standard, as well as high DO concentration, very high (and problematic) DO percent saturation level, and pH nearing the standard, likely due to the uptake of CO_2 by the abundant algae for photosynthesis.

The higher algal populations on July 7 also translated into significantly higher DO levels, saturation percentages, and pH levels. Both July 7 and July 21 were bright, sunny days, so sunlight availability should not have factored into creating the differing DO, saturation, and pH levels between dates, but rather available nutrient levels and/or flow volumes in the stream were likely responsible for the differences in algal abundances.

A plausible explanation for the lower TP values on the day with higher Chl-a concentrations is the difference in the measured DO concentrations. A well-known phenomenon is that when DO concentrations are high, phosphorus binds to sediments, and when low, phosphorus releases from sediments into the water column. The extremely high DO concentrations on July 7 likely caused much of the water-column phosphorus to become temporarily (for several hours during the mid-day period) bound to the stream-bottom sediments, taking it out of the water-column, and thus not measured in the water samples.

Photo 4. Looking upstream on JD-12 at CR-2, showing the green color of the water on July 7, 2015 when the Chl-a sample was collected.

Table 15. AUID-502 chemistry data from grab samples (concentrations in mg/L).

Site	Date	Time	TP	Chl-a	Temp.	DO	DO% Sat.	pH
S001-029, US Highway 75	July 7, 2015	14:35	0.137	131	23.59	17.62	209.6	8.98
S001-029, US Highway 75	July 21, 2015	12:55	0.391	102	25.87	8.45	103.1	8.46
S001-052, CR-2	July 7, 2015	15:15	0.101	86.2	25.61	16.62	204.3	8.87
S001-052, CR-2	July 21, 2015	15:00	0.227	73.6	26.46	10.86	135.7	8.62
S008-700, CR-2 (JD-12)	July 7, 2015	13:22	0.129	97.6	24.05	14.87	177.9	8.77

pH

The July 7, 2015 pH measurement (Table 15) was right at the aquatic life use standard. This pH level is likely this elevated due to the high amount of photosynthesis occurring during the daylight hours, as the product of photosynthesis is CO_2, which is a component of the pH buffering equilibrium of water. Because the water chemistry results of a day's photosynthesis peak at about 17:00 (5pm), and this sample was taken at 14:35 (2:35pm), it is highly likely that the pH level rose above the standard on this day.

Temperature

Water temperature (Figure 27) was good for about half of the 2013 sonde deployment, but during the second half, a number of days exceeded the temperature determined to be stressful in general to fish (that is, 30°C or 86°F). The lengths of time of exposure to this temperature in this case is much less than specified in the Minnesota standard, which is a three month average temperature of 30°C. So the temperatures recorded in this sonde deployment would not trip the standard. However, these high temperatures are likely adding some degree of stress to aquatic organisms, as these are quite uncommon temperatures. Of MPCA statewide biological sampling data, restricting data to measurements from June 15 - September 15 of 1996 - 2014, from warmwater streams, and between the hours of 12:00 - 19:00, only 2% of the measurements are above 30°C, with the maximum measurement being 34.8°C. The maximum recorded in the 2013 AUID-502 sonde deployment was 31.2 °C (88.16 °F).

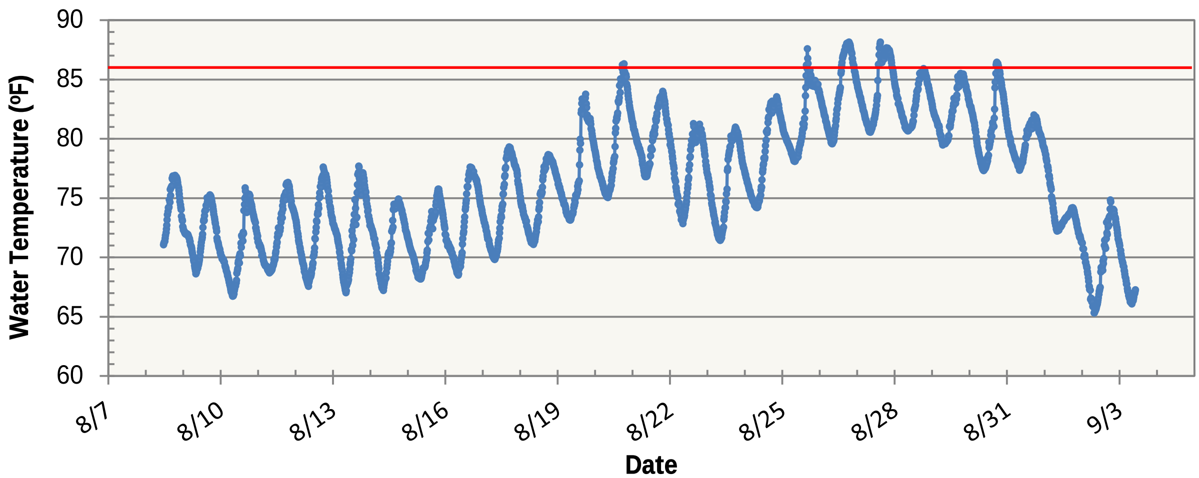
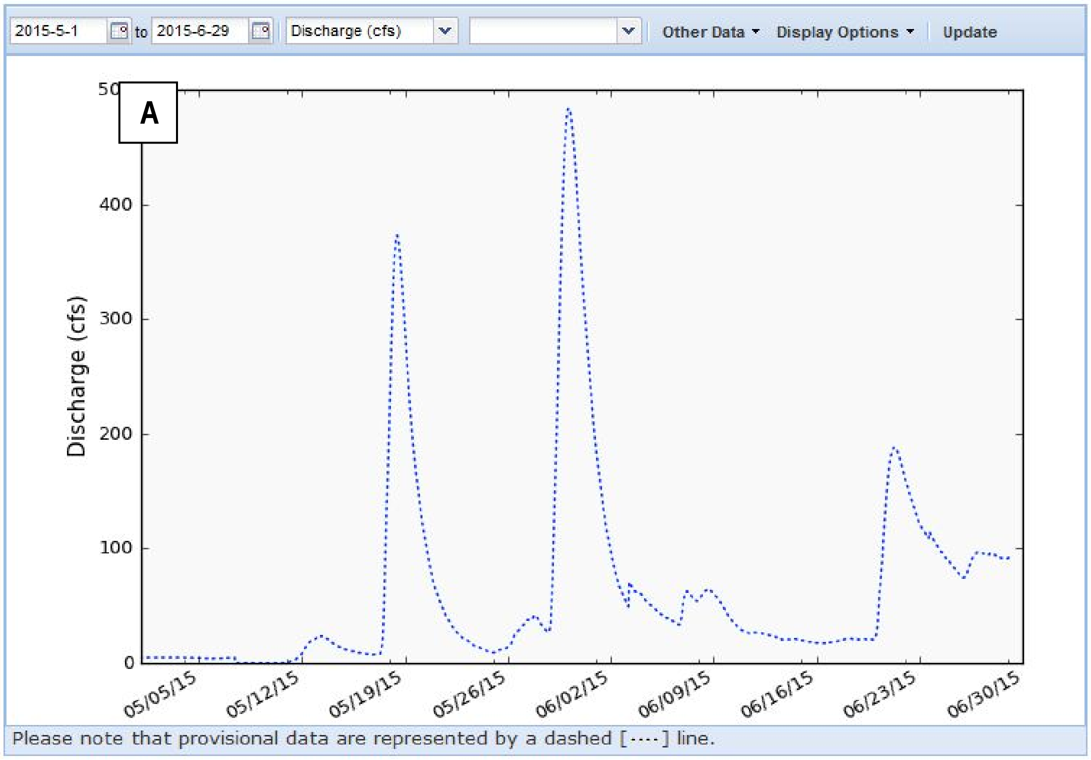


Figure 27. Recording of water temperature for the August 8 - September 3, 2013 deployment at 10RD005 (State Highway 75). The red line represents the Minnesota temperature standard.

Altered hydrology

Examples of the flashiness of flow volumes on this AUID can be seen by viewing the hydrograph measured at the USGS gage at Campbell (Figure 28). On May 17, 2015, the flow was about 10 cfs. It abruptly rose to about 375 cfs, and dropped back down to about 15 cfs within about seven days. The river rose from a level of 0.8 feet to about 6.25 feet over this same time frame. A similar rise and fall occurred about ten days later. The rain events (precipitation measured at the gage) leading to these discharge spikes were significant events, but not rare ones. The first spike was from a 1.39 inch rain event occurring over 34.5 hours. The second event was a 1.78 inch event over 14.25 hours. A flow regime that changes this abruptly and to this magnitude creates a very unstable environment for biological organisms.



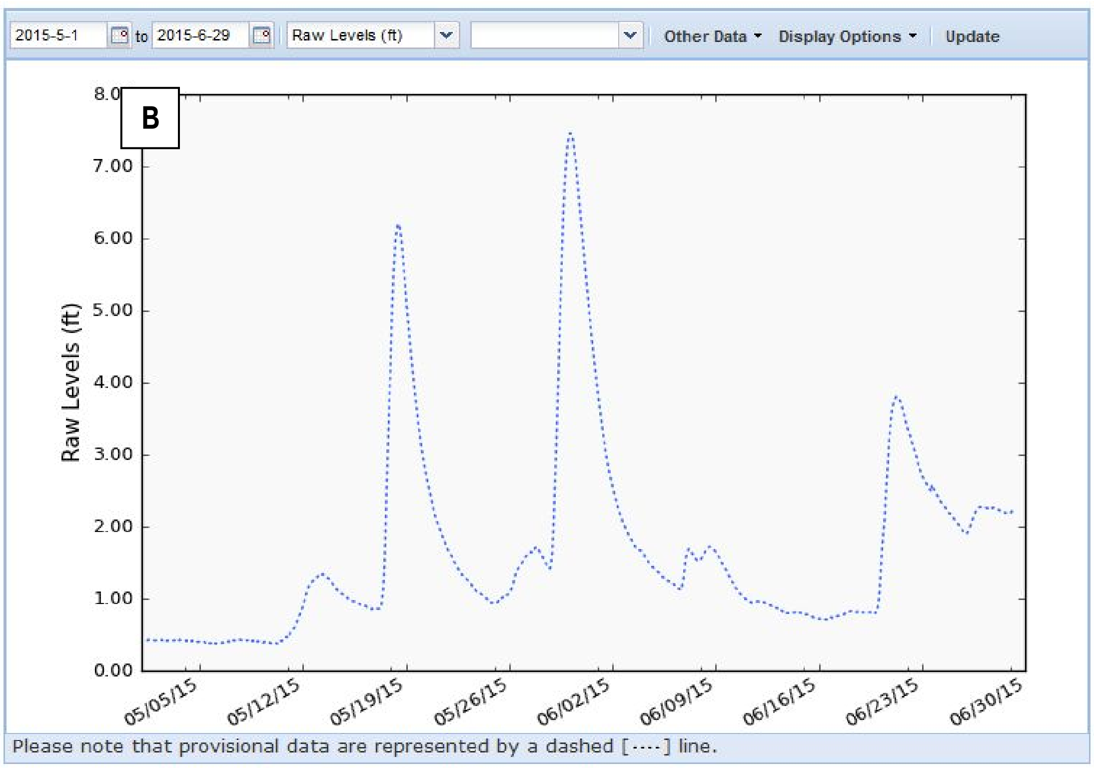


Figure 28. A) Hydrograph in cfs for USGS gage at Campbell, Minnesota from May 1, 2015 to June 29, 2015. B) The hydrograph in stage (feet).

Field observations

The author observed many locations where significant erosion was occurring, relating to infrastructure designs that are improper for the volume of water moving through them or a lack of erosion protection measures needed to keep soil in place. These situations are contributing to the TSS impairments in the BdSRW (Photos 5 - 11).

Photo set 5. A large road culvert on Township 140 was found that is installed such that it is creating a very large, eroded scour pool, and the channel below continues with raw, eroding banks. A) Aerial view – the trees on the left are growing on the bank of the Rabbit River, B) Ground photo of the scour pool. The culvert bottom is about six feet above the water surface, and erosion has occurred back almost to the road bed, C) The raw channel below the culvert.

Photo 6. A ditch that is too narrow and deep to be stable. Clods of soil are falling down from the field edge, contributing topsoil into the ditch that will be washed into streams. There is also no buffer along this field edge.

Photo 7. This ditch has incised and clearly contributes sediment to the South Fork Rabbit River, which it meets right at the bottom of this photo.

Photo 8. Surface erosion from an unvegetated field swale along State Highway 75. A significant delta of soil has been deposited in the ditch, where it can move downstream farther. There were several of these from this

Photo 9. Other fields with similar unprotected drainage topography were found while driving throughout the BdSRW.

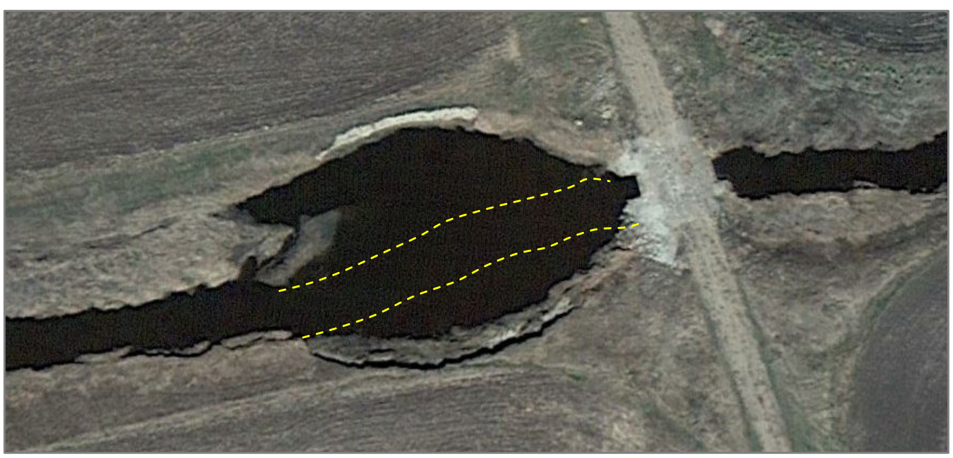


Photo 10. This culvert on AUID-502 (along CSAH-2) is undersized, and during times of higher flow volumes, it constricts flow, increasing the velocity and erosive forces of the water as it exits the culvert, causing a large scour pool. The banks of this pool are raw and steep, and the southern bank has eroded right up to the edge of the cultivated field surface. Many truckloads of soil have eroded from this scoured area. The yellow dotted lines delineate the width of the channel as it should be here.

Photo 11. The ground view of the eroding southern bank in photo 10.

Conclusions

AUID-502 has confirmed impairments for the parameters DO and turbidity. The fish and macroinvertebrate communities at the two biological sampling stations showed a strong response to the problematic levels of these parameters.

Fish species that dominated the community in terms of abundance were those that are tolerant of low DO. The communities at both sites had a very low score in terms of the percentile rank for the "Community DO TIV Index" metric within each site's respective fish stream class. This means that the fish community was highly weighted toward low-DO tolerant individuals. Both sites had a less than 50% chance that the community found in the sample would come from a site with unimpaired DO conditions. This was particularly true for 94RD002, which had a 23.8% chance. In addition, there was a definite signal of wetland-oriented macroinvertebrate taxa present in the samples. Thus, the biological communities are reflecting definite influence of low DO levels as a stressor. Several factors are likely contributing to the poor DO levels, including turbid water and over-widening of the stream channel (more sun exposure), both of which result in elevated water temperature, which decreases oxygen-holding abilities of the water. However, the biggest driver of the DO issue is significantly elevated levels of phosphorus. Evidence for this conclusion is the high daily flux of DO, driven by photosynthesis of algae, and their respiration using oxygen at night. The levels of flux occurring here have been shown to be detrimental to aquatic life (Heiskary et al., 2013). Very high Chl-a levels also corroborate this conclusion.

Both the fish and macroinvertebrate communities showed signals of a shift to being quite tolerant to elevated TSS. Besides causing turbidity, excess sediment is depositing on the river bed, providing very poor substrate for fish. This sediment looks just like the dark topsoil of the area. Due to its light consistency, it likely re-suspends during higher flows, meaning it is very unstable. Unstable habitat provides poor rearing habitat for aquatic invertebrates, which are a food source for many fish species. Unstable substrates also tend to create a more homogeneous stream bed topography. Reduced diversity of habitat translates to reduced biological diversity. The excess sediment impact of increased turbidity likely is resulting in elevated stream temperatures as dark water absorbs more solar radiation, in turn altering DO levels and likely also increasing algal metabolism and reproduction.

In addition to nutrient loading, another primary cause of the biological stress is altered hydrology from land drainage. This can lead to channel instability, causing erosion of channel banks, ditches, and drainage swales. These flowpath alterations change many other habitat features such as temperature, streambed material, and oxygen levels as excess sediment is carried into the river. Highly-manipulated drainage systems are also a challenge to infrastructure such as road crossings, where high flow volumes can create erosive situations through culverts or other discharge points. In addition to the author's documentation of such infrastructure problems, the geomorphic assessment by EOR, Inc. (2014 - also included as Appendix 1, see sec. 3.1) also noted channel instability issues at road crossings.

