Mississippi River-St. Cloud Stressor Identification Report

Minnesota Pollution Control Agency

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Executive Summary for the Mississippi River-St. Cloud Watershed Stressor Identification Report

This report summarizes the key causes or "stressors", contributing to impairment of fish and aquatic macroinvertebrate communities of the Mississippi River tributaries in the Mississippi River-St. Cloud watershed located in central Minnesota. There are eight 11-digit HUCs that will be covered in this report that contain streams which are listed on the 303(d) list of impaired waters for failing to meet established criteria for the index of biological integrity (IBI). Stream biology is scored based on a numeric value given to each of several metrics which comprise the index. Metrics are based on community diversity, and reproductive, feeding, or trophic characteristics that are specific to 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 chart 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 the stream 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

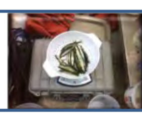
Stream Connections
Examples: dams, culverts and drainage tiles

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 Community Stressors (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 · Elevated 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** · Change in 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, nutrients** · Increased nutrients from human influence · Widely variable DO levels during the daily cycle · Increased algal and/or periphyton growth in stream · Increased nonpoint pollution from urban and agricultural practices · Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species
Stream Biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and/or macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired

Stressors in the Mississippi River-St. Cloud Watershed (8 Digit HUC)

The Mississippi River-St. Cloud (MR-SC) watershed is divided into twenty-one 11-digit HUCs, see map on Page 7. The current condition and biological integrity of streams within each subwatershed is discussed in detail in the MR-SC Assessment Report (MPCA, 2012). This Stressor Identification (SI)Report will present additional data, and discuss the candidate causes for impaired biota in each subwatershed. A comprehensive review of biological, chemical, and physical data was performed to select probable causes for the impairments. Many candidate causes were eliminated after additional data analysis, leaving six for final analysis in this report. The candidate causes for the entire MR-SC 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 seven of the MR-SC subwatersheds: Battle Brook, Clearwater River, Upper Elk River, Upper St. Francis River, St. Francis River, and Silver Creek. DO data indicated high ranges of daily DO flux along with daily minimum values below the five mg/L standard for class 2B waters. Phosphorus concentrations were also above the Minnesota Pollution Control Agency's (MPCA)s proposed standard at most of the locations where DO data indicated problems. This indicates that the DO issue is being caused by eutrophication, an overstimulation of plant growth.

Loss of habitat due to excess bedded sediment

Bedded sediment is a stressor in five of the studied MR-SC subwatersheds. This stressor is very important in Battle Brook, Upper St. Francis River, St. Francis River, Otsego, and Silver Creek Watersheds. Bedded sediment was measured during pebble counts and a visual observation of fine sediment covering rock and gravel. Bedded sediment covers the available gravel and fills interstitial spaces, which are required for gravel dwelling fish and invertebrate species. 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.

Increased nutrients

Excessive nutrients are causing increased plant and algal growth within all eight subwatersheds. This can lead to an increase in DO consumption during periods of decomposition and night-time respiration. The increased daily flux of DO is detrimental to fish and macroinvertebrate communities. Elevated phosphorus and nitrogen levels are indicative of human activities. The increased phosphorus concentrations are a direct reflection of the various land use found throughout the watershed. 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. Current land use statistics for the entire watershed reveal that 37.8 percent of the land use is row crop, 21.8 percent is range land and 10.8 percent is developed. Potential for eutrophication is high as 70.4 percent of the watershed has been altered by human disturbance. Agricultural sources of nutrients include manure application to fields and commercial fertilizers. Drainage through subsurface tile lines can readily transport nitrogen to surface waters. Residential and urban landscapes also add 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.

Altered hydrology/channelization

Ditching and drain tile 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 reduced baseflow. All eight subwatersheds that are described in this report are affected by altered hydrology. There is very little water storage in the watershed as a large percentage of wetlands have been drained. The 2001 National Land Cover Data dataset reveals that only seven percent of the land area remains in wetland. The abundance of private and public ditches within this watershed is significant to the loss of stream habitat due to channelization.

Loss of connectivity (impoundments/improper placement of culverts)

The network of road crossings scattered throughout the MR-SC 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 low head dam structures located in the Clearwater River, Battle Brook, Silver Creek, and St. Francis River that have sufficient height to impede fish passage at all stages of flow and seasons.

Elevated concentration of total suspended solids

Total suspended solids (TSS) appear to be a significant stressor in the Lower Elk River 11 HUC, where TSS is often above the proposed water quality standards to protect aquatic life. The main component of the elevated TSS is algae, which in this HUC is due to elevated algae concentrations coming out of Big Elk Lake. As discussed above, elevated phosphorus levels are directly responsible for elevated algal production.

Recommendations for implementation strategies

Direct access of cattle to the St. Francis River and Upper Elk River is causing loss of habitat, increased nutrient concentrations, and increased fine sediment transport that are filling coarse substrate for fish and macroinvertebrates. Moving the cattle out of the stream and providing a riparian buffer of preferably 50 feet would allow the stream banks to vegetate and stabilize. This would reduce the erosion of fine sediments from the 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 flow rate of water through the ditch systems are causing increased peak flows and reduced base flows in area streams. Many of the ditches in the watershed do not have adequate vegetative buffers and fine soil material is being transported through bank failures and row crop farming that is occurring next to the ditches. Wetland restoration and buffering of ditches would reduce the peak discharge rates and also help stabilize the ditch banks, reducing the amount of fine material entering the streams. In addition, wetland restoration would help restore base flow conditions that are vital to aquatic life during dry periods.

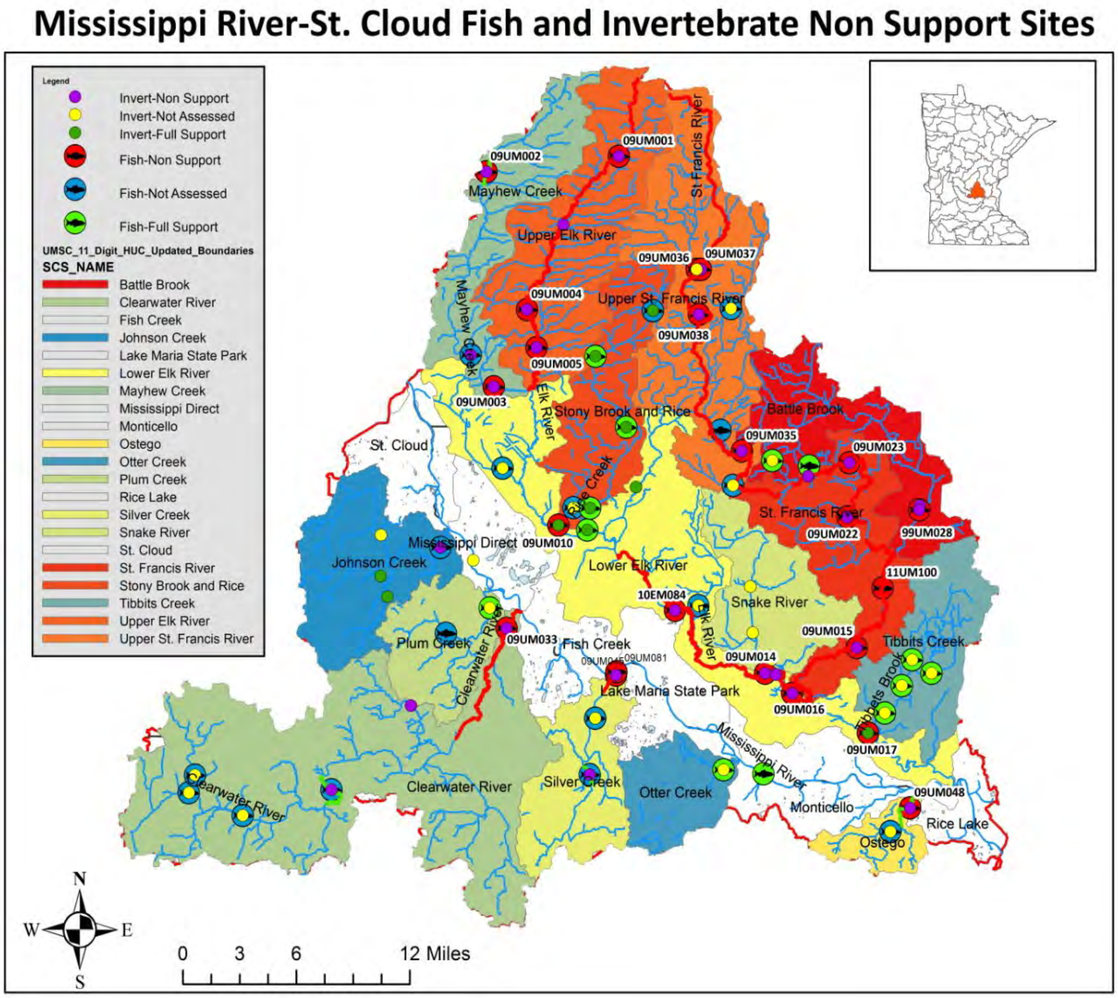


Figure 1: Spatial extent of biological impairments in the MR-SC Watershed

Table 2: Summary of Mississippi River-St. Cloud subwatersheds with probable stressors to biotic communities

	Upper Elk River	Lower Elk River	Upper St. Francis river	Battle Brook	St. Francis River	Silver Creek	Otsego	Clearwater River
Daily Dissolved Oxygen Minimum DO readings often below the 5mg/L standard. Wide daily flux also indicates increased nutrient enrichment	X		X	X	X	X	X	X
Increased sediment on stream bed Bedded sediment fills the spaces between gravel and covers the coarse substrate. This leads to loss of gravel-dwelling fish and macroinvertebrate species	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	
Altered Hydrology/Channelization Change in hydrology – altered flow rates	X	X	X	X	X	X	X	X
Lack of woody debris Wood provides cover and stable attachment material for a variety of fish and macroinvertebrates. Lack of wood reduces channel and habitat diversity and abundance of various species.			X				X	
Connectivity Loss of movement by fish species due to physical barriers (impoundments/improper placement of culverts)			X	X	X	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						

Introduction

Overview of watershed impairments

Water quality and biological monitoring in the Mississippi River-St Cloud (MR-SC) watershed has been conducted for several years with the goal of assessing water quality and aquatic life. As part of the MPCA's new Intensive Watershed Monitoring (IWM) approach, which began in 2007, monitoring activities have increased in quantity and rigor. The IWM for the MR-SC watershed occurred in 2009. Data from the IWM, as well as historic data obtained prior to 2009, 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 MR-SC streams as not supporting their aquatic life use. These reaches are placed on the 303 (d) lists. The biologically-impaired stream reaches in the watershed include the entire St. Francis River main stem, the upper and lower portion of the Elk River, the lower portion of Clearwater River and numerous tributary streams (Figure 2). Fish and macroinvertebrate data were collected at the 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 3).

MR-SC 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 MR-SC watershed streams and lakes, see the Mississippi River-St. Cloud Watershed Monitoring and Assessment Report (reference).

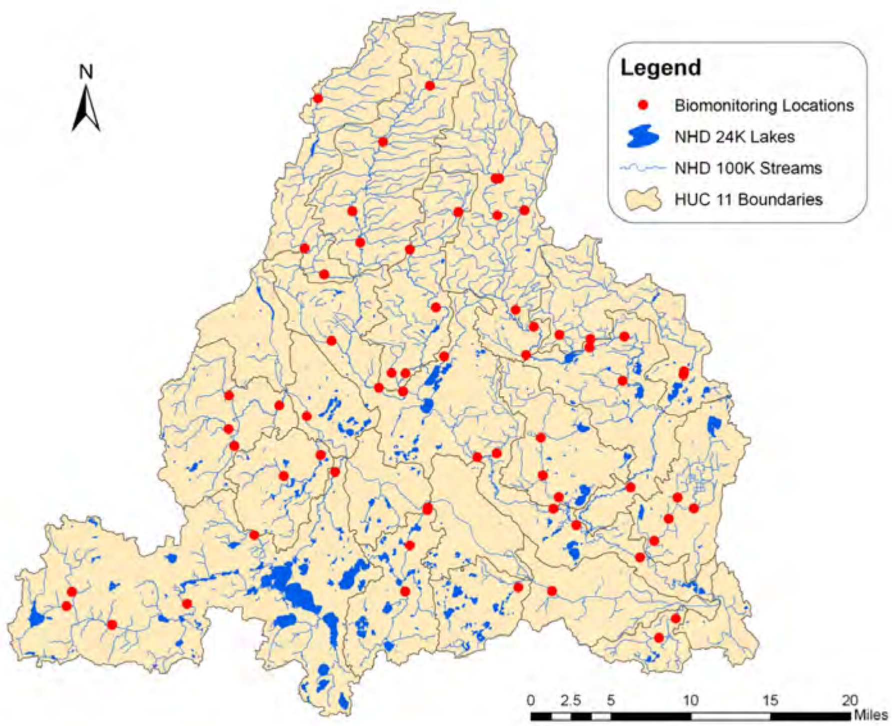


Figure 2: MR-SC Watershed biological monitoring sites

Table 3: Summary of stream reaches with biological impairments in the Mississippi River-St. Cloud Watershed water quality impairments for each stream reach are provided as well

			Impairments	
AUID #	**Stream Name**	**Reach Description**	**Biological**	**Water Quality***
07010203-508	Elk River	Headwaters to Mayhew Creek	Fish and Invertebrate IBI	
07010203-675	Mayhew Creek	Unnamed Creek to CD7	Fish and Invertebrate IBI	
07010203-509	Mayhew Creek	Mayhew Lake to Elk River	NA	DO
07010203-512	Rice Creek	Rice Lake to Elk River	MTS	DO,Turbidity
07010203-579	Elk River	Elk Lake to St Francis River	Fish IBI	Turbidity,pH
07010203-700	St Francis River	Headwaters to Unnamed Lake (71-0371-00)	Fish and Invertebrate IBI	DO
07010203-535	Battle Brook	CD18 to Elk Lake	Fish and Invertebrate IBI	DO
07010203-704	St. Francis River	Unnamed Lake (71-0731-00) to Rice Lake	Fish IBI	
07010203-702	St. Francis River	Rice Lake to Elk River	Fish IBI	DO
07010203-717	Clearwater river	Scott Lake to Lake Louisa	Fish and Invertebrate IBI	
07010203-545	Threemile Creek	Unnamed Stream to Lake Lur to T122R28WS36	Fish IBI	
07010203-511	Clearwater River	Clearwater River to Mississippi River	Fish IBI	DO
07010203-662	Silver Creek	Unnamed Creek to Silver Lake	Fish and Invertebrate IBI	
07010203-557	Silver Creek	Locke Lake to Mississippi River	Fish and Invertebrate IBI	DO
07010203-528	Unnamed Creek	T121 R23W S19, south line Mississippi River	Fish and Invertebrate IBI	

MTS=meets standard; NA=not assessable

In addition to the biological impairment listings, there are also a number of water chemistry based impairments in the MR-SC 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 (SI) process 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 depends on the quality of data available. In most cases, additional data is then collected from impaired reaches to accurately identify the stressor(s).

The SI draws upon a broad variety of disciplines, such as aquatic ecology, hydrology, geology, biology, geomorphology, chemistry, land use analysis, and toxicology. Strength of evidence analysis is used to develop cases in support of, or against various candidate causes. Typically, much of the information used in the strength of evidence analysis is from the study watershed, but evidence from other case studies and scientific literature is also used in the SI process. The identified stressor(s) is then examined further in the Total Maximum Daily Load (TMDL) study by computer models.

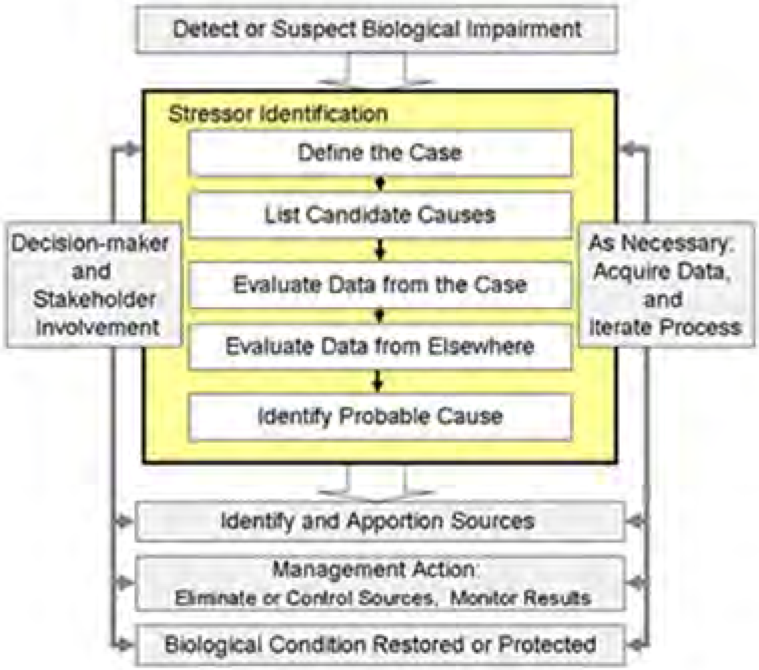


Figure 3: Conceptual model of stressor identification (SID) process

Mississippi River-St. Cloud

Ecological and administrative regions of MR-SC

The MR-SC watershed resides in the Upper Mississippi River basin, drains approximately 717,770 acres and includes portions of six counties (Figure 4). The 8 digit Hydrologic Unit Code number is 07010203. The entire watershed is contained within the Northern Hardwood Forest Level III Ecoregion.

MR-SC Watershed sub-watershed (11 HUC scale)

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 MR-SC drainage into smaller sections. Although there may be some consistent chemical and physical stressors found throughout the MR-SC Watershed, some are likely acting locally, driven by landscape characteristics specific to a certain region of the watershed. For the purpose of addressing biological impairments in the MR-SC, the watershed was stratified into the same 11HUC units, used in the MR-SC Watershed Monitoring and Assessment Report. Figure 5 shows the name and location of each 11 HUC. The color-coded 11 HUCs are included as separate chapters in this report.

The MR-SC watershed includes a segment of the Mississippi River, originating in St. Cloud and ending near Otsego. Existing data from this small segment of the Mississippi River is not included in this report. A separate monitoring strategy and reporting format is being developed that will focus on the full extent of Minnesota's largest rivers, providing a longitudinal context for interpreting the monitoring results from the headwaters to the mouth of each major basin.

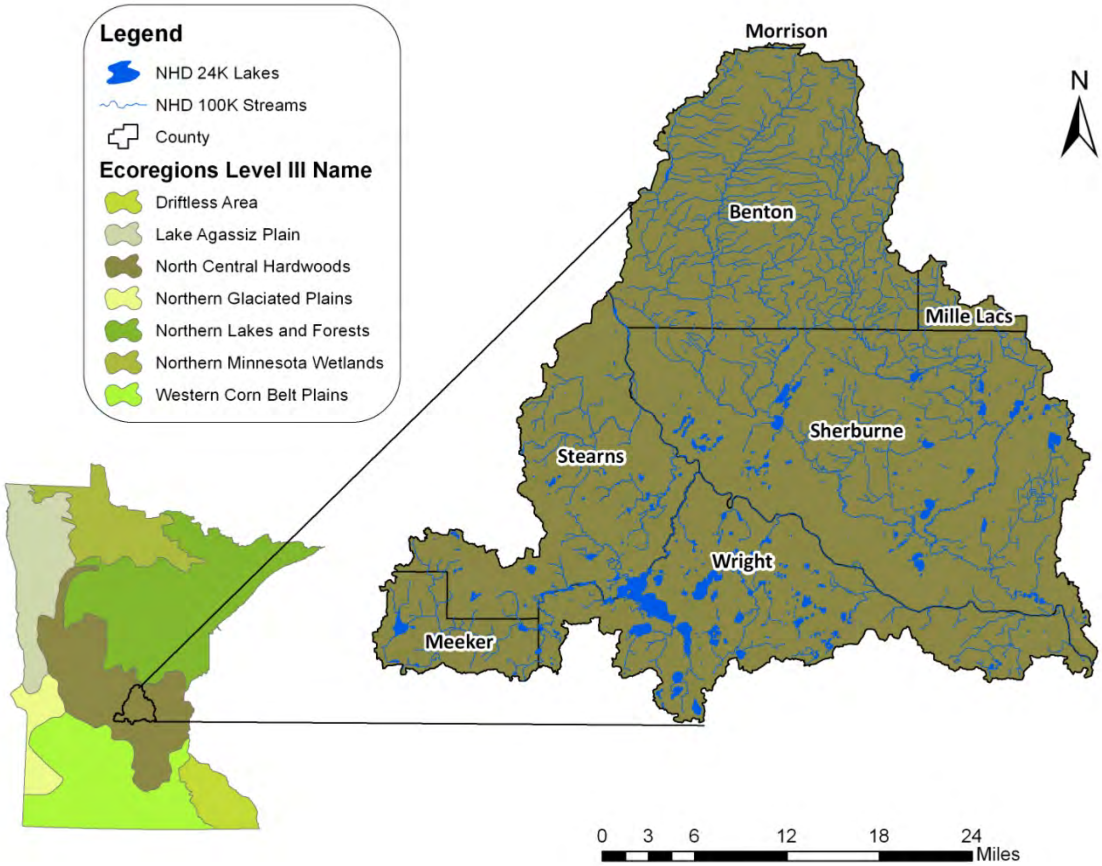


Figure 4: Location of MR-SC Watershed within North Central Hardwood Forest Ecoregion of central Minnesota

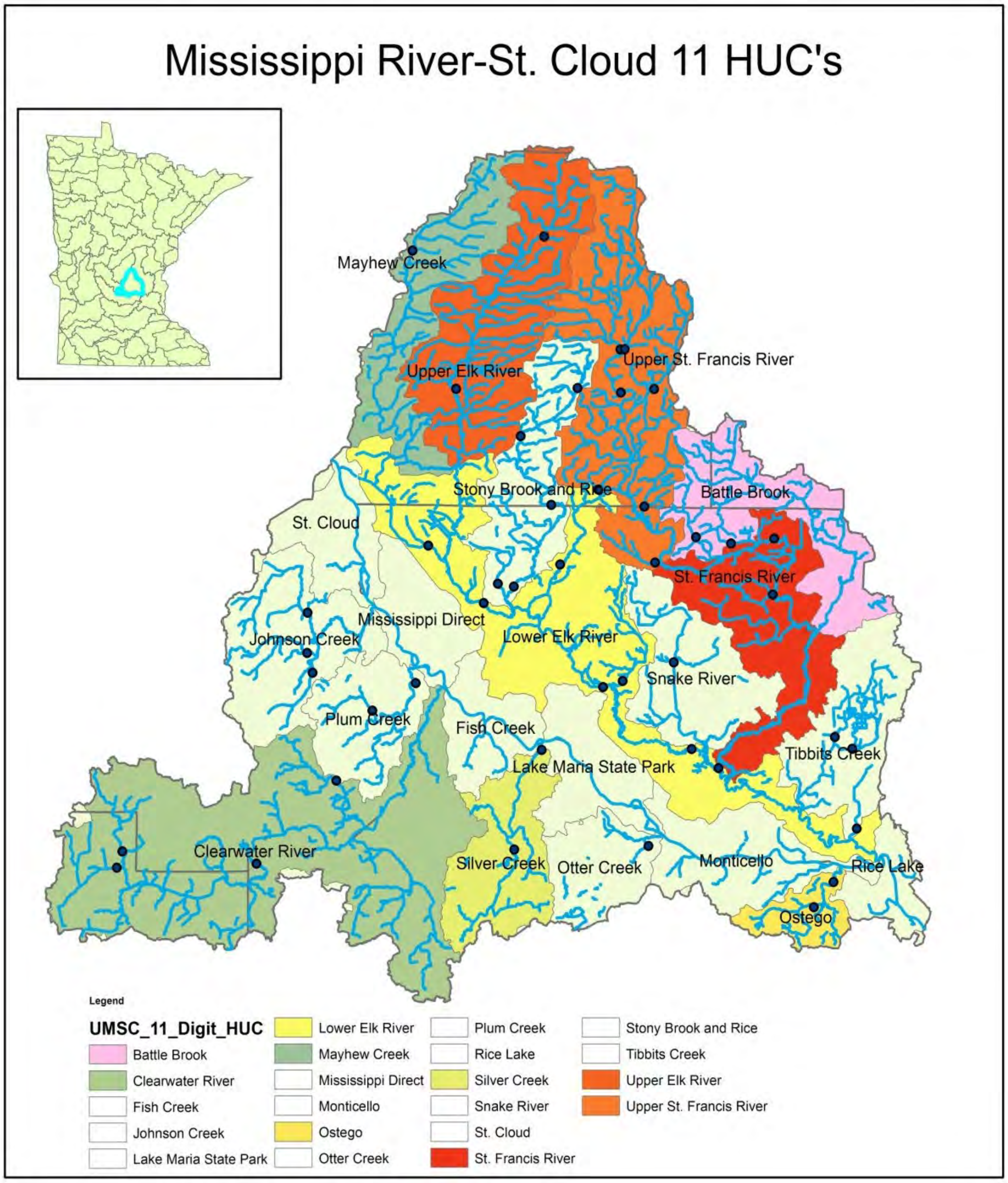


Figure 5: Map showing watershed management units in the MR-SC watershed. 11 HUC's were used to group stream reaches with similar impairment indicators and natural background conditions. The colored 11 HUCs are discussed in this report in greater detail.

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 IBI) have been developed for each class. Table 4 shows all of the impaired biological monitoring sites located in the MR-SC, the fish/invertebrate classifications as assigned by the MPCA and the associated 11 digit hydrologic unit code.

Table 4: List of Mississippi River-St. Cloud impaired biological monitoring sites, biological classifications, and corresponding 11 HUC

AUID ***Reach Name,*** *Reach Description*	Site ID	Stream Name/Biological Impairment	Fish Class	Invert Class	11 Digit HUC
	09UM001	Elk River/fish and macroinvertebrate	6	3	07010203010 (Upper Elk River)
07010203-508 ***Elk River*** *Headwaters to Mayhew Creek*	09UM004	Elk River/fish and macroinvertebrate	5	3	07010203010 (Upper Elk River)
	09UM005	Elk River/fish only	5	3	07010203010 (Upper Elk River)
07010203-675 ***Mayhew Creek*** *Unnamed Creek to CD 7*	09UM002	Mayhew Creek/fish and macroinvertebrate	6	4	07010203020 (Mayhew Creek)
	10EM084	Elk River/fish only	5	6	07010203040 (Lower Elk River)
07010203-579 ***Elk River*** *Elk Lk to St. Francis River*	09UM014	Elk River/fish only	5	5	07010203040 (Lower Elk River)
	09UM016	Elk River/fish only	5	6	07010203040 (Lower Elk River)
	09UM035	St. Francis River/fish and macroinvertebrate	5	3	07010203060 (Upper St. Francis River)
07010203-700 ***St. Francis River*** *Headwaters to Unnamed Lk*	09UM037	St. Francis River/fish and macroinvertebrate	7	4	07010203060 (Upper St. Francis River)
	09UM038	St. Francis River/fish and macroinvertebrate	6	3	07010203060 (Upper St. Francis River)
07010203-535	99UM028	Battle Brook/ fish and macroinvertebrate	7	6	07010203070 (Battle Brook)
Battle Brook *CD18 to Elk Lk*	10EM196	Battle Brook/ fish and macroinvertebrate	7	6	07010203070 (Battle Brook)
07010203-704	09UM022	St. Francis River/ fish only	5	6	07010203080 (St. Francis River)
St Francis River *Unnamed Lk to Rice Lk*	09UM023	St. Francis River/ fish only	5	5	07010203080 (St. Francis River)
07010203-702 ***St. Francis River*** *Rice Lk to Elk R*	09UM015	St. Francis River/ fish only	5	6	07010203080 (St. Francis River)
07010203-717 ***Clearwater River*** *Scott Lk to Lk Louisa*	09UM031	Clearwater River/ fish and macroinvertebrate	5	5	07010203730 (Clearwater River)
07010203-545 ***Threemile Creek*** *Unnamed stream outlet of Lk Lura to T122 R28W S36*	09UM032	Threemile Creek/ fish only	6	6	07010203730 (Clearwater River)
07010203-511 ***Clearwater River*** *Clearwater lk to Mississippi R*	09UM033	Clearwater River/ fish only	5	5	07010203730 (Clearwater River)
07010203-662 ***Silver Creek*** *Unnamed Cr to Silver Lk*	09UM046	Silver Creek/ fish and macroinvertebrate	6	6	07010203750 (Silver Creek)
07010203-557	09UM081	Silver Creek/ fish and macroinvertebrate	5	NS	07010203750 (Silver Creek)
Silver Creek *Locke Lk to Mississippi R*	09UM045	Silver Creek/ fish and macroinvertebrate	5	5	07010203750 (Silver Creek)
07010203-528 ***Unnamed Creek*** *T121 R23W S19, south line Mississippi R*	09UM048	Unnamed Creek/ fish and macroinvertebrate	6	6	07010203790 (Otsego)

NS=Not sampled

Minnesota Department of Natural Resources Watershed Health Assessment Framework

The Minnesota Department of Natural Resources (MDNR) has a web-based tool called the Watershed Health Assessment Framework (WHAF). This framework can be used to evaluate and compare the overall ecological health of a watershed based on the five components of a healthy ecological system; hydrology, geomorphology, biology, connectivity and water quality. The assessment is based on a multi-metric index for each of these five components. An overall watershed health score is compiled by combining the five component scores. The WHAF can be accessed at http://www.dnr.state.mn.us/watershed_tool/index.html.

