Sauk River Watershed Stressor Identification Report

Conditions causing deterioration of aquatic biological communities in the SRW

Minnesota Pollution Control Agency

August 2012

Legislative Charge

Minn. Statutes § 116.011 Annual Pollution Report
A goal of the Pollution Control Agency is to reduce the amount of pollution that is emitted in the state. By April 1 of each year, the MPCA shall report the best estimate of the agency of the total volume of water and air pollution that was emitted in the state the previous calendar year for which data are available. The agency shall report its findings for both water and air pollution, etc, etc.
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Executive Summary for the Sauk River Watershed Stressor Identification Report

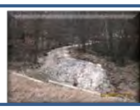
This report summarizes the key causes or "stressors", resulting in impaired fish and aquatic macro invertebrate communities of the Sauk River and its tributaries, a warm water river located in central Minnesota. The section of the Sauk River starting at Lake Osakis outlet downstream to the Horseshoe Chain of Lakes is listed on the 303(d) list of impaired waters for failing to meet established criteria for index of biological integrity (IBI). Stream biology is scored based on a numeric value given to a metric. Metrics are based on reproductive, feeding, or trophic characteristics that are specific to certain groups of fish and macroinvertebrates. Low scores indicate a lack of certain groups of fish and invertebrates which mean that the stream is not meeting expectations.

The elements of a healthy stream consist of five main components; stream connections, hydrology, stream channel assessment, water chemistry, and stream biology. The following flowchart shows the five components of a healthy stream. If one or more of the components are unbalanced, the stream ecosystem fails to function properly and is listed as an impaired water body.

The Elements of Stream Health
Stream Health is linked to the 5 main categories below. The MPCA and local partners examine many interrelated factors to identify stressors

Stream Connections
Examples: dams, culverts and drainage tiles

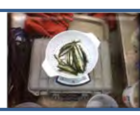
Hydrology
Examples: stream flow and runoff



Stream Channel Assessment
Example: Bank erosion and Channel Stability

Water Chemistry
Example: Dissolved oxygen, nutrients and temperature

Stream Biology
Example: fish and bugs



What conditions stress our streams?
Several factors can stress the biological condition within streams.

Too much sediment
Soil and other particles in water can make it difficult for fish and invert to breathe, feed and reproduce. Sediment can fill pools and smoother gravel and rock habitat

Low Oxygen
Fish and macro invertebrates need dissolved oxygen in the water to breathe and survive.

Temperature
Stream temperature affects metabolism of fish, especially cold water fish species and also influences oxygen content in water.

Lack or Loss of Habitat
Habitat affects all aspects of survival for fish and macro invertebrates. Habitat encompasses places to live, food to eat, places to reproduce and means of protection.

Increased nutrients
Excess nutrients, such as phosphorus and nitrogen, cause excessive algal blooms which can lead to high daily fluctuations in dissolved oxygen concentrations. High amounts of nitrogen can be toxic to fish and macro invertebrates.

The table below lists the Stream Health component along with the associated stressor(s) and their link to biological health.

Table 1: Common Stream Stressors to Biology (Fish, 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 invertebrates 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 fate and transport of chemicals.
Stream Channel Assessment	**Loss of Habitat due to excess DBS** **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 embeddings of fine material and a loss of intolerant species.
Water Chemistry	**Low Dissolved Oxygen Concentrations** **Elevated levels of TSS** · 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

Stressors in the Sauk River Watershed (8 Digit HUC)

The Sauk River watershed is divided by the Sauk River Watershed District into 10 Minor Watersheds with names such as the Osakis Lake Minor. The Minors are very similar in size to an 11 digit Hydrologic Unit Code (HUC), see map on page 7. The current condition and biological integrity of each 11 HUC is discussed in detail in the Sauk River Assessment Report (Minnesota Pollution Control Agency (MPCA) 2011). This Stressor Identification report will present data, and discuss the candidate causes for impaired biota in each Minor Watershed. A comprehensive review of biological, chemical, and physical data was performed to select probable causes for the impairments. The initial list of candidate causes used was extensive, and can be found in the main report. The initial list of candidate causes was narrowed down after additional data analysis, leaving six candidate causes for final analysis in this report. The candidate causes for the entire Sauk River watershed that were evaluated, and have enough data to show that they are a problem, are listed below:

Low dissolved oxygen concentrations

Low Dissolved Oxygen (DO) has been identified as a stressor in three of the Sauk River Management Units: Sauk Lake Minor, Grand Pearl Minor and the Chain of Lakes Minor. Field collected DO data indicated high rates of daily DO flux along with daily minimum values below the 5 mg/L standard for class 2B waters. Phosphorus concentrations were also above the proposed standard at all of the locations where DO data indicated problems. Increased phosphorus levels lead to increased algal and macrophyte growth which leads to increased decomposition and respiration rates. The excess plant material eventually dies, and bacterial activity during decomposition strips oxygen from the water. This leads to low early morning DO readings in streams.

Loss of habitat due to excess bedded sediment

Deposited and bedded sediment is a stressor in the Sauk River Minor Watersheds upstream of the Chain of Lakes Minor. This stressor is very important in Ashley Creek, Stoney Creek, and the Sauk River between Lake Osakis outlet and where Getchell Creek enters the Sauk River. Bedded sediment covers the available gravel and fills interstitial spaces. These spaces are required for gravel dwelling fish and invertebrate species.

Increased nutrients

Excessive nutrients cause increased plant and algal growth within the stream. This can lead to an increase in DO consumption during periods of decomposition and respiration. This increase in the daily flux of DO is detrimental to fish and macroinvertebrate communities. Minnesota has draft total phosphorus (TP) standard of 100 µg/L for central MN streams. TP concentrations above the 100 µg/L concentrations cause increased plant and algal growth in streams. Both elevated phosphorus levels, along with elevated nitrogen levels, are indicative of human activities. Wastewater along with agricultural practices, is among the top sources of increased nutrient concentrations in streams.

Altered hydrology/channelization

Ditching and drain tile can lead to increased rates of runoff into the receiving stream. As areas of the landscape are drained, they lose the ability to store water and slowly release it over time. This leads to flashy streams that have peak discharge immediately following rain events, and have little or no baseflow. This flashy nature leads to extreme stress on channels and on aquatic life. When the delivery of water is quick, the stream organisms are exposed to very fast velocities and may have limited places to find refuge. Also the nature of the rapid rise and fall of the stream flow places the stream banks at risk of eroding and contributing sediment which ,in turn, fills the gravel and rocky substrate with fine material. This can lead to a loss of available habitat for gravel spawning fish and EPT taxa. The abundance of private and public ditches within this watershed is significant to the loss of stream habitat due to channelization.

Loss of woody habitat

This stressor seems to be a major contributor to biological impairments in four of the studied Sauk River Management Units. Lack of woody material affects the functional feeding groups that inhabit the streams. Various genera of macroinvertebrates are dependent on woody material for feeding or case building. When there is low or no abundance of woody material, these genera disappear from the community and alter the IBI score.

Loss of connectivity (impoundments/improper placement of culverts)

The network of road crossings scattered throughout the Sauk River watershed pose a threat to the connectivity of area streams. This network has culverts that are set at an elevation that either make fish passage impossible during high flow events, or are set at such an elevation that, during mid to low flow events there is a drop in elevation on the downstream side creating a physical barrier. There are also some low head dam structures located in the Sauk Lake Minor and the Grand Pearl Minor that are causing fish passage problems.

Elevated concentration of total suspended solids

Total suspended solids (TSS) appears to be a significant stressor in the Sauk Lake Minor and (Getchell-Un-named-Stoney) GUS Plus Minor. In these two management units, TSS is often above the proposed water quality standards to protect aquatic life.

Sauk River Watershed Monitoring Sites and known impairments

The Sauk River watershed has spatially widespread biological impairments throughout all 10 management units (Figure ES-1). In all 10 management units, elevated levels of phosphorus are a stressor along with altered hydrology. There are many drainage ditches located throughout the watershed, and these ditches carry nutrients and excess water through the system faster than historically (before ditching). There is also very little water storage in the watershed as a large percentage of wetlands have been drained. The increased nutrients concentrations are above the draft state standard. The increased phosphorus concentrations are a direct reflection of the various land use found throughout the District. Intensive row crop agriculture, along with animal production, directly influence the amount of nutrients applied to the landscape, and the amount of nutrients that leave the landscape and enter the watercourses. This can be in the form of manure application, commercial fertilizers and altering the drainage through subsurface tile line installation. Residential and urban landscapes also increase the amount of excessive nutrients through wastewater discharge, lawn and gardening maintenance activities, and pet waste washing into the waterways. The accumulations of nutrients from both differing land uses are causing the streams to have excessive nutrient levels.

Excess sediment being transported down the streams and ditches is also a main stressor to biology within the Sauk River watershed. The excess amount of fine material being transported downstream is settling out and filling in pools, smothering rock riffles and causing a general degradation of in-stream habitat. The loss of coarse stream substrate directly affects the biological community that depends on this type of stream bottom. When the coarse substrate disappears, a large majority of the sensitive fish and macroinvertebrate species also disappear. The common fish metric that was lacking at the majority of the impaired fish sampling sites were a lack of gravel spawning fish species. The macroinvertebrate community was also affected by a general lack of EPT (mayfly,stonefly, caddisfly) species (which are the three taxa that are commonly referred to as the most sensitive to lack of gravel or cobble stream bottom). Table 2 below lists the main stressors found throughout the ten management units in the Sauk River watershed.

Recommendations for implementation strategies

Direct access of cattle to the Sauk River tributaries is causing loss of habitat, increased nutrient concentrations, and increased fine sediment transport that are filling coarse substrate for fish and macroinvertebrates. Stony Creek, Ashley Creek, Hoboken Creek, and the Sauk River above Melrose all have areas that have cattle pasturing with direct access to the stream. Moving the cattle out of the stream and providing a riparian buffer of at least 50 feet would allow the stream banks to vegetate and stabilize. This would reduce the amount of fines caused by failing stream banks and help reduce some of the nutrient import to the streams. Ditching is also a main stressor to the streams health. Changes in the delivery and rate of water through the ditch system are causing increased peak flows and reduced base flows in area streams. Many of the ditches in the watershed do not have adequate buffering and fine material is being transported through bank failures and row crop farming that is occurring next to the ditches. Wetland restoration along with buffering of ditches would reduce the peak discharge and also help stabilize the ditch banks, reducing the amount of available fine material entering the streams.

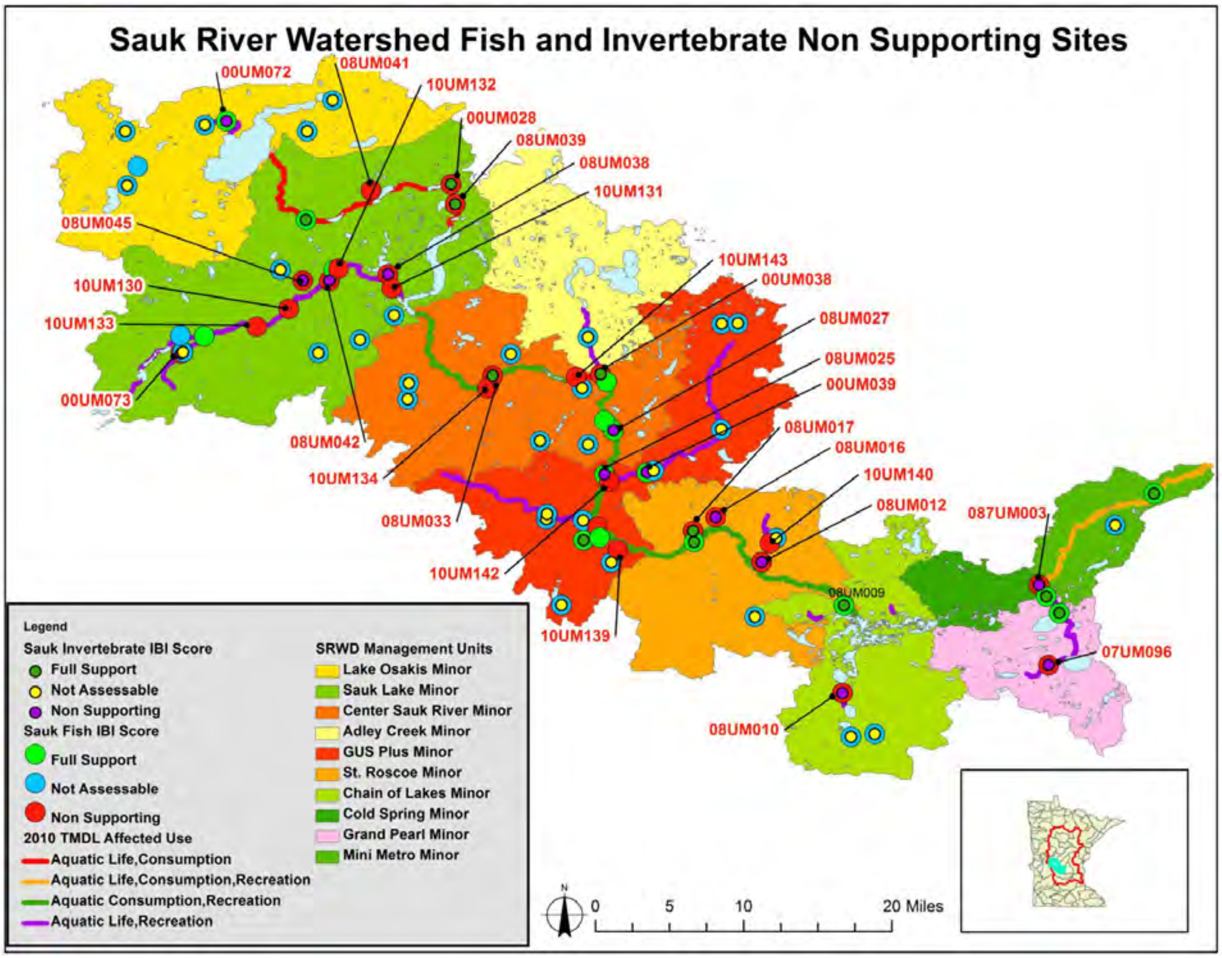


Figure 1 - Spatial Extent of Biological Impairments in the Sauk River Watershed

Table 2: Summary of Sauk River Minors with probable stressors to biotic communities

	Lake Osakis Minor	Sauk Lake Minor	Adley Creek Minor	Center Sauk River Minor	GUS Plus Minor	St Roscoe Minor	Chain of Lakes Minor	Cold Spring Minor	Grand Pearl Minor	Mini Metro Minor
Daily Dissolved Oxygen Minimum DO readings often below the 5mg/L standard. Daily Flux also indicates increased nutrient enrichment	X	X					X	X	X	
Increased bedded sediment in stream bed Bedded sediment fills the spaces between gravel and covers the coarse substrate. This leads to loss of gravel dwelling species of fish and macroinvertebrate species	X	X		X	X	X		X		
Elevated nutrients Increased plant growth leads to increased DO consumption during periods of decomposition and respiration	X	X	X	X	X	X	X	X	X	X
Altered Hydrology/Channelization Change in hydrology – altered flow rates	X	X	X	X	X	X	X	X	X	X
Lack of woody habitat Woody habitat provides food and cover for a variety of fish and macroinvertebrates. Lack of this habitat type reduces abundance of various species.	X	X		X	X					
Connectivity Loss of movement by fish species due to physical barriers (impoundments/improper placement of culverts)		X		X						
Elevated Total Suspended Sediment (TSS) Elevated TSS concentrations affect the gills of fish and macroinvertebrates, reducing their ability to uptake DO from the water.		X			X					

Introduction

Overview of watershed impairments

Water quality and biological monitoring in the Sauk River watershed has been conducted for several decades with the goal of assessing water quality and aquatic life. As part of the MPCA's new Intensive Watershed Monitoring (IWM) approach, began in 2007, monitoring activities increased in rigor. The Sauk River watershed came up for IWM in 2008. The data collected for the Sauk River Watershed Restoration and Protection Project, as well as historic data obtained prior to 2008, was used to identify stream reaches that lacked healthy fish and macroinvertebrate assemblages.

The result of this assessment monitoring effort was the discovery and listing of select Sauk River watershed streams as "impaired" for aquatic life. The biologically-impaired stream reaches in the watershed include the entire Sauk River mainstem, and numerous tributary streams (**Figure 2**). Fish and macroinvertebrate data were collected at all biological monitoring stations, and were assessed independently, making it possible for a given stream reach to be impaired for one or both of these biological indicators (**Table 2**).

Sauk River (SR) watershed streams that are not listed as impaired are either not yet assessed (lacking monitoring data), or are showing good to exceptional biological integrity based on current data. For a complete report on the condition of SR watershed streams and lakes, see the Sauk River Watershed Monitoring and Assessment Report (hyperlink/reference).

Sauk River Watershed IWM Results and 2010 Impairments

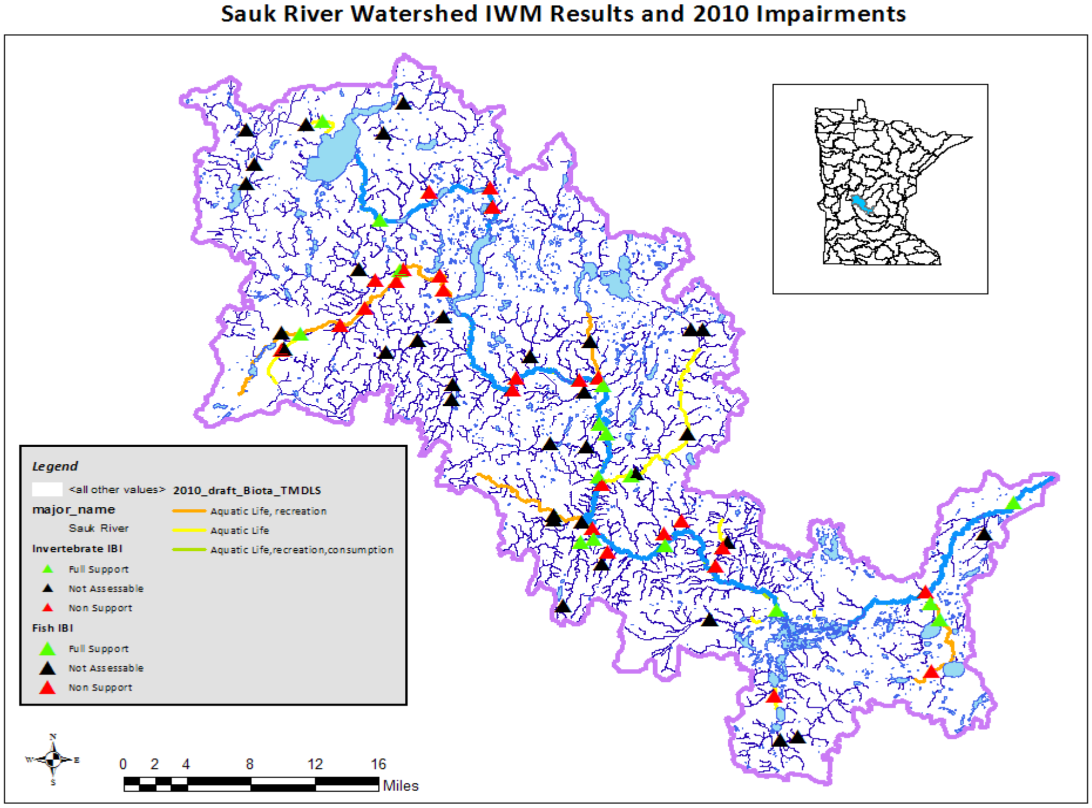


Figure 2 - Sauk River Watershed Biological Monitoring Sites along with 2010 Stream Impairments

Table 3: Summary of stream reaches with biological impairments in the Sauk River watershed. Water quality impairments for each stream reach are provided as well.

			Impairments	
AUID #	**Stream Name**	**Reach Description**	**Biological**	**Water Quality***
07010202-502	Sauk River	Headwaters (Lk Osakis) to Sauk Lk	Fish IBI	DO, NO_2&NO_3
07010202-503	Ashley Creek	Headwaters to Sauk Lake	Fish IBI	DO, NO_2&NO_3, PO_4
07010202-505	Sauk River	Adley Cr to Getchell Cr	Fish and Invertebrate IBI	NO_2&NO_3, PO_4
07010202-506	Sauk River	Melrose Dam to Adley Cr	Fish IBI	
07010202-507	Sauk River	Sauk Lk to Melrose Dam	Fish and Invertebrate IBI	
07010202-520	Sauk River	Cold Spring WWTP to Mill Cr	Fish IBI	
07010202-522	Hoboken Cr	Headwaters to Sauk Lk	Fish and Invertebrate IBI	NO_2&NO_3, PO_4
07010202-540	County Ditch 44	Headwaters to Sauk Lk	Fish and Invertebrate IBI	
07010202-541	Stoney Cr	Headwaters(unnamed Lk 73-0261-00)to Sauk R	Invertebrate IBI	NO_2&NO_3, PO_4
07010202-545	Eden Lk Outlet	Headwaters (Eden Lk 73-0150-00)to Browns Lk	Fish and Invertebrate IBI	DO
07010202-556	Unnamed Cr	Unnamed cr to Sauk R	Fish and Invertebrate IBI	
07010202-598	Unnamed Cr	Unnamed ditch to unnamed Cr	Fish and Invertebrate IBI	
07010202-613	Unnamed Cr	Unnamed cr to Silver Cr	Fish and Invertebrate IBI	
07010202-638	Unnamed Cr	Unnamed lk (77-0168-00) to Little Lk Osakis	Fish and Invertebrate IBI	
07010202-655	Unnamed Cr	Unnamed cr to Stony Cr	Fish and Invertebrate IBI	
07010202-662	Unnamed Cr	Unnamed Cr to Sauk R	Fish and Invertebrate IBI	
07010202-666	Unnamed ditch	Unnamed cr to Sauk Lk	Fish and Invertebrate IBI	
07010202-673	Sauk River	Juergens Lk to Sauk Lk	Fish IBI	DO, NO2&NO3
07010202-674	Mill Creek	Headwaters (Goodners Lk 73-0076-00) to Pearl Lk	Fish and Invertebrate IBI	

In addition to the biological impairment listings, there are also a number of water chemistry based impairments in the SR watershed. As shown in Table 3, several stream reaches listed are impaired for both biological and chemical parameters. In these cases, it is probable that the water chemistry parameter that resulted in the impairment listing is negatively affecting the aquatic life.

Organization Framework of Stressor Identification

The Stressor Identification process (SID) is prompted by an assessment of biological monitoring data as not meeting the expected community composition. 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. Confidence in the results often depends on the quality of data available to the stressor identification (SID) process. In most cases, additional data is collected 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. The identified stressor(s) is then examined further in the TMDL study.

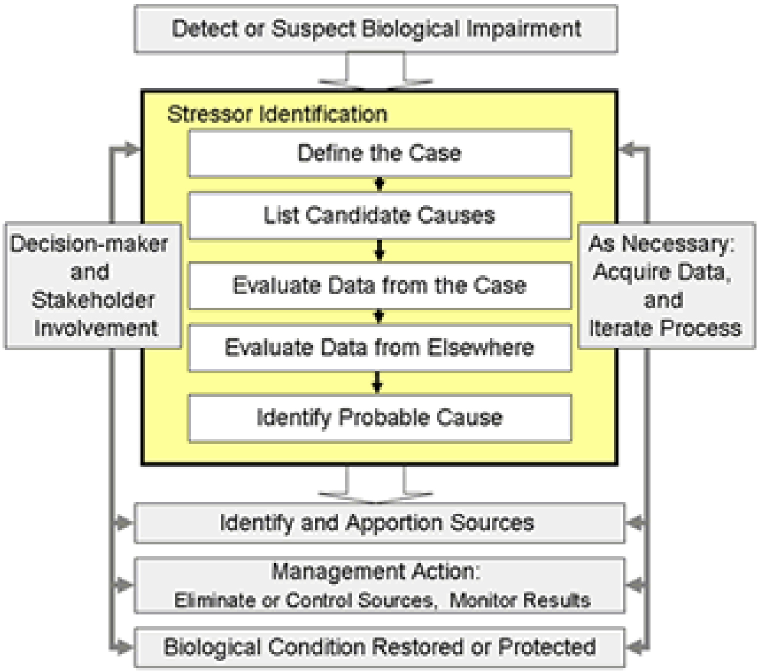


Figure 3: Conceptual model of stressor identification (SID) process

Sauk River

Definition of Sauk River Watershed Management Units (Minors)

Division of Minors

The Sauk River originates from Lake Osakis and a series of ditches in eastern Douglas County and western Todd County and flows southeasterly 134.9 river miles to the city of Waite Park, (MNDNR Watershed assessment health report, 2011) where it joins the Mississippi River. Several of the lakes in the watershed are in violation of state water quality standards and have the potential to alter river conditions and affect the distribution of fish and other aquatic life. In all, the watershed drains approximately 667,214 acres and includes portions of six counties. The 8 digit Hydrologic Unit Code number is 07010202. The Sauk River resides in the Upper Mississippi River basin.

Due to the sheer size of the watershed and the presence of channelization and reservoirs, it is difficult to evaluate potential stressors to aquatic life without further stratifying the Sauk River drainage into smaller sections. Although there may be some consistent chemical and physical stressors found throughout the Sauk River watershed, some are likely acting locally, driven by characteristics specific to a certain region of the watershed. For the purpose of addressing biological impairments in the Sauk River, the watershed was stratified into ten management units called Minors, based on Sauk River Watershed District Minor Unit boundaries. Figure 4 shows the name and location of each management unit.

Sauk River Watershed District Definition of Minor Watersheds

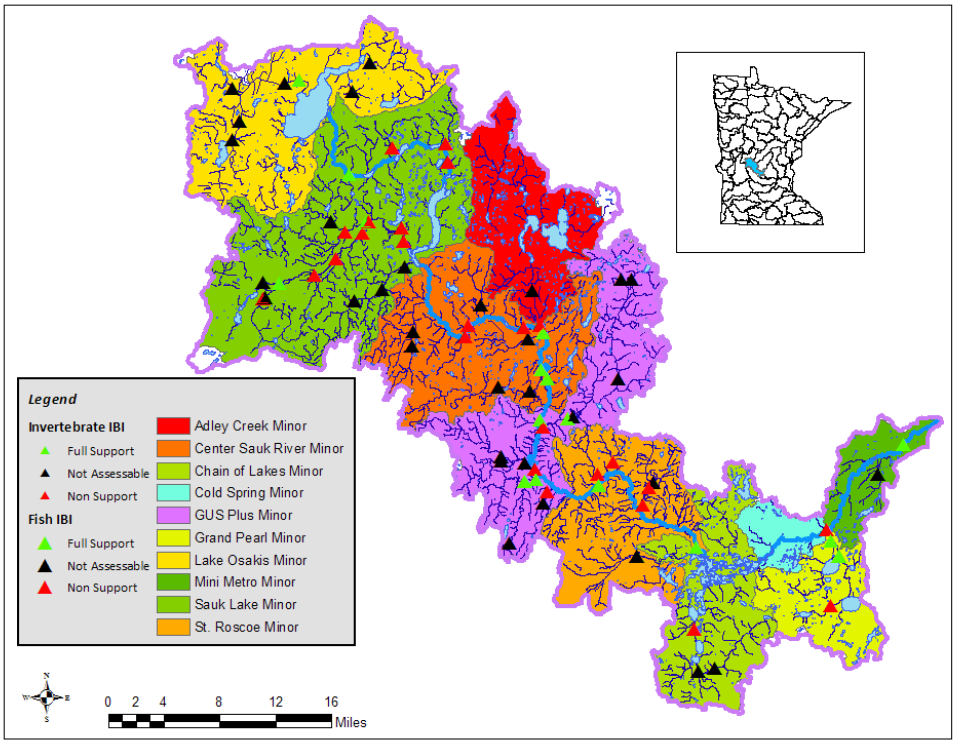


Figure 4: Map showing watershed management units in the Sauk River watershed. Watershed Management zones were used to group stream reaches with similar impairment indicators and natural background conditions.

The MPCA classifies streams based on drainage area, gradient, and geographical location in order to best understand and assess Minnesota's aquatic biological communities. Expectations (via an index of biological integrity - IBI) have been developed for each class. Table 4 shows all of the biological monitoring sites located on the Sauk River, along with the fish/invertebrate classifications as assigned by the MPCA.

Table 4: List of Sauk River biological monitoring sites, biological classifications, and corresponding watershed management unit

Site ID	County / Nearest Town	Fish Class	Invert Class	Watershed Management Unit
08UM046	Todd/ Downstream of 161st Ave, 7 mi. NE of Osakis	6	7	Osakis lake Minor
08UM050	Pope/ Upstream of Twp Rd 130, 1 mi. NW of Westport	7	NS	Sauk Lake Minor
08UM042	Stearns/ Upstream of CR 92, 4.5 mi. NW of Sauk Centre	5	5	Sauk Lake Minor
08UM039	Todd/ Upstream of Cedar Lake Rd, 7 mi. N of Sauk Centre	5	2	Sauk Lake Minor
08UM041	Todd/ Upstream of CR 4, 7 mi. E of Osakis	6	6	Sauk Lake Minor
08UM038	Todd/ Downstream of CR 11, 2 mi. NW of Westport	5	5	Sauk Lake Minor
08UM037	Stearns/ Upstream of CR 72 in Sauk Centre	6	7	Sauk Lake Minor
08UM033	Stearns/ Upstream of Hwy 4, 2.5 mi. W of Melrose	5	2	Center Sauk River Minor
08UM030	Stearns/ Downstream of Kraft Dr, .5 mi. SE of Melrose	7	7	Center Sauk River Minor
08UM027	Stearns/ Upstream of CR 30 in New Munich	4	2	Center Sauk River Minor
08UM026	Stearns/ Upstream of Overdale Rd, 1 mi. SW of New Munich	7	7	Center Sauk River Minor
08UM025	Stearns/ Downstream of CR 31, 3 mi. S of New Munich	4	2	Center Sauk River Minor
08UM023	Stearns/ Upstream of 343rd Ave, 1 mi. N of Spring Hill	6	6	GUS Minor
08UM020	Stearns/ Downstream of 260th St, 3.5 mi. SE of Spring Hill	6	NS	GUS Minor
08UM017	Stearns/ Downstream of 273rd Ave, 1.5 mi. NW of St. Martin	6	7	St. Roscoe Minor
08UM016	Stearns/ Upstream of 290th St, 6 mi. SW of Albany	6	7	St. Roscoe Minor
08UM012	Stearns/ Downstream of 260th St, 5 mi. NW of Richmond	6	7	St. Roscoe Minor
99UM064	Stearns/6 mi. NW of Richmond	6	NS	Chain of Lakes Minor
08UM010	Stearns/ Downstream of CR 21, 2.5 mi. N of Eden Valley	7	7	Chain of lakes Minor
08UM003	Stearns/ Upstream of Mill St N in Rockville	4	2	Cold Spring Minor
08UM006	Stearns/ Upstream of CR 48 in Marty	6	7	Grand Pearl Minor

NS=Not sampled

Minnesota Department of Natural Resources Watershed Assessment Tool

The Minnesota Department of Natural Resources (MDNR) has a web-based tool called the Watershed Assessment Tool (WAT). This tool can be used to determine the overall ecological health of a watershed based on the five components of a healthy stream; hydrology, geomorphology, biology, connectivity and water quality. The assessment is based on a multi-metric index, and compiles a total score based on metric values. The assessment tool can be accessed at Watershed assessment tool. This tool compares conditions from today against conditions dating back to around 1890. Scores are ranked on a scale from 0 (extremely poor) - 100 (extremely good). The overall score for the Sauk River watershed is 51, while the low and high for the state are 39 and 84. Watersheds around the Sauk River also have scores in the upper 40's to low 50's. Much of the score is driven by a land use change from native grasslands and Oak Savannah or Aspen-Oak Woodlands in the 1890's to intense agricultural crop and livestock production of today, along with areas of intense urbanization. Landscape changes alter the way water moves through the system, along with how nutrients are absorbed and transported. Below is the MDNR watershed assessment report card for the Sauk River.

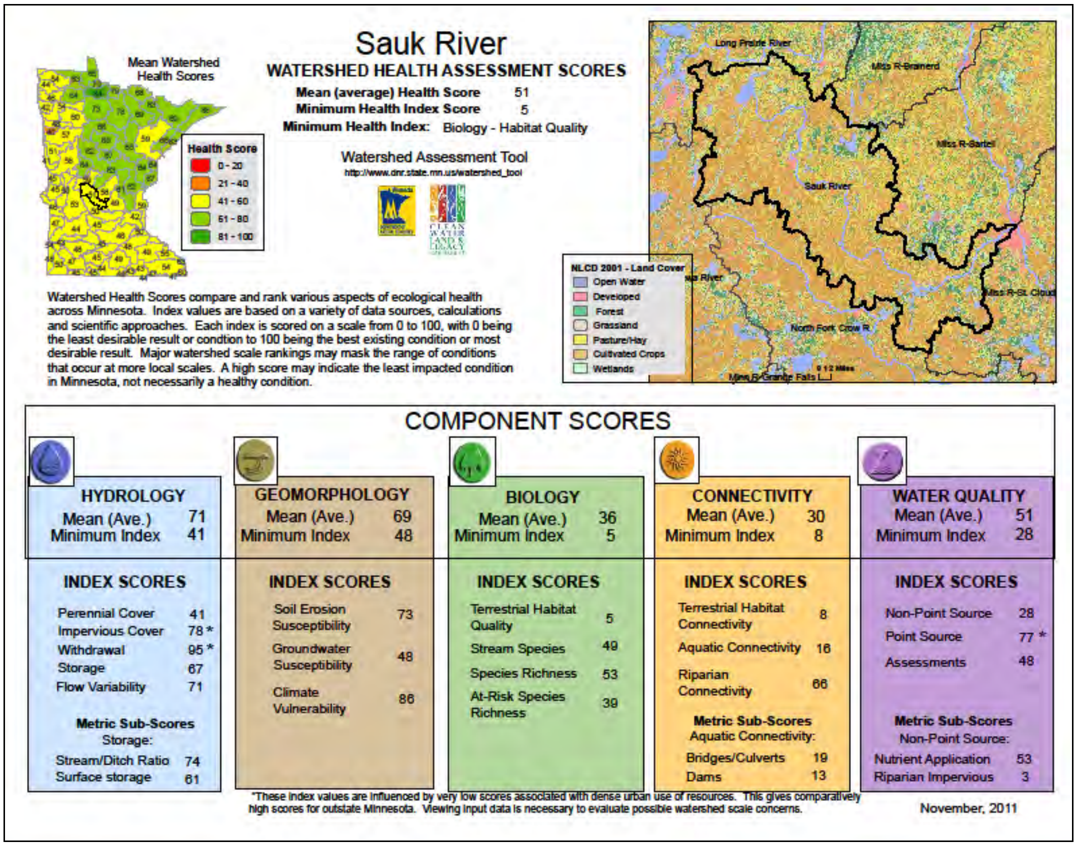


Figure 5: Sauk River Watershed assessment Tool results

From the five components evaluated by the WAT, three of the scores are average or below average. These were the biology, connectivity, and water quality. The results from this assessment are also validated throughout the stressor ID document. The fish community integrity is limited by the amount of crossings (culverts) on the watershed's streams, some of which limit fish movement. There are numerous low head dams which impede upstream movement of most fish species. The high percentage of agricultural land use, both row crop and animal production, has an impact on the water quality within the Sauk Watershed. This scored a very low 28 in the MDNR tool and the field data collected throughout the watershed shows that excessive nutrients are a watershed-wide problem. This is evident in phosphorus and nitrogen data gathered over the past 20 years. The WAT also points out that habitat quality is a limiting factor for biology in this watershed, though that also takes into account terrestrial biological communities.

Candidate causes for biological impairment

Identifying a set of candidate causes for impairment is an important early step in the Stressor Identification process. This step provides the framework for assembling key data and for making determinations as to what data are lacking for the causal analysis and strength of evidence process.

Candidate causes are defined as the "stressors" or key contributors to the adverse biological effects observed.

Eleven candidate causes were selected as potential drivers of biological impairments in the Sauk River watershed. These eleven candidates were chosen after considering a large set of "common candidate causes" developed by the U.S. Environmental Protection Agency (EPA). Due to the large size of the study watershed, potential candidate causes were evaluated using a rapid assessment of the biological, water chemistry, land use, and physical habitat data from each of the watershed management zones described in section 3.0. The process of scoping for candidate causes on a smaller scale across similar natural background conditions provided greater assurance that localized stressors were not excluded from the strength of evidence process.

The eleven candidate causes for impairment in the Sauk River can be broadly grouped into four categories; water quality, physical habitat, connectivity, and flow alteration (**Figure 5**). These categories will be used as the organization framework for the strength of evidence analysis that will ultimately define the most probable stressors leading to impaired fish and invertebrate assemblages. In order to keep the causal analysis process more succinct and avoid repetition, all eleven candidate causes will be evaluated across the entire watershed, even though several of them are likely to be operative only on a sub-watershed scale.

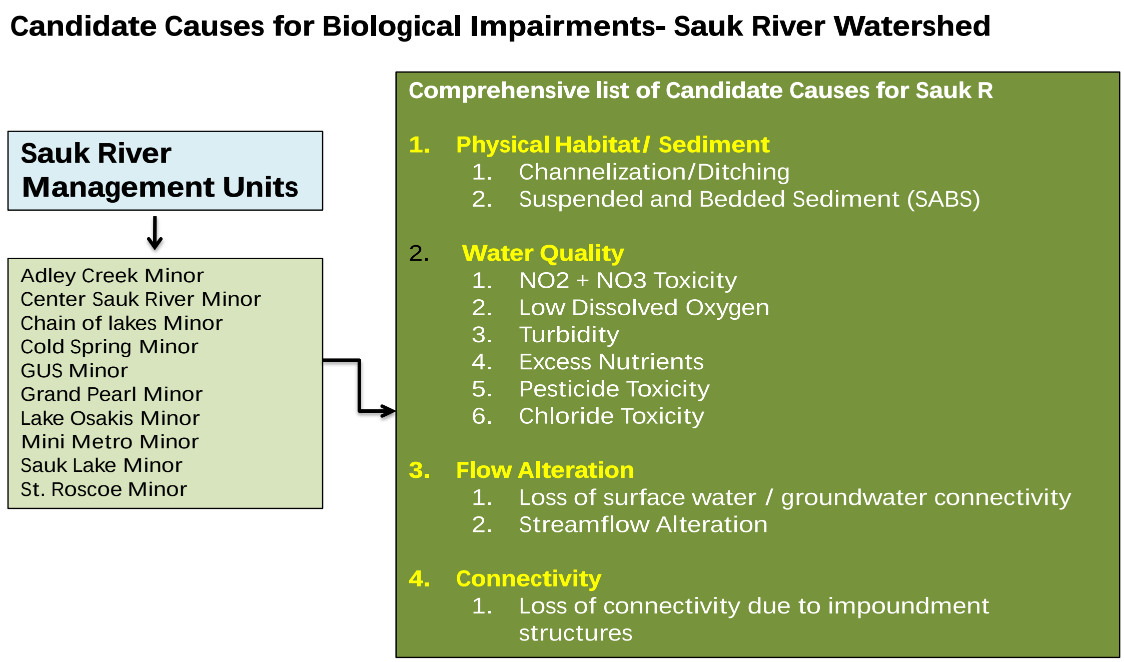


Figure 6: List of candidate causes for biological impairment in the Sauk River watershed

Candidate cause #1: ditching/channelization

Background

Drainage ditches are a common feature in Minnesota watersheds dominated by agricultural land uses. There are an estimated 27,000 miles of drainage ditches in the state, many of which have been in place since the turn of the 20th century. In the Sauk River watershed alone, there are 28 county and judicial ditch systems that serve to drain relatively large areas (Sauk River Watershed District Overall Plan). There are also many miles of private ditch networks in the watershed and many miles of buried tile system. Due to the prevalence of agricultural ditching in the Sauk River watershed, it was identified as a potential cause of fish and invertebrate impairments.

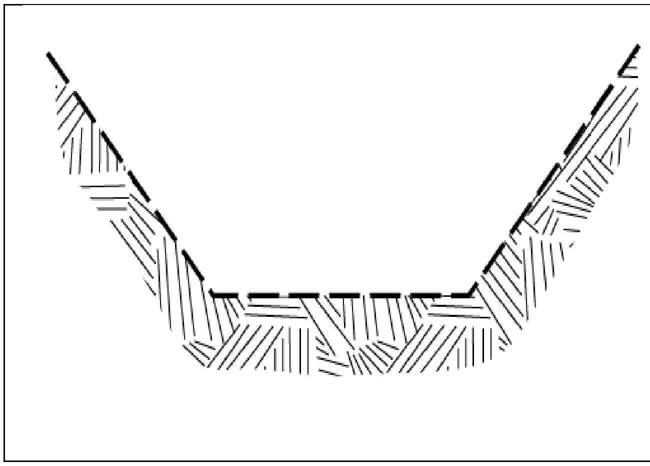


Figure 7: Cross-section of trapezoidal ditch design (left) and an example of this ditch design in Sauk River watershed (right).

In a study conducted in the east-central Indiana cornbelt region, Lau et al (2006) found that channelized streams had lower quality fish assemblages when compared to natural streams, based on IBI results. In addition, the results of this study showed a reduction in riffle and pool habitats associated with channelization was the most significant factor affecting the fish assemblage.

Numerous studies have found conventional trapezoidal ditches to be inferior to natural streams in terms of sediment transport capacity and channel stability over time (Urban and Rhoads, 2004; Landwehr and Roads, 2003). Typical drainage ditch construction consists of a trapezoidal channel cross-section designed to carry their maximum anticipated flow when filled to 80 percent of their design depth (Christner er al, 2004). The return interval for this discharge is typically greater than 50 years. In other words, conventional ditches are designed to handle low frequency, high-magnitude flood events. This design may not support adequate water depth and velocities for transporting sediment and maintaining stream facets (e.g. glide, riffle, run, pool) during low to moderate flow events. The result can be excess sedimentation of the stream bed as particles become immobile and aggrade over time. Figure 6 above displays a typical trapezoidal channel along with a photograph of a typical ditch found in the Sauk River watershed. In general, this design does not provide good habitat for aquatic species or provide stability of its bed and banks.

Sediment aggradtion in drainage ditches is often dealt with through costly and destructive clean-out operations. In order to maintain the design flood-capacity, the sediment that accumulates on the streambed is typically removed periodically via track hoe. In some instances, this sediment is merely pulled out of the stream channel and placed near or on the upper “banks” of the ditch, creating a more severely incised stream channel in the process (Figure 7). Ditch clean-out also removes aquatic and terrestrial vegetation which benefits channel stability, water quality, and aquatic habitat (Beeson and Doyle, 1995; Smiley and Dibble, 2005). The photos in Figure 4.2 were taken in June of 2009 near the confluence of a cleaned-out ditch and Ashley Creek. At this site, the ditch cleanout extended to within 150 feet of the confluence with Ashley creek (photo at the top of next page).

Figure 8: Photos of 2010 clean-out of a ditch flowing into Ashley Creek.

Conceptual mModel

A conceptual model for stream channelization is shown in **Figure 8**. This candidate cause for impairment can influence biota via numerous pathways involving water chemistry, channel geomorphology, and physical habitat changes. Figure 4.3 depicts some of the more probable pathways that this candidate stressor is operating through in the Sauk River watershed.

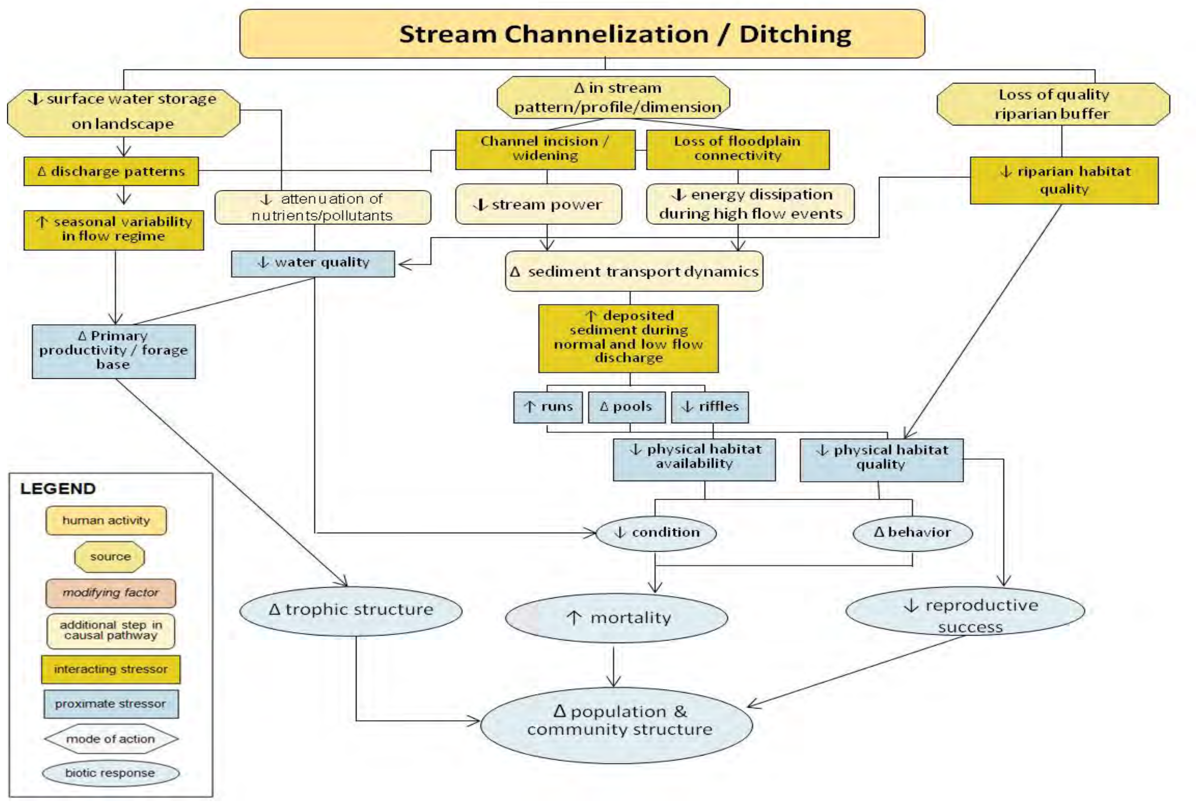


Figure 9: Candidate Cause #1: Altered biology based on Stream Channelization/Ditching

Casual analysis

Many of the Sauk River tributaries are channelized in portions of all watershed management zones (**Figure 9**). Overall, a very small percentage of the river system is channelized. However, the effects of channelization can impact reaches upstream and downstream that remain in natural channel conditions, so the effects may be more wide-reaching than the map in Figure 4.4 indicates. Ditches in the headwaters are generally deeply incised and lack healthy riparian buffers.