To summarize, the stressors acting in AUID-502 include: low DO, which ultimately is being caused by excess nutrients, and probably elevated water temperatures related to stream channel and altered hydrology too; excess TSS and bedded sediment from field surface and channel bank erosion, which is damaging substrate aspects of biological habitat. See summary Table 24.

Rabbit River, South Fork (AUID 09020101-512)

Impairment: The creek was assessed as impaired for not meeting the fish community threshold at site 10RD012 located at County Road 152, two miles SE of Campbell. The site became impounded by beavers subsequent to the fish sampling visit, and was too deep for effectively sampling macroinvertebrates, so the fish community is the only biological sample from this location. There are also conventional impairments for DO and turbidity in AUID-502.

Initial data

Chemistry

The only chemistry data, aside from DO and turbidity, available within this AUID was that collected during the fish sampling visit on June 15, 2010. The results of that sampling: DO was 6.58 mg/L, TP was 0.544 mg/L, nitrate was < 0.05 mg/L (below the lab's detection limit), ammonia was 0.11 mg/L, TSS was 37.2 mg/L, and TSVS was 12.8 mg/L. Based on this one sample set, the parameter of concern was phosphorus, which was very elevated. Nitrate was extremely low. From the suspended solid data, about 2/3 of the material is mineral, and 1/3 organic material.

Biology

Fish

The fish community at 10RD012 was heavily dominated by fathead minnows, making up 81.7% of the total abundance of fish. Also abundant were orangespotted sunfish, black bullhead, and common carp. These four species formed the bulk of the sample (95.2%). The fish community had percentile rankings that were very low (poor) for the DO TIV Index and the TSS TIV Index (Table 16). The probabilities of this fish community coming from a stream reach with standard-meeting levels of DO and TSS are very low (Table 16).

Table 16. Fish Community Tolerance Index scores at 10RD012 for DO and TSS. "Percentile" is the rank of the index score within the fish class 2 streams. "Prob." is the probability, expressed as a percent, a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined.

Site	Stream class	DO TIV index	Class avg.	Percentile w/in class	Prob. as %	TSS TIV index	Class avg.	Percentile w/in class	Prob. as %
10RD012	F - 2	6.17	6.99	8	16.8	26.8	20.19	13	10.6

Macroinvetebrates

No macroinvertebrates were collected due to a new beaver dam impoundment constructed subsequent to the fish sample, and prior to the macroinvertebrate sampling visit.

Targeted investigation and results

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

Chemistry

Dissolved Oxygen

A sonde was deployed from August 8 - September 3, 2013 at 280th Avenue, about 3/4 miles upstream of 10RD012. During this period, the DO concentration was below the standard for the majority of the time (Figure 29). Interestingly, most days show a strong spike in DO concentration between 11:00 pm and about midnight. This is quite unusual, and suggests there is a location upstream that has much higher dissolved oxygen, and that upstream water reaches the sonde location downstream at about midnight. This could be explained if there is a location that harbors significant aquatic macrophyte growth upstream. If not for this nightly influx of elevated-DO water, the site itself would almost always be below the DO standard. Even so, many days did not reach the standard at any time. Additional comments on DO are included below in the "Temperature" section. Two visits in July 2015 (7th and 21st) were made in hopes of finding suitable conditions for a sonde deployment. Flows were found to be too low both times.

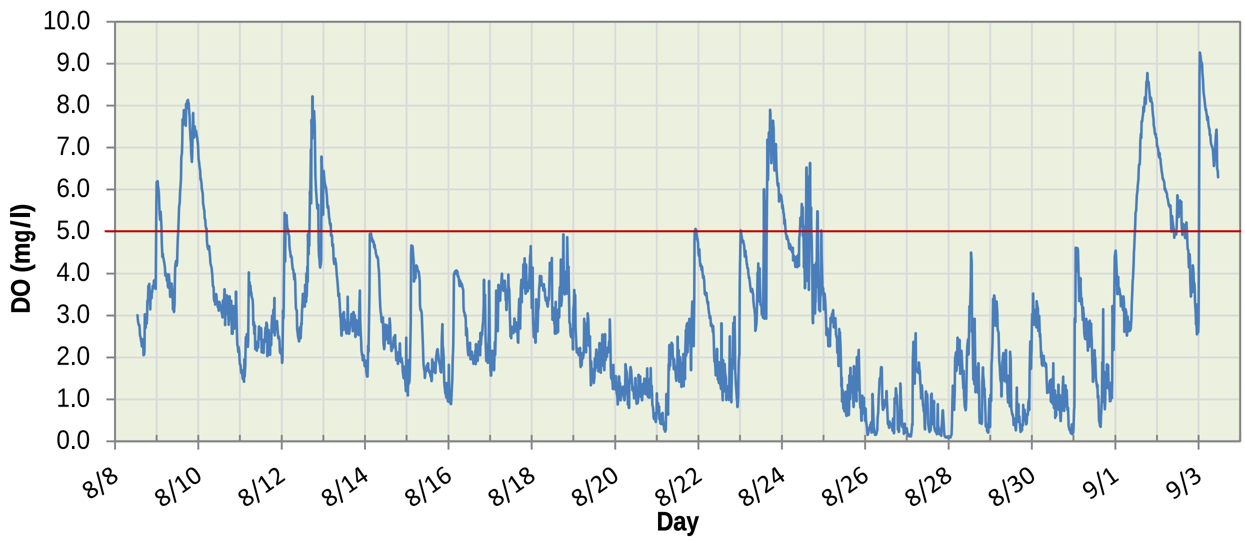


Figure 29. DO readings during the August 8 - September 3, 2013 sonde deployment at 280th Avenue. The red line is the DO standard.

Nutrients and Chl-a

As part of a systemic, concurrent sampling of TP and Chl-a for the Rabbit River system, a TP sample was collected at S004-176 (490th St.) on July 7, 2015 (Table 17). A second similar sampling was attempted on July 21, 2015, but the stream had no flow (i.e., there were only isolated pools holding water - Photo 13) and protocols require flow for stream sampling.

Table 17. TP, Chl-a, and field-sampled parameters for July 7, 2015 visit to S004-176. Values in mg/L.

Site	Date	Time	TP	Chl-a	Temp.	DO	DO % Sat.	pH
S004-176, 490th Street	July 7, 2015	16:15	0.219	54.2	30.03	16.96	227.3	8.71

Temperature

Water temperatures at 280th Avenue did not reach levels considered to be stressful to fish during the measured period in 2013; however, it was a factor influencing DO levels. Though not good throughout the period, DO minimums were generally higher the first ten days, when water temperatures were cooler, and were extremely low during the period from August 26 - September 9, when water temperatures rose substantially higher (Figure 30). DO levels improved significantly starting on September 1 when water temperatures strongly declined. DO was also better during the three day dip in water temperatures on August 22 - August 24. The instantaneous sample collected at this same location on July 7, 2015 (30.03 °C) was right at the temperature threshold for impairment (30°C), though that standard also has duration components to it, so a single measurement cannot be interpreted as a temperature impairment.

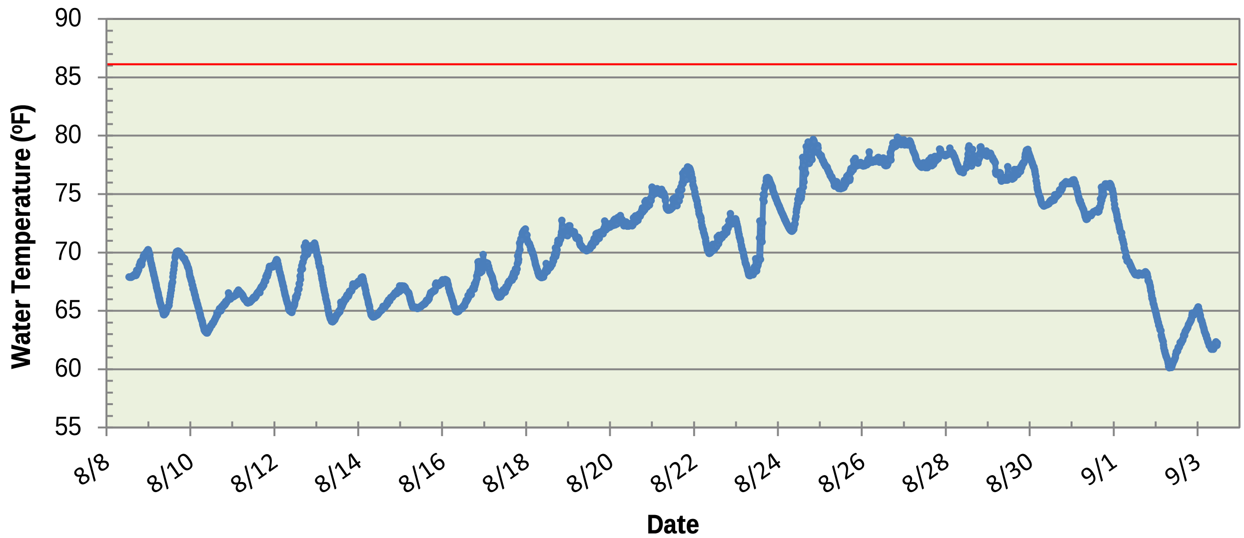


Figure 30. Water temperature during the August 8 - September 3, 2013 sonde deployment at 280th Avenue. The red line is the temperature standard.

Connectivity

One connectivity issue related to AUID-512 is that the downstream AUIDs are also impaired, those being AUIDs 502 and 501 (see Figure 1 map). Fish migrate into smaller creeks in spring, coming up from larger streams or from lakes where they have overwintering habitat. If a downstream location is impaired, migrating fish will have to go farther to find acceptable habitat. And, in spring, they will have to move through an impaired section of stream channel in order to return to AUID-512. It is over ten river-miles from the mouth of the Rabbit River to the confluence of the South Fork Rabbit River, which is the downstream end of AUID-512. Even then, the Bois de Sioux River's fish community downstream of the mouth of the Rabbit River also has an impaired fish community. The fish sample in the Bois de Sioux upstream of the mouth of the Rabbit River did score just slightly above the impairment threshold. So, in general, there just are not good source communities downstream to migrate into AUID-512, and there are miles of poor habitat conditions that must be migrated through to get into AUID-512.

More obvious forms of connectivity blockage are dams or improperly sized or installed culverts. There are no dams between the sampled site and the Bois de Sioux River. There is beaver activity in the river below the biological site, which during certain parts of the summer may impede fish movement, but at higher spring flows, these dams are probably damaged and passible for fish. Most of the road crossings between the biological site and the Bois de Sioux River are bridges, which rarely cause fish migration problems. There is only one set of culverts, at Township Road 116, and these are not perched, nor do they appear improperly sized (no downstream scour pool has developed). Therefore, connectivity related to infrastructure is not a factor in the poor fish community found at this location.

Hydrology

Water levels in the South Fork Rabbit River seem to get quite low in later summer. Comments at the Professional Judgement Group meeting during the stream assessment process confirmed this, as a representative of the Bois de Sioux Watershed District stated that AUID-512 is intermittent. Aerial photography from September, 2014 shows water levels that were extremely low (Photo 12). The low flow condition in mid-late summer likely contributes to the low DO levels via decreased water movement/mixing, and increased water temperature. A visit on July 21, 2015 found the stream in a dry condition, with ponded water in the pools (Photo 13). A synthetic hydrograph for this location was run using the HSPF model for 2001-2005 (Figure 31). Even though this model tends to over-predict baseflow, each year there were periods of the summer where discharge was below 5 cfs, and again, these discharges were probably less than the graph shows.

Low flow conditions are exacerbated by the fact that Judicial Ditch 12, which runs along CSAH-9, "steals" some of the water from what would have originally been the sub-watershed of the South Fork Rabbit.

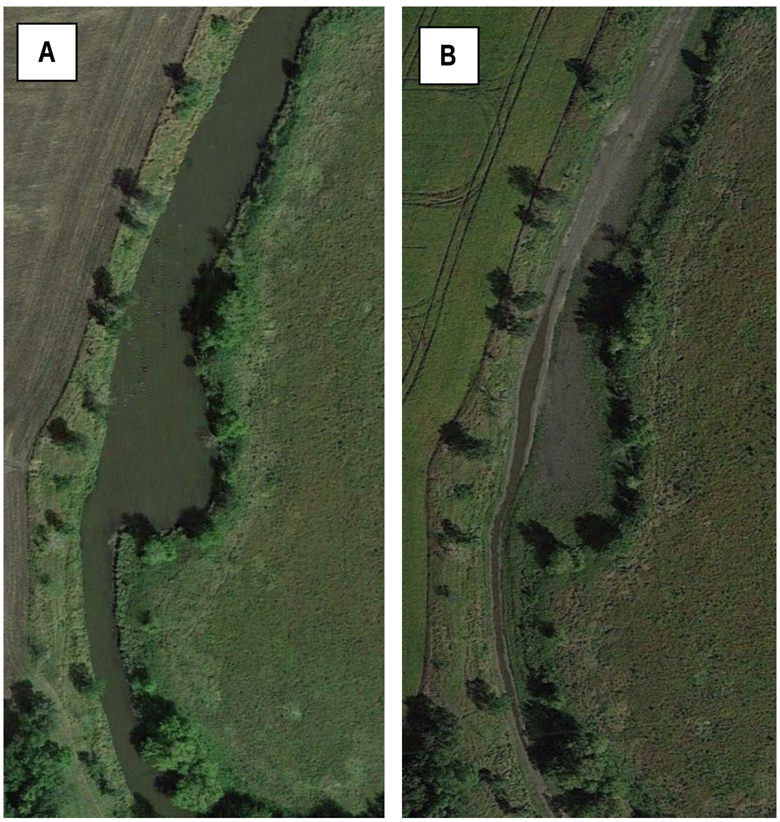


Photo 12. South Fork Rabbit River. A) September 12, 2013. B) September 15, 2014. Very different water volumes are present on almost the same day in late summer, one year apart. Only isolated pools have water in 2014.

Photo 13. South Fork Rabbit River at 490th Street on July 21, 2015. Water only was found ponded in the deeper areas of the channel.

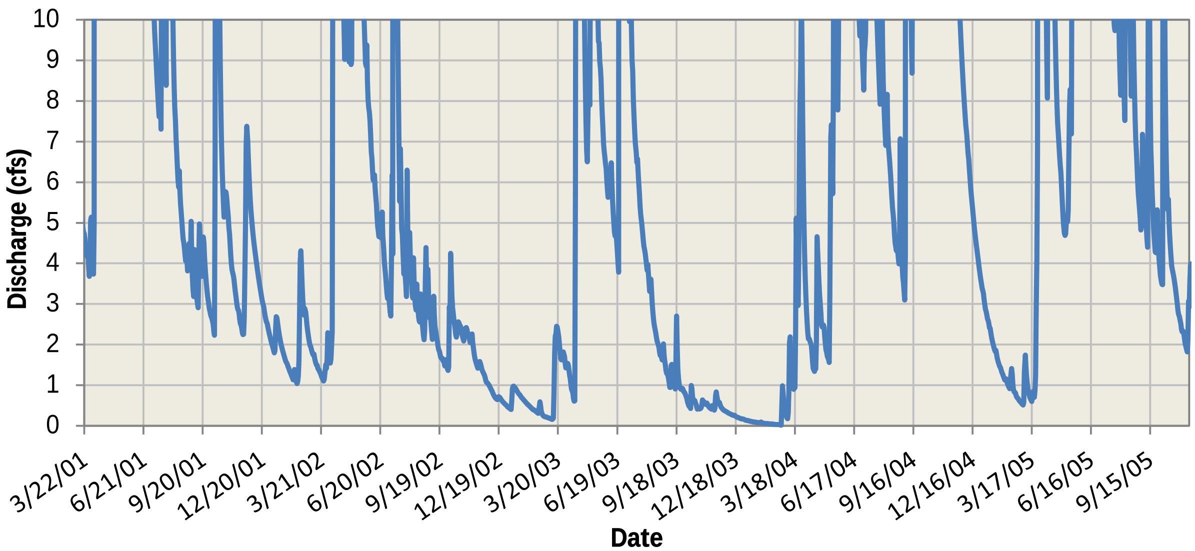


Figure 31. A synthetic HSPF hydrograph of low flow conditions for 2001-2005 for the South Fork Rabbit River at Campbell, Minnesota.

Conclusions

The issues in AUID-512 are essentially the same as for AUID-502; altered hydrology, excess sediment, and excess phosphorus, leading to reduced and degraded physical habitat, channel instability, and DO problems (both too little and too much). Metrics calculated for the fish community that was sampled in this AUID confirm low DO and high TSS as stressors. Additionally, low/no flow periods are problematic in this AUID. This was directly observed in 2010, 2013, and 2015, 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. Connectivity does not appear to be a problem.