The Watershed Health Assessment scores compare conditions found across the state of Minnesota and ranks those results on a scale of 0 to 100. The scores range from the least healthy (0) to most healthy (100) condition. Methodology for scoring each index is different, but the desired healthy condition is a functional and intact natural system. The overall score for the MR-SC Watershed is 49, while the range of overall health scores for the state is 39 to 84. Watersheds around the MR-SC 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 1890s 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 MR-SC Watershed.

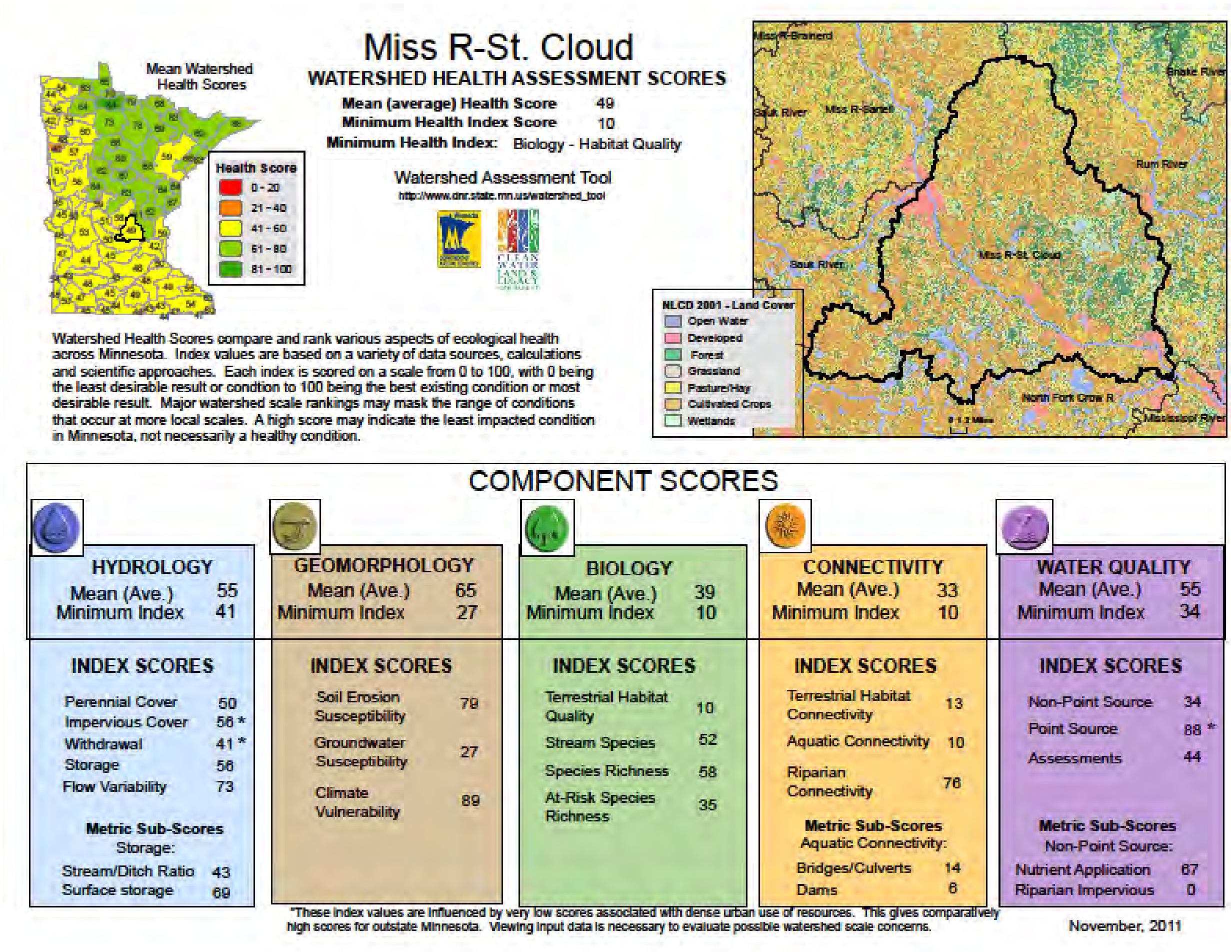


Figure 6: MR-SC watershed assessment tool results

From the five components evaluated by the WHAF, three of the components score 50 or below. These were the biology, connectivity, and water quality. The results from this assessment are also validated throughout the SI document. The fish community integrity is limited by the number of crossings (culverts and dams) 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 MR-SC Watershed. The Water Quality Component scored a very low 34 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 10 years. The WHAF scores also point out that habitat quality is a limiting factor for biology in this watershed as reflected by the low index score for terrestrial biological communities.

Candidate causes for biological impairment

Identifying a set of candidate causes for impairment is an important early step in the SI 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 MR-SC watershed. These eleven candidates were chosen after considering a large set of possible 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 eleven candidate causes for impairment in the MR-SC can be broadly grouped into four categories; water quality, physical habitat, connectivity, and flow alteration (Figure 7). These categories will be used as the organizational 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.

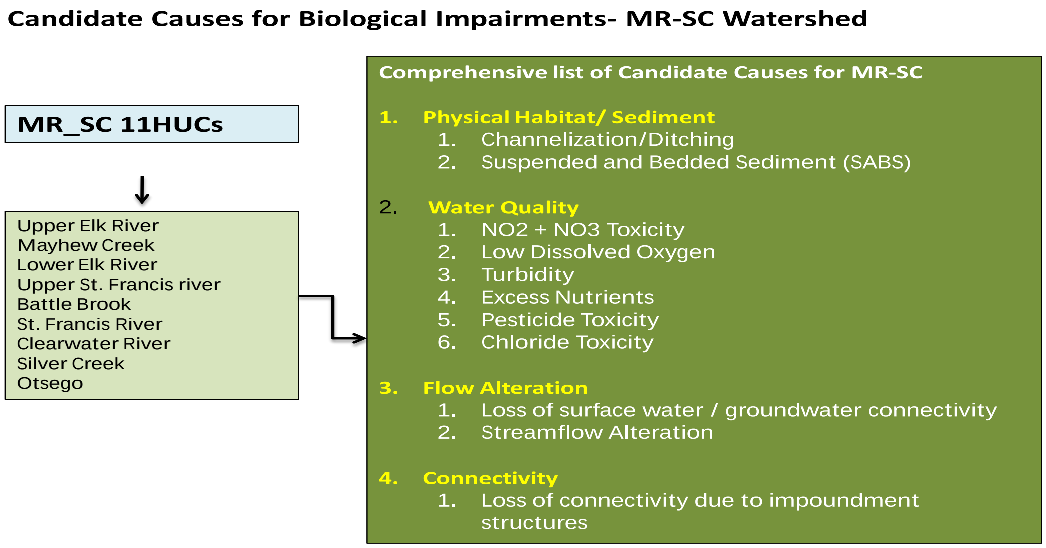


Figure 7: List of candidate causes for biological impairment in the MR-SC Watershed

Candidate cause: ditching/channelization

Background

For the purpose of this report ditching is defined as the digging of a trench to divert water where no channel previously existed. Channelization is the process of straightening a preexisting natural channel. Drainage ditches are a common feature in Minnesota watersheds dominated by agricultural land uses. There is an estimated 27,000 miles of drainage ditches in the state, many of which have been in place since the turn of the 20^{th} century. In the MR-SC Watershed alone, there are numerous county and judicial ditch systems that serve to drain relatively large areas. There are also many miles of private ditch networks in the watershed. Due to the prevalence of agricultural ditching in the MR-SC Watershed, it was identified as a potential cause of fish and invertebrate impairment.

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. Their results also showed a reduction in riffle and pool habitats associated with channelization, which they considered 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). Ditches are typically engineered to carry a 50-year or greater return interval precipitation event. 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 features (e.g. glide, riffle, run, pool) during low to moderate flow periods. The common result is excess sedimentation of the stream bed as particles become immobile and aggrade over time. In general, this design does not provide good habitat for aquatic species or provide stability of its bed and banks.

Channelization and or ditching will also change the flow regime for a waterway. The result is increased peak discharges and often reduced baseflow. As water is diverted from the landscape and routed through manmade or altered channels there are loses of habitat features. The habitat features that are affected are loss of pool depth, increased embeddedness of gravel and cobble in riffles, loss of floodplain connectivity, and often loss of woody material in the channel. The flow regime is increasingly viewed as the key driver of the ecology of wetlands, streams, and associated floodplains. The alteration of flow regimes affects ecosystem structure and function, which may shift the dominance in native community assemblages and facilitate the invasion and success of exotic and introduced species (Bunn, 2002).

Conceptual model

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.

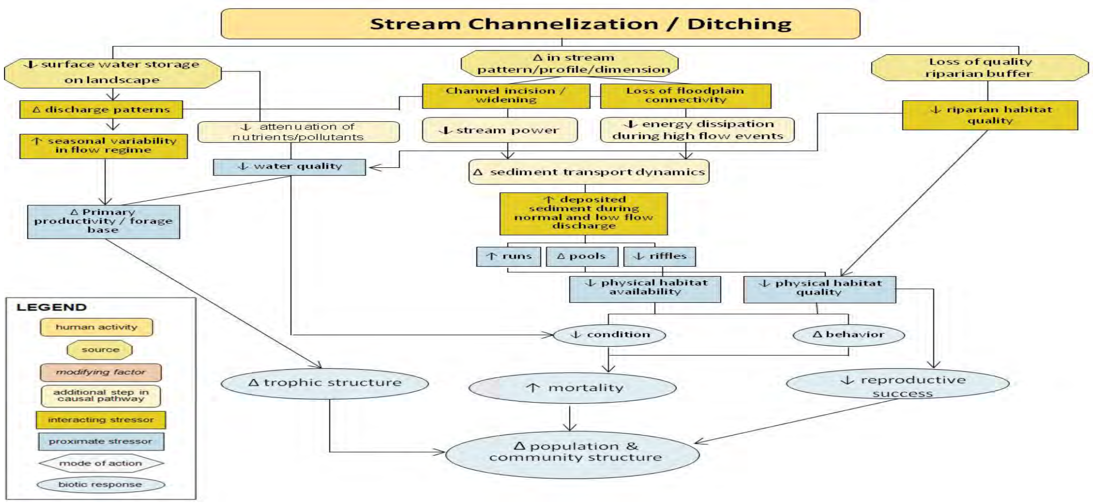


Figure 8: Candidate cause # 1: Altered biology based on stream channelization/ditching

Casual analysis

Many of the MR-SC tributaries are channelized in portions of all subwatersheds (Figure 9). 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 9 indicates. Ditches in the headwaters are generally incised and lack healthy riparian buffers.

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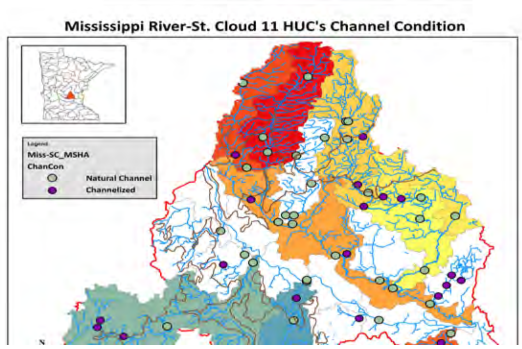

Figure 9: Biological monitoring sites that were channelized

Biological effects: fish

The conceptual model (Figure 8) 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, is shown in Table 5. Fish metric values were calculated from a total of 30 sites in Class 6 streams scattered throughout the MR-SC watershed. Of the 30 sites used to investigate biological response to channelization, 18 were channelized and 12 remain in natural channel form. The natural channel sites are affected by upstream channelization in most cases. The quality of habitat in the natural channel sites is affected by altered flow regimes and the natural sites are negatively responding to these alterations.

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

Metric	Metric Description/Definition	Expected Response to Channelization
Trophic		
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

Reproductive and tolerance metrics

Natural channel sites supported a higher percentage of simple lithophilic spawning fish species than channelized monitoring locations (Figure 10). The natural channel sites supported 14.2 percent lithophilic spawners while the channelized sites had 3.4 percent. Statistics for the two stream type populations showed a p-Value of 0.660 assuming a chi-square distribution with one degree freedom; therefore the two populations are not statistically different. Channelized monitoring sites had a slightly 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*). Very tolerant fish species made up 79.5 percent of the channelized site sample versus 76 percent for the natural channel sites. Statistics for the two stream type populations showed a p-Value of 0.790; therefore the two populations are highly non-significant and not different. The average sensitive fish percentage for natural channel sites was 16 percent, and channelized sites were 10.7 percent. The entire watershed was low in sensitive fish abundance. The statistics for the sensitive fish percent had a p-Value of 0.427 which is also non-significant. The natural channel sites are not in much better condition than the channelized sites. The natural channel sites are generally over-widened and the hydrology functions similarly to the channelized sites. The conclusion is that the natural channel sites are not significantly different than the channelized sites. This can be seen by visually observing the condition of the natural channel locations. Most of the natural channel sites are experiencing signs of altered flow regime. The stream substrate is embedded by fine sediment, the channel banks are experiencing erosion, and the pools are filling with fine sediment, all signs of a stream channel that is unstable.

Class 6 Fish IBI Metrics

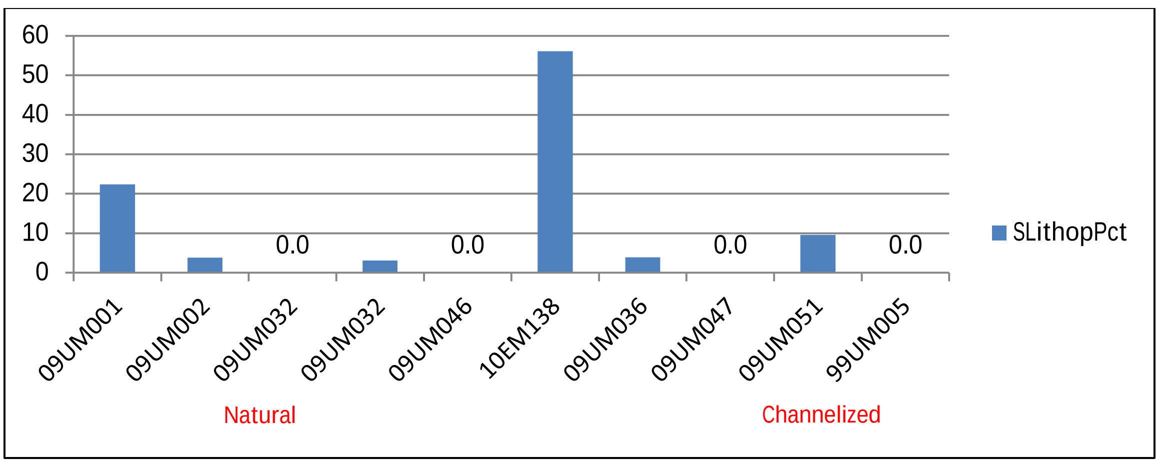

Figure 10: Relative abundance (percent) of fish that are simple lithophilic spawners

Trophic response

The fish metric GeneralPct was reviewed to determine if the relative abundance of generalist fish species increased in the channelized reaches. There was no statistical difference between the natural and channelized sites.

Biological effects: macroinvertebrates

The channelization of various streams in the MR-SC does not appear to be negatively impacting macroinvertebrate populations; statistical testing of the two channel types showed the differences were highly non-significant (p-Value 0.622) for climber taxa percent, and non-significant (p-Value 0.231) for clinger taxa percent. The macroinvertebrate data shows little difference in climber taxa between the channelized (25 percent) and non-channelized (22 percent) sites and a moderate decrease in clinger taxa from the natural stream reaches (Figure 11) Clinger taxa comprised an average of 30 percent of the natural channel sample and 24 percent of the channelized samples. Clinger taxa are best represented by the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT); mayflies, stoneflies, and caddisflies). These groups of insects are generally less tolerant to pollutants and require bottom substrate that has a coarse or rocky component. As the channelized sites are more homogenous with 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 dependent on a coarse substrate.

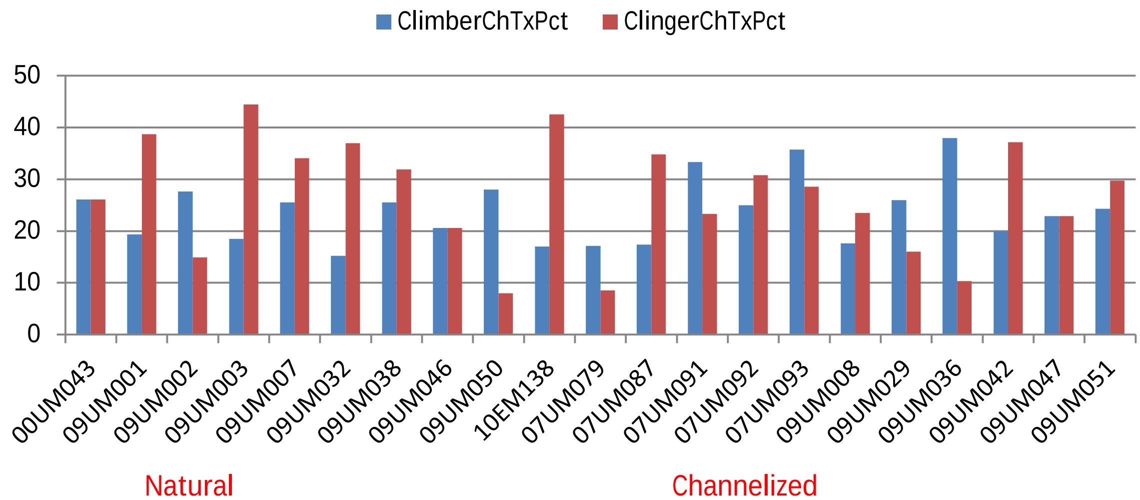

Figure 11: Macroinvertebrate taxa percent of the functional groups clingers and climbers and their relative abundance for natural versus channelized streams

Strength of evidence summary-channelization/ditching

The strength of evidence results (see Table 6) suggest that channelization/ditching is a probable cause of low fish IBI scores in the Upper St. Francis, Mayhew Creek, Upper Elk River, and Otsego 11 HUC's. There are 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, and loss of sensitive species) are evident in the MR-SC natural and channelized sites as well.

Review of the ClingerPct metric (which represents the relative abundance (percent) of clinger individuals in subsample) shows a decrease in the ClingerPct from natural channel sites (30 percent) versus the channelized sites (24 percent). The clinger taxa is adapted to cling to substrate in swift flowing water (i.e. riffles), and channelized sites are generally lacking fast flowing water. Review of the fish metrics for sensitive and tolerant metrics reveal no statistical difference between the natural channel and channelized sites. This may be due to the poor condition of the natural sites. The altered flow regime is causing the natural sites to become unstable and the habitat features that would be available in the natural channel sites are limited. There is limited pool habitat, poor substrate quality and the natural channels are limited in their ability to access the floodplains. This is causing the natural channel sites to react similarly to the channelized sites.

Table 6: Strength of evidence table for candidate cause-channelization/ditching

Types of Evidence	Upper St. Francis River, Mayhew Creek, Upper Elk River, Otsego	Silver Creek	Clearwater River,
Evidence from field collected River Data			
Spatial/temporal co-occurrence	++	++	+
Temporal sequence	NE	NE	NE
Field evidence of stressor-response	++	-	+
Causal pathway	+++	+	++
Evidence of exposure, biological mechanism	+	-	+
Field experiments /manipulation of exposure	NE	NE	NE
Laboratory analysis of site media	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
Stressor-response in other field studies	++	++	++
Stressor-response in ecological models	NE	NE	NE
Manipulation experiments at other sites	+++	+++	+++
Analogous stressors	++	++	++
Multiple lines of evidence			
Consistency of evidence	++	++	+
Explanatory power of evidence	+	+	+

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

Candidate cause: total suspended solids/turbidity/bedded sediment

Total suspended solids 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, bedded sediment has not been extensively studied in the MR-SC Watershed, in part because there is no state or federal water quality standard for this parameter. Quantitative field measurement of bedded sediment (bedload) is very difficult. 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. 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).

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Turbidity/TSS standard

Since the late 1960s, MPCA has used a turbidity standard of 25 nephelometric turbidity units 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 Lower Elk River and Rice Creek), 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 TMDL process.

For the purposes of SI, 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 MR-SC 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 Elk 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. Exposures of these areas to weathering, trampling, and sheer stress (water friction) from high flow events are increasing the quantity and severity of bank erosion.

Figure 12 shows examples of bank erosion observed throughout the MR-SC Watershed. Bank erosion occurred within urban/developed areas, along the edges of cultivated cropland, 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 MR-SC Watershed.

Figure 12: Examples of bank erosion from various land cover types in the MR-SC Watershed

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 MR-SC 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	↑collector-gatherer	
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 13 displays the relative abundance of two macroinvertebrate functional feeding groups for streams where we had collected both macroinvertebrate and stream sediment data. This subset of sites is from impaired streams. There was little substrate data from unimpaired streams to use as a reference. As water quality degrades through the increase in suspended material, or increased fine material in stream bottom, filter- feeding groups are reduced in abundance. The filter-feeding group is composed of species that create nets or have special adaptations for filtering food out of the water column. An increase in turbidity or TSS would have an impact on the ability to filter. The collector-filterer group is generally clingers. If stream embeddedness increases and particle size decreases the clingers have less rock habitat to cling to. The high mineral content of fine sand that deposits may clog nets and impede the filtering process. There is an advantage to gathering your food, and the relative abundance of this feeding group will increase.

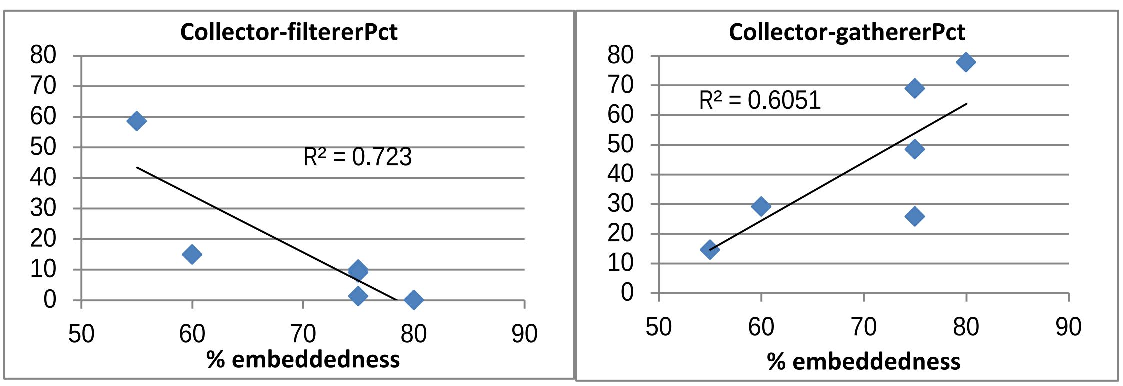

Figure 13: Macroinvertebrate functional feeding groups displaying filtering versus gathering over percent stream embeddedness

Conceptual model

The conceptual model for TSS and bedded sediment as candidate causes for impairment is shown in Figure 14. There are numerous potential sources and causal pathways associated with these candidate stressors in the MR-SC 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)

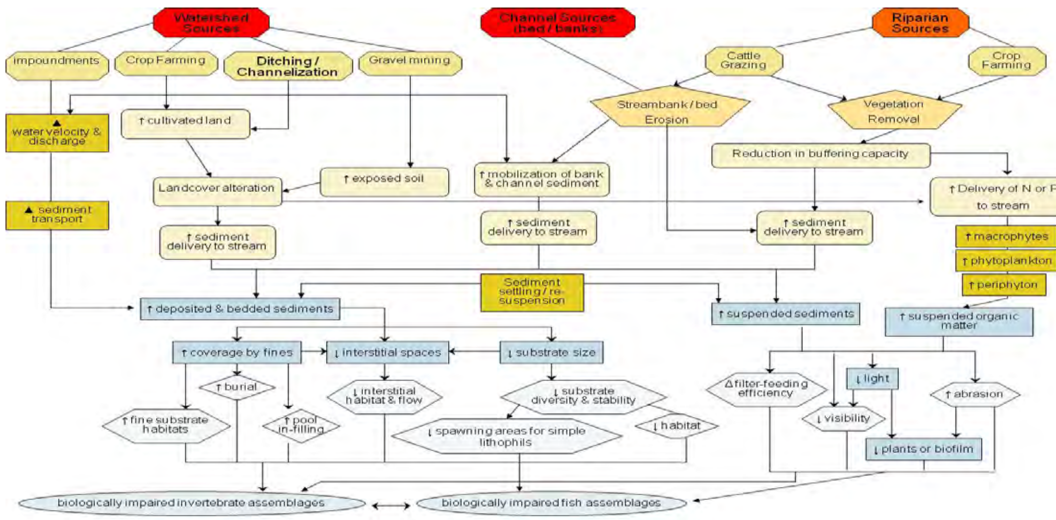

Figure 14: Conceptual model for suspended and bedded sediment

Strength of evidence summary for TSS

Based on existing water quality data and several biological indicators, there is evidence available in support of elevated TSS concentrations as a stressor to aquatic life. The negative impacts of TSS can be seen throughout the MR-SC Watershed. Bedded sediment probably plays a larger role in causing stress to the biological communities of the MR-SC. TSS is most likely a secondary stressor in the Mayhew Creek, Otsego, Upper Elk River and Silver Creek 11 HUC's.

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

Types of Evidence	Upper St. Francis	St. Francis	Upper Elk River	Mayhew Creek	Lower Elk River	Otsego	Silver Creek	Clearwater River	Battle Brook
Evidence from Mississippi River-St. Cloud Watershed Data									
Spatial/temporal co-occurrence	+	-	+	+	+	+	-	-	+
Temporal sequence	0	0	0	0	+	+	0	0	0
Field evidence of stressor-response	+	-	+	++	++	+	0	0	+
Causal pathway	+	-	+	++	++	+	-	0	0
Evidence of exposure, biological mechanism	0	-	+	+	++	+	-	+	+
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified or tested predictions	0	-	+	+	+	0	0	0	0
Symptoms	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
Manipulation experiments at other sites	NE	NE	NE	NE	NE	NE	NE	NE	NE
Analogous stressors	++	++	++	++	++	++	++	++	++
Multiple lines of evidence									
Consistency of evidence	+	++	+	++	+++	+	0	0	+
Explanatory power of evidence	0	+	++	+	++	+	0	0	+

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

Candidate cause: bedded (deposited) sediment

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 MR-SC 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, some 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, Rabeni *et al*., 2005). 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 (BS) was assessed 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 of impaired reaches that was conducted by MPCA. 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 25 percent.