Sauk River Watershed Management Units--Natural Stream Channel/Channelized

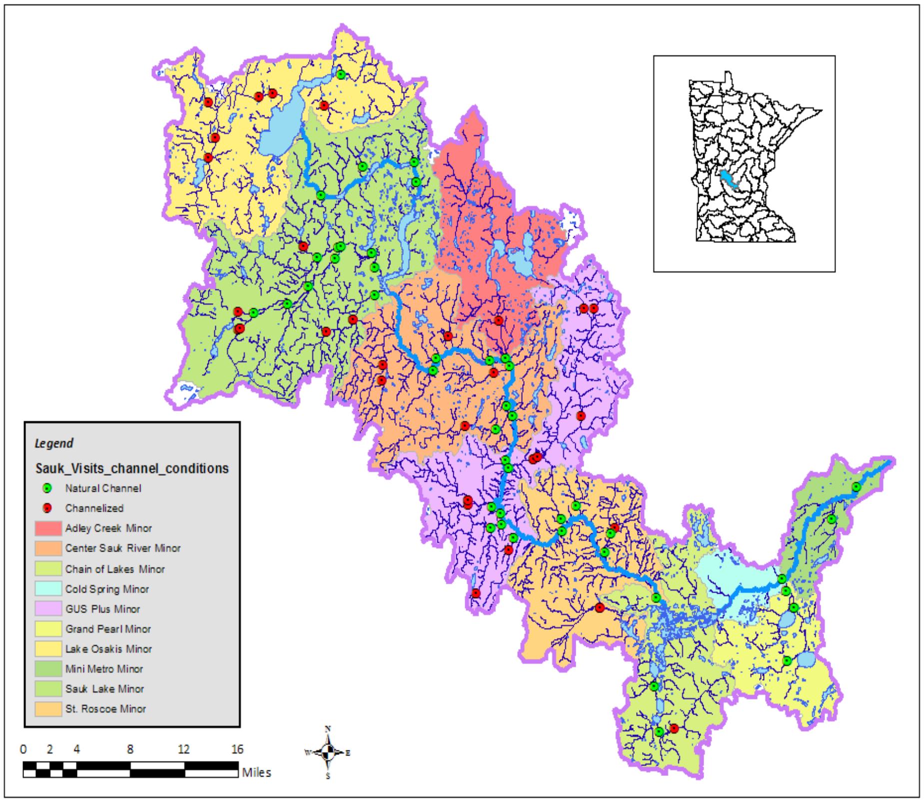


Figure 10: Biological monitoring sites that were channelized

Biological effects -- fish

The conceptual model (Figure 9) for this candidate cause highlights changes in trophic characteristics, reproductive success, and community structure as potential biological effects resulting from stream channelization. A selection of fish metrics covering these traits, along with their predicted response to stream channelization, are shown in **Table 4**. Fish metric values were observed from a total of 10 sites in Class 6 streams scattered throughout the Sauk watershed. Of the 10 sites used to investigate biological response to channelization, five were channelized and five remain in natural channel form.

Table 5: Selection of fish metrics that may be responsive to stream channelization

Metric	Metric Description	Expected Response to Channelization
Trophic		
BenthInsectPct	Relative abundance (%) of individuals that are benthic insectivore species	Decrease
BenthInsect-TOLPct	Relative abundance (%) of individuals that are non-tolerant benthic insectivore species	Decrease
BenInsectTxPct	Relative abundance (%) of taxa that are benthic insectivores	Decrease
BenInsect-TolTxPct	Relative abundance (%) of taxa that are non-tolerant benthic insectivores	Decrease
DetNWQPct	relative abundance (%) of individuals that are detritivorous (NAWQA database)	Increase
DetNWQTxPct	relative abundance (%) of taxa that are detritivorous (NAWQA database)	Increase
OmnivorePct	Relative abundance (%) of individuals that are omnivore species	Increase
OmnivoreTxPct	Relative abundance (%) of taxa that are omnivorous	Increase
GeneralPct	Relative abundance (%) of individuals that are generalist species	Increase
GeneralTxPct	Relative abundance (%) of taxa that are generalists	Increase
PiscivorePct	Relative abundance (%) of individuals that are piscivore species	Decrease
Reproductive		
SLithopPct	Relative abundance (%) of individuals that are simple lithophilic spawners	Decrease
SLithopTxPct	Relative abundance (%) of taxa that are simple lithophilic spawners	Decrease
Tolerance		
SensitivePct	Relative abundance (%) of individuals that are sensitive species	Decrease
SensitiveTxPct	Relative abundance (%) of taxa that are sensitive	Decrease
TolTxPct	Relative abundance (%) of individuals that are tolerant species	Increase
TolPct	Relative abundance (%) of taxa that are tolerant species	Increase
VtolPct	Relative abundance (%) of individuals that are very tolerant species	Increase
VTolTxPct	Relative abundance (%) of taxa that are very tolerant species	Increase
Community		
DarterSculpSucPct	Relative abundance (%) of individuals that are darter, sculpin, and round bodied sucker species	Decrease
DarterSculpSucTxPct	Relative abundance (%) of taxa that are darters, sculpins, and round bodied suckers	Decrease
NumPerMeter-Tolerant	Number of individuals per meter of stream sampled (excludes individuals of tolerant species)	Decrease

Tolerance metrics

Natural channel sites supported a much higher percentage of sensitive fish species than channelized monitoring locations (**Figure 10**). The metric *SensitivePct* was the most responsive metric of the entire set used in this analysis. Sensitive species that were present in healthy populations within natural channels, but absent or scare from channelized reaches, include longnose dace (*Rhinichthys cataractae*), horneyhead chub (*Nocomis biguttatus*), logperch (*Percina* caprodes), and tadpole madtom (*Noturus gyrinis*). Channelized monitoring sites had a higher relative abundance of fish that are classified as very tolerant, such as central mudminnow (*Umbra limi*), fathead minnow (*Pimephales promelas*), common carp (Cyprinus carpio), and bluntnose minnow (*Pimephales notatus*) **(Figure 11).**

Class 6 Fish IBI Metrics

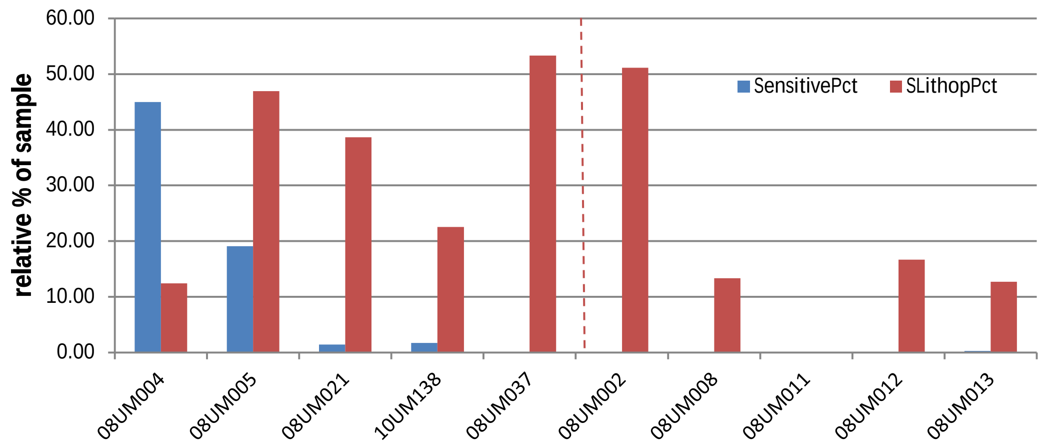


Figure 11: Relative abundance (%) of fish considered sensitive species and lithophilic spawners

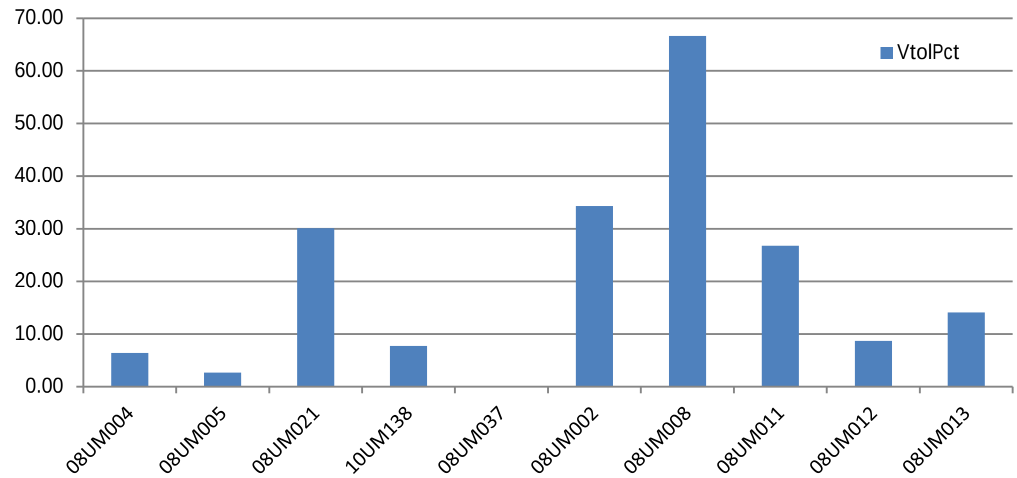


Figure 12: Percentage of very tolerant fish species

Trophic response

The values for several fish trophic metrics were compared to investigate potential changes in trophic structure caused by stream channelization (**Figure 12**). The results suggest that channelized reaches of the Sauk Watershed support fewer fish taxa that are benthic insectivores, and that a smaller portion of the overall fish community at channelized sites is composed of fish with this trophic trait, suggesting that the habitat needed for the fish food base has been altered in a way detrimental to aquatic insects.

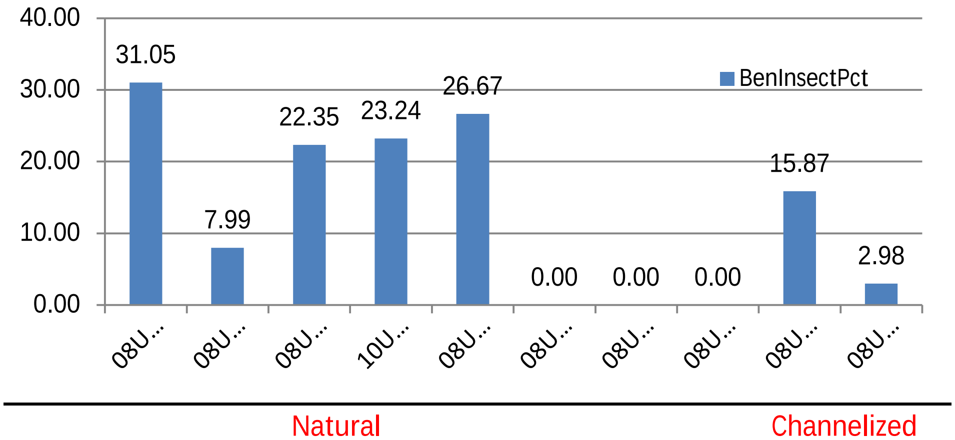


Figure 13: Relative abundance (%) of fish taxa that are benthic insectivore

The channelization of several reaches of the Sauk river tributaries appears to be limiting fish habitat and causing undesirable changes in the fish assemblage. Biological monitoring sites within channelized reaches offer limited riffle and pool habitat, and tend to be dominated by runs with homogenous depth and substrate type (Figure 13). This morphological change favors fish species that are highly adaptable to highly modified habitat conditions (e.g. omnivores, tolerant species).

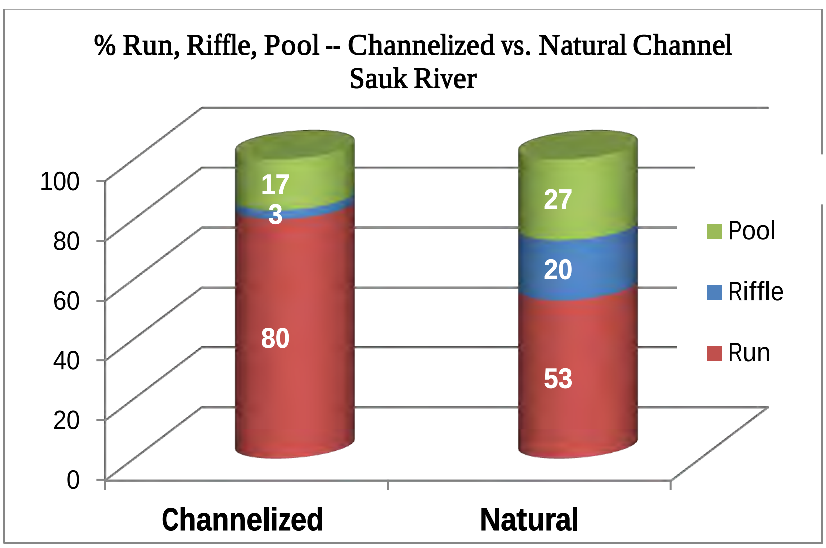


Figure 14: Average ratio of pools, riffles, and runs in channelized vs. natural channel monitoring sites on the Sauk River tributaries.

Biological effects -- macroinvertebrates

The channelization of the Sauk River does appear to be negatively impacting macroinvertebrate populations. Looking at the macroinvertebrate data reveals that the channelized sites experienced an increase in climber taxa and a general decrease in clinger taxa from the natural stream reaches (Figure 14). Clinger taxa are best represented by the order Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, and caddisflies). This group of insects is generally less tolerant to pollutants and requires bottom substrate that has a coarse or rocky component. As the channelized sites are more homogenous in fine substrate the EPT, taxa are generally reduced in abundance. The climber taxa are best represented by damselflies and dragonflies which are often associated with slower moving water and aquatic vegetation. The channelized sites can accommodate the climbers as climbers are not dependant on a coarse substrate. Although channelized stations in the Sauk area show obvious signs of degraded macroinvertebrate populations, one channelized reach achieved some of the highest M-IBI scores in the entire watershed (Adley Creek).

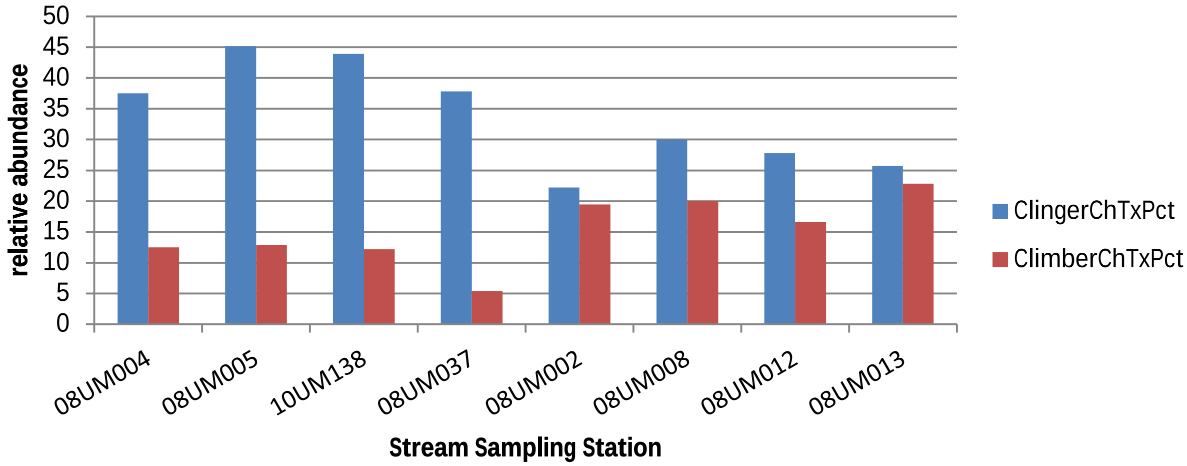


Figure 15: Macroinvertebrate taxa percent of the functional groups clingers and climbers and their relative abundance for natural versus channelized streams

The sensitive taxa of macroinvertebrates are the first to be lost when habitat conditions degrade. This response is quite prevalent when looking at the select natural channel sites versus the channelized sites. The IBI metric IntolerantPct indicates that there is a general loss of sensitive taxa in the channelized reaches of the Sauk (Figure 15).

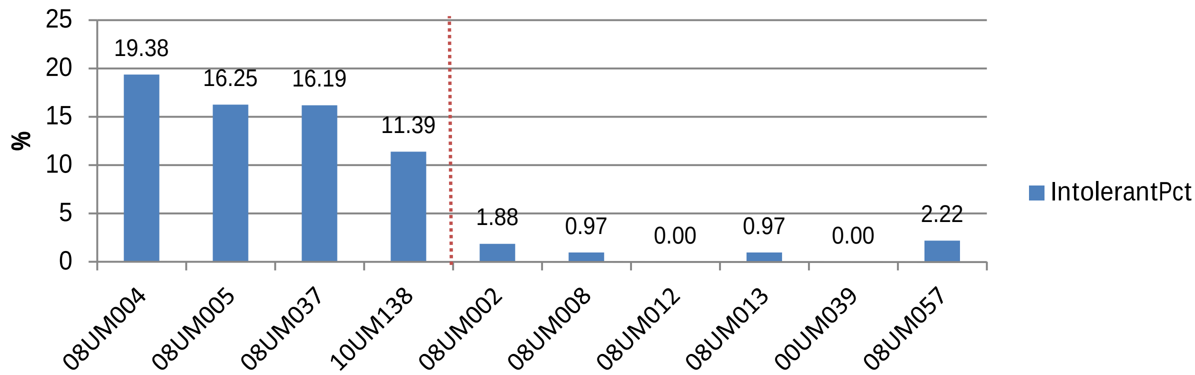


Figure 16: Macroinvertebrate percentage of intolerant taxa found in each stream sampling site.

Strength of evidence summary – channelization/ditching

The strength of evidence results (see **Table 5**) suggest that channelization/ditching is a probable cause of low fish and macroinvertebrate IBI scores in the Lake Osakis Minor, Sauk Kake minor, GUS Minor, St. Roscoe Minor and Chain of Lakes Minor. There are strong spatial co-occurrence connections between this candidate cause and biological response, particularly within the fish data. In addition, many of the predicted biological responses routinely associated with channelization in the scientific literature (e.g. loss of riffle habitat, change in trophic structure, loss of sensitive species) are evident in the Sauk watershed ditches as well.

Table 6: Strength of evidence table for candidate cause #1 – Channelization/Ditching

Types of Evidence	Lake Osakis Minor, Sauk Lake Minor, Center Sauk River Minor, GUS Plus Minor	Adley Creek Minor, Cold Spring Minor, Grand Pearl Minor	St. Roscoe Minor, Chain of Lakes Minor,	Mini Metro Minor,
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	++	-	+	-
Temporal sequence	NE	NE	NE	NE
Field evidence of stressor-response	++	-	+	-
Causal pathway	+++	-	++	-
Evidence of exposure, biological mechanism	+	-	+	-
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	+	-	+	-
Symptoms	+	-	+	-
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	+	+	-
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	++	++	++	-
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	+++	+++	+++	-
Analogous stressors	++	++	++	-
Multiple lines of evidence				
Consistency of evidence	+++	0	+	-
Explanatory power of evidence	++	0	++	-

Candidate Causes #2-4: Total Suspended Solids /Turbidity/Bedded Sediment

Total suspended solids (TSS) and bedded sediment are related through several common watershed sources and processes, but each can affect aquatic biota in different ways. Due to the inter-related nature of these parameters, they are grouped together in this report for causal analysis purposes, but ultimately each of these candidate causes will be evaluated independently in terms of impact on fish and macroinvertebrate populations.

Whereas, suspended solids and turbidity are potential stressors operating in the water column, bedded (= deposited) sediments impact the stream substrate. Excessive deposition of fine sediment can impair macroinvertebrate habitat quality and productivity (Rabeni et al., 2005). To date, this stressor has not been extensively studied in the Sauk River watershed, in part because there is no state or federal water quality standard for this parameter. Field measurement of bedded sediment (bedload) is very difficult when using traditional bedload samplers. However, a significant amount of data on substrate composition and embeddedness (the degree in which fine sediments surround coarse substrates on the surface of a stream bed) was collected with the fish sample. These data will be used to determine whether or not natural coarse substrate (a very important habitat type) is being covered up or filled in by excess fine sediment.

Biological effects of TSS, turbidity, and bedded sediment

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairment in the United States (EPA, 2003). Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat and/or 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 can thwart photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe et al., 1991). Aquatic macroinvertebrates are generally affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman 1988) and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton 1985; Gray and Ward 1982).

Turbidity/TSS standard

Since the late 1960's, MPCA has used a turbidity standard of 25 nephelometric turbidity unit (NTU) as a means of addressing aquatic life use impacts resulting from increased suspended particles (sediment, algae, etc.) in the water column of streams and rivers. Although numerous rivers remain listed as impaired for turbidity (including the GUS Minor), the agency is moving towards a water quality standard based on a TSS criteria. Unlike turbidity, TSS is a "concentration-based" parameter, which facilitates the development of load allocations during the total maximum daily load (TMDL) process.

In the fall of 2010, MPCA released draft TSS standards for public comment (Markus, 2010). The new TSS criteria are stratified by geographic region and stream class (e.g. cold water, warm water) to account for differences in natural background conditions and biological sensitivity. The draft TSS standard for the Sauk River has been set at 30 mg/L. This concentration is not to be exceeded in more than 10 percent of samples within a 10-year data window. The assessment window for these samples is April-September, so any TSS data collected outside of this period will not be considered for assessment purposes.

For the purposes of Stressor Identification, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. TSS results are available for the watershed from state-certified laboratories, and the existing data covers a much larger spatial and temporal scale in the watershed.

Sources and pathways of deposited and bedded sediment riparian grazing/bank erosion

Rangeland and pasture are common landscape features throughout the Sauk River watershed. Most of these areas are operated for cattle grazing, but several horse operations were noted during reconnaissance trips throughout the watershed. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase streambank erosion and reduce substrate quality (Kaufman and Krueger, 1984; McInnis and McIver, 2009). In some areas, the riparian corridor along the Sauk River and its tributaries has been cleared for pasture and heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect streambanks and provide shading. Exposure of these areas to weathering, trampling, and sheer stress from high flow events appears to be increasing the quantity and severity of bank erosion.

Figure 16 shows examples of bank erosion observed throughout the Sauk River watershed. Bank erosion occurred within urban/developed areas, along the edges of cultivated cropland , steep sloping valley walls, and even heavily-wooded riparian corridors . This suggests that there are multiple land uses and erosional processes contributing to increased sediment inputs and sediment-related stressors to aquatic life. Buffers of inadequate width to protect streambank integrity and aquatic habitat were observed throughout the length of the Sauk River.

Figure 17: Examples of bank erosion from various land cover types in the Sauk River watershed

Overland runoff

Nearly 50 percent of the landcover in the Sauk River watershed is cultivated cropland. During the times of the year when crops are not in the ground, these cultivated fields are especially vulnerable to erosion via overland runoff processes driven by snowmelt and precipitation events. Figure 17 below provides an example of how cultivated land can deliver sediment, nutrients, and other potentially harmful agents to aquatic life (manure, pesticides, etc.). These photos were taken during a snowmelt event in March of 2009, and sampling of the runoff indicated high NO_2+NO_3 concentrations (9.4 mg/L) and extremely high turbidity (508.9 NTU).

Figure 18: Overland flow during spring snowmelt event.

Total suspended volatile solids

The presence of algae and other volatile constituents in the water column can contribute to elevated TSS concentrations and high turbidity. Total suspended volatile solids (TSVS) are the particles in a water sample that are lost upon ignition at a temperature around 550˚ C. TSVS concentrations can provide a rough approximation of the amount of organic matter present in suspension in the water column. Examples of TSVS constituents in streams include algae and other aquatic microorganisms and detritus. Elevated TSVS concentrations can impact aquatic life in a similar manner as TSS – with the suspended particles reducing water clarity – but unusually high concentrations of TSVS can also be indicative of nutrient imbalance and an unstable dissolved oxygen regime.

Specific effects of TSS on fish and macroinvertebrates

Based on overall IBI scores alone, it is difficult to isolate the potential effects of elevated TSS on biota from other confounding stressors. In-depth analysis of certain species or biological metrics that may be sensitive to elevated TSS concentrations can offer some insight into the role of elevated TSS in biotic impairments in the Sauk river watershed. Table 7 is a compilation of observed biological responses to elevated TSS and suspended sediment gathered from other research.

Table 7: Impacts of elevated concentrations of suspended sediment on fish and macroinvertebrate assemblages

Biota Impacted	Effect	Source
Invertebrate	↓ filter feeders (esp. Hydropsychidae) (x)	Arruda et al. (1983); Lemley (1982)
Invertebrate	↓ species diversity (x)	
Invertebrate	↓ grazer taxa	
Invertebrate	↑ chironomid density	Gray and Ward (1982);
Invertebrate	↓ Ephemeroptera, Trichcoptera	
Fish	↓ abundance / feeding efficiency / growth smallmouth bass	Berry et al. (2003); Paramagian (1991)

Filter feeding groups of macroinvertebrates are reduced in sites that are impacted by TSS and substrate embeddedness. Figure 18 displays the relative abundance of two macroinvertebrate functional feeding groups. As water quality degrades through the increase in suspended material, filtering feeding groups are reduced in abundance. There is an advantage to gathering your food, and the relative abundance of this feeding group will increase. The filtering feeding group is composed of individuals that create nets or has special adaptations for filtering food out of the water column.

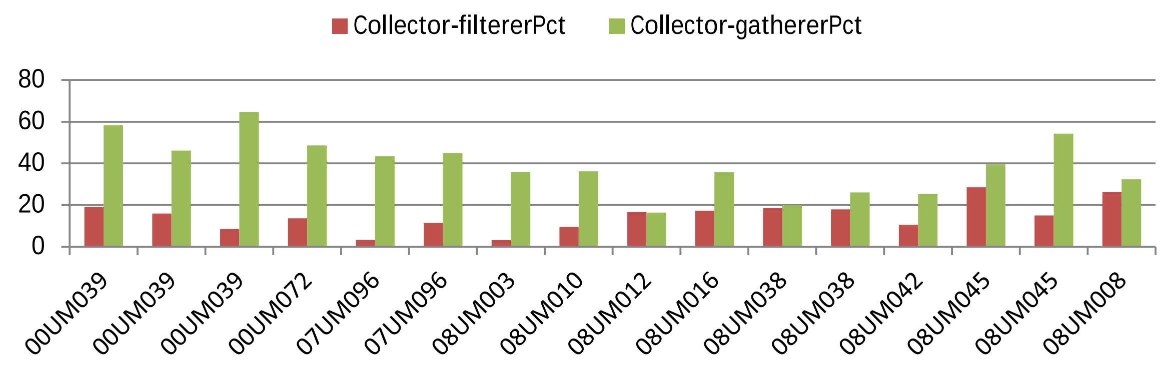


Figure 19: Macroinvertebrate functional feeding groups displaying filtering versus gathering

Conceptual model

The conceptual model for TSS and bedded sediment as candidate causes for impairment is shown in Figure 19. There are numerous potential sources and causal pathways associated with these candidate stressors in the Sauk River Watershed, most of which are associated with landcover changes resulting from agricultural land uses and erosional processes taking place in the stream corridor and ditch networks. The proximate effects, or "stress", on biota follows two potential pathways; (1) effects from elevated turbidity and/or suspended sediment (decreased visibility, gill abrasion, etc.); and/or (2) effects from bedded sediment (pool filling, loss of spawning habitat, etc.). (Bedded sediment is covered on page 30)

Suspended and Bedded Sediment (SABS)

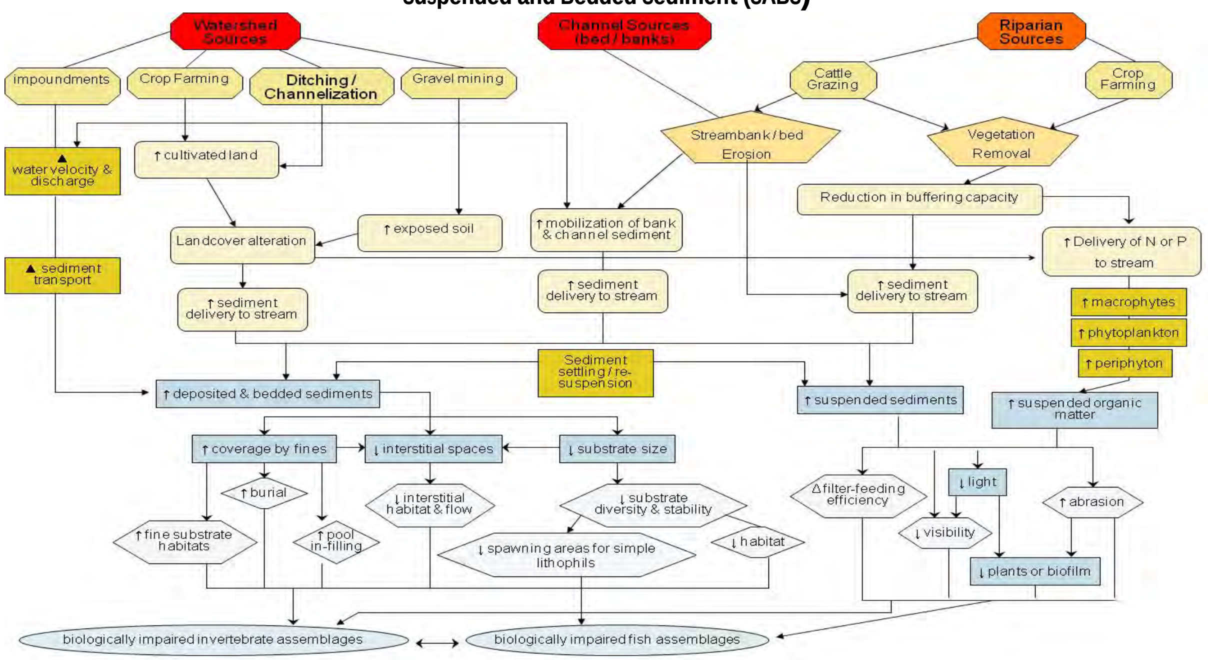


Figure 20: Conceptual model for candidate cause #2:

Strength of evidence summary for TSS

Based on existing water quality data and several biological indicators, there is evidence available in support of elevated total suspended solids (TSS) concentrations as a stressor to aquatic life. The negative impacts of TSS can be seen throughout the Sauk watershed, however, they are the most likely stressor in the GUS Plus Minor, Sauk Lake Minor, Center Sauk River Minor, and Lake Osakis Minor.

Table 8: Strength of Evidence table for elevated total suspended solids (TSS) as a cause of biological impairment by watershed zone

Types of Evidence	Lake Osakis Minor	Sauk Lake Minor	Center Sauk River Minor	Adley Creek Minor	GUS Plus Minor	St. Roscoe Minor	Chain of Lakes Minor	Cold Spring minor	Grand Pearl Minor	Mini Metro Minor
Evidence from Sauk River Management Zone Data										
Spatial/temporal co-occurrence	+	-	+	+	+	+	-	-	-	-
Temporal sequence	0	0	0	0	+	+	0	0	0	0
Field evidence of stressor-response	+	-	+	++	++	+	0	0	-	-
Causal pathway	+	-	+	++	++	+	-	0	-	0
Evidence of exposure, biological mechanism	0	-	+	+	++	+	-	+	0	0
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified or tested predictions	0	-	+	+	+	0	0	0	0	0
Symptoms	0	0	0	0	+	0	0	0	0	0
Evidence using data from other watersheds / Scientific Literature										
Mechanistically plausible cause	+	-	+	+	++	+	-	+	-	+
Stressor-response in other lab studies	++	++	++	++	++	++	++	++	++	++
Stressor-response in other field studies	++	++	++	++	++	+	++	++	+	++
Stressor-response in ecological models	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Analogous stressors	++	++	++	++	++	++	++	++	+	++
Multiple lines of evidence										
Consistency of evidence	+	++	+	++	+++	+	0	0	0	0
Explanatory power of evidence	0	+	++	+	++	+	0	0	0	0

Key: + is a positive indicator, - is negative indicator, 0 is neutral, NE is No Evidence

Bedded (deposited) sediment

Total suspended solids (TSS) and bedded sediment are related through several common watershed sources and processes, but each can affect aquatic biota in different ways. Due to the inter-related nature of these parameters, they are grouped together in this report for causal analysis purposes, but ultimately each of these candidate causes will be evaluated independently in terms of impact on fish and macroinvertebrate populations.

Whereas suspended solids and turbidity are potential stressors operating in the water column, bedded (= deposited) sediments impact the stream substrate. Excessive deposition of fine sediment can impair macroinvertebrate habitat quality and productivity (Rabeni et al., 2005). To date, this stressor has not been extensively studied in the Sauk River watershed, in part because there is no state or federal water quality standard for this parameter. Field measurement of bedded sediment (bedload) is very difficult when using traditional bedload samplers. However, a significant amount of data on substrate composition and embeddedness (the degree in which fine sediments surround coarse substrates on the surface of a stream bed) was collected with the fish sample. These data will be used to determine whether or not natural coarse substrate (a very important habitat type) is being covered up or filled in by excess fine sediment.

Biological effects of TSS, turbidity, and bedded sediment

The presence of excess bedded sediment (embeddedness) in stream habitats has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe et al., 1991). Aquatic macroinvertebrates are generally affected in several ways, including: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky 1984). Fish communities are typically influenced via: (1) a reduction in spawning habitat or egg survival (Chapman 1988) and/or (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton 1985; Gray and Ward 1982).

The presence of excess bedded sediment (embeddedness) in stream habitats has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe et al., 1991). Aquatic macroinvertebrates are generally affected in several ways, including: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky 1984). Fish communities are typically influenced via: (1) a reduction in spawning habitat or egg survival (Chapman 1988) and/or (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton 1985; Gray and Ward 1982).

Assessment of bedded sediment

Bedded sediment is assessed by using a visual observation of the amount of fine sediment surrounding the coarse substrate on the stream bottom. This measurement is part of the qualitative habitat assessment that was conducted by MPCA during the phase 2 investigation of impaired reaches. Assessment of particle size was also conducted at select biological monitoring sites to assess the D^{50} or the mean particle size of the stream bottom. Review of the percent embeddedness and percent fines reveal that the percent embeddedness is above 30 permit (Figure 20).

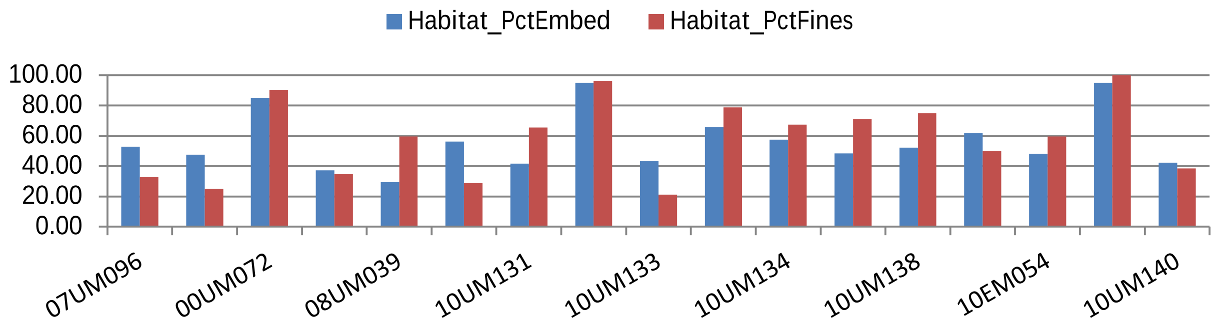


Figure 21: Biological monitoring sites that are impaired have a high percentage of embeddedness and fine substrates.

Particle size was also assessed at a select number of biologically impaired monitoring sites. There appears to be a direct correlation with particle size and the measure of stream embeddedness that is collected during the phase 2 investigations. **Figure 21** shows the relationship between embeddedness and the mean particle size (D^{50}) for each measured reach.

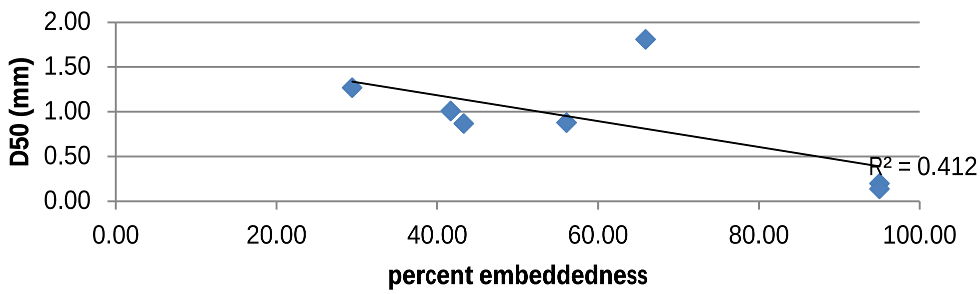


Figure 22: Relationship of particle size (D50) in millimeters to percent embeddedness in select Sauk Watershed stream locations

There also appears to be a direct relationship between the percent of riffles located at the stream sites and the percent embeddedness of coarse substrates. As riffle percentage decreases the percent embeddedness increases (Figure 22).

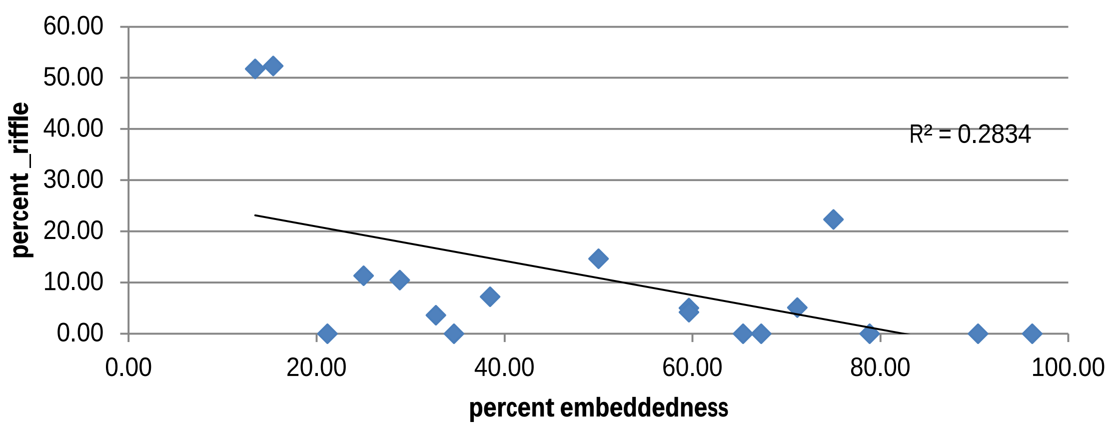


Figure 23: Relationship at select biological monitoring sites of percent riffle versus percent embeddedness

Causal analysis – bedded sediment

Elevated levels of bedded sediment (BS) can be particularly harmful to certain fish and macroinvertebrate species that depend on coarse stream substrates. **Table 9** highlights several key biological metrics that are likely to respond in a predictable way to increases in BS. The fish and macroinvertebrate species included in these metrics have certain reproductive, trophic, and habitat suitability traits that are directly affected as benthic habitats become influenced by sedimentation. Sedimentation can also have more general impacts on a biotic community, such as limiting overall species diversity or reducing the number of sensitive organisms in the assemblage.

Table 9: A selection of biological metrics that may be sensitive to increases in DBS

Metric	Metric Description	Expected Response to increase in DBS
Trophic		
BenInsectTxPct	Relative abundance (%) of taxa that are benthic insectivores	*Decrease*
SLithopPct	Relative abundance (%) of individuals that are simple lithophilic spawners	*Decrease*
SLithopTxPct	Relative abundance (%) of taxa that are simple lithophilic spawners	*Decrease*
DarterSculpSucPct	Relative abundance (%) of individuals that are darter, sculpin, and round bodied sucker species	*Decrease*
DarterSculpSucTxPct	Relative abundance (%) of taxa that are darters, sculpins, and round bodied suckers	*Decrease*
ClingerCh	Taxa richness of clingers	*Decrease*
ClingerChTxPct	Relative percentage of taxa adapted to cling to substrate in swift flowing water	*Decrease*

Review of the biological monitoring stations that have percent embeddedness shows that as there is a negative response by the macroinvertebrate group known as clingers to the amount of stream embeddedness. As substrates become more embedded with fine sediment the percent of clinger taxa in the macroinvertebrate sample is reduced (Figure 23). This ClingerChTxPct metric is a measure of relative percentage of taxa adapted to cling to substrate in swift flowing water.

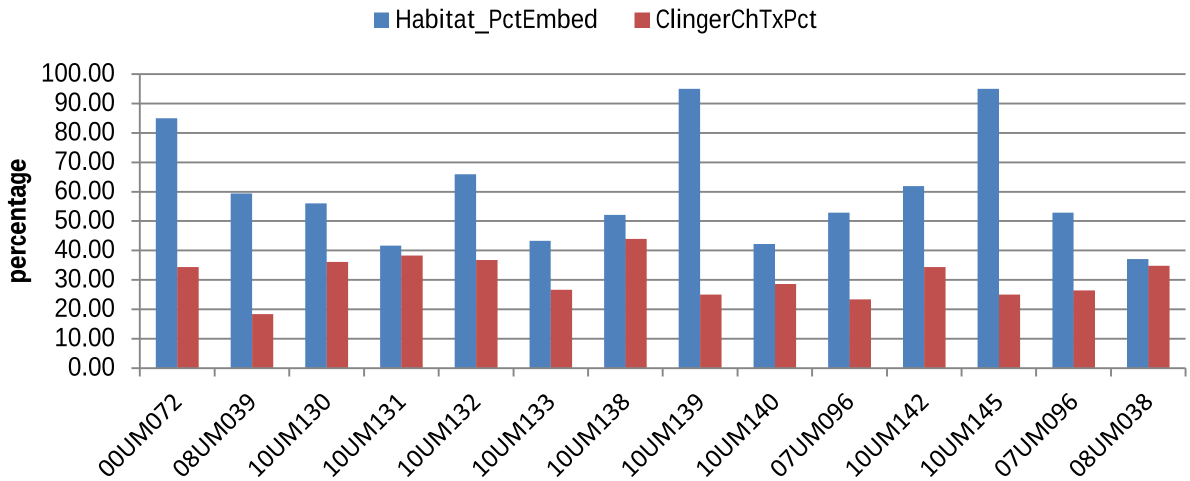


Figure 24: This graph compares the macroinvertebrate group (clinger) compared to stream substrate embeddedness. This graph looked at sites that were impaired for both fish and macroinvertebrates.

Bedded sediment is likely a factor in the abundance and diversity of benthic insectivore fish species and darter species in the Sauk River watershed. The available and preferred habitat of darters and round bodied suckers is diminished as the stream becomes embedded with fine substrates. Both functional groups of fish (DarterSculpSucTxPct, BenInsect-TolTxPct) depend on coarse substrate for either feeding or reproductive activities. Figure 24 below displays the metric scores for each functional fish group against the percent stream bed embeddedness percentage. The low metric scores are likely a direct response to the high percentage of fines in the channel.

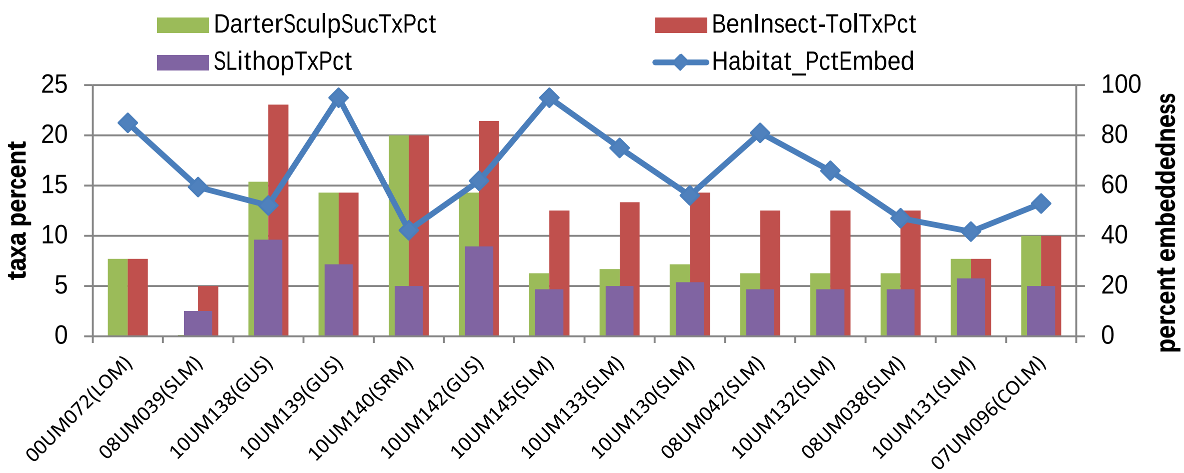


Figure 25: Benthic insectivorous fish metric and Darter sculpin round bodied sucker fish metric versus stream embeddedness percent.