An altered hydrology issue specific to AUID-512 is that significant water is diverted from entering this channel because runoff from the eastern part of AUID-512's sub-watershed is routed into Judicial Ditch 12 (JD-12), which runs along CSAH-9. This diversion exacerbates the drying down of AUID-512.The fact that this eastern runoff is routed to JD-12 may, however, be reducing the channel instability that would otherwise occur due to higher spring flows that would be in the channel of AUID-512 (due to existing drainage practices). So, under current land management, JD-12 is probably a help for AUID-512 in spring, but a hindrance in summer, when AUID-512 needs more water. The quantification of how much water is being diverted from AUID-512 would need to be determined using the HSPF model that was developed by the contractor for this WRAPS project. A more insightful understanding of the level of positive and negative influence of the diversion could be made with that information. Additionally, quantifying the overall effects of hydrological alteration (drainage) would be beneficial. 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 sub-watershed. If human activity has exacerbated the low flows, it would be advisable to work on that stressor first. Without better stabilization of flow volumes, efforts to reduce the impacts of other stressors will be less effective.

Unnamed Tributary to Lake Traverse (AUID 09020101-535)

Impairment: The creek was assessed in 2012 as impaired for not meeting fish community IBI thresholds at biological station 10RD022, just upstream of Highway 27. This reach has not received the sampling effort needed to determine whether it meets other water quality standards.

Review of the sub-watershed

The land comprising the sub-watershed of AUID-535 is heavily devoted to row crop agriculture, but there are still some areas of storage, some of which are on the creek channel, and some of which are off-channel ponds. The actual AUID-535 channel is short (0.45 miles long) and flows down the escarpment that runs along the east side of Lake Traverse. The stream has significant gradient within the AUID until it reaches the floodplain of Lake Traverse, where the topography is quite flat. There are no point source discharges in this sub-watershed, no towns, and only a handful of residences/farmsteads. Given the land use in the watershed, the only stressors that are likely candidates would be nutrients, sediment, or degraded habitat caused by surface runoff or hydrological alterations in the landscape causing channel instability or reduced baseflow volumes.

Initial data

Chemistry

This AUID has received little attention regarding water quality monitoring. One water quality sampling effort occurred on the date of the fish sample visit, June 9, 2010. Field measurements of some water quality parameters were also collected during the macroinvertebrate visit on August 4, 2010.

Dissolved Oxygen

DO was measured during each of the 2010 biological sampling visits. The 10:08am, June 6 reading was 9.07 mg/L. The August 4 reading was 8.28 gm/L (time was not recorded). These levels of DO are good, though neither likely represented the day's minimum reading. These data do not provide much insight into the DO regime of the AUID. However, this short AUID flows through a mature forest, which provides shading that cools the water, and reduces algal abundance, both of which are beneficial for good DO. In addition, the higher gradient and presence of riffles also will facilitate aeration of the water.

Phosphorus

The lone TP sample measured 0.124 mg/L, which is below the newly adopted river nutrient standard for the Red River area.

Nitrate

The lone nitrate sample measured 3.33 mg/L. This is not a trivial level of nitrate, but currently Minnesota has no nitrate standard to judge this sample against. It is thought that the toxicity levels for nitrate, currently under development, will be set at least twice as high as this measurement.

Ammonia

The lone ammonia sample measured < 0.1 mg/L, which is below the labs detection limit. This concentration would not have an associated unionized ammonia level above the Minnesota toxicity standard of 0.04 mg/L.

TSS/TSVS

The lone TSS and TSVS samples each measured < 4 mg/L, which is below the lab's reporting limit. The transparency tube measurement at the fish visit was > 100 cm. During the few visits the author has made to this reach, the water has been very clear, though these have always been at times of relatively low flow.

Habitat

Habitat diversity for macroinvertebrates was good at 10RD022 (Photo 14). There were significant amounts of hard substrates to colonize, and the sampled habitats were rock and wood. Macrophytes were not present, perhaps due to the forested (shaded) riparian corridor along with the substantial channel gradient. Undercut banks were not significant either, but those are less common on forested channels.

The MSHA score, which is somewhat more oriented to the fish community, was 57.9 at 10RD022. This score ranks in the middle of the "fair" category. None of the subcomponent scores were notably poor or good; each was "middle of the road" (Table 18). The only subcomponent which received less than half of its possible points was "Channel Morphology". The metrics that docked points from the Channel Morphology score were poor depth variability and low channel stability.

Photo 14. August 4, 2010. A nice cobble riffle - particularly good habitat for macroinvertebrates. The pool above was only a few inches deep, not a positive for fish.

Table 18. MSHA scores for biological sample site 10RD022. Heading numbers in parentheses are points possible.

Land use (5)	Riparian (15)	Substrate (27)	Cover (17)	Channel morphology (36)	Total (100)
2.5	8	18.4	12	17	57.9

Hydrologic alteration

No flow gaging has been conducted on AUID-535, so a direct analysis of hydrologic alteration cannot be conducted. As mentioned near the top of this AUID's section, there are still some areas of upstream storage present (numerous small ponds/depressions). Some of these appear (via aerial photography review) to have some level of drainage, as swales or small trenches can be seen leaving from them. It appears that flow volumes are often very low. Even in late spring, the flow volume resulted in only one to three inches of water depth in the channel (Photo 15). A very similar flow volume was found in early August, 2010. Geomorphological investigation will shed light on the variability of flow volumes and will be discussed in the geomorphology section.

Photo 15. Flow volume on June 9, 2010 is quite low, and water depths are only a few inches deep.

Biological response

Fish

The fish community was dominated by creek chubs, making up 86.2% of the sample, with blacknose dace and brook stickleback also present. All three species are quite ubiquitous statewide. Based on the DO and TSS TIV indices (Table 19), neither DO nor TSS appear to be problematic. The community TIV indices are better than average for both DO and TSS (a low score is better) for Class 3 streams. Both index scores have fair correlating probabilities that the community would come from a DO and TSS standard-meeting reach, and thus DO and sediment are likely not significant stressors.

Table 19. Community Tolerance Index scores at 10RD022 for fish and macroinvertebrates for DO and TSS. "Percentile" is the rank of the index score within streams of the appropriate stream class. "Prob." is the probability, expressed as a percent, a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined.

Biology type	Stream class	DO TIV index	Class avg.	Percentile w/in class	Prob. as %	TSS TIV index	Class avg.	Percentile w/in class	Prob. as %
Fish	F - 3	7.3	6.85	72	60.6	15.9	17.2	51	68.2
M-Invert	MI - 5	7.04	6.90	48	NA	14.05	16.15	82	NA

Macroinvertebrates

The macroinvertebrate community meets the IBI standard in this AUID. Macroinvertebrate Community TIV Indices were examined just to see if they could help shed light on what might be affecting the fish community (Table 19). Suspended sediment does not appear to be a significant influence as the macroinvertebrate community was much more oriented to a lower-TSS scenario than the class average. For low DO tolerance, the macroinvertebrate community was slightly better than the class average, so low DO does not appear to be a likely stressor either.

Targeted investigation and results

Chemistry

No additional chemistry samples have been collected.

Geomorphology

EOR, Inc. conducted a geomorphological assessment within the biological sample reach of AUID-535. Channel slope is relatively high for this area, and the bankfull shear stress was among the highest of the 14 sites EOR, Inc. studied in the BdSRW. Bank erosion was evident in the biological sample reach (Photo 16). As shear stress increases, so does the potential for stream bank erosion. The average BEHI and NBS scores were Moderate/High and Moderate, respectively. Though not a ditch, a MADRAS (Magner et. al., 2010) protocol was conducted (EOR, Inc. 2014), and that score was the highest of the 14 EOR, Inc. geomorphology study sites (higher scores are bad). The entrenchment ratio was calculated from three riffle cross-sections measured by EOR. Those ratios were 3.41, 3.93, and 2.44, for an average of 3.26. This score is interpreted as being only slightly entrenched, meaning at higher flows, water is able to spill out on a wide flood plain and thus reduce the scouring of the bed, contributing to channel stability. Yet, there are still some issues with bank stability as shown by photos, and the BEHI, NBS, and MADRAS protocols.

Photo 16. This badly-eroded bank, just upstream of State Highway 27, is evidence of channel instability. The top of the bank is about seven to eight feet above the water level in the photo.

The downstream side of Highway 27 is over-widened and has a very high width/depth ratio below the culvert, at least for the approximately 50m visible from the road shoulder. There was much exposed stream bed, and the area just below the culvert was about three inches deep all the way across the very wide channel (Photo 17). The substrate here was fine particulate material. Downstream, some cobble can be seen.

Photo 17. The view from Highway 27 looking downstream. On the left side of the channel, deposition of sediment is occurring (arrow). The whole "pool" in the foreground is only about 5cm deep, though perhaps 15m wide.

Connectivity

The biological site was located just above Highway 27, meaning there is only one road crossing separating the site from Lake Traverse. The culvert bottom on the outlet side is perched about a foot above the downstream water level. This culvert serves as somewhat of a grade-control structure for the reach upstream of the highway, which may be helpful in reducing incision and bank erosion along the reach, but is also is a barrier to fish migration into the reach above Highway 27 (Photo 18). At low flows it is certainly a barrier, and at higher flows, the water velocity coming off this lip probably precludes migration of smaller, non-game species of fish. It is possible that originally the culvert was not perched, but that the downstream channel has incised, dropping the elevation of the channel bed.

Photo 18. The culvert bottom (a cement apron) is perched above the stream bottom, resulting in a vertical drop in water surface levels of about a foot.

Conclusions

Connectivity and hydrological alteration (leading to channel instability and probably low baseflow volumes) are the main stressors here. Without fixing the connectivity issue at Highway 27, it is unlikely that addressing other stressors will be very beneficial to the stream fish community. There is probably very limited overwintering habitat in this small stream system, and so the stream would need connection to the lake and lowest reaches of the stream so that fish overwintering in those locations could repopulate the stream above Highway 27. That is actually how small streams are annually re-populated in much of Minnesota. A riffle could be constructed at the outfall of the Highway 27 culvert, angling the stream bed upward to meet the cement apron. The wide, flat apron may need some modification too, to add depth for fish to swim across when flow is lower (as in photo 18).

A good, season-long monitoring of stream flow levels should be conducted to reveal how flow conditions change from spring, to summer, to fall. This would inform a better analysis of available fish habitat upstream of the Highway 27 crossing, and provide insight into whether adding upstream storage could benefit baseflow levels in the stream channel and how much that would improve fish habitat. Additional stream channel restoration work upstream of Highway 27 would be beneficial to create varied stream depths, stabilize streambed materials, and stabilize the channel banks (using a natural channel restoration approach). Originally, the AUID-535 channel form may have been a step-pool type stream coming down the escarpment to Lake Traverse. This type of stream would have dissipated the water's energy and retained sediment. As with other AUIDs discussed in this report, HSPF or other hydrology models could potentially quantify the degree of alteration of stream flows from drainage upstream.

Other local water quality issues may provide the impetus for striving to improve the geomorphology/altered hydrology issues in this AUID, especially the attempts to improve the water quality in Lake Traverse. There is certainly room for improving the water quality of the water this stream delivers to the lake.

In the upland areas of the sub-watershed, good landscape management should be encouraged to buffer stream channels, and reduce the amount of surface runoff and eroded soils from agricultural lands. Providing storage to reduce peak discharges and improve base flows would benefit the health of the channel, and improve fish habitat, even without direct work on the stream channel. The DNR Clean Water Legacy or Stream Habitat staff should be contacted for assessment and design of work to renew/improve the stream channel and alleviate the connectivity issue facing fish that would utilize this AUID.

Traverse County Ditch 52 (AUID 09020101-540)

Impairment: The creek was assessed as impaired for not meeting the fish community health threshold. Biological station 10RD019 is located just downstream of Township Road 18. This reach has not received the sampling effort needed to determine whether it meets other water quality standards for chemistry parameters.

Review of the sub-watershed

The sub-watershed of AUID-540 is heavily devoted to row crop agriculture. There are no towns within this sub-watershed. This is a short AUID (1.65 miles long). It traverses the escarpment along the eastern side of Lake Traverse, from up on the plateau, down to the Lake's floodplain. Upstream connections to this channel are almost exclusively ditches, including some draining land area naturally located in the Mustinka River Watershed.

Initial data

Chemistry

This AUID has received little attention regarding water quality monitoring. One water quality sampling effort occurred on the date of the fish sample visit, June 8, 2010. Field measurements of some water quality parameters were also collected during the macroinvertebrate sampling visit on August 4, 2010.

Dissolved oxygen

DO was measured at each of the 2010 biological sampling visits. The 4:11pm, June 8 reading was 8.41 mg/L. The August 4, 4:55pm reading was 8.2 gm/L. These are good levels of DO, though neither likely represent each day's minimum reading. These data do not provide much insight into the overall DO regime of the AUID.

Phosphorus

The lone TP sample measured 0.041 mg/L, which is well below the newly adopted state standard for the Red River area.

Nitrate/ammonia

The lone Nitrate sample measured below the labs detection limit of 0.05 mg/L, and the ammonia sample was also below the labs detection limit of 0.1 mg/L. At this ammonia level, unionized ammonia would not be a problem.

TSS/turbidity/sediment

The June 8, 2010 TSS sample measured 36.4 mg/L, below the region's TSS standard. The TSVS reading was less than the labs reporting limit of 4 mg/L. Therefore, the suspended material in the water is almost exclusively mineral material, from field surfaces or channel banks.

Habitat

The MSHA score at 10RD019 of 51.9 is on the low end of the "fair" range. Though the Substrate and Cover subcategory scores were fairly good, Channel Morphology scored poorly (Table 20). Substantial bank erosion was noted and decreased the Riparian score. Embeddedness was categorized as moderate (50-75%). The Channel Stability metric within the Channel Morphology subcategory scored 0 of 9. These scores suggest a channel instability problem, with the root cause being excess flow during snowmelt or after precipitation events.

Table 20. MSHA score for biological sample site 10RD019. Heading numbers in parentheses are points possible.

Land Use (5)	Riparian (15)	Substrate (27)	Cover (17)	Channel Morphology (36)	Total (100)
0	8.5	17.4	13	13	51.9

Channelization/ditching

Drainage and channel habitat in the TCD-52 system, especially upstream of AUID-540, is highly altered. Implications of this drainage system are discussed in the next section "Altered Hydrology" and further down in the "Geomorphology" section.

Altered hydrology

Observations collected in the MSHA procedure, the TSS vs TSVS comparison, and field and aerial photo observations by the author together lead to a conclusion that there is too much water flowing in this stream channel during wet times, much more than it naturally formed to convey. A close analysis using aerial photography and LIDAR terrain analysis shows a channel construction that crosses the Mustinka/Bois de Sioux Watershed boundary in several places (Figure 32), at least one of which affects TCD-52 in section 28 of Wall Township, which is draining land within the adjacent Mustinka River watershed (the Eighteenmile Cr. sub-watershed) into the Lateral 1 channel of TCD-52, exacerbating the flow volumes and problems of erosion of TCD-52's channel banks. Such a situation will result in channel instability; incision, channel widening, bank instability, increased bank-derived sediment, turbidity, and sediment deposition on important habitat features.

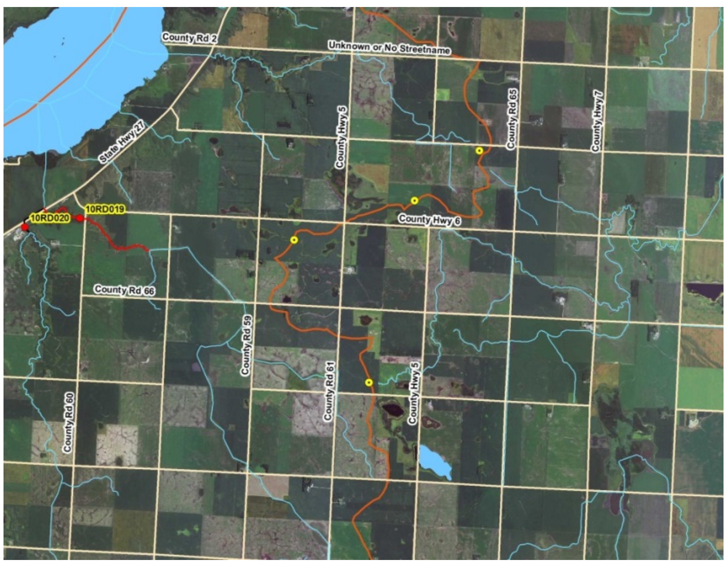


Figure 32. The orange line is the watershed divide between the Bois de Sioux and Mustinka HUC-8 Watersheds. The yellow dots are locations where ditches appear to be carrying Mustinka Watershed runoff into Bois de Sioux Watershed streams. The red dot on the left is the biological sampling site on JD-12.