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 15 shows the relationship between embeddedness and the mean particle size (D^{50}) for each measured reach.

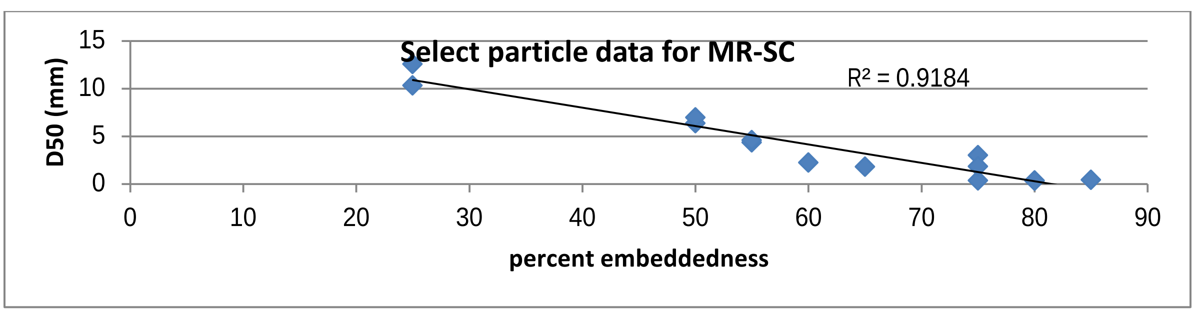

Figure 15: Relationship of particle size (D50) in millimeters to percent embeddedness in select MR-SC Watershed stream locations

Causal analysis-bedded sediment

Table 9 highlights several key biological metrics that are likely to respond 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 bedded sediment

Metric	Metric Description	Expected Response to increase in BS
BenInsectTxPct	Relative abundance (%) of taxa that are benthic insectivores	*Increase*
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 data shows a negative response by the macroinvertebrate group known as clingers to the amount of stream embeddedness. As coarse substrates become more embedded with fine sediment, the percent of clinger taxa in the macroinvertebrate sample is reduced (Figure 16). This ClingerChTxPct metric is a measure of the relative percentage of taxa adapted to cling to substrate in swift flowing water.

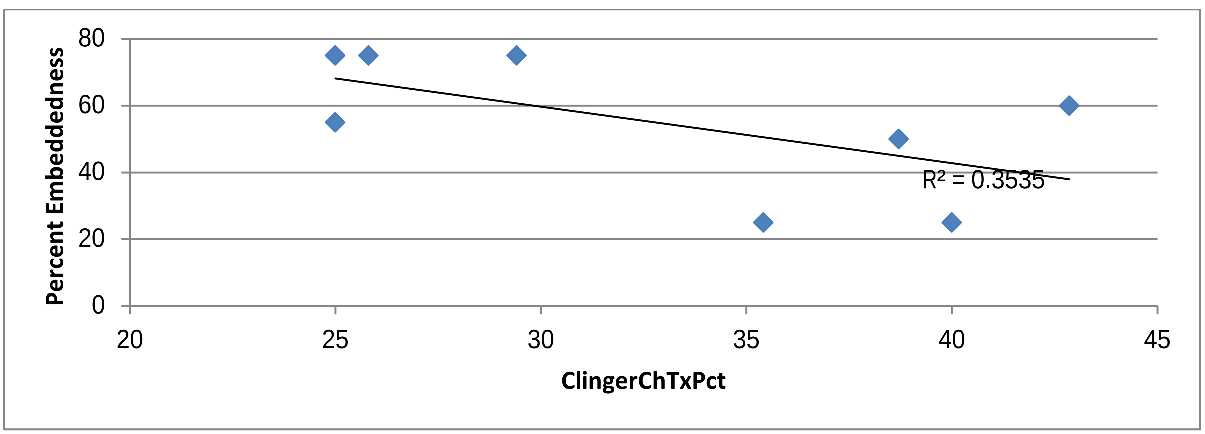

Figure 16: This graph compares the macroinvertebrate group (clinger) compared to stream substrate embeddedness. This graph includes sites that were impaired for both fish and macroinvertebrates

Review of the bedded sediment data collected as embeddedness during the Minnesota stream habitat assessment (MSHA) shows no correlation between darter relative abundance and substrate embeddedness. There is a weak correlation between DarterSculpSucTx percent and embeddedness as seen in Fig 17 below. 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 17 and 18 below displays stream embeddedness for a select group of sites that were surveyed with greater detail and pebble counts were conducted along with estimates of stream embeddedness.

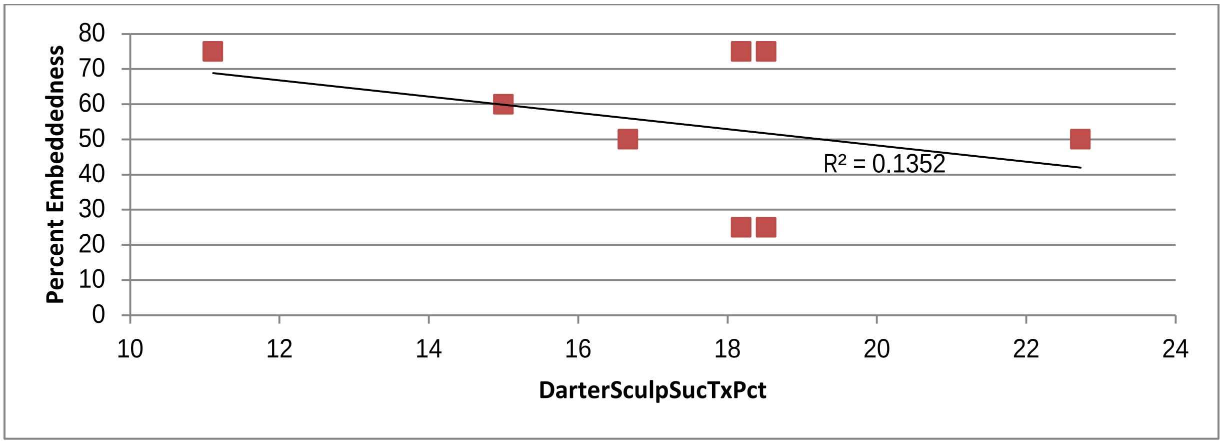

Figure 17: Darter sculpin round bodied sucker fish metric versus stream embeddedness percent

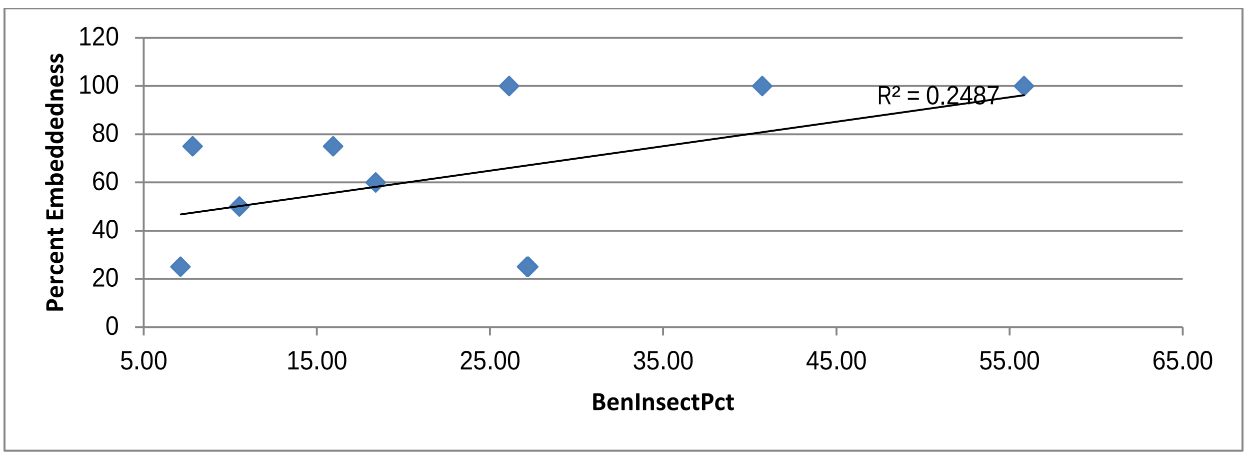

Figure 18: Benthic insectivorous fish metric versus stream embeddedness

As percent embeddedness increases there is a general increase in the functional fish group BenInsectPct. This group depends on benthic insects to feed. The increase in embeddedness should favor burrowing insects however review of the data suggests that the group of insects know as burrowers is not statitiscically different between sites that have greater than 50 percent embeddedness.

Strength of evidence summary for deposited and bedded sediment

Bedded sediments are likely a stressor to fish and macroinvertebrate assemblages in the MR-SC watershed. This is especially the case in channelized reaches in the Mayhew Creek, St. Francis River, Upper Elk River, and Silver Creek 11 HUC's. Substrate embeddedness levels were high (55-75 percent) in these areas, and the response from biota indicated a cause and effect relationship (low DarterSculpSucTx taxa richness, decrease in clingers).

The presence of excess BS and negative effects on biota is more difficult to determine in the other 11HUC's because we do not have embeddedness data and the associated particle size data from these

11 HUC's. There is qualitative data available on substrate composition and embeddedness estimates which are part of the habitat data collected during the fish survey.

Candidate cause: nitrate toxicity

NO_2 – NO_3 water quality standards/ecoregion expectations

There is currently no standard for nitrate-nitrogen (Nitrate-N) in Minnesota for streams. The MPCA has developed draft standards designed to protect aquatic life. McCollor and 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. All of the MR-SC Watershed falls within the North Central Hardwood Forest ecoregion, which has an ecoregion norm of 0.04 to 0.26 mg/L for NO2+NO3-N.

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.

Sources and causal pathways of NO_3 - NO_2 toxicity

Nitrate (NO_3) and nitrite (NO_2) forms of nitrogen are components of the natural nitrogen cycle in aquatic ecosystems. NO_2 anions are naturally present in soil and water, and are 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 one 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 treatment facilities (Alleman, 1978).

The sources and potential causal pathways for nitrate toxicity in the MR-SC watershed are shown in the conceptual model here. 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 10 lists the strength of evidence for NO_2+NO_3 within the MR-SC Watershed.

Table 10: Strength of evidence for No_2 + NO_3 in the MR-SC Watershed

Types of Evidence	**Upper St. Francis**	**St. Francis**	**Upper Elk River**	**Mayhew Creek**	**Lower Elk River**	**Otsego**	**Silver Creek**	**Clearwater River**	**Battle Brook**
Evidence from Sauk River									
Spatial/temporal co-occurrence	-	++	+	+	++	0	0	-	-
Temporal sequence	0	0	0	0	+	0	0	0	**0**
Field evidence of stressor-response	0	+	-	-	+	-	0	0	-
Causal pathway	++	++	+	+	+	+	+	+	**+**
Evidence of exposure, biological mechanism	0	0	0	0	0	0	0	0	**0**
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE	NE	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE	NE	NE	NE	NE	NE
Symptoms	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
Stressor-response in other field studies	NE	NE	NE	NE	NE	NE	NE	NE	NE
Stressor-response in ecological models	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
Explanatory power of evidence	0	+	0	0	+	0	0	0	0

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

Candidate cause: 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 U. S. Department of Agriculture (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 U.S. EPA 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 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 MDA 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 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 11.

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

	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. R. ch. 7050 as toxicity-based for aquatic organisms and is protective for an exposure duration of four days

[2] Maximum standard value for aquatic life & recreation as defined in Minn. R. ch. 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 MR-SC Watershed is very limited, as only one sampling event for pesticides targeted MR-SC 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 MR-SC will be used to characterize the concentrations of pesticides in surface water and the threats posed to aquatic life.

Sampling on the MR-SC was limited to one sampling event (rain event) in August of 2010 at nine sites (Figure 19). 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 MR-SC may not be entirely representative of herbicide and pesticide concentrations in the watershed.

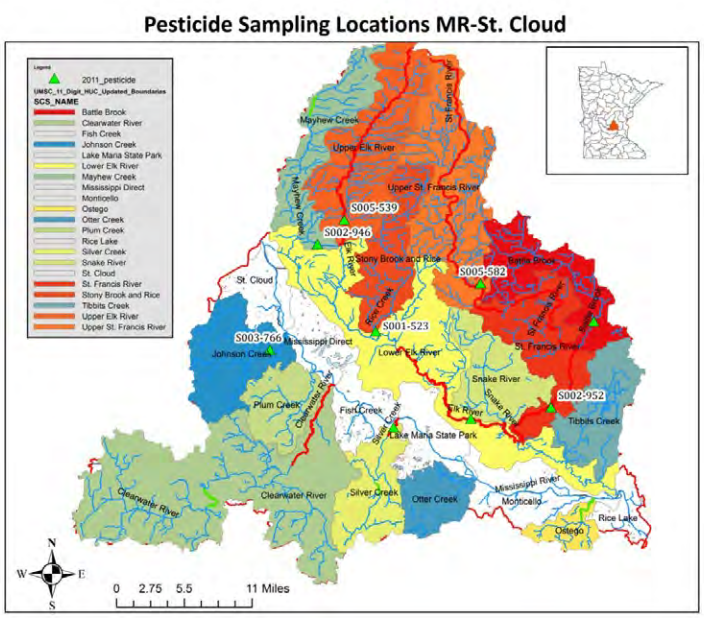

Figure 19: Pesticide sampling locations in the MR-SC Watershed

Table 12: Site descriptions and sampling years for pesticide monitoring in the MR-SC Watershed

Site ID	Description	Years Sampled	Active?
S005-582	ST. FRANCIS R AT 173RD AVE, 9.7 MI SE OF FOLEY, MN	2011	N
S005-540	SILVER CK AT CURTIS AVE NW, 3.5 MI SW OF BECKER, MN	2011	N
S005-539	ELK R AT 35TH ST NE, 6.5 MI ENE OF SAUK RAPIDS, MN	2011	N
S004-704	BATTLE BK AT CSAH-9, 4 MI NW OF ZIMMERMAN, MN	2011	N
S003-766	JOHNSON CK (AKA ST AUGUSTA CK) AT CR-7, 1 MI S OF ST AUGUSTA	2011	N
S002-952	ST. FRANCIS R. AT CSAH 15, 5.5 MI. SW OF ZIMMERMAN, MN	2011	N
S002-946	MAYHEW CK AT CSAH 8, 4.5 MI E OF ST. CLOUD, MN	2011	N
S003-686	ELK R AT CSAH-11, 2.5 MI SW OF BECKER, MN	2011	N
S001-523	RICE CK AT CSAH-16 BRG, 2.5 MI N OF CLEAR LAKE, MN	2011	N

Based on current monitoring data, Atrazine, Desethylatrazine, and Metachlor were the most commonly detected herbicides in the greater MR-SC Watershed (Table 12). This limited data set does not show any exceedances of Minnesota state pesticide standards. Much more rigorous data collection would be required to conclude that pesticides are not a stressor on the aquatic biota. It should also be noted that several of the pesticides that were detected do not currently have state water quality standards associated with them.

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 MR-SC. 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 MR-SC due to similarity of land use.

Additional monitoring is recommended to further understand the presence of herbicides/pesticides/fungicides in the MR-SC and their potential impact to fish, macroinvertebrates, and other aquatic biota. Monitoring data from various 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.

Table 13: Herbicides, insecticides, and fungicides detected in the MR-SC Watershed

	S005-582 St Francis R. at 173rd Ave.	S005-540 Silver Cr at Curtis Ave	S005-539 Elk R. at 35th St NE	S004-704 Battle Brook at CSAH-9	S003-766 Johnson Creek	S002-952 St. Francis R at CSAH-15	S002-946 Mayhew Cr at CSAH-8	S003-686 Elk R at CSAH-11	S001-523 Rice Cr at CSAH-16
Herbicide									
Acetochlor	ND	ND	ND	ND	ND	ND	**P**	ND	ND
Alachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND
Atrazine	ND	**P**	**P**	ND	ND	ND	**0.07**	**P**	ND
-Deisopropylatrazine	ND	ND	ND	ND	ND	ND	ND	ND	ND
- Desethylatrazine	ND	ND	ND	ND	ND	ND	**0.05**	P	ND
Dimethenamid	**P**	ND	ND	ND	ND	ND	ND	ND	ND
Metolachlor	**P**	**P**	ND	**0.1**	ND	ND	**P**	**P**	ND
2,4-D (ng/L)	ND	**29.6**	ND	ND	ND	ND	**13.8**	ND	ND
Propazine	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorpyrifos	ND	ND	ND	ND	ND	ND	ND	ND	ND
Propiconazole	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetraconazole	ND	ND	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

Candidate cause: chloride toxicity

The negative effects of elevated chloride concentrations on aquatic life have been well documented. 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 MR-SC watershed. There is currently no chloride data for the MR-SC, so specific conductivity was reviewed as high chloride concentrations would result in elevated specific conductivity measurements. The specific conductivity data ranged from 250 – 600 µS/cm. Reviewing data from the Shingle Creek Chloride TMDL indicated that specific conductivity readings above 1000 µS/cm indicated that chloride levels were high enough to cause toxicity problems for aquatic organisms. Unless some chloride samples are collected, chloride cannot be assessed as a stressor to aquatic life.

Candidate cause: low dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1991). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If dissolved oxygen concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Many species of fish avoid areas where DO concentrations are below five 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 temperature increases, the saturation level of DO decreases. Increased water temperature also raises the DO needs for many species of fish (Raleigh et al., 1986). Low DO 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 five 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, 2012).

Potential sources and pathways for low dissolved oxygen

Dissolved oxygen 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 DO 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 DO as a candidate stressor in the MR-SC Watershed is shown in **EPA CADDIS website by following this link: Dissolved oxygen simple conceptual diagram | CADDIS: Sources, Stressors & Responses | US EPA.**

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 MR-SC Watershed in 2011. 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 at biologically impaired sites in late summer to capture the diurnal fluctuations. This data revealed the magnitude and pattern of diurnal DO flux at each site.

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 14). MR-SC 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 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 Elk River and its tributaries. However, in the Elk River main stem, Chl-a concentration increases considerably moving from the outlet of
   Big Elk Lake downstream to the confluence with the Mississippi River. In the lower portions of the Elk River, concentrations of Chl-a are consistently above the draft river criteria of 20 µg/L and reach levels as high as 95 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. There is no BOD data from the MR-SC watershed.

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.

Candidate cause: 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 in the MR-SC. However, there are several water and/or carp control structures located at the outlet of several lakes that are hydrologically connected to the river. The United States Fish and Wildlife Service maintains two dam structures in the Sherburne National Wildlife Refuge to control wetland water elevation along the St. Francis River. These barriers also limit movement 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. There are water control structures located on the Clearwater River, Silver Creek, and Battle Brook that all impede fish movements.

The impacts of dams on the fish and invertebrate assemblages of the MR-SC rivers and streams 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 limited upstream/downstream data sets to show if there are 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 St. Francis River and Elk River may be altering fish assemblages locally. Removal or modification of these structures to allow fish passage would likely reduce the effectiveness of carp control and would jeopardize the wildlife habitat and water quality of the refuges wetlands. Given the resource value of the refuge wetlands, it is unlikely that connectivity will be restored at this location.

Groundwater withdrawal

There are a number of 11 HUCs within the MR-SC Watershed that have center pivot irrigation. The central corridor along the Mississippi River from Clear Lake down to Big Lake, has a high density of center pivot irrigation occurring. Limited information is known at this time about the volume of water being withdrawn from the Elk River 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. Areas of the upstream portion of Mayhew Creek, Upper St. Francis River, and Upper Clearwater River lack woody riparian and the associated leaf pack. These areas generally lack deep pools and quality riffles as well, because of an increase in fine sediment that is filling the pools. Bank erosion and field erosion are contributing to the increase in fine sediment.

Table 15: Conclusions and summary of probable stressor

Summary of Stressors By 11 HUC	**Upper St. Francis R**	**St. Francis River**	**Upper Elk River**	**Mayhew Creek**	**Lower Elk River**	**Otsego**	**Silver Creek**	**Clearwater River**	**Battle Brook**
Loss of Habitat due to Channelization / Ditching	+	+	+	++	0	+	+	+	++
Total Suspended Solids	0	0	0	0	+	+	0	0	0
Deposited and Bedded Sediments	+	+	+	+	0	+	+	+	+
Pesticide Toxicity	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE
Nitrate-Nitrite Toxicity	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE	- / NE
Chloride Toxicity	NE	NE	NE	NE	NE	NE	NE	NE	NE
Dissolved Oxygen	+	+/0	-	+	0/-	+	+	+	+
Irrigation – Flow Alteration	+/0	+/0	+/0	+/0	0	+	+/0	0	0
Connectivity – Loss of fish passage	+	+	0	-	0	+	+	+	+

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

MR-SC Best Management Practices

Several types of Best Management Practices (BMPs) for the MR-SC watershed are listed below. These BMPs should be considered for implementation activities that promote restoration and protection. Some of these BMPs are tied to specific locations, while others are watershed-wide and need to be considered as part of a broad management approach. These BMPs are general and a more targeted approach will be given in the Watershed Implementation Plan.

1. Channelized stream reaches

   Several reaches of the MR-SC 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, water quality, and sediment transport.

2. Riparian buffer zones

   Many riparian buffer zones within the watershed are either lacking woody vegetation or are in poor quality vegetation. Native grasses and woody vegetation provide shade for the stream, reduce stream temperatures, and stabilize the stream banks. A healthy riparian corridor will help increase biodiversity of both terrestrial and aquatic species. Reed canary grass is the dominant grass found along stream corridors currently. Reed canary grass is shallow rooted, out competes native grasses and provides little value in habitat quality. Efforts should to be made to convert theses reed canary grass dominated buffers to more diverse tree, shrub, and native grass and forbs.

3. Pasture

   Animal agriculture is a prominent land use in the MR-SC 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 MR-SC 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.

4. Nutrient management

   Excess total phosphorus is a concern throughout the MR-SC watershed. Stormwater runoff from both Urban and agricultural sources is supplying an abundance of phosphorus to area streams. Fertilizer management plans, manure management, and urban stormwater drainage plans should focus on reducing the amount of nutrients that are washing into the area streams. Application rates should be focused on using only the amounts needed to plant production.

Upper St. Francis River 11 HUC (07010203060

The Upper Saint Francis River lies in the northeast side of the Mississippi St. Cloud watershed. This watershed area starts north of Highway 23 and flows south east to the Sherburne National Wildlife Refuge (Figure 20). Historically, this area was dominated by deciduous forest, with areas of "emergent herbaceous wetland" along the riparian corridor of the river. Current land-use is predominantly agricultural (43 percent cultivated land, 33 percent range land) and only 13 percent of the area remains forest and six percent wetlands (Figure 21).

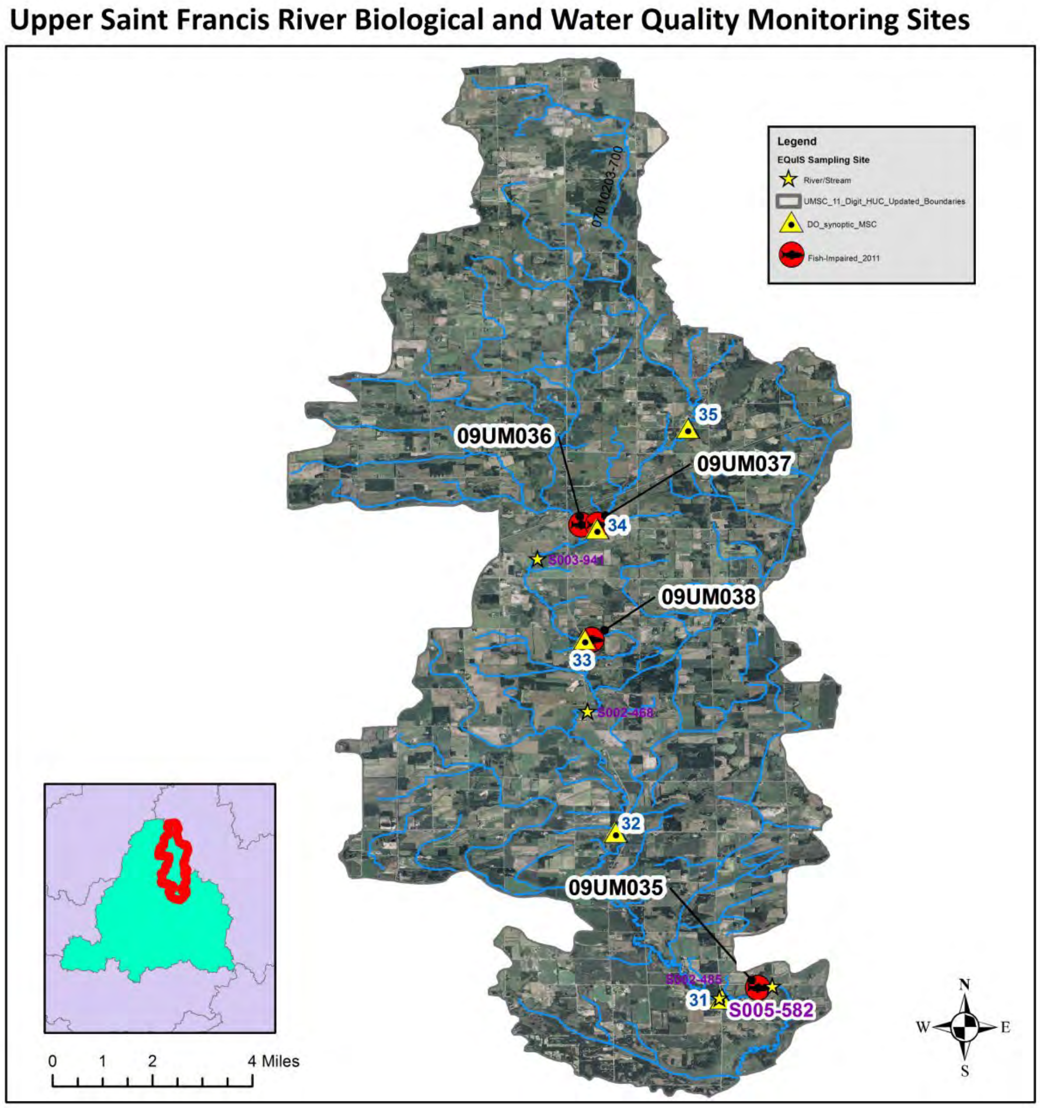

Figure 20: Upper St. Francis River 11 digit HUC (07020303060) with impaired biological and investigated water quality sampling locations

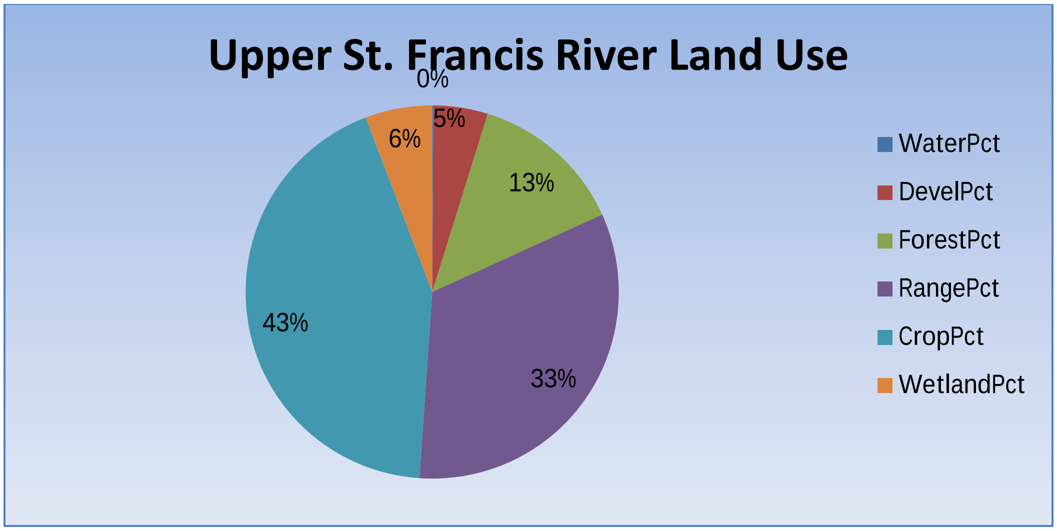

Figure 21: Upper St. Francis land use percentages

Another land-use component that may be negatively impacting ecological health is the intensity of small to medium sized feedlots here. Potential stressors related to this land-use are increased nutrient concentrations and increased bank instability due to animal trampling of banks. Once the vegetation along the banks is trampled or grazed it leaves the banks of the stream channel susceptible to erosion and mass failure. Many of the pasture operations use the streams as a source of watering, which leads to bank failure and increased nutrients from manure.

