Little Sioux River Watershed Biotic Stressor Identification Report

Minnesota Pollution Control Agency

April 2015

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Cover photo: Clockwise from Top Left: Little Sioux River at site 11MS010; County Ditch 11 at site 11MS078; Cattle around Unnamed Creek at site 11MS067

Project dollars provided by the Clean Water Fund
(From the Clean Water, Land and Legacy Amendment)

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Document number: wq-ws5-10230003a

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Executive summary

The purpose of stressor identification is to explain the results of the biological monitoring and assessment process. The information obtained answers the questions of why one stream has a low index of biological integrity (IBI) score, while another has a high score. It looks at causal factors – negative ones harming fish and insects, and positive ones leading to healthy biology. Stressors may be physical, chemical, or biological.

Stressor identification is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems, and provides a structure for organizing the scientific evidence supporting the conclusions (EPA, 2000). In simpler terms, it is the process of identifying the major factors causing harm to fish and other river and stream life. Stressor identification is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act.

This report summarizes stressor identification work in the Little Sioux River Watershed. Located in southwest Minnesota, the Little Sioux River Watershed encompasses approximately 205,802 acres within the state of Minnesota. This watershed includes many large and small tributaries to the Little Sioux River.

Over the past few years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of rivers and streams. The basic approach is to look at fish and aquatic macroinvertebrates (mostly insects), and related habitat conditions, at sites throughout a major watershed. The resulting information is used to produce an IBI. Index of biological integrity scores can then be compared to a range of regionally developed thresholds. The regional thresholds were developed to maintain a healthy community of aquatic life and meet water quality standards. Stream and river reaches are assigned an Assessment Unit Identification (AUID) number and will be referred to as the AUID in this report. AUIDs with low IBI scores are determined to have a biological impairment.

This report analyzed the biological impairments in two subwatersheds within the Little Sioux River Watershed. The subwatersheds having a biological impairment were: Little Sioux River Minor Watershed, and Ocheyedan River Minor Watershed. After examining many candidate causes for the biological impairments, the following stressors were identified for the impaired AUIDs in their respective subwatersheds (Table 1).

Table 1. Stressors to the Biologically Impaired AUIDs within the Little Sioux River Watershed
(• = stressor, - = not a stressor, and blank = inconclusive/not enough evidence)

		Stressors				
Stream name	**AUID #**	**Low Dissolved Oxygen**	**High Phosphorus**	**High Nitrates**	**High Turbidity/TSS**	**Lack of Habitat**
Little Sioux River Minor Watershed						
Little Sioux River	10230003-515	•	•	•	•	•
Ocheyedan River Minor Watershed						
Ocheyedan River	10230003-501	-	•			•

Introduction

Monitoring and assessment

As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2011-2012 and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data dated back to 2001, were used to identify AUIDs that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1).

Once a biological impairment is discovered, the next step is to identify the source(s) of stress on the biological community. A Stressor Identification (SID) analysis is a step-by-step approach for identifying probable causes of impairment in a particular system. Completion of the SID process does not result in a finished Total Maximum Daily Load (TMDL). The product of the SID process is the identification of the stressor(s) for which the TMDL may be developed. In other words, the SID process may help investigators nail down excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to restore the impaired condition.

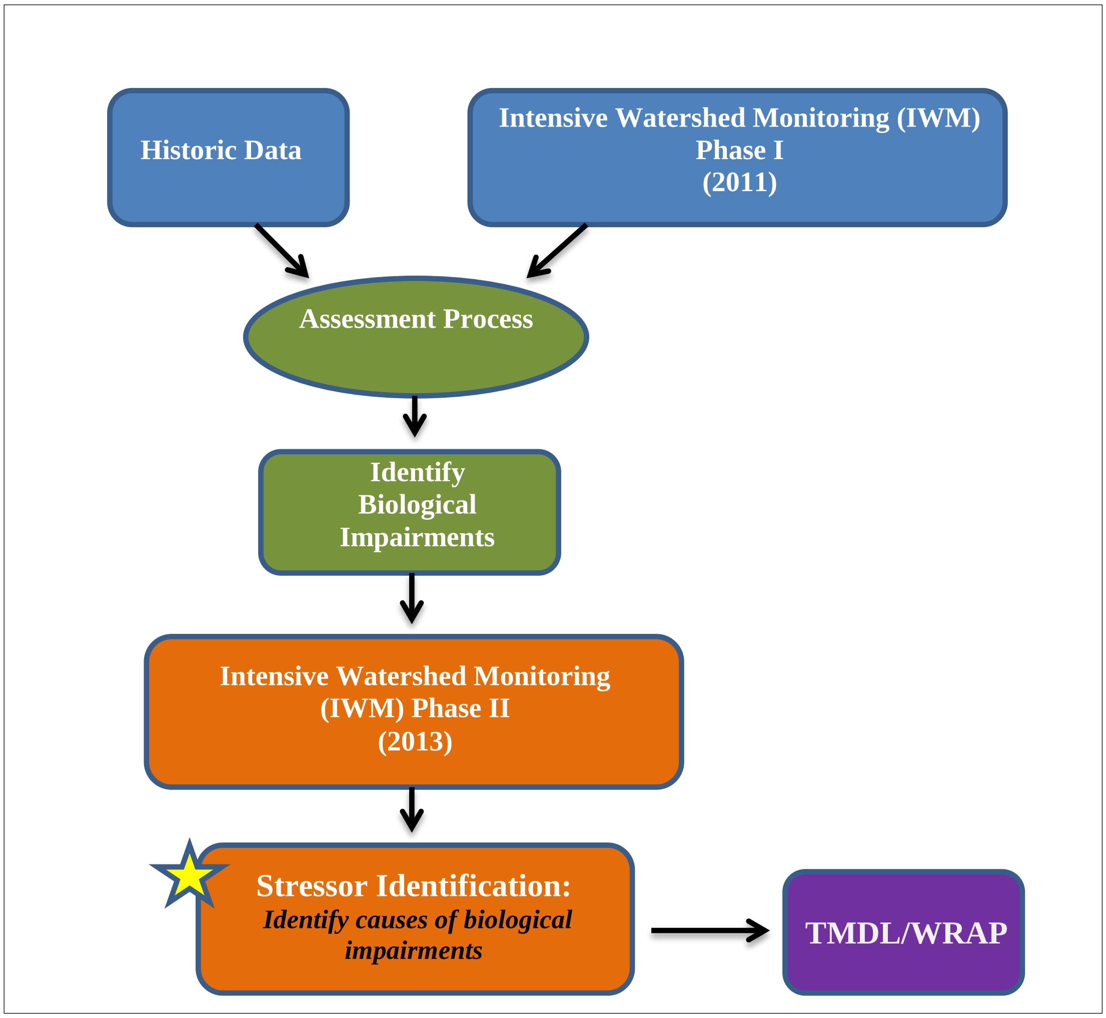

Figure 1. Process map of Intensive Watershed Monitoring, Assessment, Stressor Identification and TMDL processes

Stressor Identification process

The Stressor Identification process (SID) is used in this report to weigh evidence for or against various candidate causes of biological impairment (see Cormier et al., 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 2). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s).

SID draws upon a broad variety of disciplines, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. Strength of evidence (SOE) analysis is used to develop cases in support of, or against, various candidate causes. Typically, the majority of the information used in the SOE analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon in the SID process.

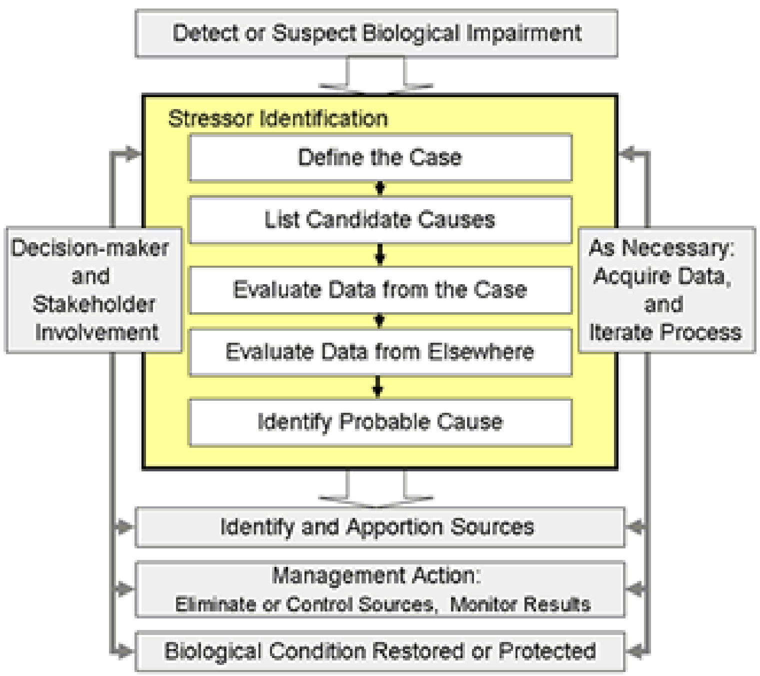

Figure 2. Conceptual model of Stressor Identification (SID) process

Completion of the SID process does not result in completed TMDL allocations. The product of the SID process is the identification of the stressor(s) for which the TMDL load allocation will be developed. For example, the SID process may help investigators identify excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to address and correct the impaired condition.

Common stream stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry, and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired waterbody. Table 2 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 2. Common Streams Stressors to Biology (i.e., fish and macroinvertebrates)

Stream health	Stressor(s)	Link to biology
Stream connections	**Loss of Connectivity** · Dams and culverts · Lack of wooded riparian cover · Lack of naturally connected habitats/ causing fragmented habitats	Fish and macroinvertebrates cannot freely move throughout system. Stream temperatures also become elevated due to lack of shade.
Hydrology	**Altered Hydrology** **Loss of habitat due to channelization** **Elevated Levels of TSS** · Channelization · Peak discharge (flashy) · Transport of chemicals	Unstable flow regime within the stream can cause a lack of habitat, unstable stream banks, filling of pools and riffle habitat, and affect the fate and transport of chemicals.
Stream Channel Assessment	**Loss of habitat due to excess sediment** **Elevated Levels of TSS** · Loss of dimension/pattern/profile · Bank erosion from instability · Loss of riffles due to accumulation of fine sediment · Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.
Water Chemistry	**Low Dissolved Oxygen (DO) Concentrations** **Elevated Levels of Nutrients** · Increased nutrients from human influence · Widely variable DO levels during the daily cycle · Increased algal and or periphyton growth in stream · Increased nonpoint pollution from urban and agricultural practices · Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

Report format

This report follows a format to first summarize candidate causes of stress to the biological communities at the 8-digit HUC scale. Within the summary, there is information about how the stressor relates broadly to the Little Sioux River Watershed, water quality standards and general effects on biology. The report is then organized into two different subwatersheds. Each of the biological impairments within the subwatersheds are evaluated and discussed in further detail.

Overview of the Little Sioux River Watershed

Background

The Little Sioux River Watershed consists of fourteen 12-digit Hydrologic Unit Code (HUC) subwatersheds (Figure 4). The Little Sioux River Watershed encompasses approximately 205,802 acres within the state of Minnesota. Land use in the watershed consists of mainly cropland (82.73%), followed by developed land (6.13%), rangeland (3.42%), and wetlands (2.72%).

This report describes the connection between the biological community and the stressor(s) causing the impairments. Stressors are the factors that negatively impact the biological community. Stressors can interact with each other and can be additive to the stress on the biota. The Missouri River Basin Monitoring and Assessment Report is available and provides background information about the watershed and the results of recent monitoring and assessment at the 10-HUC scale.

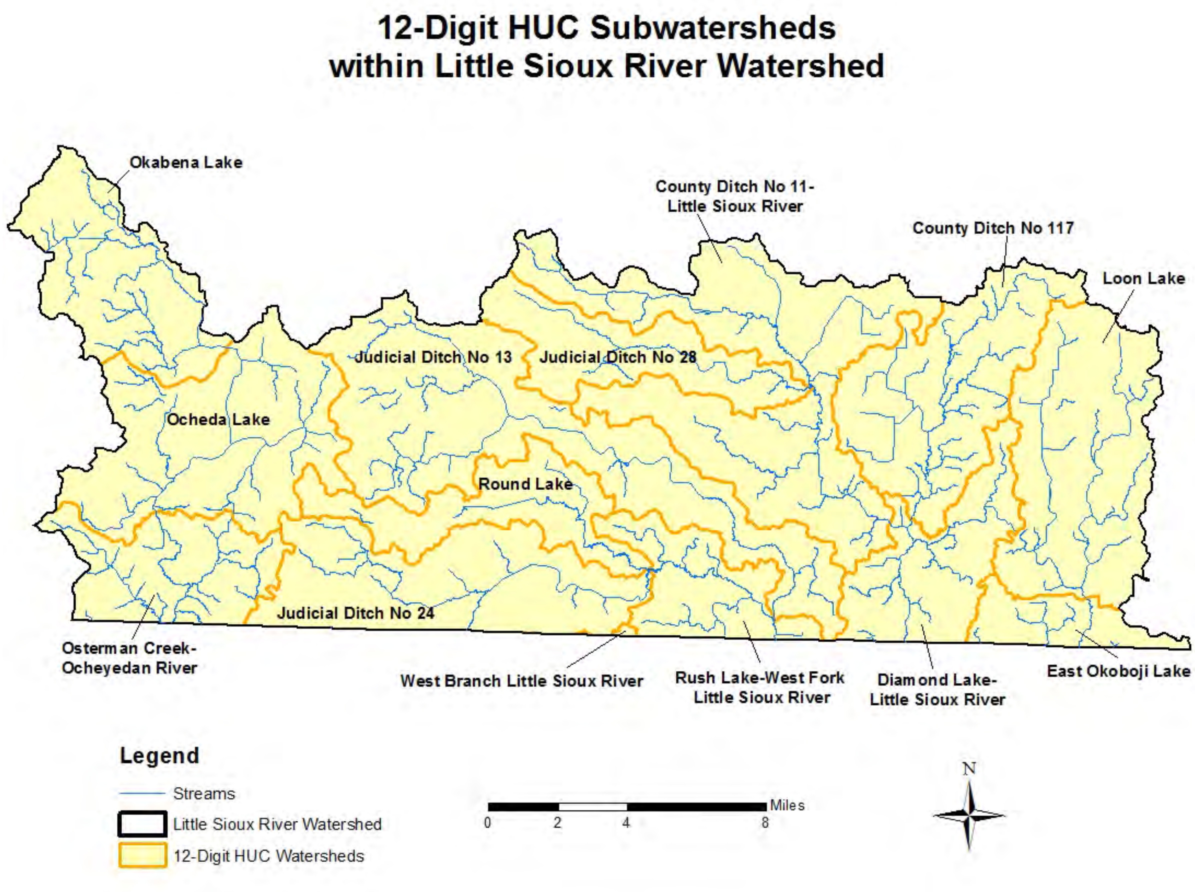

Figure 3. Map of HUC-12 watersheds within the Little Sioux River Watershed

Monitoring overview

In 2011-2012, intensive biological monitoring was performed in the Little Sioux River Watershed. This sampling effort included 26 biological monitoring sites. Additionally, another 22 chemistry monitoring stations exist in the watershed. Biological monitoring and water chemistry from these sites as well as other water monitoring data taken within ten years of the biological monitoring were used to assess the conditions of the Little Sioux River Watershed. The watershed assessment for this area occurred in 2013. Figure 5 displays all of the biological monitoring stations and the biological impairments that exist in the watershed.

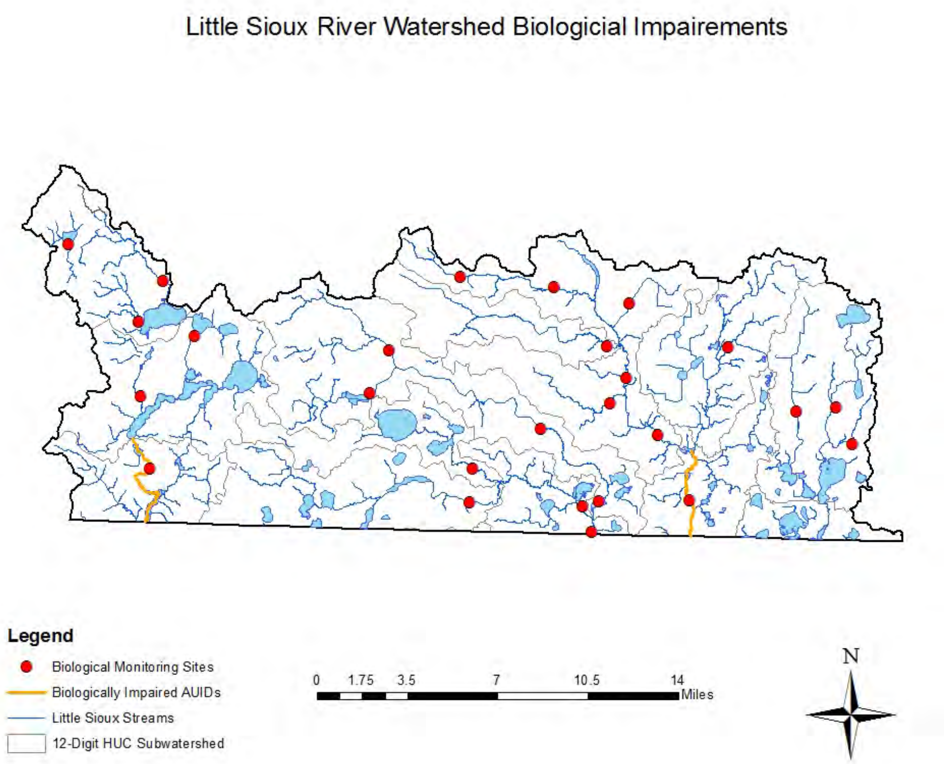

Figure 4. Biological monitoring stations and biological impairments in the Little Sioux River Watershed

Summary of biological impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrate communities and related habitat conditions at sites throughout a watershed. The resulting information is used to develop an index of biological integrity (IBI). The IBI scores can then be compared to a range of regionally developed thresholds. For further descriptions of the fish and macroinvertebrate IBI class criteria, please see Appendices 1.1-2.

The fish and macroinvertebrates within each AUID were compared to a regionally developed threshold and confidence interval and utilize a weight of evidence approach. The water quality standards call for the maintenance of a healthy community of aquatic life. IBI scores provide a measurement tool to assess the health of the aquatic communities. IBI scores higher than the impairment threshold indicate that the AUID supports aquatic life. Conversely, scores below the impairment threshold indicate that the AUID does not support aquatic life. Confidence limits around the impairment threshold help to ascertain where additional information may be considered to help inform the impairment decision. When IBI scores fall within the confidence interval, interpretation and assessment of the waterbody condition involves consideration of potential stressors, and draws upon additional information regarding water chemistry, physical habitat, and land use, etc.

In the Little Sioux River Watershed, two AUIDs are currently impaired for a lack of biological assemblage (Table 3).

Table 3. Biologically impaired AUIDs in the Little Sioux River Watershed

Little Sioux River Watershed				Impairments	
Stream name	**AUID #**	**HUC-12**	**Reach description**	**Biological**	**Water quality**
Ocheyedan River	10230003-501	102300030503	Ocheda Lake to MN/IA border	Macroinvertebrate IBI, Fish IBI	None
Little Sioux River	10230003-515	102300030304	Unnamed creek to MN/IA border	Fish IBI	Turbidity

The fish and macroinvertebrate thresholds and confidence limits are shown by class for sites found in the Little Sioux River Watershed in Table 4.

Each IBI is made up of fish or macroinvertebrate metrics that are based on community structure or function and produces a metric score. The number of metrics that make up an IBI will determine the metric score scale. For example, an IBI with eight metrics would have a scale from 0-12.5 and an IBI with 10 metrics would have a scale from 0-10.

Table 4. Fish and Macroinvertebrate classes found in the Little Sioux River Watershed with their respective IBI thresholds and Upper/Lower confidence limits

Class	Class name	Fish IBI thresholds	Upper CL	Lower CL
2	Southern streams	45	54	36
Class	**Class name**	**Macroinvertebrate IBI thresholds**	**Upper CL**	**Lower CL**
7	Prairie Streams GP	38.3	51.9	24.7

Table 5 shows the fish and macroinvertebrate IBI scores for the sites studied further in this report. The impaired AUIDs are color coded by their relationship to the IBI threshold and confidence intervals. See Table 6 for the color descriptions of the IBI scores. For a complete summary of fish and macroinvertebrate IBI scores in the Little Sioux River Watershed, please see the Missouri River Basin Monitoring and Assessment Report.