Biological response

Fish

The fish sample contained only two species, fathead minnow (166 individuals) and brook stickleback (11 individuals). The fathead minnow has been shown to be tolerant to numerous habitat variables and human disturbance levels, and sensitive to none of the parameters assessed by Rankin (2010). In the MPCA fish traits list used for calculating various metrics, the fathead minnow is categorized as "very tolerant" and also among the "wetland" species. It is also quite tolerant of low DO and moderately tolerant of high TSS. The other species present, the brook stickleback, is categorized as tolerant in the fish trait database, and is extremely tolerant to low DO - of 83 Minnesota species with tolerance values for low DO, it ranks third, surpassed only by brown bullhead and bowfin. It is also moderately tolerant of high TSS.

The fish community tolerance index metrics were calculated for DO and TSS (Table 21) to provide insight into the influence of these two stressors, since low DO and excess sediment are common stressors elsewhere in the BdSRW and neighboring Mustinka River Watershed. The known barrier downstream (i.e., the culvert/cement "dam") coupled with the small size of the stream (typically requiring repopulation in spring from downstream refuge areas) is a confounding factor in analyzing metrics for this site. Species may be missing here because they cannot overwinter in the small stream and are not able repopulate it in spring because of the barrier (i.e., it may not be another stressor, such as low DO, that is eliminating those species from the stream). The percentiles for this site, for both parameters, are very low, as is the probability this fish community would be found in a reach passing the DO and TSS standards.

Table 21. Community Tolerance Index scores at 10RD019 for fish for DO and TSS. "Percentile" is the rank of the index score within streams of the appropriate stream class. "Prob." is the probability, expressed as a percent, a community with this score would come from a stream reach with TSS or DO that meet the standards, based on all stream classes combined.

Parameter	Fish class	Community index score	Percentile within stream class	Probability as %
DO	3	6.07	15*	14.4*
TSS	3	25.04	5	15.9

*This may be an artifact of the small number (2) of species found here due to the migration barrier.

Macroinvertebrates

Macroinvertebrate data from 10RD019 were explored to add insight into possible stressors, even though the macroinvertebrate community scored above the IBI threshold. Table 22 shows DO-related metric scores for the macroinvertebrate community at site 10RD019. A fair number of EPT taxa were found, though they were not among the most sensitive of the taxa within the EPT. Though several air-breathing taxa were found, including three hemipteran taxa and several beetle taxa (two dytiscids, a hydrophilid, and a haliplid), the macroinvertebrate community does not solidly reveal a problem with low DO. The Community DO Index falls near the top of the middle third percentile-wise within the Class 5 streams. That there are four low-DO intolerant taxa, two of which are very intolerant to low DO, and that there are almost twice as many low-DO intolerant as tolerant individuals, suggests that low DO is not a primary stressor in AUID-540.

Table 23 shows TSS-related metric scores using MPCA's "through 2014 sites" version of tolerance values. There are zero taxa present which are intolerant or very intolerant to higher TSS concentrations, while there are 14 taxa which are tolerant to very tolerant of elevated TSS concentrations, including 9 taxa that are very tolerant. The percentile of 57 for this site is not terribly poor, but may reflect that the TSS material here is more clay than the more-abrasive sandy TSS found in some other locations, possibly suggesting that the TSS from this AUID is a bit less abrasive and damaging than from sandier sites. There is a thick, exposed clay strata that is eroding in AUID-540, as can be seen in Photo 19, meaning that there is indeed a clay component to the TSS in AUID-540. That there were zero TSS intolerant taxa, and 14 TSS tolerant taxa present in the macroinvertebrate sample suggests that TSS is problematic to the biological community in this AUID.

Table 22. Macroinvertebrate metrics related to DO utilizing MPCA tolerance values. The percentile rank is based on the community DO index score.

M-Invert class	# Low-DO intolerant taxa	# Low-DO very intolerant taxa	% Low-DO intolerant taxa	% Low-DO tolerant	Community DO index score	Percentile within stream class
5	4	2	31.4	16.4	7.185	60

Table 23. Macroinvertebrate metrics related to TSS utilizing MPCA tolerance values. The percentile rank is based on the community TSS index score.

M-Invert class	# TSS intolerant taxa	# TSS very intolerant taxa	# TSS tolerant taxa	# TSS very tolerant taxa	% TSS tolerant indiv.	% TSS very tolerant indiv.	Community TSS index score	Percentile within stream class
5	0	0	14	9	23.9	3.5	15.43	58

Targeted investigation and results

Chemistry

No additional monitoring of chemistry parameters was done. Given the obvious connectivity issue at Highway 27, and the other initial analysis described above, it seemed prudent to focus on the altered hydrology/channel instability issue.

Geomorphology

The profile of AUID-540 is shown in Figure 33. Within the AUID, there are several gradient facets. The two higher-gradient facets align exactly with where the serious bank erosion is occurring. One EOR, Inc. geomorphology station (Site 1) was located on AUID-540, on the upstream side of Township Road 18, within the open, pastured area. Note the biological sample was collected on the downstream side of the road. The EOR, Inc. site is in a lower-gradient reach, between two relatively higher gradient reaches. The EOR, Inc. report (2014) states: "Separate BEHI analyses were completed for two eroded banks measuring 60-feet long and 32-feet long and scored Very High and High respectively." EOR, Inc. reported overall BEHI and NBS ratings were Low/Moderate and Low, respectively. This is due to the lower gradient (meaning lower shear stress on the banks) found at EOR, Inc. Site 1. However, in nearby locations, both upstream and downstream, there are clear signs of the damage that altered hydrology is causing to the channel, with active bank erosion occurring in many locations of this short AUID. One location is just downstream of the Township Road 18 crossing. This bank is estimated to be about 20 feet high (Photo 19), and significant chunks of bank are sloughing and or washing away (Photo 20). Upstream of the pasture, there is another long stretch of raw, high banks (Photo 21, Figure 34). Significant amounts of the sediment from these eroding banks are being deposited into Lake Traverse, where there is formation of a sediment delta in the lake at the mouth of the ditch (Photo 22).

Another source of sediment is caused by incision of the channel due to excess water transport (i.e., substrate on the stream bottom is eroded away and moved downstream). Evidence that this has occurred is shown in photo 24, where the culvert's cement apron is now a few feet above the immediately-downstream channel bed. This has also increased gulley erosion in an intermittent side channel along Township Road 18 that enters AUID-540 on the southwest side of the crossing, where the channel has incised due to a headcut formed by the degradation (downcutting) of the TCD-52 channel elevation. This has led to enlargement of the gully as its banks became unstable and erode as the channel deepened, sending sediment downstream.

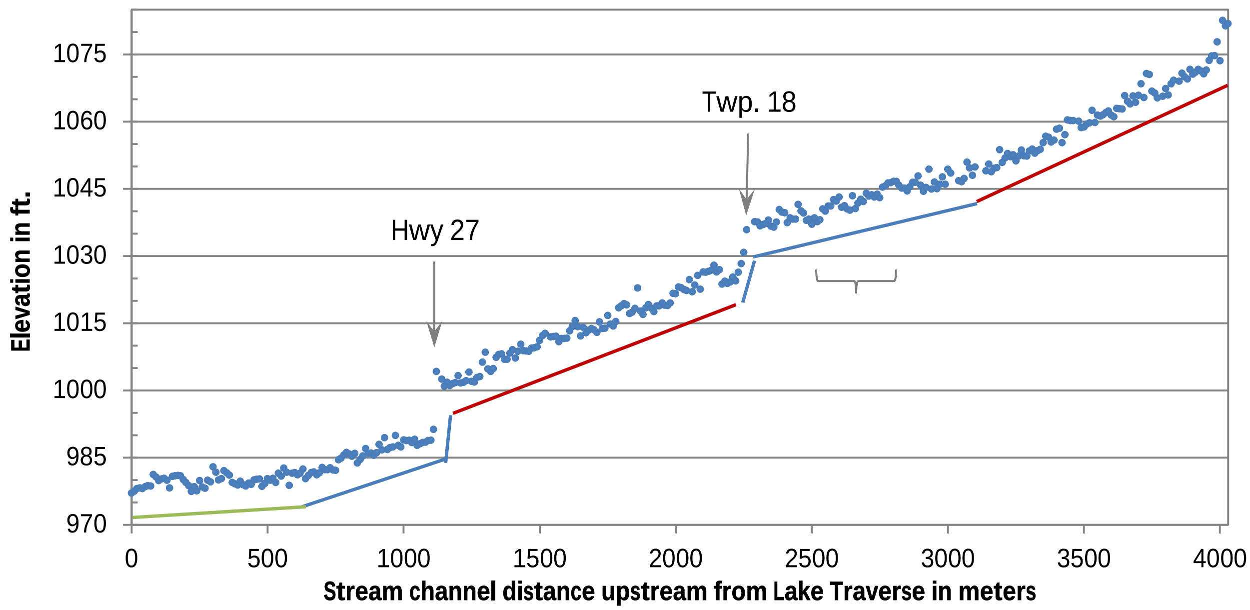


Figure 33. The profile of AUID-540, from the Lake Traverse shore upstream to one-quarter mile west of CR-66. Profile created with a finely-digitized stream trace and a custom ArcMap tool that utilized LiDAR at 1m resolution. The red lines show higher gradient reaches, with blue lines intermediate, and the green line lowest gradient. The bracket denotes the approximate location of EOR, Inc. geomorphology Site 1.

Photo 19. Mass wasting along the channel just downstream of the Township Road 18 crossing. The upper material is sandy, while the lower material is groundwater-saturated clay.

Photo 20. A massive chunk of soil and its vegetation has recently dropped into the stream bed from the forest floor high above, where the dark topsoil layer is showing.

Photo 21. This location is about 1/2 to 3/4 miles upstream of Township Road 18. A) The whitish areas along the channel are raw soil banks that are eroding, which is occurring on both the ditched section on the right and the non-ditched section on the left side. B) A closer view of part of photo A, showing the steepness and height of the raw banks. Note the small size of the baseflow channel (arrow) relative to the actively-eroding valley.

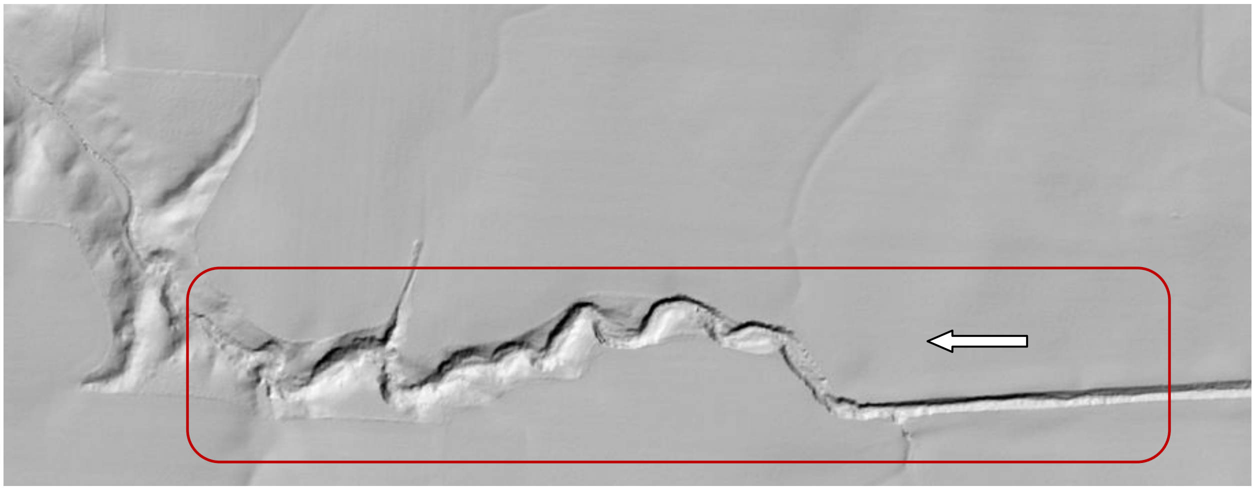


Figure 34. **Lidar relief of the area in Photo 21, A and B. The area in the red box has significantly more bank erosion than the reach upstream and downstream, until the Township Road 18 crossing where the gradient and bank erosion increase again. Arrow is flow direction.**

Photo 22. Evidence of the abundant sediment carried by AUID-540 - a large sediment delta has formed in Lake Traverse at the mouth of Traverse County Ditch 52 (AUID-540).

Connectivity

The biological site was located just above Highway 27, meaning there is only one road crossing separating the site from Lake Traverse. The culvert on Highway 27 includes a very high drop-structure. This serves as a grade-control structure for the reach upstream of the highway, which is helpful in reducing channel incision and bank erosion along the reach upstream, but it also is a complete barrier to fish migration into the reach above Highway 27 (Photo 23). There is also a strongly perched culvert at the upstream end of the biological sampling reach, on Township Road 18 (Photo 24), also preventing movement of fish from the biological reach to upstream habitats. A third perched culvert is found at County Road 66 (Photo 25).

Photo 23. Drop structure on the downstream side of the box culverts at Highway 27 with four vertical drops.

Photo 24. The culvert outlet at the Township Road 18 crossing is elevated by about two feet above the stream water level.

Photo 25. This new culvert on CR-66 is installed with the downstream end perched above the ditch's water level, making it impassable for fish needing to go upstream.

Conclusions

The impaired reach of AUID-540, a portion of TCD-52, is clearly caused by altered hydrology. The watershed area drained by TCD-52 has been enlarged to include land that is in the Mustinka River Watershed. This means that added runoff is sent into TCD-52 (including AUID-540), which exacerbates the already altered hydrology due to drainage within the natural TCD-52 sub-watershed. This excess water from land drainage (in both the BdSRW and Mustinka River Watershed portions) is causing serious channel instability problems. Tall, steep, raw banks are noted along this channel in several areas. The excess sediment from this erosion is damaging stream habitat, and is also doing damage to the water quality and habitat in Lake Traverse.

This AUID also has three fish migration barriers (State Highway 27, Township Road 18, and CR-66). The farthest downstream, Highway 27, is a tall drop structure. It is an absolute barrier to migration, however, it is providing the benefit of grade control (preventing incision) of the channel for some distance upstream of Highway 27, and thus preventing channel erosion in part of TCD-52 from being worse than it already is.

For certain, the existing alterations in hydrology need to be modified to reduce the unnatural peak flows happening in TCD-52, which are leading to serious bank instability and sediment inputs to the channel and downstream resources. Determining how to approach the channel damages that have already occurred will require a detailed geomorphological assessment, especially in the more erosive sections of the TCD-52 (i.e., including areas of TCD-52 upstream AUID-540), followed by consideration of stream restoration options to help stabilize the channel and improve fish habitat. It is recommended that a Rosgen approach to stream channel stabilization be applied, rather than a bank rip-rap approach. A Rosgen approach can be significantly less expensive, more durable, and create better fish habitat. Even with improved habitat, the fish community will be limited by the barriers at road crossings. However, downstream water quality and habitat (and in particular, Lake Traverse) will benefit from reducing erosion in this AUID and upstream sections of TCD-52, even if the barriers remain.

Overall conclusions for the BdSRW

The Stressor Identification process identified several stressors for the five biologically-impaired stream reaches (Table 24). Because of the great predominance of row crop agricultural land use in the BdSRW, and the paucity of urban/residential development, animal agriculture, or point source dischargers, these stressors primarily related to row crop agriculture, and are among those determined to be widespread in the RRB (EOR, 2009), including excess nutrients and sediment, channel alteration, connectivity loss, low dissolved oxygen concentrations, and altered hydrology. The effect of the phosphorus in the discharge of the town of Campbell's wastewater treatment system may be having a significant effect on two of the impaired AUIDs (501 and part of 502), but quantification of those contributions will need to be made in the modelling work associated with the TMDLs being written for those AUIDs, based on discharge volumes and effluent phosphorus concentrations reported by the wastewater treatment operator.

In all cases, at least two stressors are at play, and in all cases, altered hydrology plays a role. 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", with phosphorus additions being the "root" stressor. In order to correct the direct stressor, the root stressor must be corrected. See EOR, Inc. (2014, i.e., the Appendix - especially Section 4. Discussion) for additional information on the effects occurring due to altered hydrology. Many of the problems cited there could be at least partially mitigated by adoption of two-stage ditch construction, which allows for the continuation of water transport, but improves several facets of the stream's heath, especially bank stability. Though EOR, Inc. (2014) stressed the importance of preventing movement of soil off of field surfaces, there are also substantial areas with badly-eroding stream banks.

Road crossing infrastructure is a stressor in this watershed. In a few of the instances, the built structure associated with the culverts causes a barrier, while in other cases, the culverts are perched, and thus a barrier to fish migration, or undersized, leading to significant erosion issues, and thus suspended and bedded sediment problems (see EOR, Inc., 2014, Appendix 1, sec. 3.1 for additional discussion).

Table 24. Summary of stressors causing biological impairment in BdSRW streams by location (AUID).