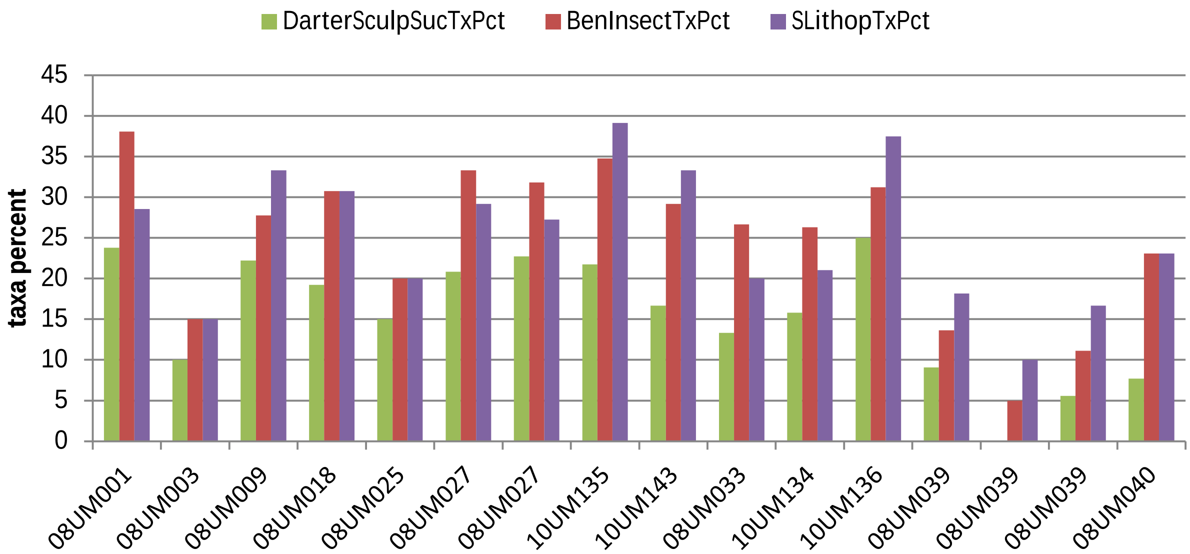


Figure 26: Sauk River fish metrics moving upstream from Waite Park to Lake Osakis

Strength of evidence summary for deposited and bedded sediment

Bedded sediments (BS) are likely a stressor to fish and macroinvertebrate assemblages in the Sauk River watershed. This is especially the case in channelized reaches in the Lake Osakis (LOM), Sauk Lake Minors (SLM) and Getchell-Unnamed-Stony Minor (GUS). Substrate embeddedness levels were high (45-95 percent) in these areas, and the response from biota indicated a cause and effect relationship (low darter taxa richness, decrease in simple lithophils).

The presence of excess BS and negative effects on biota are more difficult to determine in the main Sauk River Minors. There is very little data available on substrate composition and embeddedness estimates. Overall, it is believed that embeddedness and overall substrate quality generally improve in the main Sauk River reaches as we move downstream (on Figure 25; 08UM40 is the farthest upstream site, while Site 08UM001 is located in Waite park). Site 08UM003, which is located in Rockville, scored poorly in all three metrics as did site 08UM039, which is located off Cedar Lake Road upstream of Sauk Lake. Both of these sites had bottom substrates that were dominated by sand, however, no pebble counts or measure of embeddedness was conducted to quantify and compare against select metric scores for fish. Scores of simple lithophilic spawning fish generally are higher in stream sites that have coarse substrate. Most of the Sauk River sites that passed the IBI for fish have metric taxa percentages of 20 or greater for SLithopTxPct and BenInsectTxPct.

Nitrate toxicity

NO_2 – NO_3 water quality standards/ecoregion expectations

There is currently no standard for nitrate-nitrogen (Nitrate-N) in Minnesota. MPCA has developed draft standards designed to protect aquatic life. The draft acute value (maximum standard) for class 2A (coldwater streams) and 2B (general streams) waters is 41 mg/L nitrate-N for a 1-day duration. Draft chronic values for 2A and 2B are 3.1 and 4.9 mg/L nitrate-N respectively for a 4-day duration (Monson, 2010).

McCollor & Heiskary (1993) compiled NO_2 – NO_3 data for minimally impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. Nearly all of the Sauk

River Watershed falls within the North Central Hardwood Forest (NCHF) ecoregion (**Figure 26**) (Omernik, 1987). The annual 75th percentile nitrate-N values for minimally impacted streams in each ecoregion of Minnesota are shown in Figure 4.3-1. Nitrate-N concentrations appear to increase from north to south, with significantly higher concentrations in the Western Corn Belt Plains (WCBP) ecoregion.

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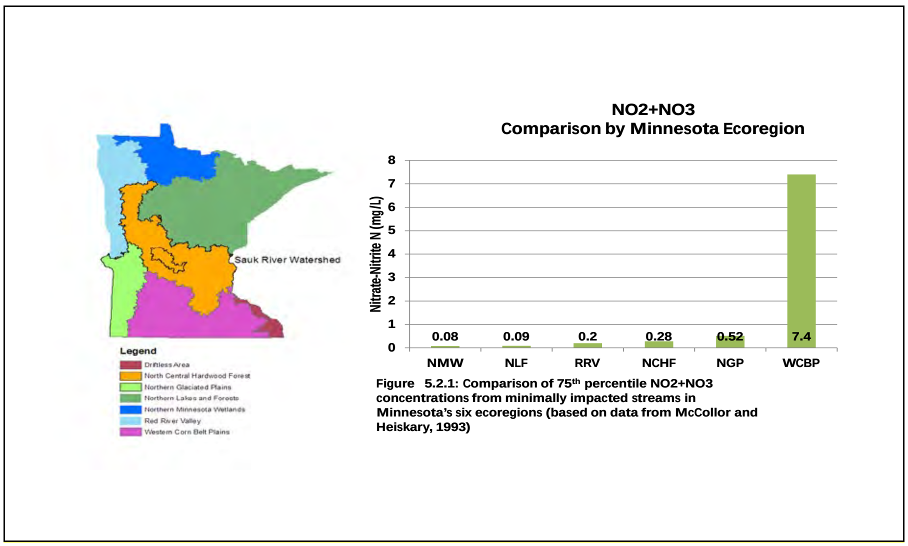

Figure 27: Comparison of 75th percentile NO2+NO3 concentrations from minimally impacted streams in Minnesota's six ecoregions (based on McCollor and Heiskary, 1993).

Effects of nitrate-N toxicity on aquatic organisms

The intake of nitrite and nitrate by aquatic organisms has been shown to convert oxygen-carrying pigments into forms that are unable to carry oxygen, thus inducing a toxic effect on fish and invertebrates (Grabda et al, 1974; Kropouva et al, 2005). Certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity (Camargo and Alonso, 2006).

Nitrate toxicity to freshwater aquatic life is dependent on concentration and exposure time, as well as the overall sensitivity of the organism(s) in question. Comargo et al (2005) cited a maximum level of 2 mg/L nitrate-N as appropriate for protecting the most sensitive freshwater species, although in the same review paper, the authors also offered a recommendation of NO_3 concentrations under 10 mg/L as protective of several sensitive fish and aquatic invertebrate taxa.

The difficulty in applying current knowledge of nitrate toxicity to Minnesota waters is that most of the research has been focused on species that are either not native to North America, or coldwater (salmonid) fish species (no coldwater impairments in the Sauk watershed). The draft nitrate standard under development by MPCA (3.1 and 4.9 mg/L chronic; 41 mg/L acute) incorporates toxicology data from a number of studies that have used aquatic organisms commonly found in Minnesota. In addition, due to the difficulties in isolating nitrate toxicity effects on individual species or biological metrics in the Sauk watershed, the MPCA draft nitrate standard will be the criteria used to evaluate this stressor.

Sources and causal pathways of NO_3 - NO_2 toxicity

Nitrate (NO_3) and nitrite (NO_2) forms of nitrogren are components of the natural nitrogen cycle in aquatic ecosystems. NO_2 anions are naturally present in soil and water, and are routinely converted to NO_3 by microorganisms as part of the nitrification and denitrification processes involved in the nitrogen cycle. Nitrogen cycling in the environment results in nitrogenous compounds such as ammonia denitrifying into the more stable and conservative nitrate ion (NO_3).

In Minnesota, natural inputs of nitrate to surface waters vary by geographic location. However, when nitrate concentrations in surface water samples from “reference” areas (i.e., areas with relatively little human impact) are compared to samples from areas of greater human impact, the reference areas exhibit much lower nitrate concentrations (Monson and Preimesberger, 2010). Nitrate concentrations under “reference” conditions in Minnesota are typically below 1 mg/L (Heiskary and Wilson, 2005).

Elevated nitrate concentrations in surface water have been linked to a variety of sources and pathways. Anthropogenic alterations of the landscape, namely an increase in agricultural land use, have increased ambient nitrate concentrations in some watersheds to levels that can be toxic to some fish and macroinvertebrates (Lewis and Morris, 1986; Jensen, 2003). In addition to agricultural sources, elevated NO_2 and NO_3 concentrations have also been linked to effluent from facilities producing metals, dyes, and celluloids (Kimlinger, 1975) and sewage (Alleman, 1978).

The sources and potential causal pathways for nitrate toxicity in the Sauk watershed are shown in the conceptual model in figure 27. Given the abundance of cultivated cropland in the watershed, it is feasible that fertilizer application is a prominent source of nitrate in surface water. Lefebvre et al. (2007) determined that fertilizer application and land-cover were the two major determinants of nitrate signatures observed in surface water, and that nitrate signatures in surface waters increased with fertilization intensity. Table 9 lists the strength of evidence for NO_2+NO_3 within the Sauk River Watershed.

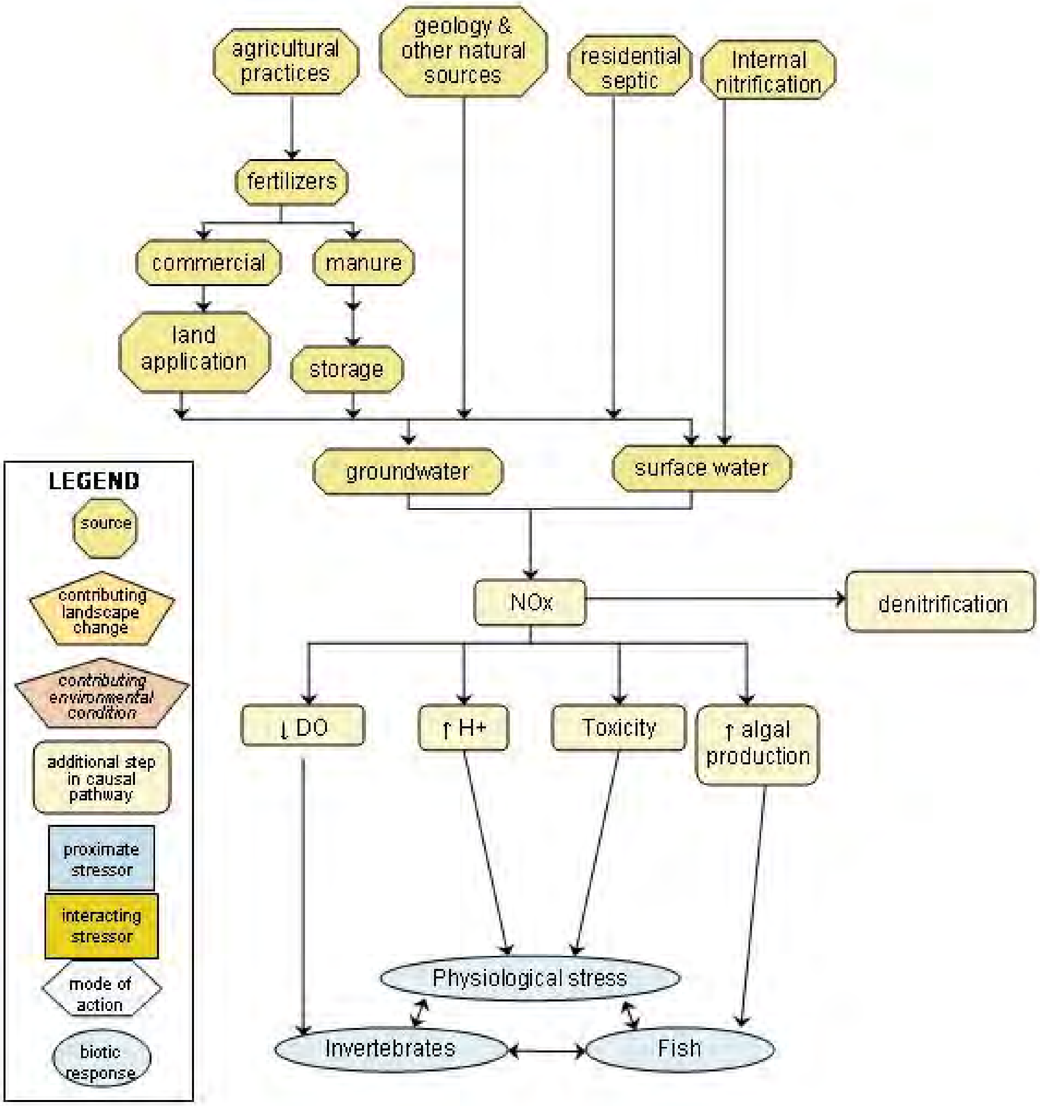

Figure 28: Conceptual model for nitrate-N / nitrite-N toxicity (from EPA, 2011)

Table 10: Strength of evidence for NO2+NO3 in the Sauk River Watershed

Types of Evidence	Lake Osakis Minor	Sauk Lake Minor	Center Sauk River Minor	Adley Creek Minor	GUS Plus Minor	St Roscoe Minor	Chain of Lakes Minor	Cold Spring Minor	Grand Pearl Minor	Mini Metro Minor	
Evidence from Sauk River											
Spatial/temporal co-occurrence	-	++	+	+	++	0	0	-	**-**	**0**	**0**
Temporal sequence	0	0	0	0	+	0	0	0	**0**	**0**	
Field evidence of stressor-response	0	+	-	-	+	-	0	0	**-**	**0**	**0**
Causal pathway	++	++	+	+	+	+	+	+	**+**	**+**	
Evidence of exposure, biological mechanism	0	0	0	0	0	0	0	0	**0**	**0**	
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE	NE	NE	NE	**NE**	**NE**	
Laboratory analysis of site media	NE	NE	NE	NE	NE	NE	NE	NE	**NE**	**NE**	
Verified or tested predictions	NE	NE	NE	NE	NE	NE	NE	NE	**NE**	**NE**	
Symptoms	0	0	0	0	0	0	0	0	**0**	**0**	
Mechanistically plausible cause											
Stressor-response in other lab studies	0	0	0	0	0	0	0	0	**0**	**0**	
Stressor-response in other field studies	NE	NE	NE	NE	NE	NE	NE	NE	**NE**	**NE**	
Stressor-response in ecological models	NE	NE	NE	NE	NE	NE	NE	NE	**NE**	**NE**	
Manipulation experiments at other sites											
Analogous stressors											
Consistency of evidence	0	+	0	0	+	0	0	0	**0**	**0**	
Explanatory power of evidence	0	+	0	0	+	0	0	0	**0**	**0**	

Toxicity from insecticides and herbicides

Background and Conceptual Model (text courtesy of EPA CADDIS) For a more detailed explanation on herbicides, follow this link: http://www.epa.gov/caddis/ssr_herb_int.html.

Herbicides are chemicals used to manipulate or control undesirable vegetation. The most frequent application of herbicides occurs in row-crop farming, where they are applied before or during planting to maximize crop productivity by minimizing other vegetation. They also may be applied to crops in the fall, to improve harvesting. In suburban and urban areas, herbicides are applied to lawns, parks, golf courses and other areas. Herbicides are also applied to water bodies to control aquatic weeds that impede irrigation withdrawals or interfere with recreational and industrial uses of water (Folmar et al. 1979).

Herbicides may cause biological impairments if they occur in water or sediment at sufficient concentrations. Most commonly, they enter surface water in runoff or leachate. Herbicides have relatively low toxicity to fish and invertebrates, therefore, acute toxicity is likely only when they are deliberately or accidentally applied directly to water bodies. Direct applications may result in direct toxicity to non-target plants and animals or indirect effects due to the death and decomposition of plants.

Insecticides are chemicals used to control insects by killing them or preventing them from engaging in behaviors deemed undesirable or destructive. Many insecticides act upon the nervous system of the insect (e.g., Cholinesterase (ChE) inhibition) while others act as growth regulators. Insecticides are commonly used in agricultural, public health, and industrial applications, as well as household and commercial uses (e.g., control of roaches and termites). The USDA (2001) reported that insecticides accounted for 12 percent of total pesticides applied to the surveyed crops. Corn and cotton account for the largest shares of insecticide use in the United States. To learn about insecticides and their applications along with associated biological problems refer to the USEPA website on insecticides and causal analysis located at http://www.epa.gov/caddis/ssr_ins_int.html.

Pesticide monitoring in Minnesota and water quality standards

Since 1985, the Minnesota Department of Agriculture (MDA) and Minnesota Department of Health (MDH) have been monitoring the concentrations of common pesticides in groundwater near areas of intensive agricultural land use. In 1991, these monitoring efforts were expanded to include surface water monitoring sites on select lakes and streams. To learn more about the Minnesota Department of Agriculture pesticide monitoring plan and results, go to the following website: http://www.mda.state.mn.us/protecting/cleanwaterfund/pesticidemonitoring.aspx.

Surface water reference values (text from MDA, 2010)

"The Minnesota Pollution Control Agency (MPCA) has developed toxicity-based (for aquatic life) or human health-based enforceable chronic standards for pollutants detected in surface water. The toxicity-based standard is designed to be protective of aquatic life exposure, and is typically based on exposure duration of four days. The human health-based standard (protective for drinking water plus fish consumption) is based on exposure duration of 30 days. For the most current MPCA water quality rules see, Minn. R. ch. 7050: Standards for Protection of Waters of the State (www.revisor.leg.state.mn.us/rules/?id=7050)." A summary of MPCA's chronic and maximum standard values for common pesticides used in Minnesota are shown in **Table 10**.

Table 11: Summary of MPCA surface water standards associated with target pesticide analytes

	Chronic[1] and Maximum[2] Standards (µg/L)		
Pesticide Analyte	**Class 2A[3]**	**Class 2B[4]**	**Maximum Standard[4]**
Acetochlor	3.6	3.6	86
Alachlor	59	59	800
Atrazine	10	10	323
Chlorpyrifos	0.041	0.041	0.083
Metachlor	23	23	271

[1] Chronic standards are defined in Minn. Rule Chap. 7050 as toxicity-based for aquatic organisms and is protective for an exposure duration of 4 days

[2] Maximum standard value for aquatic life & recreation as defined in Minn. Rule Chap. 7050. Values are the same for all classes of surface waters.

[3] State water classification for coldwater streams and all recreation.

[4] State water classification for cool and warm water streams and all recreation.

Causal analysis – pesticide toxicity

Pesticide data from the Sauk River watershed is somewhat limited, as only one sampling event for pesticides targeted Sauk River sites. However, multiple years of pesticide data have been collected in surrounding watersheds that have similar agricultural land uses, and likely comparable rates and types of pesticide application. Historically, MDA has collected data from four locations in the greater Crow River watershed as part of their statewide survey of surface water. Two of these stations are located on the South Fork Crow River, one is located on the Middle Fork Crow River, and the fourth site is located on the Crow River in Rockford, Minnesota. Data from these surrounding watersheds, as well as the limited data from the Sauk River will be used to characterize the concentrations of pesticides in surface water and the threats posed to aquatic life.

Eleven pesticides and two degradates were detected at surface water monitoring stations in the greater Crow River watershed. The majority of the sampling events were conducted in the Middle and South Forks of the Crow River, and as a result most of the detections of pesticides occur in those streams. Sampling on the Sauk River was limited to one sampling event in August of 2010 at seven sites (Figure 28). Herbicides are often detected in surface waters with greater regularity and higher concentrations in spring and early summer after significant rain events. Therefore, the sampling results for the Sauk River may not be entirely representative of herbicide and pesticide concentrations in the watershed.

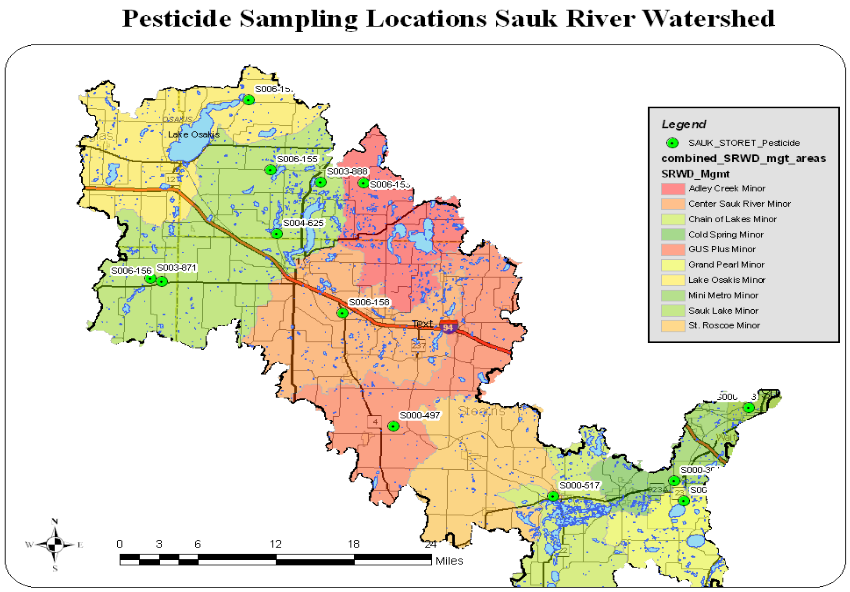

Figure 29: Pesticide sampling locations in the Sauk River watershed

Table 12: Site descriptions and sampling years for pesticide monitoring in the Sauk River watershed

Site ID	Description	Years Sampled	Active?
S000-498	Getchell Creek@CSAH12-New Munich	2010	N
S004-625	Ashley Creek@CSAH11-Sauk Centre	2010	N
S000-497	Stony Creek-Spring Hill	2010	N
S003-303	Crooked Lake Ditch@CR73-Osakis	2010	N
S000-503	Sauk River@CSAH4-St. Cloud	2010	N
S000-916	Eden Lake Outlet@MN22-Eden Valley	2010	N
S006-155	Unnamed Tributary to Little Sauk Lake	2010	N

Based on current monitoring data, Atrazine, Desethylatrazine,and Metachlor were the most commonly detected herbicides in the greater Sauk River watershed (Table 12). This limited data set does not show any exceedences of Minnesota state herbicide/pesticide standards. Much more rigorous data collection would be required to conclude that there are no herbicide/pesticide issues here. It should also be noted that several of the pesticides that were detected do not currently have state water quality standards associated with them.

Table 13: Herbicides, insecticides, and fungicides detected in the Sauk River watershed

	S000-498[A] Getchell Creek@CSAH 12	S004-625[A] Ashley Creek@CSAH11	S000-497 Stony Creek	S003-303 Crooked Lake Ditch	S000-503 Sauk River@CSAH4	S000-916 Eden Lake Outlet	S006-155 Unnamed Trib to Little Sauk Lake
Herbicide							
Acetochlor	ND	ND	ND	ND	ND	ND	P
Alachlor	ND	ND	ND	ND	ND	ND	**ND**
Atrazine	P	**P**	**ND**	**P**	**P**	**P**	**P**
-Deisopropylatrazine	ND	ND	ND	ND	ND	**ND**	**ND**
- Desethylatrazine	**P**	P	P	0.05	**0.05**	**0.05**	**ND**
Dimethenamid	ND	ND	**ND**	ND	ND	**ND**	ND
Metolachlor	ND	ND	**ND**	**P**	P	**P**	**P**
Prometon	ND	ND	ND	ND	ND	**ND**	**ND**
Propazine	ND	ND	ND	ND	ND	**ND**	**ND**
Chlorpyrifos	ND	ND	ND	ND	ND	**ND**	ND
Propiconazole	ND	ND	ND	ND	ND	**ND**	ND
Tetraconazole	ND	ND	ND	ND	ND	**ND**	ND

[A] These stations were only sampled once during low-flow conditions in August 2010

P – Present, but below detection limits

ND – non-detect

NA – parameter not available

Strength of evidence/conclusions

A review of historical and current monitoring data for common herbicides, pesticides, and fungicides within this three-watershed region revealed no exceedances of current state water quality standards developed to protect aquatic life from these compounds. Thus, there is little evidence that herbicide/pesticide/fungicide toxicity is a significant cause of fish and macroinvertebrate impairments in the Sauk River. Although much of the existing data is from adjacent and/or surrounding watersheds, there is reason to believe that the pesticide values observed from comparable rivers in close proximity (South Fork Crow / Middle Fork Crow) can be applied to the Sauk River due to similarity of land use.

Additional monitoring is recommended to further understand the presence of herbicides/pesticides/fungicides in the Sauk River and their potential impact to fish, macroinvertebrates, and other aquatic biota. Monitoring data from spring or early summer rain events would improve confidence in the ability to diagnose or refute pesticide toxicity as a stressor in this watershed. Given these current gaps in the herbicide/pesticide/fungicide data, it is difficult to rule out pesticide toxicity as a possible stressor.

Chloride toxicity

The negative effects of elevated chloride concentrations on aquatic life have been well documented, especially in urban areas. The use of road salt and de-icing products has increased considerably in the United States since 1950, putting more urban streams at risk for this stressor (Kostick, 1993). The EPA recommended chronic criterion for aquatic life is a four-day average chloride concentration of 230 mg/L with an occurrence interval of once every three years, and the recommended acute criterion concentration for chloride is 860 mg/L (USEPA, 1988).

Chloride toxicity was considered a candidate cause for impairment due to the expanding urban, commercial, and residential development in the lower portion of the Sauk River watershed. Existing chloride data were evaluated for the Sauk River Management zones that were established earlier in this report (see section 3.0). Chloride concentrations were well below the chronic standard for class 2B waters of Minnesota (**figure 29**). It does not appear that chloride toxicity is a stressor to aquatic life in the Sauk River watershed.

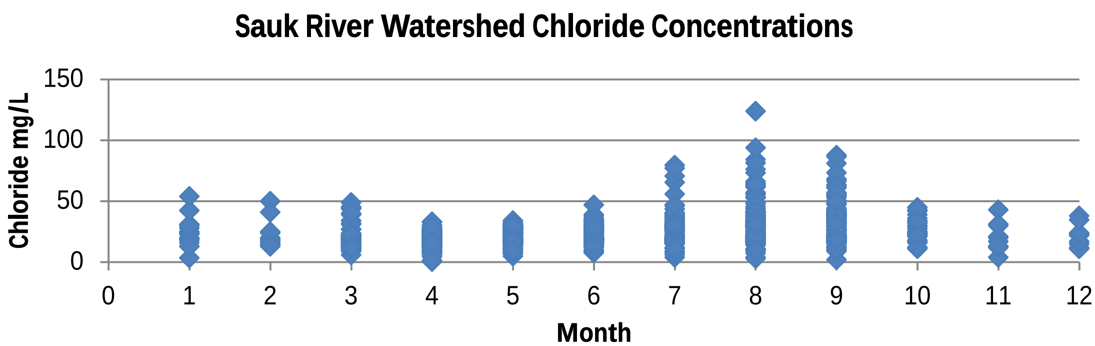

Figure 30: Surface water chloride concentrations by Sauk River Watershed Management zones collected from 1995-2009.

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). Many species of fish avoid areas where dissolved oxygen concentrations are below 5 mg/L (Raleigh et al., 1986).

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 base flow. As temperatures increase, the saturation levels of dissolved oxygen decrease. 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).

The class 2B* water quality standard for DO in Minnesota is 5 mg/L as a daily minimum. Additional stipulations have been recently 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 five-month period of May through September and the seven-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 five-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.

Potential sources and pathways for low dissolved oxygen

Dissolved oxygen (DO) concentrations in streams are 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 Sauk River watershed is shown in **Figure 30.**

Types of dissolved oxygen data

1. 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. Because DO concentrations can vary significantly with changes in 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.

2. Longitudinal (Synoptic)
   A series of longitudinal synoptic DO surveys were conducted throughout the Sauk River Watershed in 2010. A synoptic monitoring approach gathers data across a large spatial scale and minimal temporal scale (as close to simultaneously as possible). In terms of DO, the objective was to sample a large number of sites from upstream to downstream under comparable ambient conditions. For the most part, the surveys took place in mid to late summer when low DO is most commonly observed. Dissolved oxygen readings were taken at pre-determined sites in the early morning in an attempt to capture the daily minimum DO reading.

3. Diurnal (Continuous)
   YSI sondes were deployed for 7-12 day intervals throughout the 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.

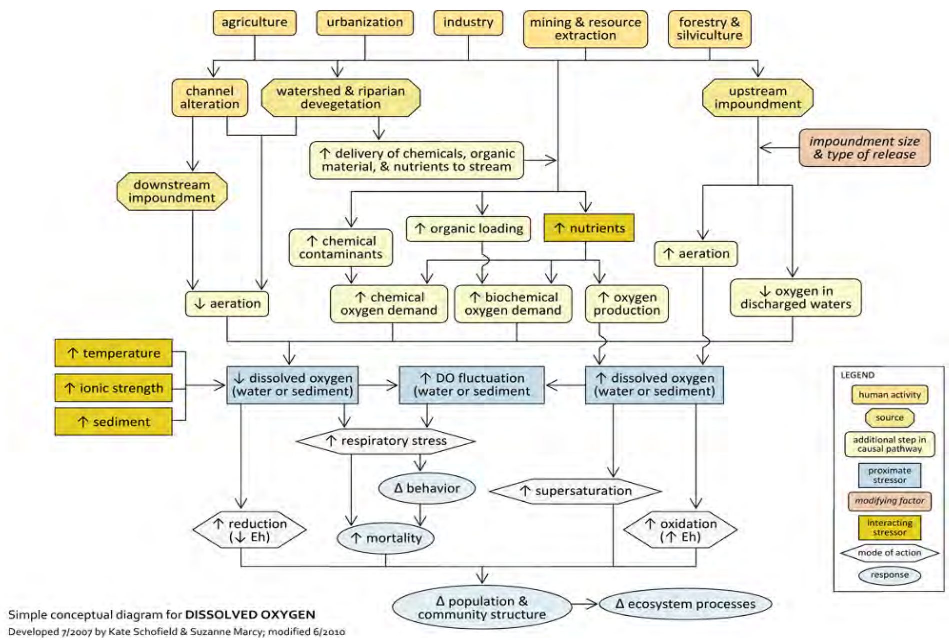

Figure 31: Conceptual model for low Dissolved Oxygen as a stressor in the Sauk River

Evidence of causal pathways –nutrients/chlorophyll-a, and oxygen demand

Nutrient enrichment, chlorophyll-a (Chl-a) concentrations, and measures of biological oxygen demand (BOD) are all factors in the dissolved oxygen balance of streams. Currently, the MPCA is developing nutrient criteria for Minnesota Rivers with targets for total phosphorous and several stressor effects that excess nutrients can cause – high diurnal DO flux, high Chl-a concentrations, and elevated BOD levels (Table 13). Sauk River data for these parameters and the river nutrient criteria in development can be used to investigate potential pathways and sources of low dissolved oxygen.

Table 14: Draft river eutrophication criteria ranges by River Nutrient Region for Minnesota

	Nutrient	Stressor		
Region	TP µg/L	Chl-a µg/L	DO flux mg/L	BOD_5 mg/L
Central	100	<20	≤4.5	≤2.0

1. Total Phosphorous
   Elevated Total Phosphorus (TP) levels can cause excessive growth of algae and periphyton in streams, along with excessive submerged aquatic plant growth. Phosphorus is not toxic to aquatic life, and in small amounts is essential to the functioning of healthy aquatic ecosystems. However, excessive TP concentrations can lead to an increase in turbidity, decrease DO concentrations, and increase fluctuations in diurnal DO levels. Those changes can result in reduction or absence of intolerant species, benthic insectivores, and top carnivores typical of high-quality streams, leading to less desirable assemblages of tolerant species, niche generalists, omnivores, and detritivores typical of degraded streams (Ohio EPA 1999). Phosphorus is typically the limiting nutrient to primary productivity in streams and rivers under natural conditions.

2. Chlorophyll-a
   Chlorophyll-a (Chl-a) concentration is used to measure algal productivity in surface water, and have shown correlations to maximum DO concentrations and DO flux in non-wadable rivers (Heiskary et al., 2010). There is limited chlorophyll-a data collected from the Sauk River and its tributaries. However, in the Sauk River mainstem, Chl-a concentration increases considerably moving from the headwaters downstream to the confluence with the Mississippi River. In the lower portions of the Sauk River, concentrations of Chl-a are consistently above the draft river criteria of 20 µg/L and reach levels as high as 80 µg/L.

3. Biological Oxygen Demand
   Biological oxygen demand (BOD) is an important measure of potential stress on a biological community. Heiskary et al. (2010) documented a relationship between BOD and biological condition. Increases in BOD lead to lower DO levels and, thus, may result in a shift in fish and invertebrate trophic structure. Heiskary et al. (2010) observed that many biological metrics indicated a negative shift in biological condition (stress response) at about 2-3 mg/L BOD. The majority of the Sauk River sites fall within this range, and the lower river exhibited BOD concentrations as high as 10 mg/L. Based on these observations, it is likely that elevated BOD is a prominent causal pathway for low DO conditions.

4. Dissolved Oxygen Flux
   Hieskary et al. (2010) observed several strong negative relationships between fish and macroinvertebrate metrics and DO flux. Their study found that a diurnal (24 hour) DO flux over 4.5 mg/L reduced macroinvertebrate taxa richness and the relative abundance of sensitive fish species in a population.

Loss of Connectivity and Habitat

Stream impoundments

Impoundment structures (dams) on river systems alter steamflow, water temperature regime, and sediment transport processes – each of which can cause changes in fish and macroinvertebrate assemblages (Cummins, 1979; Waters 1995). Dams also have a history of blocking fish migrations and can greatly reduce or even extirpate local populations (Brooker, 1981; Tiemann et al., 2004). In Minnesota, there are over 800 dams on streams and rivers for a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

There are no hydroelectric dams located on the Sauk River. However, there are several water and/or carp control structures located at the outlet of several lakes that are hydologically connected to the river. The City of Sauk Centre maintains a permanent dam structure at the outlet of Sauk Lake to control lake water elevation. This barrier also limits movements of desirable fish species (e.g. northern pike and walleye) that are known to move between riverine and lacustrine habitats for spawning, feeding, and/or refuge.

The impacts of dams on the fish and invertebrate assemblages of the Sauk River are difficult to quantify, but this is probably a low priority stressor relative to some of the other stressors discussed in this report. There are no dramatic upstream/downstream differences in biological integrity in reaches with impoundment structures, although comparisons are difficult when there are other confounding stressors present. The loss or reduction of connectivity between the Sauk River and Sauk Lake may be altering fish assemblages locally. Removal or modification of this structure to allow fish passage would likely reduce the effectiveness of carp control and could jeopardize the fishery and water quality of Sauk Lake. Given the resource value of Sauk Lake, it is unlikely that connectivity will be restored at this location.

Groundwater withdrawal

There are a number of Management Units within the Sauk River Watershed that have center pivot irrigation. The Ashley creek watershed, within the Sauk Lake Minor, has much center pivot irrigation occurring near Westport and Southwest of Westport. Limited information is known at this time about the volume of water being withdrawn from Ashley Creek or nearby groundwater wells. Further study should be conducted to determine the volume of water being used for irrigation, along with the amount of fertilizer used in the fertigation process.

Habitat

Habitat features in streams range from deep pools to gravel riffles, along with areas of woody habitat both in the forms of trees shading the riparian corridor, and branches and leaves falling into the stream channel. A lack of woody vegetation along the stream corridor causes increased stream temperatures, lack of suitable habitat for invertebrates that feed on leaf material (shredders), and general bank instability from missing root structure to armor the banks. Increased fine sediment can fill the interstitial spaces between the gravel and cobble substrate limiting the available habitat for clingers and desirable EPT taxa. The increase in fine sediment also limits benthic insectivore fish and lithophilic spawning taxa.

Table 15: Conclusions and Summary of Probable Stressor

Summary of Stressors By Watershed Zone	Lake Osakis Minor	Sauk Lake Minor	Center Sauk River Minor	Adley Creek Minor	GUS Plus Minor	St Roscoe Minor	Chain of Lakes Minor	Cold Spring Minor	Grand Pearl Minor	Mini Metro Minor
Loss of Habitat due to Channelization / Ditching	+++	++	+++	++	++	+	++	0	+	-
Total Suspended Solids	+	+	-	0	+++	0	0	0	0	+
Deposited and Bedded Sediments	++	+	++	0	+++	0	0	+	0	++
Pesticide Toxicity	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE
Nitrate-Nitrite Toxicity	++	-	-							-
Chloride Toxicity	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen	++	++	-	NE	+	NE	++	NE	++	NE
Irrigation – Flow Alteration	0	+	0	0	+	0	0	0	0	-/NE
Connectivity – Loss of fish passage	+	++	-	NE						-

Key: + is a positive indicator, - is negative indicator, 0 is neutral, NE is No Evidence

Stressor identification for Watershed Management Zones (Minors)

Lake Osakis Minor

The Lake Osakis Minor (LOM) consists of a system of small, channelized tributaries to Lake Osakis in portions of Todd and Douglas Counties (Figure 31). The mainstem of the Sauk River begins at the outlet of Lake Osakis at EQuIS sampling location S002-649, and most of the tributaries in this zone are entirely channelized due to agricultural ditching. Historically, this area was dominated by tall grass prairie, Big Woods –Hardwoods (oak, maple, basswood, hickory) with areas of “wet prairie” along the riparian corridor of the ditch before entering Lake Osakis. Current land use is predominantly agricultural (44 percent cultivated land) and only 26 percent of the area remains in non-native grassland and 7 percent wetlands (Figure 31).

Another land use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots within this management area. The potential stressors related to this land use will be discussed in greater detail in section 4.

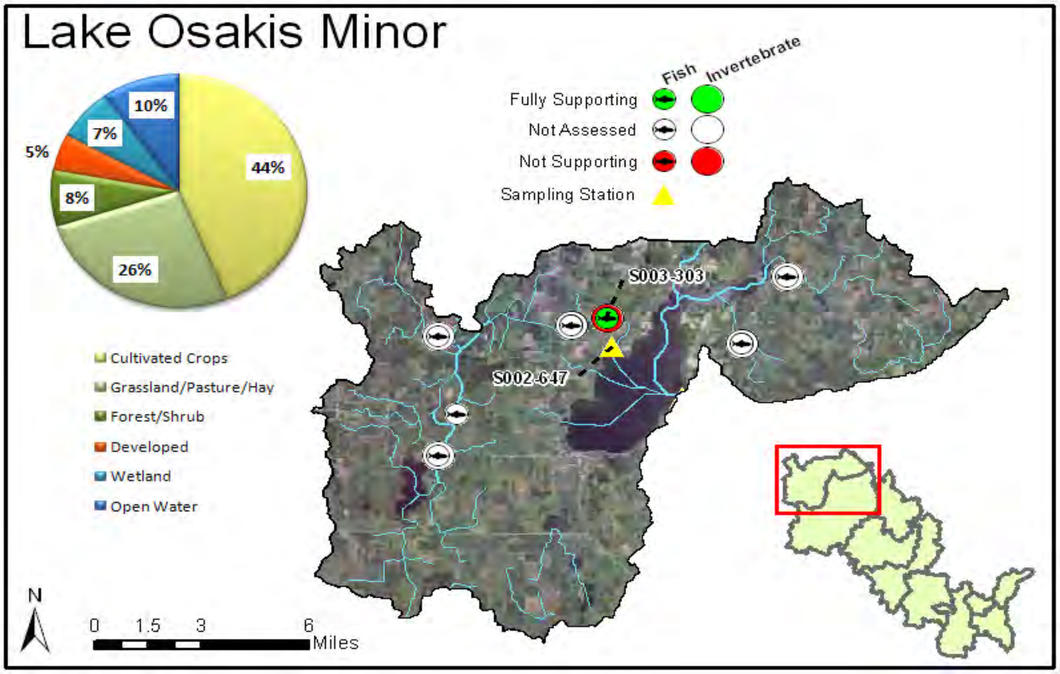

Figure 32: Location of Channelized Headwaters watershed zone and local land-cover.

Nutrients: evidence for causal pathways

Nutrient enrichment, chlorophyll-a (Chl-a) concentration, and biological oxygen demand (BOD) are all factors in the dissolved oxygen balance of streams. Currently, the MPCA is developing nutrient criteria for Minnesota rivers with targets for total phosphorous and several stressor effects that excess nutrients can cause – high diurnal DO flux, high Chl-a concentrations, and elevated BOD levels (see Section 4.6.0). Crooked Lake Ditch data for these parameters and the proposed river nutrient criteria are used to investigate potential pathways and sources of low DO.

The main tributary in the Lake Osakis Minor is Judicial Ditch 2 (Crooked Lake ditch). This drainage was sampled periodically from 1989-2009 for a variety of water quality parameters. Analysis of the data shows that Total Phosphorus (TP) data is well above the proposed TP nutrient criteria of 0.10 mg/L for much of the sampling record (Figure 32). EQuIS site S003-303 has a record of 200 samples collected from spring of 2005 through the fall of 2009: minimum = 0.02 mg/L, maximum = 0.92 mg/L, mean = 0.166 mg/L. EQuIS site S002-647 has a record of 88 samples collected from spring 2002 through fall of 2009: minimum= 0.041 mg/L, maximum= 0.706 mg/L, mean= 0.127 mg/L. The TP values are well above nutrient criteria during snowmelt periods and also during periods of runoff. High TP values stimulate growth of algae and other aquatic plants which, in turn, can lead to high DO flux.

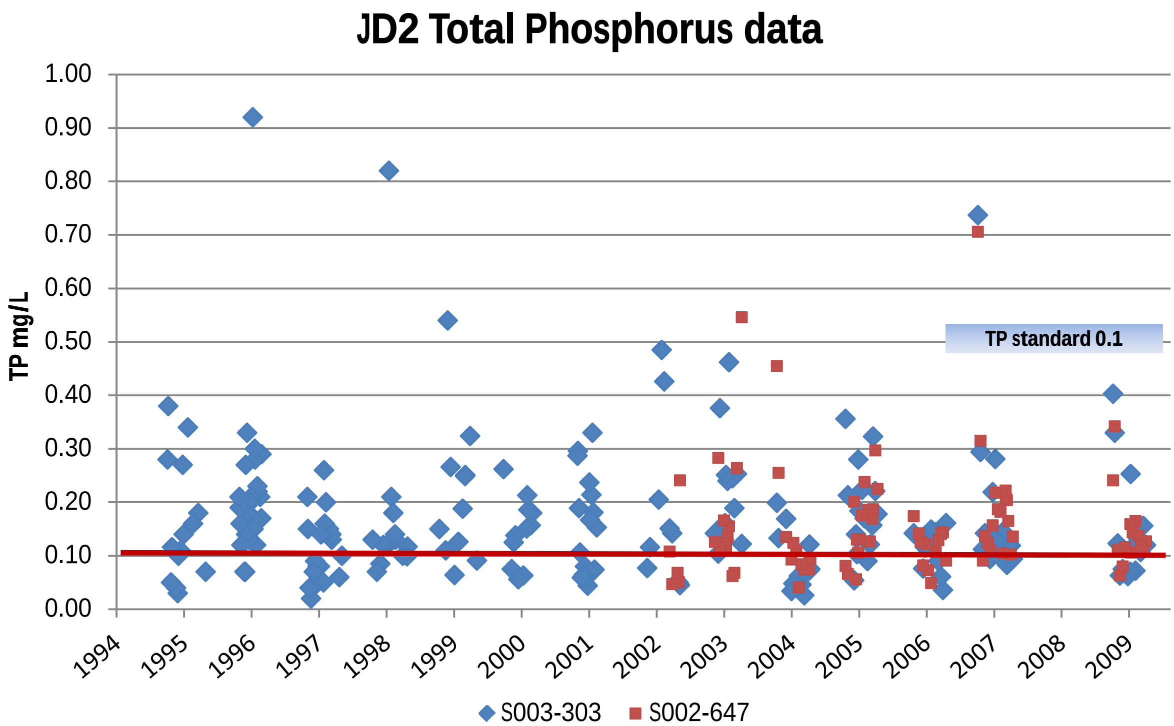

Figure 33: TP values over time collected from Crooked Lake Ditch (JD2)

Total suspended solids

The two EQuIS sites also had a large set of Total Suspended Solids (TSS) data collected from 1989 through 2009. **Figure 33** shows that, for much of the recorded period the concentration of TSS was above the standard. EQuIS site S003-303 has a record of 139 samples collected from spring of 2005 through the fall of 2009. The following statistics were computed from this record: minimum = 0.05 mg/L, maximum value= 250 mg/L, mean = 37 mg/L. Storet site S002-647 has a record of 88 samples collected from spring 1989 through fall of 2009. The following statistics were computed from this record: minimum= 1 mg/L, maximum= 80 mg/L, mean= 15.7 mg/L. The TSS values are well above TSS standards values during snowmelt periods and also during periods of runoff.