Table 5. Fish and Macroinvertebrate IBI Scores by Biological Station within AUID with Descriptive Color

AUID & Reach	Station	Year	Fish IBI score	Fish class	Macroinvertebrate IBI score	Macroinvertebrate class
10230003-501 (Ocheyedan River)	11MS022	2011	-	2	**28.4**	7
		2012	**27**		-	-
10230003-515 (Little Sioux River)	11MS010	2011	-	2	**41.7**	7
		2012	**29**		-	-

Table 6. IBI Color Descriptions

At or Below Lower Confidence Limit	At or Below Threshold, Above Lower Confidence Limit	At or Above Threshold, Below Upper Confidence Limit	At or Above Upper Confidence Limit

Hydrological Simulation Program - FORTRAN (HSPF) Model

The Hydrological Simulation Program - FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale Agricultural Runoff Model (ARM) and Non-Point Source (NPS) models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.

The HSPF watershed model contains components to address runoff and constituent loading from pervious land surfaces (PERLNDs), runoff and constituent loading from impervious land surfaces (IMPLNDs), and flow of water and transport/transformation of chemical constituents in stream reaches (RCHRESs). Primary external forcing is provided by the specification of meteorological time series. The model operates on a lumped basis within subwatersheds. Upland responses within a subwatershed are simulated on a per-acre basis and converted to net loads on linkage to stream reaches. Within each subwatershed, the upland areas are separated into multiple land use categories.

The HSPF watershed model was run for the Little Sioux River Watershed to help simulate outputs used for analysis. In this report, AUIDs with biological impairments used the model results to supplement information that was not collected to further confirm or refute a stressor. See Figure 6 for a map of the HSPF model numbered subwatersheds. Subwatersheds included in this study are numbered 90 (Little Sioux River), along with 224 (Ocheyedan River).

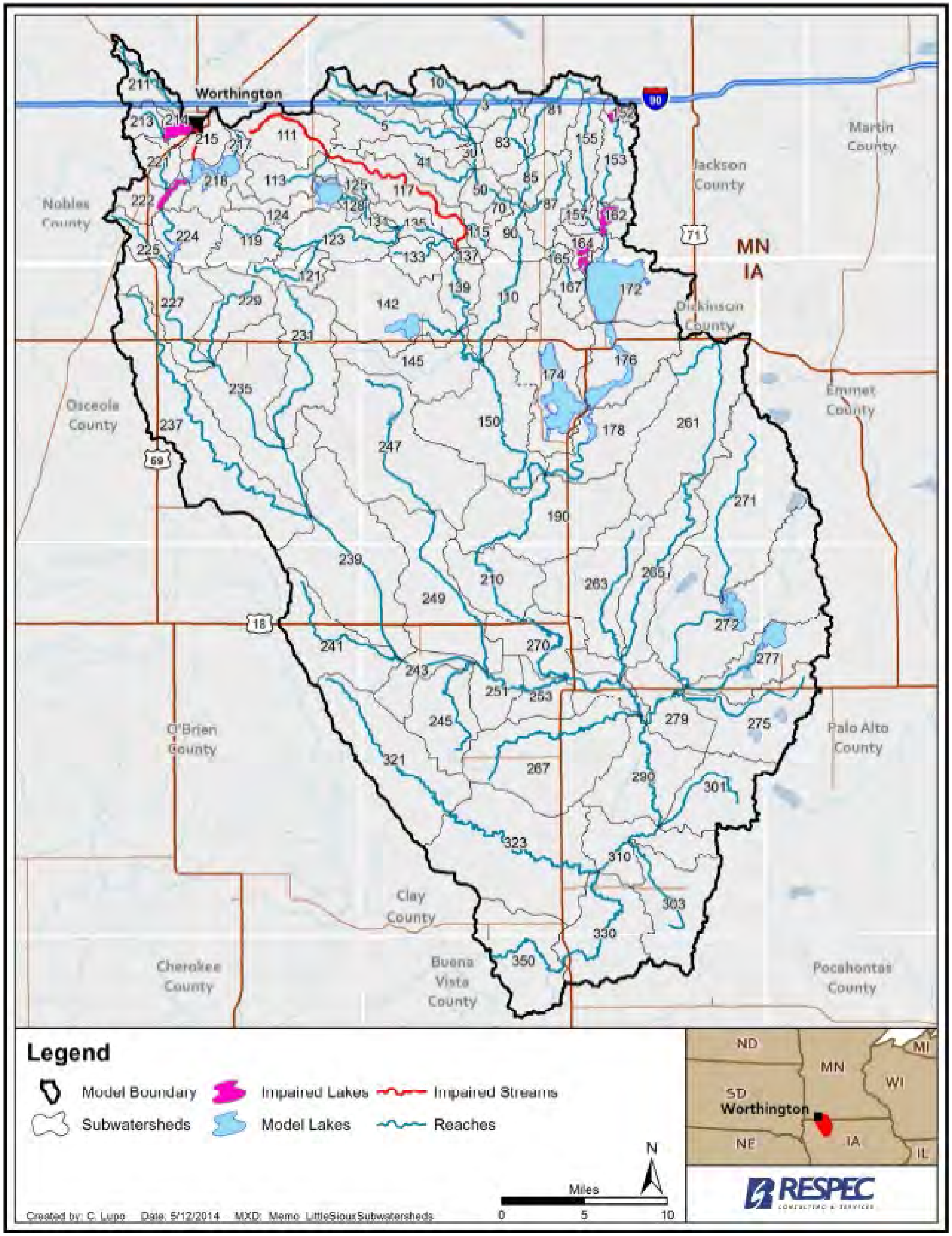

Figure 5. HSPF model subwatersheds in the Little Sioux River Watershed

Candidate cause: Low dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1991). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If dissolved oxygen concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Some macroinvertebrates that are intolerant to low levels of dissolved oxygen include mayflies, stoneflies and caddisflies (Marcy, 2007). Many species of fish avoid areas where dissolved oxygen concentrations are below 5 mg/L (Raleigh et al., 1986). Additionally, fish growth rates can be significantly affected by low dissolved oxygen levels (Doudoroff and Warren, 1965).

In most streams and rivers, the critical conditions for stream DO usually occur during the late summer season when water temperatures are high and stream flows are reduced to baseflow. As temperatures increase, the saturation levels of dissolved oxygen decreases. Increased water temperature also raises the dissolved oxygen needs for many species of fish (Raleigh et al., 1986). Low dissolved oxygen can be an issue in streams with slow currents, excessive temperatures, high biological oxygen demand, and/or high groundwater seepage (Hansen, 1975).

Water quality standards

In Class 2B and 2C streams, the Minnesota standard for DO is 5.0 mg/L as a daily minimum. Additional stipulations have recently been added to this standard. The following is from the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2009):

> *Under revised assessment criteria beginning with the 2010 assessment cycle, the DO standard must be met at least 90 percent of the time during both the 5-month period of May through September and the 7-month period of October through April. Accordingly, no more than 10 percent of DO measurements can violate the standard in either of the two periods.*
>
> *Further, measurements taken after 9:00 in the morning during the 5-month period of May through September are no longer considered to represent daily minimums, and thus measurements of > 5 DO later in the day are no longer considered to be indications that a stream is meeting the standard.*
>
> *A stream is considered impaired if 1) more than 10 percent of the "suitable" (taken before 9:00) May through September measurements, or more than 10 percent of the total May through September measurements, or more than 10 percent of the October through April measurements violate the standard, and 2) there are at least three total violations.*

Types of dissolved oxygen data

Point measurements

Instantaneous DO data is available throughout the watershed and can be used as an initial screening for low DO. These measurements represent discrete point samples, usually conducted in conjunction with a surface water sample collection utilizing a YSI sonde. Because DO concentrations can vary significantly as a result of changing flow conditions and time of sampling, instantaneous measurements need to be used with caution and are not completely representative of the DO regime at a given site.

Diurnal (continuous)

A YSI sonde was deployed for a 14-day interval at one location in the Little Sioux River Watershed in late summer to capture diurnal fluctuations over the course of a number of diurnal patterns. This information was then used to look at the diurnal flux of DO along with the patterns of DO fluctuation. Heiskary et al. (2010) observed several negative correlations between fish and macroinvertebrate metrics and DO flux. The study found that a diurnal (24-hour) DO flux over 4.5 mg/L is correlated with reduced macroinvertebrate taxa richness and the relative abundance of sensitive fish species in a population.

Overview of dissolved oxygen in the Little Sioux River Watershed

Dissolved oxygen was measured throughout the watershed. Continuous dissolved oxygen monitoring was performed along the Little Sioux River in 2013. This AUID had a daily flux exceeding 4.5 mg/L along with daily minimum values below the threshold of 5 mg/L. Sites along both impaired AUIDs had reduced macroinvertebrate taxa richness and few sensitive fish species.

Unfortunately, due to vast numbers of biological impairments in the entire Missouri basin, continuous dissolved oxygen monitoring could not feasibly be done at all impaired AUIDs. Frequent dissolved oxygen monitoring was performed along these AUIDs instead. This data, along with the modeling data and biological responses will be used to determine the degree of stress dissolved oxygen is having on the impaired AUIDs.

Sources and causal pathways for low dissolved oxygen

Dissolved oxygen concentrations in lotic environments are often driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the dissolved oxygen regime of a waterbody. Agricultural and urban land-uses, impoundments (dams), and point-source discharges are just some of the anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. The conceptual model for low dissolved oxygen as a candidate stressor in the Little Sioux River Watershed is modeled at EPA's CADDIS Dissolved Oxygen webpage. (MPCA 2012, PdT)

Candidate cause: High phosphorus

Phosphorus is an essential nutrient for all aquatic life, but elevated phosphorus concentrations can result in an imbalance which can impact stream organisms. Excess phosphorus does not result in direct harm to fish and macroinvertebrates. Rather, its detrimental effect occurs as it alters other factors in the water environment. Dissolved oxygen, pH, water clarity, and changes in food resources and habitat are all stressors that can result when there is excess phosphorus.

Water quality standards

There is no current water quality standard for total phosphorus; however there is a draft nutrient standard for rivers of Minnesota as well as ecoregion data to show if the data is within the expected norms. The current draft standard is a maximum concentration of 0.15 mg/l. For more information, please reference the Missouri River Basin Monitoring and Assessment Report.

Total phosphorus concentrations in the Little Sioux River Watershed

From 2001-2012, there have been 226 phosphorus samples collected in streams in the Little Sioux River Watershed. Of those samples, 152 (67.26%) were above the current draft standard of 0.15 mg/L. The highest reading was 1.54 mg/L, roughly ten times the draft standard. The high rate and degree of exceedance of the standard shows that phosphorus is a watershed-wide issue which needs to be addressed.

Sources and causal pathways for high phosphorus

Phosphorus is delivered to streams by wastewater treatment facilities, urban stormwater, agriculture, and direct discharges of sewage. The causes and potential sources for excess phosphorus in the Little Sioux River Watershed are modeled at EPA's Nutrient CADDIS webpage.

Candidate cause: High nitrate - nitrite

Exposure to elevated nitrite or nitrate concentrations can lead to the development of methemoglobinemia. The iron site of the hemoglobin molecule in red blood cells preferentially bonds with nitrite molecules over oxygen molecules. Methemoglobinemia ultimately limits the amount of oxygen which can be absorbed by fish and macroinvertebrates (Grabda et al., 1974). According to Camargo and Alonso (2006), certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity.

Water quality standards

Streams classified as Class 1 waters in the state of Minnesota, which are designated for domestic consumption, have a nitrate-N (nitrate plus nitrite) water quality standard of 10 mg/L. At this time, none of the AUIDs in the Little Sioux River Watershed that are impaired for biota are classified as Class 1 streams. Minnesota currently does not have a nitrate standard for other waters of the state besides for Class 1.

Ecoregion data

McCollor & Heiskary (1993) developed a guidance of stream parameters by ecoregion for Minnesota streams. The Little Sioux River Watershed falls entirely within the Western Corn Belt Plains (WCBP) ecoregion. The annual 75th percentile nitrate-N values were used for comparison (Table 7).

Table 7. Ecoregion in the Little Sioux River Watershed with the Associated Annual 75 Percentile Nitrate-Nitrite Level

Ecoregion	75 Percentile value (mg/L)
Western Corn Belt Plains (WCBP)	6.9

Collection methods for nitrate and nitrite

Water samples analyzed for nitrate-N were collected throughout the watershed. Nitrate-N is comprised of both nitrate (NO_3^-) and nitrite (NO_2^-). Typically, water samples contain a small proportion of nitrite relative to nitrate due to the instability of nitrite, which quickly oxidizes to nitrate. The water samples collected were analyzed for nitrate-N at a Minnesota Department of Health certified lab.

Nitrate and nitrite in the Little Sioux River Watershed

From 2011-2012, there were 133 nitrate samples collected throughout the Little Sioux River Watershed. Values ranged from 0.2 mg/L up to 11.4 mg/L. In general, the months with the highest nitrate values were April through June. There are many high values throughout the watershed and a nitrate reduction plan is needed to control and reduce the impact nitrate is having on water quality.

Sources and causal pathways for nitrate and nitrite

The elevated nitrate levels during the spring months coincide with fertilizer applications and periods of snowmelt/runoff. The abundance of row crop agriculture in the watershed makes this a large scale issue. For a complete model of causes and potential causes of nitrates in the Little Sioux River Watershed, please see the EPA's CADDIS Nitrogen webpage.

Candidate cause: Altered hydrology/connectivity/geomorphology

Increased flows may directly impair the biological community or may indirectly contribute to additional stressors. Increasing flows increase channel shear stress, which often causes increased scouring of stream banks and bank destabilization. With these stresses added to the stream or compounded by high flows, the fish and macroinvertebrate community may be influenced by the negative changes in habitat and sediment.

High flows can also cause the displacement of fish and macroinvertebrates downstream if they cannot move into tributaries or refuges along the margins of the river; or if refuges are not available. Such aspects as high velocities, the mobilization of sediment, woody debris, and plant material can be especially detrimental to fish and macroinvertebrates, which can cause significant dislodgement. When high flows become more frequent, species that do not manage well under those conditions will be reduced, leading to altered population. Macroinvertebrates may shift from those of long life cycles to short life cycles needing to complete their life history within the bounds of the recurrence interval of flow conditions (CADDIS, 2011).

Across the conterminous U.S., Carlisle et al. (2010) 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 a decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space and when flows are reduced beyond normal baseflow, competition for resources increases. Pollutant concentrations often increase when flows are lower than normal, making it more difficult for populations to maintain a healthy diversity. Often, tolerant individuals that can outcompete in limiting situations will thrive. Low flows of prolonged duration tend to lead to macroinvertebrate and fish communities that have preference for standing water or are comprised of generalist species (CADDIS, 2011).

Altered hydrology/connectivity/geomorphology in the Little Sioux River Watershed

The Little Sioux River Watershed has experienced heavy channelization. 62.5% of the entire watershed has been identified as being altered (channelized). To get a better scope of the amount of altered waterways within the watershed, see Figure 7 below. Figure 8 shows examples of channelized streams located in the Little Sioux River Watershed.

The Minnesota Department of Natural Resources (MDNR) has done a comprehensive study on altered hydrology, connectivity, and geomorphology in the entire Missouri River basin. This report analyzes historical gage data along the Rock River, stream crossing data, and applied fluvial geomorphology assessment to find relationships that would create better understanding of water quality and biological impairments throughout the watershed. Please refer to the document titled, "Missouri River Watershed Hydrology, Connectivity, and Geomorphology Assessment Report" for a detailed look at these conditions throughout the watershed. This report will not cover this candidate cause any further.

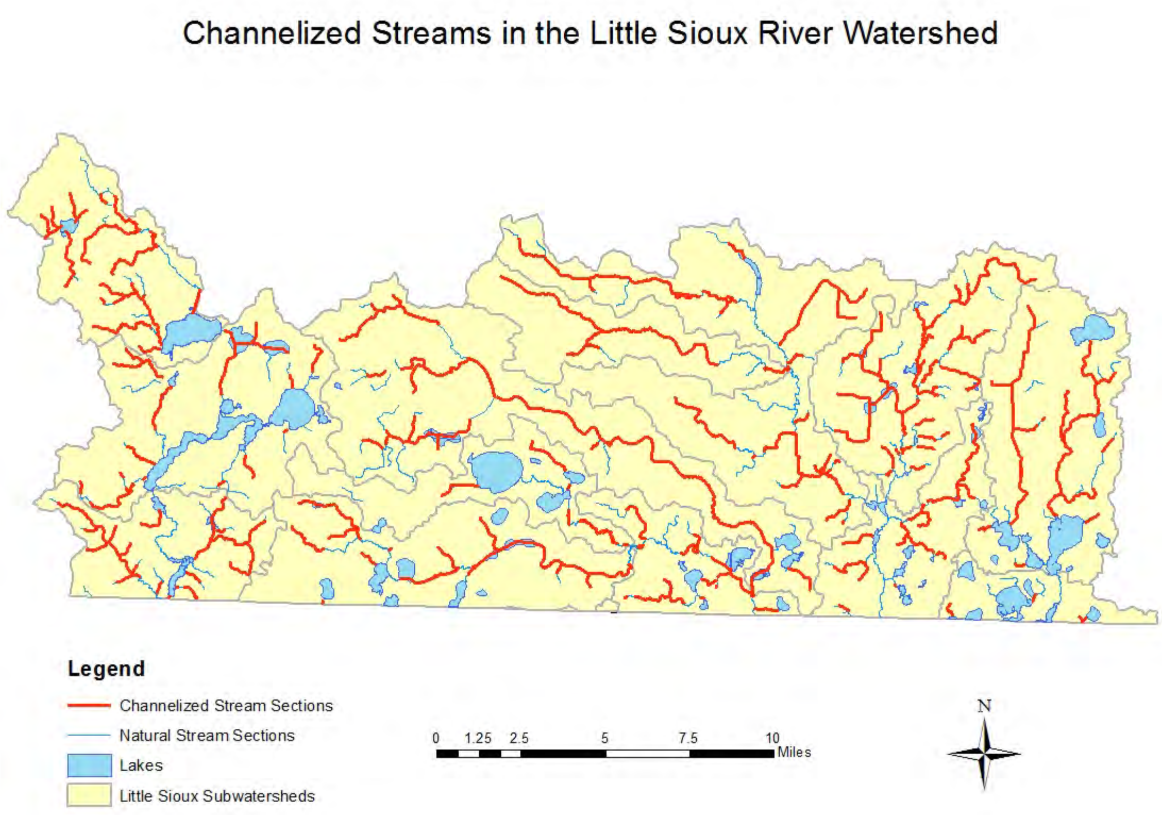

Figure 6. The Little Sioux River Watershed and its many altered waterways

Figure 7. Examples of channelized streams in the Little Sioux River Watershed (left to right) – Judicial Ditch 13 (Skunk Creek) site 11MS079; County Ditch 11 site 11MS078

Candidate cause: High turbidity/total suspended solids

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairments in the United States (U.S. EPA, 2003). Although sediment delivery and transport are important natural processes for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat in addition to the direct harm to aquatic organisms. 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 TSS concentrations can reduce the penetration of sunlight and thus impede photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

Elevated Volatile Suspended Solids (VSS) concentrations can impact aquatic life in a similar manner as TSS – with the suspended particles reducing water clarity – but unusually high concentrations of VSS can also be indicative of nutrient imbalance and an unstable dissolved oxygen regime.

Water quality standards

The water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2B and 2C waters for protection of aquatic life. Turbidity is a measure of reduced transparency that can increase due to suspended particles such as sediment, algae and organic matter. Total suspended solids and transparency tube measurements can be used as surrogate standards.

A strong correlation exists between the measurements of TSS concentration and turbidity. New draft 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 draft TSS standard for the Little Sioux River has been set at 65 mg/L. For assessment, this concentration is not to be exceeded in more than 10% of samples within a 10-year data window.

As well as TSS, sestonic algae can lead to increases in turbidity and can be evaluated by tests which measure the percentage of the solids from a sample that are burned off (volatile suspended solids – VSS) and by total phosphorus. There are no current standards for either.

For the purposes of stressor identification, transparency tube measurements, TSS, VSS, and HSPF modeling results will be relied upon to quantify the suspended material present from which inferences can be made regarding the effects of suspended solids on fish and macroinvertebrate populations.

Turbidity in the Little Sioux River Watershed

The most recent assessments for the Little Sioux River Watershed determined there were four turbidity impairments. These impairments are located on Little Rock River (AUID: 10170204-512), Judicial Ditch 6 (AUID: 10230003-502), Judicial Ditch 13 (AUID: 10230003-511), and Little Sioux River (AUID: 10230003-515).

Streams with more than 10% of exceedances of the turbidity standard that were not listed due to channelization deferments include: Little Sioux River West Fork (AUID: 10230003-508), Little Sioux River West Fork (AUID: 10230003-509), and Little Sioux River (AUID: 10230003-514). For a spatial reference of turbidity issues in the Little Sioux River Watershed, please see Figure 9 below.