					Stressor							
Stream	**AUID last 3 digits**	**Reach description**	**Biological impairment**	**Impairment category**	Dissolved oxygen	Phosphorus	Sediment/turbidity	Connectivity	Altered hydrology*	Channel alteration	Pesticides	Habitat
Bois de Sioux River	501	Rabbit River to Otter Tail River	Fish	5	•	··,+	•		··	◊	**?**	•
Rabbit River	502	Wilkin County line to Bois de Sioux River	Fish and MI	5	•	··,+	•		··	•	**?**	•
South Fork Rabbit River	512	Wilkin County line to Rabbit River	Fish	5	•	··,+	•	o	··		**?**	•
Unnamed Trib. to Lake Traverse	535	Unnamed Creek to Lake Traverse	Fish	5				··	··		**?**	
Judicial Ditch 52	540	Unnamed Creek to Unnamed Creek	Fish	5			•	··	··	··	**?**	•

*Includes intermittency and/or geomorphology/physical channel issues

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

◊ Possible contributing root cause.

• Determined to be a direct stressor.

o A stressor, but anthropogenic contribution, if any, not quantified. Includes beaver dams as a natural stressor.

+ Based on river nutrient concentration threshold, but not officially assessed and listed for this parameter.

? Inconclusive - not enough is known to make a conclusion either way. See reports on pesticide monitoring in Minnesota conducted by the MDA.

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Appendix 1. EOR, Inc. memo on geomorphological study of the BdSRW

Bois de Sioux River Watershed

Geomorphic and Hydrologic Influences on TMDL Impairments

Minnesota Pollution Control Agency

EOR water ecology community

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1. INTRODUCTION

Stream biological health is measured by MPCA using fish and macroinvertebrate index of biological integrity scores (IBI). IBI scores are based on a variety of attributes ("metrics") of the biological community, each of which responds in a predictable way to anthropogenic disturbance. Stream morphology is one way to assess anthropogenic disturbances in a watershed, which influence the health of the fish and macroinvertebrate communities. Aspects of stream geomorphology that will be assessed in this report include sediment load, turbidity, bedded sediment, channelization, stream stability, and stream connectivity.

There are many known interactions between geomorphology and fish and invertebrate health. High turbidity can stress filter-feeding invertebrates such as aquatic mussels and caddisflies (Newcombe and MacDonald 1991). Excess bed sediment can reduce the habitat available for invertebrates by burying coarse materials with fine sediment (measured by embeddedness), reducing IBI but also overall invertebrate productivity. Sedimentation reduces the number of sensitive taxa such as mayflies and stoneflies and favor tolerant taxa such as black flies. In the fish community, turbidity reduces the ability of sight predators (*piscivores*) such as smallmouth bass, to obtain food. Fish that feed on invertebrates (*invertivores*) are negatively impacted by reduced invertebrate populations while omnivores such as white suckers may increase in relative abundance. Following droughts or floods invertebrate populations are usually reduced and re-colonization must occur from "refugia" such as hyporheic zones (areas of coarse sand and gravels beneath the streambed with groundwater-surface water exchange), longitudinal drift, or aerial deposition of eggs. Other factors related to geomorphology include the presence or absence of large pieces of wood. Removal of wood for ditch maintenance further reduces colonization sites for aquatic invertebrates reducing overall invertebrate numbers (Seger et al. 2012

Stream health is determined by five major factors: hydrology, geomorphology, connectivity, water quality, and ecology (MN DNR 2014). This report focuses on the role of geomorphology on the health of stream biological communities and ways in which geomorphology can cause biological impairments. However, hydrology, connectivity, water quality, and ecology also impact stream geomorphology. Stream flow directly influences stream geomorphology via sediment transport and deposition, shaping the channel particularly with the frequently occurring floods with one to two year recurrence intervals. Water quality is in turn directly influenced by sediment loading from fields and stream banks which determines the turbidity and suspended sediment levels and plays a strong role in phosphorus loads.

Channelization, or ditching, is likely the most widespread stream geomorphology problem in the Red River basin and has many direct impacts on aquatic biota. The stability of streams is directly altered by ditch maintenance which causes a series of channel adjustments. Streams that are actively adjusting to changes in slope, width or depth (such as recently dredged ditches) tend to contribute more sediment to the local stream environment. Many ditches develop stable, somewhat meandering low-flow channels on the bottom of the ditch trapezoid over many years (Magner et al. 2012). However ditch maintenance effectively sets the clock back on streams achieving equilibrium, putting the stream into a state of active adjustment again. Construction of berms alongside the ditch and bed excavation has also disconnected the stream from its floodplain, greatly reducing lateral connectivity to wetland or floodplain areas. Channelization greatly reduces pool-riffle sequences that are needed by certain fish and invertebrates for different life history functions, with pools providing refuge and riffles providing spawning areas. And, the homogenization of the streambed provides little structure for colonization of invertebrates.

Hydrologic change has occurred throughout the region from evolving land-use, increases in sub-surface drainage, and climate change. All factors have a large influence on the conditions for aquatic life in streams. There have been large increases in stream flow in most western Minnesota streams over the past 20 – 30 years (Lenhart et al. 2011). Sediment carried by high flows in the form of turbidity degrades habitat quality for fish and inverts, and reduces the survival of sight-predatory fish and filter-feeding organisms. Embeddedness, the burial of coarse particles on the streambed, reduces the substrate available for invertebrate colonization and fish nesting, and fine sediment stored on the stream bed may contribute to turbidity during high flows when the sediments are re-mobilized.

Reduced connectivity is also an important factor influencing aquatic biota that may be affected by stream geomorphic variables. Most of the streams in the region are intermittent. Without perennial streamflow, fish need to migrate to refugia and deeper water areas during periods of low flow. There is perennial stream habitat in the Red River, lower tributaries, and Lakes Traverse and Mud which form the headwaters of the Bois de Sioux River. Upper stream reaches on the glacial ridge (the eastern edge of the Rabbit River subwatershed and the far southwestern corner of the Bois de Sioux) can have significant groundwater discharge creating permanent water sources in some stream reaches (Cowdery et al. 2008). However connection between these habitats can limit the viability of aquatic life in the intermittent areas at low flows. Lastly, ditching and drainage of wetlands has hydrologically disconnected them laterally from the stream network reducing refuge areas for fish and invertebrates and spawning areas for some fish such as northern pike (Euliss and Mushet 1999).

2. BACKGROUND

2.1. Site Setting

The Bois de Sioux River serves as the state boundary of Minnesota, northeastern South Dakota and southeastern North Dakota from roughly the City of Wheaton to Breckenridge. The Bois de Sioux River joins the Otter Tail River to form the Red River of the North in Breckenridge, Minnesota. The Red River flowing through the Lake Agassiz glacial lake plain is very flat within the former lake bed although it is flanked by steeper glacial till and moraine areas. The headwaters of the Bois de Sioux River originate in Lake Traverse and then flow into Mud Lake. These lakes both have impoundments which are managed for the water supply of several downstream cities. Downstream of Mud Lake, the Rabbit River contributes another 300 square miles of land that is extensively drained by ditches and tiles. The North Ottawa Impoundment, located on JD2 and JD12 was created for flood control, treating about 25% of the Rabbit River watershed with 4 square miles of area. The project should also provide significant water quality benefits for the basin.

2.2. Hydrologic setting

The Bois de Sioux River Watershed lies on the southern end of the Lake Agassiz Plain and on the eastern edge of the prairie biome. It borders on a semi-arid climate, with precipitation between 16-24 inches per year over the last century (UM - Soil Climate Water 2008), and about 24-26 inches over the past 30 years. Mean annual runoff has been estimated at about two inches over most of the Red River Valley, with a range of one to four inches within the basin (Lorenz et al. 1997). Annual potential evapotranspiration is in excess of precipitation by four to six inches, resulting in a water deficit in terms of soil moisture for most of the year (Hart and Ziegler 2008).

Most streamflow occurs between April and July from snow-melt runoff when saturated soil conditions exist and following increasing rainfall amounts. Streamflow is highly variable compared to streams in eastern Minnesota with a very high peak in April to May followed by low flow for about eight months of the year (Lenhart et al. 2011). Therefore most streams have intermittent streamflow. In the Bois de Sioux Watershed hydrologic unit (09020101) there are 116.9 miles of perennial streams, 549.1 miles of intermittent streams, and 138.3 miles of "canals" or ditches based on coarse scale GIS data (Figure 1) (ESG, 2014). The Bois de Sioux Watershed lists over 400 miles of public ditches in the watershed, which includes some of the natural intermittent and perennial streams (Bois de Sioux Watershed District 2011).

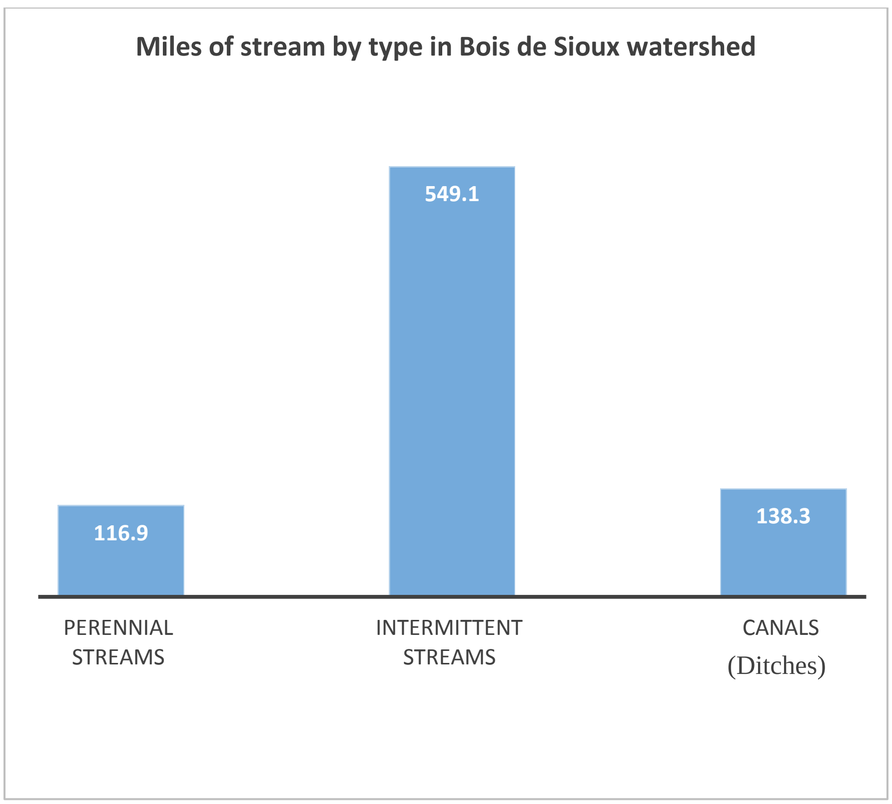

Figure 1. Miles of perennial, intermittent and ditched streams in Bois de Sioux Watershed. Data obtained from Environmental Statistics Group website (2014). The Bois de Sioux Watershed District lists 138 miles of ditches (here labeled as canals) in the Bois de Sioux Watershed.

2.3. Description of Channel Types and Existing Conditions

The vast majority of the stream network is either ditched natural streams or created channels for surface water drainage, particularly in the Rabbit River and Doran slough subwatersheds. There are some "natural" stream miles on the main Bois de Sioux channel. Channelized streams are usually very entrenched limiting their floodplain connectivity and function due to berm placement on the side of the ditches and channel down-cutting caused by dredging and/or natural channel adjustment. Many of the streams prior to European settlement were broad grassy wetland swales that were well-connected to their floodplain (EOR 2009).

Most of the streams are characterized by low-gradient and fine-textured (silt or clay) streambed. The steepest parts of the Bois de Sioux Watershed are in the far eastern and southwestern parts of the watershed. Despite the steep terrain in those areas, the Rabbit River TMDL study (MPCA 2010) predicted that the greatest rates of channel erosion and sediment loading were from the lower Rabbit River and the middle to lower Bois de Sioux River based on a SWAT model (EERC 2008). Much of the lower Bois de Sioux River was channelized in the 1900s so that the stream could still be adjusting and contributing sediment from lateral migration and subsequent bank erosion. Other streams in the region have been shown to have undergone substantial channel change due to channelization projects in the early to mid-1900s. For example Bill Christner found in a study of channel evolution in the Laq qui Parle River that stream cross sections in the upper and middle parts of the watershed increased in area by 14-30% between 1966 and 2003 (Christner 2009). This was thought to be caused by increased tile drainage, land-cover change (decreasing pasture for row crops) and rainfall.

In the Rosgen stream classification system most remaining natural streams in the watershed are classified as types E or C. E types are narrow streams relative to their depth that are highly sinuous with well-vegetated stream banks, while C types are slightly wider and shallower.

Many existing streams, especially in the headwaters, were either swales or wetlands with more gradual sheet flow before channelization created larger, entrenched channels. These streams are completely contained within the large ditch berms and rarely overtop the side berms. In many cases the stream network was expanded by creating a network of ditches where concentrated flow in channels did not exist naturally prior to the 1900s.

2.4. Relationship between Geomorphology, Hydrology, Sediment Transport and Biotic Impairments

Channelization, hydrologic alteration, and intermittent flow are some of the primary physical stressors in ditched agricultural watersheds. An objective of this study was to understand how these stressors influence fish and invertebrate populations and Index of Biotic Integrity (IBI) scores in Bois de Sioux River Watershed. There currently are a mix of aquatic life use impairments due to fish and macroinvertebrate IBI scores, turbidity and DO.

Overall the most likely geomorphic stressors on aquatic life in the region include:

- Over the long-term, land-cover change and channelization have led to increased sediment loading and reduced quality and quantity of in-stream habitat for invertebrates and fish
- Turbidity in streams is increased by sediment from field and gully erosion in farmland

- Ditched streams tend to be fairly stable in terms of lateral erosion but are often aggrading (filling with sediment) because of low in-stream shear forces, over-widening and intermittent flow that are common in Red River basin channelized streams and ditches
- Sediment from wind and water-driven field erosion filling in channels

2.5. Methods

Field geomorphic surveys, the Minnesota Agricultural Ditch Reach Assessment for Stability (MADRAS), and Minnesota Stream Health Assessment (MSHA) indices were completed in October 2013 at 14 sites (Figure 2). Geomorphic surveys were completed using the Rosgen methodology at 14 sites. Data was collected for stream cross section, longitudinal profile, bed materials (median diameter particle size or D_{50}) and planform geometry. From the survey data other hydraulic and streamflow metrics were calculated including velocity, discharge and bankfull shear force.

Measurements of the Bank Erosion Hazard Index (BEHI) and the Near Bank Shear Stress (NBS) were taken by the Minnesota DNR and EOR, Inc. in eight stream reaches providing estimates of potential bank erosion rates in those areas. In each stream reach, BEHI was estimated at 3-16 stream bank locations.

The Indicators of Hydrologic Alteration (IHA) software program was used to assess the Bois de Sioux River at White Rock, South Dakota (USGS gauge 05050000 located approximately 9 river miles north of Wheaton) - the stream gauge with the longest record in the watershed. IHA assessment calculates various metrics of streamflow change over a selected time period (Richter et al. 1996, Lenhart et al. 2010 and 2011).

Data on the relationships between the geomorphic and hydrologic metrics and biotic impairments are presented in the results and examined in more detail in the discussion section.

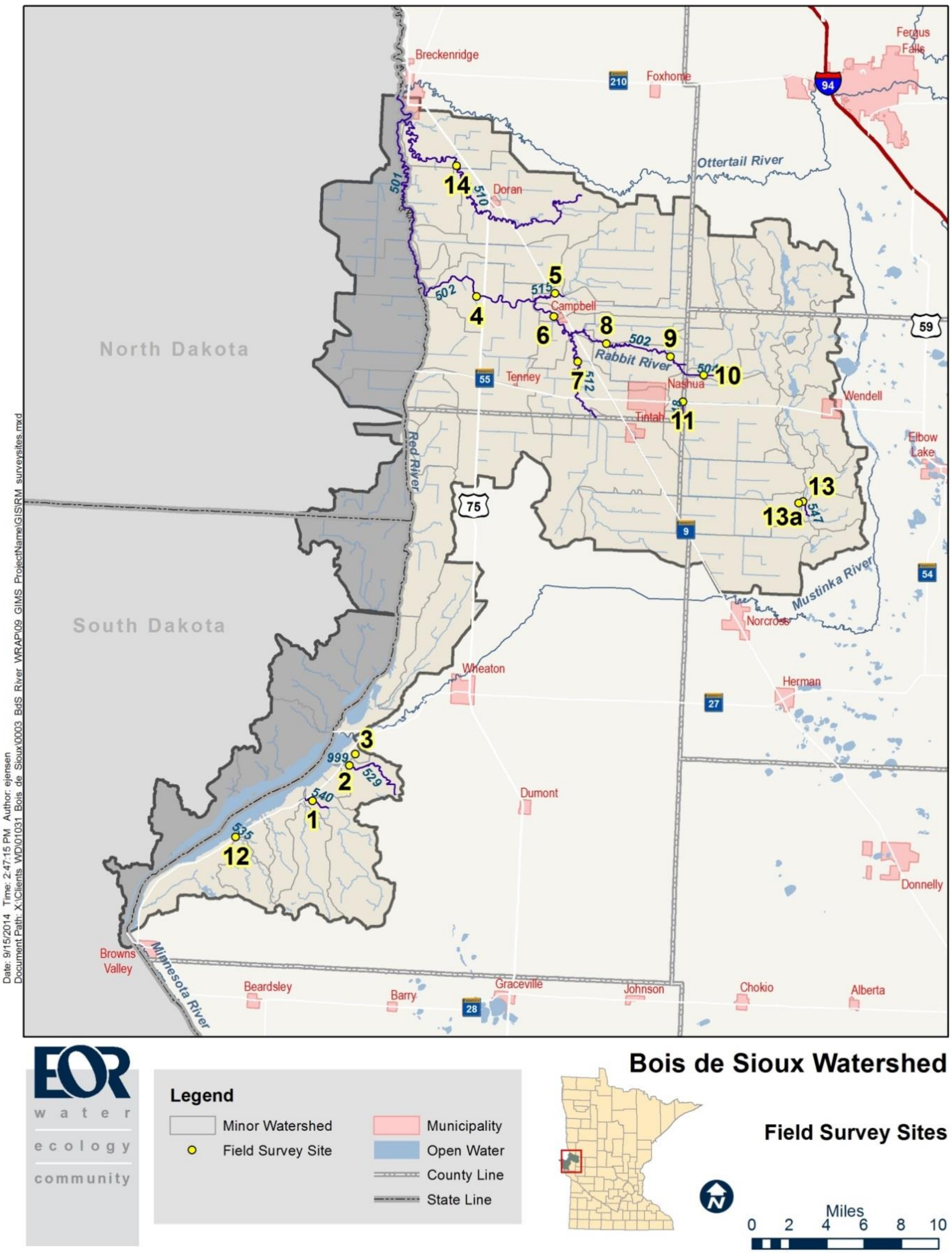

Figure 2. Geomorphic survey and stream index data collection locations.
Data was collected for MSHA and MADRAS indices and for Rosgen geomorphic assessment in August and September, 2013.