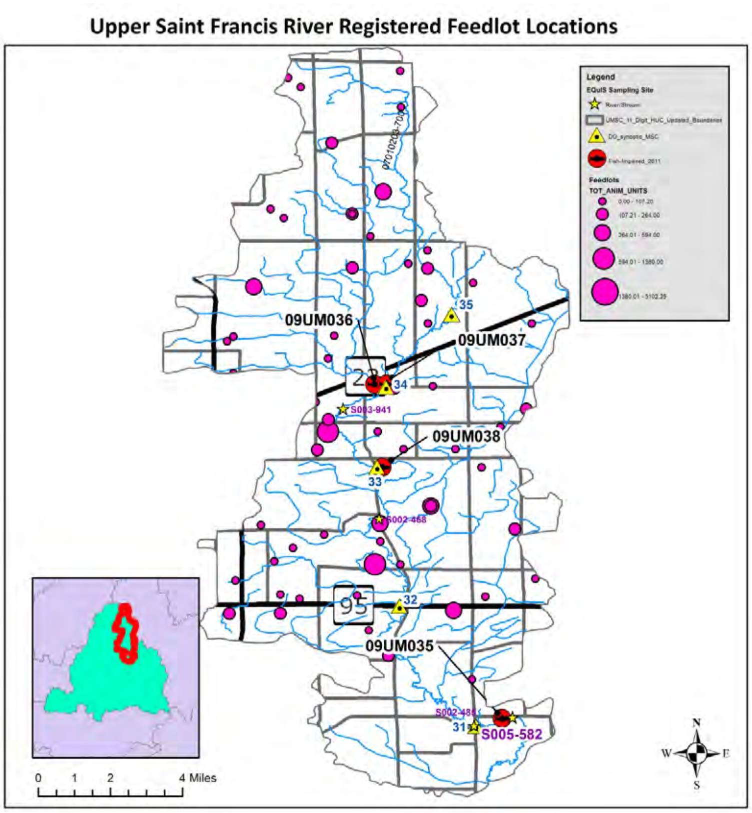

Figure 22: Feedlot density in the Upper St. Francis 11 HUC

Nutrients

Evidence of causal pathways-DO flux, chlorophyll-a, and oxygen demand

Total Phosphorus data was collected in 2009 and 2011 at EQuIS site S005-582. This site is located at the downstream end of the 11HUC near biological monitoring site 09UM035. Total Phosphorus (TP) data are well above the proposed River criteria of 0.1 mg/L for much of the sampling record in 2011; Figure 23. Stream flow in 2011 was higher than in 2009.Stream flow was computed from a nearby gage at Elk River on CR16; the summer mean (May-October) discharge in 2009, was 51 cubic feet per second (cfs), and in 2011 was 261 cfs. Precipitation was higher in 2011 and the associated watershed runoff was also higher. The TP values are highest during periods of high flow. The current land use in this area is 76 percent agricultural. The high TP concentration is coming from manure runoff and agricultural fertilizer applications. This will help us target TP reductions by reducing erosion with its high TP concentrations and concentrate on better management of TP runoff from pastures, feedlots, row crop fields, and improperly functioning septic systems. 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 watershed. Efforts should be made to reduce the export of TP within this watershed.

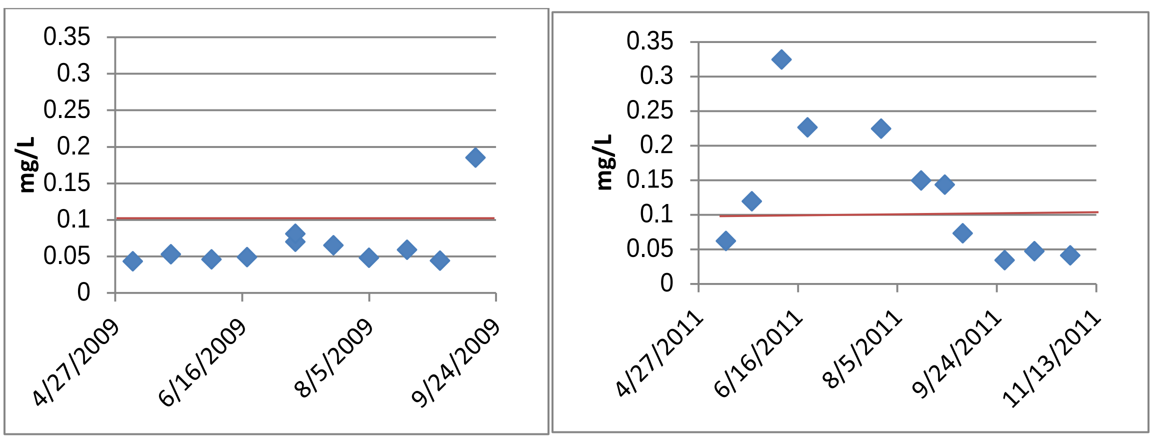

Figure 23:TP values over time collected from St. Francis River EQuIS site S005-582

Chlorophyll-a

Chlorophyll-a (Chl-a) concentrations are commonly used to measure algal productivity in surface water, and have been shown to correlate with maximum DO concentrations and DO flux in non-wadable rivers (Heiskary et al., 2010). During field data collection it was noted that submerged aquatic plant growth along with periphyton growth increased as we moved longitudinally downstream. Field visits at biological monitoring site 09UM037 revealed a lot of submerged plant growth (Figure 24).

Figure 24: Photos of submerged aquatic plant growth at biological site 09UM037

Dissolved oxygen flux

A YSI water chemistry sonde was deployed at biological monitoring site 09UM037. During the 12-day deployment, DO routinely dipped below the five mg/L standard and the daily flux ranged from 4-7 mg/L. During the 2011 monitoring season, DO is a cause of stress for the biological community. Figure 25 displays the continuous record for the YSI sonde readings.

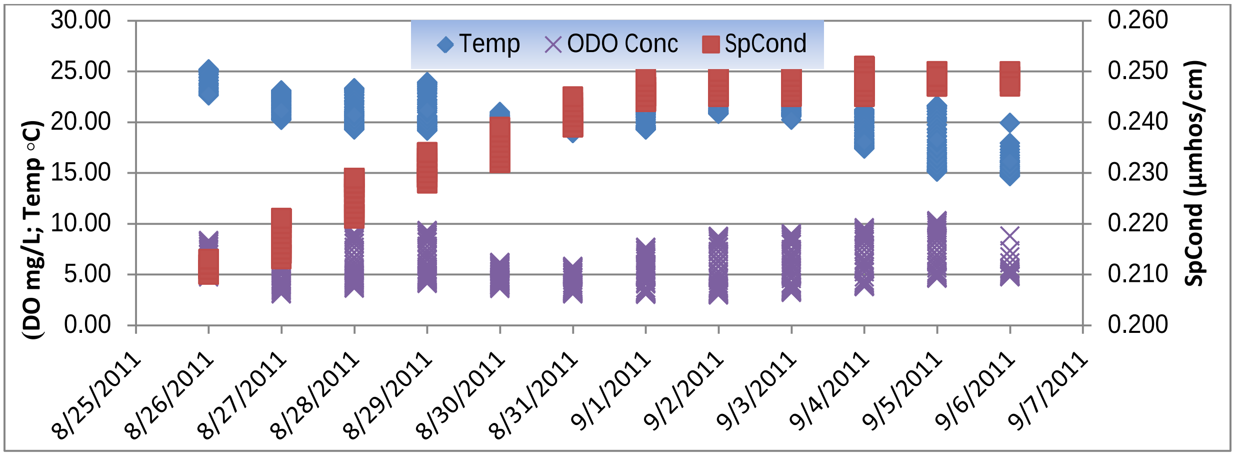

Figure 25: Site 09UM037 continuous sonde readings from St. Francis River at 75th Street NE, SE of Highway 23

Sediment: total suspended solids and bedded sediment

Total suspended solids

Elevated TSS concentrations have been identified as a primary water quality concern in the Mississippi River watershed. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is no evidence showing elevated TSS concentrations as a candidate cause for biological impairments in the Upper St Francis River.

Turbidity/TSS standard

The draft TSS standard for the St. Francis River has been set at 30 mg/L. This concentration is not to be exceeded in more than 10 percent of samples (collected April-September) within a 10-year data window. Figure 26 below displays the TSS concentrations for EQuIS sites S005-582 and S002-952. Site S005-582 which is the outlet of this 11 HUC had 2 samples that were above the proposed 30 mg/L TSS standard. The June 21, 2011 TSS sample was collected on the rising limb of a significant storm event. The St Francis gage at Santiago had a discharge of 55.9 cfs on 6/19/2011, 108 cfs on 6/21/2011, and peaked at 3028 cfs on 6/24/2011. There is no flow data for the 2009 dataset. Review of the discharge data from the neighboring Elk River does not reveal that there were any significant storm events in September of 2009. This sample appears to be taken during baseflow. There were no samples collected in April of 2009 which was the peak flow period for 2009. This limited data set is not enough to evaluate if TSS is a stressor to the aquatic community.

Meador and Carlisle ranked fish species tolerance to TSS concentration in 2007. The fish list from each Upper St. Francis River sampling location was ranked according to the associated weighted average (WA) concentration. The rankings were then divided into quartiles that represent the fish species percent based on WA TSS concentrations. Figure 27 displays the percent of the sample that fits each quartile. The upper range for Q1 is 28 mg/L. This is near the proposed standard of 30 mg/L for the Upper St. Francis River. The majority of the fish sampled in all three locations had a tolerance for TSS above the 30 mg/L standard. There was a very small percentage of the fish sample with a WA-TSS value below the 30 mg/L standard (Q1_28mg/L). This suggests that current fish communities at the sampled locations are tolerant of increased TSS concentrations.

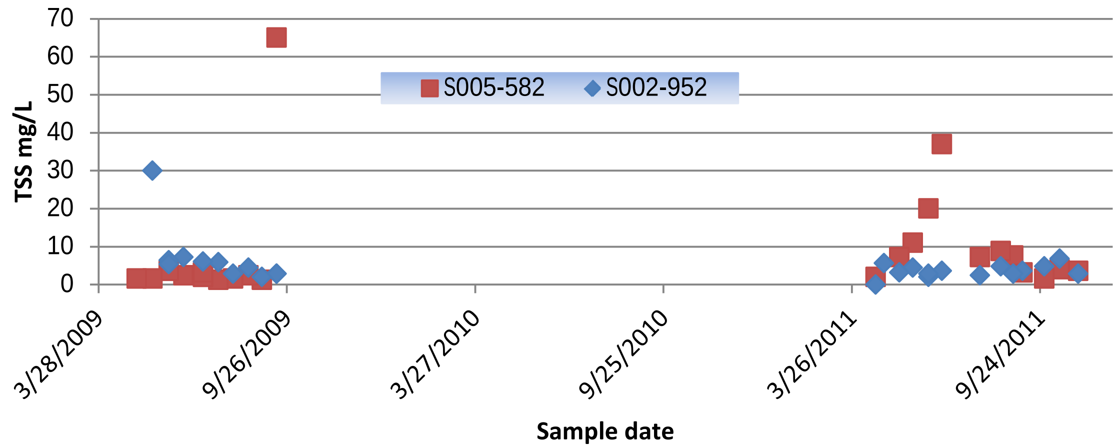

Figure 26: TSS concentrations for EQuIS site S005-582 and S002-952 for the St. Francis River

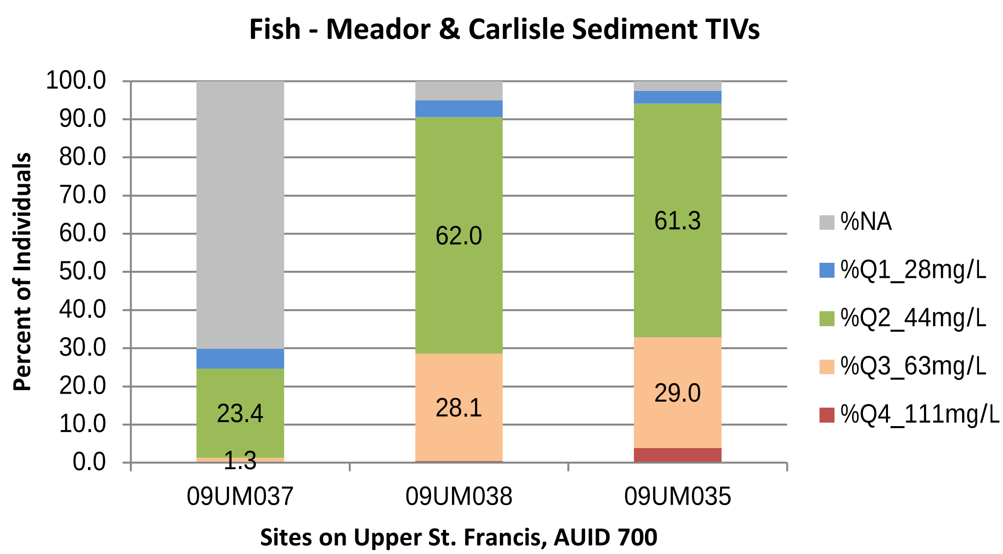

Figure 27: Percentage of fish that are TSS sensitive based on M and C weighted average TSS values

Bedded sediment

Sources and pathways of bedded sediment

Riparian grazing/bank erosion

Rangeland and pasture are common landscape features throughout the Upper St Francis River Watershed. Most of these areas are operated for cattle grazing but several small horse farms were noted during reconnaissance trips on the river. In some areas, the riparian corridor along the St. Francis and its tributaries has been cleared for pasture and 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.

Areas of bank erosion were also observed along the edges of cultivated cropland and even 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 Upper St. Francis River 11 HUC.

Strength of evidence summary for bedded sediment

Bedded sediments are likely a stressor to fish and macroinvertebrate assemblages in the Upper St. Francis River. Substrate embeddedness levels were very high (>70 percent) at site 09UM037, the D50 for particle size was 4.28 mm which is coarse sand, and the response from biota indicated a cause and effect relationship (high abundance of sticklebacks and mud minnow taxa and decrease in simple lithophilic spawners). Review of the MSHA data shows that the substrate is moderately embedded at all St. Francis monitoring locations. The pools are dominated by sand substrate as well as the runs. Riffles were characterized as gravel, however the quality of the gravel is unknown and may be embedded by sand, losing the interstitial spaces that are important for macroinvertebrate and gravel spawning fish. Monitoring sites 09UM037, 09UM038 and 09UM035 are located in this upper 11 HUC while 09UM023 and 09UM015 are located in the downstream 11 HUC. The farthest upstream sampling location 09UM037 shows that the percent of simple lithophilic fish is low along with an abundance of tolerant fish species such as sticklebacks and mud minnows (Figure 28, 29). As we move downstream and the stream substrate conditions improve the gravel dwelling species also improve in abundance.

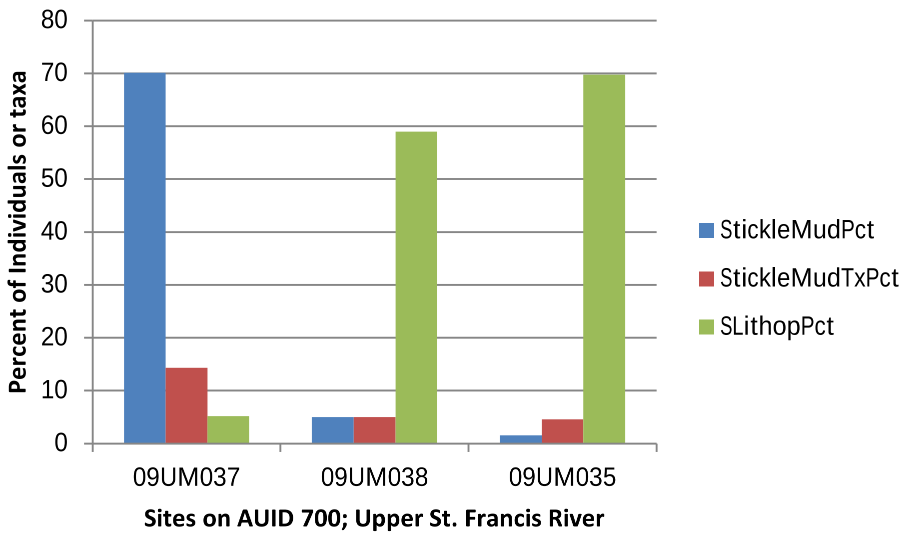

Figure 28: Percentage of fish in the sample that are very tolerant to pollutants

The individual macroinvertebrates were analyzed using weighted average Tolerance Values (TIV) developed by (Yuan, 2007) to determine the percent of the sample that is tolerant to fine sediment. Figure 29 shows that the majority of the samples in AUID 700 fall into Q1 and Q2. Q1 and Q2 are the most tolerant to fine sediment. This suggests that fine sediment is a driving factor in this AUID. Quartiles three and four are less tolerant to fine sediment and the samples have a very low percentage of individuals in this range. The not assigned (NA) quartile is individuals that are not assigned a TIV in the paper. The high percentage of individuals in the macroinvertebrate sample that are tolerant to fine sediment supports the theory that excessive BS is a stressor to the biological community.

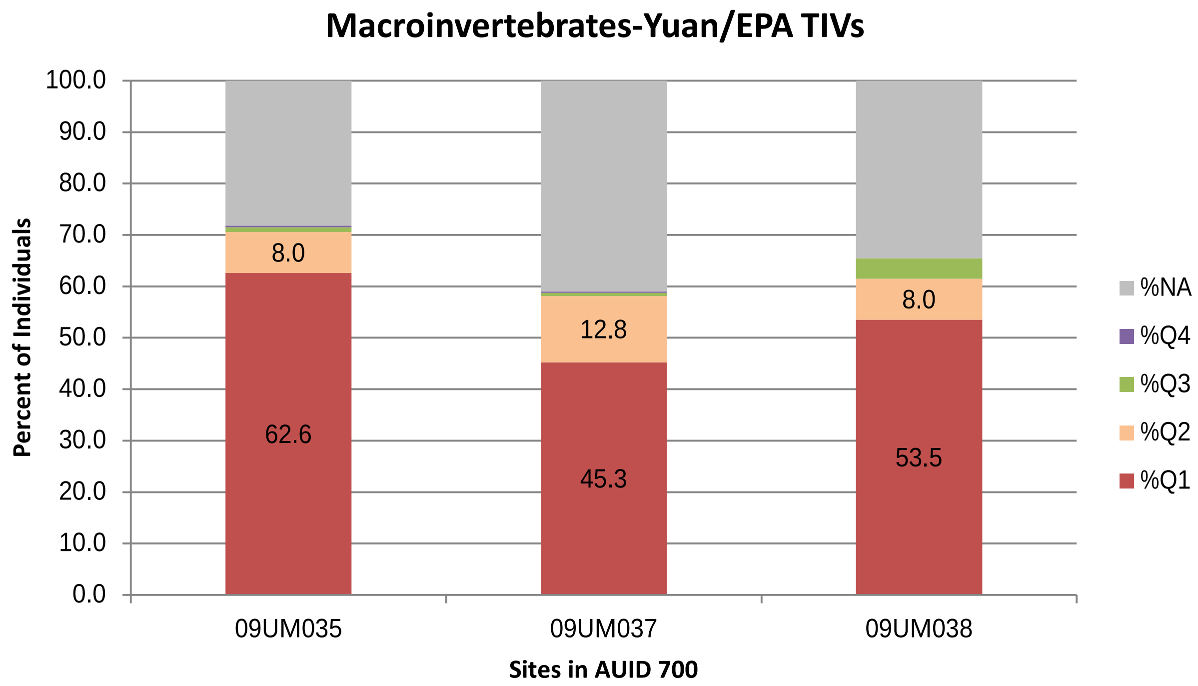

Figure 29: Percent of macroinvertebrate that are very tolerant to fine sediment

Dissolved oxygen

Early morning longitudinal DO readings were collected in the summer of 2011 in the Upper St Francis River at five locations. Figure 30 indicates that early morning DO concentrations were routinely below the state standard of five mg/L, which indicates that low DO is a stressor to aquatic life.

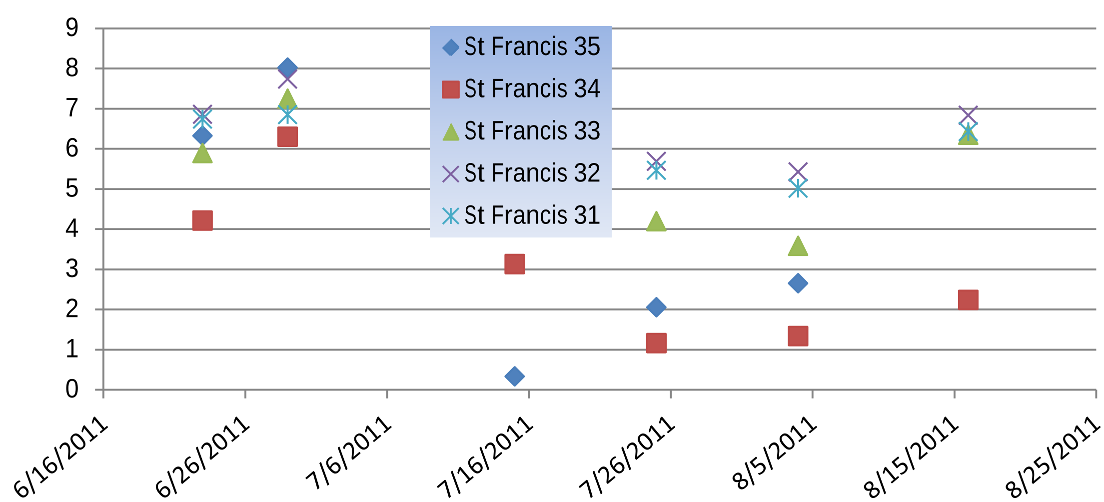

Figure 30: Early morning DO readings

Site 35 is the farthest upstream location for DO monitoring. As we move downstream the DO concentrations improve below site 34. Site 34 is located at 75th St. NE and is collocated at biological monitoring site 09UM037. This site has an abundance of macrophyte growth and has high nutrient concentrations that are dependent on high flow as well.

Meador and Carlisle (Meador & Carlisle, 2007) created tolerance metrics for fish based on weighted average TIV for a variety of water chemistry parameters. DO

Nitrate toxicity

NO_3 - NO_2 water quality standards / ecoregion expectations

Review of the Nitrate data that was collected at site S005-582 reveals that Nitrate levels are elevated, however they do not exceed 4.9 mg/L and are often below three mg/L. There is not enough evidence to determine that Nitrate is a stressor to aquatic life.

Conclusion

The three main stressors to the biotic community in the Upper St Francis River are elevated TP, low DO concentrations, and bedded sediment. 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 that is developed. Stream channel instability, along with rill and gully erosion, are causing a general degrading of instream habitat, and elevated growth of aquatic plants is leading to abnormal fluctuations (around 4.5 mg/L per day) in the DO concentrations of these streams. The macroinvertebrate individual percentages revealed that a high percentage of the sample is tolerant to increased fine sediment. The individual fish samples reveal a high percentage of stickleback/mudminnow percentage along with other species that are tolerant of low DO levels present throughout the AUID.

St. Francis River 11 HUC (07010203080)

The St. Francis River 11 HUC (07010203080) lies in the northeast side of the Mississippi St Cloud watershed. This watershed area starts north of Highway 23 and flows south east through the Sherburne National Wildlife Refuge (Figure 31). The Upper St Francis 11 HUC (07010203060) lies directly upstream and water and pollutants leaving (07010203060) affect the water quality and quantity within this HUC. Historically, this area was dominated by deciduous forest, with areas of “emergent herbaceous wetland” along the riparian corridor of the river. Current land-use is a mixture of agricultural (25 percent cultivated land, 12.5 percent range land) and natural areas (34 percent of the area remains forest and 21.5 percent wetlands) (Figure 32).

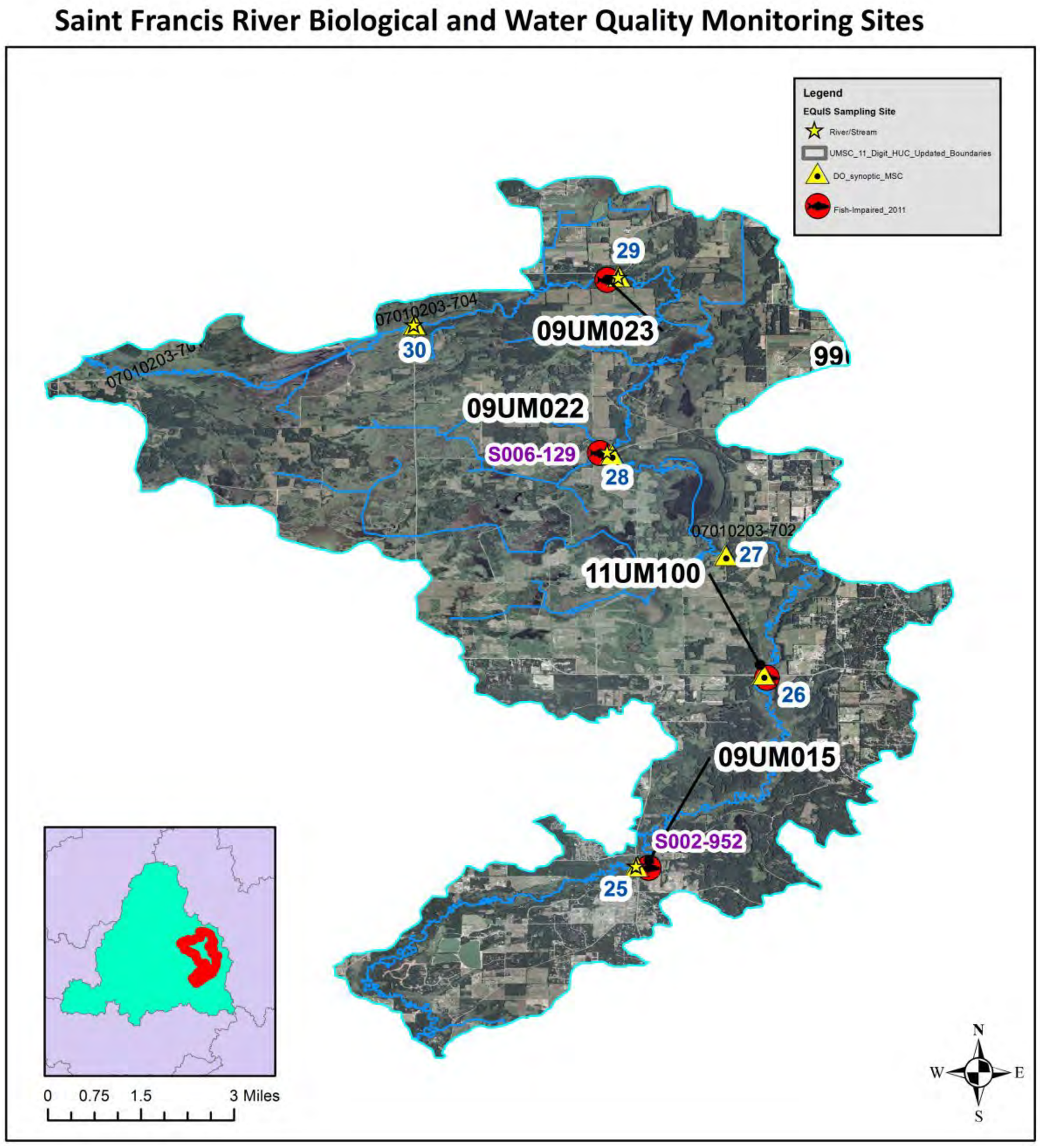

Figure 31: St. Francis River 11 digit HUC (07010203080) with sampling locations

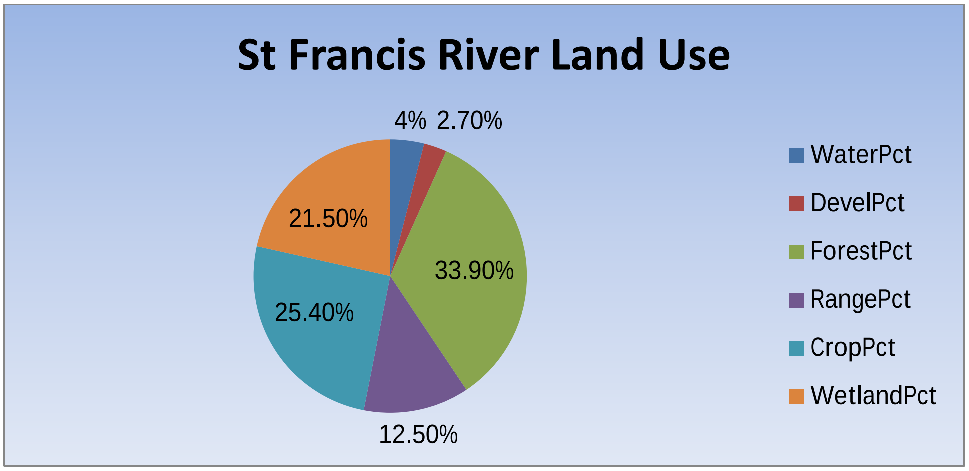

Figure 32: St. Francis River (07010203080) land use percentages

There are no registered feedlots located along the river corridor or its tributaries. There are only two registered feedlots within this 11 HUC. There may be smaller unregistered pasturing operations that are in this HUC that may be contributing to nutrient levels and bank failure due to animal access and trampling.