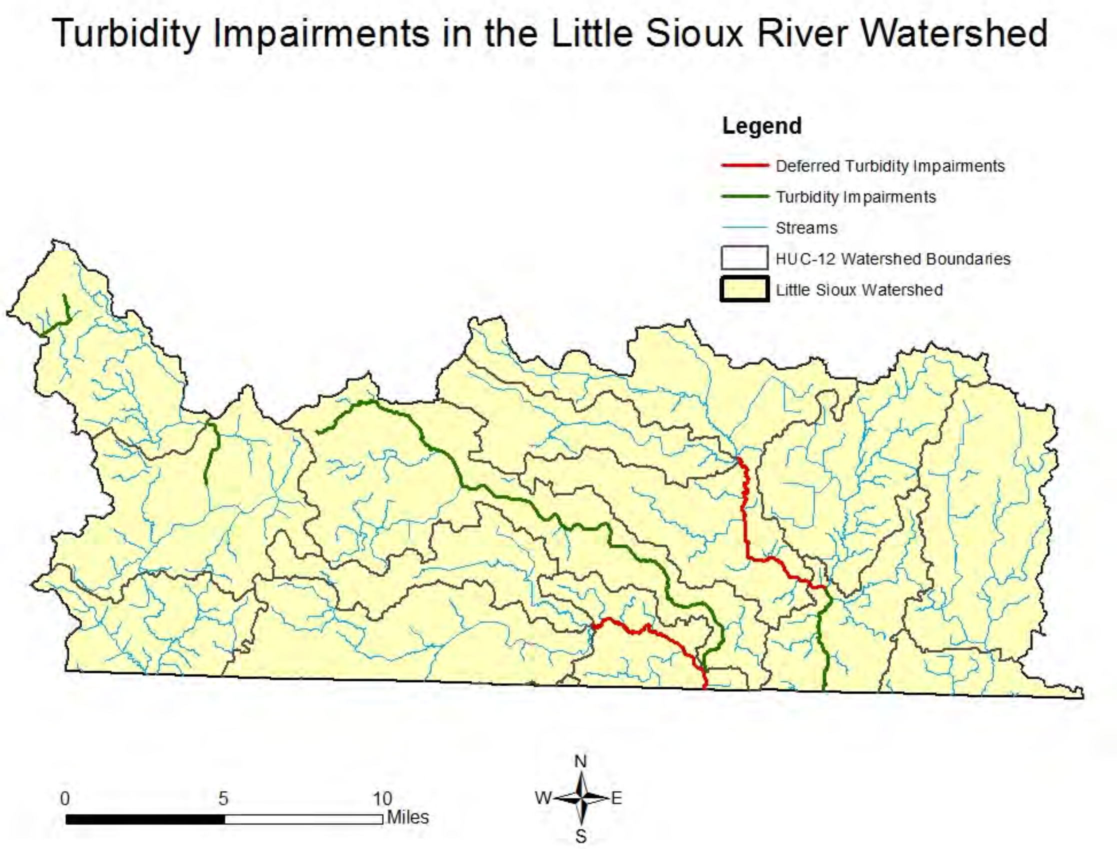

Figure 8. Little Sioux River Watershed turbidity impairments

Sources and causal pathways for turbidity

The causes and potential sources for increases in turbidity in the Little Sioux River Watershed are modeled at EPA's CADDIS Sediments webpage. High turbidity occurs when heavy rains fall on unprotected soils, dislodging the soil particles which are transported by surface runoff into the rivers and streams (MPCA and MSUM, 2009). The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently vegetated pastures. Decreases in bank stability may also lead to sediment loss from the stream banks, often caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration, and increases in impervious surfaces.

Candidate cause: Lack of habitat

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. This section will focus on the physical habitat structure including geomorphic characteristics and vegetative features (Griffith et al., 2010). Physical habitat is often interrelated to other stressors (e.g., sediment, flow, dissolved oxygen) and will be addressed separately. Fish passage will also be addressed in a separate section.

Physical habitat diversity enables fish and macroinvertebrate habitat specialists to prosper, allowing them to complete their life cycles. Some examples of the requirements needed by habitat specialists are: sufficient pool depth, cover or refuge from predators, and riffles that have clean gravel or cobble which are unimpeded by fine sediment (Griffith et al., 2010).

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on our landscape by way of resource extraction, agriculture, forestry, silviculture, urbanization, and industry. These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat; or reduced habitat quality, such as embedded gravel substrates. Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (Griffith et al., 2010).

Water quality standards

At this time there are no applicable standards for lack of habitat for biotic communities.

Habitat characteristics in the Little Sioux River Watershed

Habitat quality differs throughout the Little Sioux River Watershed and is an essential tool when understanding and describing the biological communities. Habitat was measured using the Minnesota Stream Habitat Assessment (MSHA) during the fish sampling event. The MSHA is useful in describing the aspects of habitat needed to obtain a healthy biological community. It includes five subcategories: land use, riparian zone, substrate, cover, and channel morphology.

In the Little Sioux River Watershed, habitat scores were predominantly fair or poor throughout (see Figure 10). Many of these areas are farmed intensely or, in some cases, have been channelized.

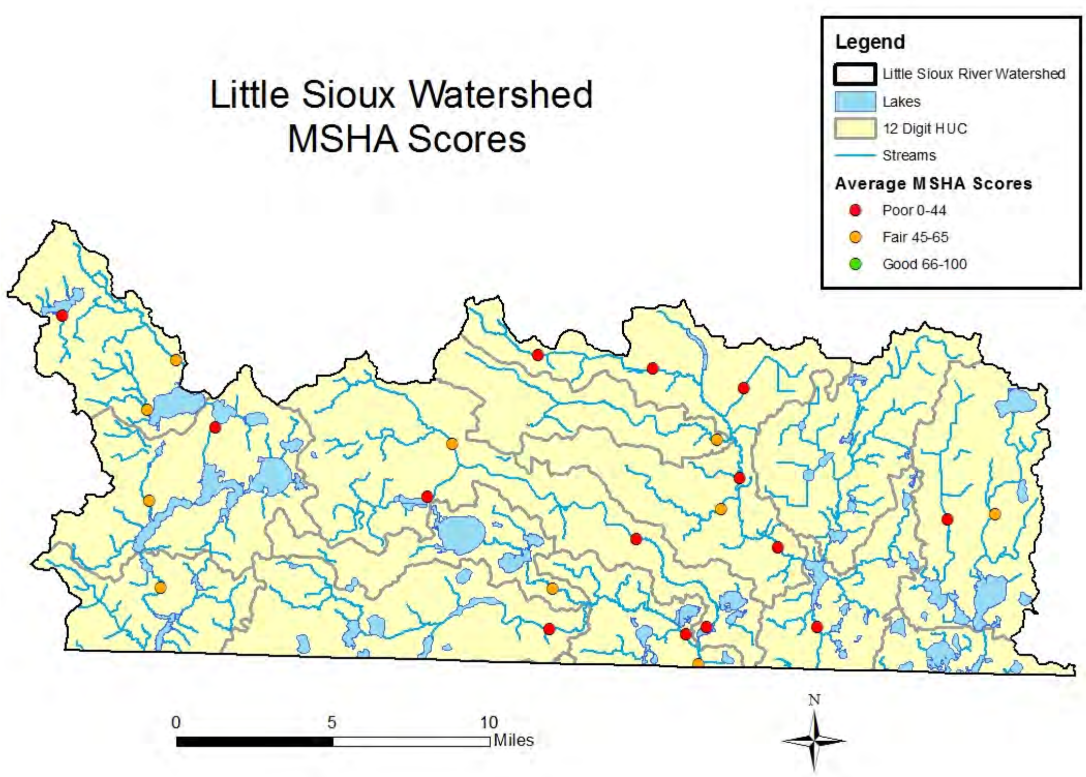

Figure 9. Average MSHA scores at biological sampling stations in the Little Sioux River Watershed

In addition, the National Fish Habitat Partnership has created a national data set measuring the amount of human disturbance on the landscape. For a spatial reference of the amount of landscape disturbance in the Little Sioux River Watershed, please see Figure 11 below. For reference, see the website: http://ecosystems.usgs.gov/fishhabitat/.

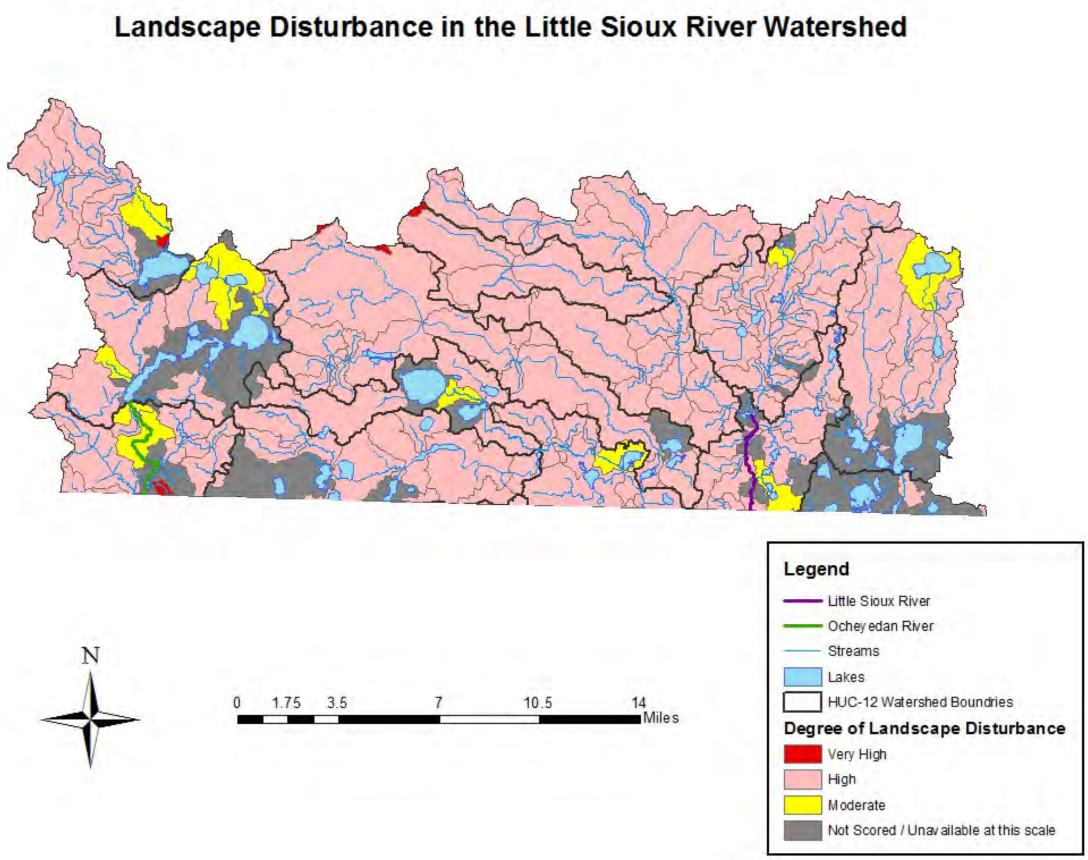

Figure 10. Human-caused landscape disturbance in the Little Sioux River Watershed produced by the National Fish Habitat Partnership

Sources and causal pathways model for habitat

The causes and potential sources for lack of habitat in the Little Sioux River Watershed are modeled at EPA's CADDIS Physical Habitat webpage. Many riparian areas in this watershed are dominated by row crops and intensive grazing, which decreases the riparian and bank vegetation, which leads to unstable and erodible banks.

Subwatersheds with biological impairments

Little Sioux River Minor Watershed

Little Sioux River Minor Watershed is located in the southeastern region of the Little Sioux River Watershed. There is one impaired AUID, the Little Sioux River (AUID: 10230003-515) which was sampled in 2011 for macroinvertebrates and 2012 for fish. This AUID was determined to be impaired for aquatic life due to its fish assemblages, along with turbidity. The impaired AUID stretches 4.05 miles from an unnamed lake to the Minnesota/Iowa border. See Figure 12 below for a detailed map of the Little Sioux River Minor Watershed. The Little Sioux River Minor Watershed has a landscape dominated by cropland (78.5%) along with wetlands (7.3%), rangeland (6.4%), and developed land (5.1%).

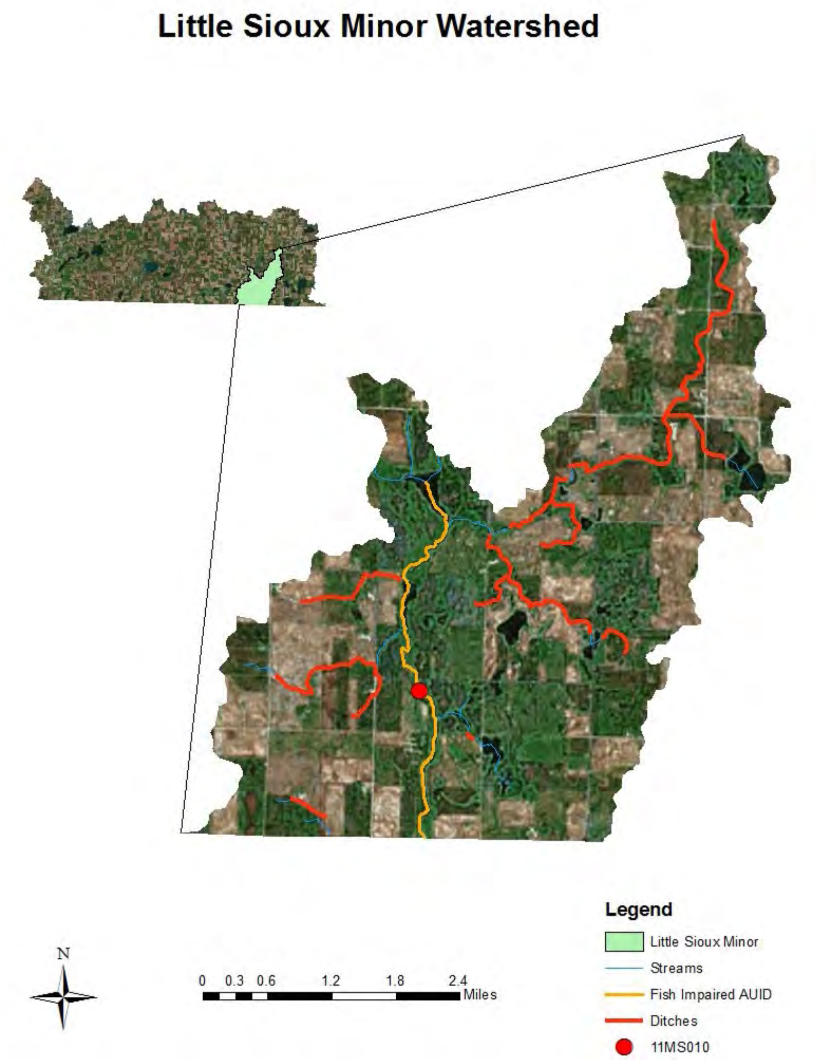

Figure 11. Little Sioux River Minor Watershed with biologically impaired AUIDs highlighted

Biology in Little Sioux River Minor Watershed

Fish

There is one biological sampling station, 11MS010, located along the impaired AUID of the Little Sioux River. This site is located 290 yards south of 715th Street and 1.5 miles north of the Iowa border and was sampled for fish on June 18, 2012. This site scored below the fish index of biological integrity (F-IBI) threshold and lower confidence limit for a Class 2 (Southern Streams) stream. The metric values for 11MS010 are shown below (Figure 13).

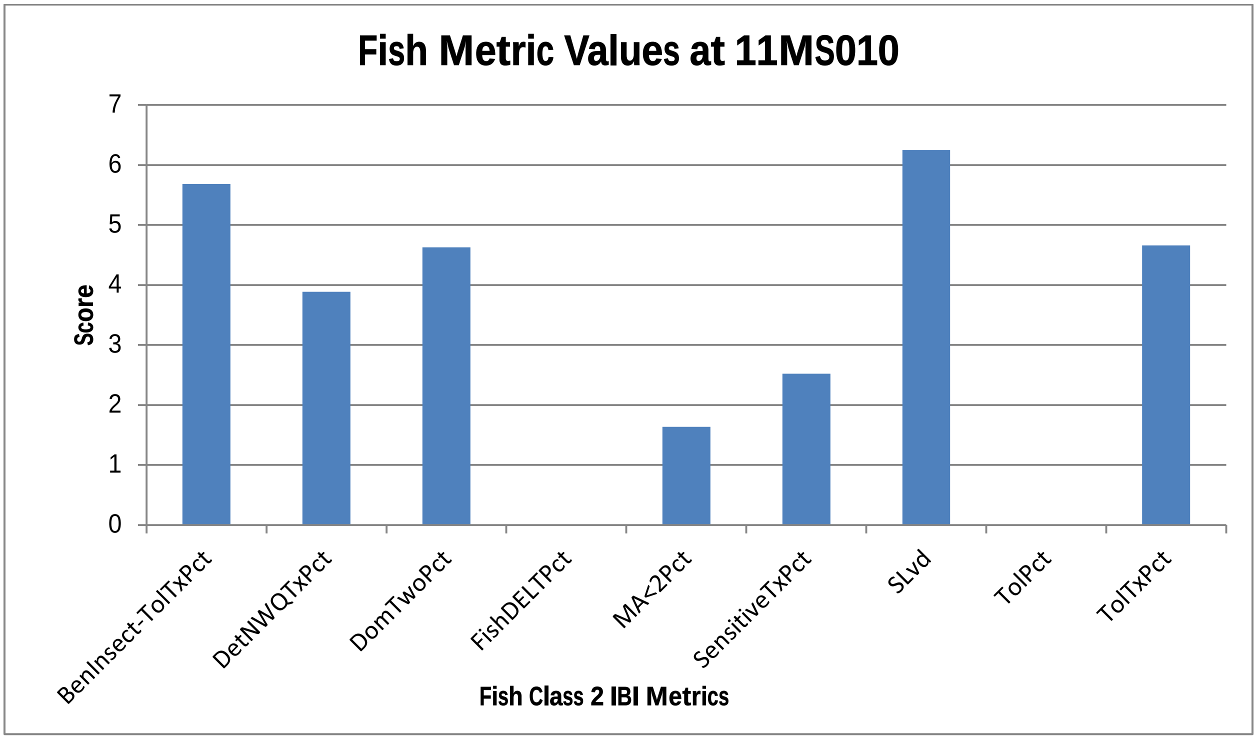

Figure 12. Fish IBI metric values at 11MS010 in the Little Sioux River Minor Watershed

The F-IBI threshold for a fish class 2 stream is 45. To reach this, each metric would need to average a score of 5. The only metrics to do so in the Little Sioux River were BenInsect-TolTxPct and SLvd. All other metrics scored below the average, especially MA<2Pct and TolPct.

Benthic Insectivores (BenInsect-TolTxPct) are the taxa percentage of fish which feed on insects along the stream bed. In order to maintain a healthy community, these species need a clean substrate to feed. A high metric score indicates a high presence of these species within this system. Short Lived (SLvd) is the taxa richness of species which are short lived. Short lived species prosper in systems with frequent stress due to their short life cycles. A high metric score indicates few short lived species at this bio site. Early maturing individuals (MA<2Pct) are the relative abundance of females that are two-years and younger. Early maturation is a trait adaptation to unstable habitats subject to environmental extremes. When environmental stress is present, the most successful species are those which quickly recover their populations. Therefore, communities that display a high percentage of early maturation individuals express the presence of environmental stress. As shown in Figure 13, there is a high presence of early maturing individuals. Tolerant percentage (TolPct) is the relative abundance of individuals that are tolerant in the sampled community. Tolerant fish are adapted to survival in conditions other, more sensitive fish are not. These conditions include low DO, lack of course substrate, high stream temps, etc. The low metric score indicates a high presence of these individuals in the sampled community.

Macroinvertebrates

Macroinvertebrates are not impaired in the Little Sioux River; however the MIBI score just surpasses the threshold of 38.8 for a class 7 stream with a metric score of 41.7. Some further investigation into specific metrics allows for an understanding as to why the metric score is so close to the threshold value and provides further insight to the conditions present at 11MS010. As seen in Figure 14, several metrics are responsible for the relatively low overall IBI score.