3. RESULTS

There has been significant hydrologic change since European settlement within the Red River basin as a result of land cover, drainage and climate changes. The land-use is currently about 90% agricultural and has undergone substantial drainage. Water that was once stored in wetlands and wet prairies is now drained more quickly to surface ditches or subsurface drainage pipes. Rainfall has also increased within the region likely contributing to greater streamflow as well (MPCA 2013). Streamflow which is highly concentrated in the spring months of April-June (Figure 3) has increased substantially.

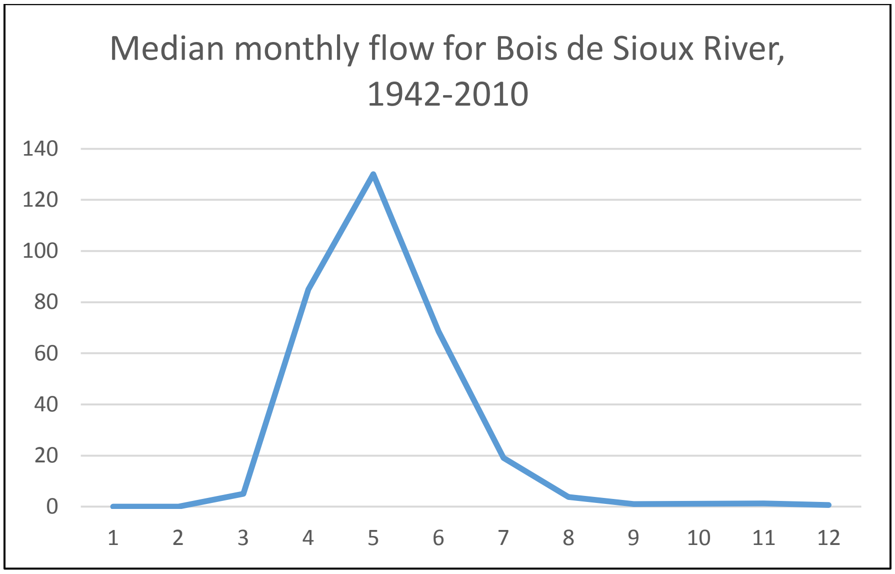

Figure 3. Seasonal variation in streamflow for the Bois de Sioux River at White Rock, SD. Streamflow data shown is median monthly flow in cubic feet/second (cfs) at (USGS gauge 05050000.

The total annual volume of stream flow has increased at the Bois de Sioux River gauge at White Rock, South Dakota as indicated by increasing median annual stream flow values since the 1990s (Figure 4). The median annual stream flow in the past three decades is about 3-5 times that measured between the 1940s and the 1980s.

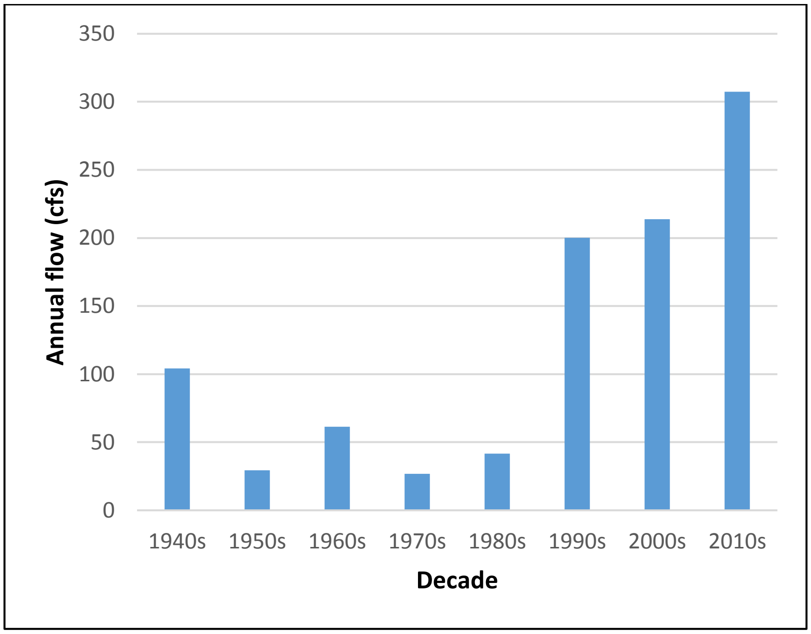

Figure 4. Median annual flow by decade at the Bois de Sioux stream gauge.
Data was obtained from IHA analysis. The 1940s period included 1942-1949, while the 2010s included years 2010-2013.

The duration of high flows (less than bankfull level but greater than mean annual flow) have increased during the 1980-2010 time period relative to the 1942-1979 time period (Figure 5). The 1-day, 3-day and 7-day maximum stream flow all increased significantly ($p<0.1$). There were also less days with zero flow, with the pre-1980 period averaging 98 days per year of zero flow, while the post-1980 period averaged no zero flow days. Likely causes may be tiling, watershed impoundments and/or changes in precipitation. The timing of stream flow has changed since the 1942-1979 time period as well. High flows have occurred increasingly early as evident in Figure 4, which shows an increase in the median March flow from 0.7 cfs in the pre-1980 time period to 83 cfs in the post-1980 time period.

While flow volumes have increased at all stages, the changes to high flows and flood peaks have been less pronounced. High flows (defined in the IHA program as approximately a 75% flow, or in between the mean annual flow and the small flood (2 year) level), increased from 39 to 119 cfs and the duration increased from 4 to 10 days. Small and large flood peaks have not increased during the post- 1980 period at the Bois de Sioux stream gauge relative to the 1942-1979 time period.

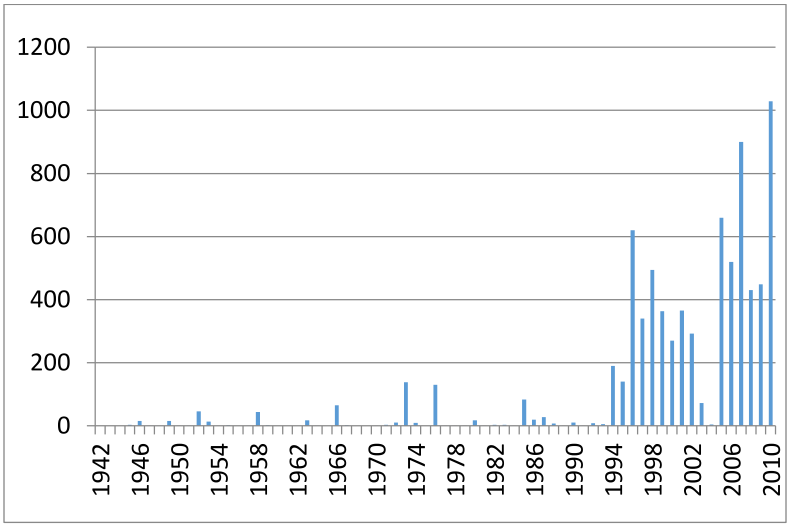

Figure 5. Mean monthly flow for March at the Bois de Sioux River stream gauge. The 1940s period included 1942-1949, while the 2010s included years 2010-2013. March stream flow has been much higher since the 1990s.

3.1. Stream Health and Stability Indices

The Minnesota Stream Health Assessment (MSHA) scores (Table 2) showed widespread low stream health with an average score of 37 out of 100 for sites surveyed (Figure 6). There were 88% streams ranked poor, 12% fair and 0% rated as good. The substrate, cover and channel morphology sub-categories rated lowest. Substrate and channel morphology are typically very low in channelized stream networks as the shape and bed materials are altered by ditch maintenance. The riparian health score was highest, averaging eight out of a possible score of fifteen, indicating that many of the stream reaches had good vegetation cover.

The MADRAS index, which measures geomorphic stability of man-made ditches and channelized natural streams, provided additional information on potential causes of biological impairment related to geomorphology. MADRAS scores in the Bois de Sioux watershed averaged 25 on a scale of 0-60 indicating that the channels were fairly stable, with low MADRAS scores indicating greater geomorphic stability (green = stable, yellow = moderately stable and red = unstable in Figure 7). The biggest problem category was road crossings with a median score of eight, indicating potential stability problems from culvert / road alignment or design. Sediment deposition scores were moderate to high indicating that there were high rates of aggradation in many ditched streams. Bank erosion was low with median scores of two (of eight possible) on the left and right bank.

Table 1. Minnesota Stream Health Assessment (MSHA) scores for Bois de Sioux River Watershed.

		Category (score range)						Rating
SITE 09020101- (-AUID)	**Location/ watershed**	**Surrounding Land use** (0-5)	**Riparian** (0-15)	**Substrate** (0-27)	**Cover** (0-17)	**Channel morphology** (0-36)	**Total** (0-100)	
Site 1 -540	County Ditch 52	5	7	20	17	13	62	Fair
Site 2 -529	Un-named	5	10	10.5	8	21	54.5	Fair
Site 3 Lower -999	Un-named	2	9	2	0	3	16	poor
Site 3 Upper -999	Un-named	2	10	3	3	13	31	poor
Site 4 -502	Rabbit River	5	6	7	2	15	35	poor
Site 5 -515	Trib. To Rabbit River	0	6	7	12	9	34	poor
Site 6 upper -502	Rabbit River	0	12.5	9	2	13	36.5	poor
Site 6 -502	Rabbit River	0	11	20	4	19	54	fair
Site 8 -502	Rabbit River	0	8.5	8	12	13	41.5	poor
Site 9 lower -502	Rabbit River	0	4	6.2	2	17	29.2	poor
Site 9 upper -502	Rabbit River	0	7	3.35	2	19	31.35	poor
Site 10 -504	Un-named	0	5	2	1	5	13	poor
Site 11 -548	JD 2	0	6	3	11	17	37	poor
Site 12 -535	Un-named	5	7.5	13	6	13	44.5	poor
Site 13 -547	Un-named - East	3	9	2	11	13	38	poor
Site 13A -520	Un-named - West	0	9	6.75	12	6	33.75	poor
Site 14 -510	Un-named	0	11	8	3	17	39	poor
	Average	**2**	**8**	**8**	**6**	**13**	37	
	Median	**0**	**9**	**7**	**4**	**13**	37	

MSHA Qualitative habitat ratings:

Good: MSHA score above the median of the least-disturbed sites (MSHA>66)

Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)

Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

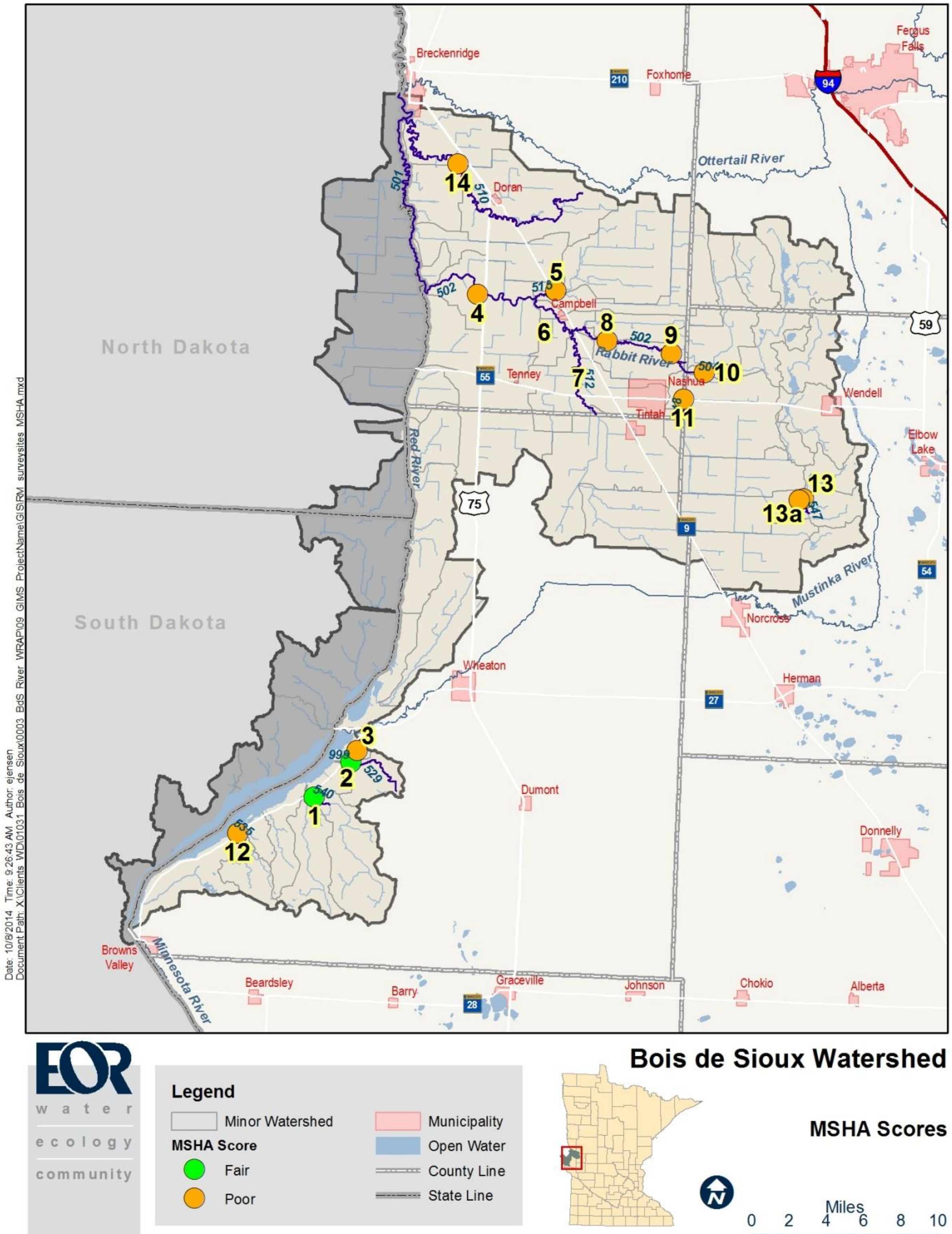

Figure 6. MSHA scores at each field survey site.

Table 2. MADRAS scores for ditches in the Bois de Sioux Watershed.

	Left Bank (0-8)	Right Bank (0-8)	Bed Deposition (0-12)	Channel Slope (0-8)	Bank Angle (0-8)	Scour (0-8)	Crossing (0-8)	Score (0-60)
Site 1 -540	8	8	6	1	6	2	4	35
Site 2 -529	2	2	6	1	1	2	8	22
Site 3 -999	1	1	1	4	8	2	1	18
Site 5 -515	2	2	6	1	1	2	8	22
Site 8 -502	4	2	12	8	2	1	8	37
Site 9 -502	2	2	12	4	2	2	8	32
Site 10 -504	2	2	2	1	1	1	4	13
Site 11 -548	2	1	6	8	2	1	8	28
Site 12 -535	8	8	6	2	6	6	8	44
Site 13 -547	1	1	1	4	1	1	8	17
Site 13A -520	2	2	2	4	2	2	8	22
Site 14 -510	2	2	6	2	1	1	1	15
Average	**3.0**	**2.8**	**5.5**	**3.3**	**2.8**	**1.9**	**6.2**	**25.4**
Median	**2.0**	**2.0**	**6.0**	**3.0**	**2.0**	**2.0**	**8.0**	**22.0**

*Low MADRAS scores indicate greater geomorphic stability.