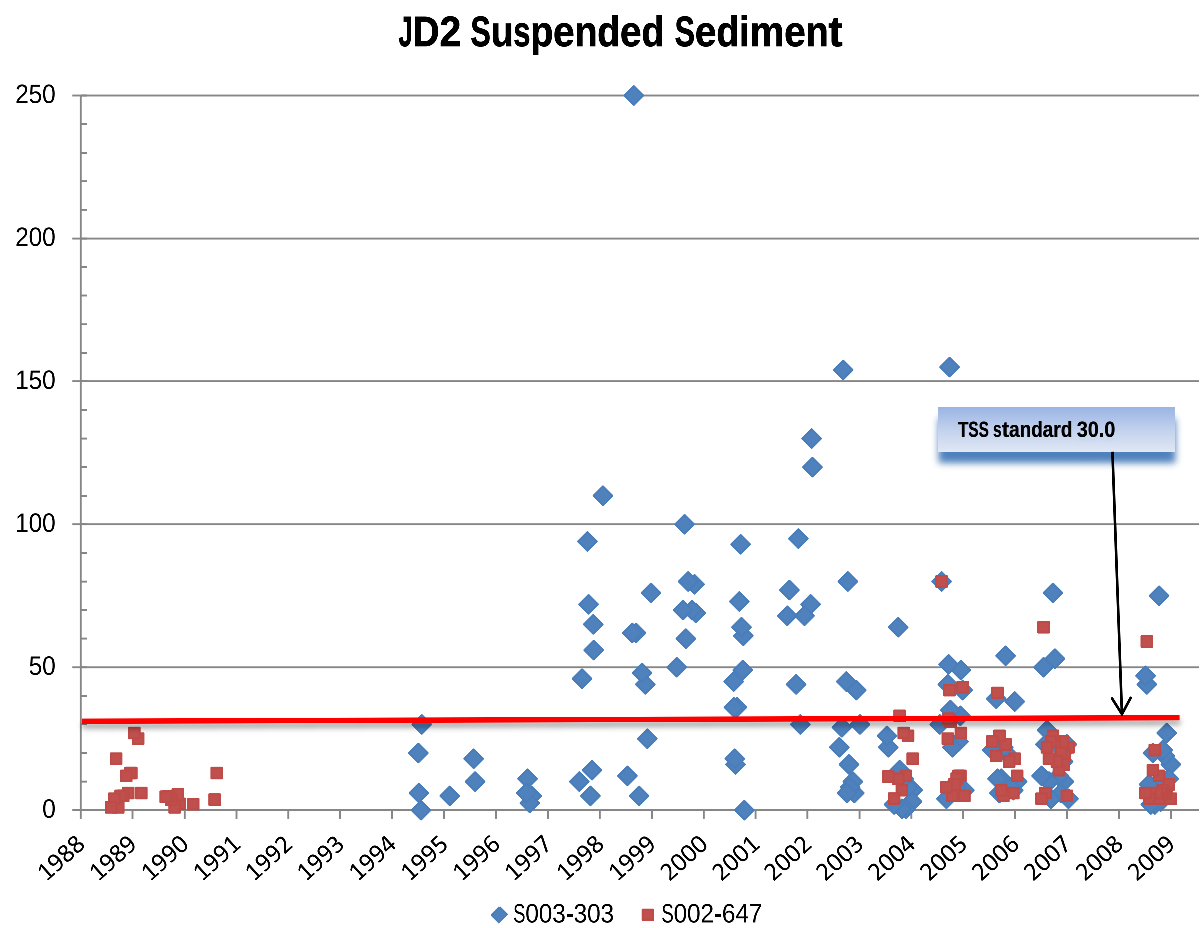

Figure 34: Crooked Lake Ditch (JD2) Total Suspended Sediment data from 1993-2009.

Reconnaissance of the JD2 system did not indicate severe bank erosion along the channel. However, with the frequency of the SRWD having to clean out the sediment basin on the downstream section of JD2, there is a problem with excess sand. The sediment basin is excavated approximately every three years, which indicates there is a high volume of sediment moving through the system. The TSS values are indicating a sediment problem which, in turn, is causing increase in fine substrate and a loss of coarse substrate habitat features. The macroinvertebrate impairment from biological site 00UM072 is directly attributed to the high percent of fine sediment (90.38 percent) and high embeddedness value (85 percent) for this reach. The invertebrates metrics reviewed that tend to show a negative response to TSS are: ClingerPct and Collector-filtererPct. Both metrics scored relatively low (22.4 and 13.7 percent) when compared to sites that have available coarse substrates.

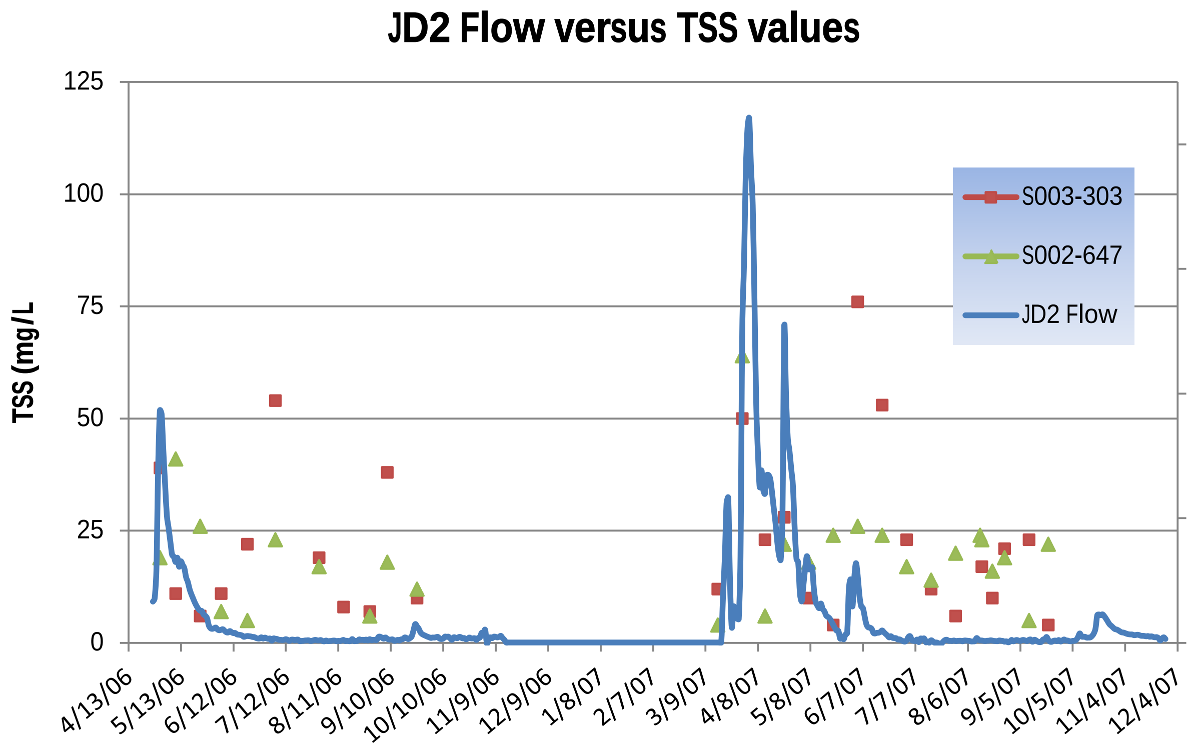

Figure 35: JD2 Flow versus TSS

(note: high percentage of TSS load comes during low flow indicating high algal productivity)

Dissolved oxygen

Instantaneous DO readings in JD2 were collected from 2005 through 2009 (Figure 35). There are recurring periods during these years where DO drops below 5 mg/L. This may be altering the biological community. **Figure 36** below displays DO readings versus discharge. During the low flow periods appears to coincide with the most DO observations below 5 mg/L. The low flow periods also would have periods of algal and duckweed growth which are affecting the DO concentrations.

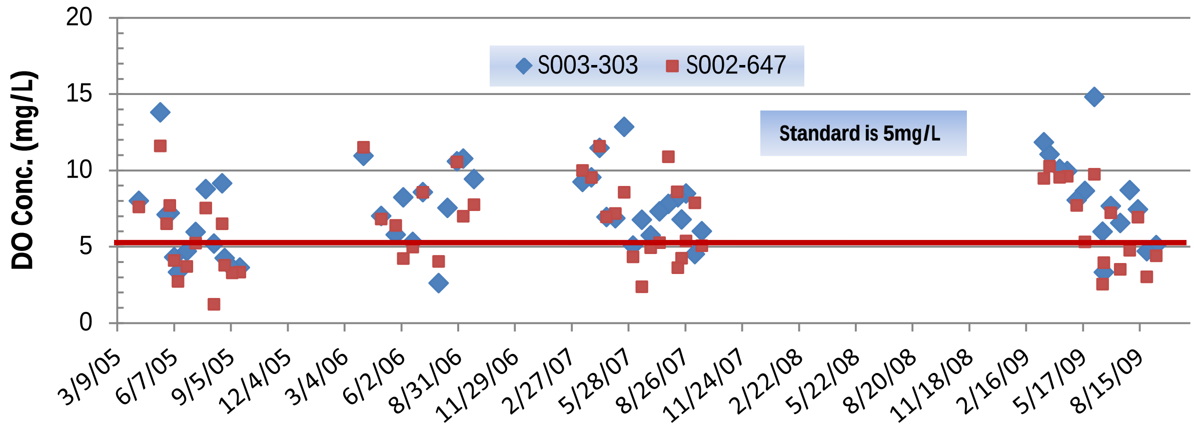

Figure 36: Dissolved Oxygen data versus State 2B standard of 5 mg/L from 2005-2009.

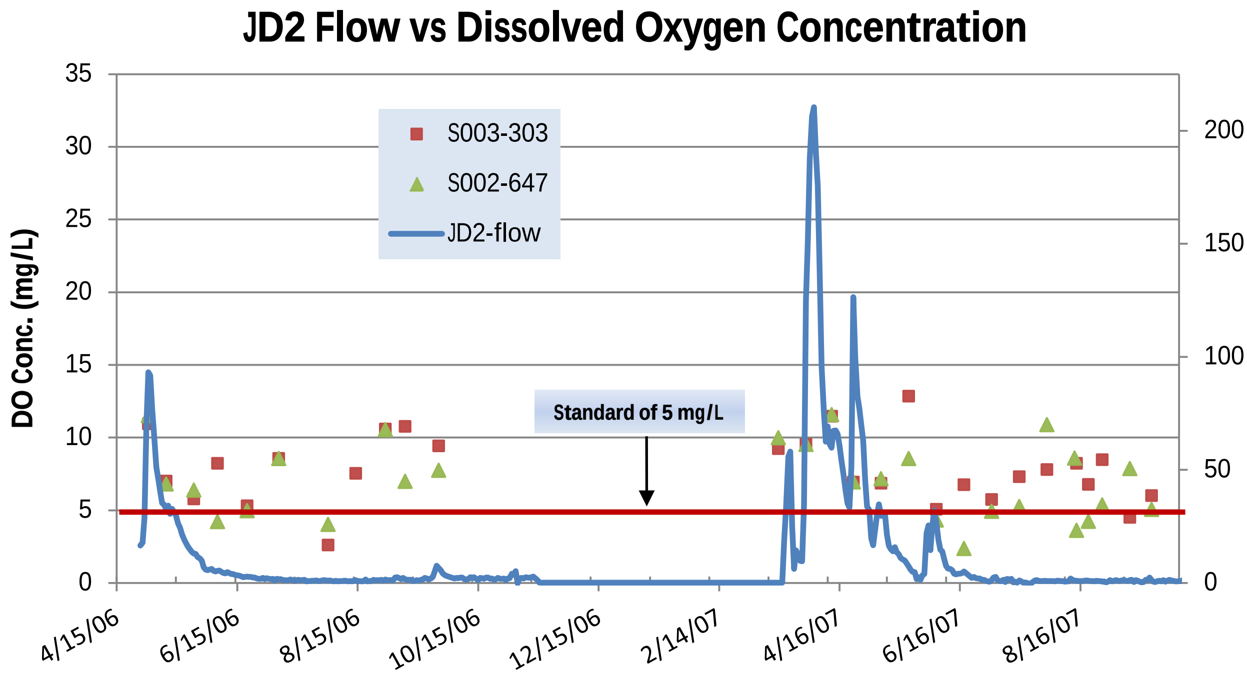

Figure 37: Dissolved Oxygen data versus discharge data for JD2 from 2006-2007.

No continuous water quality sonde data was collected in this Minor so DO flux cannot be computed. However, it is strongly suspected that the daily DO Flux is high and is a primary stressor in the Lake Osakis Minor. There were many observations during the period of 2005 through 2009 where DO concentrations fluctuated from 2 to 12 mg/L.

Conclusions

Review of the nutrient data along with the high TSS data and frequency of low DO concentrations indicates that a primary stressor on the biological community is nutrient enrichment and lack of suitable habitat for the macroinvertebrate communities. The channel bottom is dominated by highly mobile sand that is moving downstream during mid to high flow events. Channelization is also a primary stressor in JD2 as it has changed the rate and delivery of water. Peak flow conditions appear to occur rapidly and have less duration but higher frequency than a natural channel. Low flow conditions seem to dominate the hydrograph as most water storage has been removed from the upstream reservoirs.

Figure 38 below displays the monitoring locations for JD2. The monitoring locations are both within the AUID that was listed for macroinvertebrate impairment in 2006.

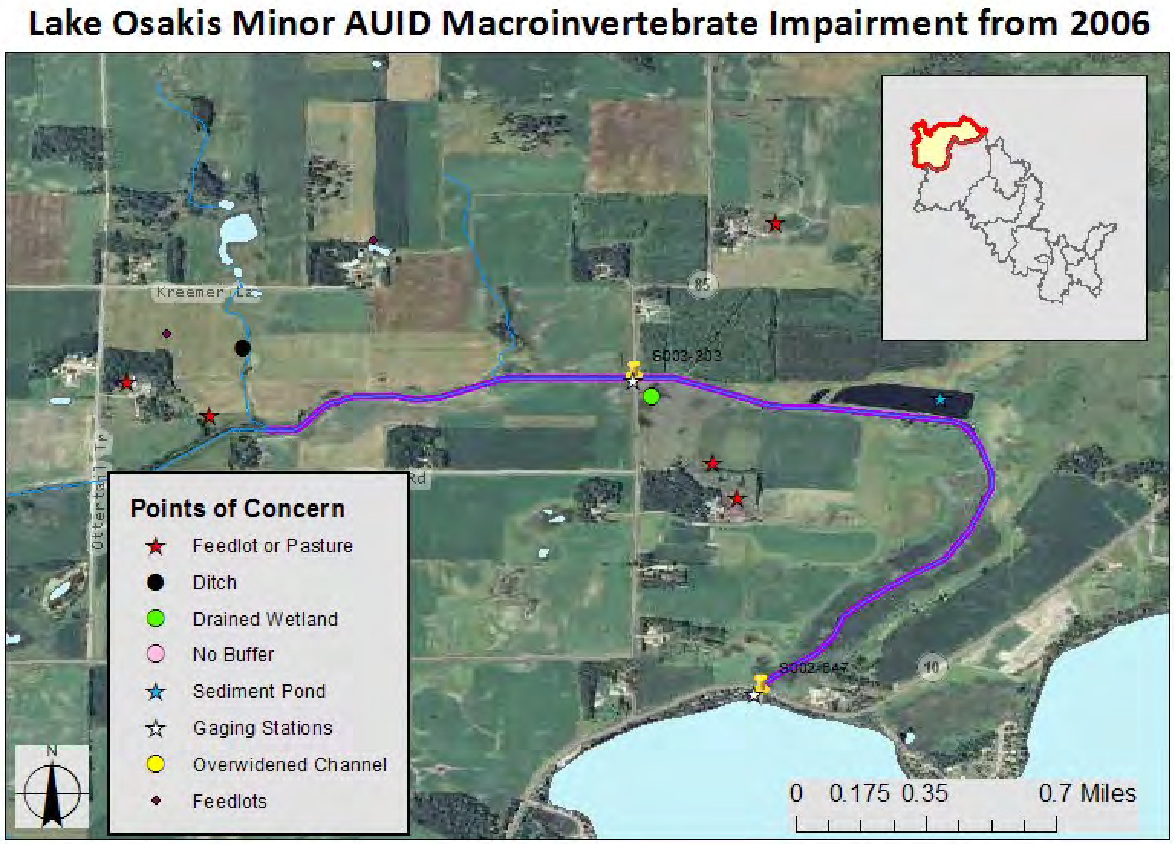

Figure 38: Impaired AUID in the Lake Osakis Minor. Lower portion of JD2 before entering Lake Osakis

Sauk Lake Minor

The Sauk Lake Minor zone of the Sauk River encompasses the stretch from the Lake Osakis outlet to the outlet of Sauk Lake. There are three main tributary streams in this minor, Ashley, Silver, and Hoboken Creeks (Figure 38), and most of the tributaries are partially channelized due to agricultural ditching. The mainstem of the Sauk River begins at the outlet of Lake Osakis at EQuIS site S002-649. Historically, this area was dominated by tallgrass prairie to the south of the Sauk River, and Big Woods-Hardwoods and Aspen-Oak Land to the north of the Sauk River, with areas of "wet prairie" along the riparian corridor of the river. Current land use is predominantly agricultural (56 percent cultivated land) and only 24 percent of the area remains in nonnative grassland and 5 percent wetlands (Figure 38). Another land use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots within this management area.

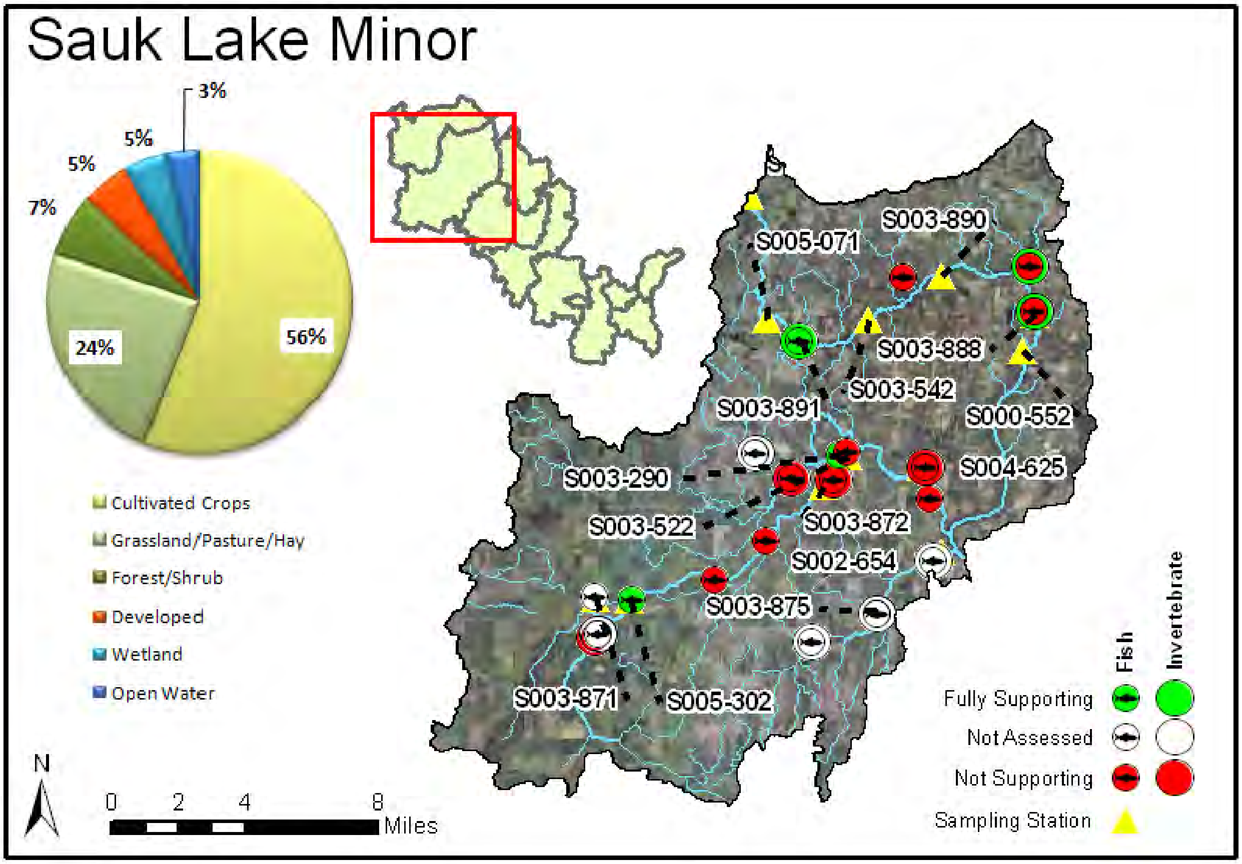

Figure 39: Location of Sauk lake Minor Management area and local land-cover.

Nutrients

Evidence of causal pathways – nutrients/chlorophyl-a, and oxygen demand

Section 4.6 of this report explains the association of elevated nutrients, chlorophyll-a concentrations and oxygen demand. The two main stream features in the Sauk Lake Minor that were investigated are Ashley Creek and the Sauk River. Ashley Creek was sampled periodically from 2001-2009 for a variety of water quality parameters. Analysis of the data shows that Total Phosphorus (TP) data is well above the proposed River criteria of 0.1 mg/L for much of the sampling record **Figure 39**. The two EQuIS sites have a record of 106 samples collected from spring of 2001 through the fall of 2009. The following statistics were computed from this record: minimum = 0.005 mg/L, maximum = 0.638 mg/L, mean = 0.116 mg/L. The TP values are above proposed river criteria standard values during snowmelt and also during periods of runoff. High TP values accelerate growth of algae and other aquatic plants which in turn leads to high dissolved oxygen flux.

Further evidence of nutrient enrichment in Ashley Creek was the observation of excessive growth of aquatic vegetation. Various species of *Potomogeton sp*. were abundant within the channel (Figure 39).

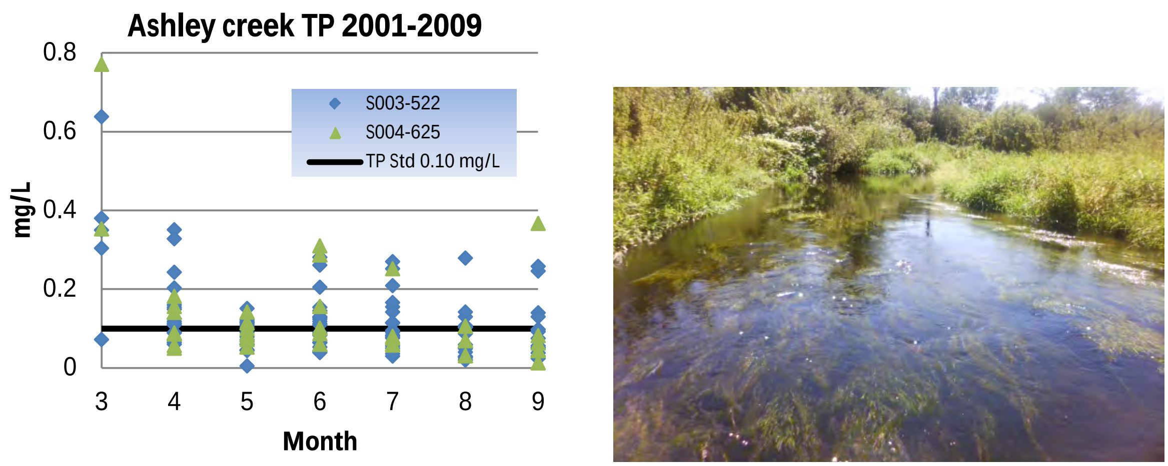

Figure 40: TP values over time collected from Ashley Creek STORET sites, excessive plant growth.

Nutrient levels are also high in the Sauk River. From 2004 to 2010 there is an upward trend in TP levels at the four EQuIS monitoring locations (Figure 41). Sauk river TP data is displayed longitudinally from S002-649 (outlet of Lake Osakis) downstream to S000-552 (Sauk River entering Sauk Lake). As samples are collected, the TP concentrations rise until entering Sauk Lake.

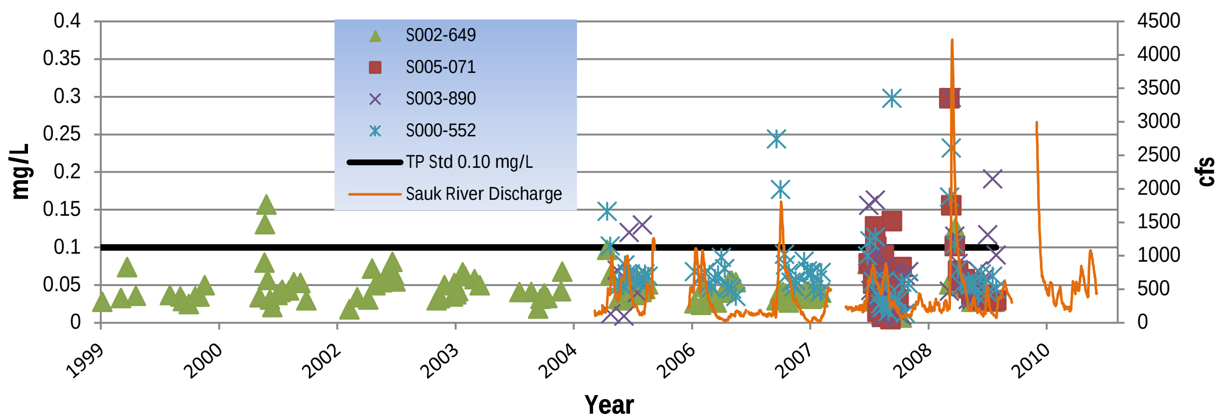

Figure 41: Longitudinal TP concentrations in the Sauk River with discharge data from Sauk River in Cold Spring

The EQuIS site leaving Little Sauk Lake (S003-890) and the site entering Sauk Lake (S000-552) are often above the TP standard of 0.10 mg/L. High TP concentrations also are highest during periods of high flow. This may indicate that bank erosion and high TSS concentrations are contributing to high TP values.

Chlorophyll-a (Chl-a) concentrations are commonly used to measure algal productivity in surface water, and have shown correlations to maximum DO concentrations and DO flux in non-wadable rivers (Heiskary et al., 2010). In Ashley creek no Chl-a samples were collected, however, during field data collection ,it was noted that submerged aquatic plant growth along with periphyton growth increased as we moved longitudinally downstream.

Dissolved oxygen flux

DO flux information was collected using YSI 6720 sondes deployed for one to two week intervals. DO flux appears to increase longitudinally moving downstream within the Ashley Creek watershed. The DO flux ranged from 2.5 to 8 mg/L per day at both the sampling sites on Ashley Creek **(Figure 41). Figure 42** shows the locations of the DO longitudinal profiles along with continuous data sampling sites.

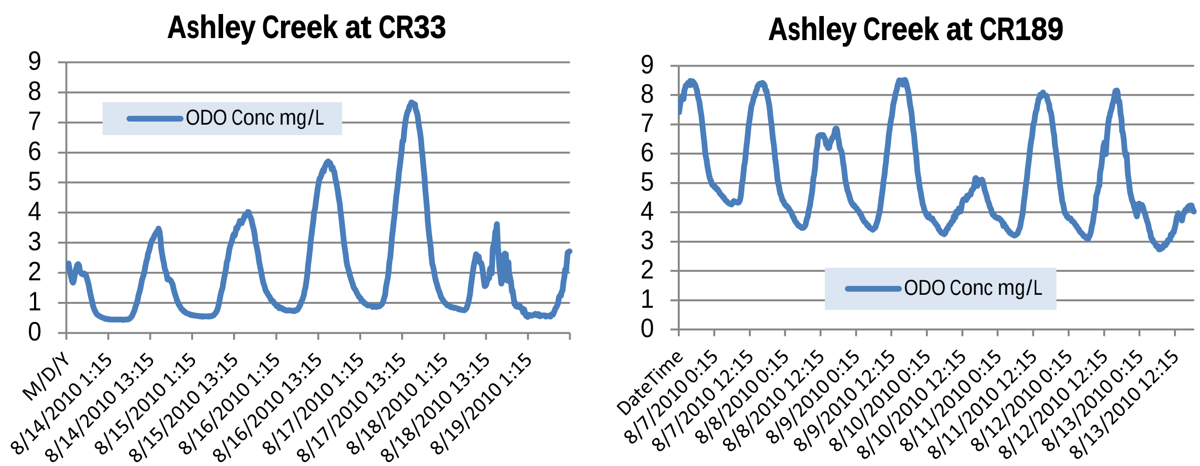

Figure 42: Show the DO flux for Ashley Creek at stream crossings at CR33 and at CR189.

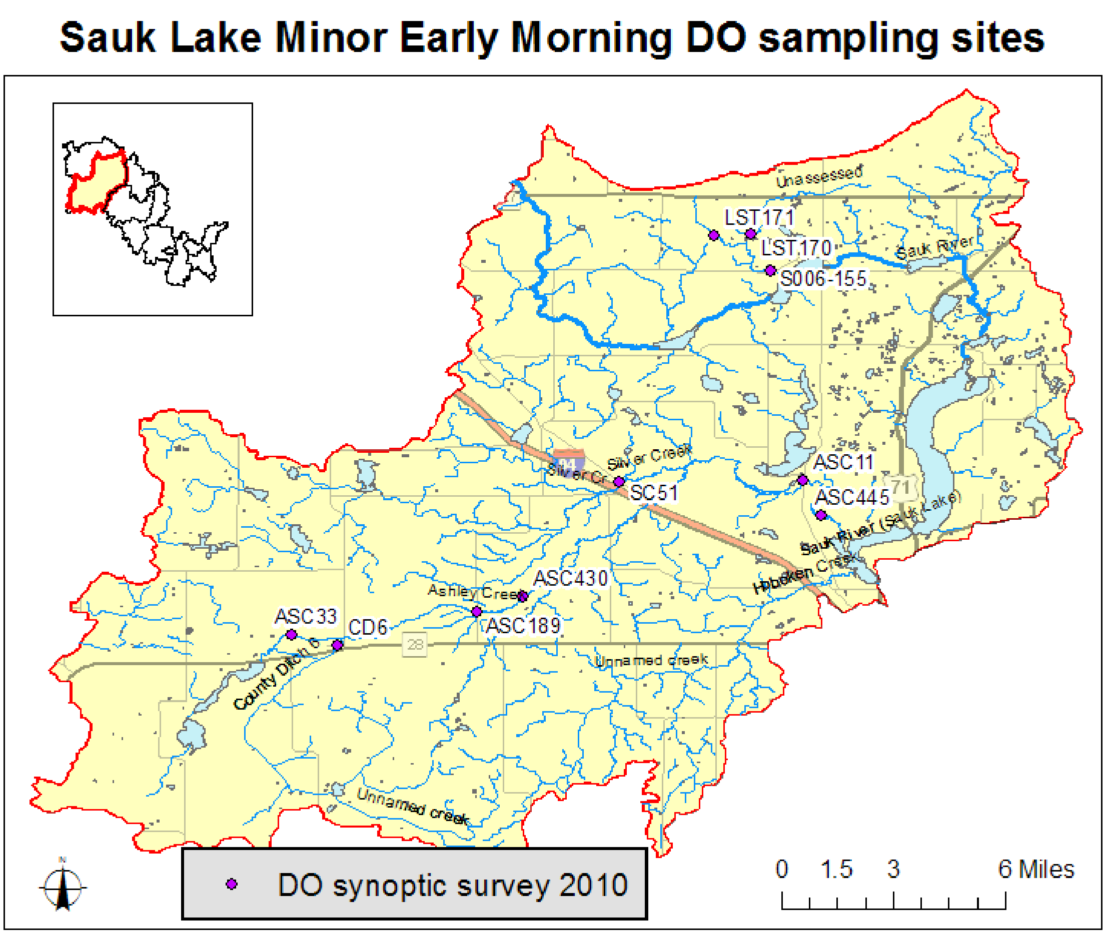

Figure 43 42: Sampling locations for Longitudinal DO sampling and Sonde deployment

These data related to DO concentrations and river eutrophication suggest that excess nutrients and resulting primary productivity (excessive plant growth in the channel) are likely causal pathways for low dissolved oxygen concentrations in specific reaches of the Ashley Creek system and the Sauk Lake

Minor. These lines of evidence are particularly strong for Ashley Creek. No synoptic or continuous DO data was collected in the Sauk River, however, the high TP concentrations would suggest that daily DO fluctuations may be problematic near EQuIS site S000-552. Review of the historical DO data that was collected from 1989 through 2009 indicates that during July-September there may be a DO issue. **Figure 43** graphically displays all instantaneous DO data from this reach of the Sauk River.

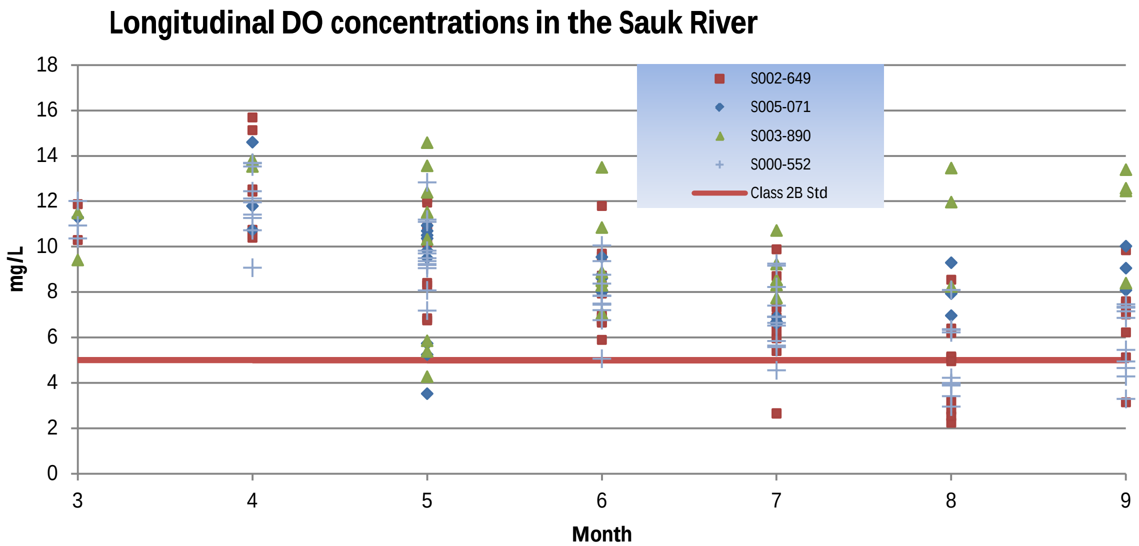

Figure 44: DO data collected from the upper portions of the Sauk River from 1989-2009

Dissolved oxygen

DO data were collected from 2006-2009 for the two STORET sites on Ashley Creek. This data shows only a very few readings below the 5 mg/L standard (Figure 44).

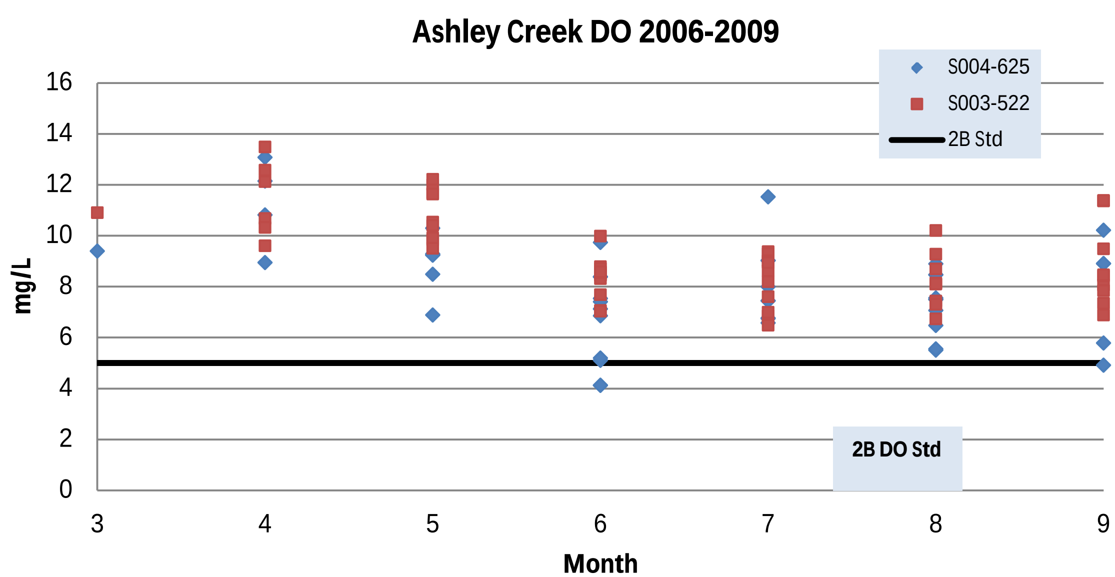

Figure 45: Dissolved Oxygen data versus State 2B standard of 5 mg/L

Early morning longitudinal DO readings were collected in the summer of 2010, in Ashley Creek along with its two main tributaries (Silver Creek and CD6). There are many DO readings below the standard of 5 mg/L in the upper part of Ashley Creek watershed (Figure 45). Moving longitudinally downstream, the

DO recovers and is not viewed as a primary stressor. The upper portion of Ashley creek is dominated by wetland riparian drainage, and has low gradient with a general lack of a pool-riffle-run system. The main stream feature in this reach is run with a sand-dominated substrate. Moving longitudinally downstream, the channel increases in gradient and riffles become more prominent. The substrate also changes to small gravel.

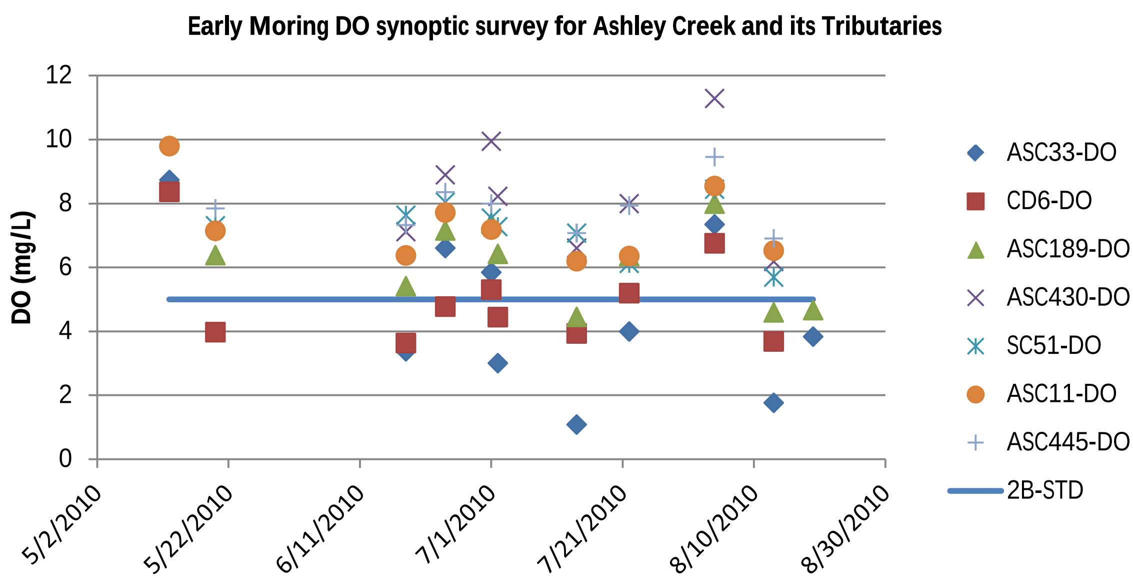

Figure 46: Dissolved Oxygen data versus State 2B standard of 5 mg/L.

Biotic reponse – Sauk Lake Minor

Dissolved oxygen concentrations in Ashley Creek are routinely below the class 2B standard, including a low measurement of 0.5 mg/L at biological station 08UM050. Several biological indicators of low dissolved oxygen are also present in this reach:

1. Lack of Sensitive Fish Taxa
   The five biological monitoring sites in this watershed zone exhibited a general lack of sensitive fish taxa and low overall taxa richness of minnow species. The sampling events at 08UM038, 08UM042, and 08UM045, revealed a fish community dominated by pioneering species and tolerant taxa.

2. Low fish abundance
   Biological monitoring stations in this watershed zone scored low in the fish metric *NumPerMeter-Tolerant*, which is a measure of fish density (number fish/meter) excluding tolerant fish species. Although this metric could be responsive to a variety of stressors, it is likely that the sustained low DO conditions observed within this reach limit fish population size, especially those species that are not considered tolerant of adverse conditions. (Figure 46).

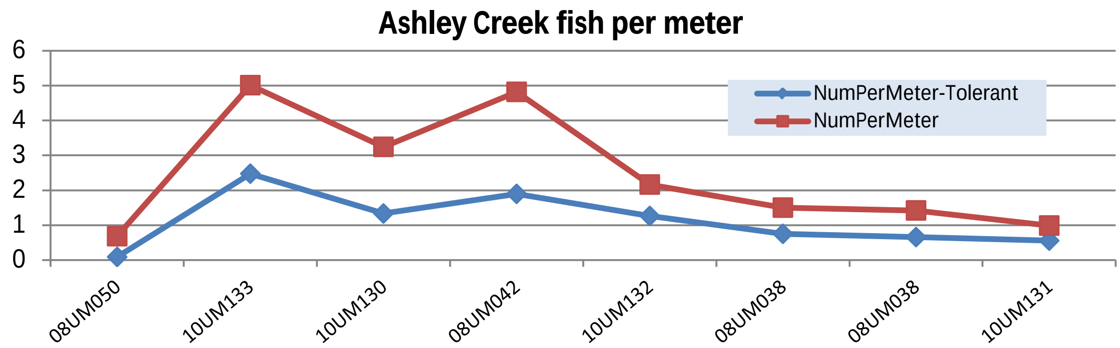

Figure 47: Ashley Creek fish abundance per meter

3. Lack of sensitive macroinvertebrate taxa
   Both biological sites (07UM084 and 07UM032) in this reach lacked intolerant macroinvertebrate taxa, each scoring a "0" for the metric Intolerant2Ch, which counts the number of macroinvertebrate taxa with low tolerance to a variety of stressors.

4. Low Plecoptera Richness
   Macroinvertebrates from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) are widely used bio-indicators that are typically abundant in healthy streams. Plecoptera are especially sensitive to low dissolved oxygen concentrations and are not often found in streams with unstable or low concentrations of DO. There were no Plecoptera taxa present at the three biological monitoring sites in this reach of the Ashley Creek.

Sediment: Total suspended sediment and bedded sediment

Total suspended sediment

Elevated total suspended solids (TSS) concentrations have been identified as a primary water quality concern in the Sauk Lake Minor watershed. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is ample evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the Sauk Lake Minor. See section 4.5.0 for more detailed information on sediment.

The draft TSS standard for the Sauk River has been set at 30 mg/L. For the purposes of Stressor Identification, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations

The three Storet sites had a large set of Total Suspended Solids (TSS) data collected from 2001 through 2009. For much of the recorded period, the concentration of TSS was above the ecoregion mean of 22.5 mg/L **(Figure 47)**. Storet site S003-303 has a record of 139 samples collected from spring of 2005 through the fall of 2009 with the following statistics: minimum = 0.05 mg/L, maximum = 250 mg/L, mean = 37 mg/L. Storet site S002-647 has a record of 88 samples collected from spring 1989 through fall of 2009 with the following statistics: minimum= 1 mg/L, maximum= 80 mg/L, mean= 15.7 mg/L. The TSS values are well above ecoregion mean values during snowmelt periods and also during periods of runoff.

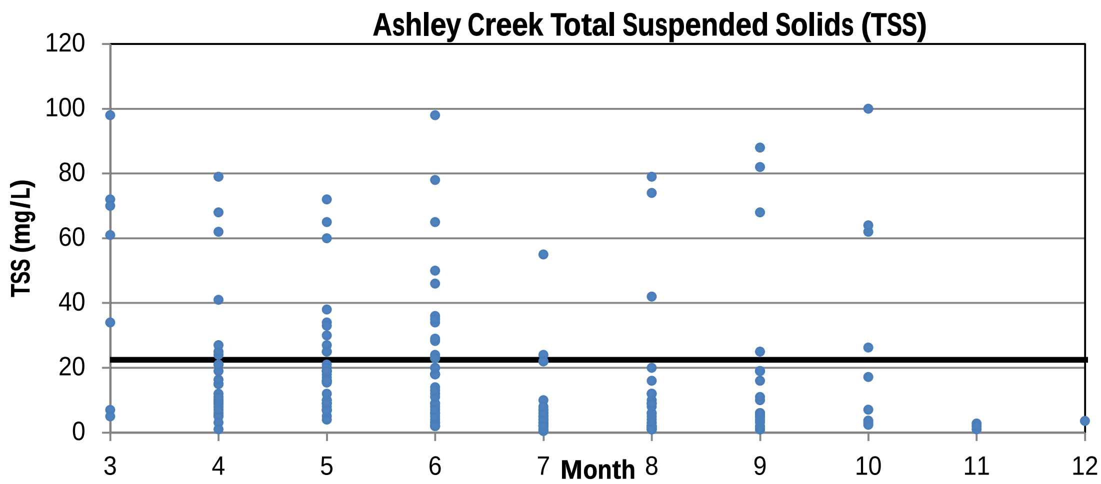

Figure 48: Ashley Creek Total Suspended Sediment data from 2001-2009

Figure 48 displays stream discharge at CR11 of Ashley Creek versus TSS concentrations, which were highest during periods of high flow. The observed TSS concentrations in the Sauk River were highest during spring snowmelt or early spring rainfall (**Figure 49**), during periods when agricultural land was tilled and before active crop growth. Field rill and gully erosion occur readily during this spring period. The photo below was taken in the spring in 2010, near CR 33 in the Ashley Creek watershed. This photo is typical of the type of gully erosion that occurs during the spring before crops are planted.

This photo was taken on 4/28/2011 and shows typical gully erosion that occurs before crops are planted in the spring. This type of erosion contributes TSS to the stream. Note the manure on the surface of the field which will also contribute e-coli and TP to the stream.