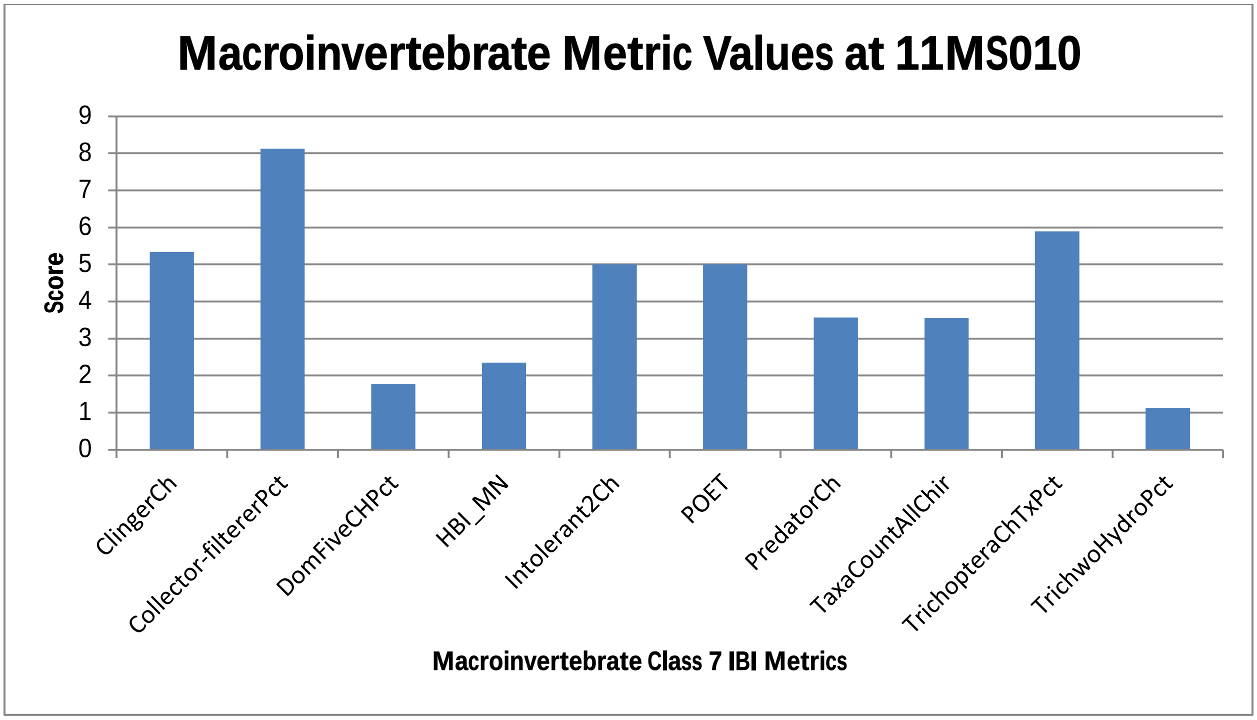

Figure 13. Macroinvertebrate IBI metric values at 11MS010 in the Little Sioux River Minor Watershed

To meet the MIBI threshold for a macroinvertebrate class 7 stream (Prairie Streams), each metric must average a score of 3.83. As shown in Figure 14, metrics limiting the macroinvertebrate IBI score are DomFiveCHPct, HBI_MN and TrichwoHydroPct, which are well below the average needed. Metrics PredatorCH and TaxaCountAllChir were just below the average metric value needed. The individual metrics show that the macroinvertebrate sample lacked abundance of the dominant five taxa (DomFiveCHPct), shows a high measure of pollution based on tolerance values (HBI_MN), had a low percentage of taxa belonging to the sensitive species Trichoptera (TrichwoHydroPct), had poor richness of predators (PredatorCh), and had poor total taxa richness (TaxaCountAllChir). All of these are indicators of stress on the macroinvertebrate community.

Candidate cause: Low dissolved oxygen

The daily minimum standard for DO in Minnesota Class 2C streams is 5 mg/L. All streams along the Little Sioux River Minor Watershed have either a 2B or 2C classification. No streams in this grouping are currently listed as impaired for DO.

There were a total of 45 dissolved oxygen readings taken in the Little Sioux River from 2011-2012 (Figure 15), 15 of those were taken before 9AM. Out of the 45 DO readings, 10 were lower than the daily minimum standard of 5 mg/L with only one of those measurements occurring before 9AM. The high value of 13.99 mg/L could potentially indicate a problem with daily flux, which was investigated using continuous sonde data.

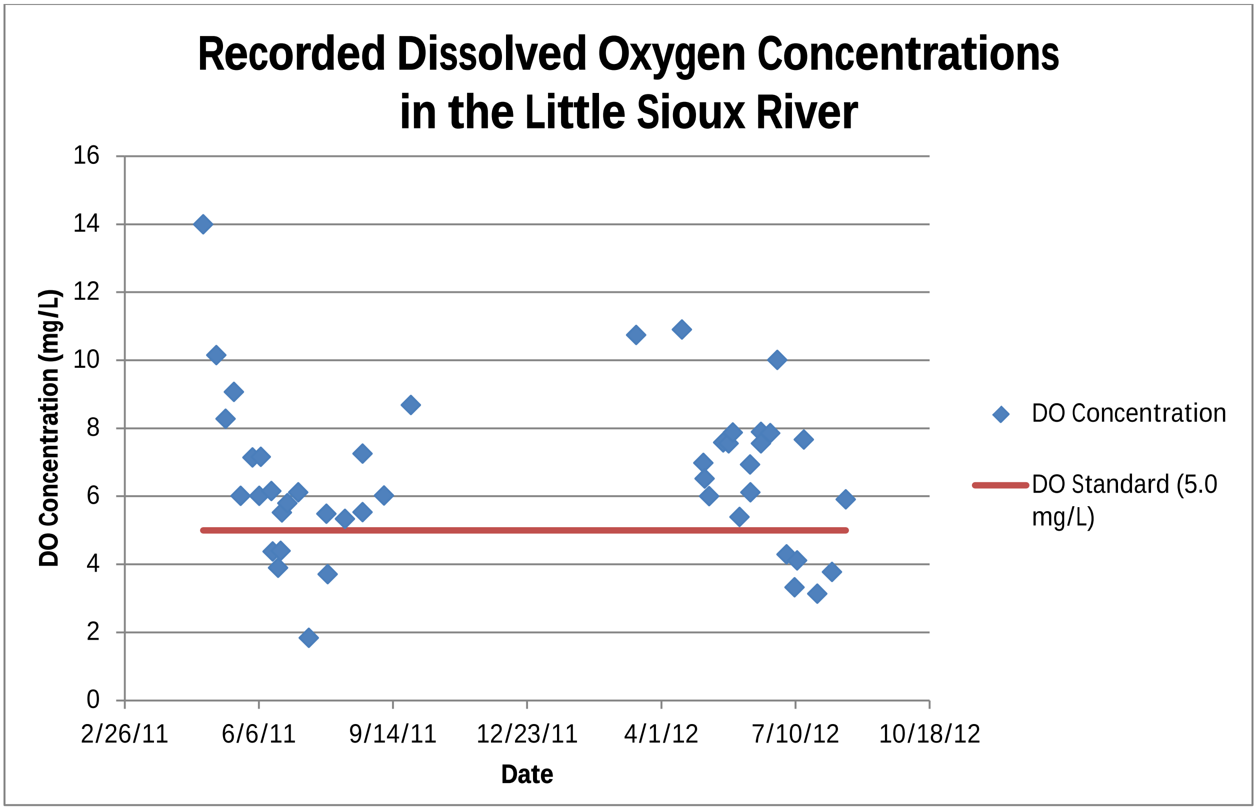

Figure 14. Dissolved oxygen values in the Little Sioux River from 2011-2012

Continuous DO data was collected at 11MS010 (S006-549) in the Little Sioux River from July 16 to July 30, 2013 (Figure 16). The continuous data shows that on 13 of the 14 days the sonde was deployed, the values dipped below the standard of 5 mg/L. Conditions below 5 mg/L can be detrimental to biological communities by reducing the growth rate as well as causing fatality in extreme cases (Allan, 1995) (Doudoroff and Warren, 1965). Along with dipping lower than the standard of 5 mg/L, the daily DO fluctuation exceeds the proposed regional standard of 4.5 mg/L (Figure 17). DO flux values between 2-4 mg/L are typical in a 24-hour period (Heiskary et al., 2010), but excessive daily flux is an indicator of stress on the aquatic community. Algal respiration and photosynthesis are considered the primary drivers of daily flux in DO, and high daily fluctuations of DO are connected to nutrient concentrations. Excess phosphorus values help fuel photosynthesis and algal respiration, which in turn is effecting the daily oxygen production and oxygen demand within the stream system. The resulting consequences can be seen in the high values of daily DO fluctuations.

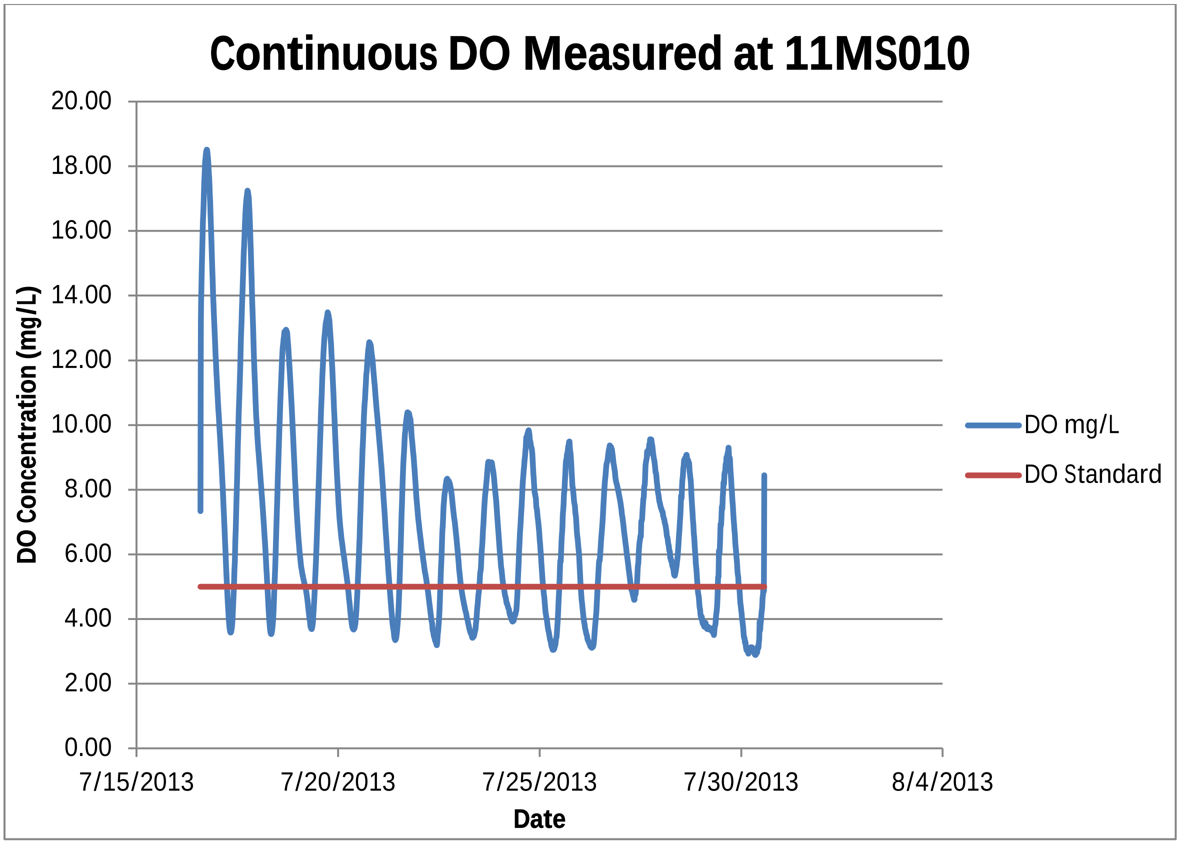

Figure 15. Continuous DO at station 11MS010

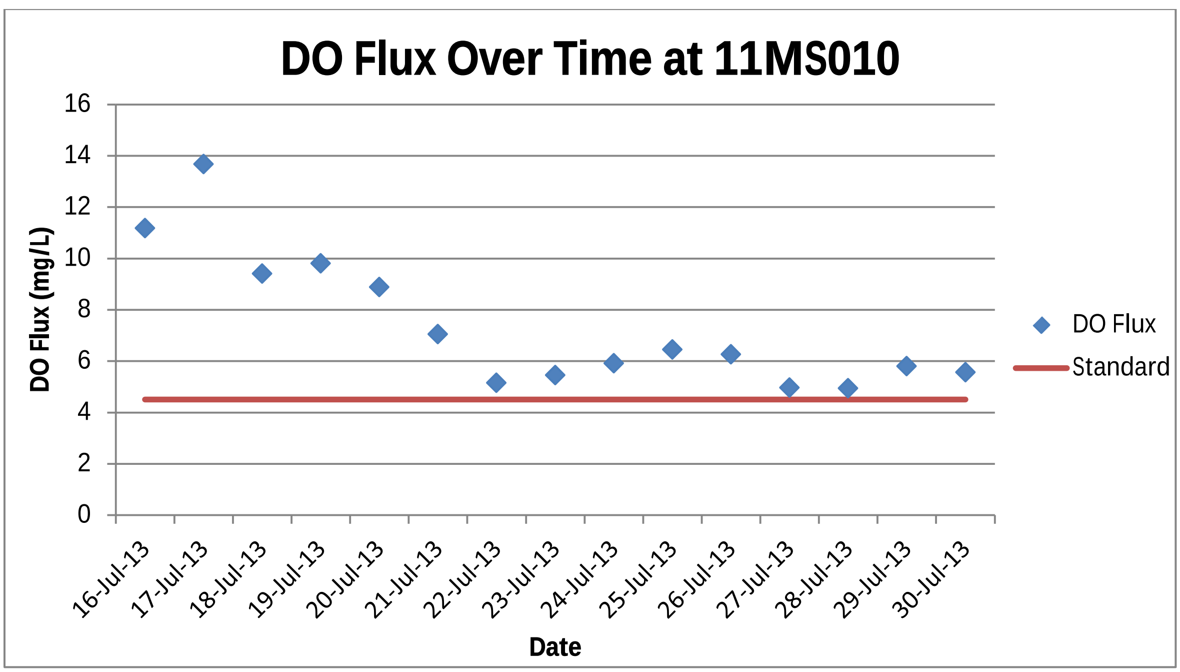

Figure 16. Daily DO fluctuations in the Little Sioux River

Biologically, the Little Sioux River had a below average amount of macroinvertebrate taxa (21) and above average EPT taxa (25.81%) when compared to the state average. These metrics tend to decrease if the stream is stressed by low dissolved oxygen levels. There were also above average amounts of tolerant macroinvertebrates (64.52%), tolerant fish taxa (63.64%), and serial spawning fish species (36.36%) compared to the state average. Serial spawning fish species are more prevalent in streams with low dissolved oxygen conditions. The percentage of late maturing fish, a group that is also affected by low DO, occurred near the state average (18.18%). Of the fish sampled, sand shiners, green sunfish and common carp helped make up a majority (62%) of the fish community sampled in the Little Sioux River (Figure 18). Each of these species are known to be tolerant to low DO conditions.

Figure 17. Sand Shiner left (dnr.cornell.edu) and Green Sunfish right (tnfish.org)

There are numerous amounts of DO standard exceedances in which the measured DO dips below the standard of 5 mg/L. Continuous sonde data also shows that daily DO flux is a problem along the Little Sioux River. This data, along with the biological metrics, supports DO as a stressor to the impaired fish community at this time. Although the macroinvertebrate community is not currently impaired, it is also stressed by the degraded dissolved oxygen conditions.

Candidate cause: High phosphorus

The proposed draft standard for total phosphorus for streams in the Missouri River basin is currently 0.15 mg/L. Although phosphorus is an essential nutrient for all aquatic life, elevated levels can lead to an imbalance, which impacts stream ecology. In the Little Sioux River Minor Watershed, phosphorus levels have exceeded this proposed standard multiple times.

From 2005-2012 a total of 82 phosphorus samples were taken from the Little Sioux River. Of these samples, 70.7% (58 samples) were above the proposed draft standard of 0.15 mg/L (Figure 19). Because TP is not a direct stressor, the high levels need to coincide with an elevated response variable of DO flux, chlorophyll-a, or BOD. There were a total of 16 chlorophyll-a measurements taken at S006-549 with one reading exceeding the proposed standard of 35 ug/L with a value of 45.9 ug/L. This value coincided with a high phosphorus value of 0.557 mg/L. The rest of the measurements were below the draft standard. There was no BOD data available for this reach. Continuous DO was measured from July 16, 2013 through July 30, 2013 by a YSI sonde with levels continually dipping below 5.0 mg/L and daily flux exceeding 4.5 mg/L on all days.

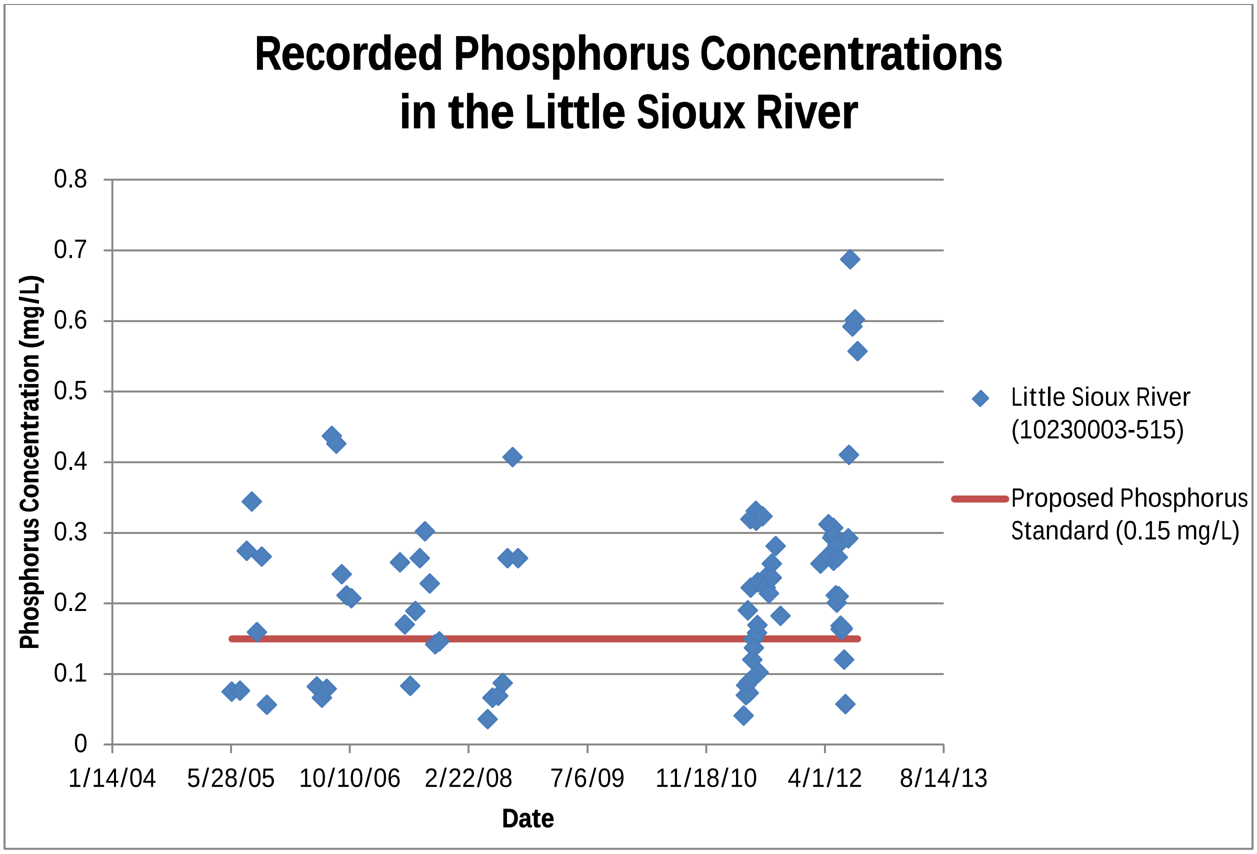

Figure 18. Phosphorus values in the Little Sioux River from 2005-2012

The Little Sioux River had an above average amount of EPT taxa (25.81%) when compared to other Minnesota streams. EPT taxa are inversely related to low phosphorus. This stream also had lower than average amounts of intolerant taxa (3.23%) and above average tolerant taxa (64.5%) compared to the state averages. Taxa count (21) at this bio site showed less taxon than the state average. There was a high amount of Collector-Filterer taxa (16.13%) but a low amount of Collector-Gatherer taxa (32.26%) when compared to the state averages. Both of these metrics decrease with increases in stress by phosphorus.

The Little Sioux River had a low amount of sensitive fish species (9.09%) and an above average amount of tolerant fish taxa (63.64%) when compared to state averages. There was a higher amount of darters/sculpin/round-bodied sucker (18.18%) compared to the state average. There was also a below average amount of simple lithophilic spawners (9.09%) along with a low taxa count (11) compared to state averages. These are results that are expected in steams with high levels of phosphorus.