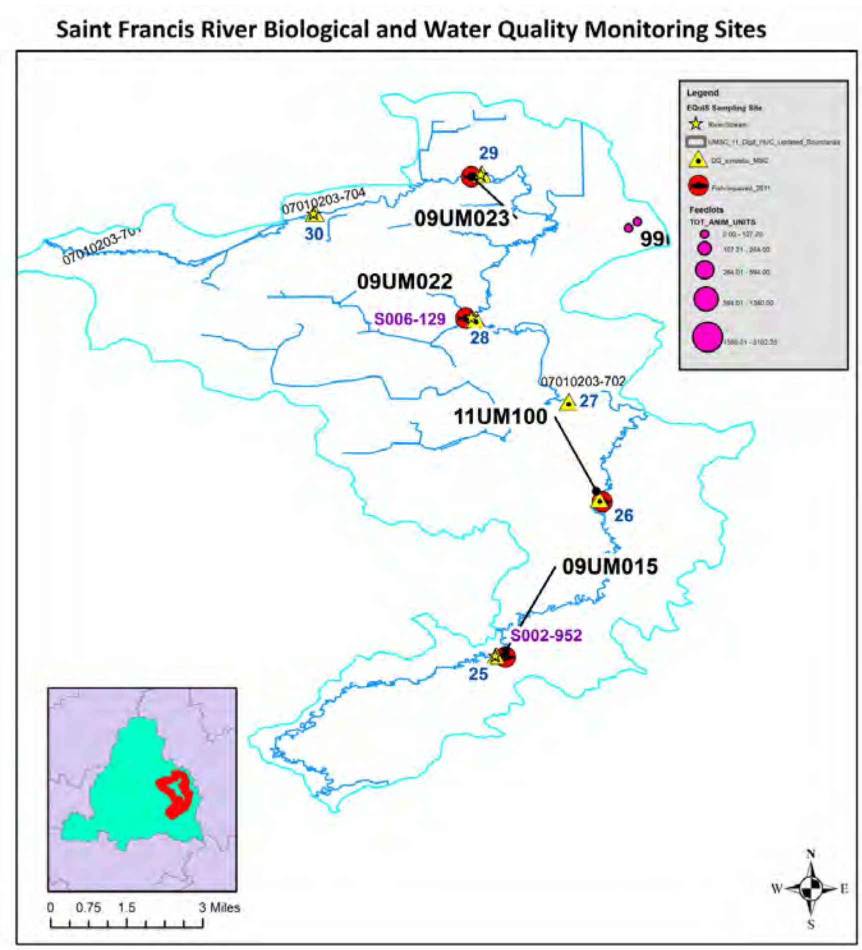

Figure 33: Feedlot density in the Upper St. Francis 11 HUC (07010203080)

Nutrients

Evidence of causal pathways-DO flux, chlorophyll-a, and oxygen demand

Total Phosphorus data was collected from 1997 through 2011 at EQuIS site S002-952. This site is located at the downstream end of the 11HUC near biological monitoring site 09UM015. Total Phosphorus data was also collected at EQuIS site S005-582 which is the pour point of 11 HUC (07010203060). Total Phosphorus data are well above the proposed river criteria of 0.1 mg/L for much of the sampling record in 2011; Figure 34. Table 15 shows the comparison of both St Francis River pour point TP data. The Upper St Francis 11 HUC is slightly higher in all categories. The TP values are highest during periods of high flow (Figure 35). TP concentrations are also slightly elevated during the summer growing season for agricultural crops. This data suggests targeting TP reductions by reducing erosion with its high TP concentrations in the early summer and better management of TP movement during planting season for row crops. 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 watershed.

Table 16: Comparison of total phosphorus statistics for St. Francis River pour points

EQuIS Site ID	TP (minimum) mg/L	TP (maximum) mg/L	TP (average) mg/L
S002-952	0.022	0.311	0.0967
S005-582	0.034	0.324	0.0968

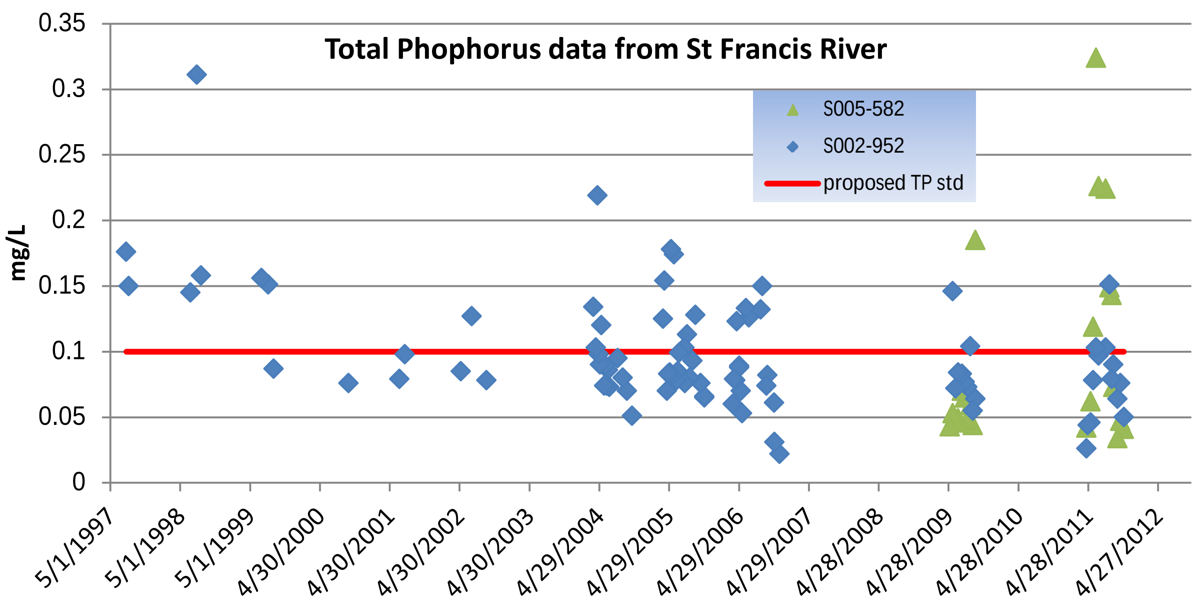

Figure 34: TP values over time collected from St. Francis River EQuIS sites

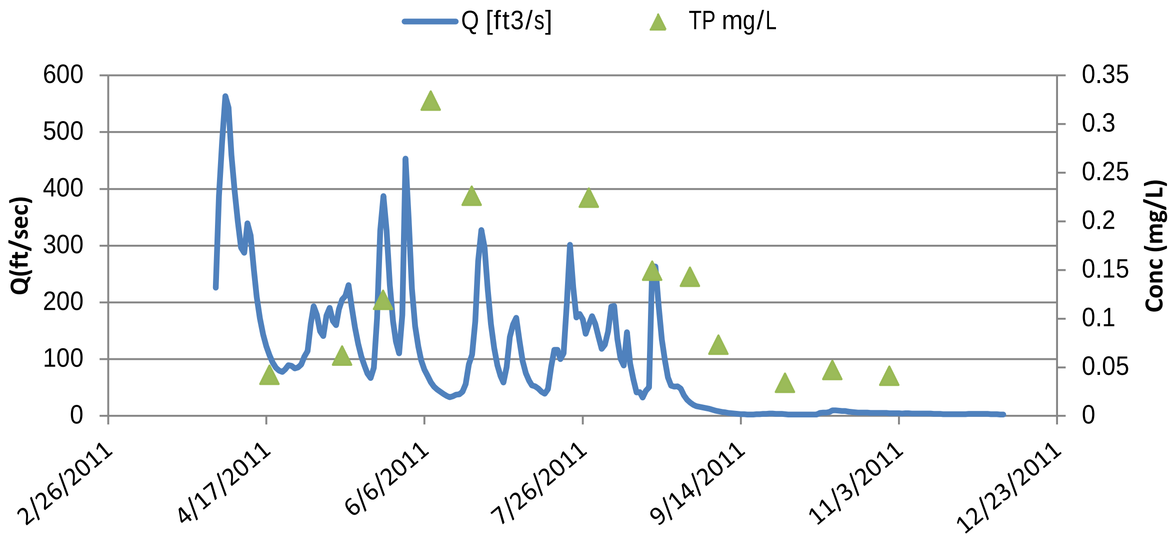

Figure 35: EQuIS site S005-582 TP data over discharge from St. Francis River at Santiago, Minnesota

Chlorophyll-a

Chlorophyll-a concentrations are commonly used to measure algal productivity in surface water, and have been shown to correlate with maximum DO concentrations and DO flux in no-wadable rivers (Heiskary et al., 2010). Field visits at biological monitoring site 09UM015 revealed significant submerged plant and algal growth (Figure 36). This site lies below the Sherburne National Wildlife Refuge which is currently managed for waterfowl production and has several wetland impoundments. These impoundments slow down the river flow and allow for plants to grow and export algal biomass downstream. Two samples were collected on June 25, 2009, and analyzed for chlorophyll-a (chl-a).These samples represented the water column algae and a periphyton algae sample taken from scraping rocks. The results were 11.2 and 1320 µg/L. Pheophyton for these samples were 3.38 and 275 µg/L. Pheophyton is a by-product of algal growth and is typically a percentage of the chl-a concentration.

Figure 36: Photos of submerged aquatic plant growth at biological site 09UM015

Sediment: total suspended solids and bedded sediment

Total suspended solids

Elevated TSS concentrations have been identified as a primary water quality concern in the Mississippi River Watershed. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is no evidence showing elevated TSS concentrations as a candidate cause for biological impairments in the St. Francis River.

Turbidity/TSS standard

For the purposes of SI, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macro invertebrate populations. TSS results are available for the 8HUC watershed from state-certified laboratories and the existing data covers a much larger spatial and temporal scale in the 8HUC watershed. Figure 27 displays the TSS concentrations from the outlet of the Upper St. Francis River 11 HUC and the outlet of the Lower St. Francis River 11 HUC. Data from the lower sampling site indicates the majority of the TSS concentrations are below 10 mg/L. This indicates that TSS is not a suspected source of stress to the aquatic community.

Strength of evidence summary for bedded sediment

Deposited and bedded sediments are likely a stressor to fish and macroinvertebrate assemblages in the St. Francis River. Substrate embeddedness levels were very high (>70 percent) at site 09UM015, the D50 for particle size was 1.8 mm which is medium fine sand, and the response from biota indicated a cause and effect relationship (high abundance of sticklebacks and mud minnow taxa and decrease in simple lithophilic spawners) (Figure 37). The macroinvertebrate community was slightly better than the fish. The very tolerant taxa metric was 22 percent of the sample and the intolerant taxa metric was 15 percent. As we move longitudinally downstream in the St. Francis River the Very Intolerant macroinvertebrate metric decreases which indicates an improvement in community structure.

The individual macroinvertebrates were analyzed using weighted average Tolerance Values (TIV) developed by (Yuan/EPA 2006) to determine the percent of the sample that is tolerant to fine sediment. Figure 38 shows that the majority of the samples in AUID 700 fall into Q1 and Q2. Q1 and Q2 are the most tolerant to fine sediment. This suggests that fine sediment is a driving factor in this AUID. Quartiles three and four are less tolerant to fine sediment and the samples have a very low percentage of individuals in this range. The NA quartile is individuals that are not assigned a TIV in the paper. The high percentage of individuals in the macroinvertebrate sample that are tolerant to fine sediment supports the theory that excessive BS is a stressor to the biological community.

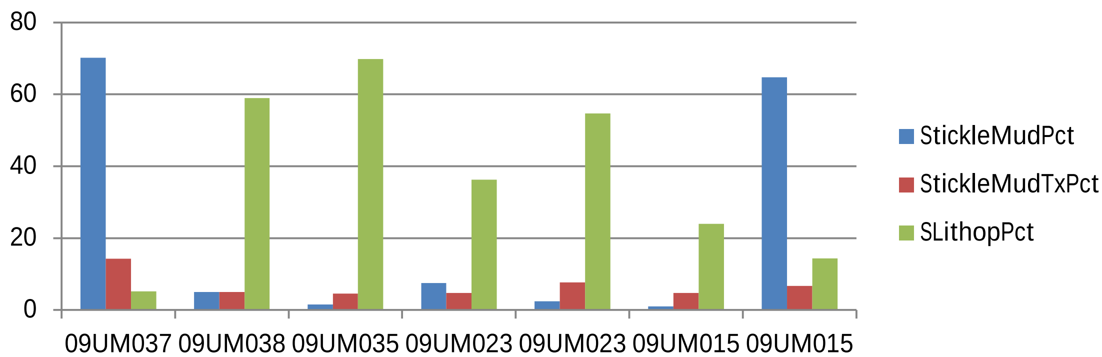

Figure 37: Percent of fish that are gravel spawners and tolerant to pollution

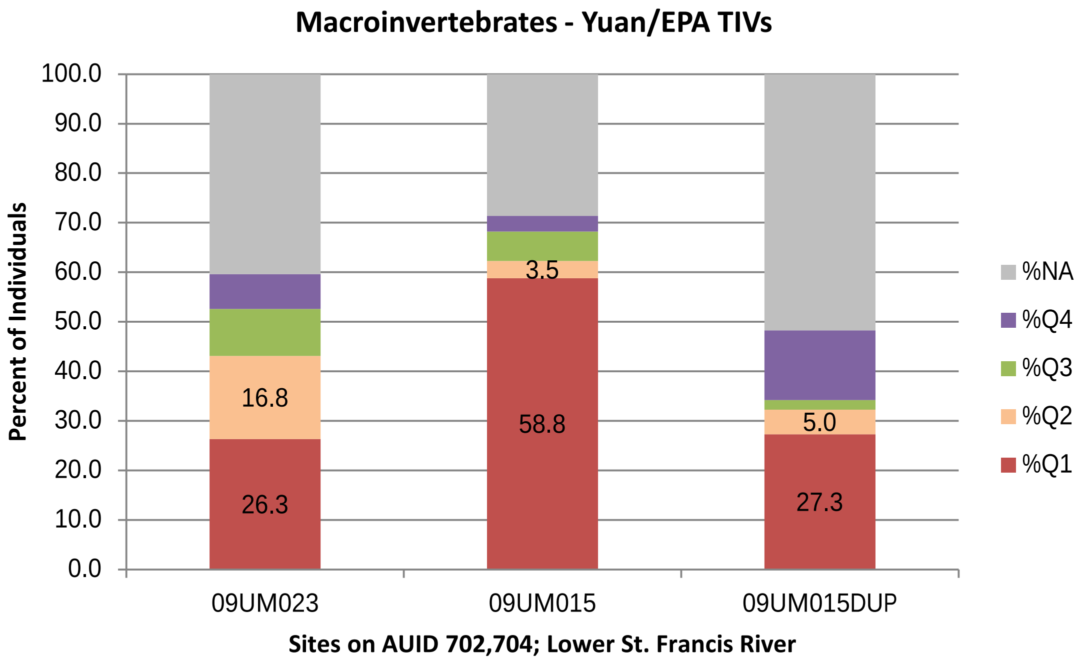

Figure 38: Macroinvertebrate individual percent that are tolerant to fine sediment (Q3-Q4 are tolerant to fine sediment)

Dissolved oxygen

Early morning (pre-9am) longitudinal DO readings were collected in the summer of 2011 in the St Francis River at five locations. Early morning DO concentrations were routinely below the state standard of five mg/L (Figure 39), which indicates that low DO is a stressor to aquatic life. DO sampling has occurred for many years at site S002-952 (CR 15), though samples were collected throughout the day and the readings prior to 2011 may not be representative of the daily minimum (Figure 39). However, review of this data indicates that DO readings below five mg/L have been documented in previous years as well.

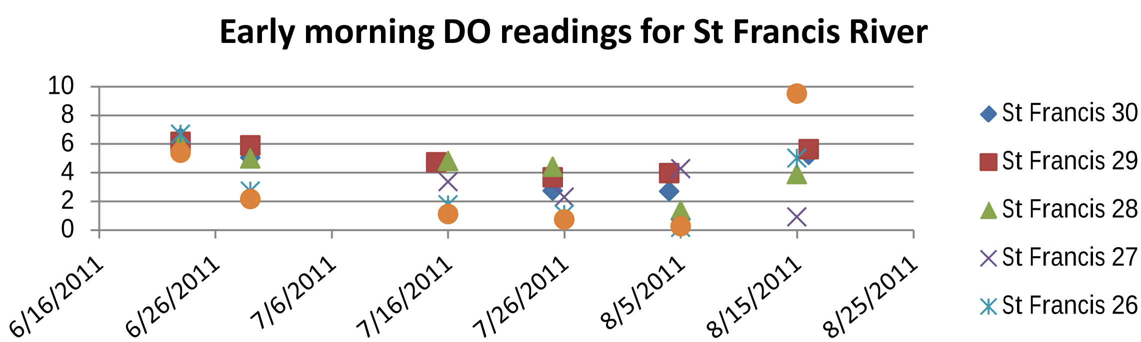

Figure 39: Early morning DO readings St. Francis River mainly downstream of the Sherburne Refuge waterfowl impoundments

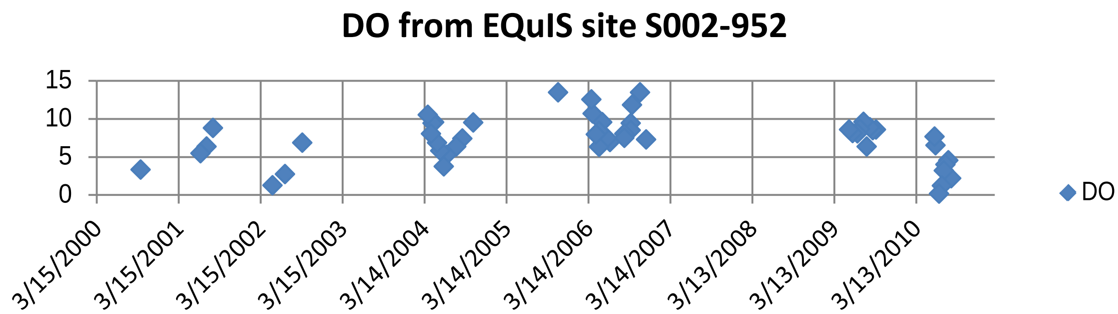

Figure 40: Instantaneous DO readings from site S002-952. Readings occur through the day and may not represent daily minimums

Review of the individual fish samples show that a significant percentage of the fish sample has fish that are tolerant to low DO readings. Site 09UM023 has greater than 50 percent of the sample tolerant to low DO and site 09UM015 has >50 percent tolerance during the June 15, 2009 sample. 2009, was a low water year and flows were at or near baseflow for much of the summer (Figure 60). During 2011 the flows in the river were considerably higher. This could have caused the change in fish community that was represented in the 2011 sample at site 09UM015.

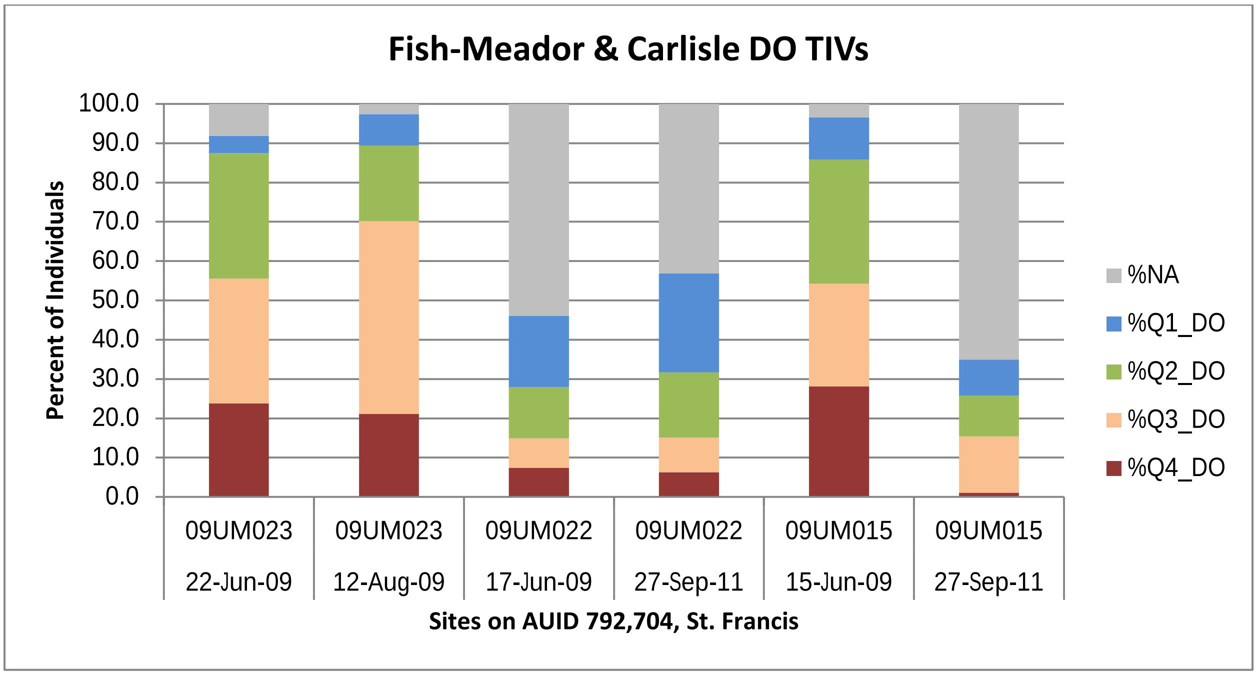

Figure 41: Individual weighted average tolerance values for DO for fish sample. Q3 and Q4 represent the most tolerant to low DO concentrations

Nitrate toxicity

NO_3 - NO_2 water wuality standards / ecoregion expectations

Nitrate data from site S002-952 reveals that nitrate levels are slightly elevated; however they do not exceed levels high enough to cause toxicity and are often below 0.5 mg/L. There is not enough evidence to determine if Nitrate is a stressor to aquatic life.

Connectivity

The St. Francis River flows through the Sherburne National Wildlife Refuge. This refuge is managed for waterfowl production and has two impoundments that are located on the St Francis River. The impoundments are effective at blocking fish passage and also will increase the water temperature of the river. The impoundments are capable of holding back or drawing down water to accommodate the growth of wetland vegetation that is beneficial to waterfowl production. The impoundments act as an effective barrier to fish and need to be considered as a candidate cause of the low diversity of fish species. The impoundments would also raise the water temperature which in effect lowers the amount of soluble DO that the river can carry. This stressor should be further evaluated to determine the impacts on water temperature, DO solubility, and the potential of blocking migrating fish.

Conclusion

The four main stressors to the biotic community in the St Francis River are elevated TP, low DO concentrations, bedded sediment, and connectivity. Many of these stressors are related to the agricultural production that is occurring in the Upper St. Francis 11 HUC. Row crop production and animal pasturing in the upper watershed are contributing pollutants to this downstream section along with the wetland impoundments that are increasing the primary plant production within the created wetlands. Wetlands make up 21.5 percent of the land use in this 11 HUC and many are impoundments on the main stem of the St. Francis River. These impoundments may have high sediment oxygen demand (SOD) and can be affecting the DO solubility of the river. Channel slope is also affected by the impoundments which are causing deposition of sand in the lower gradient sections. Stream channel instability from increased bed load appear to be causing a general lack of in-stream habitat along with elevated growth of aquatic plants which is partially causing abnormal fluctuations in the DO concentrations of streams.

Battle Brook 11 HUC (07010203070)

Battle Brook 11 HUC (07010203070) lies in the northeast side of the Mississippi St. Cloud Watershed. This watershed area starts north of Highway 95 and flows south east into Elk Lake, five miles south of Princeton (Figure 42). Battle Brook flows into the St. Francis River (07010203080) one mile south of the outlet of Elk Lake ½ mile west of CR 1. Historically, this area was dominated by deciduous forest, with areas of “emergent herbaceous wetland” along the riparian corridor of the river. Current land-use is a mixture of agricultural (39 percent cultivated land, 18.5 percent range land) and natural areas (19.5 percent of the area remains forest and 15.6 percent wetlands) with five percent of the watershed being developed (Figure 44).