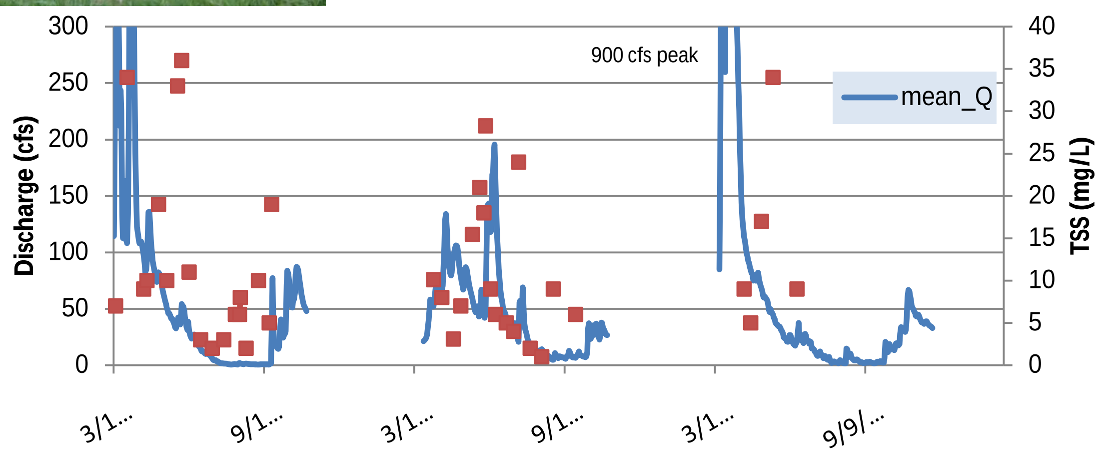

Figure 49: Ashley Creek at CR11; Flow versus TSS

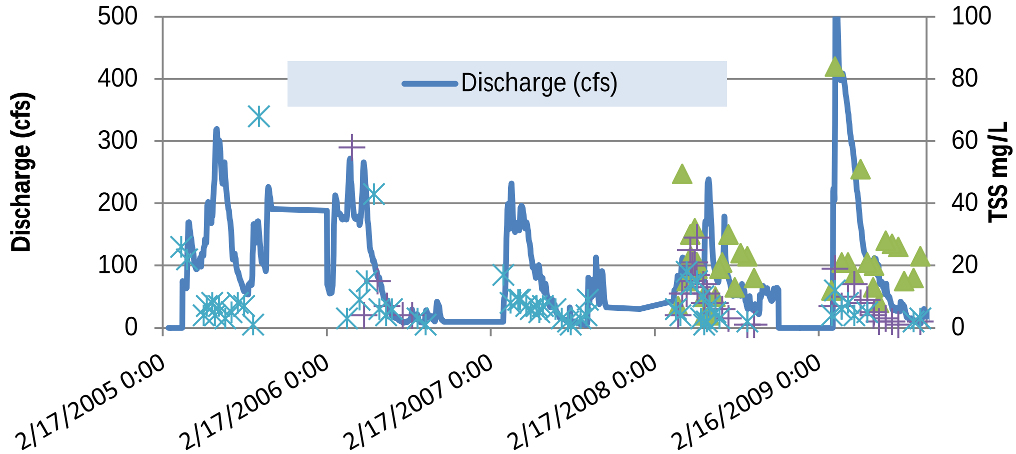

Figure 50: Sauk River discharge near Little Sauk with observed TSS concentrations

TSS values in the Sauk River were above the 30 mg/L standard at all sites. The high TSS values help validate that excess sediment is a stressor in the Sauk River. Channel morphology data was also collected at biological monitoring station 08UM039 on Cedar Lake Road. This site had a low gradient, and pebble count indicated a sand dominated substrate (D50 of 1.27mm). This reach experienced heavy aquatic plant growth validating the increased TP levels.

Channel characteristics were surveyed during the 2010 field season using the Rosgen methodology to classify rivers **(Table 15)**. Representative channel cross sections, along with a longitudinal profile that was 30 times the bank full width in length were surveyed. Stream pebble counts were conducted to calculate the D50 (mean substrate size) for each reach. Channel dimension, pattern and profile are analyzed to understand the stability of a stream channel. Unstable channels have low entrenchment ratios (ER) which impedes the stream from accessing its floodplain. When high flows cannot spill onto the floodplain, the water's energy (stream power) accelerates bank erosion which, in turn, moves excess sediment into the channel.

Table 16: Stream channel characteristics for Ashley Creek and Sauk River at Cedar Lake Rd

Stream Feature			Site Name			
	ASC189	ASC470	ASC430	ASC183	ASC-acorn	08UM039
Wbkf(width)	19.5	32.37	19.86	23.27	21.37	50.46
Dbkf(depth)	2.25	1.5	2.06	1.42	1.7	1.93
Abkf(area)	42.9	48.71	40.86	33	36.25	97.58
W/D ratio	8.66	21.58	9.64	16.39	12.57	26.15
Wfpa(floodplain)	175	226	335	67	300	500
ER	8.97	6.99	16.87	2.87	14.04	9.91
D50 (particle)	.55	0.88	0.88	0.75	6.81	1.27
Slope(water)	.0005	0.0015	0.00106	0.00055	0.00177	.00086
Classification	C5c-	C5	E5	C5c-	C4	C5

Rosgen stream type C5 are sand dominated substrates with limited habitat features, C4 stream type is gravel dominated, and E5 is sand dominated with a low Width/Depth ratio and a high entrenchment ratio.

Connectivity

In the Sauk Lake Minor Watershed, the primary connectivity concern is the ability of a biological organism to freely move amongst its habitat. This is typically a measure of blockage to fish passage, such as dams or impassable (perched) culverts. There are no hydroelectric or flood control dams located in the Sauk Lake Minor. However, there are several water and/or carp control structures located at the outlet of several lakes that are hydologically connected to the river. The City of Sauk Centre maintains a permanent dam structure at the outlet of Sauk Lake to control lake water elevation. Although effective for carp control, this barrier also limits movements of desirable fish species (e.g. northern pike and walleye) that are known to move between riverine and lacustrine habitats for spawning, feeding, and/or refugia. There are two low head dams located on Ashley Creek that can impede or block fish movement. Below are pictures of these structures.


Figure 51: Potential fish barriers located on Ashley Creek

Both structures could impede movements of fish species at both low and high flows. It is unclear if these structures are causing low fish abundance or diversity.

The impacts of dams on the fish and invertebrate assemblages of the Sauk River are difficult to quantify, but this is probably a low priority stressor relative to some of the other stressors discussed in this report. There are no dramatic upstream/downstream differences in biological integrity in reaches with impoundment structures, although comparisons are difficult when there are other confounding stressors present. The loss or reduction of connectivity between the Sauk River and Sauk Lake may be altering fish assemblages locally. Given the resource value of Sauk Lake, it is unlikely that connectivity will be restored at this location.

Conclusion

The Sauk Lake Minor was broken down into two main study areas-Ashley Creek and the Sauk River. Both study areas show that excess fine sediment, measured as stream embeddedness and particle size (D50) are causing impairments to both the fish and macroinvertebrate communities. DO concentrations are also often below the Class 2B standard of 5 mg/L causing stress on the biological communities. This is supported by the fact that there are high TP concentrations and excessive plant growth was observed in all studied stream reaches. Connectivity of Ashley Creek is also a stressor based on the location and type of blockages located in the creek. Restoration of the Sauk Minor biological communities should be focused on reducing the high TP concentrations in the streams and providing BMPs that address nutrient and sediment export from agricultural fields and riparian pasture management. There are numerous animal pasturing areas that have direct access to the stream and are causing bank failures which are providing nutrients and sediment at an accelerated rate to the streams.

Adley Creek Minor

The Adley Creek Minor zone of the Sauk River encompasses the stretch from the Adley Creek outlet where it enters the Sauk River. Prairie Creek flows into Little Birch Lake and eventually enters Adley Creek and the Sauk River. The main water chemistry site is at STORET site S000-369. Most of the tributaries in this zone are partially channelized due to agricultural ditching and are not currently assessed. Historically, this area was dominated by Big Woods-Hardwoods forest, with areas of "wet prairie" along the riparian corridor of Adley Creek. Current land use is predominantly agricultural (38 percent cultivated land), 30 percent grassland, 16 percent forested and 4 percent wetlands (**Figure 50**). This Minor has the greatest percentage of forested area and maintains the best water quality in the Sauk River watershed.

Another land use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots within this management area (**figure 51**). Also see section 4 of this report for discussion about potential stressors related to this land use. Adley Creek Minor does not have any assessable biological monitoring sites; therefore, this section will look at conventional water quality parameters and compare existing data to proposed water quality standards.

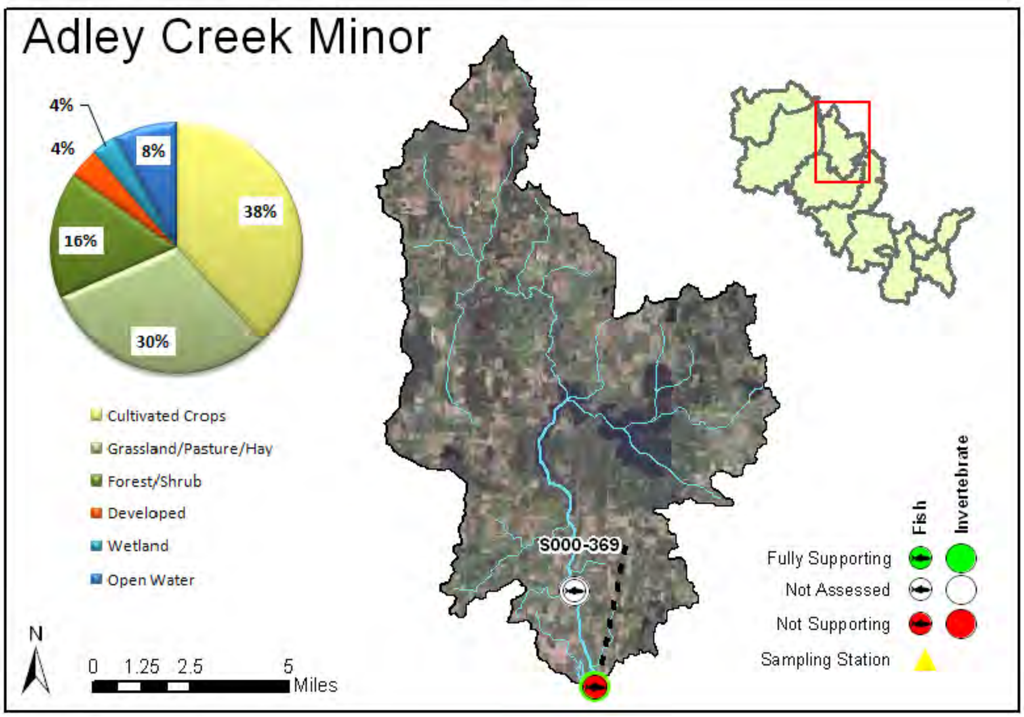

Figure 52: Location of Adley Creek Minor and local land-cover.

Adley Creek Minor Biological Sites/Points of Concern

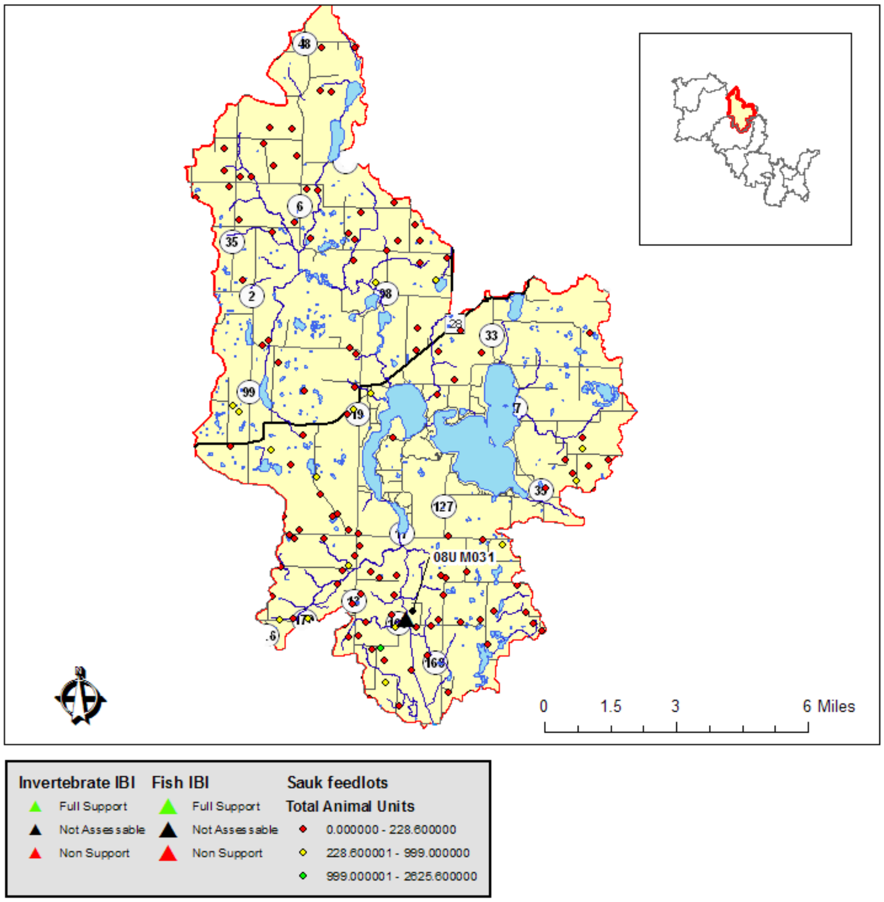

Figure 53: Points of Concern and Feedlot Density in the Adley Creek Minor

Nutrients

Evidence of causal pathways – nutrients/chlorophyl-a, and oxygen demand

Nutrient data was collected in 2005-2009 in the Adley Creek Minor. Analysis shows that Total Phosphorus (TP) is above the proposed River criteria of 0.1 mg/L for some of the sampling record (**Figure 53**). The two EQuIS sites have a record of 117 samples collected from spring of 2005 through the fall of 2009 with the following statistics: minimum = 0.0008 mg/L, maximum = 0.686 mg/L, mean = 0.057 mg/L. The TP values are well above proposed river criteria mean values during snowmelt periods and also during periods of low flow in late summer through early fall. This information may help target TP reductions, such as reducing spring runoff with its high TP concentrations.

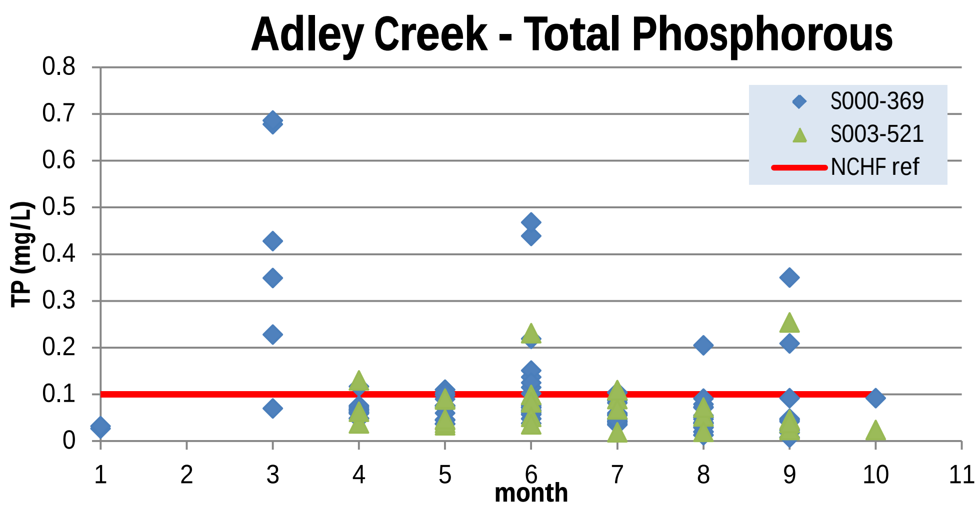

Figure 54: 2005-2009 TP values composited by month from Adley Creek EQuIS sites.

Dissolved oxygen flux

No sondes were deployed in this minor because instantaneous DO readings did not justify further investigation. Total Phosphorus concentrations show enough readings above the proposed TP standard to justify implementing nutrient reduction strategies throughout the watershed.

Sediment

Total suspended sediment

Elevated total suspended solids (TSS) concentrations have been identified as a primary water quality concern in the Adley Creek Minor watershed. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is ample evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the Adley Creek Minor. Refer to section 4.5 for more detailed discussion on sediment.

The two EQuIS sites had a large dataset of TSS data collected from 2003 through 2009 (**Figure 53).** For much of the period, the concentration of TSS was below the proposed standard. EQuIS sites S000-369 and S003-544 have a record of 144 samples collected with the following statistics: minimum = 0.05 mg/L, maximum = 144 mg/L, mean = 13.0 mg/L. The TSS values are above proposed TSS standard values during snowmelt periods as well as during periods of lower runoff (**Figure 54**).

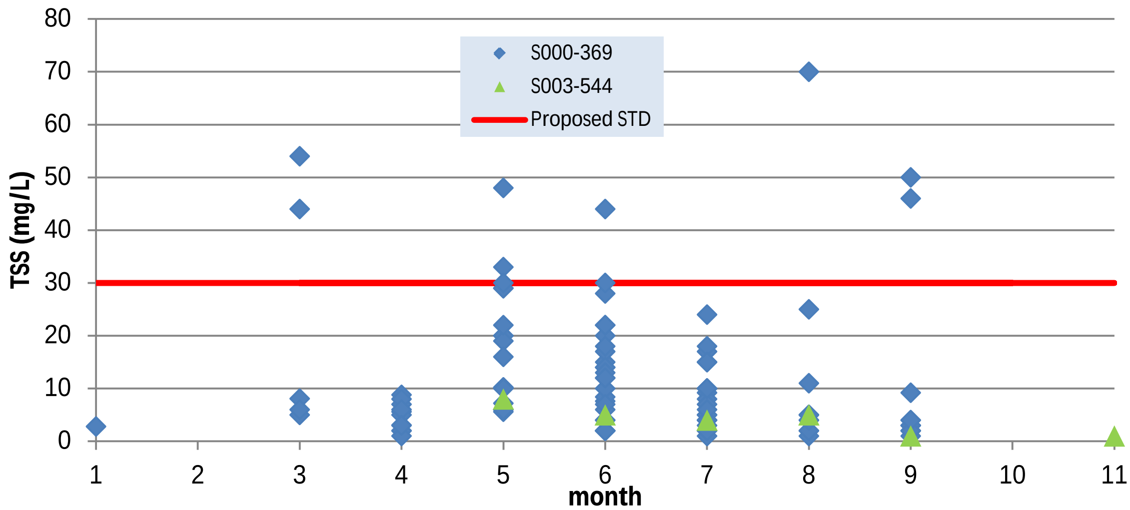

Figure 55: Adley Creek Minor Total Suspended Sediment data from 2003-2009.

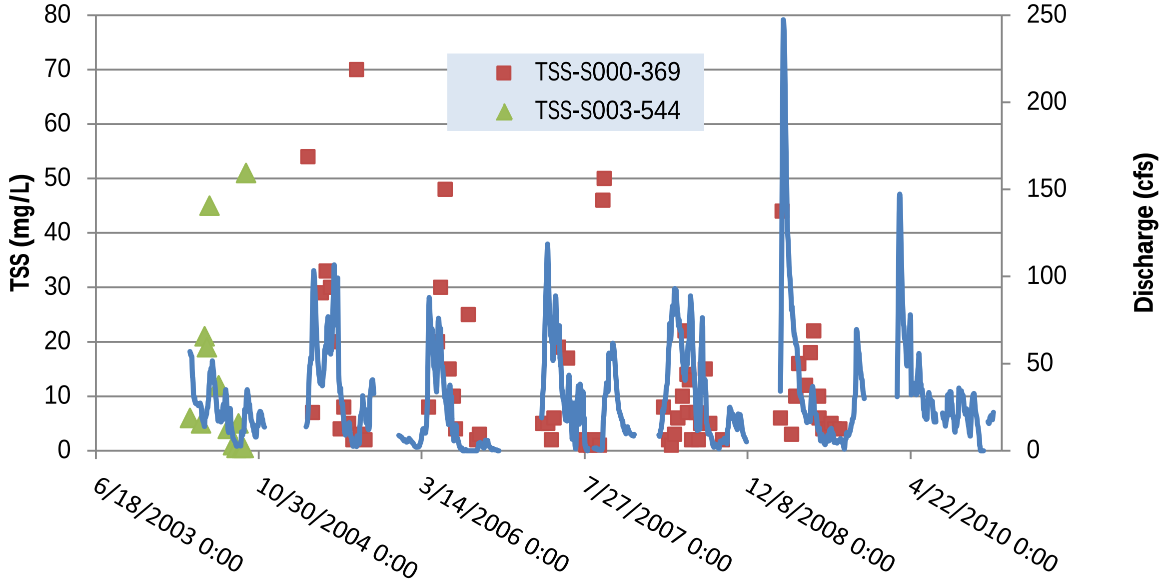

Figure 56: TSS versus discharge data for Adley Creek

Dissolved Oxygen

Figure 55 shows the DO data collected at EQuIS site S000-369. There were no violations of the DO standard in this dataset so DO is not considered a potential stressor in this Minor.

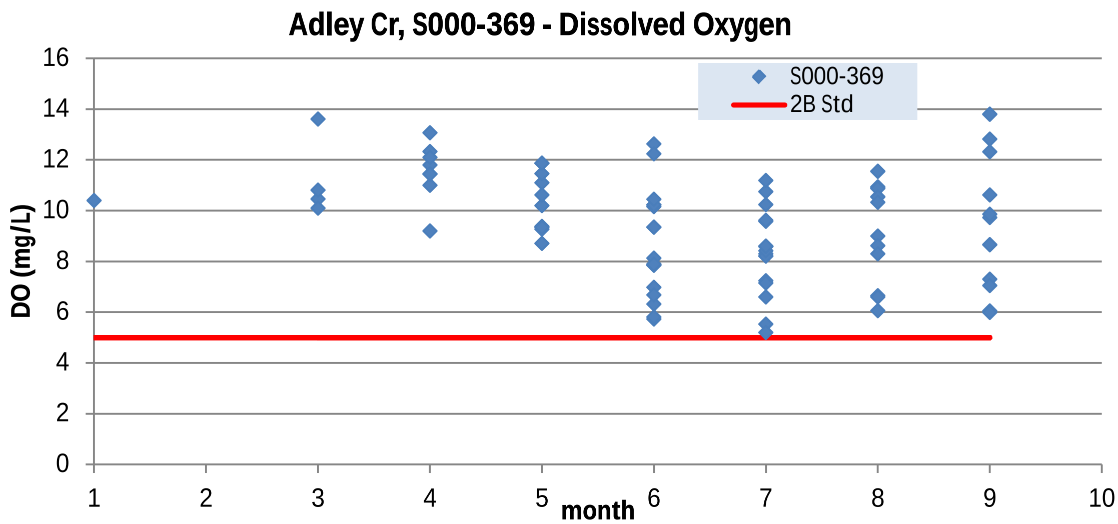

Figure 57: Dissolved Oxygen data from 2003-2009 versus DO standard of 5 mg/L

Conclusion

Historical data was used to evaluate potential stressors to the aquatic community in the Adley Creek Minor. Currently there are no biological impairments in the Adley Creek Minor because the streams are ditched and thus not officially assessed. This will change in the future when the State of Minnesota adopts the tiered aquatic life use standard. When this approach is adopted ditches will have to meet a new standard. For this report, water chemistry data was reviewed to make recommendations on likelihood of biological problems that may be related to water chemistry stressors. The Adley Creek Minor has elevated nutrient concentrations, particularly total phosphorus. TSS data also suggest that there is a problem with high suspended sediment concentrations in the spring. Steps should be taken in this watershed to reduce TP and TSS concentrations.

Center Sauk River Minor

The Center Sauk River Minor zone of the Sauk River encompasses the stretch from the Sauk Lake outlet to the confluence of Getchell Creek with the Sauk River. The mainstem of the Sauk River flows out of Sauk Lake at EQuIS site S000-373. Most of the tributaries in this zone are partially channelized due to agricultural ditching. Historically, this area was dominated by tallgrass prairie to the south and west of the Sauk River, and aspen-oak with Big Woods hardwoods to the north and east of the Sauk River. Current land use is predominantly agricultural (49 percent cultivated land), with 31 percent pasture/grassland and 4 percent wetlands (F**igure 56**).

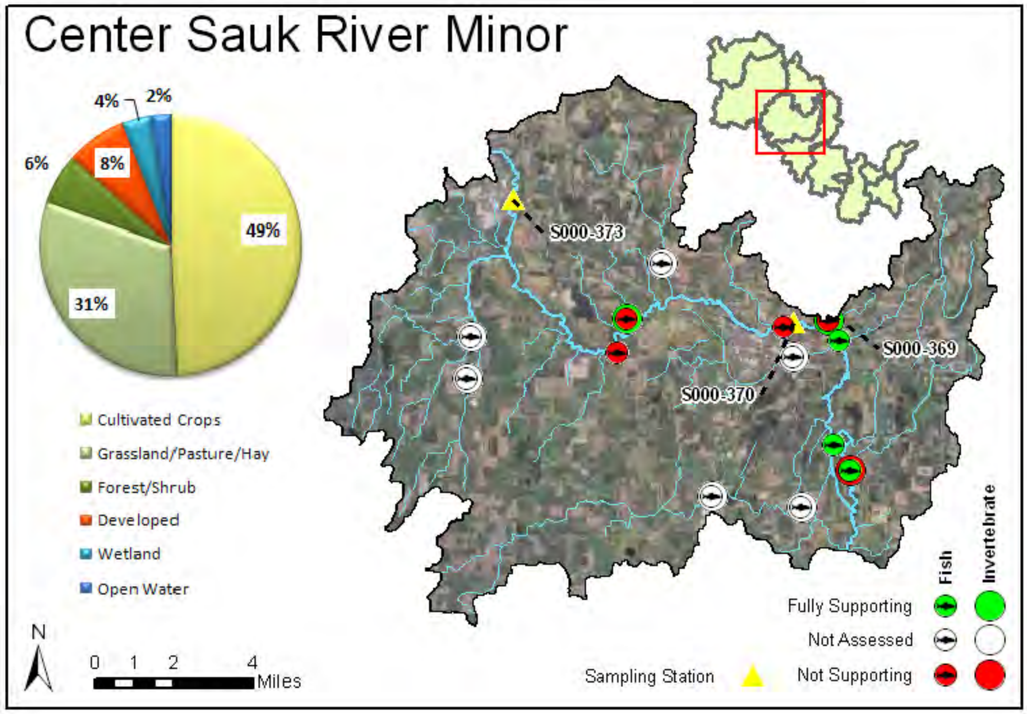

Figure 58: Location of Center Sauk River Minor and local land-cover

Another land use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots within this management area (**Figure 57**). There are 1504 feedlots within the Sauk River watershed and the Center Sauk Minor has 315 feedlots (21 percent). The potential stressors related to this land use are discussed in greater detail in the stressor identification section of this report (see section 4).

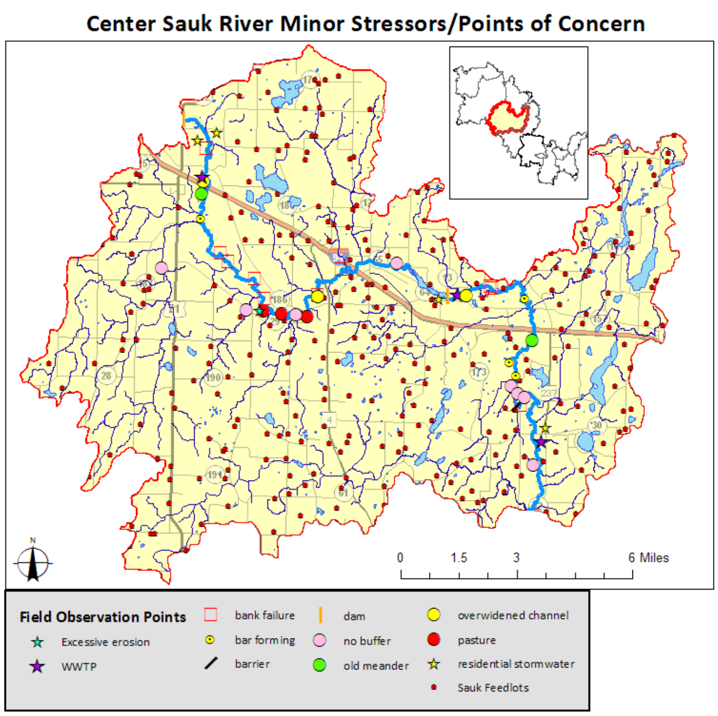

Figure 59: Feedlot density and areas of concern in the Center Sauk River Minor

Nutrients

Evidence of causal pathways – nutrients/chlorophyl-a, and oxygen demand

The main stream feature in the Center Sauk River Minor that was investigated was the Sauk River. The Sauk River was sampled periodically from 2000-2009 for a variety of water quality parameters. TP is well above the proposed River criteria of 0.1 mg/L for much of the sampling record **Figure 58**. The two EQUIS sites have a record of 117 samples collected from spring of 2000 through the fall of 2009 with the following statistics: minimum = 0.021 mg/L, maximum = 0.722 mg/L, mean = 0.106 mg/L. The TP values are above proposed river criteria mean values during snowmelt periods and also in late summer through early fall. The late summer increases in TP may be a result of increased TP export from Sauk Lake. If Sauk Lake has a large concentration of curly-leaf pondweed, annual dieoff would occur in early July which would send a pulse of available TP downstream. This increase may be due to high algal productivity coming out of Sauk Lake. This may help us target TP reductions by reducing erosion with its high TP concentrations in the spring and concentrate on better management of TP discharge (reduce the amount of algal production in Sauk lake) during low flow periods.

Further evidence of nutrient enrichment is documented in the Sauk River through the excessive growth of aquatic vegetation. Various species of *Potomogeton sp*. are growing within the channel. In the Center Sauk River Minor there were no Chl-a samples collected.

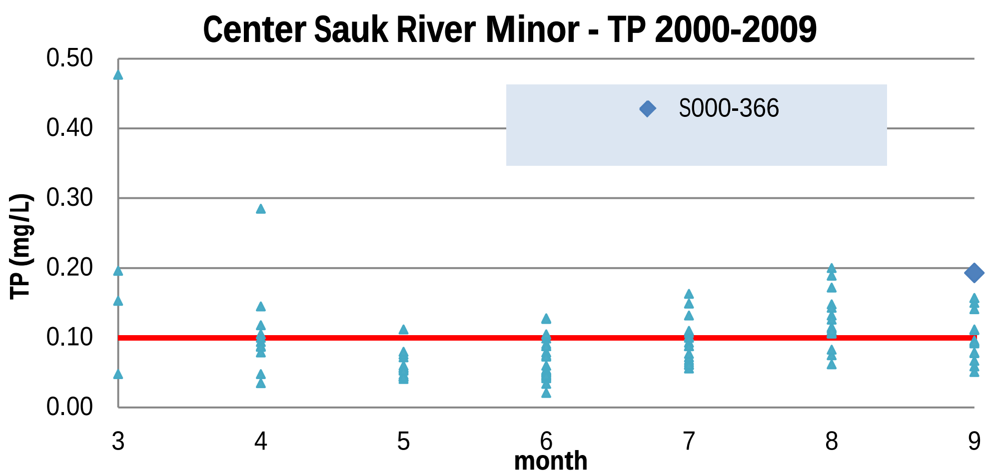

Figure 60: TP values composited by month from Sauk River EQuIS sites

Dissolved oxygen flux

There were no sondes deployed in this minor because instantaneous DO readings did not justify further investigation.

Sediment

Total suspended sediment

Elevated TSS concentrations have been identified as a primary water quality concern in the Center Sauk River Minor watershed. Based on current and ongoing suspended-solids-related work and several stream reconnaissance trips, there is ample evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the Center Sauk River Minor.

Areas of bank erosion were also observed within urban/developed areas, along the edges of cultivated cropland and turfgrass lawns, and on steep-sloping valley walls (**Figure 60**). This suggests that there are multiple land uses and erosional processes contributing to increased sediment inputs and sediment-related stressors to aquatic life. Buffers of inadequate width to protect streambank integrity and aquatic habitat were observed throughout the length of the Sauk River and many of its tributaries.

Various sources of sediment are available to the river through bank failures caused by cattle access or lack of streamside woody vegetation to secure the banks.

Figure 61: Kayak reconnaissance of the Sauk River revealed several areas of bank erosion

The two EQuIS sites had a large set of TSS data collected from 2003 - 2009. For much of the recorded period, the concentration of TSS was below the proposed standard **(Figure 61)**. EQuIS site S000-373 has a record of 104 samples collected from spring of 2003 through the fall of 2009 with the following statistics: minimum = 1 mg/L, maximum = 126 mg/L, mean = 15.4 mg/L. Storet site S000-284 has a record of 116 samples collected from spring 2003 through fall of 2009 with the following statistics: minimum= 1 mg/L, maximum= 82 mg/L, mean= 15.5 mg/L. The TSS values are above proposed TSS standard values during snowmelt periods and also during periods of lower runoff (**Figure 61**). The summer exceedances occur during both high and low flow periods. The sediment in this area of the Sauk

River is dominated by sand. Most riffles are nearly 100 percent embedded with sand and the available gravel substrate is covered. This excess sediment is limiting habitat for fish that are lithophilic spawners.

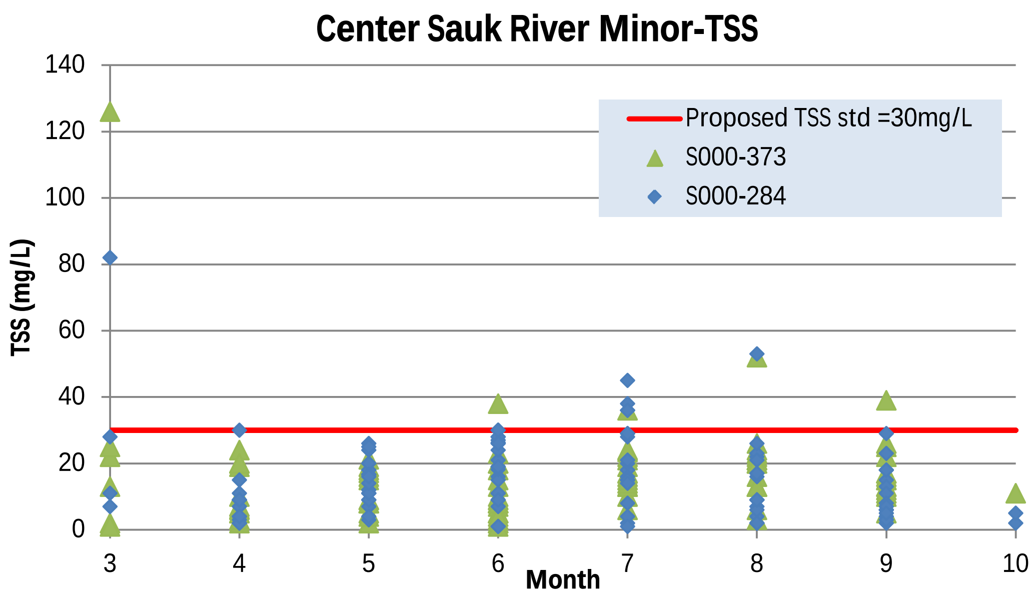

Figure 62: Center Sauk River Minor Total Suspended Sediment data from 2001-2009.

Bedded sediment

The D50 particle size in this reach is 1.0 mm which is very coarse sand. Kayaking the stretch from the dam at Sauk Lake downstream the MN Highway 4 crossing revealed the dominant substrate type was coarse sand. During this trip, it was noted that most pools were less than twice the depth of the runs and filling with sand. The sand is being transported from bank failure during high flow events, and is then depositing on the stream bottom, covering available coarse substrate habitat for fish and macroinvertebrates.

Increased fine material in the stream bed is a stressor to the biological community.

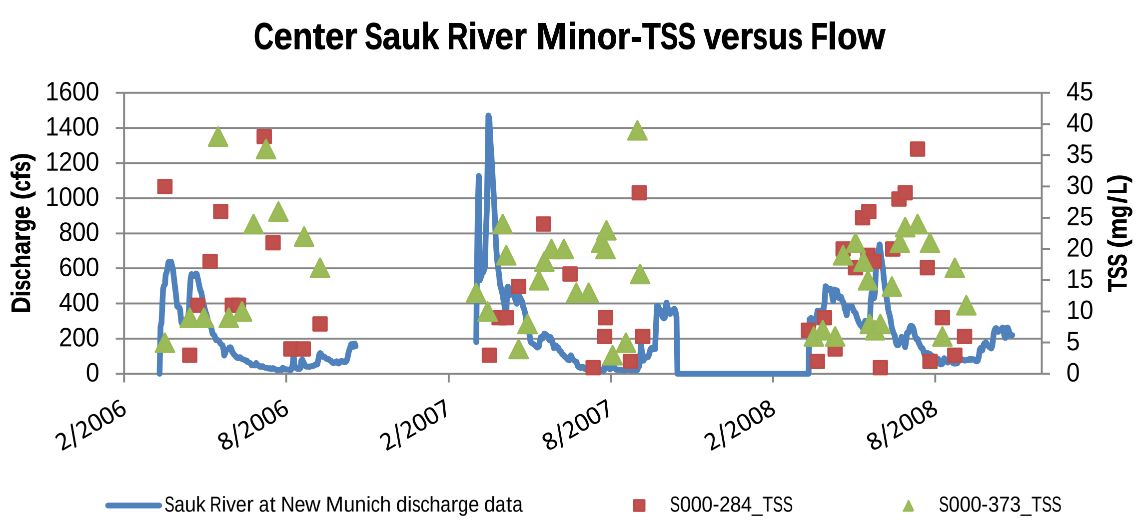

Figure 63: TSS concentrations versus discharge data

Early morning longitudinal DO readings were not collected in 2010 in the Center Sauk River Minor. Review of existing data did not indicate low DO as a potential stressor.

Dissolved oxygen

Instantaneous DO data was reviewed from the two EQuIS sites. Site S000-373 is located at CR 186 bridge in Sauk Center and site S000-284 is located at CSAH 31 just south of New Munich. Both sites had DO data from 2003-2009. This DO record was collected during the late morning and early afternoon. Figure 63 below graphically displays the results of the historical sampling effort.

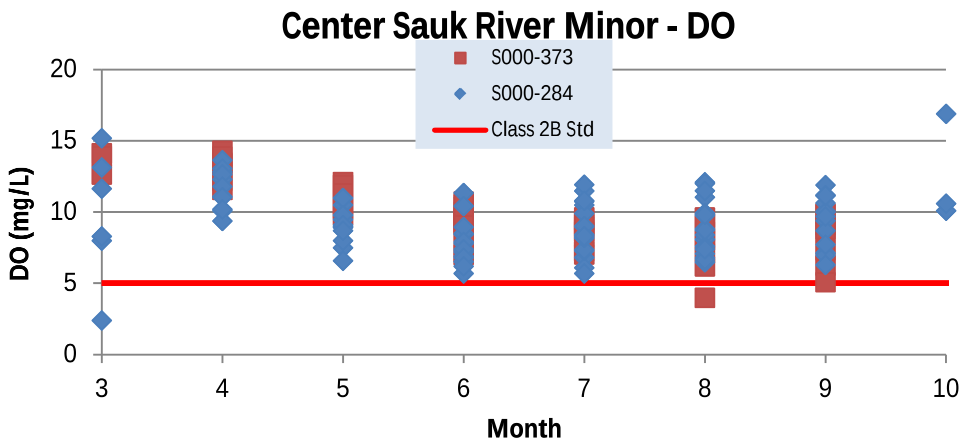

Figure 64: Dissolved Oxygen data relative to the 2B standard of 5 mg/L

Habitat and connectivity

This reach of the Sauk River generally lacks woody vegetation along the riparian area. This lack of woody vegetation is a contributing factor to the biological impairment. Kayak reconnaissance revealed that the substrate was dominated by sand. The observed pools were filling with sand and there is a general lack of riffle-pool habitat in this reach.

There are two dams located within this reach on the Sauk River, located at the outlet of Sauk Lake and in Melrose mid-way down the reach. Dams impede free movement of fish and isolate fish populations between the dams. The reservoirs above the dams will favor more lake-specific species of fish. The dams in this reach are a suspected stressor on the fish communities within this reach.

Conclusion

The main stressors to the biological community in the Center Sauk Minor are a lack of habitat diversity due to a sand-dominated substrate (loss of riffle-pool complex), bank failure along the Sauk River corridor from the dam at Sauk Lake downstream to Melrose (increase in TSS concentration, deposition of sediment), and elevated nutrients, particularly TP during the summer through early fall period.

GUS plus minor

The Getchell, Un-Named, Stony Creeks (GUS) Plus Minor zone of the Sauk River encompasses the stretch from the Getchell Creek confluence down to the Sauk River just upstream of Saint Martin. Getchell Creek flows into the Sauk River about one mile south of County road 31 and ½ mile west of County road 12. The EQuIS site S003-289 represents the water quality for Getchell creek. Getchell creek is primarily channelized (agricultural ditching) and, therefore, was not assessed during the 2010 assessment cycle. Stoney Creek is a cold water creek that flows into the Sauk River approximately 1/3 mile upstream of County Road 14 and east of 325th Avenue. Stoney Creek is also partially channelized in the upstream portions and is heavily influenced by agricultural activity throughout its length. The other main tributary in this minor is Un-Named creek which is located just south of Stoney Creek and crosses 318th Avenue. Both Un-Named creek and Stoney Creek have massive bank failures near the lower third of their drainage areas, and are exporting large volumes of sediment into the Sauk River. Historically, the Stony and Un-Named creek area was dominated by tallgrass prairie, with areas of "wet prairie" along the riparian corridor of the river, while the Getchell Creek subwatershed was dominated by aspen-oak and Big Woods hardwood forest.

Current land use is predominantly agricultural (56 percent cultivated land), 32 percent pasture/grassland, and 2 percent wetlands (**figure 64**).

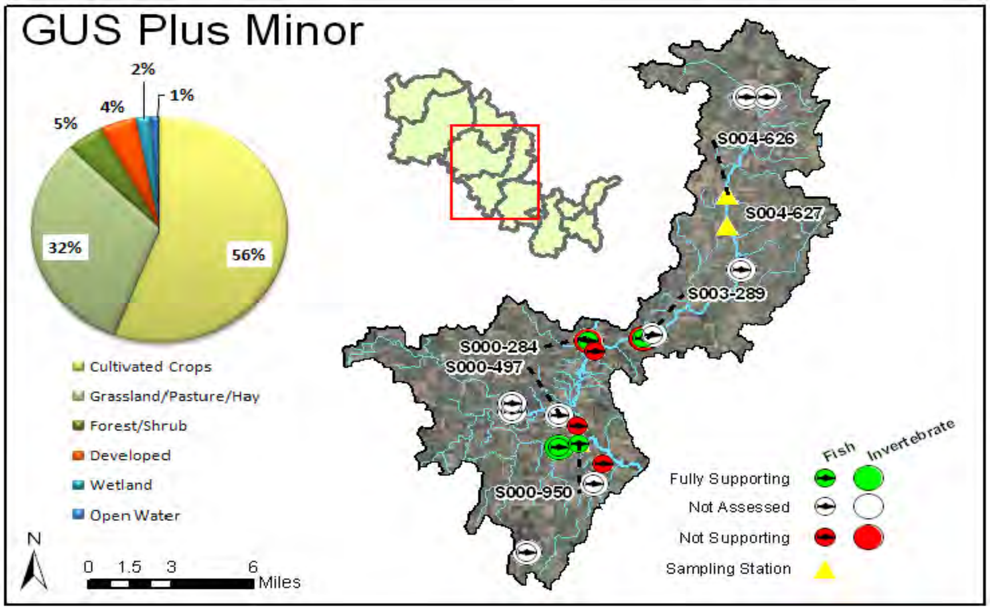

Figure 65: Location of GUS Plus (Getchell, Un-Named, Stoney Creek) management zone and local land-cover.

Figure 65 displays the spatial distribution of feedlots along with points of concern that were identified during aerial review or field observations. This Minor has massive bank failures as a result of altered hydrology and free animal access to the streams. Another land use component that may be negatively impacting ecological health is the intensity of feedlots here. There are 1504 registered feedlots in the Sauk River watershed, of which 310 feedlots are located in the GUS Plus minor. One fifth of the feedlots in the Sauk are located in the GUS Plus minor. Stressors related to pasturing and access to the streams is discussed in chapter 4 of this report. Management concerns should be related to direct access of animals to the stream, manure management, and exposure to E.coliform bacteria.