Given the biological metric responses, the extremely high number of exceedances of the proposed phosphorus standard, along with the impaired DO and daily DO flux, phosphorus is a stressor to the impaired fish communities in the Little Sioux River.

Candidate cause: High nitrates

Currently, the State of Minnesota does not have a nitrate standard in place for streams not used as a drinking water source. However, an overabundance of nitrates can stress a biological community. Nitrates in the Little Sioux River did, at times, reach levels that could potentially be harmful to the biological assemblages.

From 2011-2012 a total of 51 nitrate samples were taken in the Little Sioux River. Macroinvertebrates are not impaired within this AUID, but as noted in the biology section, the IBI barely meets the threshold. A quantile regression showed with 90% confidence that a stream class 7, the same macroinvertebrate class as the Little Sioux River, will score below the designated MIBI threshold when nitrate values are over 11.5 mg/L (See Figure 20). Of the 51 samples taken at the Little Sioux River, no values were above 11.5 mg/L. Although no measurements exceed 11.5 mg/L, there are many values over the ecoregion value of 6.9 mg/L (27) indicating a potential issue with excess nitrates.

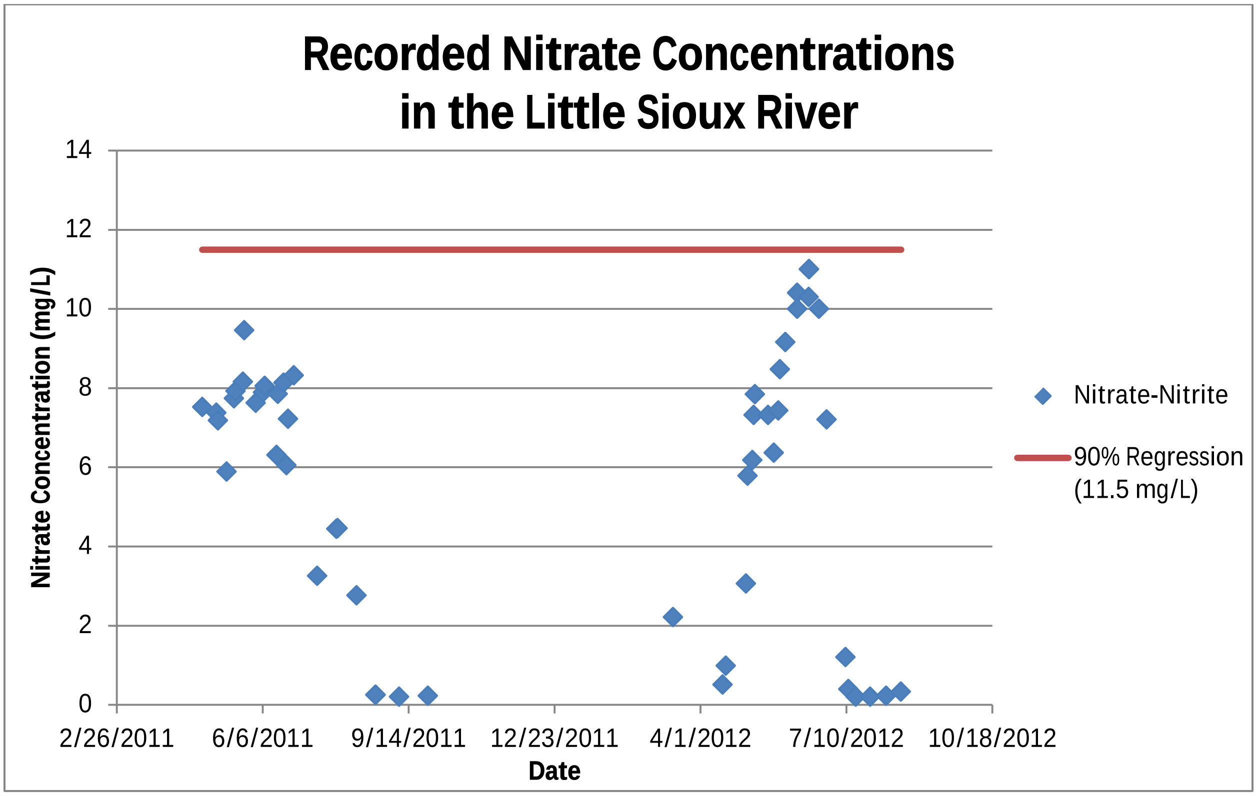

Figure 19. Observed nitrate levels in the Little Sioux River

Biologically, the Little Sioux River had below average amounts of fish taxa (11) and macroinvertebrate taxa (21) compared to state averages. Trichoptera taxa, which tends to decrease with increases in nitrogen, was below the state average (9.68%). The Little Sioux River also had a lower than average amount of sensitive fish taxa (9.09%). Sensitive fish species are more prevalent in streams with low nitrate values. There was a very high percentage of nitrate-tolerant macroinvertebrates sampled at this bio site with a community that had 74.8% of its individuals tolerant to nitrate. Additionally, there were 16 nitrate-tolerant individuals sampled at 11MS010 while only one nitrate-intolerant individual was sampled.

With the elevated nitrate values, poor biological metrics, and the high percentage of nitrate-tolerant macroinvertebrate individuals sampled, nitrate is a stressor to the impaired fish community and macroinvertebrate community in the Little Sioux River.

Candidate cause: High turbidity/TSS

The water quality standard for Turbidity is 25 NTU, 65 mg/L for TSS, and 20 cm for a transparency tube (at time of assessment) for class 2C and 2B warmwater streams in the Little Sioux River Minor Watershed. Excess sediment is a commonly recognized stressor in many biologically impaired streams because it can reduce habitat, cause direct physical harm to the biological communities, reduce visibility, and increase oxygen demand. The Little Sioux River (10230003-515) is currently impaired for aquatic life due to turbidity with the AUID immediately upstream also being impaired for turbidity, but is not listed as it is a channelized stream. These impairments are in addition to their biological impairments.

There were a total of 74 transparency measurements taken from 2005-2012 in the Little Sioux River using a Secchi tube. Of these measurements, 42 (56.8%) were below the transparency standard of 20 cm (Figure 21). There were also a total of 42 TSS samples taken from the Little Sioux River from 2011-2012. Of these samples, 10 (23.8%) were above the TSS draft standard of 65 mg/L (Figure 22).

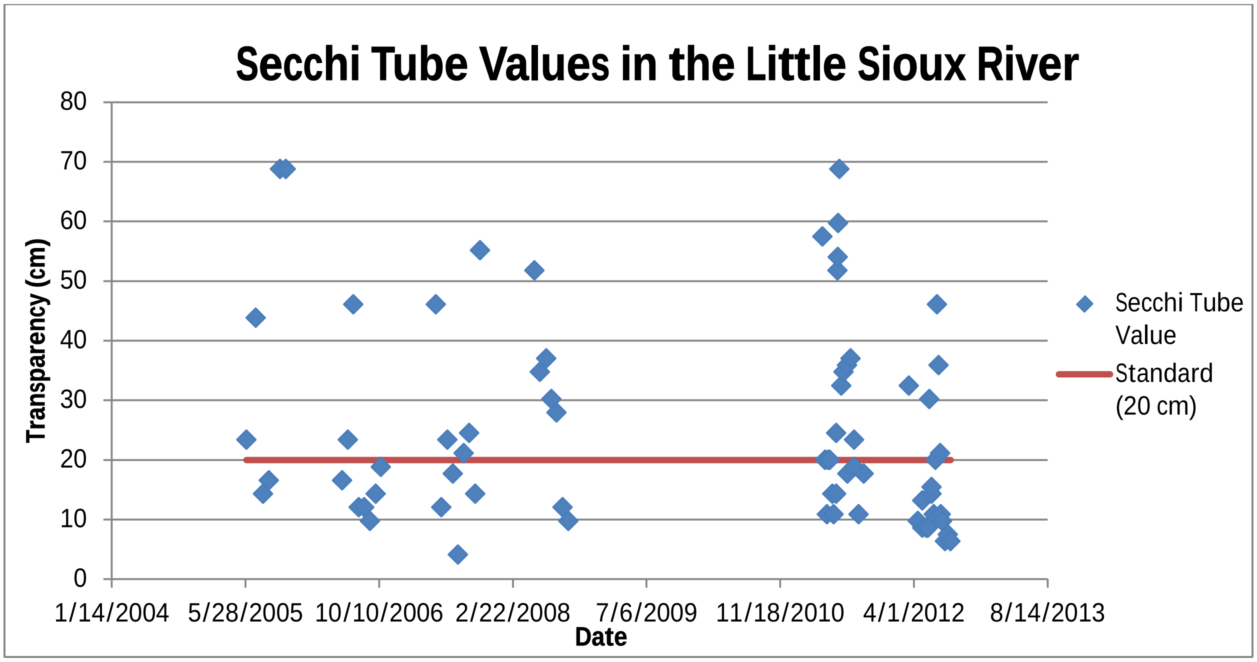

Figure 20. Measured Secchi tube values for the Little Sioux River from 2005-2012

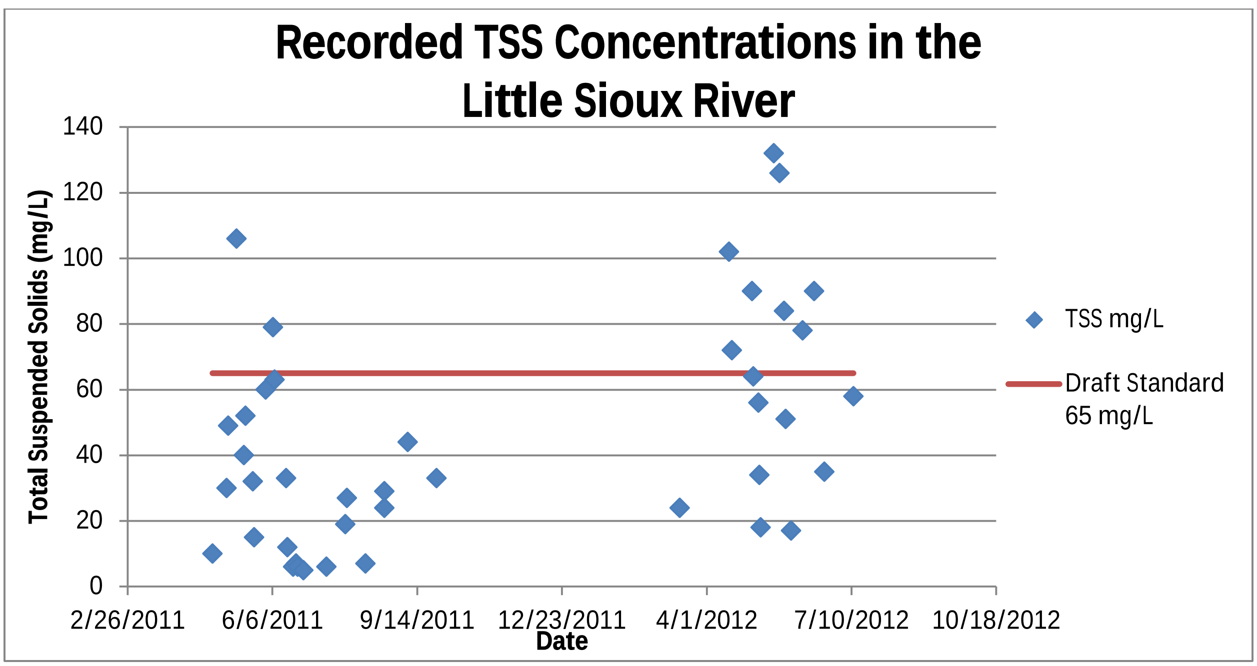

Figure 21. Recorded TSS concentrations in the Little Sioux River from 2011-2012

Pictures were taken during visits to the bio site, two of which are shown below. Figure 23 shows the transparency as well as the substrate. An s-tube value was collected at the time of the picture with a value of 40 cm. Figure 24 depicts scum and algae built-up along the bank near the bio site.

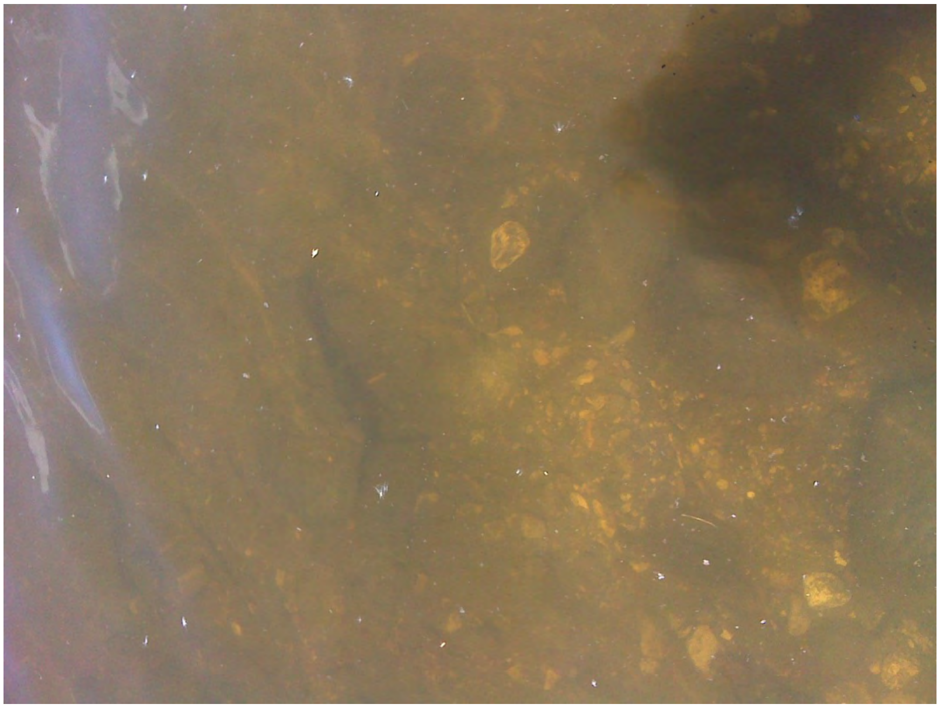

Figure 22. Transparency in shallow water at 11MS010

Figure 23. Scum build-up along banks at 11MS010

Biologically, there was an above average amount of Ephemeroptera taxa (16.13%), and just below average Trichoptera taxa (9.68%) when compared to state averages. These types of macroinvertebrates are typically found more frequently in clear/transparent streams. Collector-filterers occurred at an above average amount (16.13%) and long-lived species (9.68%) were just below the state average. Both of these metrics decrease with an increase in turbidity and TSS. The Little Sioux River also had a below average amount of macroinvertebrate taxa (21) and a higher than average amount of tolerant macroinvertebrate taxa (64.52%) when compared to other streams across the state. There was a very high percentage of TSS-tolerant macroinvertebrates sampled at this bio site with a community that had 75.1% of its individuals tolerant to TSS. Additionally, there were 15 TSS-tolerant individuals sampled at 11MS010 while no TSS-intolerant individuals were sampled.

The fish assemblage in the Little Sioux River did not have a presence of herbivorous fish taxa (0%). Herbivorous fish tend to prefer clear, transparent water and struggle in streams with high TSS values. Simple lithophilic spawners were well below the state average (9.09%) while riffle-dwelling fish were also below the state average (9.09%). Both of these metrics increase in clear/transparent streams. Sensitive fish taxa existed at a lower than average rate (9.09%) compared to other streams throughout the state. Of the sampled fish community, 89.7% of the individuals were moderately to very tolerant of turbidity (Sand Shiner, Red Shiner, Green Sunfish, Common Carp, Yellow Bullhead, Black Bullhead, Bluntnose Minnow, and Quillback). These responses are expected when the fish communities experience stresses from increased TSS values.

With the numerous s-tube and TSS measurements exceeding their respective standard, along with the biological responses, excess turbidity/TSS is a stressor to the impaired fish community in the Little Sioux River. The metrics also indicate the macroinvertebrate community is impacted by the turbidity/TSS conditions present in the Little Sioux River, supporting the current turbidity impairment designation.

Candidate cause: Lack of habitat

Habitat quality in the Little Sioux River is poor in the biologically impaired AUID. The Minnesota Stream Habitat Assessment (MSHA) was the main tool used for evaluating this potential stressor and the results of the habitat score can be seen in Figure 25.

The habitat for site 11MS010 on the Little Sioux River had a MSHA score of 42.5 out of 100 (poor). Habitat conditions were mainly limited by the surrounding land use, a narrow riparian buffer, lack of shade, and moderate channel stability. Course substrates (Figure 23) were present but there was a high percentage of embeddedness with fine sediments. The Little Sioux River surrounding the impaired site was a low gradient system lacking prominent stream bed features, such as glides and riffles. Below, Figure 26 shows the limited surrounding land use, while Figure 27 shows the poor bank stability near 11MS010.

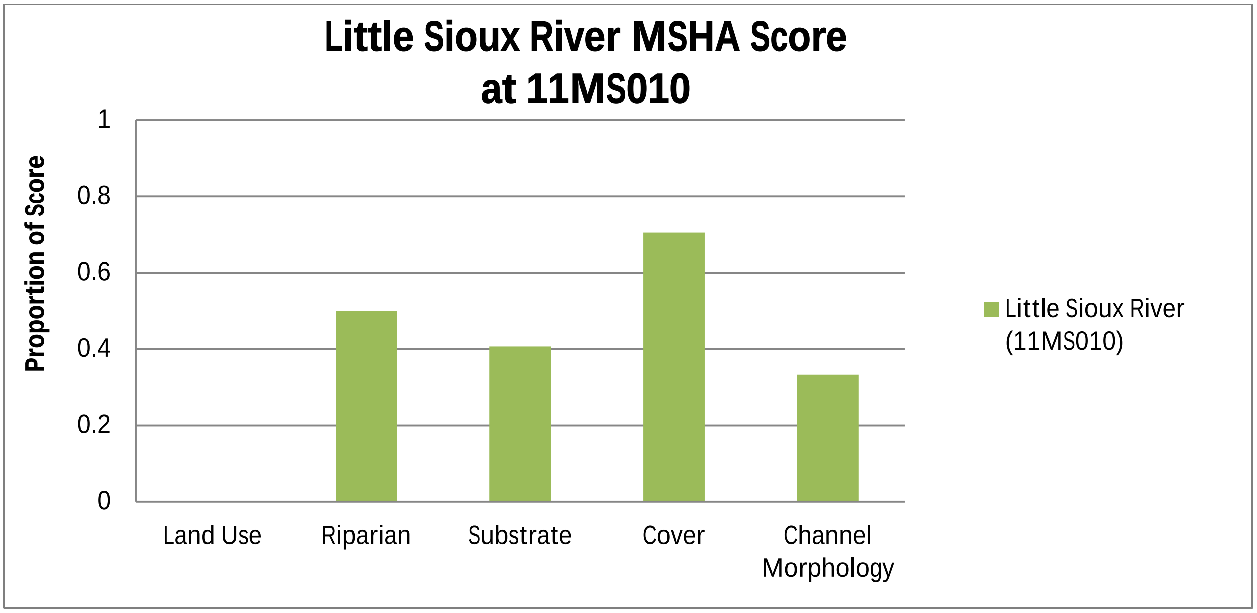

Figure 24. Proportion of possible MSHA subcategory scores in the Little Sioux River at site 11MS010

Figure 25. Land use surrounding 11MS010

Figure 26. Eroded bank on the Little Sioux River near 11MS010

Fish populations had an above average amount of tolerant taxa (63.6%) compared to state averages, which are common in streams with a degraded habitat. There was a below average amount of simple lithophilic spawning taxa (9.09%), and riffle dwelling fish (9.09%) compared to state averages. Burrowers (16.13%), which prefer fine sediment as a substrate, occurred above the state average. There were below average numbers of benthic insectivore taxa (18.18%), and above average darters/sculpin/round-bodied sucker taxa (18.2%) when compared to state averages. These types of fish species need clean gravel to spawn/maintain their healthy life cycles.

The majority of habitat-related metrics reflect the poor MSHA score for this AUID. As a result, the lack of habitat due to surrounding land use, narrow riparian buffer, lack of shade and moderate channel stability, is a stressor to the impaired fish communities in the Little Sioux River.

Weight of evidence

Weight of Evidence tables for the biologically impaired streams in the Little Sioux River Minor Watershed, as well as all of the biologically impaired AUIDs are available in Appendix 3.1 and 3.2. A table summarizing the individual metric values for both impaired biological sites as well as the state averages is available in Appendix 2.1.

Conclusions

In the Little Sioux River, low dissolved oxygen, high phosphorus and nitrates, turbidity/TSS, and lack of habitat were all found to be stressors causing the fish community to be impaired.