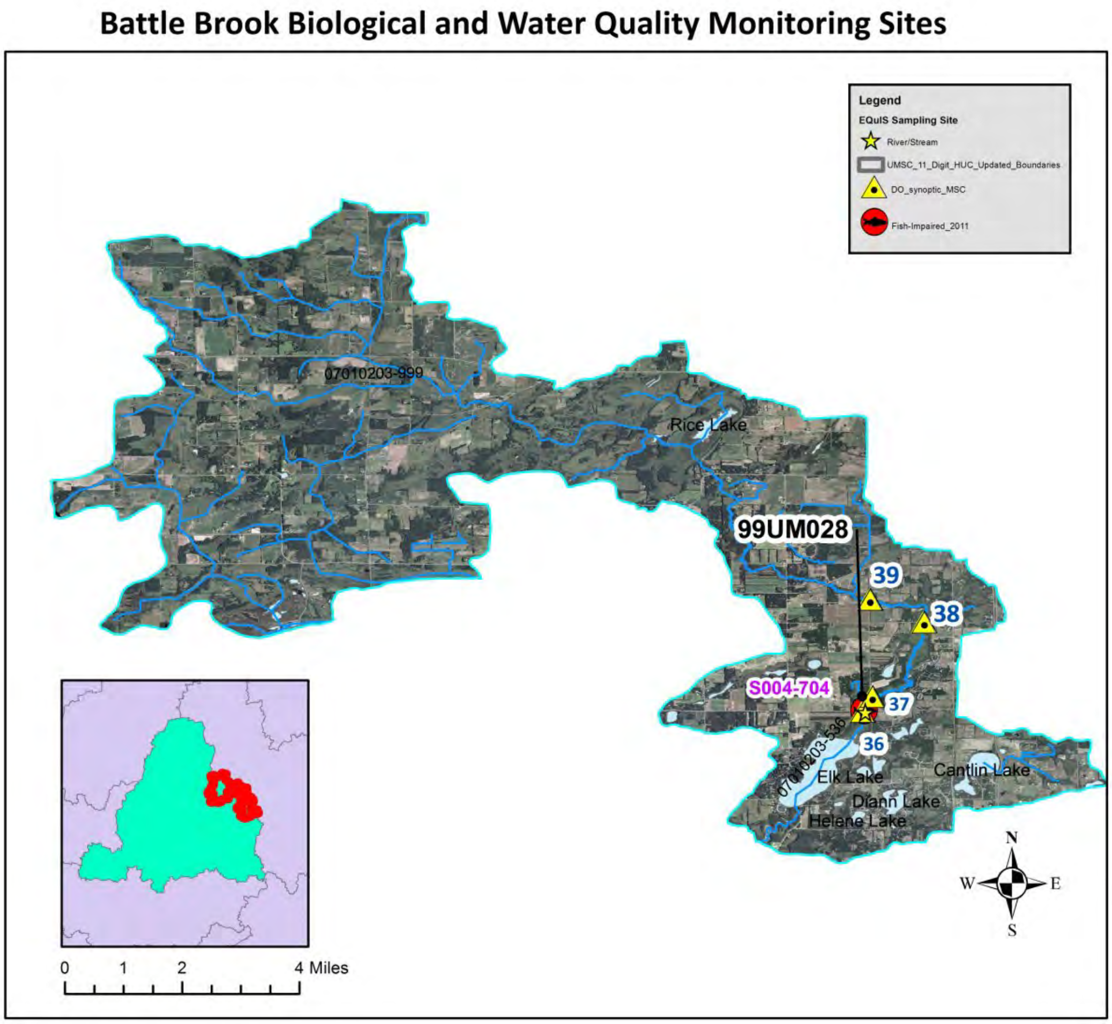

Figure 42: Battle Brook 11 digit HUC (07010203070) with sampling locations

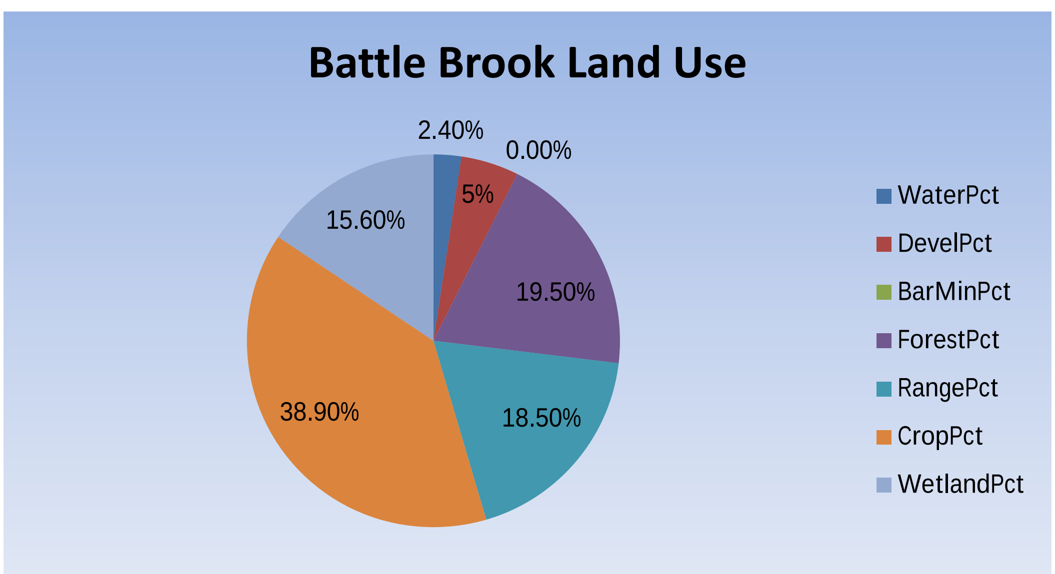

Figure 43: Battle Brook (07010203070) land use percentages

There are 10 registered feedlots located along the river corridor or its tributaries in this subwatershed (Figure 44) and likely also some smaller unregistered pasturing operations. These animal production locations may be contributing to increased nutrient levels.

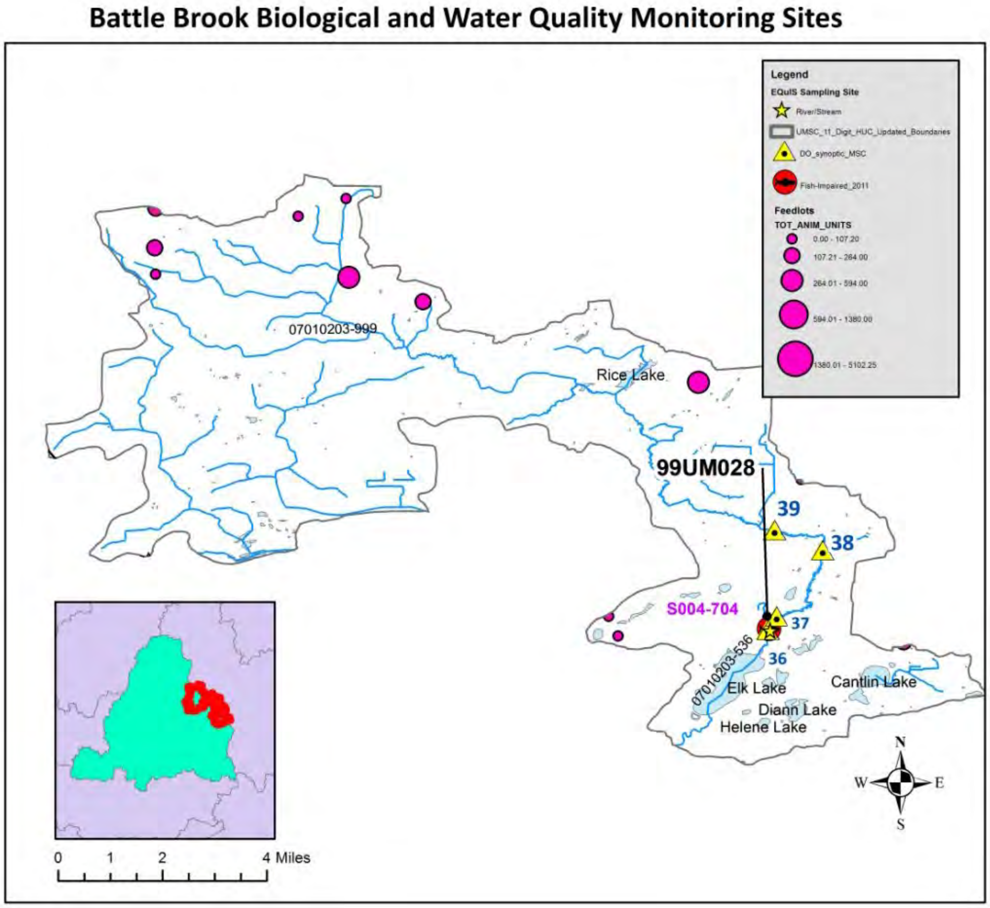

Figure 44: Feedlot density in the Battle Brook 11 HUC (07010203070)

Nutrients

Evidence of causal pathways-DO flux, chlorophyll-a, and oxygen demand

Total Phosphorus (TP) data was collected during 2009 and 2011 at EQuIS site S004-704, near biological monitoring site 99UM028, and at EQuIS site S005-582 which is the pour point of 11 HUC (07010203060). TP data were above the proposed River criteria of 0.1 mg/L twice during the sampling record in 2011 (Figure 45). These two values were collected during periods of high flows. In the early summer months, this area experienced above average rainfall and the wetland complexes were full of water and discharged continuously for a longer period than normal. Table 17 shows the comparison of both St Francis River pour point TP data along with the Battle Brook site. The Upper St Francis 11 HUC is slightly higher in all categories. Elevated TP concentrations do not appear to be a stressor within this watershed as they are in the adjacent St. Francis subwatersheds. It appears that the abnormally high water in 2011 was the probable driving factor for the low DO situations which occurred that year.

Table 17: Comparison of total phosphorus statistics for St. Francis River pour points

EQuIS Site ID	TP (minimum) mg/L	TP (maximum) mg/L	TP (average) mg/L
S002-952(St. Francis)	0.022	0.311	0.097
S005-582(Upper St. Francis)	0.034	0.324	0.097
S004-704(Battle Brook)	0.036	0.143	0.067

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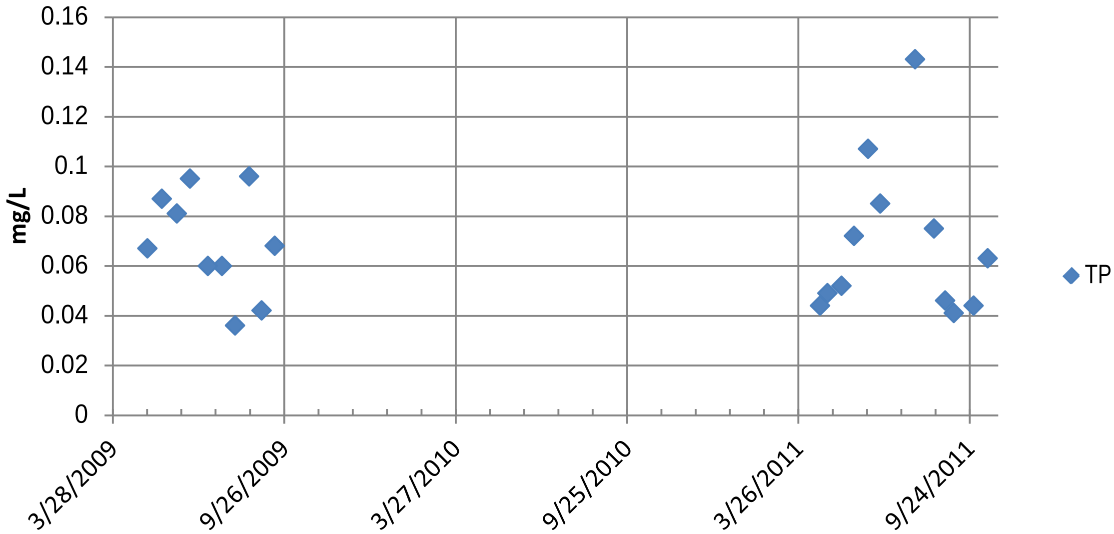


Figure 45: TP values over time collected from Battle Brook EQuIS site S004-704

Chlorophyll-a

During field data collection it was noted that submerged aquatic plant growth along with periphyton growth increased as we moved longitudinally downstream. Field visits at biological monitoring site 99UM028 revealed abundant submerged plant growth. This site is located downstream of a large wetland complex that is partially drained. These partially drained wetlands slow down the river flow and allow for plants to grow and export algal biomass downstream. No samples were collected for CH-la in Battle Brook. Visual observation did reveal that there is a substantial amount of periphyton growing within the channel of Battle Brook.

DO Site 36 **DO Site 36** **DO Site 38**

Photos of submerged aquatic plant growth and abundant duckweed at biological site 09UM028 and upstream.

Dissolved oxygen flux

During the summer of 2012 water quality sondes were deployed at three locations in Battle Brook. Site 1 was located at biological site 99UM028, and oxygen readings are shown in Figure 46.

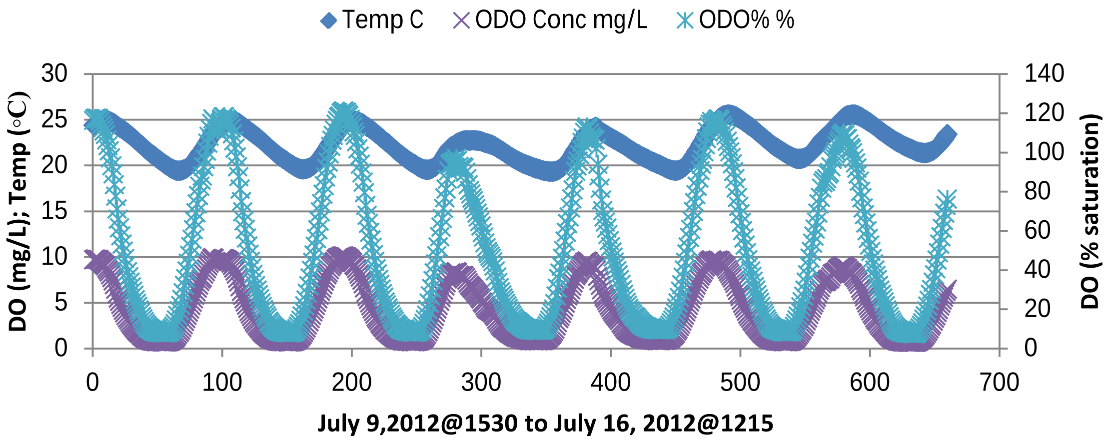


Figure 46: Battle Brook site 36 continuous DO and temperature data from July 9th, 2012 to July 16th, 2012.

The high DO flux (around 10 mg/L/day) is supported by reviewing the biological metrics that would be associated with low DO concentrations and high DO flux. The fish communities from the two sampling locations have low percentages of sensitive fish. Sampling location 10EM196 recorded 10 percent of the sample as sensitive fish and site 99UM028 had 0.53 and 0 percent sensitive fish species for two sampling events. The 2009 fish sampling event was dominated by two species; central mudminnow and yellow perch. Both of these fish species are tolerant to low levels of DO and can survive short term intervals of DO below the five mg/L standard. The fish samples were analyzed based on Meador and Carlisle weighted mean DO TIVs. The fish that are most tolerant to low DO are represented in Quartiles 3 and 4. Figure 47 displays the abundance of fish that are tolerant to low DO readings (Meador & Carlisle, 2007). The NA quartile does not have a DO TIV number associated with the fish species. The NA category only has one fish species present and that is central mudminnow. The central mudminnow has the ability to gulp air when DO conditions are extremely low. This information reveals that over 70 percent of the fish samples are made up of low DO tolerant fish. Review of the 1999 macroinvertebrate data also reveal that site 99UM028 had a low EPT taxa richness. There were only six species present that are in this group, two Ephemeroptera and four Trichoptera species. There were no intolerant macroinvertebrate species found at this site.

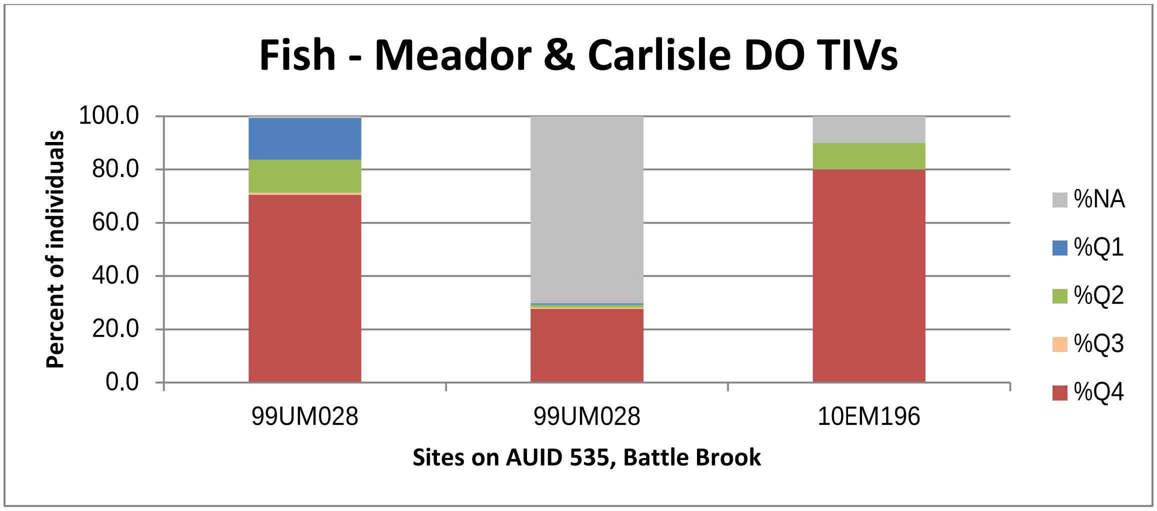


Figure 47: Percent of individual fish that are tolerant to low DO readings based on Meador and Carlisle weighted mean DO TIVs

Biological sampling site 99UM028 is located 2.13 stream miles above the dam on Elk Lake (much of this distance is lake distance, actual stream miles is closer to 0.5 miles). The invert for the culvert at site 09UM028 is 946.72 feet and the dam elevation of Elk Lake is 949.28 feet. The dam on Elk Lake is 2.5 feet higher than the road culvert invert at site 09UM028. The backwater created by this low culvert setting is causing a slope change in Battle Brook. This slope change is causing the riparian wetland to be saturated at all times and probably contributing to the high rate of DO flux. The large wetland complexes appear to be affecting the SOD and BOD in this lower section of Battle Brook. The high daily DO flux is in part being caused by the amount of wetland soils that are intermittently being exposed to wet and dry conditions.

Review of the biological data suggests that the two sampling locations in Battle Brook have a very high percentage of wetland taxa present for fish along with a high abundance of stickleback and mudminnow (Figure 48). This data shows that the fish community is more typical of a wetland type community that would experience frequent periods of low DO. There are very few stream species found at these two locations.

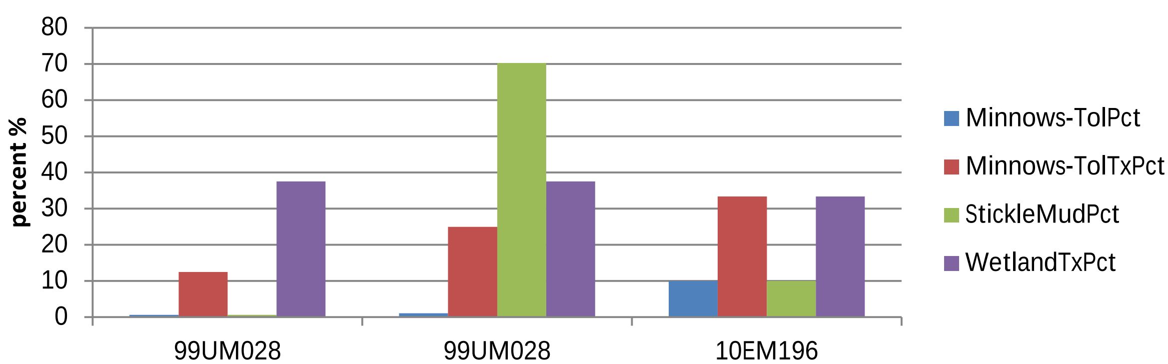


Figure 48: Battle Brook fish metrics for wetland and low DO response taxa

The daily DO flux at Site 2 averaged 6.5 mg/L/day. The daily low DO readings ranged from 2.54 to 3.93 mg/L. The daily maximum DO readings 6.21 to 12.22 mg/L/day. Site 3 the sonde did not function properly during the seven-day deployment.

High daily DO flux is a stressor to the aquatic community.

Dissolved oxygen

Early morning longitudinal DO readings were collected in the summer of 2011 in Battle Brook at four locations. Early morning DO concentrations were always below the state standard of five mg/L (Figure 49), which indicates that low DO was a stressor to aquatic life in 2011. Figure 50 shows all DO readings that were collected at site S004-702 from 2009 to 2011. Data collected later in the day shows an elevated DO concentration. This indicates that there is a high daily DO flux driven by elevated periphyton growth in the stream as seen in Figure 47 above.

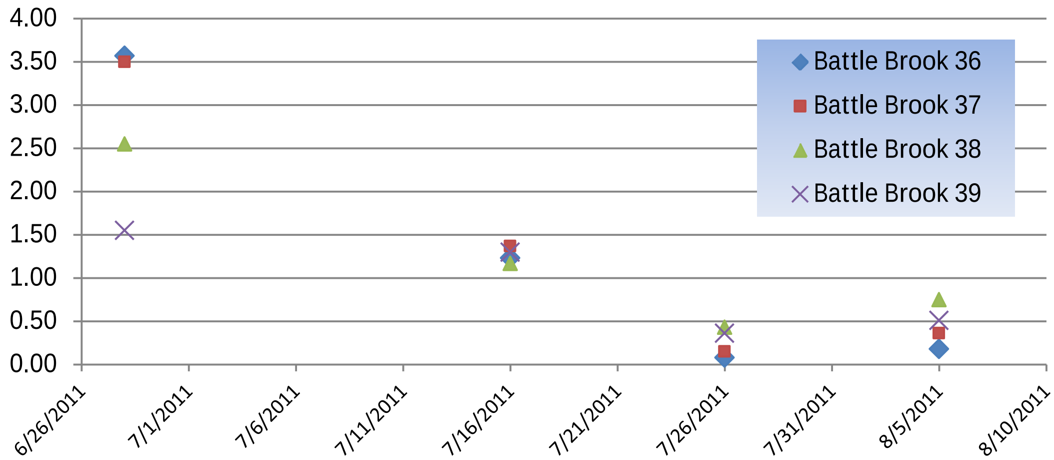


Figure 49: Early morning DO readings pre 9 am for Battle Brook

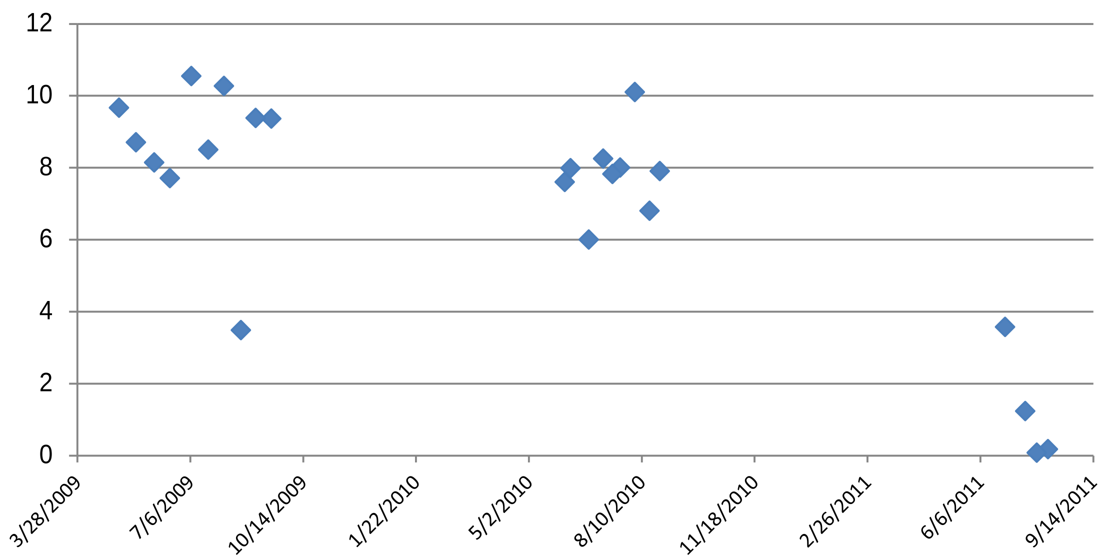


Figure 50: EQuIS site S004-702 DO readings from 2009-2011

Sediment: total suspended solids and bedded sediment

Total suspended solids

Review of the TSS data, collected in 2009 at site S004-704, suggests that TSS is not an issue in the Battle Brook subwatershed (Figure 51)

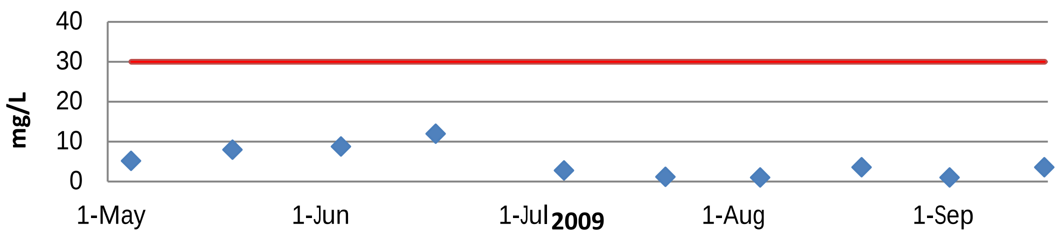


Figure 51: TSS concentrations for Battle Brook at EQuIS site S004-704 for 2009 sampling season

Bedded sediment is a problem within the sampling location at 99UM028. The substrate at this location is 100 percent silt and muck. This is due to the very low gradient in this stretch of stream. The dam located at Elk Lake is nearly 2.5 feet higher than the invert of the culvert at this site. This backs up water from the lake and allows for the settling of fine organic material on the stream bed. Bacterial decomposition of this organic material strips DO from the water column. Additionally, the fine material covers hard substrates which are habitat for macroinvertebrate clingers or scrapers, two important groups contributing to healthy, diverse biological community. Figure 52 shows the individual macroinvertebrate sampled broken into quartiles which represent sensitivity to bedded sediment. Q1 and Q2 are the most tolerant groups to increased fine sediment (Yuan, 2007). The NA group was not assigned a TIV value. The largest percentage of the macroinvertebrate sample with TIVs values is very tolerant to increased fine sediment. With a lack of this group of macroinvertebrates the sample is dominated by wetland species which do not score well when compared to other stream dwelling macroinvertebrate taxa groups. The water flow in this reach is very slow and allows for minimal self-cleaning of the coarser substrate.

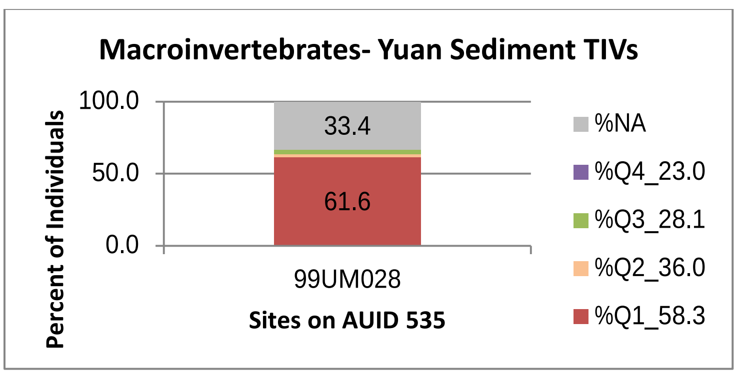


Figure 52: Percent individuals by biological site sampled in Battle Brook, for each quartile based on sediment weighted averages (Carlisle, 2007)

Nitrate toxicity

NO_3 - NO_2 water quality standards / ecoregion expectations

Nitrate data was collected at site S004-702 which revealed that nitrate levels are elevated, however they do not exceed levels high enough to cause toxicity and are often below two mg/L. There is not enough evidence to determine if Nitrate is a stressor to aquatic life.

Connectivity/altered hydrology

Battle Brook is disconnected from the Elk River via a dam located on Elk Lake on 140th Street. The elevation of the dam is 949.28 feet. This dam affects the movement of fish and also impacts the slope of Battle Brook for 2.57 miles upstream. The culvert invert elevation of the next road crossing at CR9 is 946.72 feet and is located 2.13 miles upstream. The culvert invert elevation of the road crossing at 136th street is 949.90 feet, which is 2.57 miles upstream from the dam. Figure 54 below shows the elevation of the downstream inverts of the road crossings for 17.48 miles above Elk Lake.