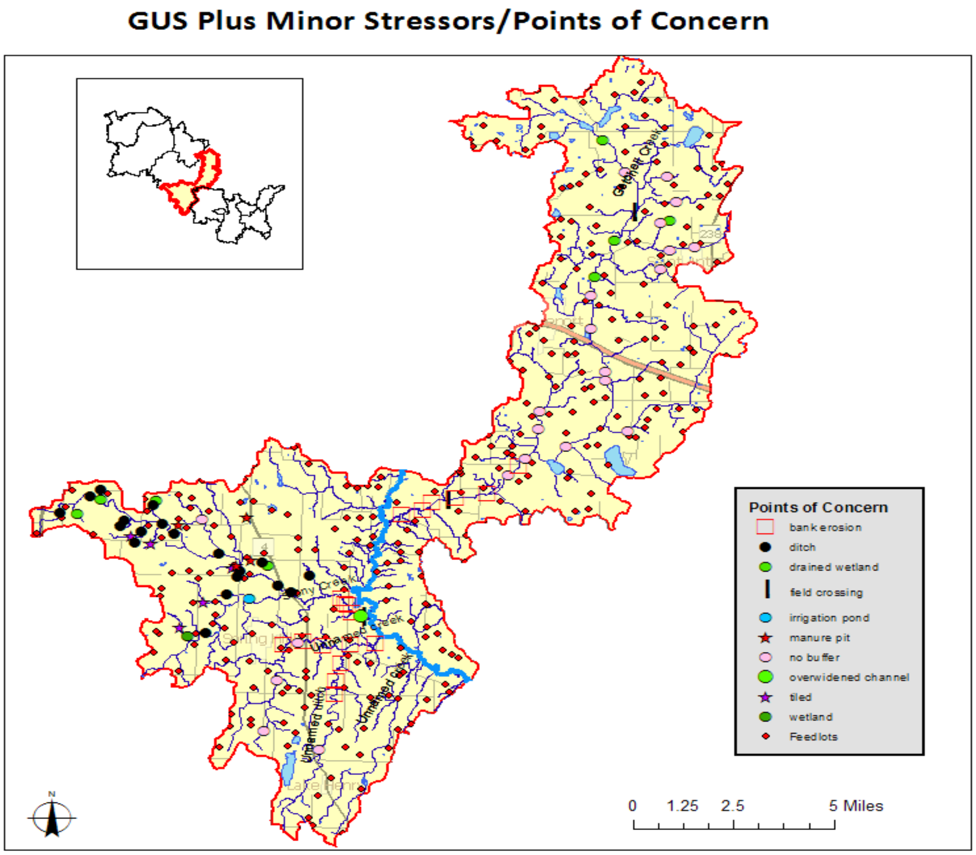

Figure 66: Feedlot Density in the GUS Plus Minor

Nutrients

Evidence of causal pathways – excess nutrients

The main streams in the GUS Minor that were investigated were Stoney, Getchell, and Un-Named Creeks. Stoney Creek was sampled at EQuIS site S000-497, Getchell Creek at S003-289, and Un-Named Creek at S000-950. These sites were sampled periodically from 2000-2009. Though occasionally near the ecoregion norm, Total Phosphorus (TP) data are also routinely well above the proposed River criteria of 0.1 mg/L for most of the sampling record (Figures 46, 47, 48). High TP values promote excess growth of algae and other aquatic plants which, in turn, can lead to high dissolved oxygen flux as they decay. Elevated TP concentrations should be considered a stressor within this Minor. Efforts should be made to reduce the export of TP within this watershed.

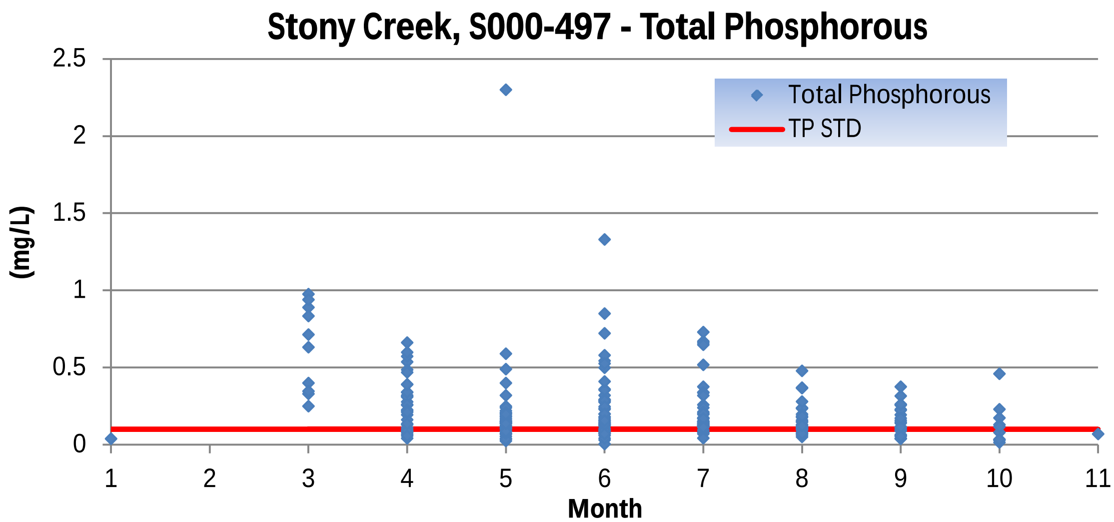

Figure 67: TP values composited by month from Stoney Creek EQuIS sites (1980;1995-2009).

Chlorophyll-a

No Chl-a samples were collected in the GUS minor.

Dissolved oxygen flux

There were no sondes deployed in this minor because instantaneous DO readings did not justify further investigation.

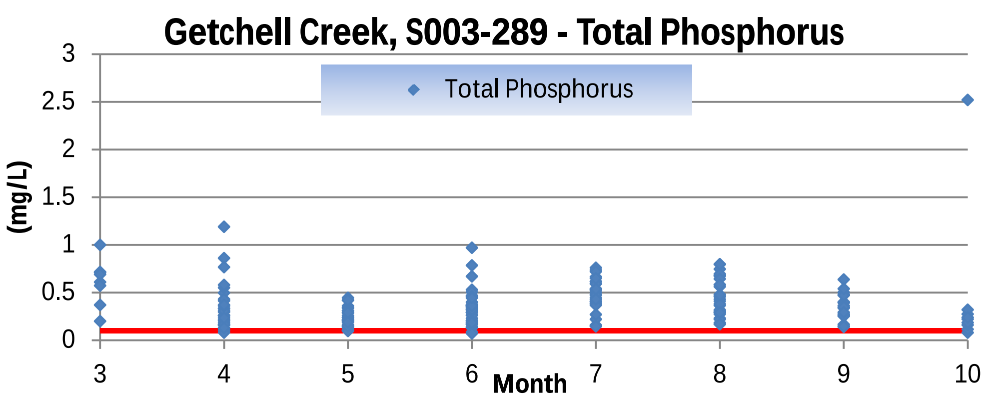

Figure 68: TP values composited by month from Getchell Creek EQuIS sites (1995-2009).

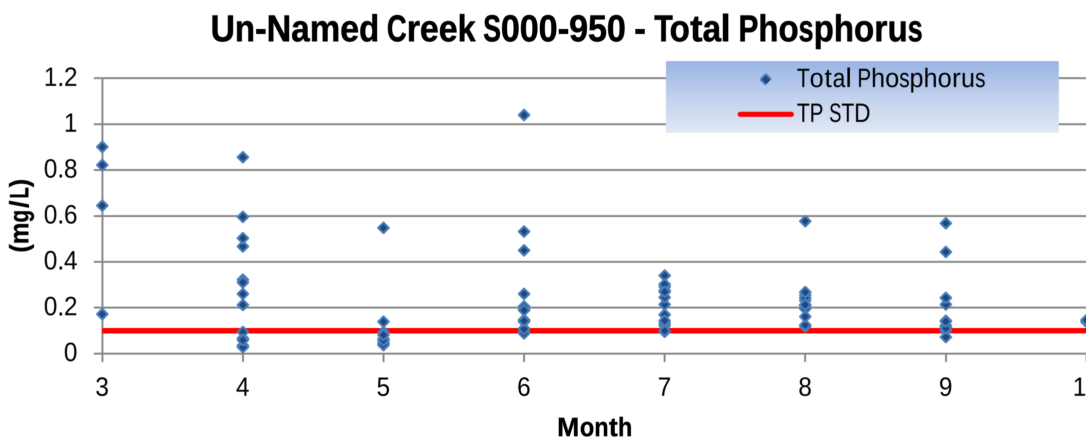

Figure 69: TP values composited by month from Un-named Creek EQuIS sites (2000-2010).

Sediment

Total suspended solids

Elevated TSS concentrations have been identified as a primary water quality concern in the GUS Plus Minor watershed. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is ample evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the GUS Plus Minor.

Sources and pathways of bedded sediment

Riparian grazing/bank erosion

Rangeland and pasture are common landscape features throughout the GUS Plus Minor. Most of these areas are operated for cattle grazing. It is common to place pastures along streams to give animals free access to water. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase streambank erosion and reduce stream bed substrate quality (look at pictures on following page). In some areas, the riparian corridor along the GUS Plus streams and its tributaries have been cleared for pasture and are heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect stream banks and provide shading. Exposure of these areas to weathering, trampling, and sheer stress from high flow events appears to be increasing the quantity and severity of bank erosion. Within the Sauk watershed, there appears to be more riparian pasturing in the GUS Plus Minor than in the other management zones. The graph and photos below are from Stony Creek. The stream banks in the lower portions of Stony Creek are collapsing, and TSS values for Stony Creek are well above the proposed standard of 30 mg/L (**Figure 49**). Currently there is a approved TMDL for turbidity in the GUS Plus Minor which addresses many of the concerns for TSS.

Stony Creek TSS values by Month

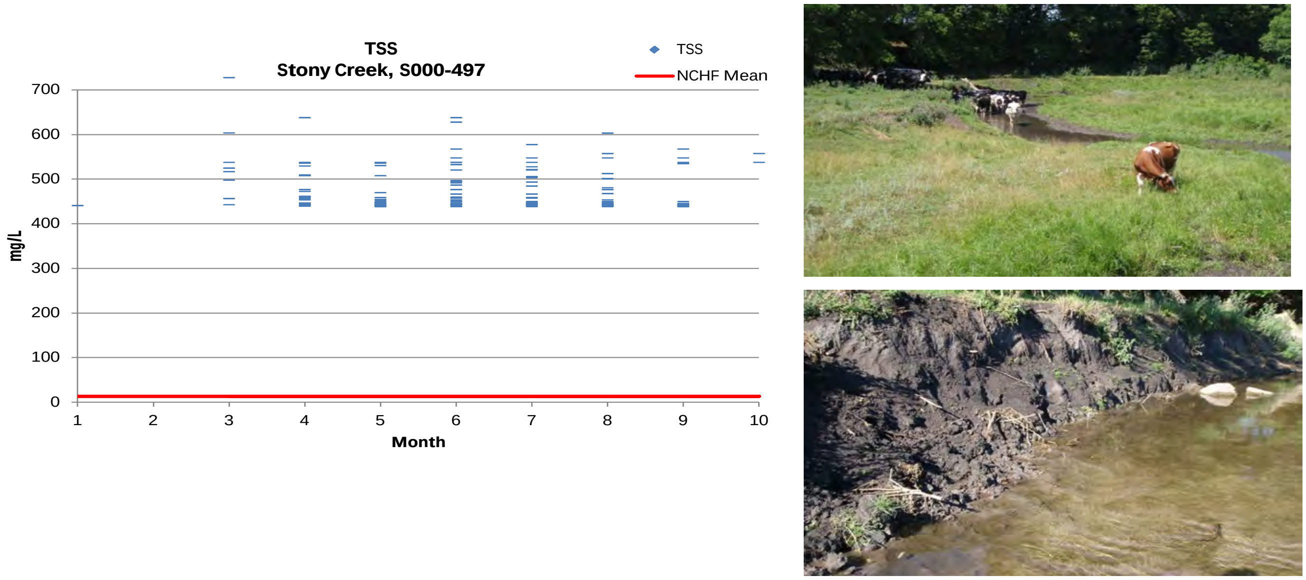

Figure 70: TSS concentrations in Stony Creek along with potential sources

Stony Creek upstream of 325th Ave Deposition of fine sediment in floodplain

Stony Creek downstream of 325th Avenue

Getchell Creek near CR 176

Un-Named Creek near 318th Avenue

Areas of bank erosion were also observed throughout Getchell and Un-Named Creek. Although there is still a considerable amount of pasturing in these two watersheds, many areas where bank erosion is occurring are not in the pasture areas. Delivery of water through the alteration of drainage and storage is causing bank instability. Peak flows occur at a higher rate and more frequently, causing bank failure. This suggests that there are multiple land uses and erosional processes contributing to increased sediment inputs and sediment-related stressors to aquatic life. Buffers of inadequate width to protect streambank integrity and aquatic habitat were observed throughout the GUS Plus Minor.

Strength of evidence summary for bedded sediment

Bedded sediments (BS) are likely a stressor to fish and macroinvertebrate assemblages in the GUS Plus Minor. Substrate embeddedness levels were very high (>70 percent) in the study areas, and the response from biota indicated a cause and effect relationship (low darter taxa richness and decrease in simple lithophilic spawners). Review of Invertebrate data shows that all sampled stream reaches in the GUS Plus Minor had low EPT percentage (less than 30 percent of sample), low Scraper and Shredder percentage (less than 20 percent of sample). The invertebrate data reviewed that there is a general increase in the metric Tolerant2Pct, which is a measure of relative abundance (percent) of macroinvertebrate individuals in a subsample with tolerance values equal to or greater than six, using Minnesota tolerance values. This metric ranged from 78 percent in Stony Creek to 98.6 percent in the farthest upstream Getchell Creek sampling site. The metric Collector-filterer was also reviewed as a means of looking at BS as a stressor. This metric looks at the relative abundance of invertebrates that are collector-filterer taxa. Generally these taxa require clean substrates and will live in riffles actively collecting and filtering food from passing water. Figure 70 displays the macroinvertebrate metrics for the GUS-Plus sampling sites.

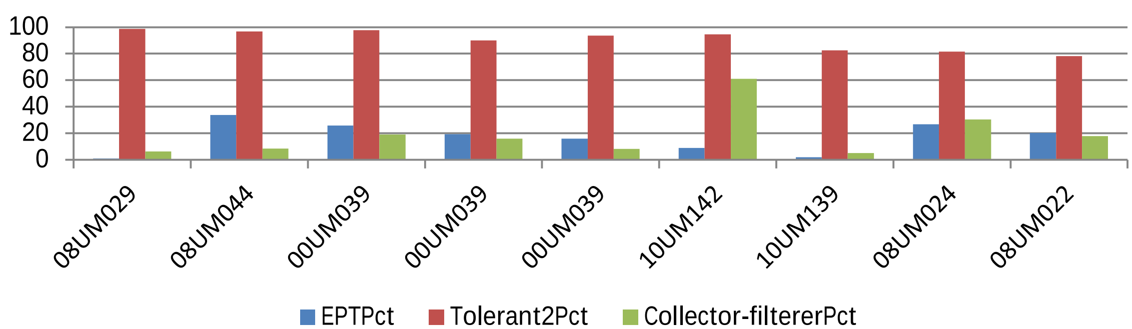

Figure 71: GUS Plus biological sampling locations with metric scores showing the lack of macroinvertebrate taxa which would be found in riffle habitat. Sites 08UM024 and 08UM022 are located in Stony Creek which is a coldwater stream.

The MPCA has completed a TMDL for turbidity for Getchell, Unnamed, and Stoney Creeks (see http://www.pca.state.mn.us/water/tmdl/project-getchelcreek-turbidity.html). The report details the reductions needed to meet the turbidity standard in the GUS Plus Minor. Turbidity and bedded sediment are significant stressors to aquatic life in this Minor.

Dissolved oxygen

The critical period for oxygen levels on a daily basis occurs in the early morning hours around sunrise. Early morning longitudinal DO readings were not collected in the summer of 2010 in the GUS Minor. Review of the existing data from EQuIS shows that for Stony Creek there are many DO readings well into the 14 mg/L and above (Figure 51). This may indicate superstauration of DO which may indicate high periphyton or algal growth within the channel. Future data collection of DO should occur at this site to capture the early morning DO and a daily range from the late afternoon to early morning. This data would help us understand if DO is a stressor in Stony Creek. Getchell Creek has a extensive variation of DO readings, ranging from less than 2mg/L to 15 mg/L (Figure 71). The data from Getchell also should be augmented with a new data set from early morning to determine if DO is a stressor.

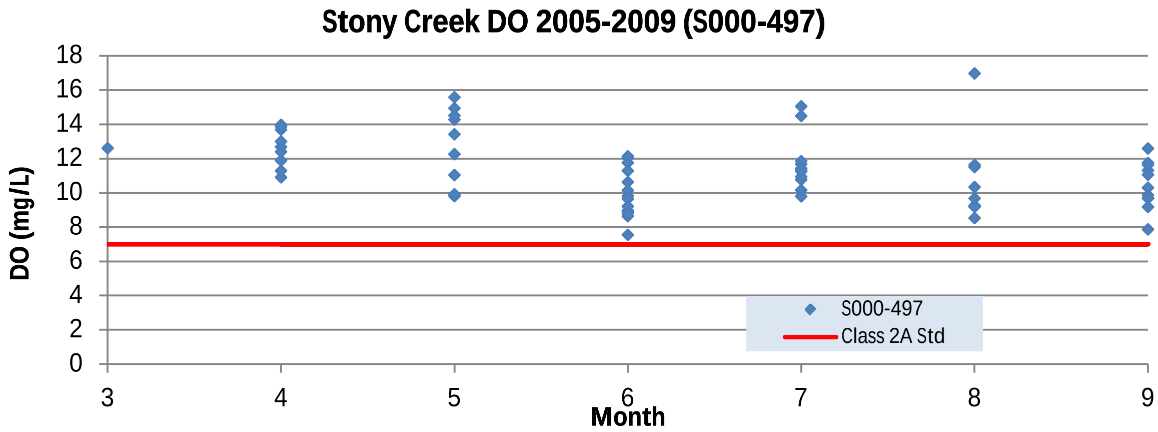

Figure 72: Dissolved Oxygen by month relative to State 2A standard of 7 mg/L for coldwater streams

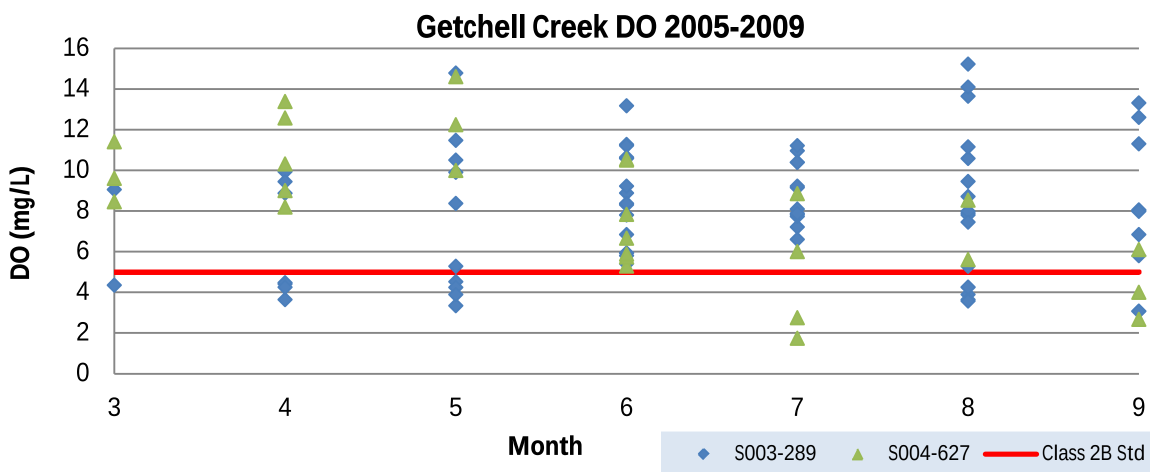

Figure 73: Dissolved Oxygen by month relative to 2B standard of 5 mg/L for warmwater streams

Un-Named Creek has a much smaller data set from EQuIS than either Stony or Getchell. The DO observations did not indicate any readings, below the standard (Figure 53), however the data is lacking early morning readings and a daily range or flux cannot be reviewed. Future data needs would involve the collection of early morning and late afternoon DO data at this site. This data would reveal if DO is a stressor to the aquatic life.

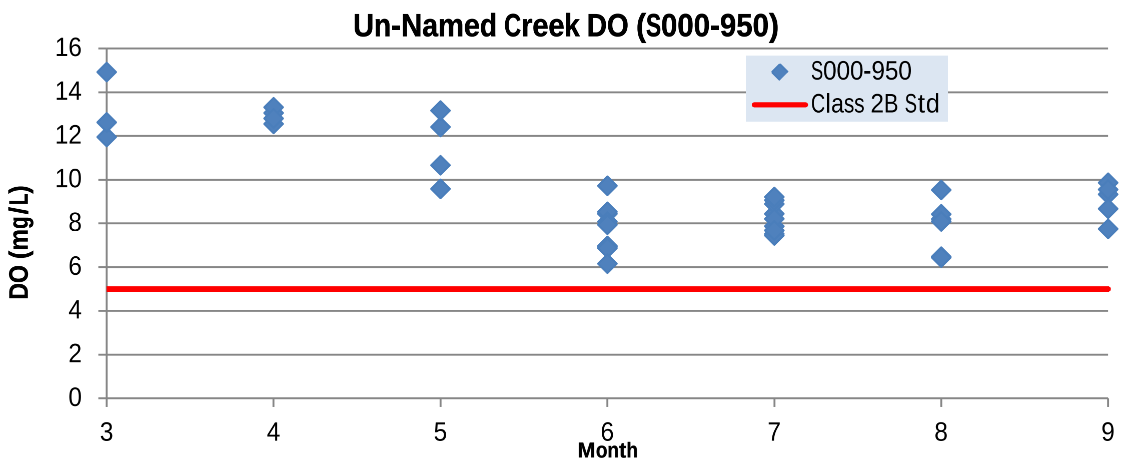

Figure 74: Dissolved Oxygen by month relative to State 2B standard of 5 mg/L for warmwater streams (2000-2010).

Nitrate Toxicity

See Section 4.3.0 earlier in this report for more details on Nitrate.

Causal Analysis -- Nitrate Toxicity

Nitrate-N concentrations in the GUS plus minor

Water Quality data for NO_2 + NO_3 concentrations in Stony, Un-Named and Getchell Creeks are displayed in Figures 54 through 56. Nitrate-N concentrations appear to be higher during the April through June sampling events for all creeks, which likely represents some inputs from fertilizer application.

Nitrate-N concentrations in the GUS Plus Minor are several times higher than the "minimally impacted" reference streams of the North Central Hardwood Forest (NCHF) ecoregion selected by McCollor and Heiskary (1993). However, there were very few samples in exceedance of the Minnesota draft chronic nitrate standard value of 4.9 mg/L in Getchell Creek. Stony Creek had samples above the 3.1 mg/L NO_x standard throughout the monitoring period. Over75 percent of the samples in Un-Named Creek exceeded the proposed chronic standard of 4.9 mg/L. Additional sampling would be required to determine if those concentrations exceeding 4.9 mg/L remained at or above that level for duration of four days and violated the draft nitrate-N chronic standard. However, NO_2 + NO_3 are likely a stressor causing biological impairment in this Minor.

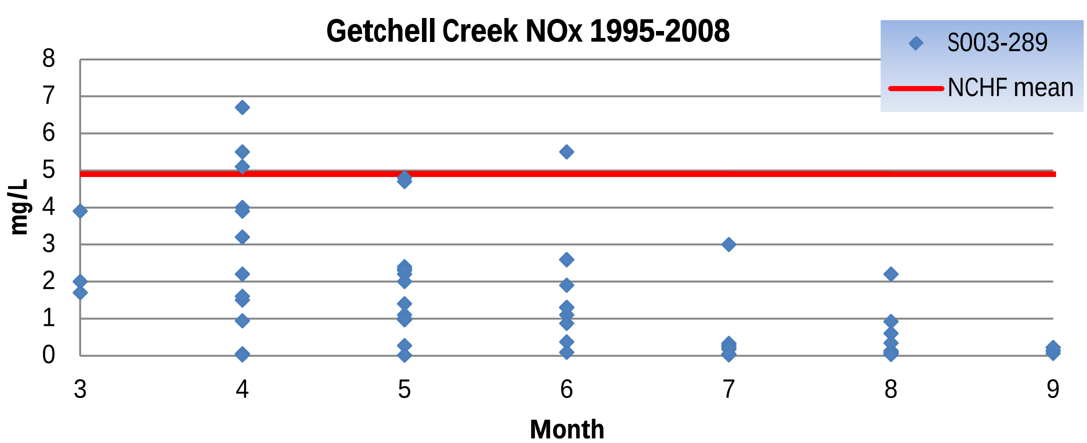

Figure 75: Getchell Creek NO2+NO3 data with Class 2B Standard

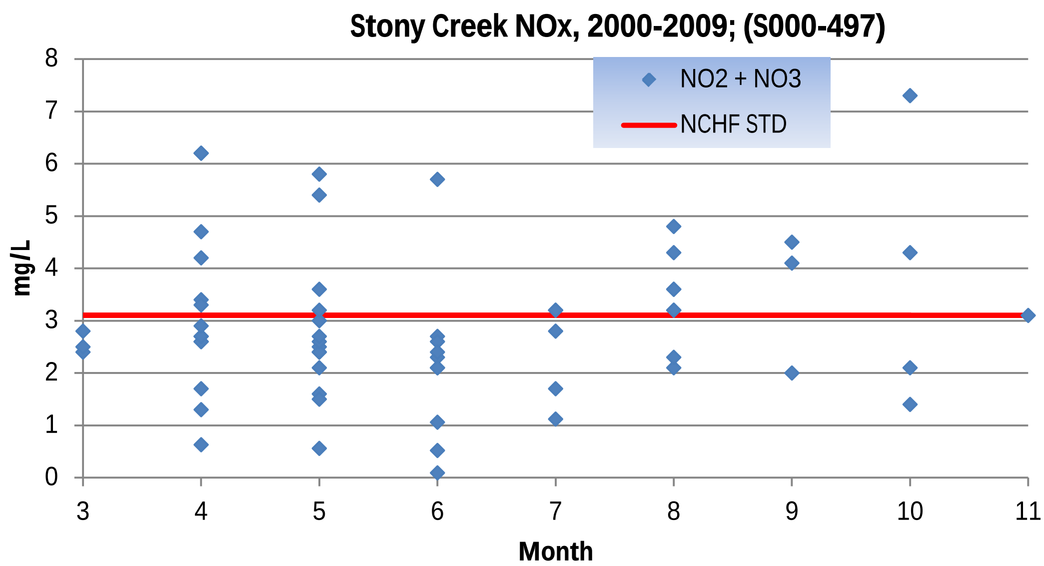

Figure 76: Stony Creek NO2+NO3 data with Class 2A Standard

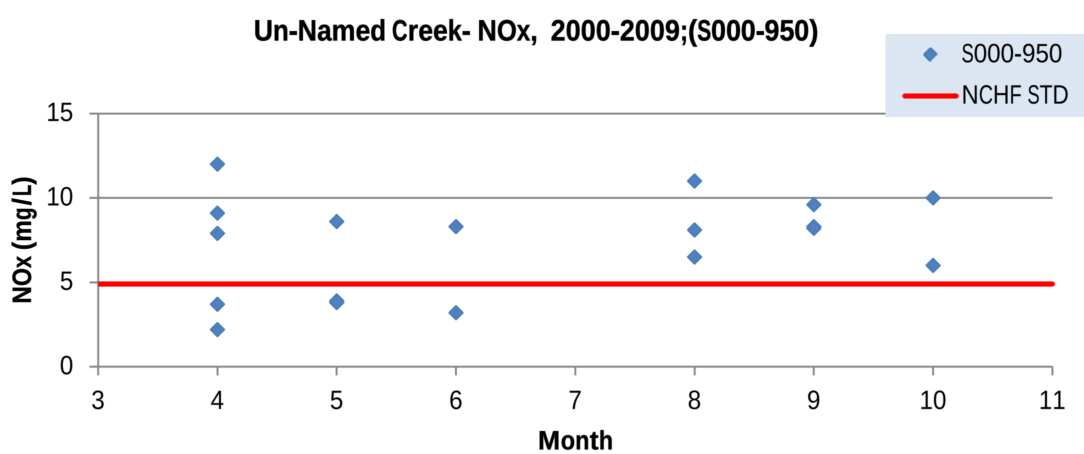

Figure 77: Un-Named Creek NO2+NO3 (= NOx) data with Class 2B Standard

Conclusion

The three main stressors to the biotic community in the GUS Minor are elevated TP, NO_2+NO_3, and Turbidity/bedded sediment. The high NO_2+NO_3 readings in Un-Named Creek and Stony Creek may be causing chronic toxicity, causing a reduction in macroinvertebrate taxa and abundance. These stressors are all related to the large percentage of land (88 percent) that is currently farmed for row crops or utilized as pasture for cattle or horse operations, and four percent of the land is developed. Stony Creek and Un-Named Creek have extensive bank failure that is contributing a large amount of sediment to the channel. This sediment is causing high turbidity levels along with smothering of the coarse substrate which is beneficial to the biological community. The documented reduction of stream channel stability, along with rill and gully erosion are causing a general lack of in-stream habitat along with elevated growth of aquatic plants and a potential for abnormal fluctuations in the DO concentrations of streams. Due to the lack of early morning DO readings, DO cannot be targeted as a primary stressor. Collection of pre 9 am DO readings would help us understand the role that the high nutrients are playing with the daily DO fluctuation and narrow down our focus on DO as a possible stressor and implement the appropriate BMP's to reduce the high nutrient concentrations.

St. Roscoe Minor

The St. Roscoe Minor zone of the Sauk River encompasses the stretch from the Horseshoe Chain of Lakes inlet on the Sauk River to two miles downstream of the outlet of Stony Creek to the Sauk River, just north of the City of St Martin. There are no main tributary streams in this minor, there are four assessable tributaries in this Minor each one is un-named (**Figure 57**). The mainstem of the Sauk River flows into the chain of Lakes at STORET sampling location S000-517 and most of the tributaries in this zone are partially channelized due to agricultural ditching. Historically, this area was dominated by tallgrass prairie, with areas of "wet prairie" and river bottom forest along the riparian corridor of the river. The northwestern section of this minor was originally aspen-oak forest with a small area of conifer bogs and swamp. Current land use is predominantly agricultural (62 percent cultivated land), with 25 percent of the area as grassland/ pasture and two percent wetlands (figure 57). The Chain of lakes is currently impaired for nutrients and a nutrient TMDL is being completed Sauk River Horseshoe Chain of Lakes - Excessive Nutrients - Minnesota Pollution Control Agency.

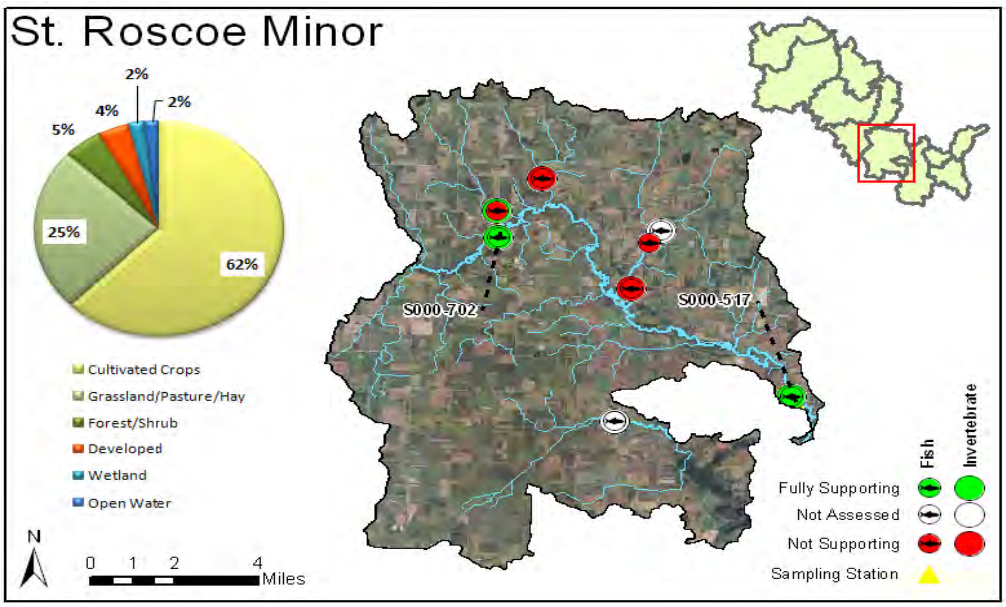

Figure 78: Location of St. Roscoe Minor and local land-cover

Nutrient enrichment

The main stream feature in the St. Roscoe Minor that was investigated for nutrient enrichment was the Sauk River. The Sauk River was sampled periodically from 1995-2009 and the data shows that Total Phosphorus (TP) is well above the proposed river criteria of 0.1 mg/L for much of the sampling record (**Figure 58)**. The two EQuIS sites (S000-517 and S000-702) have a record of 316 samples collected from spring of 1995 through the fall of 2009 with the following statistics: minimum = 0.02 mg/L, maximum = 0.844 mg/L, mean = 0.171 mg/L. The TP values are well above the ecoregion norm level as well as the proposed river criteria during snowmelt periods and also during periods of runoff.

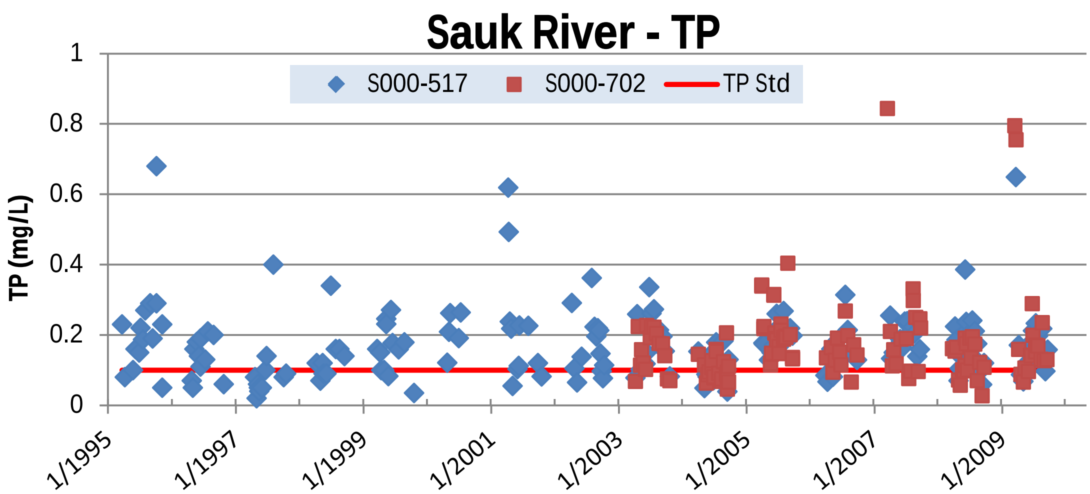

Figure 79: TP concentrations in the Sauk River upstream of Chain of Lakes

Review of land use information along with the spatial distribution riparian pasturing within this Minor can help to explain the high Phosphorus levels found in the Sauk River. Many of the tributary drainage ways have nearly 100 row crop production along them, in addition to a fairly high density of feedlots. **Figure 59** displays the spatial distribution of feedlots along with other observed areas of concern throughout the watershed. Most of the unnamed tributaries in this minor have a very narrow grassed or no riparian buffer along with sections of stream that have been ditched. The St Roscoe Minor has 86 percent of the landuse in agricultural production.

Nitrite plus nitrate levels are also potentially a concern in this Minor. Out of 59 samples collected between 1983 and 2005, 16 samples were above 2 mg/L. The average for the sampling record was 1.59 mg/L and the highest observed value was 6.0 mg/L. Additional NO_2+NO_3 samples should be collected in this Minor. There are no NO_2+NO_3 samples from the tributaries. The potential toxicity levels of NO_2+NO_3 cannot be determined at this time.

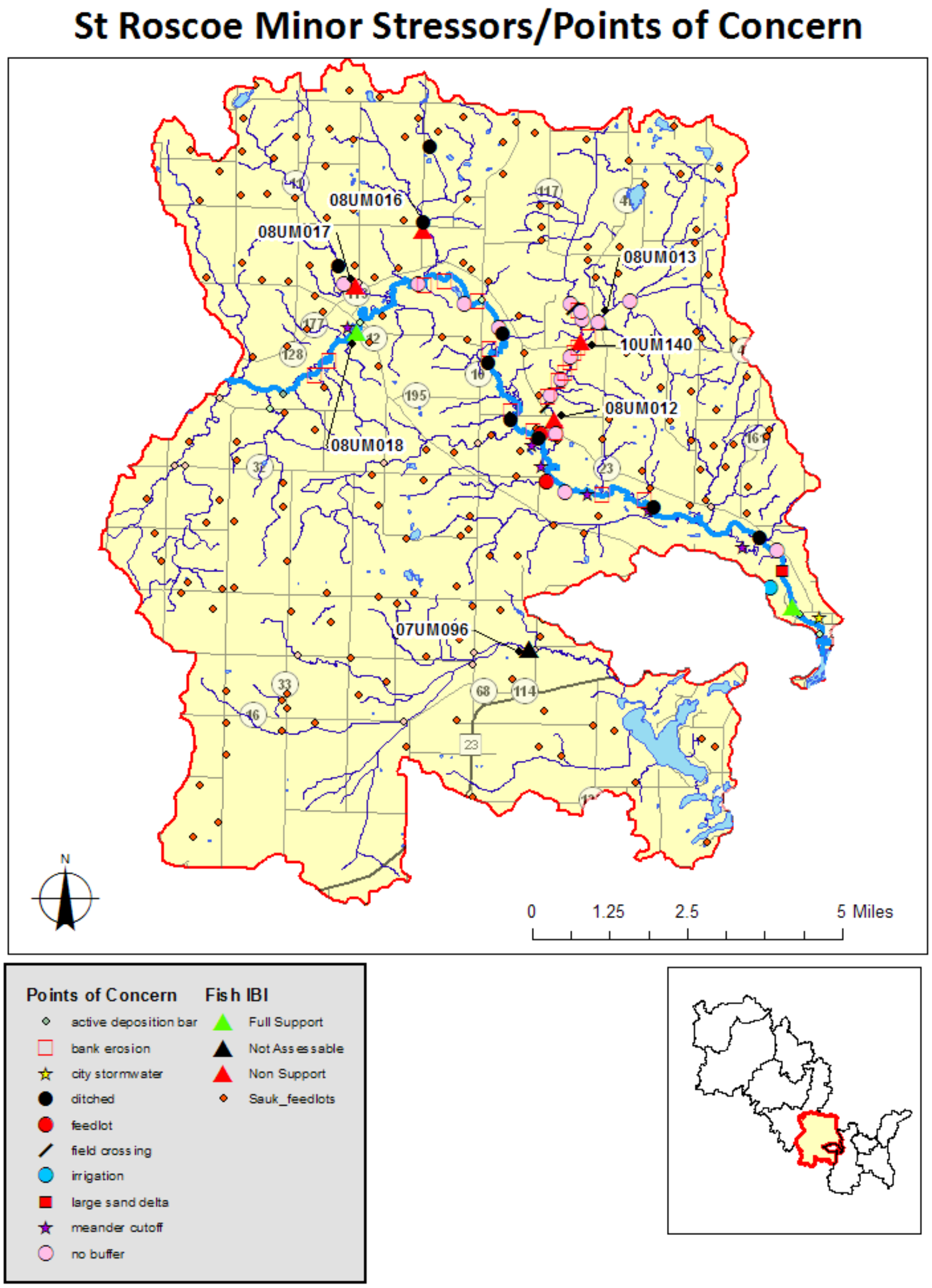

Figure 80: St. Roscoe Points of Concern map with registered feedlots.

The elevated NO_2+NO_3 and TP concentrations are driving the increased abundance of algal and periphyton growth in the Sauk River. Visual observations both during biological sampling and stressor identification field work revealed that the Sauk River has a high abundance of periphyton growth along the stream bottom. The elevated nutrient concentrations are delivered to the Sauk River via the many ditches and small tributary streams feeding the river. The nutrient data, particularly for TP, suggests that there is a high probability of excessive algal productivity within the Sauk River. This data suggests a likely causal pathway for low dissolved oxygen concentrations in specific reaches of the St Roscoe Minor system.

Sediment

Total suspended sediment

Total suspended solids concentrations have been sampled and evaluated in the St Roscoe Minor watershed. Observations were also made during several stream reconnaissance trips made from road crossing observations. There is ample evidence to support elevated TSS concentrations as a candidate cause for biological impairments in the St Roscoe Minor. TSS samples were collected at EQuIS sites S000-702 and S000-517 with a minimum value of 2 mg/L and a maximum of 230 mg/L, which is well above the proposed 30 mg/L TSS standard for the Sauk watershed **(Figure 80).**

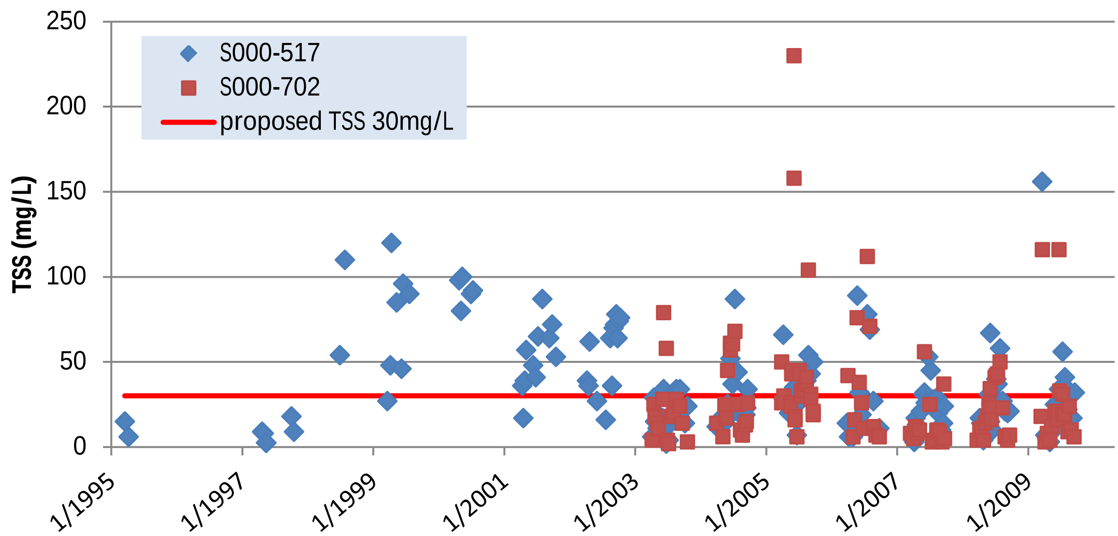

Figure 81: TSS concentrations for sampling record at Sauk River sites (1995-2009).

Aerial photography was studied to look for potential sources of sediment within this Minor. This review revealed some bank failures, along with existance of a large amount of row crop agriculture with limited riparian buffers **(Figure 61)**. There are also a significant number of riparian pasturing areas where cattle have free access to the stream.

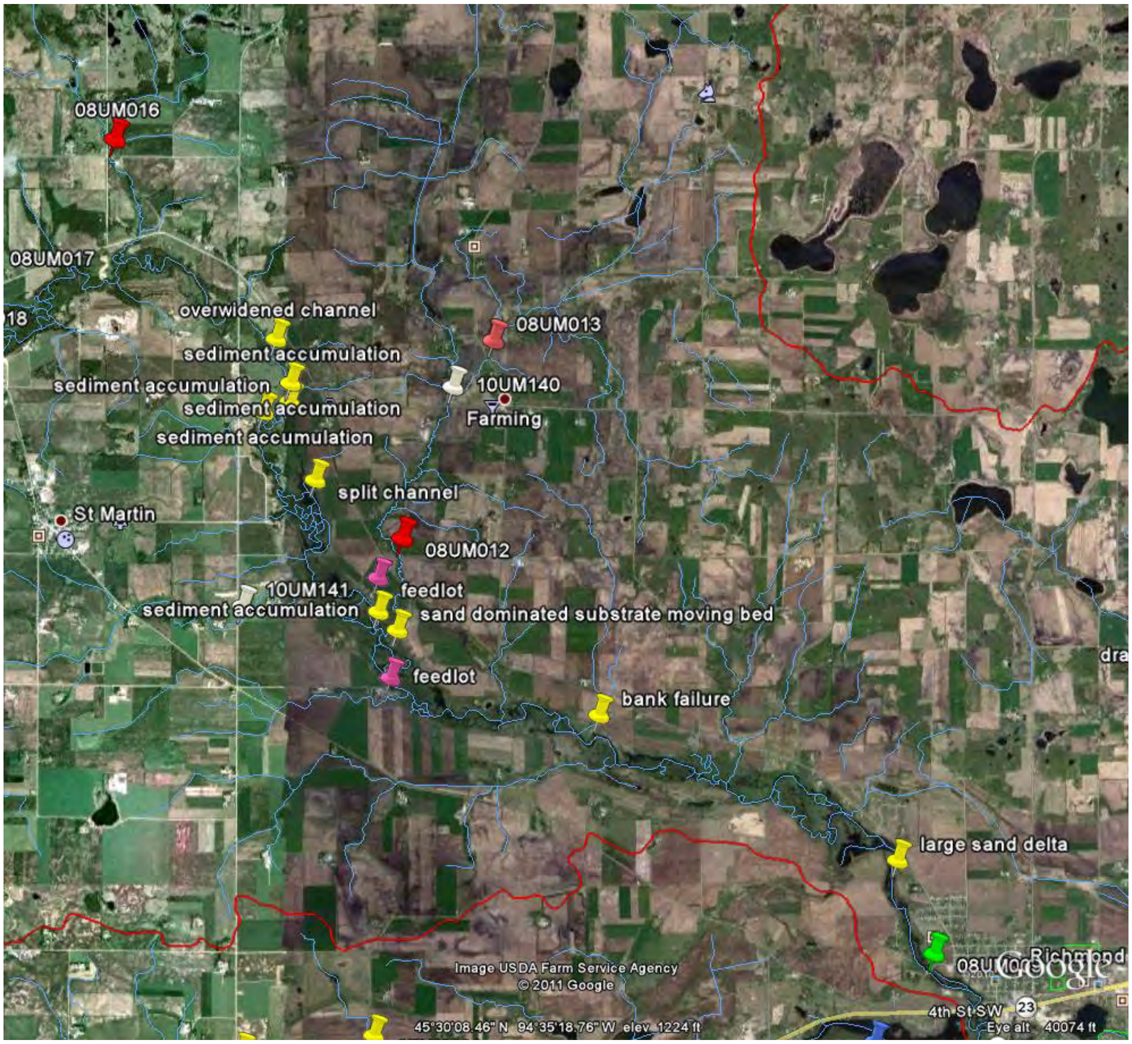

Figure 82: the St Roscoe Minor with observations made reviewing aerial photos in Google Earth

Field reconnaissance along with aerial photo review has also revealed that this Minor has a sand-dominated channel with a moving bed. The bed load is smothering important habitat features, which is significantly contributing to the poor IBI scores for macroinvertebrates. Most rock riffle substrate is nearly 100 percent embedded with sand.