Low dissolved oxygen conditions exist in the Little Sioux River and are affecting the overall health of the fish community. The supporting evidence for this is the numerous amounts of measured data that exceeds the standard along with the continuous sonde data that shows frequent daily DO fluctuations exceeding the standard. Biology in the Little Sioux River supports the chemical data with a low overall fish taxa count, a high presence of serial spawning fish species, and high amounts of tolerant fish taxa. The high presence of phosphorus within this watershed is likely driving this impairment.

Phosphorus levels were elevated in the watershed with 70.7% of samples exceeding the phosphorus standard. Excess phosphorus itself does not directly result in harm to biological communities; however, it does cause imbalances in the stream system affecting other factors that do, in particular low DO and high DO flux. The abundant agricultural fields are one of the likely sources for these amounts of phosphorus to enter the Little Sioux River.

High nitrates were also found to be stressing the fish community in the Little Sioux River. Nitrate concentrations were found to exceed 6.9 mg/L for 53% of the samples collected. These conditions created fish communities with few fish taxa and few sensitive fish taxa. Fertilizer runoff from fields adjacent to these streams, as well as tile and drainage practices throughout the watershed, are a likely source of these high nitrate concentrations. Installing a proper riparian buffer, bioreactors, treatment wetlands, and a nutrient management plan would help limit the abundance of nitrates entering the stream system.

Turbidity and TSS both had levels that exceeded their current standards. Secchi tube measurements fell below the standard at a high rate (56.8%), while TSS had 10 (23.8%) measurements exceeding the standard. The timing of the high TSS values is important, as the two highest values (132 mg/L, 126 mg/L) came during spring melt. Due to the timing of the high values, it can be concluded that land use in the area has a great effect on the TSS values.

In-stream habitat was also determined to be a stressor to fish communities in the Little Sioux River with an MSHA score of 42.5 (poor). The habitat was mainly limited by poor land use, narrow riparian buffer, limited stream shading, poor channel development, and low channel stability. Habitat improvement projects would help alleviate the stress caused by lack of habitat to the biological communities in this AUID.

Overall, the biological community in the Little Sioux River will remain limited if the numerous stressors impacting the fish assemblage are not mitigated. Significant changes need to be made to the land use and agricultural practices prevalent in this watershed.

Table 8. Biologically Impaired AUID in the Little Sioux River Minor Watershed and its Stressors
(• = stressor, - = not a stressor, and blank = inconclusive/not enough evidence)

		Stressors				
Stream name	**AUID #**	**Low Dissolved Oxygen**	**High Phosphorus**	**High Nitrates**	**High Turbidity/TSS**	**Lack of Habitat**
Little Sioux River Minor Watershed						
Little Sioux River	10230003-515	•	•	•	•	•

Ocheyedan River Minor Watershed

Ocheyedan River Minor Watershed is located in the southwestern corner of the Little Sioux River Watershed. There is one impaired AUID, the Ocheyedan River (AUID: 10230003-501) which was sampled in 2011 for macroinvertebrates and 2012 for fish. This AUID was determined to be impaired for aquatic life due to its macroinvertebrate and fish assemblages. The impaired AUID extends 2.58 miles from Peterson Slough downstream to Bella Lake. See Figure 28 below for a more detailed map of the impaired AUID and watershed. The land use in the Ocheyedan River Minor Watershed is dominated by cropland (78.85%). Other land uses that constitute the rest of the 12-digit HUC watershed are rangeland (9.04%), developed land (5.72%), and wetlands (3.24%).

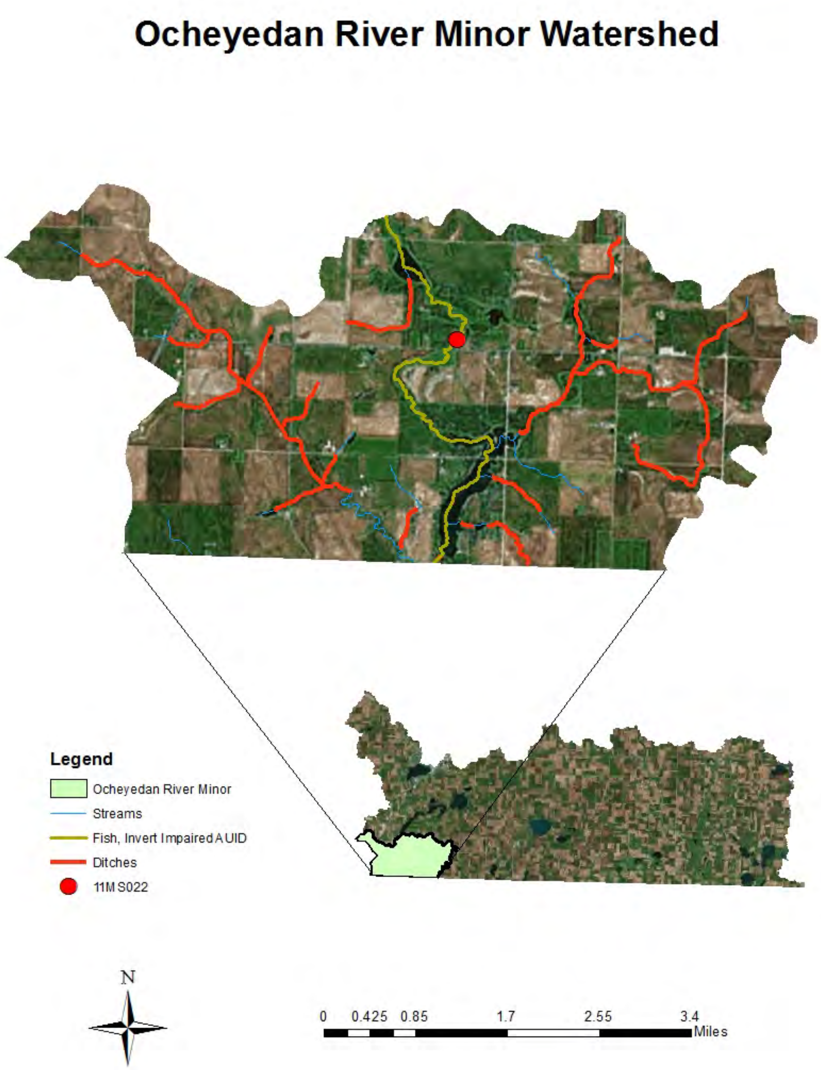

Figure 27. The Ocheyedan River Minor Watershed with the fish and macroinvertebrate impaired AUID highlighted

Biology in the Ocheyedan River

Fish

There is one biological sampling station, 11MS022, located 1471 yards downstream of Peterson Slough and 172 yards upstream of CSAH 4 (320th St.). This site was sampled on June 19, 2012 for fish and scored below the F-IBI threshold for a class 2 (Southern Streams) stream and below the lower confidence limit. The metric values for 11MS022 are shown below (Figure 29).

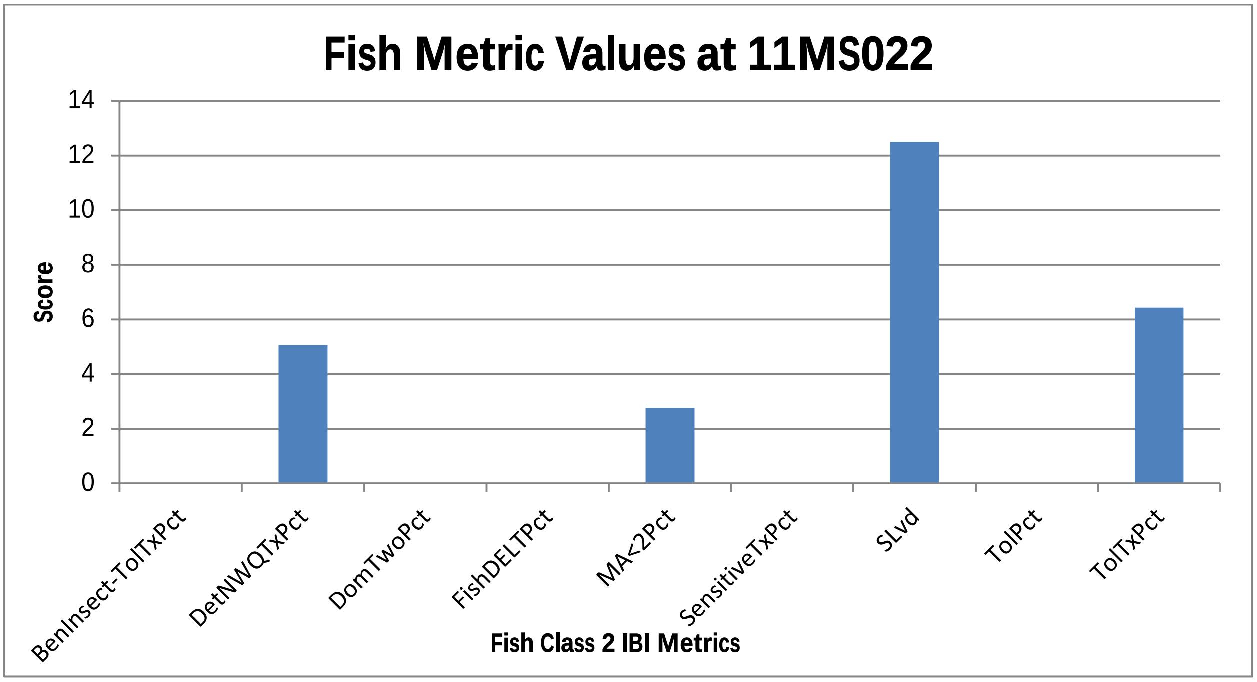

Figure 28. Fish IBI metric values in the Ocheyedan River at biological sampling station 11MS022

The F-IBI threshold for a fish class 2 stream is 45. To reach this threshold, each metric would need to average a score of 5. As shown above, there is only one metric that meets this score; short-lived species (SLvd). Fish IBI metrics scoring below average in the Ocheyedan river are benthic insectivores (BenInsect-TolTxPct), dominant two species (DomTwoPct), fish with deformities or lesions (FishDELTPct), early maturing individuals (MA<2Pct), sensitive species (SensitiveTxPct), and tolerant individuals (TolPct).

BenInsect-TolTxPct is the taxa percentage of fish which feed on insects along the stream bed. In order to maintain a healthy community, these species need a clean substrate to feed. A low metric score indicates a low presence of these species within this system and is an indication of embeddedness.

DomTwoPct is the relative abundance of the two most abundant taxa. The increase in abundance of the two most dominant taxa indicates a lack in overall taxa richness. It is a negative indicator for the biological community to have poor taxa richness. As indicated by a low metric score, this site has poor taxa richness.

MA<2Pct is the relative abundance of early maturing individuals, or females that are two-years and younger. Early maturation is a trait adaptation to unstable habitats subject to environmental extremes. When environmental stress is present, the most successful species are those which quickly recover their populations. Therefore, communities that display a high percentage of early maturation individuals expresses the presence of environmental stress. As shown in Figure 29, there is a high presence of early-maturing individuals.

SensitiveTxPct is the relative abundance of taxa which are sensitive in the sampled community. Sensitive fish are not adapted to survival in adverse conditions that other, more tolerant fish are. A low metric score indicates a lack of sensitive taxa in the fish community.

TolPct is the relative abundance of individuals that are tolerant in the sampled community. Tolerant fish are adapted to survival in conditions which other, more sensitive fish are not. These conditions include low DO, lack of course substrate, high stream temps, etc. The low metric score indicates a high presence of these individuals in the sampled community.

Macroinvertebrates

The macroinvertebrate sample also scored below the MIBI threshold for a class 7 (Prairie Streams GP) stream, but within the lower confidence limit with an overall score of 28.4. Figure 30 below shows a specific metric by metric breakdown of the overall MIBI score for 11MS022.

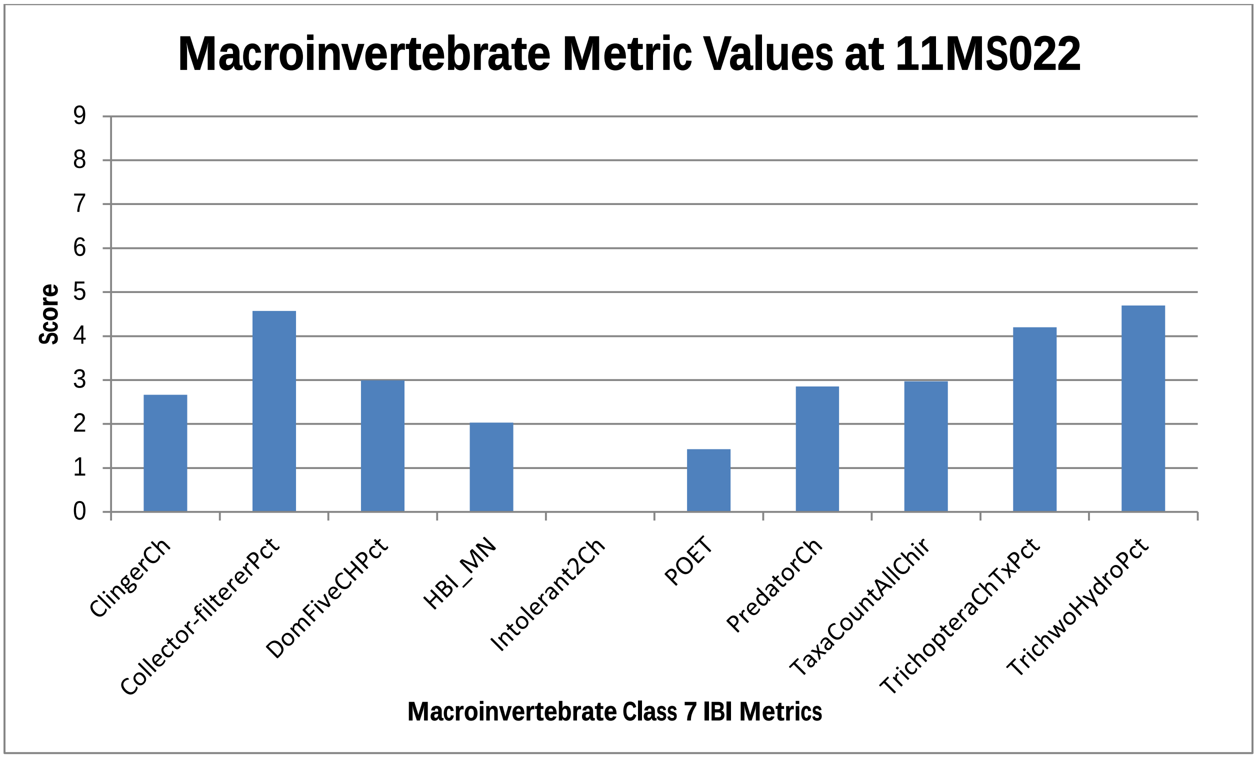

Figure 29. Individual macroinvertebrate metric scores for 11MS022

To meet the MIBI threshold for a macroinvertebrate class 7 stream, each metric would need to average 3.83. The only metrics to do so in the Ocheyedan river were collector-filterers (Collector-filtererPct), Tirchoptera (TrichopteraChTxPct), and non-hydropsychid Trichoptera individuals (TrichwoHydroPct). All other metrics scored below the average. The lowest scoring metrics were HBI_MN, Intolerant2Ch, and POET. This indicates that the macroinvertebrate sample lacked intolerant taxa (Intolerant2Ch), it shows there is a stress to the community based on tolerance indicator values (HBI_MN), and lacks taxa richness of Plecoptera, Odanata, Ephemereoptera and Trichoptera (POET); taxa that are considered good indicators of overall stream health due to their sensitive nature.

Candidate cause: Low dissolved oxygen

The daily minimum standard for DO in Minnesota Class 2B streams is 5 mg/L. All streams along the Ocheyedan River Minor Watershed have a 2B classification. No streams in this grouping are currently listed as impaired for DO.

There were a total of 42 dissolved oxygen measurements taken at Ocheyedan River from 2010-2012 (Figure 31). Of these, zero exceeded the daily minimum standard of 5 mg/L with the highest recorded value being 12.26 mg/L. Twelve of these samples were taken before 9 AM.

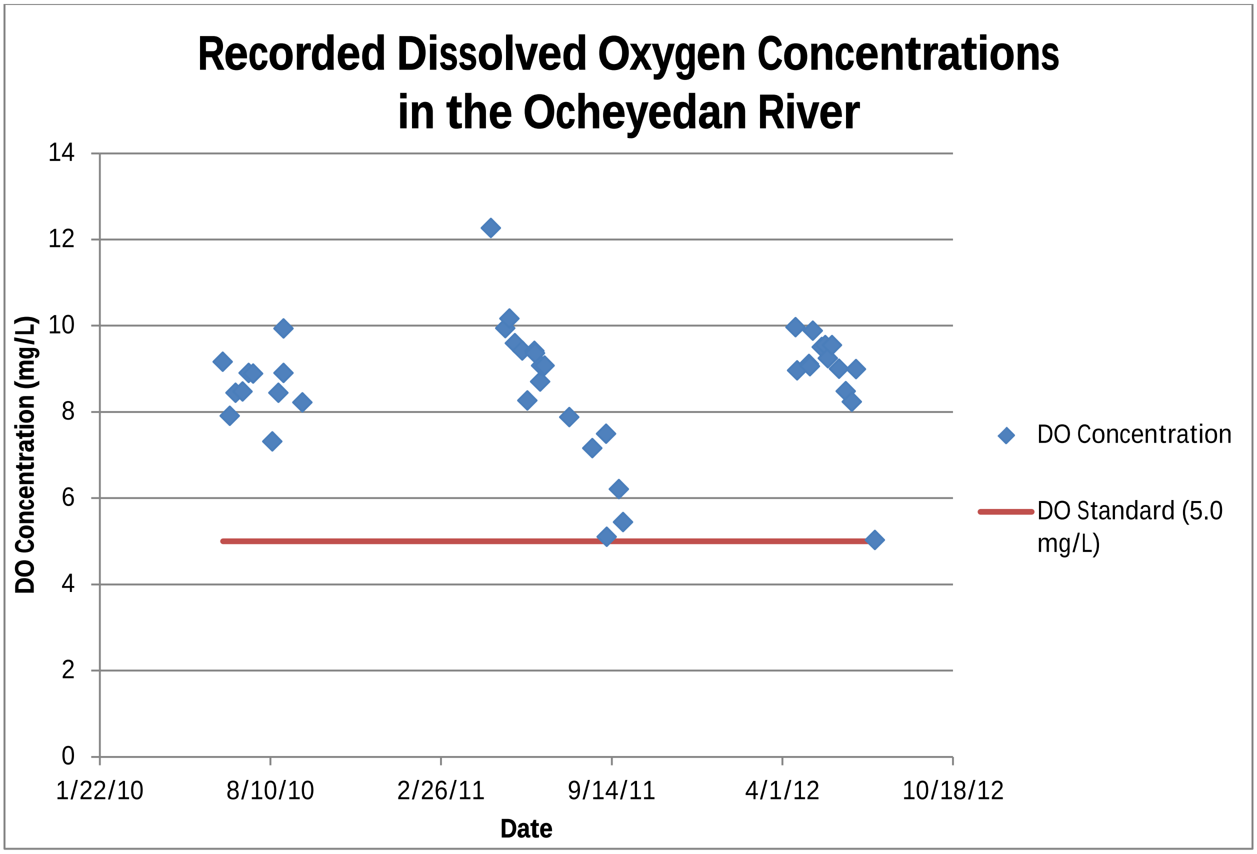

Figure 30. Dissolved oxygen values in the Ocheyedan River from 2010-2012

The HSPF model calculated hourly dissolved oxygen concentrations along this AUID from 1996-2009. During this time frame, there were zero values that were below the 5 mg/L daily minimum standard. Daily flux values were also calculated during this time frame, there were no exceedances of the 4.5 mg/L daily fluctuation standard.

Biologically, the Ocheyedan River had a below average amount of macroinvertebrate taxa (21) and EPT taxa (10.3%) when compared to state averages. These metrics decrease if the stream is stressed by low dissolved oxygen levels. There was also an above average amount of tolerant macroinvertebrates (72.4%) and tolerant fish taxa (55.6%), as well as serial spawning fish species (33.3%) compared to state averages. These species are more prevalent in streams with low dissolved oxygen conditions. The Ocheyedan River also exceeded the state average for late-maturing fish (44.4%), something that is uncommon in streams with low dissolved oxygen. Of the fish sampled, fathead minnows (71.2%), and common carp (9.2%) made up the majority of the fish community in the Ocheyedan River. These two species are known to be tolerant to low dissolved Oxygen.

The biological response by the macroinvertebrate and fish communities indicate stress from dissolved oxygen, however with the chemistry and model data showing no measurements exceeding the DO standards, dissolved oxygen is not a stressor to the impaired fish and macroinvertebrate communities. This indicates the negative biological responses are likely due to another stressor. Continuous dissolved oxygen monitoring with a sonde is recommended to further evaluate the DO conditions in this reach.