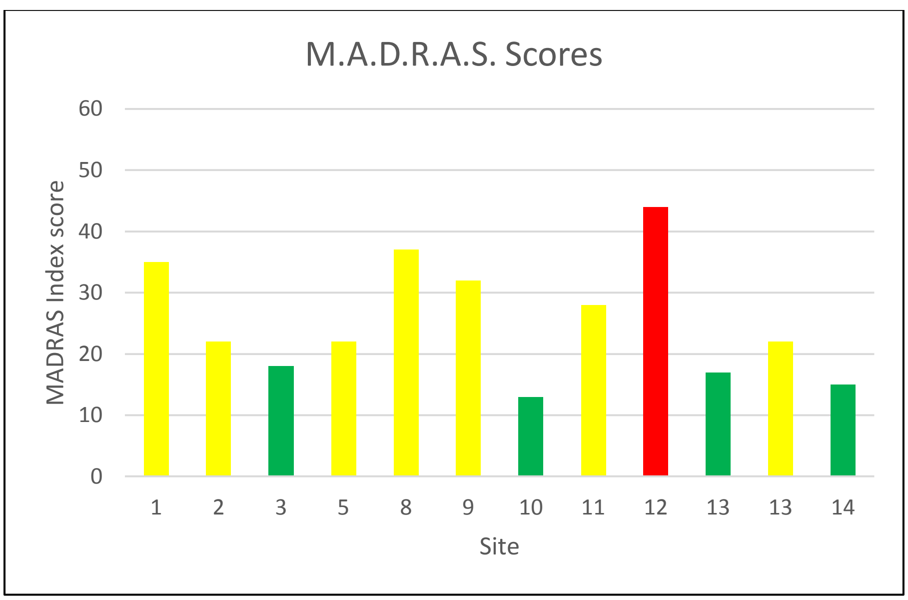

Figure 7. MADRAS scores for stability of channelized streams and ditches.
Green is stable (index value <20), yellow is fairly stable (index value 20-40) and red is unstable index value >40.

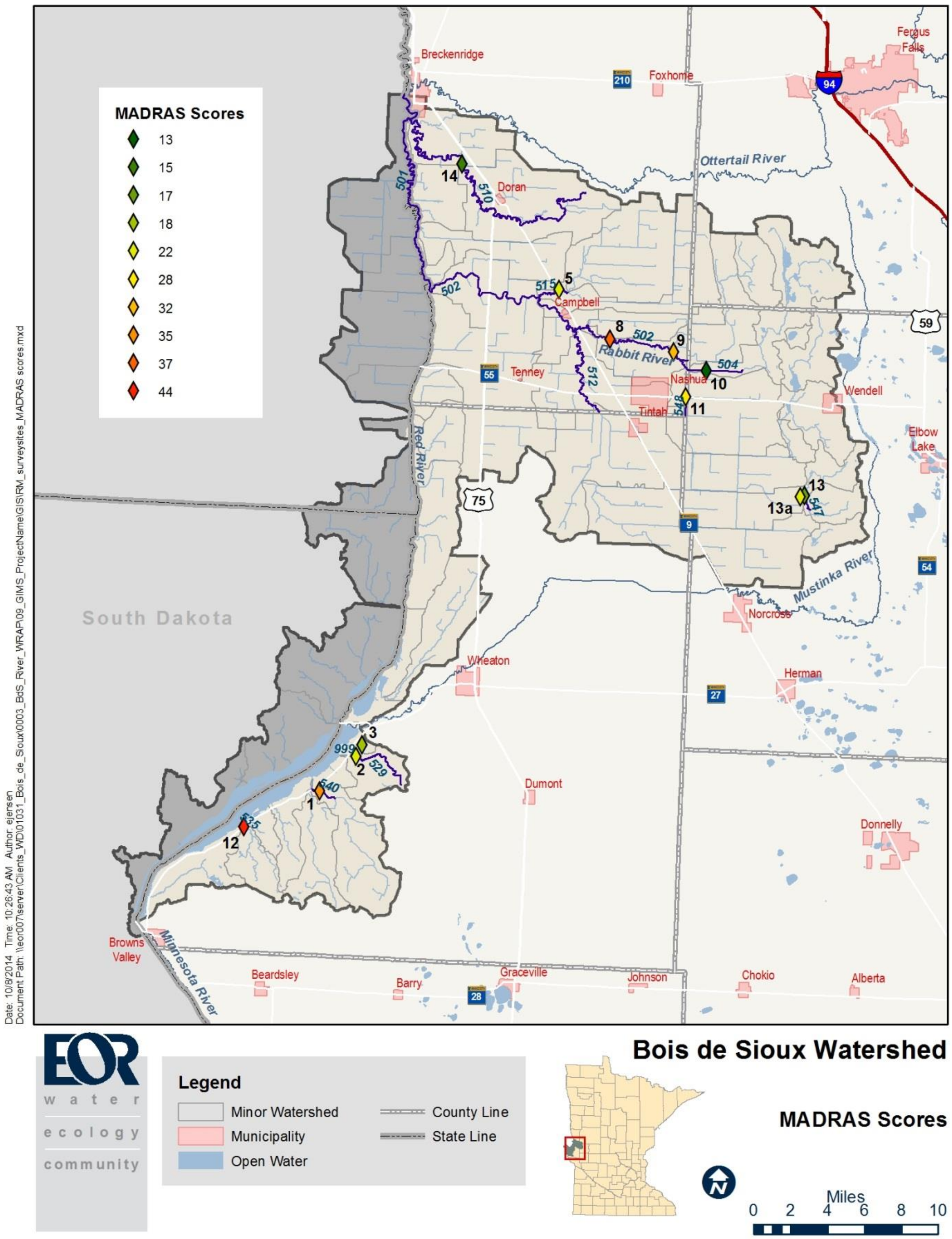

Figure 8. MADRAS scores at each field survey site.

Table 3. Rosgen stream assessment data.

Stream name and 09020101- (-AUID)	Site #	Rosgen type	Entrench-ment Ratio	Width: Depth Ratio	Bed Traits (D_{50})	Bankfull Discharge (cfs)	Bankfull Shear Stress (lbs/ft^2)	Sinuosity (stream length/ valley length)
County Ditch 52 -540	1	E4	2.2	5.2	Gravel	158	.50	1.1
Un-named -529	2	E4	4.3	17.5	Gravel	74	.34	2.1
Un-named -999	3	E6 & swale	1.7	44	Silt/clay	227	.47	1.2
Rabbit River -502	4	C6c-	1.4	18.2	Silt/clay	1771	.003	2.2
Trib. to Rabbit -515	5	C6c-	>2.2	92	Silt/clay	584	.02	1.6
Rabbit River -502	6	C5c-	>2.2	27	Sand	2970	.20	1.2
Rabbit River -502	8	E5	>2.2	8	Sand	467	.19	1.5
Rabbit River -502	9	E5	5.2	8.2	Sand	158	.09	1.1
Un-named -504	10	Ditch	>2.2	9.6	Sand	564	.60	1.1
JD-2 -548	11	Ditch	? >2.2	9.5	Silt/clay	995	.09	1.0
Un-named -535	12	C4	2.4	11.2	Gravel	294	.53	1.4
Un-named - east -547	13	ditch	>2.2?	22.9	Silt/clay	834	.15	1.0
Un-named -west -520	13A	Ditch	>2.2	14.9	sand	277	.07	1.0
Un-named -510	14	C6c-	1.9	170	Silt/clay	163	.002	1.7

- Entrenchment ratio is classified as > 2.2 = low; 1.4-2.2 = moderate; < 1.4 = entrenched
- Bankfull discharge was estimated by estimates of the bankfull channel dimensions in the field along with velocity calculations based on Manning's equation
- Bankfull shear stress was calculated using the equation

3.1.1. Rosgen Stream Classification

Stream types were mostly ditches while natural stream types were primarily E5-E6 or C5c- to C6c-. Bed type was mostly in the silt/clay or sand size range for the median particle size (D_{50}) although three sites had a D_{50} of gravel. Entrenchment scores were mostly >2.2 meaning that most of the ditches and streams were not very entrenched based on this metric which is the floodplain width divided by the bankfull width. The landscape is flat and the streams are very low-energy (low shear stress) limiting the potential for channel incision.

Sinuosity was low across the all sites with many having 1.0 – 1.1 in "ditches". (A sinuosity of 1.0 is straight line). Sinuosity was low to moderate in many natural streams at 1.2-1.5 and high at two sites In-stream hydraulics were indicative of a low energy ditch system where the channel has insufficient flow energy to transport all the sediment. The bankfull shear stress was low in most streams ranging from 0.003 to 0.60 lbs/ft^2, creating an environment that promotes sediment aggradation.

In terms of data from the longitudinal stream profile the number of pools and depth variability was both very low, typical of low-energy ditch systems that are periodically dredged. Many of the sites had zero or one pool that were at least a foot deep over the stream reach surveyed, typically 500-1500 feet, indicating a lack of deep water areas need by fish for critical refuge and feeding functions.

3.1.2. Sediment Sources in Streams

Overall estimates of streambank erosion potential from the BEHI index indicated that 75% of the sites assessed had moderate or low scores. Only 6% of stream sites assessed were very high and 13% had high BEHI scores. In terms of lateral bank erosion rates, when combined with Near Bank Stress (NBS) to obtain an annual erosion prediction, the values ranged from 0.1 to 0.76 ft/year. Many of the small ditches were stable with low BEHI scores, which were also indicated by the MADRAS index scores. Within MADRAS, the average scores for left and right bank erosion, scour and bank angle were all low, averaging 2 of 8 possible points. The BEHI and MADRAS data suggest that channel loading of sediment is likely of less importance than field erosion as a sediment source in the watershed. Past sediment source studies have also shown field erosion to be the dominant source of sediment in small streams of this region (EOR 2009 and Lauer et al. 2006).

3.1.3. Summary of Additional Data Collected

Additional data were collected in the field that made a visual estimation of the distance between the stream survey point and a wind-blocking stand of trees. This estimate was made in all directions at each survey point and could guide future restoration projects that prevent wind-blown sediment from entering the stream and ditch channels.

Data were collected at most sites estimating the width of the buffer to the stream, the cropping taking place adjacent to the channels and an estimate of crop residue left in the areas that were under agricultural production. These data could be useful in future projects relating to landuse BMP’s on the lands adjacent to the channels.

In-channel habitat observations were made noting if barriers for biotic movement existed at the sites, and the density and make-up of the aquatic vegetation communities. These observations can become useful in future project planning relating to improvements in the connectivity of the stream systems and the vegetation improvements for wildlife.

4. DISCUSSION

4.1. Connecting Geomorphic Variables to Biotic Impairments in the Bois de Sioux Watershed

Sediment issues that contribute to biotic impairment include excess fine sediment which buries existing coarse bed substrates and increases turbidity. This is particularly harmful to the lithophilic spawner group of fishes. Lithophilic spawners are those that require relatively fine, sediment-free course substrate to support species reproduction. Turbidity is problematic in many reaches of the watershed and detrimental to aquatic life in a variety of ways.

The most widespread impact on channel stability and stream health in the watershed is likely ditch maintenance. By over-widening the area within the ditch, many of them function as sinks for sediment until they are dredged again (Landwehr and Rhoads 2003), keeping them in a constant state of disequilibrium. Many of the channelized streams in the area have evolved to a more stable E-type channel (meandering, narrow and deep) with stable floodplain benches within the larger ditch trapezoid over many years since ditch dredging. The removal of sediment also causes a localized increase in slope between the field and the ditch, re-instigating local headcutting of field gullies entering the ditch.

Connectivity between the lower Bois de Sioux River and the headwaters of the Rabbit River is likely poor due to intermittent flow preventing access in late summer to fall, reducing fish and invertebrate access to “refugia” during periods of low flow. This might make it more difficult for fish and invertebrates to survive due to the lack of flow and poor stream bed conditions (i.e. lack of water and coarse bed materials) (Miller and Golladay 1996). The ditches were also found to have little vegetative cover and structure within the stream to support fish habitat.

Lack of lateral connectivity to wetlands that have since been mostly drained may also be a contributing stressor for aquatic life. Wetlands would have provided habitat next to streams for invertebrates to access. Some fish that are tolerant of shallower, warmer water, such as northern pike, utilize wetlands for spawning as well. Conversion of wetlands that were well-connected by highly meandering streams were well-connected to their floodplains, with a low width-to-depth ratio (known as Rosgen Type E channels) to over-widened ditches leads to shallower and warmer flow. The current channel geometry and connectivity contributes to low dissolved oxygen (DO) and impairment in headwaters reaches from the Headwaters to County Ditch 2. Low DO is a consequence of biological oxygen demand (BOD) which is worsened in over-widened ditches with shallow, warm water.

Another factor that could be contributing to low invertebrate IBI scores is vertical connection to groundwater-fed hyporheic zones, or lack thereof. A hyporheic zone that stays wet in the summer with good interstitial space (i.e., gravelly, coarse bed materials) would provide habitat for invertebrates to burrow into at low flow. Yet a very small percentage of the Bois de Sioux Watershed has type A or A/D (sandy) soils that would typically have coarse substrates in the headwaters regions. The predominance of fine-textured glacial till and lakebed soils limits groundwater interactions within the hyporheic zone. This limits the availability of areas where invertebrates can burrow deeper into the stream bed to survive droughts.

4.2. Management Implications

Geomorphic and hydrologic management could improve conditions for fish and aquatic life in the Bois de Sioux River Watershed. With intermittent flow, a greater abundance of deep pools and variable stream depths in otherwise homogenous ditches would be beneficial to biota. Sediment sources to streams are thought to come mostly from fields in flat watersheds of the Red River basin with low streambank heights (Lauer et al. 2006). Much of the field erosion likely occurs in gullied areas during high flows. Therefore control of field and gully erosion, both water and wind-driven, are important for stream health in this region. Data were collected in the field that made a visual estimation of the distance between the stream survey point and a wind-blocking stand of trees. This estimate was made in all directions and could guide future restoration projects that prevent wind-blown sediment from entering the stream and ditch channels.

Interrelationships between water quality and geomorphology suggest that stream geometry could be managed to promote lower water temperatures and higher dissolved oxygen levels. This could be done by allowing channelized streams to form a more natural meandering stream that is narrow but deep (described as an E type channel in the Rosgen system) within the larger ditch trapezoid or constructing 2-stage ditches.

Connectivity could be improved both longitudinally and laterally. Laterally, two-stage ditches, either constructed or self-forming, allow for re-establishment of floodplain function in this intensively drained landscape (Powell et al. 2007). Longitudinally, fish blockages at dams and culverts could be modified to allow for aquatic life passage. Finally the reintroduction of large wood pieces such as root wads or engineered logjams could help improve invertebrate productivity by creating more surfaces for colonization and a variety of stream depths and velocities that are also beneficial to fish (Dolph 2012).

There are many research and information gaps that need to be filled in order to better focus management on improving stream health in the western Minnesota and the Red River basin region. Hydrologic, geomorphic and water quality inter-relations in channelized stream systems of western Minnesota are still poorly understood. Specifically, it would be helpful to understand how alternative ditch management practices could improve IBI and turbidity impairments and where those practices could be better targeted. Also the predominance of intermittent streams in the region calls for a better understanding of the drivers of biotic impairments in this type of environment which is by nature, stressful to aquatic life.

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6. APPENDIX A: STREAM SUMMARIES

The following section is a summary of the geomorphic assessment of the Rabbit and Bois de Sioux watersheds and their tributaries completed as part of this project. Figure 9 illustrates the location and identification of the survey sites. The following tables provide a summary for each site assessed.

Point of clarification: geomorphic data and analyses contain herein should be reviewed with an understanding of the unique morphology of Red River Valley streams and land use. These results are often a complex derivative of ditch morphology and the frequency and scale of Red River Valley flooding.