The unnamed tributaries within this Minor that were assessed for biotic integrity do not have an accompanying TSS and nutrient dataset. Aerial photograph review along with field data collection is being used to evaluate the potential for sediment as a stressor to the biotic community. The aerial interpretation revealed that the majority of the headwater areas of these tributaries do not have riparian buffers and/or are channelized. The lack of buffer strips, along with the channelization, would indicate that there is a high probability of having a large amount of sediment moving downstream through these systems. Bank instability appears to be an issue when reviewing aerial photographs, along with the access of cattle at feedlot sites. Aerial photograph review reveals that nearly all channel dimensions are over-widened at the pasture site which indicates that the channels are wider, stream temperature would be higher and available habitat would be degraded. With over widening of the channels the rock riffles become embedded with fine particles and the stream pools fill with fines, leaving no or very little habitat available for fish and macroinvertebrates. **Figure 82** shows the condition of the stream channel at a farm site in Stearns County.

Figure 83: Aerial photo shows the overwidened stream channel and lack of woody riparian vegetation to provide shade where cattle have access. Contrast with stream channel at bottom edge of photo.

Altered hydrology

The streams in this Minor have experienced a high degree of channelization. This broad-scale alteration, along with the drainage of water storage areas, moves water through the system at an increased rate. This increased peak discharge transfers energy to stream banks and increases the erosive capability of the water, causing instability of stream banks. As banks fail, the eroded material settles onto the stream bed where it smothers important stream habitat (coarse streambed materials are buried and pools fill).

Dissolved oxygen

Instantaneous DO readings were collected at two sites on the Sauk River from 2005-2009. The DO data shows a large distribution of readings (**Figure 63**). Reviewing this data suggests that the abnormally high readings (above 11 mg/L) may suggest that there is excessive algal or periphyton growth within the river. Due to the lack of early morning DO readings it is difficult to access the condition of DO in this Minor. It is recommended that early morning DO readings be collected to help determine the flux of DO within the river. The majority of the DO readings are at or above the 5 mg/L standard. There were 129 DO readings recorded at the two EQuIS sites from 2005 through 2009, of those 129 readings 126 were above the 5 mg/L standard. Because of the elevated TP and DO readings, it is suspected that there would be a large flux of daily DO causing a potential stressor to aquatic biota.

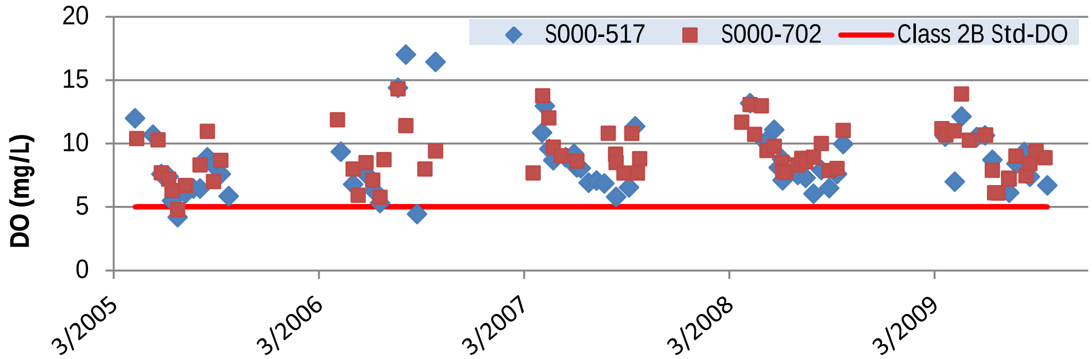

Figure 84: Dissolved Oxygen data relative State 2B standard of 5 mg/L

Conclusion

Review of the existing data along with aerial photographic review suggest that the three main stressors to the biotic community are Total Suspended Sediment (Bedload), increased nutrient levels and altered hydrology (channelization). Ample evidence suggests that the increased rate of flow is causing bank instability which in turn is delivering excessive amounts of sediment to the channel. The channel cannot transport this volume of material, therefore, it is settling and causing a lack of gravel and cobble substrate, which is the preferred substrate for intolerant macroinvertebrate taxa and lithophilic spawning fish. The increased nutrient concentrations are driving the increased algal and periphyton production which is also limiting available substrate and potentially causing a high daily flux of DO.

Chain of Lakes Minor

The Chain of Lakes Minor zone of the Sauk River encompasses the stretch from the Horseshoe Chain of Lakes inlet on the Sauk River to the outlet of the Sauk River at Knaus Lake near Cold Spring. There is one main tributary stream in this minor, Eden Valley Creek (**Figure 64**). The mainstem of the Sauk River flows into the Chain of Lakes at EQuIS site S000-517. Most of the tributaries in this zone are partially channelized due to agricultural ditching. Historically, this area was dominated by Aspen-Oak, Big Woods-Hardwoods, with areas of brush prairie. Current land use is predominantly agricultural (50 percent cultivated land), with 24 percent of the area as grassland/pasture and five percent wetlands (Figure 5.7-1). The Chain of Lakes is currently impaired for nutrients and a nutrient TMDL is being completed.

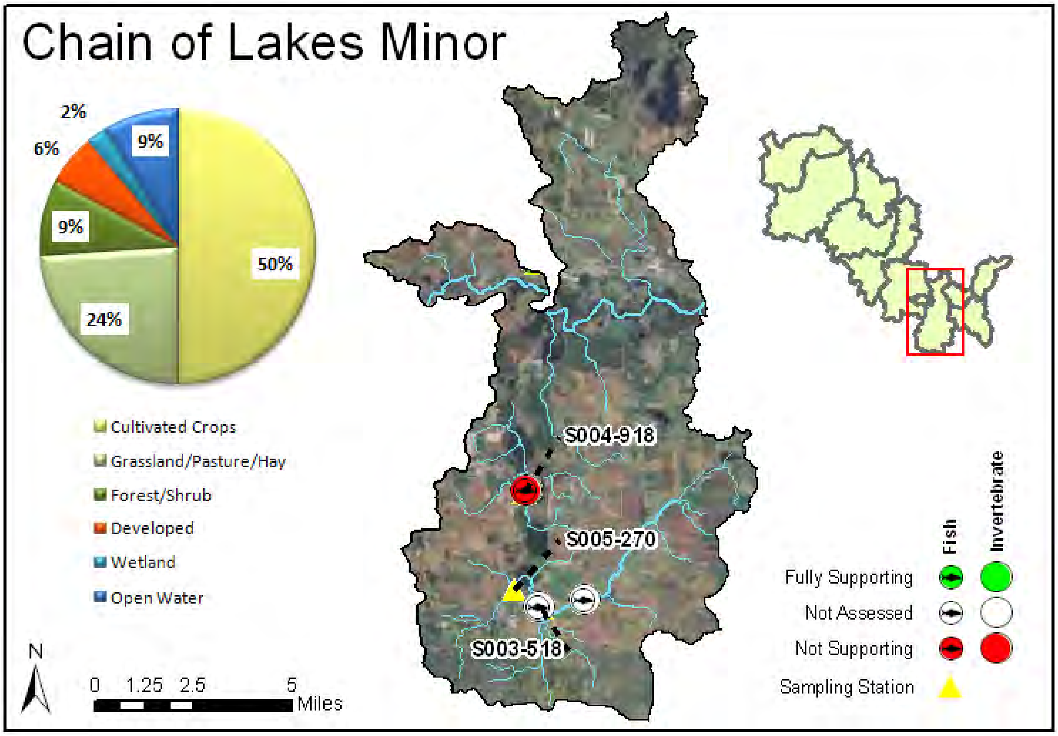

Figure 85: Location of Chain of Lakes Minor zone and local land-cover

The Chain of Lakes Minor contains extensive row crop and animal agriculture. **Figure 64** shows the spatial distribution of registered feedlots located in this Minor. As the map indicates some of these operations are located on waterways and animal manure can freely flow to the downstream waterbodies.

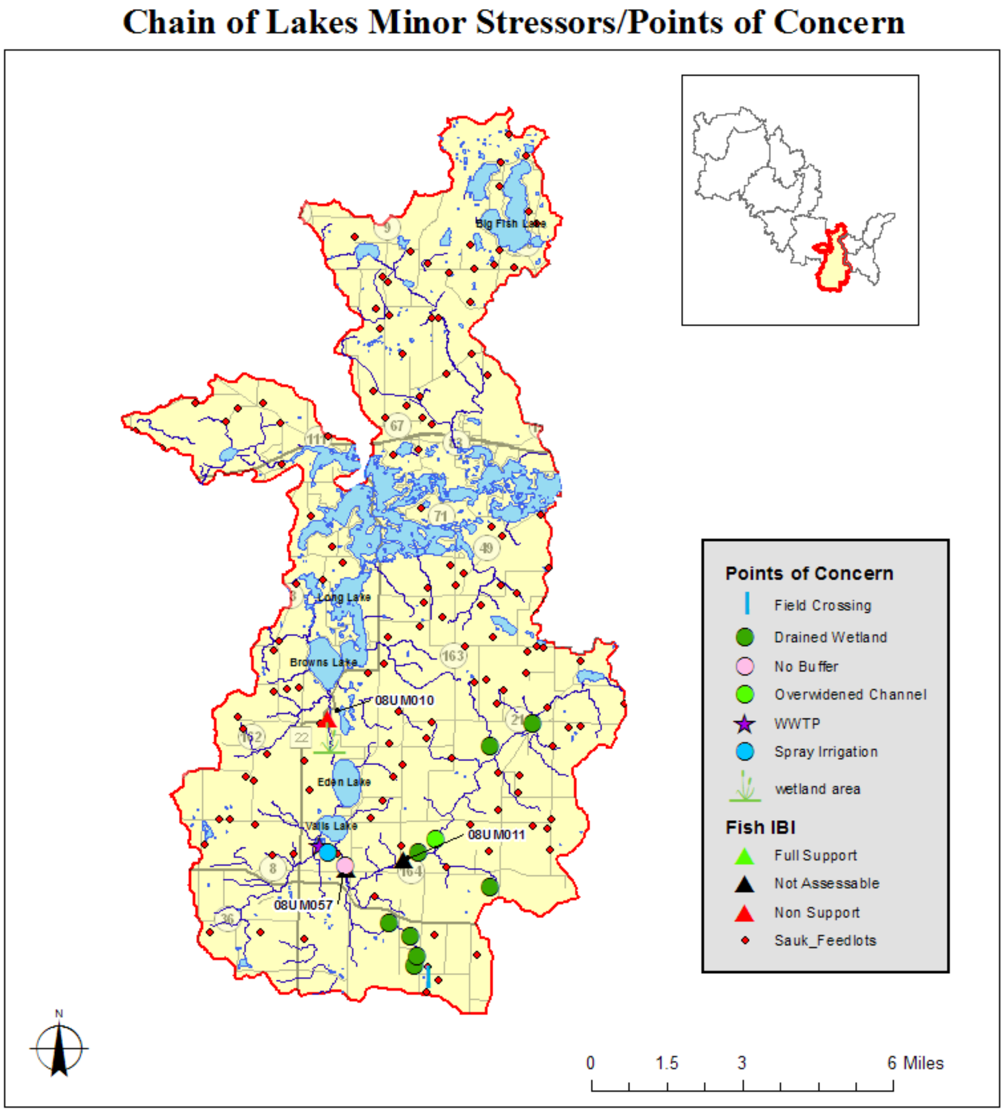

Figure 86: Chain of Lakes Minor points of concern from field reconnaissance along with distribution of feedlots.

Nutrients

The main stream feature in the Chain of Lakes Minor that was investigated for excess nutrients was Eden Valley Creek above Browns Lake. Total Phosphorus (TP) data is well above the proposed River criteria of 0.1 mg/L for much of the sampling record (**Figure 66)**. The two EQuIS sites have a record of 15 samples collected from spring of 2007 through the fall of 2008 with the following statistics: minimum = 0.058 mg/L, maximum = 1.04 mg/L, mean = 0.192 mg/L. For the impaired AUID within Eden Valley Creek, there were two sampling locations (S002-040 and S004-918). The Creek is a low gradient stream that grows excessive rooted aquatic plants and peryphyton, a symptom of elevated nutrient levels (**Figure 86**).

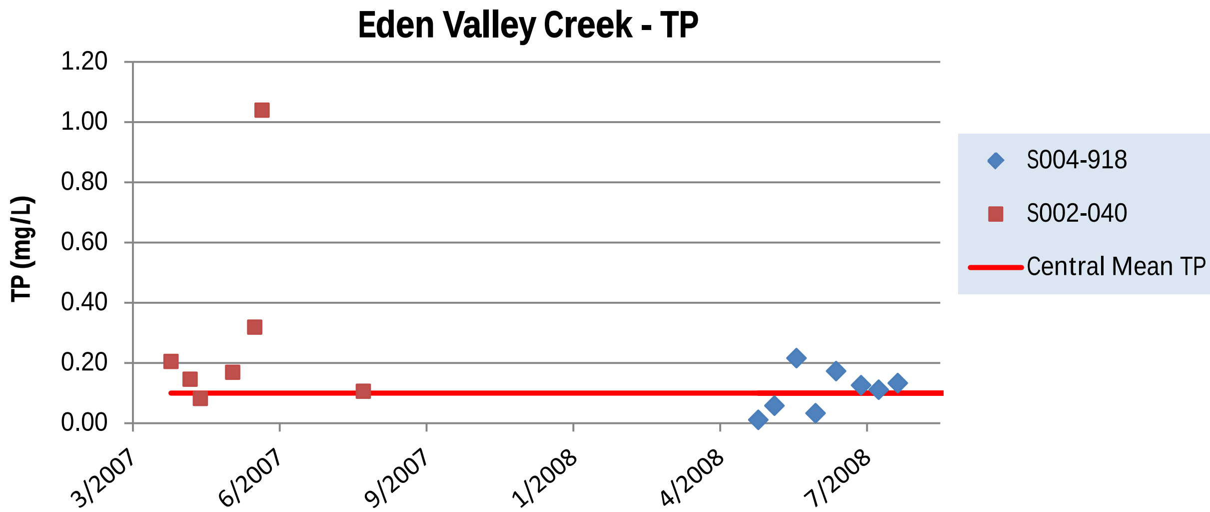

Figure 87: TP concentrations in Eden Valley Creek upstream of Browns Lake

Figure 88: Eden Valley Creek excessive plant growth in channel.

Dissolved oxygen flux

Diurnal DO was collected using YSI 6720 sonde deployed for a one week interval. The DO flux ranged from 4 to 8.5 mg/L per day at the EDC_170 sampling site on Eden Valley creek (Figure 68). The DO peaked near 10 mg/L in late afternoon and dropped to near 0 mg/L during the early morning hours. The daily minimum DO concentration during sampling was always below 0.5 mg/L for the one week sonde deployment. DO concentrations this low and this frequent would have an impact on the taxa and abundance of individuals in the biotic community.

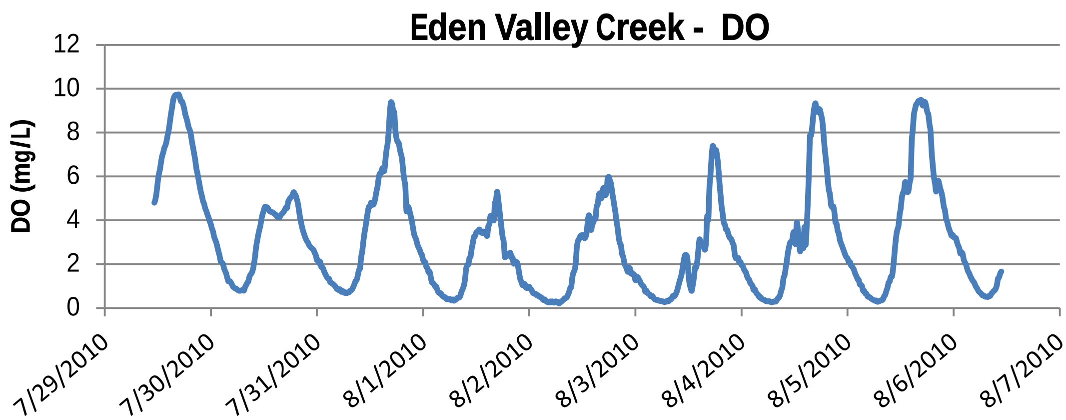

Figure 89: Show the DO flux for Eden Valley Creek at stream crossings at 170th St.

These data related to DO concentrations and river eutrophication suggest that excess nutrients, leading to elevated primary productivity (represented by visual observations of plant growth within the channel) is a likely causal pathway for low DO concentrations in specific reaches of the Eden Valley Creek system. The wetland that outlets at site EDC-170 is probably one of the contributing factors for the very low DO readings at this site. These lines of evidence are particularly strong for Eden Valley Creek.

Causal analysis – biological response

Biotic response – Chain of Lakes Minor

Dissolved oxygen concentrations in this reach are routinely below the class 2B standard, including a low measurement of 0.5 mg/L at biological station 08UM010. Several biological indicators of low dissolved oxygen are also present in this reach:

Lack of sensitive fish taxa

The most upstream biological monitoring site in this watershed zone exhibited a general lack of sensitive fish taxa and low overall taxa richness of headwaters minnow species. The sampling event at 08UM010 revealed a fish community dominated by central mudminnow (*Umbra limi*) and Sticklebacks, both of which are especially tolerant of low dissolved oxygen conditions. Tolerant species accounted for 93 percent of the total fish population and 89 percent of the sample was wetland-tolerant species. A total of 46 fish were sampled at 08UM010, of which three fish were intolerant.

Low fish abundance

Biological monitoring stations in this watershed zone scored low in the fish metric NumPerMeter-Tolerant, which is a measure of fish density (# fish/meter) excluding tolerant fish species. Although this metric could be responsive to a variety of stressors, it is likely that the sustained low DO conditions observed within this reach limit fish population size, especially those species that are not considered tolerant of adverse conditions. The NumPerMeter fish sampled was 0.219 while the NumPerMeter-Tolerant was 0.014.

Lack of sensitive macroinvertebrate taxa

Both biological sites in this reach lacked intolerant macroinvertebrate taxa. Site 08UM010 scored a "0" for the metric Intolerant2Ch, which counts the number of macroinvertebrate taxa with low tolerance to a variety of stressors.

Low plecoptera richness

Macroinvertebrates from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) are widely used bio-indicators that are typically abundant in healthy streams. Plecoptera are especially sensitive to low dissolved oxygen concentrations and are not often found in streams with unstable or low concentrations of DO. Plecoptera taxa are generally associated with cobble riffles or woody substrate in the channel. The sampled reach would be lacking cobble riffles, however, there was wood present within the channel. There were no Plecoptera taxa present at the biological monitoring site in this reach of Eden Valley Creek.

Total suspended solids

Total suspended solids (TSS) concentrations were sampled at two locations in the Chain of Lakes Minor, at EQuIS sites S004-918 and S002-040. Statistics from that sampling showed a minimum TSS value of <1 mg/L and a maximum of 10 mg/L, which is well below the proposed 30 mg/L TSS standard for the Sauk watershed. Based on those numbers and several stream reconnaissance trips, there is no evidence to suggest elevated TSS concentrations as a candidate cause for biological impairments in the Chain of Lakes Minor).

Dissolved oxygen

During the summer of 2010, from mid June through August, early morning DO readings were taken at 4 sampling locations along Eden Valley Creek (**Figure 90**).

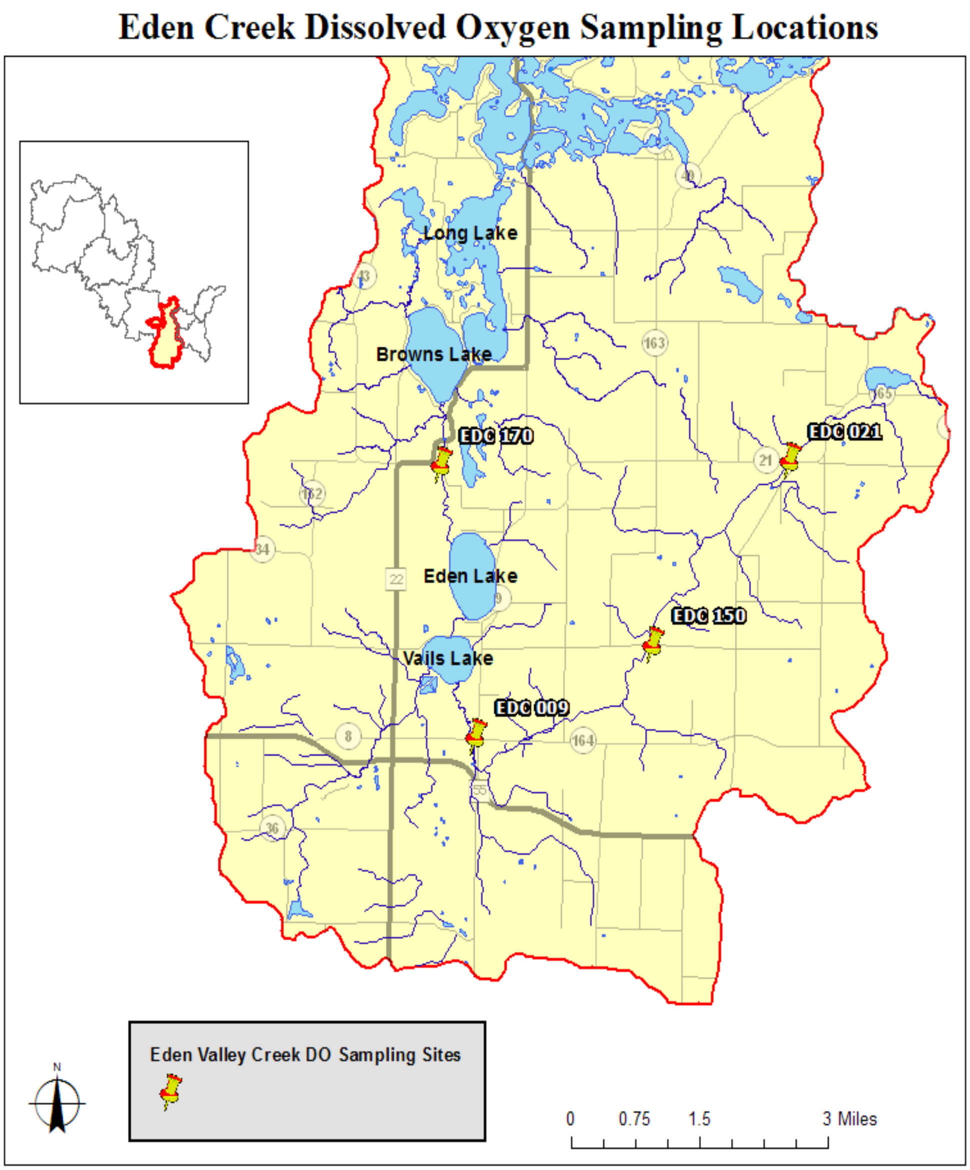

Figure 90: Synoptic Dissolved Oxygen sampling locations for Eden Valley Creek, part of Chain of Lakes Minor

Sampling locations EDC 009 and EDC 170 had DO readings that were almost always below 5 mg/L **(Figure 90)**. Further upstream, at site EDC 150, the DO readings were often above the 5 mg/L standard. Site EDC021 went dry after one DO reading was taken. This suggests that the drainage below sampling site EDC 150 is contributing the majority of the DO removal. The creek is low gradient throughout and has very limited ability to re-aerate from riffle activity. Eden Valley has a wastewater treatment facility located downstream of EDC009. The facility spay irrigates on two fields adjacent to Eden Valley Creek that flows into Vails Lake. It is likely that the increased TP and high fluctuation in DO is partly caused by this source.

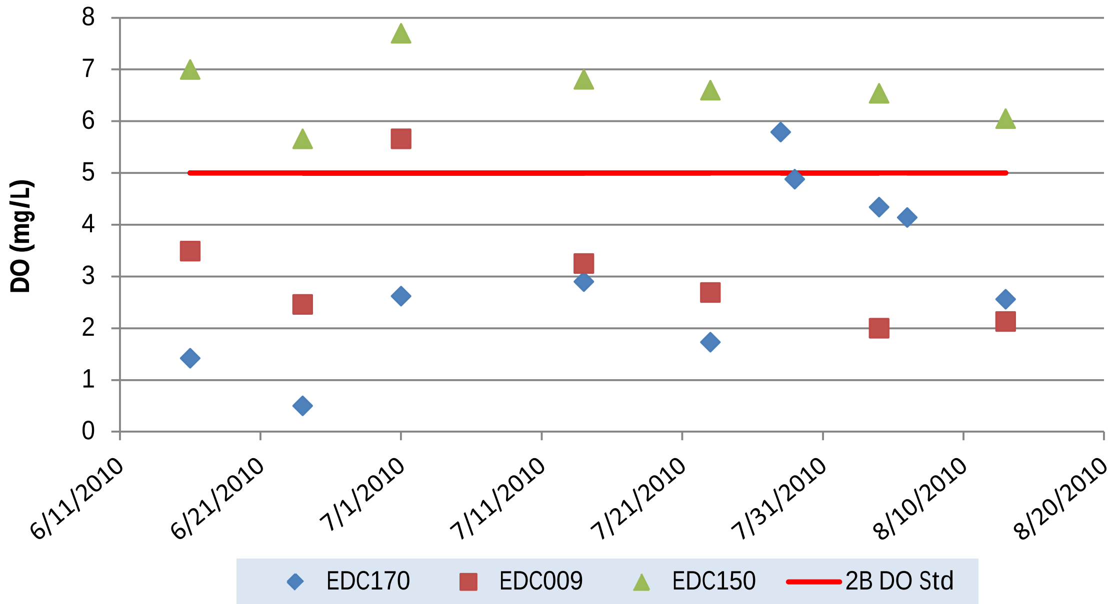

Figure 91: Dissolved Oxygen data relative to the 2B standard of 5 mg/L

When the instantaneous DO data is compared with flow volume records **(Figure 92)**, it is shown that DO is below the 5 mg/L standard during a variety of flow regimes.

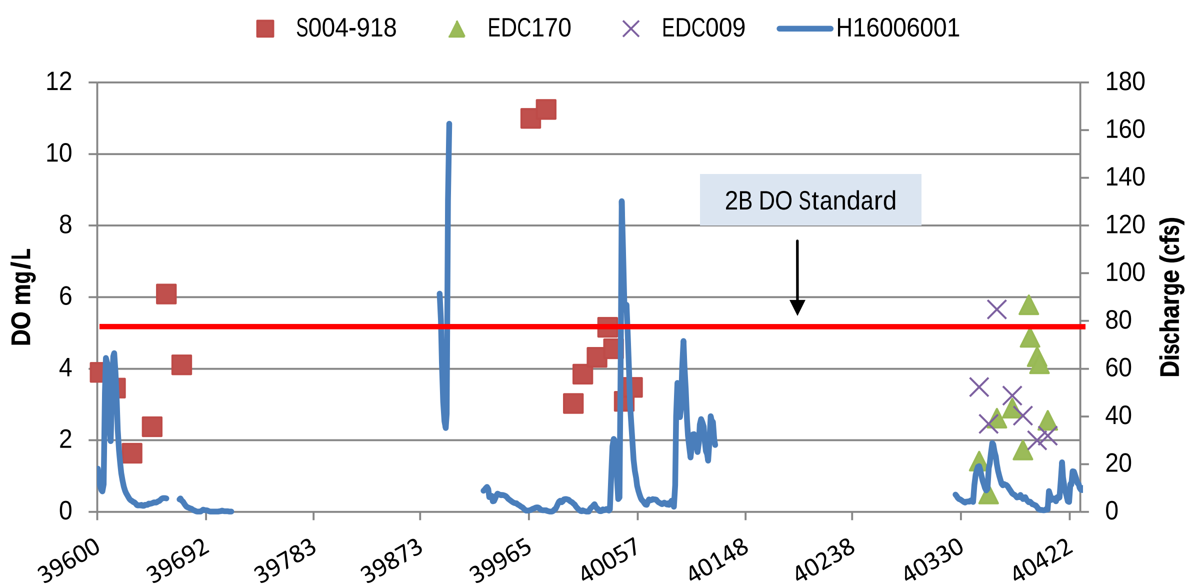

Figure 92: Eden Valley Creek instantaneous Dissolved Oxygen readings versus flow

The data suggests that Eden Valley Creek is impaired for DO and this may be the leading cause of fish and invertebrate impairments. The limited data set suggests that the farthest downstream area experiences the lowest DO readings throughout the low flow period summer months. Continuous data shows a high rate of flux in DO readings throughout the course of the diurnal pattern.

Conclusion

Dissolved Oxygen and elevated Total Phosphorus levels are the main stressors for the biological communities in the Chain of Lakes Minor. Lack of suitable stream substrate also is causing stress on the biology. The stream channel for Eden Valley Creek is channelized above Vails Lake. This channelization has altered the hydrology causing increased peak flows and unstable base flow. The upstream landscape has been altered by the drainage of most of the wetlands, thus reducing water storage and slow release. Restoration of wetlands in this watershed could help lower peak flow volumes and create a more stable base flow condition within Eden Valley Creek. Reductions in TP concentrations would help reduce the increased plant growth within the channel which in turn would result in more favorable DO concentrations and a reduction in the high diurnal DO flux.

Cold Spring Minor

The Cold Spring Minor zone of the Sauk River encompasses the stretch from the Horseshoe Chain of Lakes outlet on the Sauk River near Cold Spring downstream to CR 139 in Rockville. There is one impairment in this Minor, 08UM003, which is located on the Sauk River just upstream of CR139 (**Figure 93**). The downstream boundary of this management unit is the confluence of Mill Creek in Rockville. This site is just downstream of EQuIS site S000-361. Brewery Creek is the main tributary in this management unit. It is a cold water stream that flows through the town of Cold Spring. Historically there was a self sustaining population of brook trout residing in Brewery Creek. Historically, this area was dominated by Aspen Oakland, Oak openings and barrens, and prairie, with areas of river bottom forest along the riparian corridor of the river. Current land use is a mix of agricultural types (34 percent cultivated land, 30 percent Grassland/ pasture/hay), while 18 percent of the area is forested and 13 percent developed (**Figure 93**).

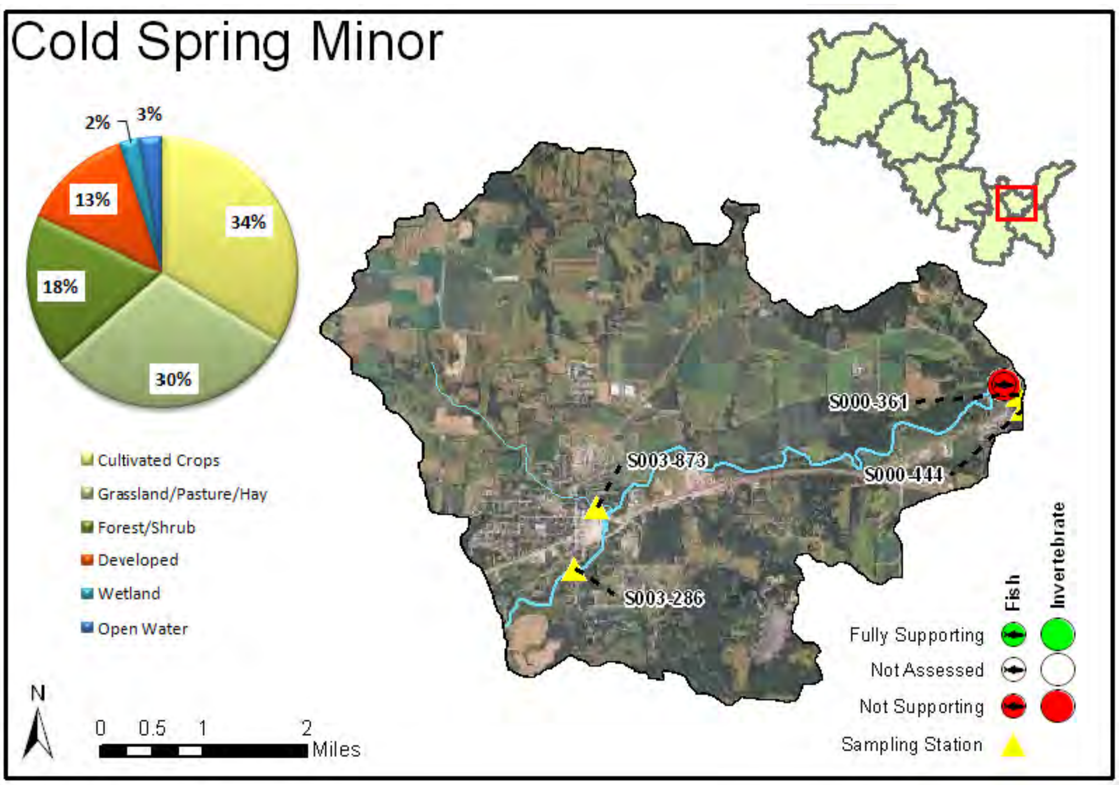

Figure 93: Location of Cold Spring Minor watershed zone and local land-cover.

Nutrients

Evidence of Causal Pathways – Nutrients / Chlorophyll-a, and Oxygen Demand

The main stream feature in the Cold Spring Minor that was investigated was the Sauk River upstream of the City of Rockville. Two sampling locations, S003-286 and S000-361, are found in the impaired Sauk River reach here. These sites have a record of 220 TP samples collected from spring of 1995 through the fall of 2009, with the following statistics: minimum = 0.026 mg/L, maximum = 0.657 mg/L, mean = 0.151 mg/L. Total Phosphorus is well above the proposed River criteria of 0.1 mg/L for much of the sampling record (**Figure 94**).

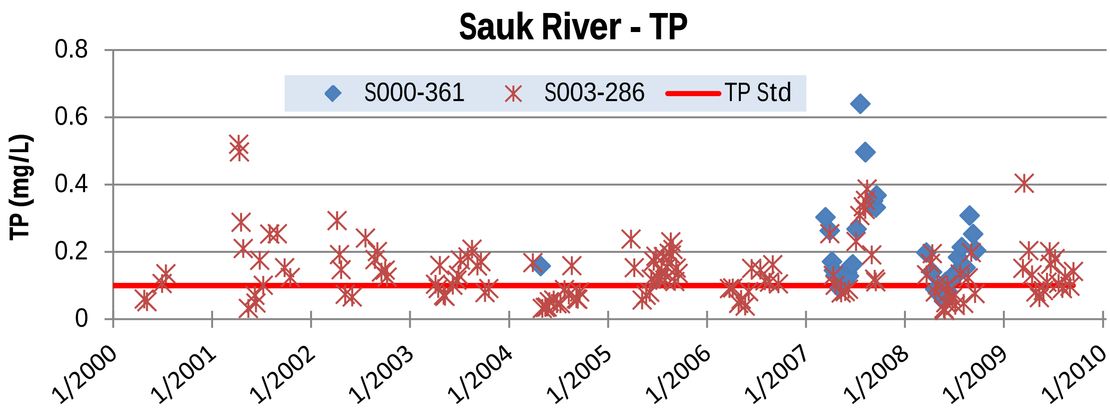

Figure 94: Sauk River downstream of Chain of Lakes and in Rockville; TP concentrations

Chlorophyll-a (Chl-a) concentrations are commonly used to measure algal productivity in surface water, and have shown correlations to maximum DO concentrations and DO flux in non-wadable rivers (Heiskary et al., 2010). In the Sauk River, at EQuIS site S003-286, 17 Chl-a samples were collected, having a maximum value of 116 ug/L and minimum value of 5 ug/L. The chl-a criterion for central Minnesota rivers is 20 ug/L. Almost all chl-a samples for EQuIS site S003-286 were above the criterion. **Figure 95** displays the chlorophyll-a data.

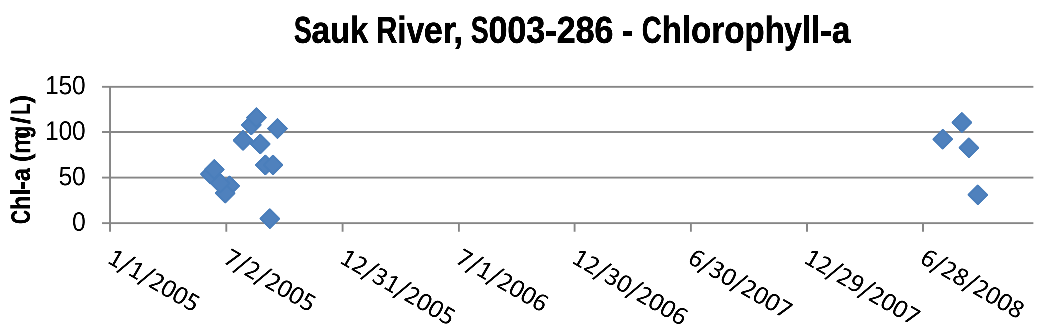

Figure 95: Chlorophyll-a data from EQuIS site S003-286

Dissolved oxygen flux

Diurnal DO data was not collected in this Minor during the 2010 study year. Among instantaneous measurements from 2008, 6 of the 17 DO sampling events were below the State Class 2B standard of 5 mg/L (**Figure 96**). The DO readings were all collected during the early afternoon between 11:53 am and 3:06 pm. During this time of day the daily DO should be increasing in value and points out that the daily minimum must be significantly lower than the observed values. This helps support the theory that lack of DO during the low flow time period is a stressor to aquatic life.

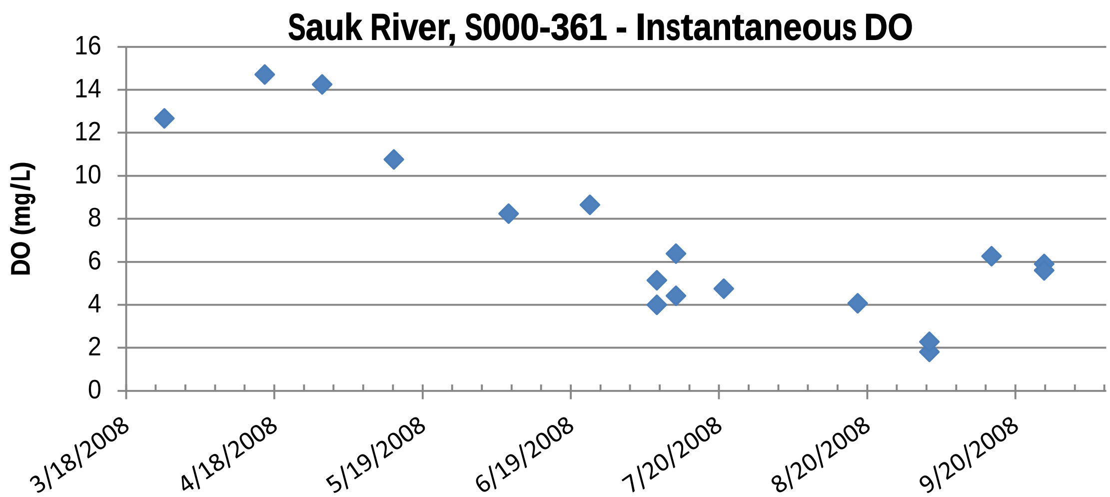

Figure 96: EQuIS site S000-361 Dissolved Oxygen instantaneous readings from early afternoon.

There appears to be seasonal trend in DO observations. As the stream temperature warms during the summer months and the DO concentrations are experiencing an inverse relationship.

Casual analysis

Biotic reponse

Dissolved oxygen concentrations in this reach are below the class 2B standard during the mid to late summer months, including a low measurement of 1.81 mg/L at biological station 08UM003. Several biological indicators of low dissolved oxygen are also present in this reach:

Low abundance of sensitive fish taxa

The most upstream biological monitoring site in this watershed zone exhibited a general lack of sensitive fish taxa and low overall taxa richness of headwaters minnow species. Tolerant species accounted for 45 percent of the total fish population. A total of 292 fish were sampled at 08UM003 of which 161 fish were intolerant.

Lack of sensitive macroinvertebrate taxa

Both biological sites in this reach lacked intolerant macroinvertebrate taxa. Site 08UM003 scored a "0.6" for the metric Intolerant2lessCh, which counts the number of macroinvertebrate taxa with low tolerance to a variety of stressors.

High abundance of tolerant taxa

Tolerant taxa were very abundant at sampling location 08UM003. The most abundant taxa found were tolerant to pollutants and made up 79 percent of the sample. The two most abundant taxa made up 87.5 percent of the sample and were also tolerant.

Low EPT taxa richness

Macroinvertebrate taxa from the orders Ephemeroptera, Plecoptera, Trichoptera (EPT) are generally regarded as indicators of good to excellent water quality. The taxa richness of EPT species was 4.2 percent in the sample at site 08UM003. This low abundance of EPT taxa may be directly reflected by the low DO concentration in this reach of the Sauk River. Generally EPT require adequate DO concentrations and cobble or gravel riffle substrate.

Sediment: Total suspended solids and bedded sediment

Total suspended solids

Based on TSS samples, there is limited evidence to suggest elevated TSS concentrations as a candidate cause for biological impairments in the Cold Spring Minor. Data from the two EQuIS sites (S000-361 and S003-286) showed a minimum TSS value of <1 mg/L, a maximum of 82 mg/L, and a mean of 22 mg/L, which is below the proposed 30 mg/L TSS standard for the Sauk watershed (**Figure 97**).

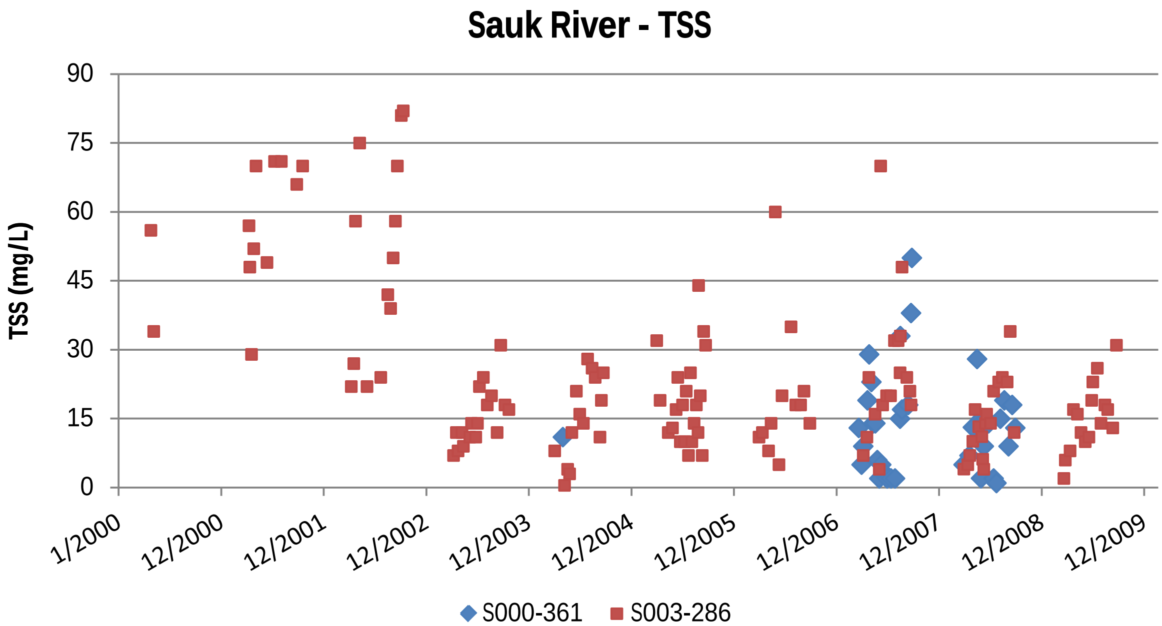

Figure 97: TSS concentrations for the Sauk River upstream of Rockville

Bedded Sediment

The filling of gravel and rock interstitial spaces by fine sediment is detrimental to the life cycle of many beneficial macroinvertebrates and fish. The loss of gravel for lithophilic spawning fish species limits reproductive capacity. The channel substrate in the Sauk River in this Minor is dominated by sand. The D50 particle size was 1 mm which relates to coarse sand. This sand has the ability to move along the channel bottom and fill pools and smother the gravel and stones in riffles. The suspected cause of sand in the channel is bank erosion, induced by altered stream flow from landscape changes and the physical trampling and sheering of bank material due to domestic animal activity.

Dissolved oxygen

Figure 98 shows the historical samples collected for DO within the Cold Spring Minor. EQuIS site S003-286 is located above the dam, and therefore, is more representative of lake conditions. **Figure 98** shows the sampling locations within this minor along with areas of concern that could be impacting water quality. EQuIS site S000-361, located downstream near the city of Rockville, experienced some low DO readings during 2008. This site is downstream from the dam far enough where the influence from the lake is no longer applicable.

Figure 98: Dissolved Oxygen data versus State 2B standard of 5 mg/L

It appears that high algal biomass is being produced in the reservoir, as indicated by Chl-a concentrations discussed earlier in this section. As the high algal biomass is washed downstream via the Sauk River, bacterial activity in the accumulations of dead and decomposing algae is a contributing factor in DO decline in the water column. The high nutrient concentrations are driving the production of algal biomass. A reduction in TP should result in lower algal biomass which in turn would reduce the amount of plant material decay and DO stripping from the water column.