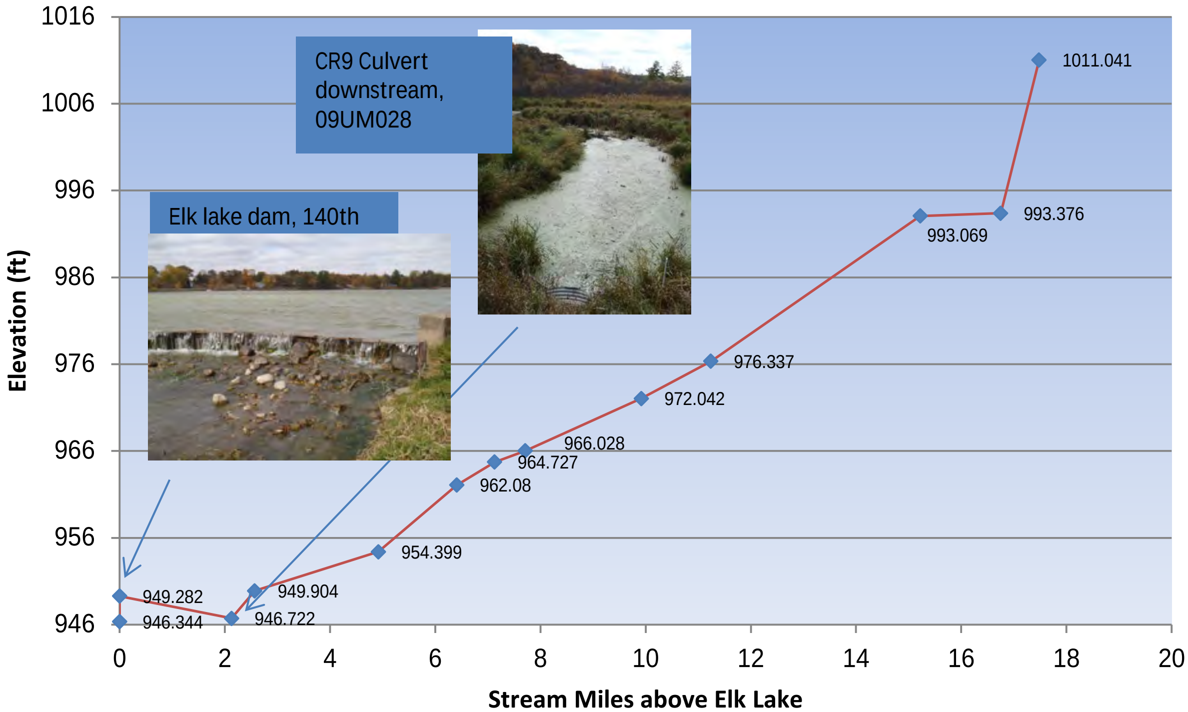


Figure 53: Battle Brook culvert elevations along all roads crossing above Elk Lake and spanning 17.48 miles of stream

The slope change caused by the dam at Elk Lake has caused a change in the hydrology of the lower section of Battle Brook. With the dam controlling the gradient of the lower section of channel and causing water to be permanently backed up for 0.6 miles above the lake, the character of the river here has been changed into a wetland.

Figure 54 shows the 1939 versus the 1991 aerial photos of the reach. Review of this figure shows that the change in water level from the dam has affected the lower wetland riparian area within the stream corridor. There is an increase in wetland riparian and the vegetation appears to have changed as well. This change in slope in the lower portion of Battle Brook has allowed for deposition of fine material and the channel substrate in the bottom 2.5 miles is dominated by silt and muck. There is no suitable gravel or even sand substrate for macroinvertebrates or lithophilic spawning fish species.

Conclusion

The main stressors to the biotic community in the Battle Brook Watershed are low DO concentrations, loss of connectivity/altered hydrology, and excess bedded sediment. The stream channel in the lower reaches of Battle Brook is filled with fine substrates that provide minimal macroinvertebrate habitat. These stressors are related to the flat slope caused by the dam on Elk Lake and large percentage of land (57.5 percent) that is currently farmed for row crops or utilized as pasture for cattle or horse operations, and 15 percent wetlands. During high and low flow conditions there is a large DO daily flux. High nutrient concentrations are causing elevated growth of aquatic plants and periphyton which generally results in abnormal fluctuations in the DO concentrations of streams.

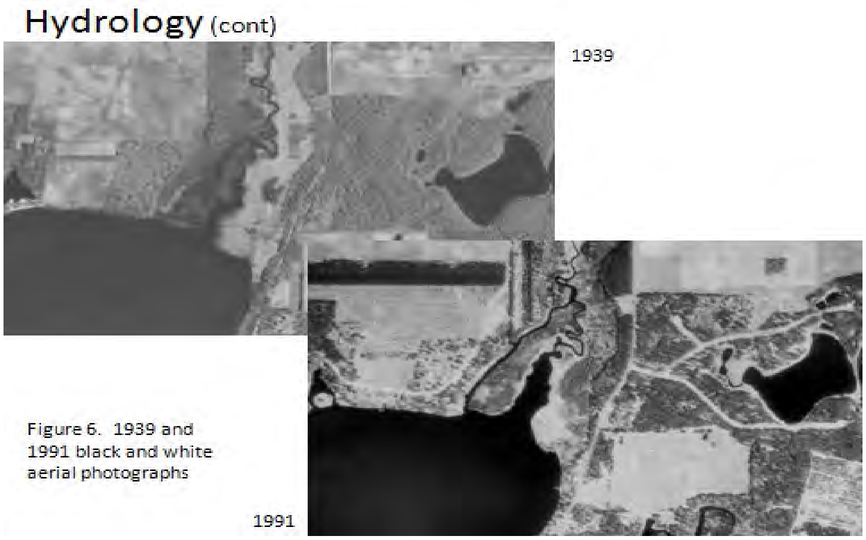


Figure 54: Battle Brook lower section near Elk Lake comparing the 1939 aerial to the 1991 aerial, note the increase in wetland riparian corridor

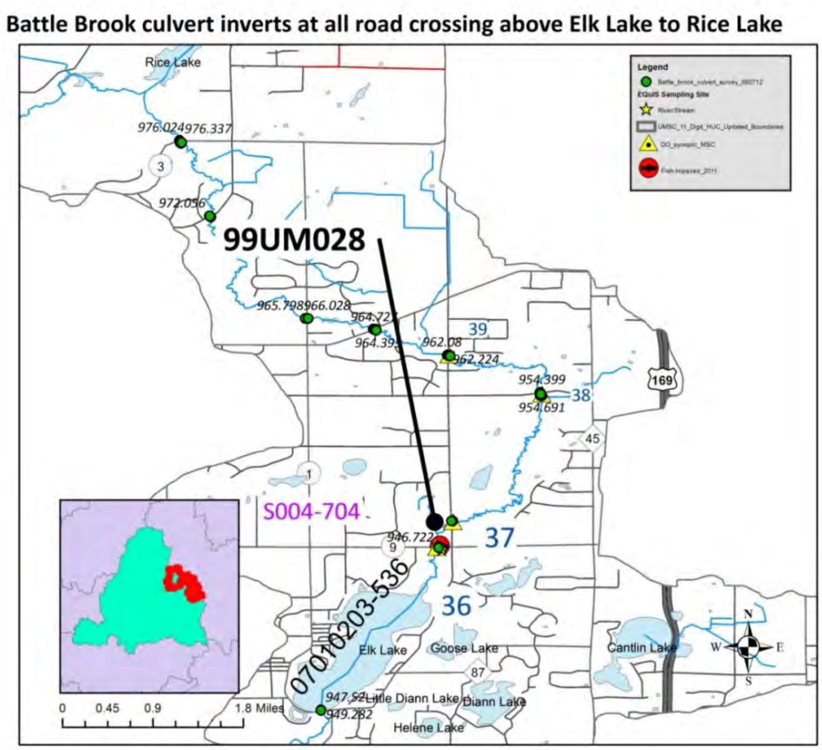


Figure 55: Culvert locations along with culvert invert elevations along Battle Brook from Elk Lake upstream to Rice Lake

Upper Elk River 11 HUC (07010203010)

This 11 HUC is the headwaters to the Elk River which eventually flows into the Mississippi River in the City of Elk River (Figure 56). Historically, this area was dominated by deciduous forest, with areas of “emergent herbaceous wetland” along the riparian corridor of the river. Current land-use is a mixture of agricultural (45 percent cultivated land, 36 percent range land) and natural areas (10 percent of the area remains forest and 4.5 percent wetlands) (Figure 58).

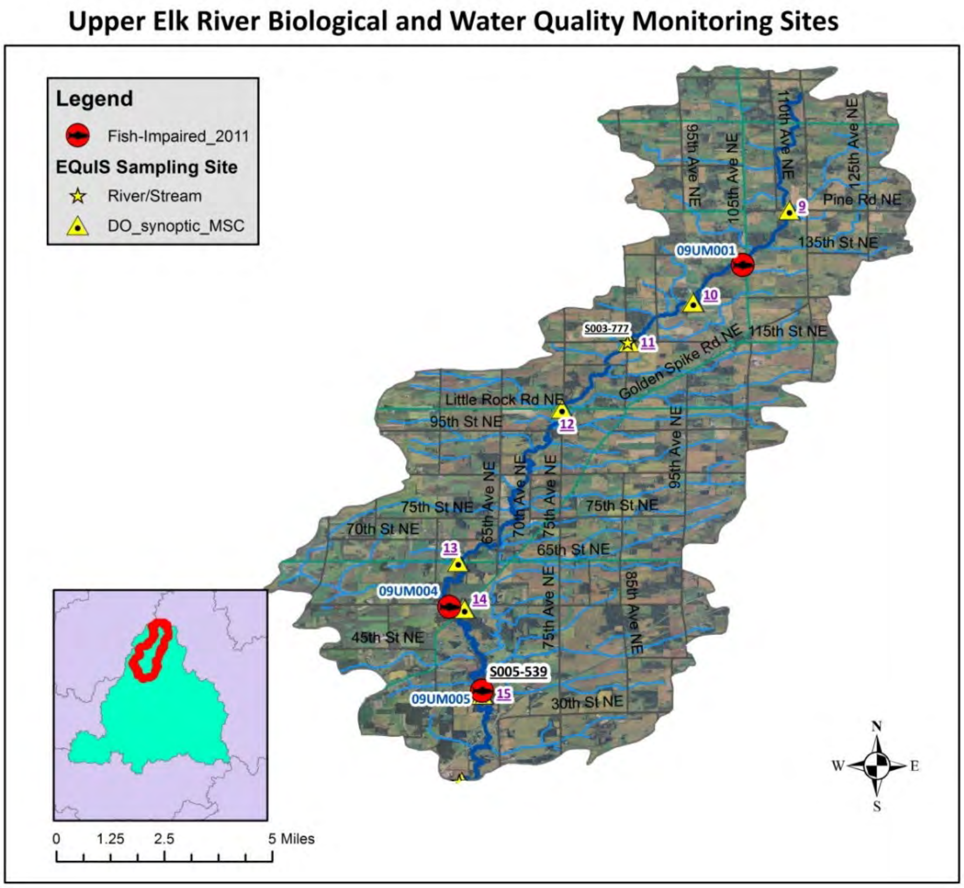


Figure 56: Upper Elk River 11 digit HUC (07010203010) with sampling locations

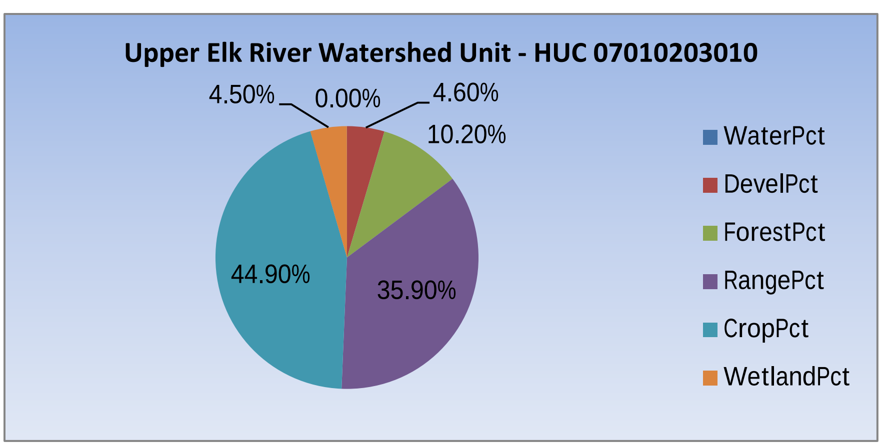


Figure 57: Upper Elk River (07010203010) land use percentages

There are 89 registered feedlots located along this 11 HUC river corridor and its tributaries (Figure 58). There also may be smaller unregistered pasturing operations that are in this HUC that may be contributing to increased nutrient levels and stream bank failure due to animal access and trampling along the banks.

Upper Elk River Registered Feedlot Locations

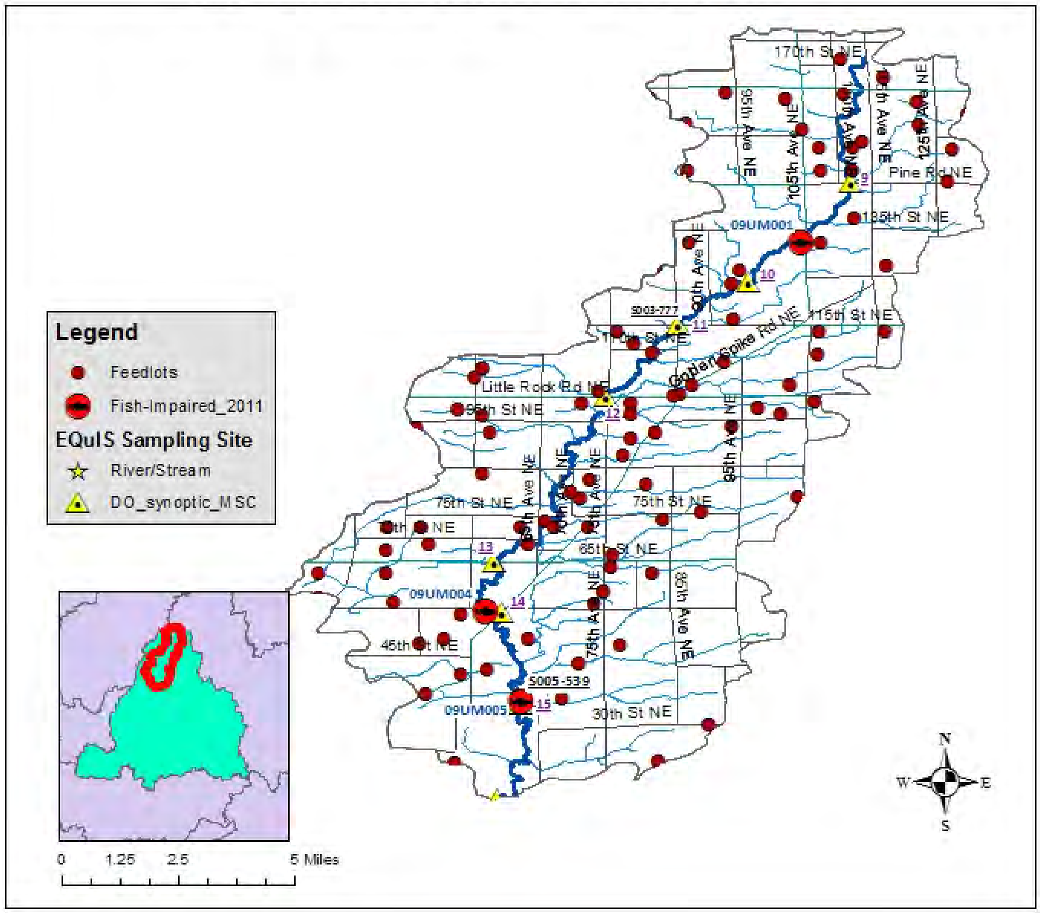


Figure 58: Feedlot density in the Upper Elk River 11 HUC (07010203010)

Nutrients

Evidence of causal pathways-DO flux, chlorophyll-a, and oxygen demand

Total Phosphorus data was collected in 2009 and 2011 at EQuIS site S005-539. This site is located at the downstream end of the 11HUC near biological monitoring site 09UM005. TP data are often well above the proposed criteria of 0.1 mg/L for much of the sampling record Figure 59. TP values are highest during mid to late summer and occurred during low flows in 2009, and medium range flows in 2011(Figure 60). High phosphorus concentrations promote excess growth of algae and other aquatic plants which in turn can lead to high dissolved oxygen flux as these plant material decays. Elevated phosporus concentrations should be considered a stressor within this watershed. Efforts should be made to reduce the movement of phosphorus into streams within this watershed.

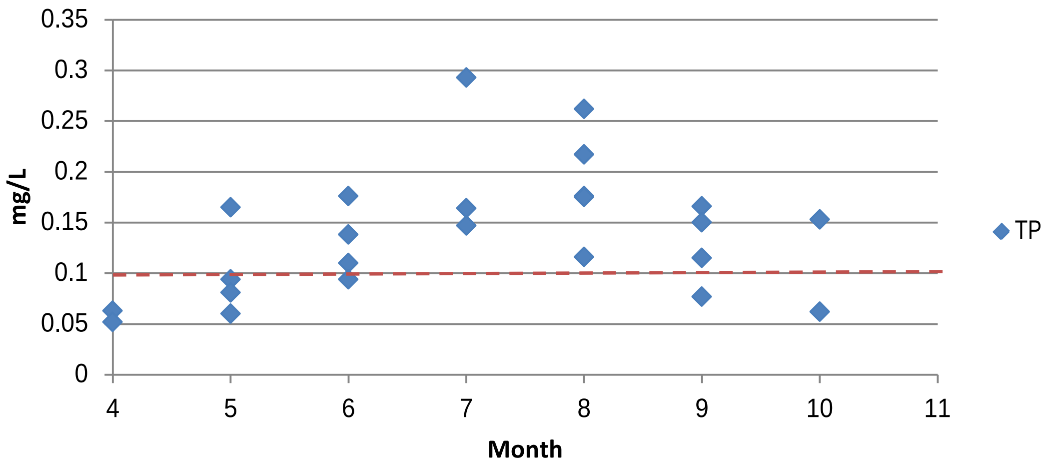


Figure 59: TP values by month collected from Upper Elk River EQuIS site S005-539

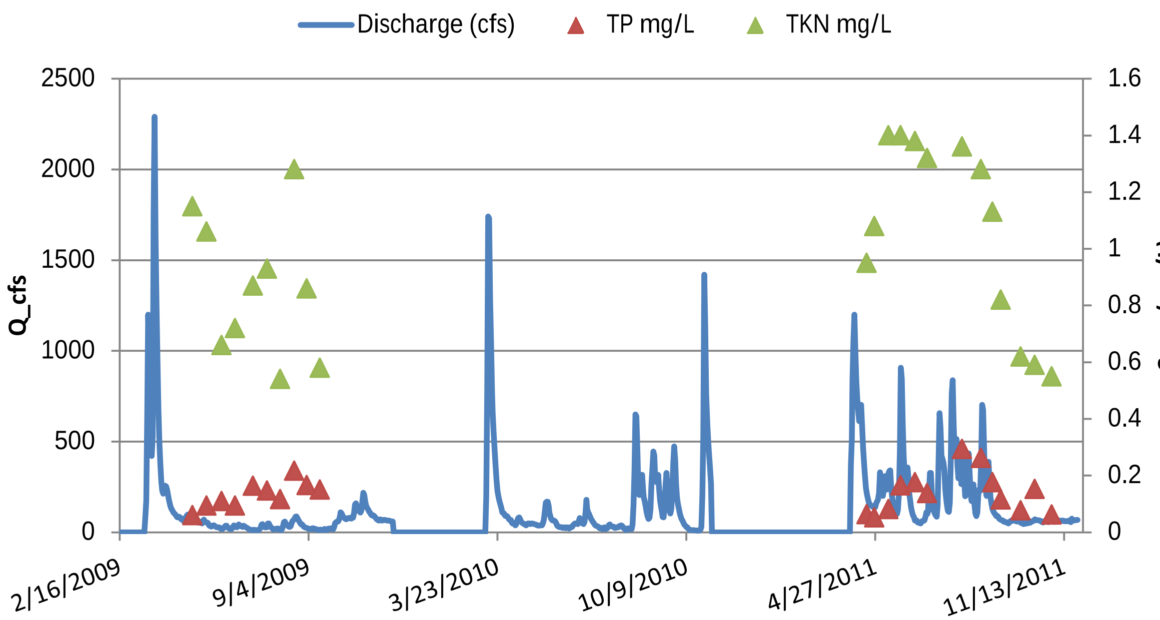


Figure 60: EQuIS site S005-539 TP and TKN data over discharge from Elk River at CR16 gage

Chlorophyll-a

No Chl-a samples were collected in this region however the growth of periphyton along with the color of the water indicate that there is excessive Chl-a in the system (Figure 61). The growth of Chl-a producing plants is a result of the high phosphorus concentrations in the stream. The excessive plant growth will also lead to an increase in daily DO flux. As the plants actively grow during the day they produce oxygen, however at night respiration with consume oxygen. This leads to high fluctuation in daily DO concentrations.

Figure 61: Photos of over widened channel at biological site 09UM001, along with green coloration to water

Sediment: total suspended solids and bedded sediment

Total suspended solids

TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. The TSS data does not indicate that TSS is a stressor to aquatic biology. TSS concentrations were well below the 30 mg/L proposed standard. Across two years of monitoring, with different hydrologic characteristics, TSS was typically below five mg/L and no measurements above 15 mg/L occurred. However, because the TSS values are low does not mean that there is not a significant sediment issue within this 11 HUC. Bank erosion from animal access and altered riparian vegetation, and elevated peak flows caused from ditching and other hydrologic alterations from landscape change are causing excess sediment to be delivered to the stream. Buffers of inadequate width to protect stream bank integrity and aquatic habitat were observed throughout the Upper Elk River 11 HUC. Some of the influx of sediment is being deposited, filling pools and smothering riffles, thus resulting in the loss of important fish and macroinvertebrate habitat.

Bedded sediment

Bedded sediments is likely a stressor to fish and macroinvertebrate assemblages in the upper Elk River. Substrate embeddedness levels were very high (>70 percent) at site 09UM004, the D50 for particle size was 3.0 mm which is very coarse sand, and the response from biota indicated a cause and effect relationship (high abundance of pioneering taxa and high abundance of sediment tolerant individuals) (Figure 62 and 63). Individual fish were ranked based on sediment tolerance values (TIV) developed by Meador and Carlisle (2007). Quartiles 3 and 4 are most tolerant to an increase in TSS concentration. The weighted average TSS concentration is placed on the graph along with the percent of individuals in each quartile. The percent NA are fish that are not assigned a TIV in this paper. The species at site 09UM001 that are not assigned a TIV are central mudminnow and brook stickleback. Both species are tolerant to low DO concentrations and survive in less than ideal conditions.

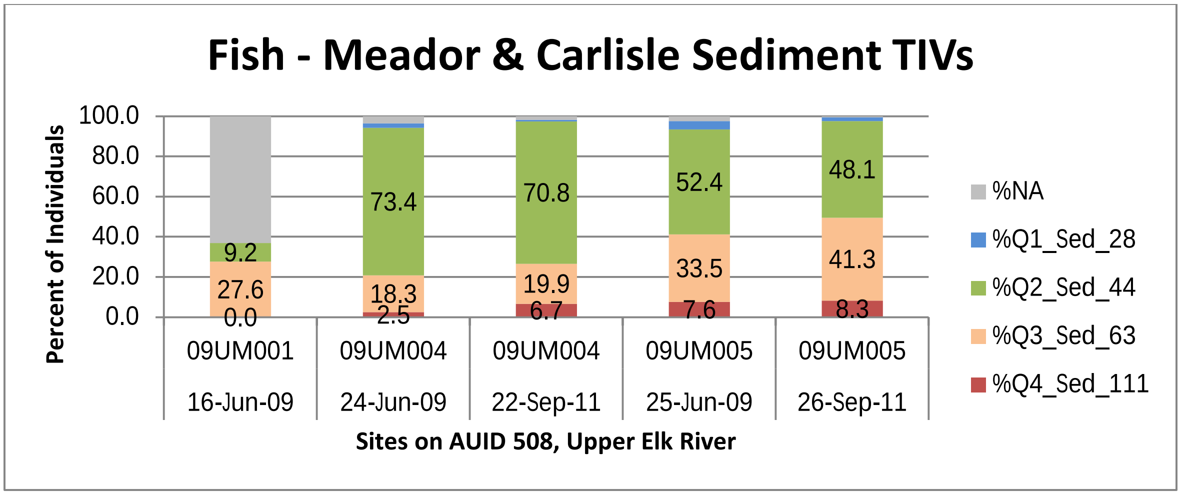


Figure 62: Percentage of fish by biological site sampled in the Upper Elk River, for each quartile based on suspended sediment weighted averages (Meador and Carlisle, 2007)

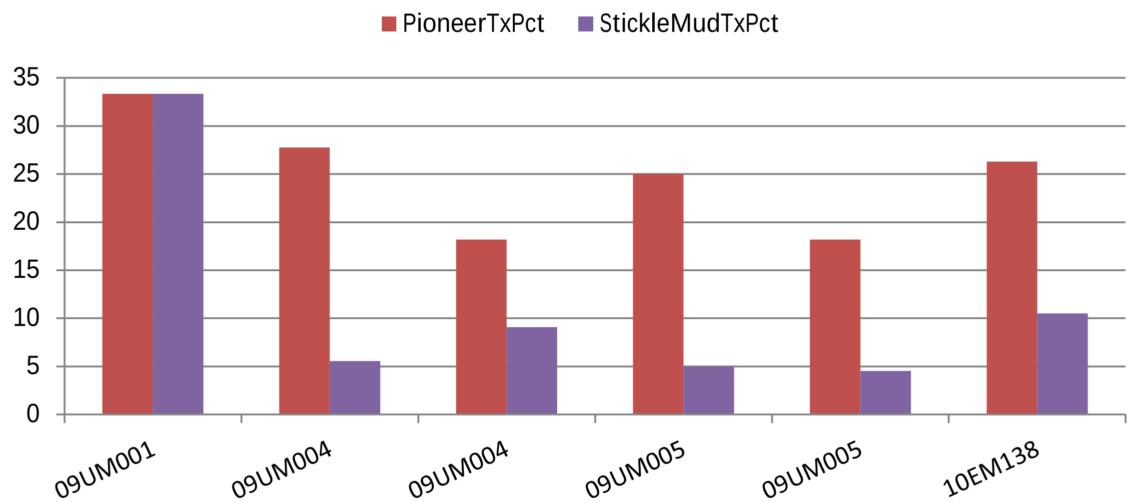


Figure 63: Percentage of fish in the sample that is very tolerant to pollutants or pioneering species

The macroinvertebrate community was slightly worse than the fish. The balance of tolerant to intolerant groups was heavily skewed toward the tolerant taxa. At the farthest upstream site (09UM001), very tolerant organisms made up 79 percent of the sample vs. intolerant ones at 0.3 percent. Moving downstream, the Very Tolerant metric progressively decreases, indicating an improvement in community structure (Figure 64). The macroinvertebrate sample was analyzed based on sediment tolerance values (percent sands and fines) calculated by Carlisle. The individuals in the macroinvertebrate sample were assigned a Quartile value based on 1-4 to indicate there tolerance to increased fines or bedded sediment. Quartile 1 and 2 are the most tolerant to increased bedded sediment. Figure 65 shows that as we move from the headwaters downstream the percent of macroinvertebrates that are tolerant to excess bedded sediment decreases. The high percentage of Q1 and Q2 macroinvertebrates at the two locations farthest upstream indicate that excess fines is a stressor in the farthest upstream reaches of this AUID. As we moved longitudinally downstream, the percent of less tolerant macroinvertebrates increases significantly. This may indicate an improvement in coarse substrate downstream.