Candidate cause: High phosphorus

The proposed draft standard for total phosphorus for streams in the Missouri River basin is currently 0.15 mg/L. Although phosphorus is an essential nutrient for all aquatic life, elevated levels can lead to an imbalance which impacts stream ecology. In the Ocheyedan River Minor Watershed, phosphorus levels have exceeded this proposed standard multiple times.

A total of 45 phosphorus measurements were taken from the Ocheyedan River from 2011-2012. Of these samples, 84.4% were above the proposed draft standard of 0.15 mg/l (Figure 32). There were two chemical monitoring sites for phosphorus, one at the bio site and one located downstream of Bella Lake. In the future, the effect of the surrounding lakes on the Ocheyedan River phosphorus concentration should be investigated further as both the upstream lake (Ocheda Lake) and downstream lake (Bella Lake) are impaired for nutrients. Because TP is not a direct stressor, the high levels need to coincide with an elevated response variable of DO flux, chlorophyll-a, or BOD. There was no chlorophyll-a or BOD data collected at this site. There was also no sonde deployed at this site to capture daily DO flux.

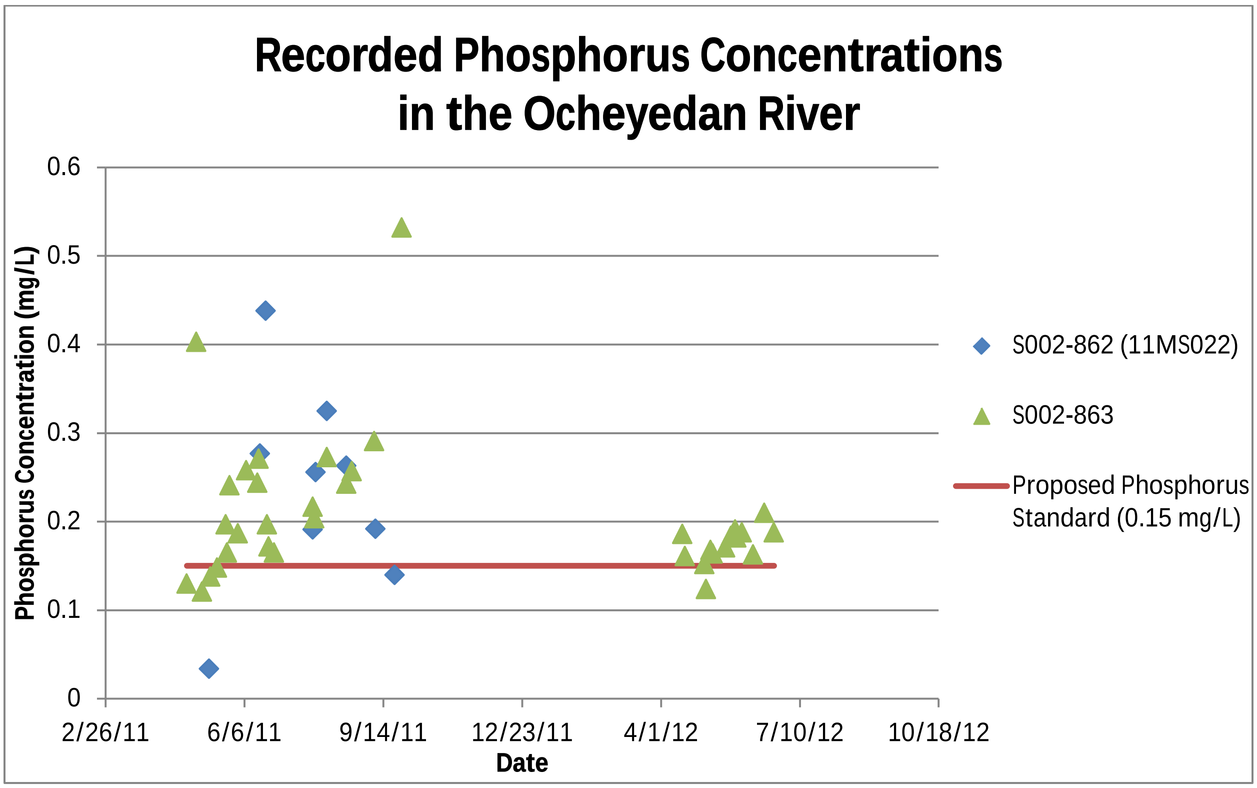

Figure 31. Phosphorus values in the Ocheyedan River from 2011-2012

The HSPF model calculated daily phosphorus concentrations along the Ocheyedan River from 1996-2009. Of these calculations, 42.1% were above the 0.15 mg/L proposed draft standard. Biologically, the Ocheyedan River had a below average amount of EPT taxa (10.3%) when compared to other Minnesota streams. EPT taxa are much more common in streams with low phosphorus. This stream also had below average intolerant macroinvertebrate taxa (0%), and above average tolerant macroinvertebrate taxa (72.4%) compared to state averages. Taxa count was below the state average with 21 different macroinvertebrate taxa sampled at the bio site. There was a below average amount of collector-filterers (3.5%) and above average collector-gatherers (37.9%) compared to state averages.

The Ocheyedan River had no sensitive fish species (0%) and an above average amount of tolerant fish taxa (55.6%) compared to state averages. There were no darters/sculpin/round-bodied sucker (0%)

present in the Ocheyedan River, and simple lithophilic spawners (22.2%) were below the state average. There was also a low taxa count (9) compared to the state average.

With the frequent violations of the proposed draft standard, along with the negative biological responses, phosphorus is a stressor to the impaired fish and macroinvertebrate communities in the Ocheyedan River at this time.

Candidate cause: High nitrates

Currently, the State of Minnesota does not have a nitrate standard in place for streams not used as a drinking water source. However, an overabundance of nitrates can stress a biological community. A total of 45 nitrate measurements were taken in the Ocheyedan River from 2011-2012. A quantile regression of macroinvertebrate class 7 streams in Minnesota shows with 90% confidence that if a stream has a Nitrate-Nitrite concentration of 11.5 mg/l or higher, the MIBI score will be below the designated threshold. Using measured data, the Ocheyedan River had 0 of 45 measurements above 11.5 mg/L (See Figure 33).

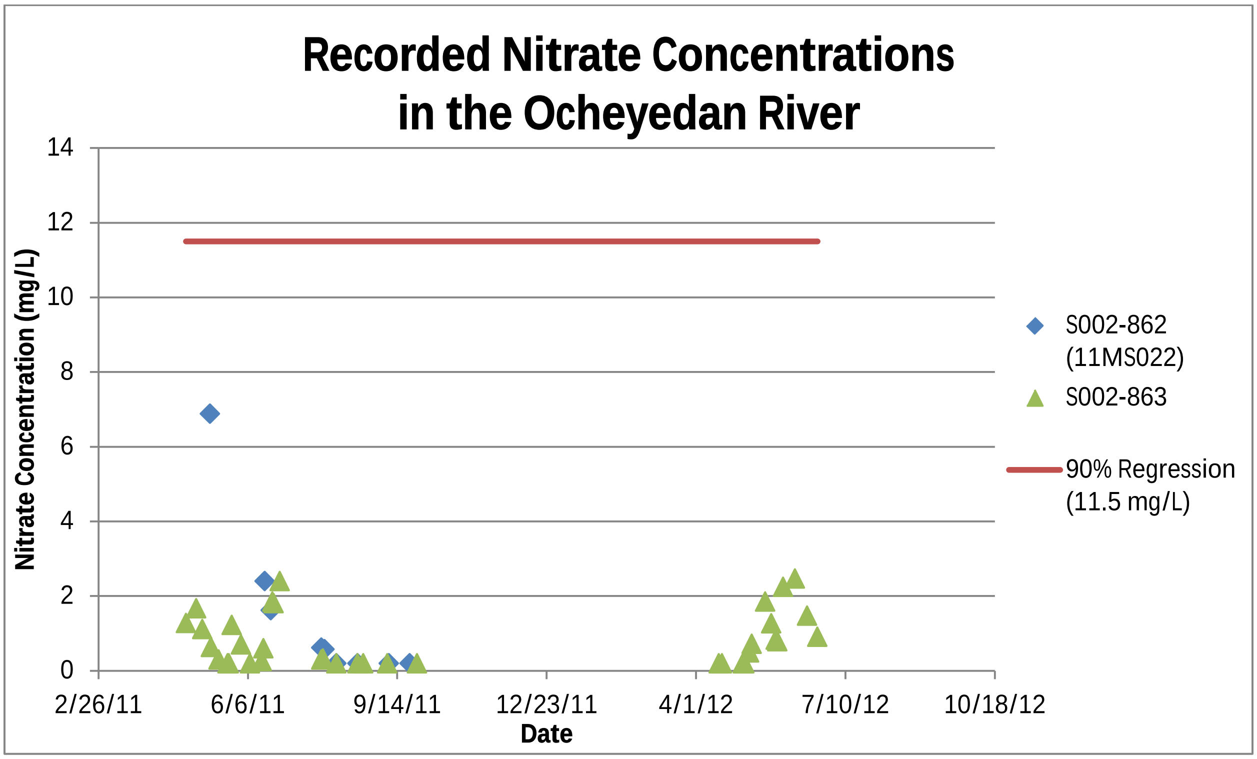

Figure 32. Recorded nitrate concentrations in the Ocheyedan River from 2011-12

The HSPF model calculated daily nitrate concentrations along Ocheyedan River from 1996-2009. Of these calculations, no values were above 11.5 mg/L. There were 432 (8.4%) values that exceeded 6.9 mg/L, indicating values do reach higher levels that could cause stress to the biological communities.

Biologically, the macroinvertebrate sample collected in 2011 showed a below average amount of nitrate-sensitive Trichoptera taxa (6.9%) compared to the state average. The Ocheyedan River also had below average amounts of fish taxa (9) and macroinvertebrate taxa (21) when compared to the state average along with no sensitive fish species present. There was a very high percentage of nitrate-tolerant macroinvertebrates sampled at this bio site with a community that had 81.3% of its individuals tolerant to nitrate. Additionally, there were 16 nitrate-tolerant individuals sampled at 11MS022 while no nitrate-intolerant individuals were sampled.

The measured nitrate values as well as the HSPF results do not exceed the 90% regression value. Biological metric response and tolerance indicator values indicate a possible issue due to nitrates, but due to the contradicting chemical data, it is inconclusive if nitrates are a stressor to the biological communities in the Ocheyedan River. It is recommended that further nitrate and biological monitoring be done at 11MS022 in the future.

Candidate cause: High turbidity/TSS

The water quality standard for Turbidity is 25 NTU, 65 mg/L for TSS, and 20 cm for a transparency tube (at time of assessment) for class 2B warmwater streams in the Ocheyedan River Minor Watershed. Excess sediment is a commonly recognized stressor in many biologically impaired streams because it can reduce habitat, cause direct physical harm to the biological communities, as well as reduce visibility and increase oxygen demand.

A total of 52 Secchi tube measurements were taken from 2010-2012 in the Ocheyedan River. Of these measurements, 32 (61.5%) were below the transparency standard (Figure 35). From 2011-2012, 45 TSS measurements were taken from the Ocheyedan River and five (11.1%) exceeded the draft standard (Figure 36). Those five exceedances were limited to 2011 and did not occur in 2012. Three of those readings were at levels more than two times the draft standard. These high levels were measured at times during or immediately following a rain event, or during a time of high runoff conditions in late winter/early spring.

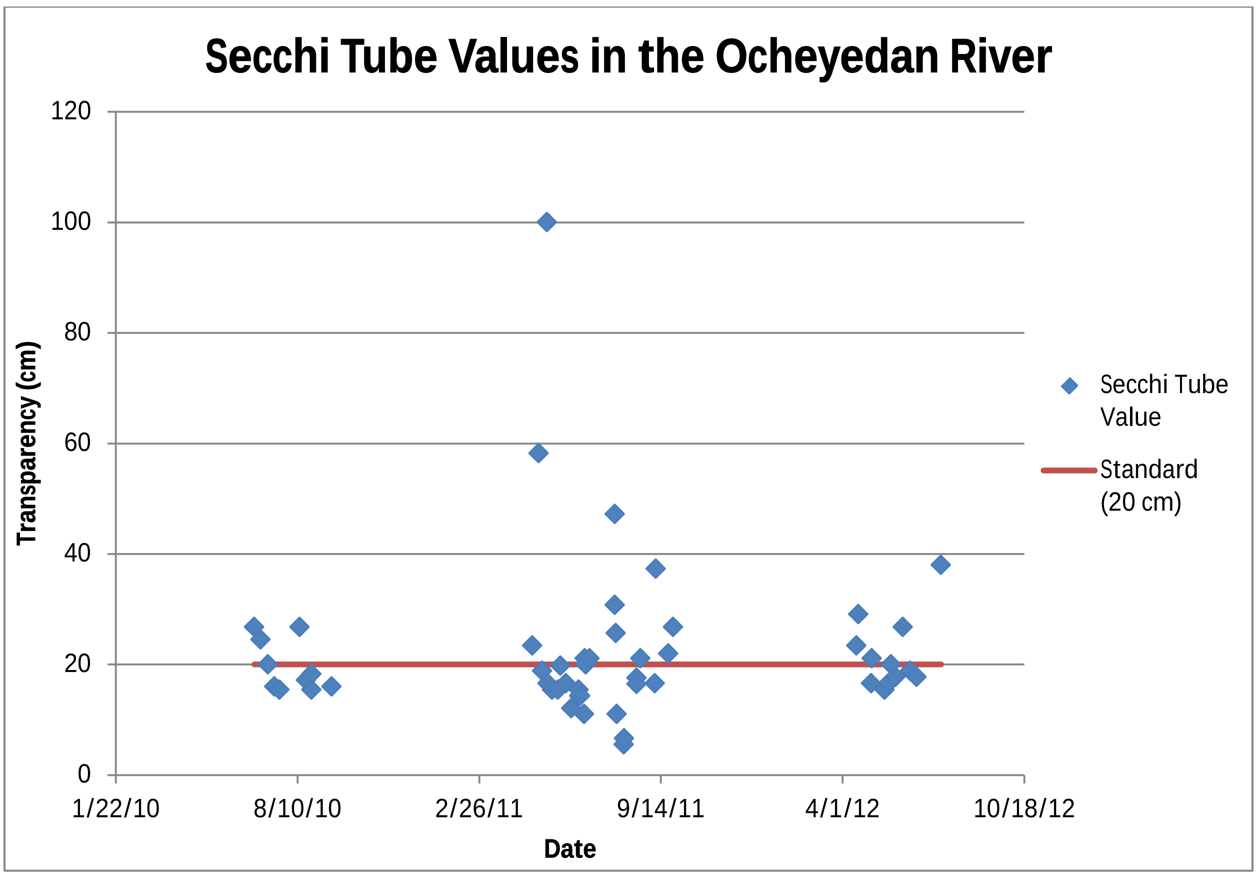

Figure 33. Measured Secchi tube values for the Ocheyedan River from 2010-2012

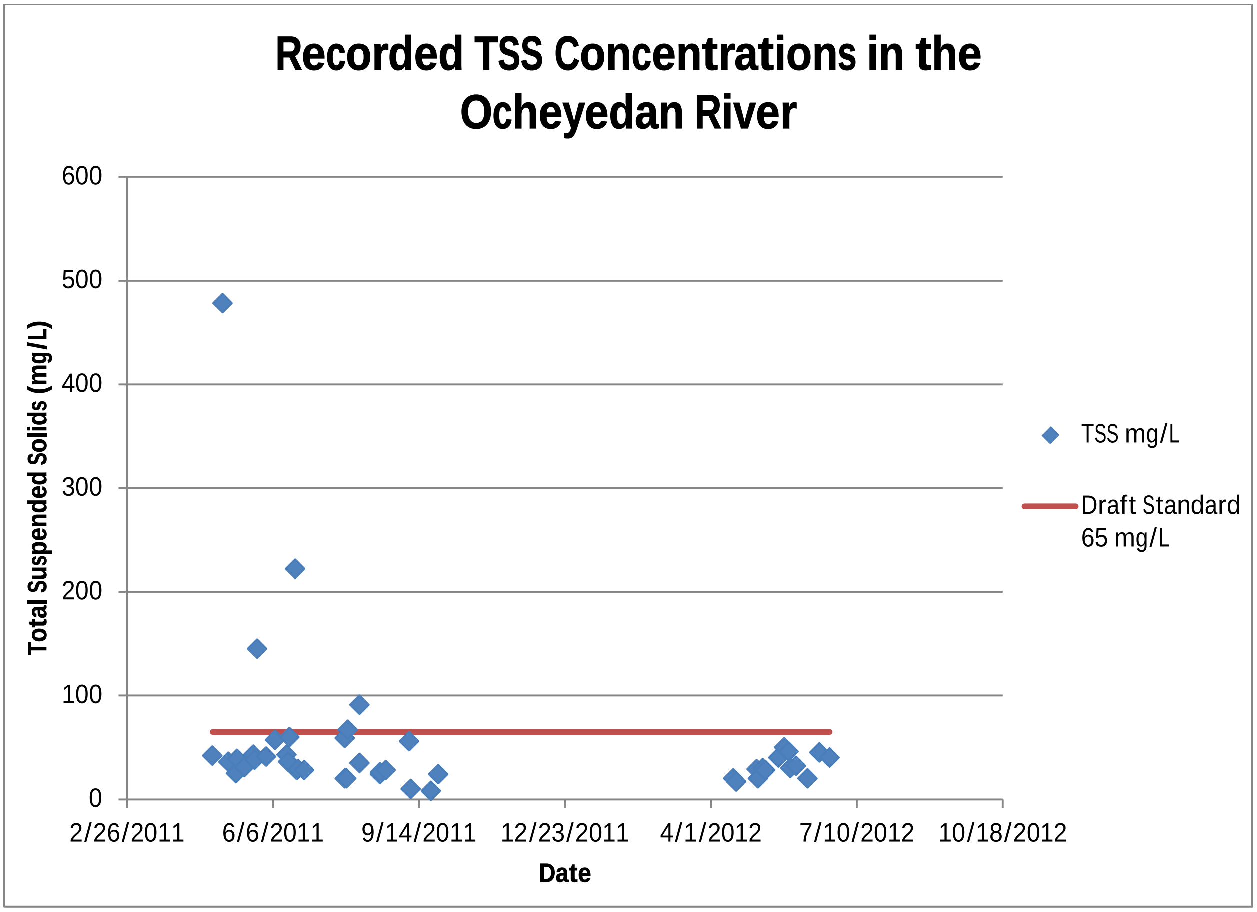

Figure 34. Recorded TSS concentrations in the Ocheyedan River from 2011-2012

Biologically, the Ocheyedan River had a below average amount of Ephemeroptera taxa (3.45%) and below average amount of Trichoptera taxa (6.90%) compared to state averages. These types of macroinvertebrates are typically found more abundantly in clear/transparent streams. Collector-filterers occurred at a below average amount (3.45%) and long-lived species (10.34%) were at the state average. Both of these metrics decrease with an increase in stress from turbidity and high TSS. The Ocheyedan River also had a below average amount of macroinvertebrate taxa (21) and higher than average amount of tolerant macroinvertebrate taxa (72.41%) when compared to other streams across the state. There was a very high percentage of TSS tolerant macroinvertebrates sampled at this bio site with a community that had 72.18% of its individuals tolerant to TSS. Additionally, there were 14 TSS-tolerant individuals sampled at 11MS022 while no TSS-intolerant individuals were sampled.

The fish assemblage in the Ocheyedan River did not have a presence of herbivorous fish taxa (0%). Herbivorous fish tend to prefer clear, transparent water. Simple lithophilic spawners were right below the state average (22.2%) while riffle dwelling fish were also below the state average (11.1%). Both of these metrics increase in clear/transparent streams. There were no sensitive fish taxa present in the Ocheyedan River. Of the sampled fish, 100% were either tolerant or moderately tolerant of turbidity (Fathead Minnow, Common Carp, White Sucker, Yellow Perch, Black Bullhead, Channel Catfish, Orange-Spotted Sunfish, Walleye, and Yellow Bullhead).

While the majority of biological metrics indicate local fish and macroinvertebrate communities could be stressed due to high turbidity and TSS, the overall low TSS values along with no TSS value exceeding the draft standard in the last year indicates mixed results. Secchi tube readings are low, but due to the discrepancies in the data, it is inconclusive as to whether or not high turbidity and TSS are a stress to the local fish and macroinvertebrate communities at site 11MS022. It is recommended that more Secchi tube and TSS samples be collected as well as further biological monitoring be carried out in the Ocheyedan River.

Candidate cause: Lack of habitat

Habitat quality in the Ocheyedan River is fair in the biologically impaired AUID. The MSHA was the main tool used for evaluating this potential stressor and the results of the habitat score can be seen in Figure 37. The habitat for site 11MS022 on the Ocheyedan River had a MSHA score of 49.2 out of 100 (fair). Habitat conditions were mainly limited by the lack of a riparian buffer, lack of shade, and poor channel stability.