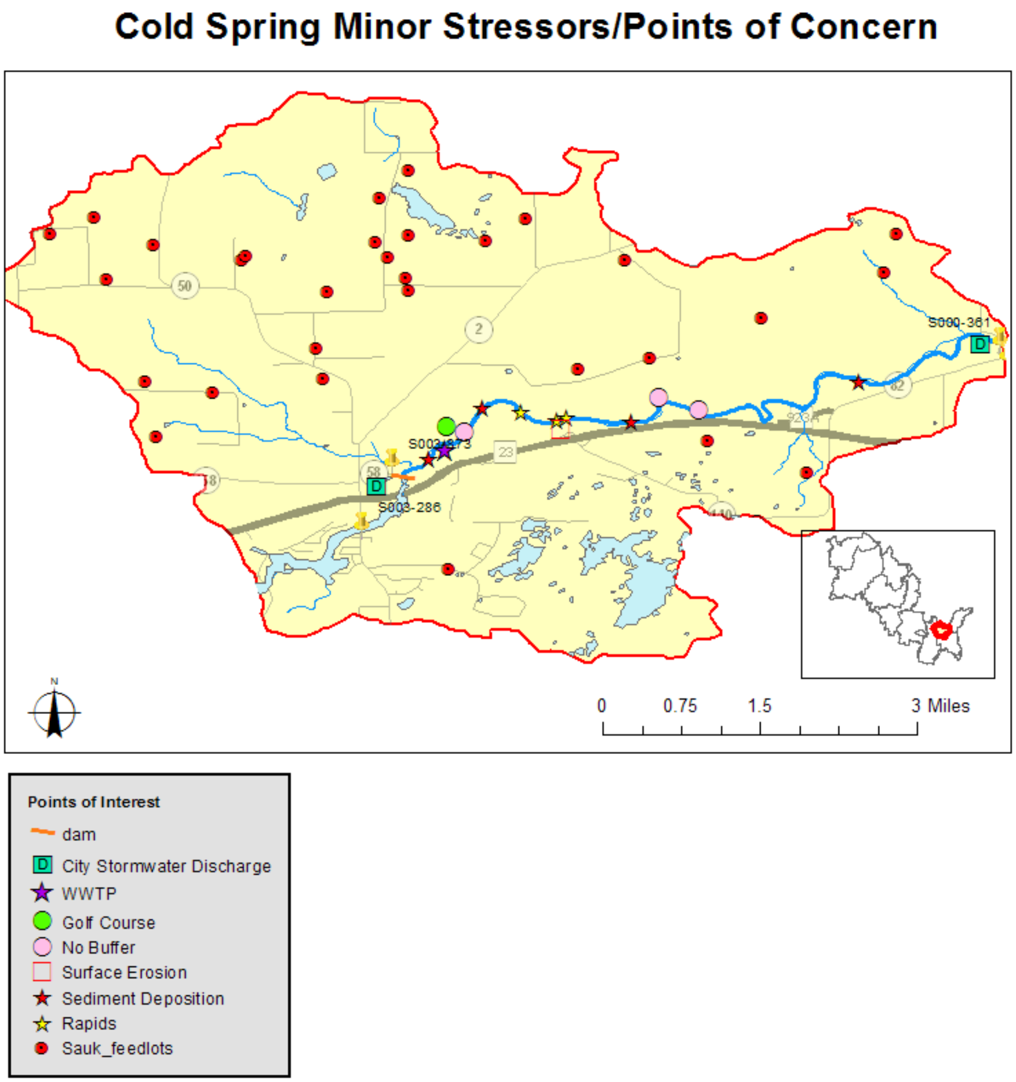

Figure 99: Cold Spring Minor with EQuIS sampling locations and points of concern that may be affecting water quality.

Conclusions

The data suggests that the Cold Spring Minor has elevated nutrient concentrations along with very high algal biomass which is impacting the DO. This is likely a leading cause of fish and invertebrate impairments. Channel substrate is dominated by sand and this is also causing habitat constraints for macroinvertebrates and lithophilic-spawning fish. Stormwater discharge and agricultural drainage are causing altered flow patterns which are causing some bank failure and variability in stream flow patterns.

Grand Pearl Lake Minor

The Grand Pearl Lake Minor zone of the Sauk River encompasses the Mill Creek drainage, which includes Pearl Lake, Grand Lake and Goodners Lake. There are two main tributary streams in this minor, Mill Creek and the outlet of Grand Lake (**Figure 100**). Current land use is predominantly agricultural (46 percent cultivated land), with 22 percent as grassland/pasture, and 16 percent forested. Another land use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots within this management area.

Three biological sampling sites were located in this Minor. One of these, site 08UM006 on Mill Creek above Pearl Lake, is assessed as impaired (Figure 101). The potential stressors related to this land use are increased nutrients; free access of cattle to stream corridors causing bank failure; and increased manure runoff causing increased BOD5 levels and negatively impacting the DO solubility in the water column. **Figure 101** shows the spatial distribution of registered feedlots within this Minor. This map also shows the potential stressors and areas of concern that may be negatively impacting the water quality.

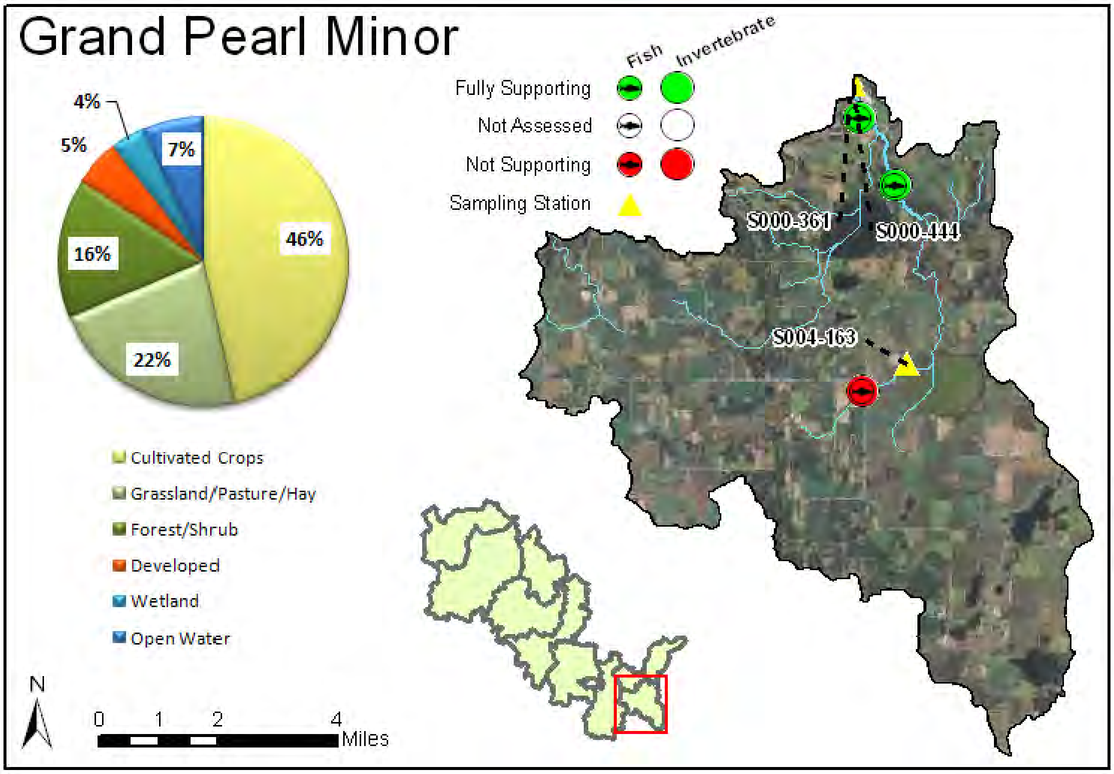

Figure 100: Location of streams and local land-cover.

Land use practices that may be causing biological stress to the fish and invertebrate communities were identified by field visits along with aerial photographic interpretation.

Grand Pearl Minor Stressors/Points of Concern

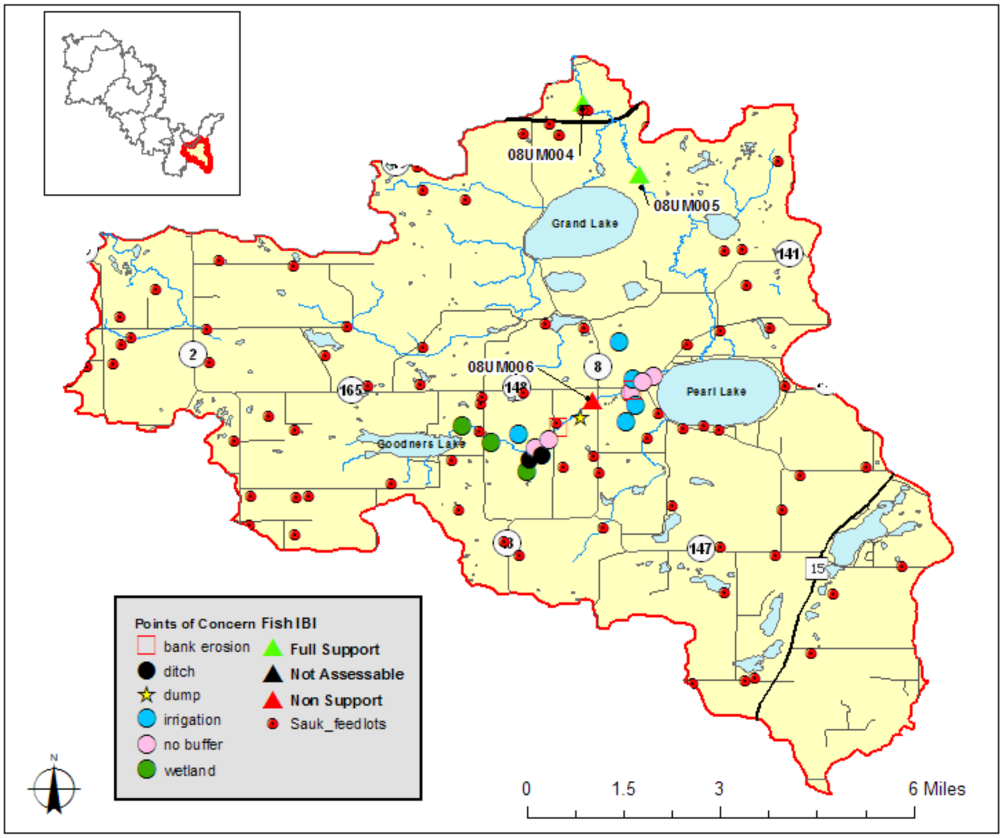

Figure 101: Mill Creek drainage areas of concern that may be affecting water quality

Evidence of causal pathways – nutrients/chlorophyl-a, and Oxygen Demand

The main stream feature in the Grand Pearl Lake Minor that was investigated was Mill Creek above Pearl Lake. Mill Creek was sampled periodically from 2006-2009 for a variety of water quality parameters. Total Phosphorus (TP) levels are well above the proposed river criteria of 0.1 mg/L for much of the sampling record (**Figure 102)**. The EQuIS site has a record of 53 samples collected from spring of 2006 through the fall of 2009. The following statistics were computed from this record: minimum = 0.027 mg/L, maximum value= 0.5 mg/L, mean = 0.113 mg/L. For the impaired AUID within Mill Creek there was one sampling location (S004-163). The TP values are well above proposed river criteria mean values during snowmelt periods and also during periods of runoff. High TP values can accelerate growth of algae and other aquatic plants which in turn can lead to high dissolved oxygen flux.

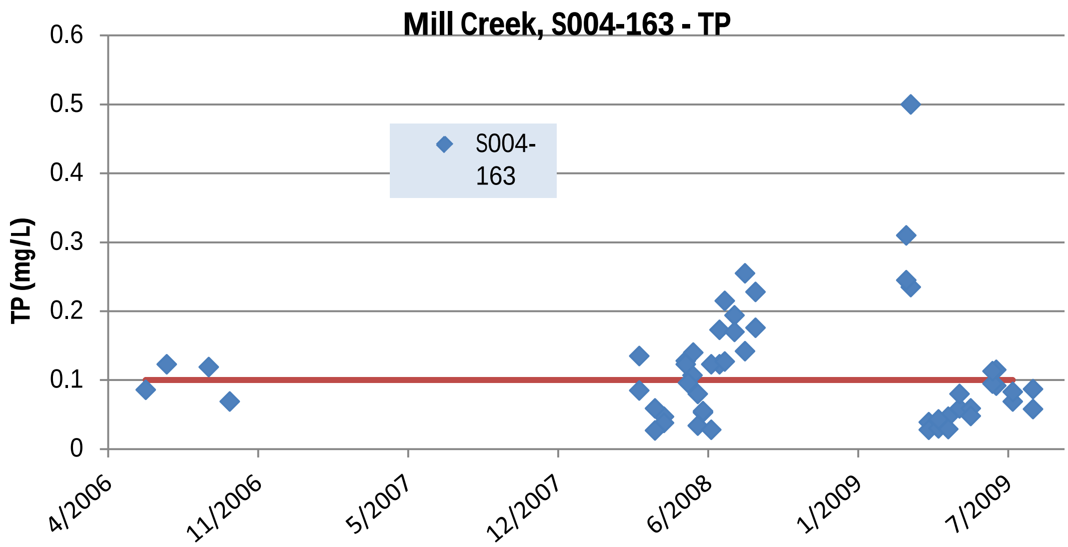

Figure 102: Mill Creek upstream of Pearl Lake TP concentrations

No Chl-a samples were collected in Mill Creek , however field observations noted that submerged aquatic plant growth along with periphyton growth was prevalent throughout the stream.

Dissolved oxygen

Review of historical EQuIS data led to the theory that low DO levels, as well as the daily DO flux, could be causing the low IBI scores for fish and macroinvertebrates. A monitoring plan was developed to discern daily DO minimums and the spatial distribution of sub-standard DO concentrations. DO flux information was collected using YSI 6720 sondes deployed for a one week interval.

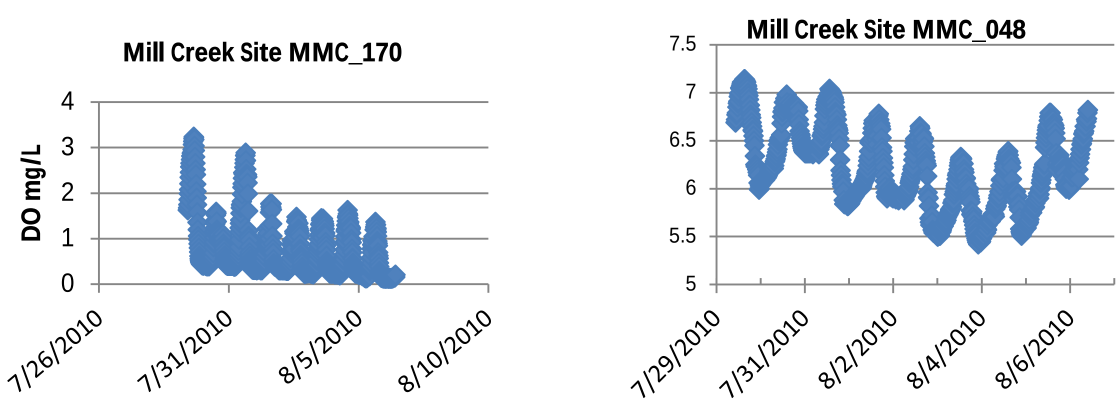

Figure 103: Range of DO flux for Mill Creek at stream crossings at 170th St and at CR48

The DO ranged from 0.1 to 3.5 mg/L at the MMC_170 sampling sites on Mill creek (**Figure 103**). The daily flux ranged from about 1.5 to 2.5 mg/L. Farther downstream, at sampling site MMC_048, the DO began to recover and ranged from 5.3 to 7.3 mg/L. The daily flux of DO at both sites averages about 1.1-1.5 mg/L per day (**Figure 103**).

These data related to dissolved oxygen concentrations and river eutrophication suggest that excess nutrients, elevated BOD concentrations, and primary productivity (represented by visual observations) are likely causal pathways for low DO concentrations in specific reaches of the Mill Creek system. Goodners Lake outlets at site MMC-170 is probably one of the drivers for the very low DO readings at this site. Goodners Lake is currently impaired for nutrients. This indicates that the TP concentrations in

Goodners Lake are high and there is a high probability that the algal biomass is also very high. This increased productivity can lead to the DO conditions seem at sampling site MMC_170.

Casual analysis – biological response

Biotic Reponse – Pearl Grand Lake Minor

Dissolved oxygen concentrations in this reach are routinely below the class 2B standard, including a low measurement of 0.5 mg/L at biological station 08UM006. Biological monitoring site 08UM006 is located upstream of Pearl Lake and is impaired for both fish and macroinvertebrates. Several biological indicators of low dissolved oxygen are also present in this reach:

Lack of sensitive fish taxa

The most upstream biological monitoring site in this watershed zone exhibited a general lack of sensitive fish taxa and low overall taxa richness of headwaters minnow species. The sampling event at 08UM006 revealed a fish community dominated by central mudminnow (*Umbra limi*), a species that is especially tolerant of low dissolved oxygen conditions. Tolerant species accounted for 92 percent of the total fish population and 54 percent of the sample was pioneering species. A total of 12 individual fish were sampled at 08UM006.

Low fish abundance

Biological monitoring station 08UM006 scored low in the fish metric NumPerMeter-Tolerant, which is a measure of fish density (pound fish/meter) excluding tolerant fish species. Although this metric could be responsive to a variety of stressors, it is likely that the sustained low DO conditions observed within this reach limit fish population size, especially those species that are not considered tolerant of adverse conditions.

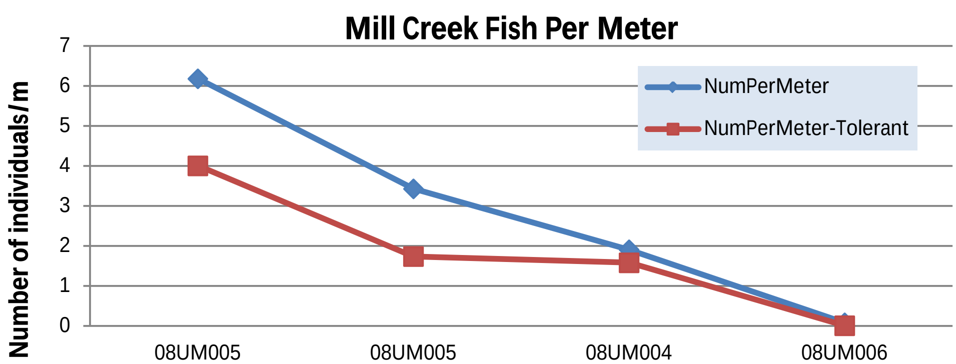

Figure 104: Number of fish sampled per meter of stream

Lack of sensitive macroinvertebrate taxa

Both biological sites in this reach lacked intolerant macroinvertebrate taxa. Site 08UM006 scored a “0” for the metric Intolerant2Ch, which counts the number of macroinvertebrate taxa with low tolerance to a variety of stressors.

Dominant five taxa

Sampling site 08UM006 has a low abundance of EPT taxa. Macroinvertebrates from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT) are widely used bio-indicators that are typically abundant in healthy streams. Plecoptera are especially sensitive to low dissolved oxygen concentrations and are not often found in streams with unstable or low concentrations of DO. Plecoptera taxa were not present at site 08UM006. The dominant five taxa in the sample made up 74 percent of the abundance at 08UM006. The metric Collector-gathererPct was also high (62 percent) at 08UM006. Taxa in this metric are mobile and not confined to riffle substrate, therefore, they can move around there environment to seek out food and refuge.

Total suspended solids

Total suspended solids (TSS) concentrations have been sampled in the Pearl Grand Lake Minor watershed. Analysis did not find problem levels of TSS, nor did several stream visits during the DO collection trips. Isolated locations of bank failure were identified. These locations are a direct result of cattle access to the stream and are limited to a few hundred feet of impact. Thus, evidence is lacking to suggest elevated TSS concentrations as a candidate cause for biological impairments in the Pearl Grand Lake Minor.

The four EQuIS sites had a large set of Total Suspended Solids (TSS) data collected from 2003 -2009. For much of the recorded period, the concentration of TSS was well below the proposed standard (**Figure 105**). EQuIS site S004-163 has a record of 39 samples collected from spring of 2006 through the fall of 2009. Only one exceedance occurred in this record.

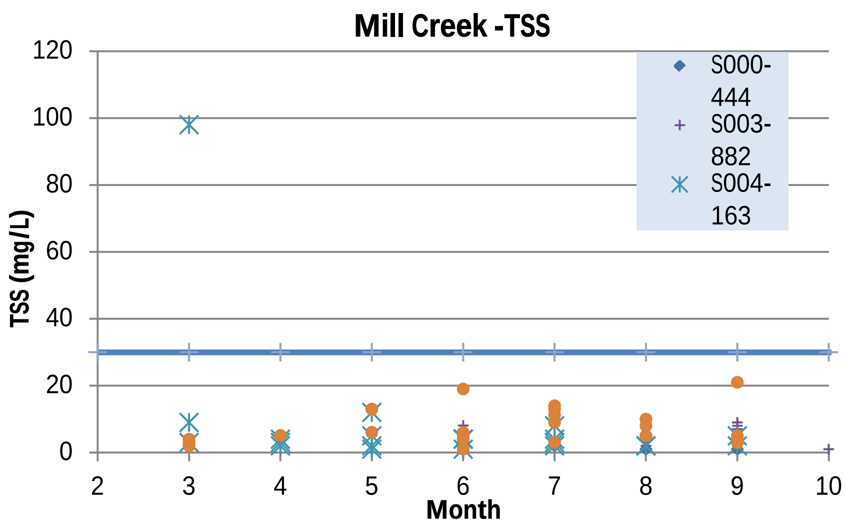

Figure 105: Mill Creek Total Suspended Sediment data from 2003-2009, composited by month.

Dissolved oxygen

Figure 106 displays the DO dataset from three available EQuIS sites from 2005-2009. The collection times for this data ranged from 10:00 am to 02:30 pm. DO readings should be on the rise at this time of day. Among these three sites, some problematic DO levels were found at site S004-163, which is the farthest upstream, the inlet to Pearl Lake.

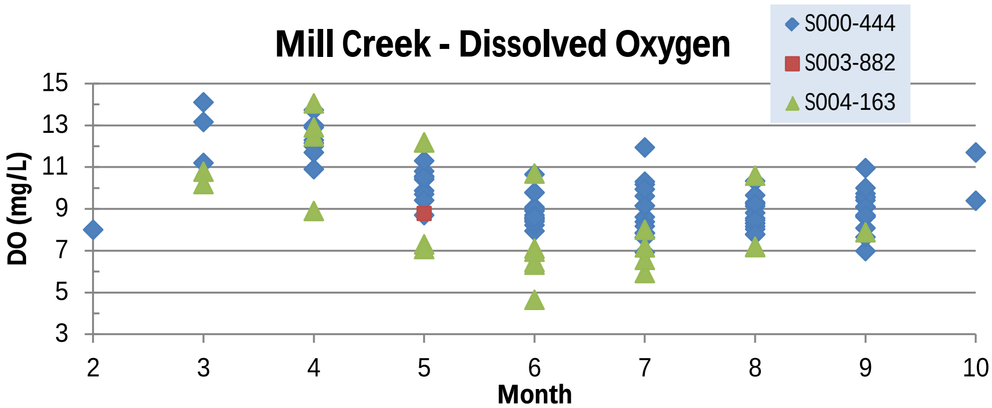

Figure 106: Dissolved Oxygen data from 2005-2009, composited by month, versus State 2B standard of 5 mg/L.

Because of the low readings in this upstream section, further investigation of this section of Mill Creek occurred during the summer of 2010. Four additional DO sampling locations were added to determine the extent of the DO impairment. Site MCC 141 is the same location as EQuIS site S004-163 and is located at the Mill Creek confluence with Pearl Lake. **Figure 107** shows the locations of the DO sampling sites for Mill Creek.

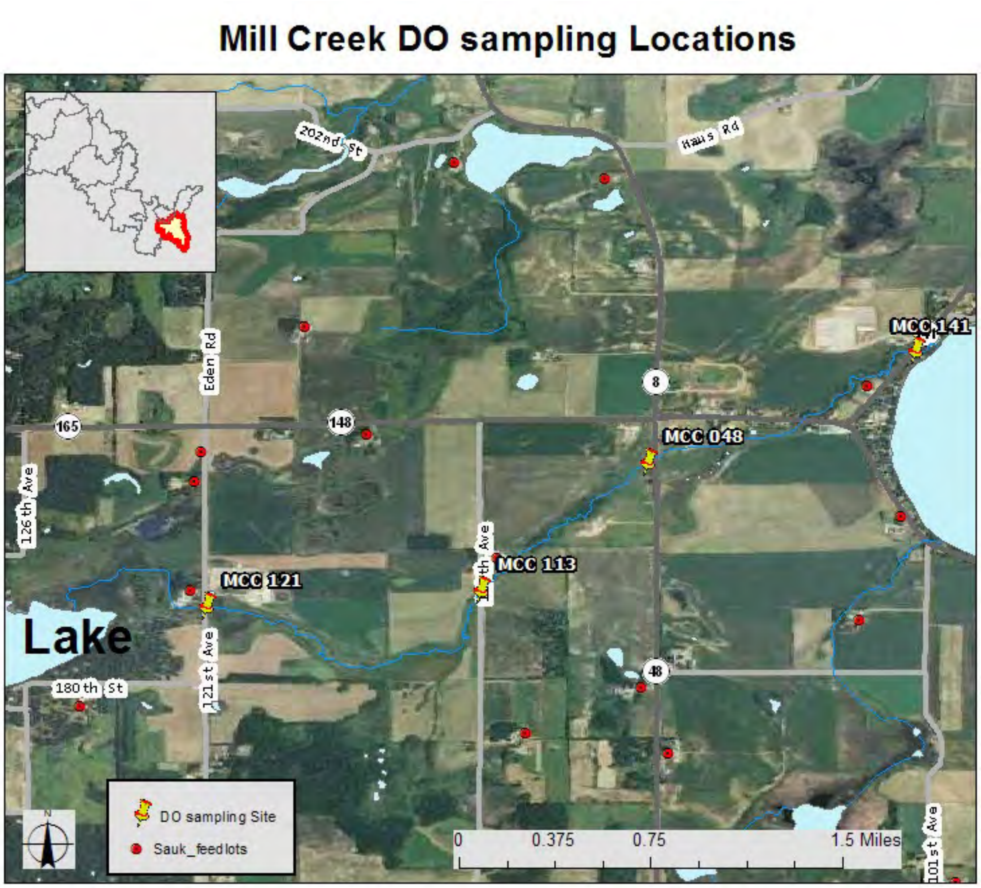

Figure 107: 2010 early morning DO sampling sites for Mill Creek above Pearl Lake

This 2010 early morning sampling revealed that DO is definitely a stressor in the upper-most portion of Mill Creek. Sampling location MCC121 is located at the outlet of Goodners Lake which is a large open water wetland. The data collected at this location revealed that the daily minimum DO readings where always below 5 mg/L (**Figure 108).** Moving downstream from this point, the stream meanders through some wet meadows and its gradient increases. Stream DO levels begin to rebound. At MCC113, which is 1.39 miles downstream, the DO concentrations have increased somewhat (**Figure 109)**. Levels do not seem to continue to increase in the next reach between MCC113 and Pearl Lake. The improved readings at stations somewhat downstream of Goodners Lake suggest that occurrences in the Lake (wetland) are one of the primary drivers to the low DO readings in Mill Creek.

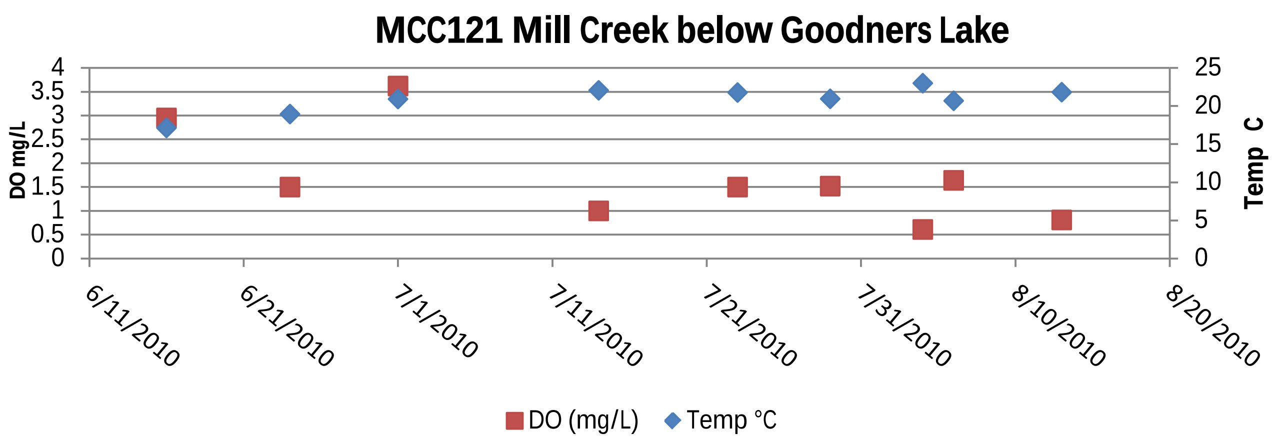

Figure 108: Early morning DO readings at the outlet of Goodners Lake

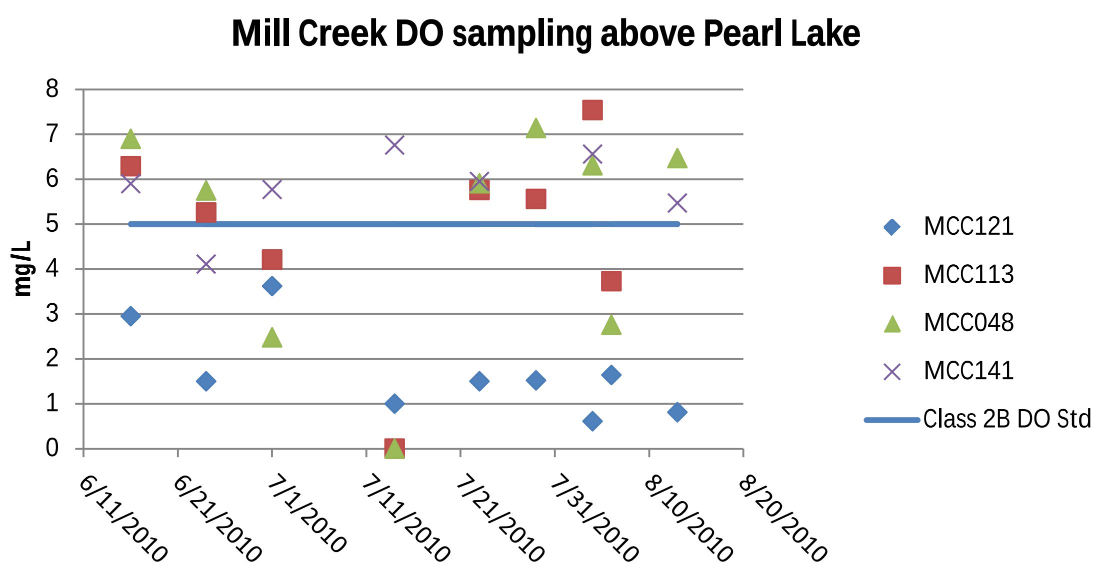

Figure 109: Early morning DO readings from sites above Pearl Lake

Conclusion

The lack of DO in the upstream portion of Mill Creek is a primary stressor to aquatic life. The low DO readings are a result of a combination of excessive nutrients and wetland drainage. There are a couple of cattle pasturing areas riparian to Mill Creek that also are directly contributing to the high nutrients and channel instability. Localized poor habitat due to bank failures may also be a stressor in this Minor.

Mini Metro Minor

The Mini Metro Minor zone of the Sauk River encompasses the stretch from CR 139 in Rockville downstream to the confluence with the Mississippi River in Waite Park. There are no biological impairments in this Minor (**Figure 110**). Historically, this area was dominated by tallgrass prairie and Oak openings and barrens, with areas of "wet prairie" along the riparian corridor of the river. Current land use is a mix of agricultural (25 percent cultivated land, 30 percent Grassland, pasture, hay), and 16 percent of the area remains forested with 28 percent developed (**Figure 110**).

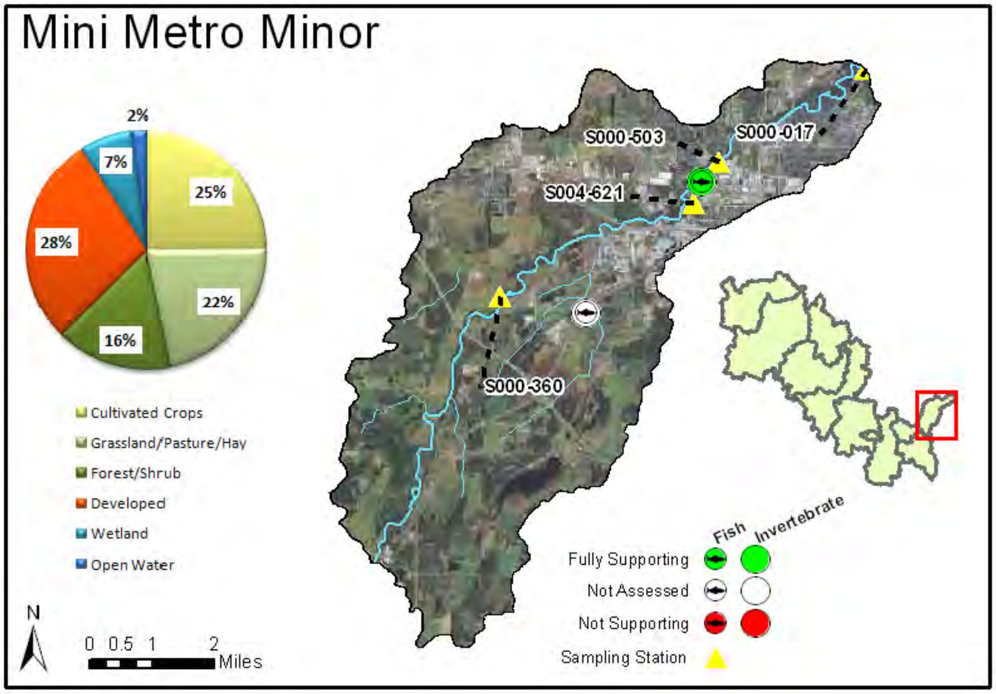

Figure 110: Location of watershed zone and local land-cover.

Even though there were no biological impairments located in the Mini Metro Minor, the water chemistry data that was collected was reviewed to see if any future issues may arise. The Total Phosphorus along with Total Suspended and Volatile Suspended Sediment was reviewed. The following page gives a breakdown of the analytical results.

Nutrients

The Sauk River at sampling Site S000-503 (CSAH-4 in St Cloud) was investigated for water quality parameters. This site for the Sauk River was sampled in 2005 and again in 2008. Analysis of the data shows that Total Phosphorus (TP) data is well above the proposed River criteria of 0.1 mg/L for much of the sampling record **Figure 111**. The site has a record of 47 samples collected from the open water season of 2005 and the open water season of 2008. The following statistics were computed from this record: minimum = 0.045 mg/L, maximum value= 0.321 mg/L, mean = 0.148 mg/L. High TP values can accelerate growth of algae and other aquatic plants which in turn can lead to high dissolved oxygen flux.

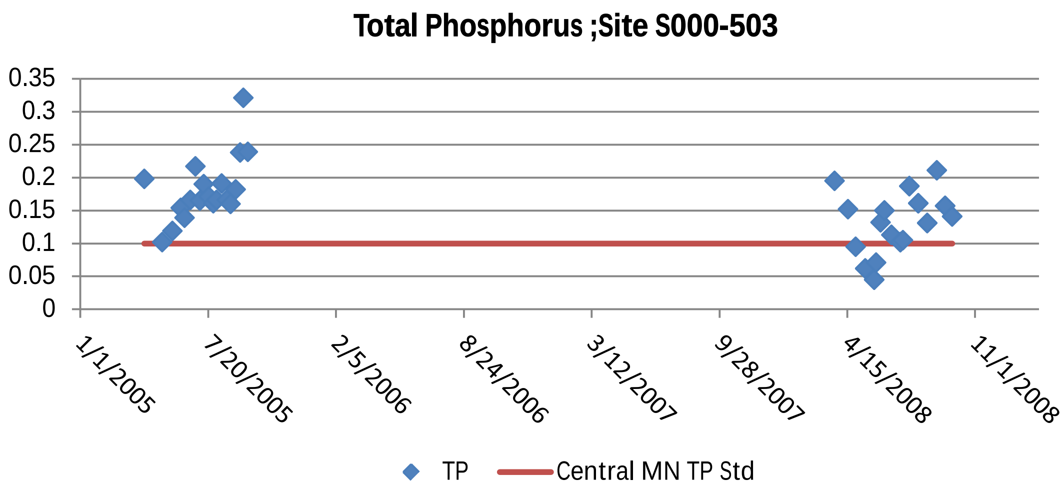

Figure 111: Sauk River downstream of CSAH-4 in St Cloud; TP concentrations

Due to the fact that there were no biological impairments in this Minor, no further analysis of nutrient concentrations were conducted. The TP concentrations were high during the study period and reductions in TP concentrations would benefit the Mississippi River.

Total suspended solids

Total suspended solids (TSS) concentrations have been sampled and evaluated in the Mini Metro Minor watershed. Based on suspended-solids sampling and several stream site visits via observations from road crossings, there is limited evidence to suggest elevated TSS concentrations as a potential problem in the Mini Metro Minor. Review of the STORET site S000-503 reveal the minimum TSS value is <1 mg/L and the maximum TSS value is 78 mg/L, the mean of the dataset was 20 mg/L which is below the proposed 30 mg/L TSS standard for the Sauk watershed (Figure 112). The high percentage of VSS to TSS may indicate a large portion of suspended sediment is in the form of organic material (algal biomass).

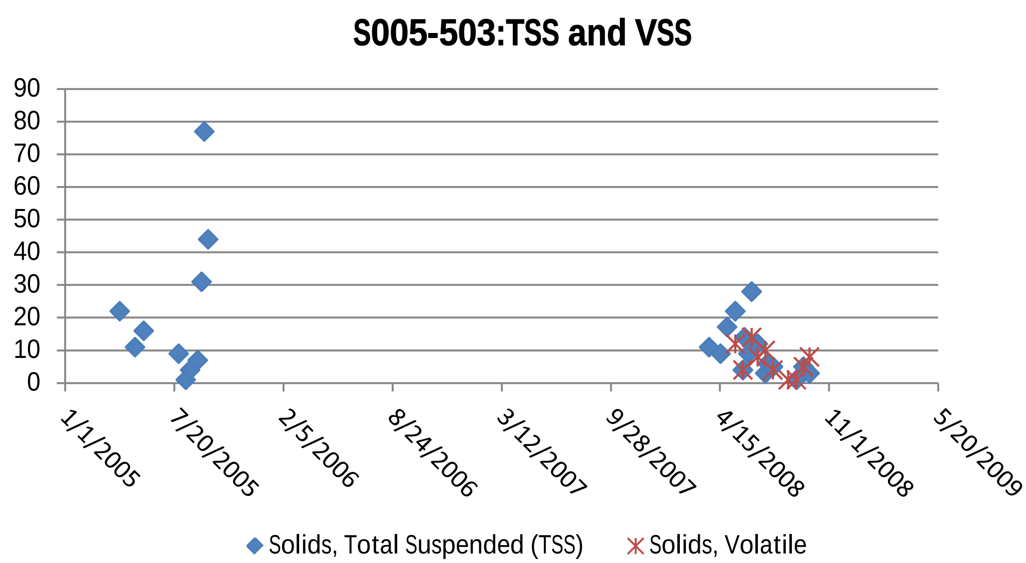

Figure 112: TSS and VSS concentrations for the Sauk River in St Cloud at CSAH4.

Conclusions

The data suggests that the Mini Metro Minor has elevated nutrient concentrations along with high algal biomass. This may have the potential of impacting the DO and may the lead to fish and invertebrate impairments. Stormwater discharge and agricultural drainage are causing altered flow patterns which are causing some bank failure and variability in stream flow patterns.

Sauk River Priority Management Zones

Priority management zones (PMZ) are presented in Magner (2011) as a means to concentrate resources for watershed restoration and protection, with the ultimate goal of obtaining measurable results. Through watershed investigations and data collection, PMZs emerge as those areas where a problem has been identified (e.g. point source discharge, eroding stream bank) and pertinent landowners and stakeholders are willing to implement corrective measures. PMZs can also represent areas of high environmental integrity. In this case, strategies for PMZ management focus on protection measures and additional monitoring to assure that conditions do not deteriorate.

Several types of PMZs for the Sauk River watershed are listed below. These areas should be considered key areas for implementation activities that promote restoration and protection. Some of these PMZs are tied to specific locations, while others are watershed-wide and need to be considered as part of a broad management approach.

Channelized stream reaches

Several reaches of the Sauk River and many of its tributaries have been channelized. Where feasible, implementation activities should focus on returning channelized stream reaches to a pattern, dimension, and profile similar to stable reference reaches in the area. If public sentiment and ditch management policy is such that these ditches must remain straightened and channelized, then a two-stage ditch design is a possible compromise that could improve stream habitat and water quality.

Riparian Buffer Zones

2A. Pasture

Animal agriculture is a prominent land use in the Sauk River watershed. Large tracts of pasture land are common features of the landscape in this region of Minnesota, supporting herds of cattle, horses, sheep, and swine. In the Sauk River watershed, pasture areas in the riparian corridor are quite common throughout.

Uncontrolled grazing of riparian corridors can negatively impact habitat for fish, macroinvertebrates, and other organisms found in riparian zones. Some common impacts are (1) wider, shallower, less stable stream channel (Rosgen, 1996); (2) increased bank erosion and sediment deposition; and (3) reduced shading, woody debris, and fish cover.

Bibliography

Allan, J.D. *Stream Ecology: structure and function of running waters.* Dordrecht, Netherlands: Kluwer Academic Publishers, 1995.

Arruda, J.A., G.R. Marzolf, and R.T. Faulk. "The Role of Suspended Sediments in the Nutrition of Zooplankton in Turbid Reservoirs." *Ecology*, 1983: 64:1225–1235.

Beeson, C.E., and P.F. Doyle. "COMPARISON OF BANK EROSION AT VEGETATED AND NON-VEGETATED CHANNEL BENDS." *Journal of the American Water Resources Association*, 1995: 31: 983-990.

Berry, W., N. Rubinstein, B. Melzian, and B. Hill. *The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review.* United States Environmental Protection Agency, 2003.

Christner, Jr., W.T., J.A. Magner, E.S. Verry, and K.N. Brooks. "Natural Channel design for agricultural ditches in south-western Minnesota." *In Proc. of Self-sustaining Solutions for Streams, Wetlands, and Watersheds.* St. Joseph, MI: ASAE.

Coble, D.W. *Smallmouth Bass.* Washington D.C.: Sport Fish Inst., 1975.

Easton, R.S., D.J. Orth, and Jr., J.R. Voshell. "Spatial and annual variation in the diets of smallmouth bass." *Environmental Biology of Fishes*, 1996: 46: 383-392.

Gray, L.J., and J.V. Ward. "Effects of sediment releases from a reservoir on stream macroinvertebrates." *Hydrobiologia*, 1982: Volume 96, Number 2, 177-184.

Kerr, S.J. "Silt, Turbidity, and suspended sediments in the aquatic environment: an annotated bibliography and literature review." *Ontario Ministry of Natural Resources, Southern Region Science and Technology Transfer Unit Technical Report TR-008*, 1995: 277p.

Landwehr, K., and B.L. Rhoads. "Depositional response of a headwater stream to channelization, East Central Illinois, USA." *River Research and Applications*, 2003: Vol. 19, p. 77-100.

Larimore, R.W., Q.H. Pickering, and L. Durham. *An inventory of the fishes in Jordan Creek, Vermillion County, Illinois.* State of Illinois. Biolog. Notes 29 p, 1952.

Lau, J.K., T.E. Lauer, and M.L. Weinman. "Impacts of Channelization on Stream Habitats and Associated Fish Assemblages in East Central Indiana." *The American Midland Naturalist*, 2006: 156(2):319-330.

Lemley, D.A. "Modification of benthic communities in polluted streams: combined effects of sedimentation and nutrient enrichment." *Hydrobiologia*, 1982: 229-245.

Munavar, M., W.P. Norwood, and L.H. McCarthy. "A method for evaluating the impacts of navigationally induced suspended sediments from the Upper Great Lakes connecting channels on the primary productivity." *Hydrobiologia*, 1991: 219: 325-332.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. "Effects of canopy modification and accumulated sediment on stream communities." *Transactions American Fisheries Society*, 1981: 110: 469-478.

Newcombe, C. P., and D. D. MacDonald. "Effects of suspended sediments on aquaticecosystems." *North American Journal of Fisheries Management 11:72-82*, 1991: 11:72-82.

Powell, G.E., A.D. Ward, D.E. Mecklenberg, J. Draper, and W. Word. "Two-stage channel systems: Part 2, case studies." *Journal of Soil and Water Conservation*, 2010 : 65(6):131A-136A.

Sigler, J. W., T. C. Bjornn, and F. H. Everest. "Effects of chronic turbidity on density andgrowth of steelheads and coho salmon." *Transactions of the American Fisheries Society*, 1984: 113:142-150.

Smiley, P.C., and E.D. Dibble. "Implications of a hierarchical relationship among channel form, in-stream habitat, and stream communities for restoration of channelized streams." *Hydrobiologia*, 2005: 548: 279-292.

Strand, M.R., and R.W. Merritt. "Effects of episodic sedimentation on the net-spinning caddisflies Hydropsyche betteni and Ceratopsyche sparna (Trichoptera:Hydropsychidae)." *Environ. Poll.* , 1997: 98: 129 - 134.

Urban, M.A., and B.L. Rhoads. "Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA." *Annals of the Association of American Geographers*, 2003: Vol. 93, pp 783-796.

Welsh, S.A., and S.A. Perry. "Habitat partitioning in a community of darters in the Elk River, West Virginia." *Environmental Biology of Fishes*, 1998: 51: 411–419.