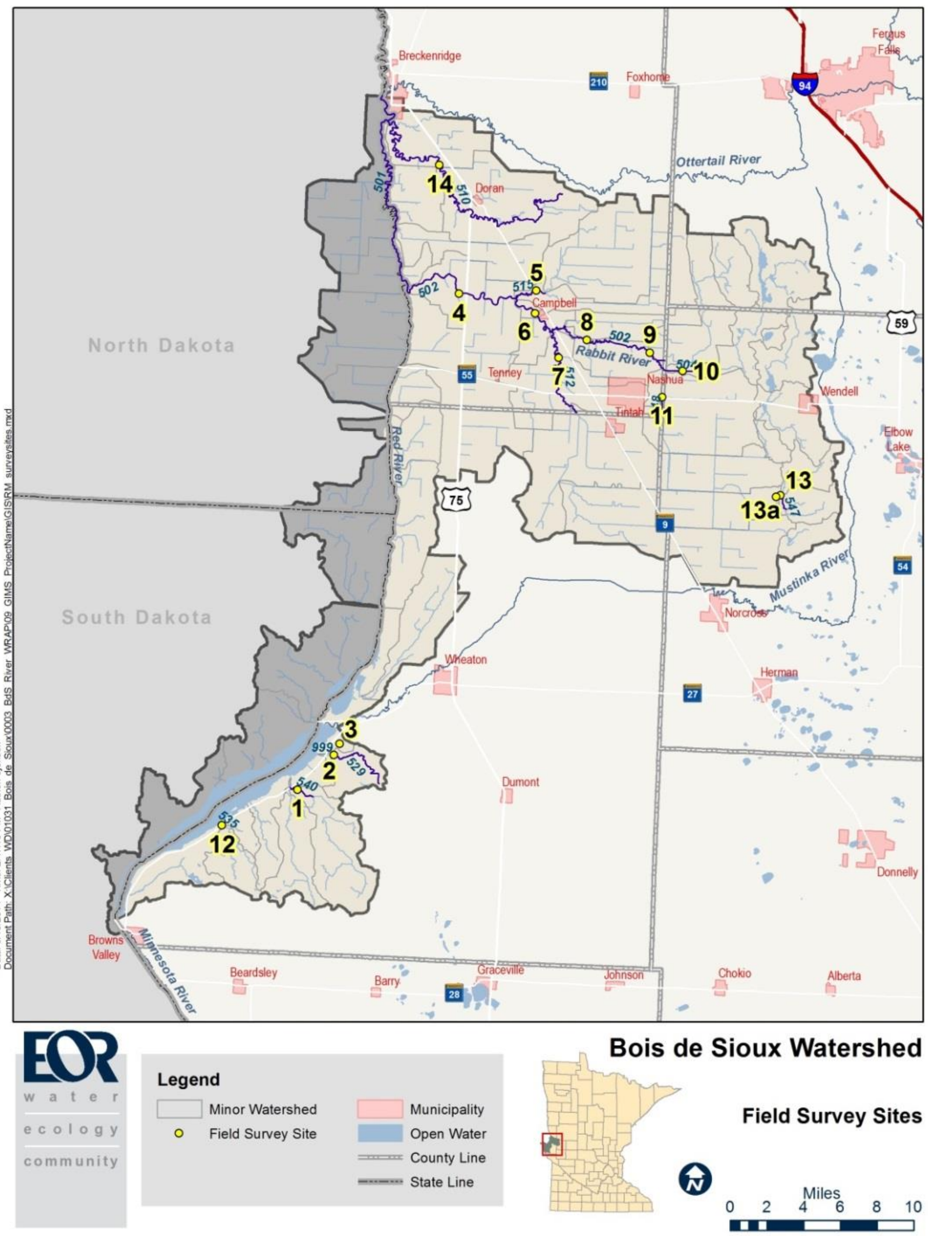


Figure 9. Location and identification of stream geomorphic assessment sites.

REACH INFORMATION	
AUID	09020101-540
Stream/River	CD52
County	Traverse
Drainage Area	17.1 sq. mi.
Date	10/22/13
Field/Site ID	1
Bio Monitoring	10RD019
MSHA Score	62

GEOMORPHIC SUMMARY	
Channel Type	E4
Est. Bankfull El.	1039.2’
Channel Slope	0.53%
Sinuosity	1.1
Bankfull Width	10.7’
W/D Ratio	5.2
Material (D50)	5.4 mm
BEHI Rating	Low/Moderate
NBS Rating	Low
MADRAS Score	35

NOTES & OBSERVATIONS

Due to channel incision, most flow events are contained within the stream banks, resulting in very low width to depth ratios. Two small headcuts were observed within the channel, but overall instream erosion was minimal. Separate BEHI analyses were completed for two eroded banks measuring 60-feet long and 32-feet long and scored Very High and High respectively. Field observations include; good buffers on both sides of the channel, CRP was evident on adjacent ag lands, low distances of wind fetch, barrier to biotic movement observed, and light grassy type aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-529
Stream/River	Unnamed
County	Traverse
Drainage Area	5.8 sq. mi.
Date	10/21/13
Field/Site ID	2
Bio Monitoring	No
MSHA Score	54.5

GEOMORPHIC SUMMARY	
Channel Type	E4
Est. Bankfull El.	1005.2’
Channel Slope	0.61%
Sinuosity	2.1
Bankfull Width	14.0’
W/D Ratio	14.5
Material (D50)	6.1 mm
BEHI Rating	Low
NBS Rating	Low
MADRAS Score	22

NOTES & OBSERVATIONS

A significant change in channel geomorphology occurs immediately below the fence at the downstream end of the segment. The stream enters a cattle pasture where riparian vegetation is heavily grazed and stream bank erosion is high. Field observations include; good buffers on both sides of the channel, hay ground seemed to be the cropping taking place on adjacent ag lands, moderate distances of wind fetch, barrier to biotic movement observed, and light grassy type aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-999
Stream/River	Unnamed
County	Traverse
Drainage Area	0.4 sq. mi.
Date	10/21/13
Field/Site ID	3
Bio Monitoring	No
MSHA Score	23.5

GEOMORPHIC SUMMARY	
Channel Type	E6 to grass swale
Est. Bankfull El.	1021.1'
Channel Slope	0.95%
Sinuosity	1.2
Bankfull Width	8.5' (E6)
W/D Ratio	5.4 (E6)
Material (D50)	Silt
BEHI Rating	Low/Very Low
NBS Rating	Low
MADRAS Score	18

NOTES & OBSERVATIONS

This stream transitions from an E6 channel at the upstream end of the reach to a wide, grassy swale at the downstream end. A large stock pond exists immediately downstream of the study reach and has caused an aggregation of sediments in the stream. Field observations outside of the pasture area include; poor buffers on both sides of the channel, soybeans with little crop residue was evident on adjacent ag lands, moderate distances of wind fetch, barrier to biotic movement observed, and dense grassy type aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-502
Stream/River	Rabbit River
County	Wilkin
Drainage Area	304.0 sq. mi.
Date	10/22/13
Field/Site ID	4
Bio Monitoring	05RD005
MSHA Score	35

GEOMORPHIC SUMMARY	
Channel Type	C6c-
Est. Bankfull El.	971.0’
Channel Slope	0.0005%
Sinuosity	2.2
Bankfull Width	202.6’
W/D Ratio	24.2
Material (D50)	Silt
BEHI Rating	Moderate/High
NBS Rating	Moderate
MADRAS Score	None

NOTES & OBSERVATIONS

This very low gradient river contains a substrate dominated by silt and clay particles. Very little instream habitat exists and no defined riffles or pools were observed.

REACH INFORMATION	
AUID	09020101-515
Stream/River	Trib to Rabbit R
County	Wilkin
Drainage Area	43.2 sq. mi.
Date	10/22/13
Field/Site ID	5
Bio Monitoring	No
MSHA Score	34

GEOMORPHIC SUMMARY	
Channel Type	C6c-
Est. Bankfull El.	974.7’
Channel Slope	0.018%
Sinuosity	1.6
Bankfull Width	146.7’
W/D Ratio	91.8
Material (D50)	Silt
BEHI Rating	Moderate
NBS Rating	High
MADRAS Score	22

NOTES & OBSERVATIONS

An abandoned road crossing was found within the stream reach and is functioning like a large riffle. Slight aggregation was observed at the historical cross section when compared to the 2013 survey data. Field observations include: poor buffers on both sides of the channel, corn with low crop residue was evident on adjacent ag lands, high distances of wind fetch, barriers to biotic movement were not observed, and extensive tall emergent type of aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-502
Stream/River	Rabbit River
County	Wilkin
Drainage Area	251.9 sq. mi.
Date	10/22/18
Field/Site ID	6
Bio Monitoring	No
MSHA Score	45.25

GEOMORPHIC SUMMARY	
Channel Type	C5c-
Est. Bankfull El.	974.0’
Channel Slope	0.058%
Sinuosity	1.2
Bankfull Width	123.0’
W/D Ratio	17.9
Material (D50)	18.0 mm
BEHI Rating	Moderate
NBS Rating	High
MADRAS Score	None

NOTES & OBSERVATIONS

This very low gradient river contains a substrate dominated by silt and clay particles. Very little instream habitat exists and no defined riffles or pools were observed.

REACH INFORMATION	
AUID	09020101-512
Stream/River	S. Fork Rabbit R
County	Wilkin
Drainage Area	56.9 sq. mi.
Date	10/22/13
Field/Site ID	7
Bio Monitoring	10RD012
MSHA Score	None

GEOMORPHIC SUMMARY	
Est. Bankfull El.	N/A
Channel Slope	N/A
Sinuosity	N/A
Bankfull Width	N/A
W/D Ratio	N/A
Material (D50)	N/A
BEHI Rating	N/A
NBS Rating	N/A
MADRAS Score	None

NOTES & OBSERVATIONS

Entire reach found to be influenced by beaver dam, therefore geomorphic survey was not completed. Of note – in the absence of wood, beaver lodge was entirely constructed of corn stalks and beaver dam was partially constructed of corn stocks.

REACH INFORMATION	
AUID	09020101-502
Stream/River	Rabbit River
County	Wilkin
Drainage Area	116.8 sq. mi.
Date	10/22/13
Field/Site ID	8
Bio Monitoring	94RD002
MSHA Score	41.5

GEOMORPHIC SUMMARY	
Channel Type	E5
Est. Bankfull El.	980.7’
Channel Slope	0.1%
Sinuosity	1.5
Bankfull Width	29.0’
W/D Ratio	8.3
Material (D50)	1.3 mm
BEHI Rating	Moderate
NBS Rating	Low
MADRAS Score	37

NOTES & OBSERVATIONS

Substantial and stable buffer comprised predominately of *Phalaris arundinacea* and ≤ *Spartina pectinata*. Low relative stream power with predominately silt bottom.

Reach contains a surface drainage inlet, which was actively eroding

Field observations include: good buffers on both sides of the channel, corn with crop residue seemed to be the cropping taking place on adjacent ag lands, no barriers to biotic movement observed, and no aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-502
Stream/River	Rabbit River
County	Wilkin
Drainage Area	108.4 sq. mi.
Date	10/22/13
Field/Site ID	9
Bio Monitoring	No
MSHA Score	30.28

GEOMORPHIC SUMMARY	
Channel Type	E5
Est. Bankfull El.	996.9’
Channel Slope	0.061%
Sinuosity	1.1
Bankfull Width	21.7’
W/D Ratio	8.2
Material (D50)	0.25 mm
BEHI Rating	Moderate
NBS Rating	Low
MADRAS Score	32

NOTES & OBSERVATIONS

Township Road 165 bisects surveyed reach. This section of the Rabbit River includes numerous straightened reaches (including surveyed) with abandoned channel readily apparent (currently farmed). Field observations include: good buffers on both sides of the channel, corn with crop residue was evident on adjacent ag lands, no barriers to biotic movement observed, and no aquatic plant communities were present.

REACH INFORMATION	
AUID	09020101-504
Stream/River	Unnamed
County	Grant
Drainage Area	25.3 sq. mi.
Date	10/21/13
Field/Site ID	10
Bio Monitoring	10RD009
MSHA Score	13

GEOMORPHIC SUMMARY	
Channel Type	Ditched
Est. Bankfull El.	1015.3’
Channel Slope	0.38%
Sinuosity	1.1
Bankfull Width	26.5’
W/D Ratio	9.6
Material (D50)	0.27 mm
BEHI Rating	Moderate
NBS Rating	Moderate
MADRAS Score	13

NOTES & OBSERVATIONS

330th Avenue bisects surveyed reach. CMP and RCP road culverts perched by 12”± & 8”± respectively. Pockets of courser bed material exist downstream of crossing where gradient is higher. Habitat was poor.

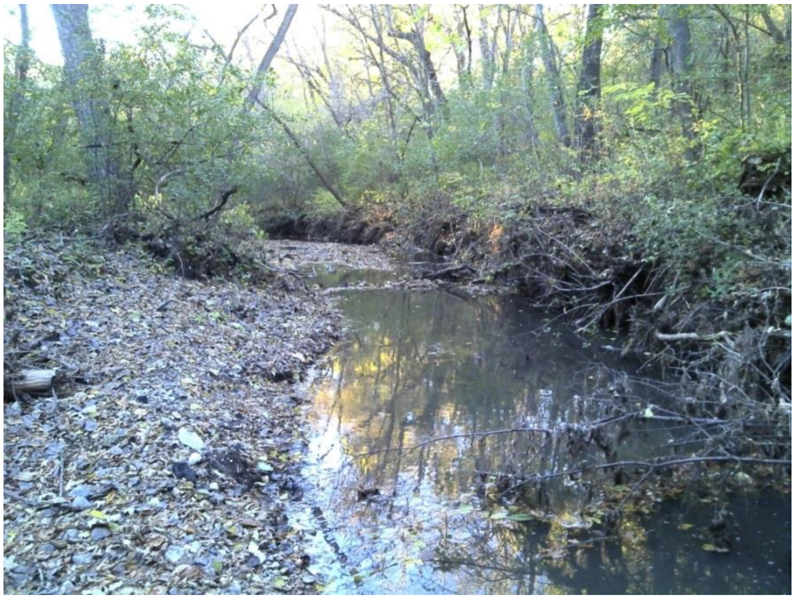
REACH INFORMATION	
AUID	09020101-548
Stream/River	JD2
County	Wilkin
Drainage Area	59.4 sq. mi.
Date	10/21/13
Field/Site ID	11
Bio Monitoring	10RD010
MSHA Score	37

GEOMORPHIC SUMMARY	
Channel Type	Ditched
Est. Bankfull El.	1006.0’
Channel Slope	0.033%
Sinuosity	1.0
Bankfull Width	48.0’
W/D Ratio	9.5
Material (D50)	Silt
BEHI Rating	Moderate
NBS Rating	Moderate
MADRAS Score	28

NOTES & OBSERVATIONS

State Highway 55 and parallel rail road immediately north of highway bisect surveyed reach. Surveyed reach was parallel to and likely entirely within the R.O.W of County Road B. Relatively stable ditch contained a subtle 2-stage ditch bench. Habitat was poor.

REACH INFORMATION	
AUID	09020101-535
Stream/River	Unnamed
County	Traverse
Drainage Area	6.9 sq. mi.
Date	10/21/13
Field/Site ID	12
Bio Monitoring	10RD022
MSHA Score	44.5



GEOMORPHIC SUMMARY	
Channel Type	C4
Est. Bankfull El.	991.4’
Channel Slope	0.42%
Sinuosity	1.4
Bankfull Width	24.8’
W/D Ratio	11.2
Material (D50)	20.0 mm
BEHI Rating	Moderate/High
NBS Rating	Moderate
MADRAS Score	44

NOTES & OBSERVATIONS

Instream habitat within this reach includes riffles, pools, small log jams, and coarse substrates. This reach occurs within a heavily wooded area and contains a well-defined bankfull bench.

REACH INFORMATION	
AUID	09020101-547
Stream/River	Unnamed ditch
County	Grant
Drainage Area	5.7 sq. mi.
Date	10/21/13
Field/Site ID	13 (East)
Bio Monitoring	10RD0016
MSHA Score	38

GEOMORPHIC SUMMARY	
Channel Type	Ditched
Est. Bankfull El.	1064.0’
Channel Slope	0.12%
Sinuosity	1.0
Bankfull Width	46.9’
W/D Ratio	22.9
Material (D50)	Silt
BEHI Rating	Low
NBS Rating	Moderate
MADRAS Score	17

NOTES & OBSERVATIONS

Adequate buffer with adjacent perennial crop. Intermittent flow was apparent and channel was dominated by emergent vegetation.

REACH INFORMATION	
AUID	09020101-520
Stream/River	Unnamed ditch
County	Grant
Drainage Area	11.2 sq. mi.
Date	10/21/13
Field/Site ID	13A (West)
Bio Monitoring	No
MSHA Score	33.75
GEOMORPHIC SUMMARY	
Channel Type	Ditched
Est. Bankfull El.	1061.4’
Channel Slope	0.041%
Sinuosity	1.1
Bankfull Width	39.8’
W/D Ratio	14.9
Material (D50)	0.27
BEHI Rating	Moderate
NBS Rating	Moderate
MADRAS Score	22

NOTES & OBSERVATIONS

2000’ downstream of Site 13 (East), with slightly larger drainage area. Contrast to Site 13 (East) this reach has little to no buffer with immediately adjacent row crop.

REACH INFORMATION	
AUID	09020101-510
Stream/River	Unnamed Creek
County	Wilkin
Drainage Area	30.1 sq. mi.
Date	10/22/13
Field/Site ID	14
Bio Monitoring	No
MSHA Score	39

GEOMORPHIC SUMMARY	
Channel Type	C6c-
Est. Bankfull El.	962.9’
Channel Slope	0.0031%
Sinuosity	1.7
Bankfull Width	185.6’
W/D Ratio	163.5
Material (D50)	Silt
BEHI Rating	Very Low
NBS Rating	Very Low
MADRAS Score	15

NOTES & OBSERVATIONS

Overall instream habitat is poor in this reach with no defined riffles or pools and a fine substrate, but a few large logs were observed in the stream channel. This reach contains a wide, grassy buffer strip on both sides of the stream that greatly reduces the potential for bank erosion.