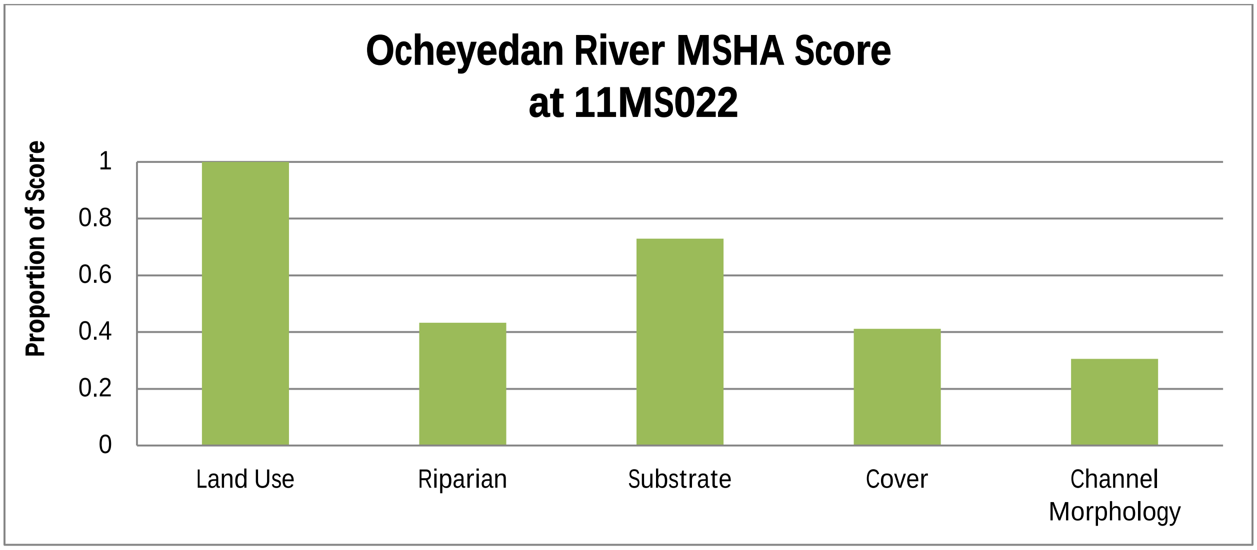

Figure 35. Proportion of possible MSHA subcategory scores in Ocheyedan River at site 11MS022

The surrounding land use is the predominant land use on each bank within approximately two to three square miles, with an emphasis placed on upstream land use. At station 11MS022, there is an abundance of prairie land at and upstream of the sampling site. This resulted in a score of five out of five for the Land Use category. This is important to note because this is not representative of the overall land use surrounding the entire impaired AUID. See Figure 38 for images of land use practices near 11MS022.

Figure 36. Surrounding land uses at 11MS022.

There was some evidence of a lack of bank stability along this AUID as seen in Figure 39. However, with the surrounding land use it does not seem to be a significant problem immediately surrounding 11MS022.

Figure 37. Bank erosion near 11MS022

Biologically, the Ocheyedan River had an above average amount of tolerant macroinvertebrate taxa (72.41%) and below average amount of Clinger taxa (20.69%) compared to state averages. Clinger taxa have a tendency to be less abundant in streams with degraded habitat conditions. The dominant two species exceeded the state average (47.2%) which is expected in a steam stressed by poor habitat conditions.

The fish assemblage in this AUID had lower numbers of riffle dwelling taxa (11.11%) and lacked benthic insectivore species (0%) compared to state averages. There was also a higher amount of tolerant fish taxa (55.56%) and below average numbers of simple lithophilic spawning species (22.22%) compared to state averages. Also, there was a lack of darters/sculpin/round-bodied sucker taxa (0%) at 11MS022, these fish species require clean gravel to spawn and maintain their healthy life cycles.

Despite the fair MSHA score, each of the habitat related metrics indicates a negative response. As a result, the lack of habitat due to poor channel stability, lack of a riparian buffer and lack of shading, is a stressor to the impaired fish and macroinvertebrate communities in the Ocheyedan River.

Weight of Evidence

Weight of Evidence tables for the biologically impaired streams in the Ocheyedan River Minor Watershed, as well as all of the biologically impaired AUIDs are available in Appendix 3.1 and 3.2. A table summarizing the individual metric values for both impaired biological sites as well as the state averages is available in Appendix 2.1.

Conclusions

In the Ocheyedan River, high phosphorus and lack of habitat were found to be stressors causing the fish and macroinvertebrate communities to be impaired.

Phosphorus levels were elevated in the watershed with 84.4% of samples exceeding the proposed phosphorus standard. Excess phosphorus itself does not directly result in harm to biological communities; it does however cause imbalances in the stream system affecting other factors that do. The abundant agricultural fields are the likely pathway for these amounts of phosphorus to enter the Ocheyedan River.

In-stream habitat was also determined to be a stressor to biological communities in the Ocheyedan River with an MSHA score of 49.2 (fair). The habitat was mainly limited by the limited stream shading, a lack of riparian buffer, poor channel development, and low channel stability. Habitat improvement projects would help alleviate the stress caused by lack of habitat to the biological communities in this AUID.

Overall, the biological conditions in the Ocheyedan River will remain limited with these stressors impacting the fish and macroinvertebrate assemblages. Until significant changes are made to the land use and agricultural practices prevalent in this watershed, expect to see unhealthy biological communities throughout.

Table 9. Biologically Impaired AUID in the Ocheyedan River Minor Watershed and its Stressors
(• = stressor, - = not a stressor, and blank = inconclusive/not enough evidence)

		Stressors				
Stream name	**AUID #**	**Low Dissolved Oxygen**	**High Phosphorus**	**High Nitrates**	**High Turbidity/TSS**	**Lack of Habitat**
Ocheyedan River Minor Watershed						
Ocheyedan River	10230003-501	-	•			•

Summary and recommendations

The Little Sioux River Watershed is impaired for aquatic life due to its biological assemblages at two different AUIDs across two subwatersheds.

Dissolved oxygen is determined to be a stressor in one of the AUIDs. Out of the entire dissolved oxygen data set for the Little Sioux River Watershed, few samples were collected prior to the 9 AM cutoff for determining daily minimums. It is recommended that more early-morning monitoring be executed, as well as deploying sondes to gain continuous data at sites with few current data points. By deploying a sonde, one will get a clearer picture of what the dissolved oxygen conditions are within a specific stream.

Phosphorus is determined to be a stressor at both impaired AUIDs. Samples taken throughout the Little Sioux River Watershed display a similar level of exceedance when compared to the two impaired AUIDs, indicating phosphorus is an issue throughout the entire watershed. To further the understanding of phosphorus in the Little Sioux River Watershed, more chlorophyll-a, BOD and continuous sonde-monitoring should be conducted. To solve the problem of high phosphorus in the Little Sioux River Watershed, a large scale plan to reduce phosphorus levels is greatly needed. This plan should include efforts to improve the timing and rate of fertilizer application, as well as increasing the presence and width of riparian buffers. Without these changes, phosphorus will continue to easily runoff into the stream system and negatively impact the biological assemblages within this watershed.

Elevated nitrate values are also a concern in the Little Sioux River Watershed. This study concluded that nitrate is a stressor at one of the impaired AUIDs. This was supported by low numbers of trichoptera taxa, as well as many tolerant fish and macroinvertebrate taxa among other nitrate-related biological metrics. Similar to phosphorus, a large scale plan to reduce nitrate levels is needed in this watershed. Often, nitrate levels spiked during times of fertilizer application. Reducing the application time and rate, and improving the riparian buffers, will greatly improve the nitrate conditions in this watershed. Until improvements are made, expect the biological conditions to degrade.

To read more about nitrate conditions, trends, sources, and ways to reduce nitrates throughout Minnesota, please refer to *Nitrogen in Minnesota Surface Waters* (MPCA 2013).

Excess amounts of turbidity and TSS are issues that will also need to be addressed in the Little Sioux River Watershed. This study concluded that one of the impaired AUIDs is stressed by high turbidity and TSS. Currently, there are four AUIDs in this watershed which are impaired due to the current turbidity conditions, including two others which are deferred impairments due their classification as channelized streams. This indicates a long-standing issue of high turbidity within the Little Sioux River Watershed. Ways to reduce this watershed-wide issue would be to limit cattle access to streams, maintain an ample riparian corridor, plant cover crops, adopt rotational grazing, and install deep rooted vegetation along the stream banks. These improvements would help stabilize the stream channel and banks, which often lead to eroded banks and the release of sediment throughout the water column. Planting cover crops can also help by reducing the amount of sediment lost to early spring snow melt and rain events which carry sediment off of the bare ground and into the streams. These upgrades would also help lessen the impact on stream banks during high flow events.

The habitat conditions in the Little Sioux River Watershed often limited the success and health of the biological assemblages. This study identified both of the AUIDs are found to be stressed due to the lack of suitable habitat conditions. Habitat conditions in the Little Sioux River Watershed were mostly fair to poor. Commonly found problems were the poor surrounding land use, lack of ample riparian buffer, minimal stream shading, eroding banks, low channel stability, the high presence of silt or sand substrates, and sparse fish cover. Like the other stressors found, habitat conditions will improve by increasing the immediate riparian area and limiting cattle access to the stream. Stabilizing the stream banks, planting cover crops, and adopting rotational grazing will also help limit the amount of sediment entering the stream which covers the course substrates that are preferred by many types of sensitive types of fish species. Other habitat improvement projects that provide more cover for fish are greatly needed in this watershed.

Overall, significant problems and stressors to the biological communities exist in the Little Sioux River Watershed. Substantial changes are needed watershed-wide to help mitigate the damages caused by the prolonged poor land use and lack of riparian buffer. Until these improvements and long term changes are made, expect the fish and macroinvertebrate assemblages in the Little Sioux River Watershed to remain stressed and impaired.

Appendix 1.1 – MPCA fish IBI class criteria for Little Sioux River Watershed streams

Fish IBI Class	Class Name	Drainage Area	Gradient
2	Southern Streams	> 30 mi^2, < 300 mi^2	not specified

Appendix 1.2 – MPCA macroinvertebrate IBI class criteria for Little Sioux River Watershed streams

M-IBI IBI Class	Class Name	Drainage Area	Description
7	Prairie Streams (Glide/Pool Habitats)	<500 mi^2	Sites in Minnesota that are representative of the Prairie Parklands and Tall Aspen Parklands ecological provinces

Appendix 2.1 – Table of Metric Values for Impaired Sites

	Metric	11MS010	11MS022	State Average Taxa Pct	Metric Response to stress
Inverts	EPTChTxPct	25.81	10.34	22.99	↓
	TolerantChTxPct	64.52	72.41	61.7	↑
	Taxa Count	21	21	24.4	↓
	ScraperChTxPct	9.677	13.79	12.16	↑
	TrichopteraChTxPct	9.68	6.9	10.31	↓
	EphemeropteraChTxPct	16.13	3.45	11.53	↓
	IntolerantChTxPct	3.23	0	9.39	↓
	CrustMollChTxPct	16.13	17.24	11.73	↑
	ClingerChTxPct	32.26	20.69	29.59	↓
	Collector-filtererChTxPct	16.13	3.45	13.02	↓
	Collector-gathererChTxPct	32.26	37.93	35.06	↓
	ChironomidaeChTxPct	35.48	31.03	33.3	↑
	LonglivedChTxPct	9.68	10.34	10.48	↓
	DomTwoChTxPct	49.2	47.19	42.1	↑
	BurrowerChTxPct	16.13	13.8	13.19	↑
Fish	TolTxPct	63.64	55.56	50.7	↑
	SSpnTxPct	36.36	33.33	21.7	↑
	MA>3TxPct	18.18	44.44	21.3	↓
	Taxa Count	11	9	12.22	↓
	HerbvTxPct	0	0	5.25	↓
	SensitiveTxPct	9.09	0	19.8	↓
	BenInsectTxPct	18.18	0	19.2	↓
	SLithopTxPct	9.09	22.22	24.88	↓
	RiffleTxPct	9.09	11.11	16.32	↓
	DarterSculpSucTxPct	18.18	0	13.94	↓
Metric that responded negatively to stress					

Appendix 3.1 – Weight of evidence table for Little Sioux River Minor Watershed

	Low Dissolved Oxygen	High Phosphorus	High Nitrates	Turbidity/TSS	Lack of Habitat
Spatial/temporal co-occurrence	+ (Chosen because data from 2011-2013 has a number of values below 5 mg/L, sonde data strongly indicate high flux, bio data supports chemical data)	+ (Chosen because similar streams throughout region with similar fish and macroinvertebrate populations had phosphorus problems, many measurements, and many samples above 0.15 mg/l)	+ (Chosen because sample data exceeded the ecoregion 75% regression value, model data had elevated values, bio metric data supported chemical data.)	+ (Chosen because of the TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data that supports the chemistry data.)	+ (Chosen because site 11MS010 had a poor MSHA score, photos of very degraded conditions)
Temporal sequence	+ (Chosen because data from 2011-2013 has a number of values below 5 mg/L, sonde data strongly indicate high flux, bio data supports chemical data)	+ (Many measurements dating back to 2005 with a high percentage above 0.15 mg/L.)	+ (Chosen because many measurements dating back to 2011 along with support from model)	+ (Chosen because many measurements dating back to 2005 with many Secchi values below 20 cm.)	0 (Chosen because there are no historical measurements before the bio samples in 2012)
Field evidence of stressor-response	++ (Chosen because data from 2011-2013 has a number of values below 5 mg/L, sonde data strongly indicate high flux, bio data supports chemical data)	++(Chosen because of very high values exceeding standard, many tolerant fish and macroinvertebrates)	++ (Chosen because sample data exceeded the Nitrate ecoregion 75% regression value, model data had elevated values, bio metric data supported chemical data)	++ (Chosen because of the TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data that supports the chemistry data.)	+ (Chosen because of very poor MSHA score, majority of habitat related bio metrics reflect the conditions)
Causal pathway	+ (Chosen because of high amounts of ag in watershed, elevated phos levels, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, elevated nitrate levels, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers in watershed)
Evidence of exposure, biological mechanism	NE	NE	NE	NE	NE
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE

	Low Dissolved Oxygen	High Phosphorus	High Nitrates	Turbidity/TSS	Lack of Habitat
Verified or tested predictions	+++ (Chosen because data from 2011-2013 has a number of values below 5 mg/L, sonde data strongly indicate high flux, bio data supports chemical data)	+++(Chosen because of very high values exceeding standard, many tolerant fish and macroinvertebrates)	+++ (Chosen because sample data was high, model had many elevated values, bio metric data was supportive of chemical data.)	+++ (Chosen because of the TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data which supports the chemical data.)	++ (Chosen because of poor MSHA score, photo evidence of bad conditions, poor scoring bio habitat metrics)
Symptoms	+ (Chosen because chemistry data has many elevated values, model shows elevated results, bio results somewhat mixed)	+ (Chosen because of extremely tolerant fish and macroinvertebrate communities, high levels in many samples, other stressors present)	+ (Chosen because sampled data exceeded limit numerous amounts of times, model had many elevated values, bio metric data was supportive.)	+ (Chosen because of the TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data supports the chemical data.)	+ (Chosen because of poor MSHA score, photo evidence of bad conditions, poor scoring bio habitat metrics)
Mechanistically plausible cause	+ (Model predicted many values below 5 mg/L)	+ (Model and measured levels suggest that phos is a major problem)	+ (Model predicted a high exceedance rate of ecoregion value)	+ (Model predicted values above TSS standard at similar rate compared to field data)	NE
Stressor-response in other lab studies	NE	NE	NE	NE	NE
Stressor-response in other field studies	+ +	+	+	+	+
Stressor-response in ecological models	NE	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE	NE
Analogous stressors	NE	NE	NE	NE	NA
Consistency of evidence	+++ (Good data which is supported by biological metric response and model data)	+++ (Chosen because biology and sample data has values above standard, model data shows high exceedance.)	+++ (Good data which is supported by biological metric response and model data)	+++ (Majority of evidence available suggests this is a stressor)	+++ (Majority of evidence available suggests this is a stressor)
Explanatory power of evidence	++ (All evidence suggests that it is a stressor at this time given the data collected)	++ (Majority of evidence available suggests this is a stressor)	++ (All evidence suggests that it is a stressor)	++ (Majority of evidence available suggests this is a stressor)	++ (Majority of evidence available suggests this is a stressor)

Appendix 3.2 – Weight of evidence table for Ocheyedan River Minor Watershed

	Low Dissolved Oxygen	High Phosphorus	High Nitrates	Turbidity/TSS	Lack of Habitat
Spatial/temporal co-occurrence	- - - (Chosen because data from 2010-2012 has no value below 5 mg/L, model data simulates no values below 5 mg/L and bio results mixed)	+ (Chosen because similar streams throughout region with similar fish and macroinvertebrate populations had phosphorus problems, many measurements, and many samples above 0.15 mg/l)	0 (Chosen because sample data values were low, model data had some elevated values, strong bio metric data not supported by chemical data.)	+ (Chosen because of the TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data that supports the chemistry data.)	+ (Chosen because site 11MS022 had a fair MSHA score, photos of degraded conditions, bio metrics reflect conditions)
Temporal sequence	- - - (Chosen because sonde data from 2010-12 shows no values below 5 mg/L, not much for fluctuations)	+ (Many measurements dating back to 2011 with a high percentage above 0.15 mg/L.)	0 (Chosen because many low measurements dating back to 2011 along with support from model)	+ (Chosen because many measurements dating back to 2005 with many Secchi values below 20 cm.)	0 (Chosen because there are no historical measurements before the bio samples in 2012)
Field evidence of stressor-response	- (Chosen because data from 2010-2012 has no values below 5 mg/L, bio results mixed)	++(Chosen because of very high values exceeding standard, many tolerant fish and macroinvertebrates)	- (Chosen because sample data was very low, some of the model data had elevated values, bio metric data indicates impairment)	0 (Chosen because of the few TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data that is only supported by Secchi tube values.)	+ (Chosen because of fair MSHA score, majority of habitat related bio metrics reflect the conditions)
Causal pathway	+ (Chosen because of high amounts of ag in watershed, elevated phos levels, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, elevated nitrate levels, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers prevalent in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers in watershed)	+ (Chosen because of high amounts of ag in watershed, minimal buffers in watershed)
Evidence of exposure, biological mechanism	NE	NE	NE	NE	NE
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE

	Low Dissolved Oxygen	High Phosphorus	High Nitrates	Turbidity/TSS	Lack of Habitat
Verified or tested predictions	- (Chosen because data from 2010-2012 has no values below 5 mg/L, bio results mixed)	+++(Chosen because of very high values exceeding standard, many tolerant fish and macroinvertebrates)	0 (Chosen because sample data had relatively low values, model had some elevated values, bio metric data was not supportive of chemical data.)	0 (Chosen because of the few TSS samples above 65 mg/L, numerous Secchi values below 20cm, and bio data which supports the TSS data.)	++ (Chosen because of fair MSHA score, photo evidence of bad conditions, poor scoring bio habitat metrics)
Symptoms	- - - (Chosen because data from 2010-2012 has no values below 5 mg/L, bio results mixed)	+ (Chosen because of extremely tolerant fish and macroinvertebrate communities, high levels in many samples, other stressors present)	+ (Chosen because many biological metrics support case for nitrate as a stressor.)	+ (Chosen because many biological metrics support turbidity/TSS as a stressor.)	+ (Chosen because of fair MSHA score, photo evidence of bad conditions, poor scoring bio habitat metrics)
Mechanistically plausible cause	- - (Model predicted no values below 5 mg/L)	+ (Model and measured levels suggest that phos is a major problem)	0 (Model predicted some high nitrate values)	0 (Model predicted values above TSS standard at similar rate compared to field data)	NE
Stressor-response in other lab studies	NE	NE	NE	NE	NE
Stressor-response in other field studies	+ +	+	+	+	+
Stressor-response in ecological models	NE	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE	NE
Analogous stressors	NE	NE	NE	NE	NA
Consistency of evidence	- (Pretty good data that suggests this is not a stressor)	+++ (Chosen because sample data has values above standard, model data shows high exceedance, and modeled results confirm bio and chem data)	0 (Low measured nitrate values which are contradicted by biological metric response)	0 (Low measured TSS values which are contradicted by biological metric response)	+++ (Majority of evidence available suggests this is a stressor)
Explanatory power of evidence	- (Evidence suggests that it is not a stressor at this time given the data collected)	++ (Majority of evidence available suggests this is a stressor)	0 (Evidence is mixed and more sampling needs to be conducted)	0 (Evidence is mixed and more sampling needs to be conducted)	++ (Majority of evidence available suggests this is a stressor)

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