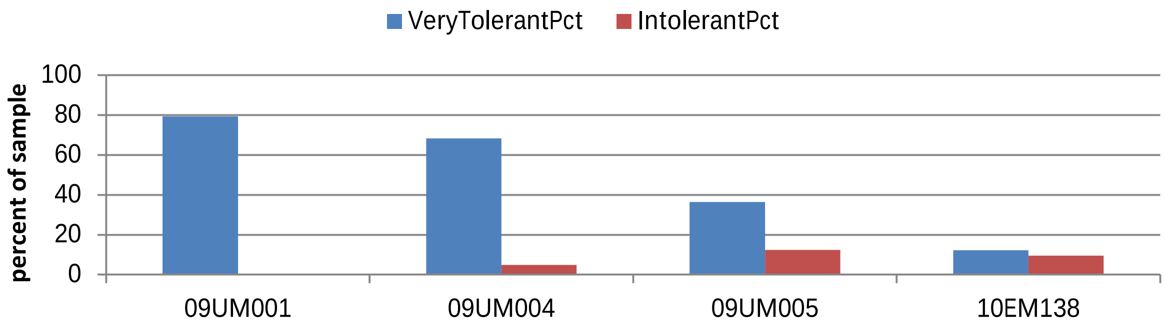


Figure 64: Macroinvertebrate community indices for very tolerant species versus intolerant species

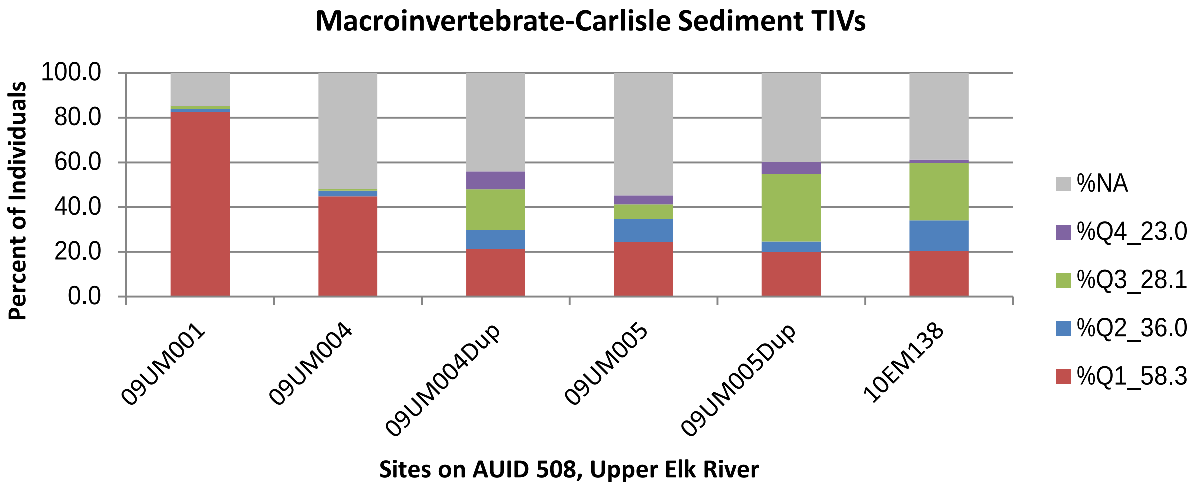


Figure 65: Percent individuals by biological site sampled in Upper Elk River, for each quartile based on sediment weighted averages (Carlisle, 2007)

Dissolved oxygen

Early morning (pre-9am) DO readings were collected in summer 2011 at six locations. Early morning DO concentrations were routinely below the state standard of five mg/L at site Elk 9, the farthest upstream location (approximately one mile upstream of 09UM001). These measurements indicate that low DO is likely a stressor to aquatic life in the farthest upstream reaches of the Elk River. Figure 64 above also supports that low DO is an issue at 09UM001; stickleback taxa percentage is high and pioneering species dominate the fish sample at this site.

A 28-day continuous DO record for site S005-539 at 35th Street NE shows no DO violations this far down in the watershed during 2011. Also, the daily flux ranged from 1.5 to 2 mg/L, which is very good. The increased gradient and coarse substrate in riffles are creating a well oxygenated stretch of stream. Review of weighted average DO TIVs created by Meador and Carlisle show that 70 percent of the fish sample are tolerant of low DO at site 09UM001. This decreases to around 30 percent at sites 09UM004 and 09UM005. This indicates that low DO is a stressor in the farthest upstream reaches of the Upper Elk River.

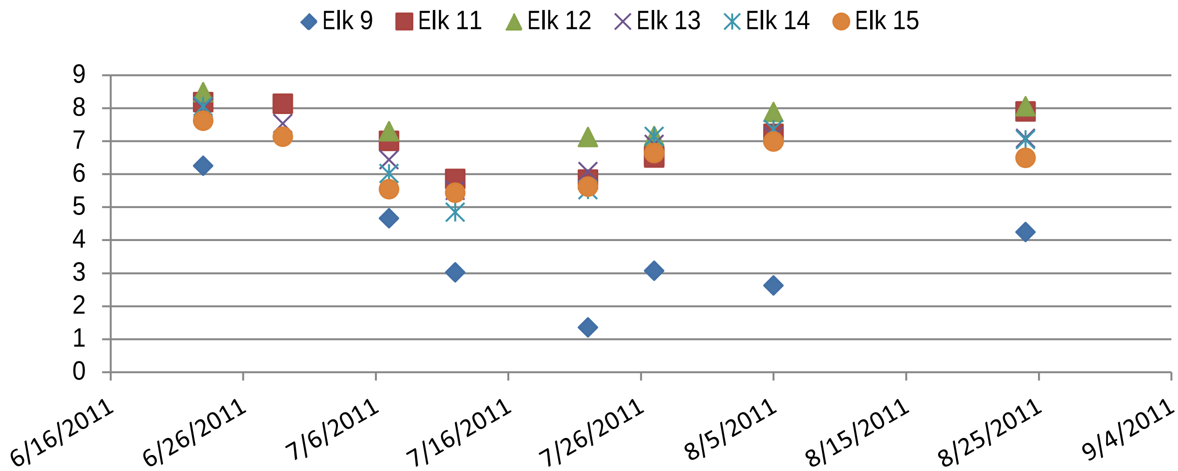


Figure 66: Early morning DO readings for the Upper Elk River AUID 508

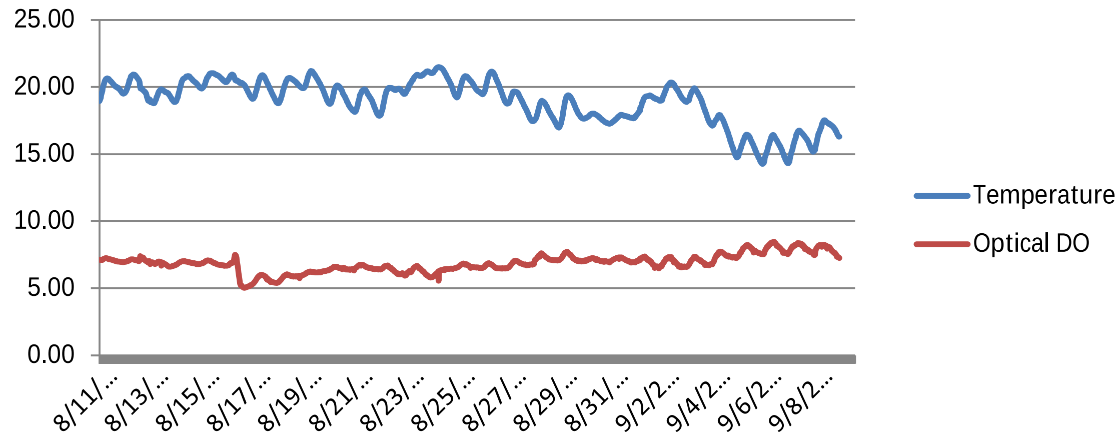


Figure 67: Continuous sonde deployment at Elk River on 35th Street NE

Conclusion

The three main stressors to the biotic community in the Upper Elk River are elevated phosphorus, low DO concentrations in the headwaters, and bedded sediment causing a lack of habitat. These stressors are all related to the large percentage of land (81 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. Stream channel instability is causing a general lack of in stream habitat. Pools are filling with fine sediment and riffles are lacking coarse substrate in the far headwaters of the Elk River. Cattle pastures are common in the upstream watershed and free animal access to the stream banks is accelerating bank erosion and increasing nutrient concentrations through manure runoff and bank erosion. Increased nutrient concentrations are causing elevated growth of aquatic plants and a potential for abnormal fluctuations in the DO concentrations of streams.

Lower Elk River 11 HUC (07010203040)

The Lower Elk River 11 HUC lies in the central portion of the Mississippi St. Cloud watershed. This watershed area starts just southeast of the St. Cloud Municipal Airport and runs southeast to the city of Elk River (Figure 68). This 11 HUC is the headwaters to the Elk River which eventually flows into the Mississippi River in the city of Elk River. Historically, this area was dominated by deciduous forest, with areas of "emergent herbaceous wetland" along the riparian corridor of the river. Current land-use is a mixture of agricultural (37 percent cultivated land, 19 percent range land), natural areas (24 percent of the area remains forest and seven wetlands), and 10 percent is developed (Figure 70).

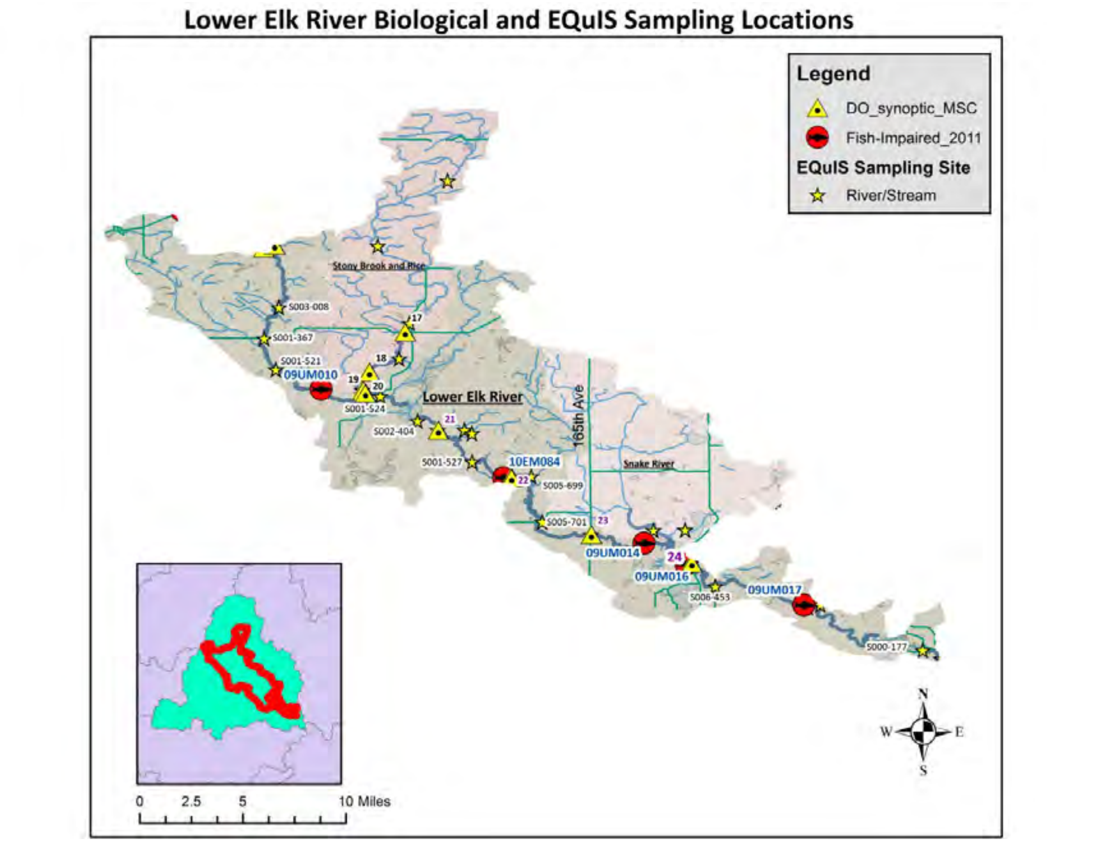


Figure 68: Lower Elk River 11 digit HUC (07010203040) with sampling locations. Also shown is the Stony Brook and Rice Creek 11 HUC and the Snake River 11 HUC for reference

A completed TMDL for this section of the Elk River for excessive nutrients and Turbidity is located at the following website: Elk River Watershed Association TMDL Report. This TMDL will help address the biological impairments located in this 11 HUC.

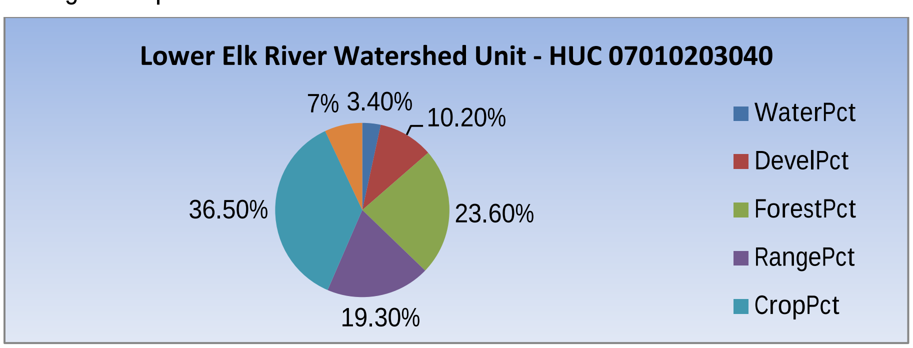


Figure 69: Lower Elk River land use percentages

There are 22 registered feedlots located along the river corridor and its tributaries (Figure 70). There also may be smaller unregistered pasturing operations that are in this HUC that may be contributing to nutrient levels and bank failure due to animal access and trampling along the stream banks. The Stony Brook and Rice 11 HUC has 21 registered feedlots that drain directly into the Lower Elk River. This drainage area exports high nutrients and is currently listed as impaired for DO.

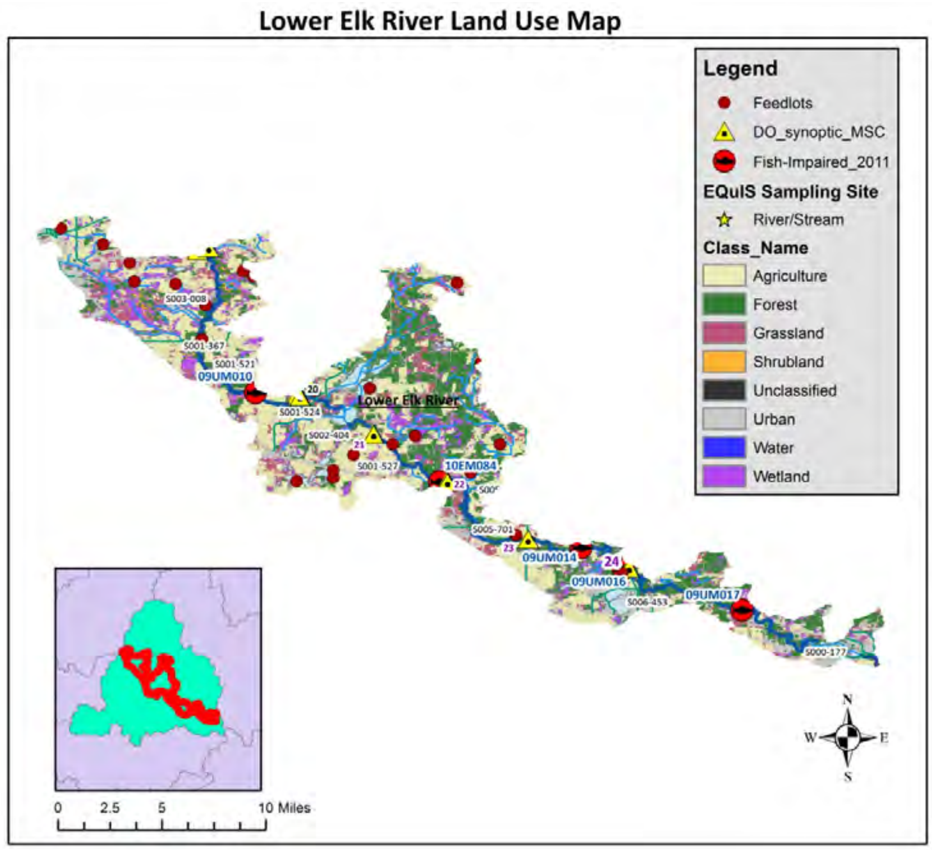


Figure 70: Land use in the Lower Elk River 11 HUC (07010203040)

Nutrients

Evidence of causal pathways-DO flux and chlorophyll-a concentrations

Total phosphorus data was collected from 1996 through 2009 at EQuIS site S000-278. This site is located at the downstream end of the 11 HUC near biological monitoring site 09UM016. TP data are often above the proposed criteria of 0.1 mg/L for much of the sampling record (Figure 71). The TP values are highest during snowmelt and again in mid to late summer. The average concentration for the period was 0.11 mg/L while the maximum concentration was 0.336 mg/L. The record has 224 samples for this location, of which 126 were above 0.100 mg/L. The early spring high concentrations are attributed to sediment being washed into the stream via overland flow and bank failure, while the midsummer peaks are associated with algal growth in the channel and the high TP concentrations coming out of Big Elk Lake. TP concentrations from 2009 increase as the summer progressed (Figure 72). This may help us target TP reductions by reducing TP concentrations in the mid-summer and concentrate on better management of phosphorus discharge from Big Elk Lake. Big Elk Lake has a completed TMDL that can be found here: Elk River Watershed Association TMDL Report. Strategies for phosphorus reductions can be found in this report. Elevated phosphorus concentrations should be considered a stressor within this watershed due to its role in lowering DO.

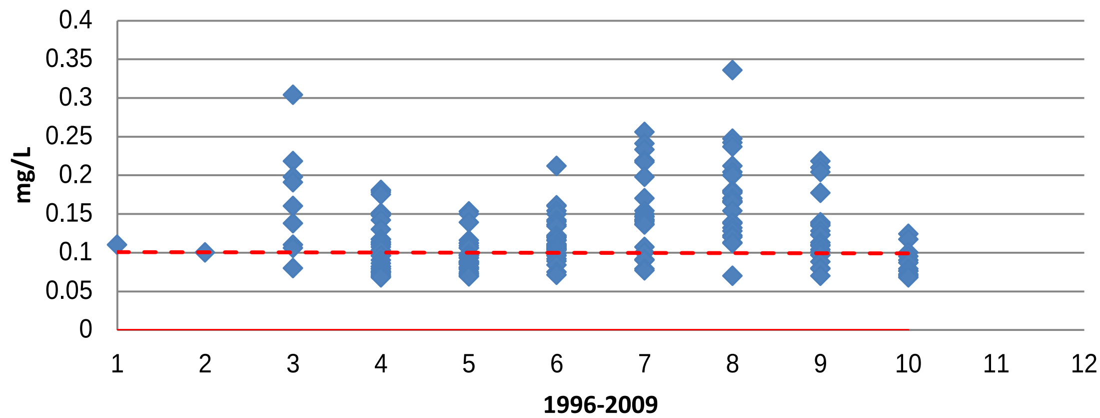


Figure 71: TP values by month collected from Lower Elk River EQuIS site S000-278

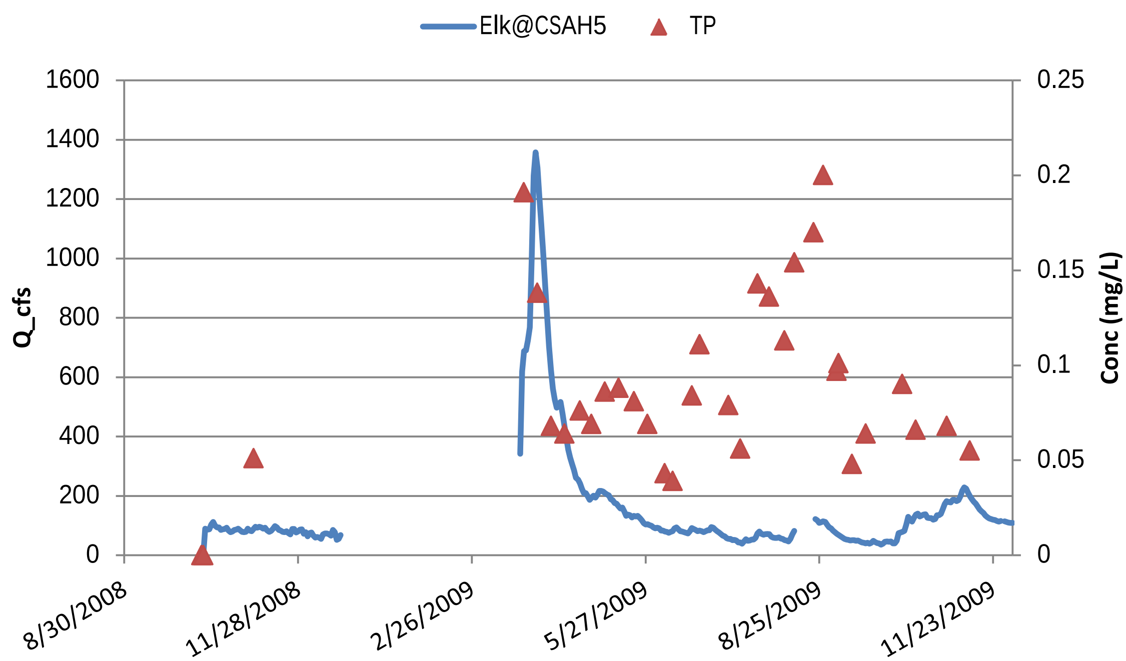


Figure 72: EQuIS site S000-278 TP data over discharge from Elk River at CR5 gage

Chlorophyll-a

No Chl-a samples were collected in this region however the growth of periphyton along with the color of the water indicate that there is excessive Chl-a in the system (Figure 73). Since chlorophyll levels are directly related to phosphorus levels efforts to reduce phosphorus concentrations will in turn reduce chlorophyll levels.

Elk River at CR11 (upstream of 09UM014) **Elk River at CR11**

Figure 73: Photos of heavily vegetated channel, one mile upstream of biological site 09UM014, along with green coloration to water

Sediment: turbidity and bedded sediment

Turbidity

The Lower Elk River 11 HUC currently is listed on the 303d list as impaired for turbidity, which has been addressed with the Elk River Watershed-Multiple Impairments TMDL Project, completed and approved by EPA in the summer of 2012. Turbidity is a source of impairment to biological community within this 11 HUC and the corresponding TMDL should address the issue of turbidity. The link listed at the front of this section will connect to the final report on the MPCA webpage.

TSS results were used to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. The TSS data does not indicate that TSS is a stressor to aquatic biology. TSS concentrations were well below the 30 mg/L proposed standard. However, TSS at the sampled levels does not necessarily mean that there is not a significant sediment issue within this 11 HUC. Bank erosion from animal access, riparian vegetation change, and excessive high flows caused from ditching and altered hydrology are causing excess sediment to be delivered to the stream. Buffers of inadequate width to protect streambank integrity and aquatic habitat were observed throughout the Upper Elk River 11 HUC. Some of this sediment input is deposited, filling pools and smothering riffles, resulting in the loss of important fish and macroinvertebrate habitat.

Strength of evidence summary for bedded sediment

Bedded sediments (BS) are likely a stressor to fish and macroinvertebrate assemblages in the Lower Elk River, as substrate embeddedness levels were very high (75 percent) at site 09UM016, and the D_{50} for particle size was 0.35 mm which is very fine sand. The response from biota indicated a cause and effect relationship with low abundance of fish (less than 15 percent of taxa in the fish samples) that require riffles. The fish samples were analyzed to determine the sensitivity to suspended sediment using Meador and Carlisle sediment tolerance values (TIV) (Meador & Carlisle, 2007). Quartile 1 has the lowest sensitivity to suspended sediment. Quartile 4 has the most tolerance to increased suspended sediment. If the TSS concentration for aquatic life impairment is set at 30 mg/L for the Elk River, the fish quartiles at Q2-Q4 would be considered tolerant. Figure 74 displays the distribution of individual fish based on the ranking system from Meador and Carlisle.

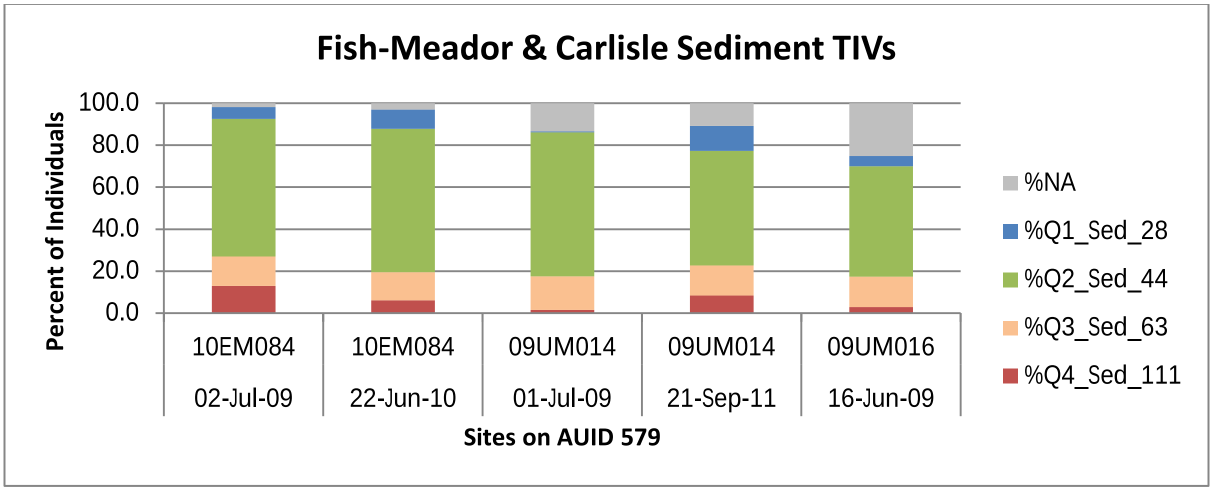


Figure 74: Percentage of fish that are sensitive to suspended sediment based on Meador and Carlisle (2007). Quartile 2 through Quartile 4 would be tolerant to TSS values above the proposed TSS standard for the Elk River

The current fish community is tolerant to elevated TSS concentrations. It can then be concluded that the fish community would also be tolerant to an increase in fine sediment. An increase in fine sediment equates to an increase in bed sediment and a decrease in available coarse substrate.

Traveling downstream from sample site 10EM084, the macroinvertebrate community changes from a collector-filterer to a collector-gatherer assemblage. There is a reduction of pollutant intolerant species farther downstream. At site 09UM016 the percent of intolerant individuals was very low (less than three percent). The Snake River 11 HUC discharges into the Elk River between sampling site 09UM014 and 09UM016. This 11 HUC was not assessed due to the high amount of channelization. These channelized reaches may be carrying a high sediment load contributing some of the fine material and substrate embeddedness seen at site 09UM016.

Dissolved oxygen

Early morning (pre- 9am) longitudinal DO readings were collected in the summer of 2011 at four locations and concentrations were routinely below 5 mg/L at site Elk 23-24 which is the downstream of the city of Becker. This indicates that low DO is a likely stressor to aquatic life in these reaches of the Elk River. The DO sampling was conducted to determine the effect of the high algal abundance in this river reach flowing out of Big Elk Lake. It appears that as the algae move downstream there is some diurnal response that is causing significant drops in the early morning DO concentrations of the river. The readings were collected within an hour of each other and the data solidifies the case that the elevated nutrients in Big Elk Lake are affecting the downstream section of the Elk River by exporting high algal biomass, increased water temperature, and causing a high daily flux in DO concentrations.

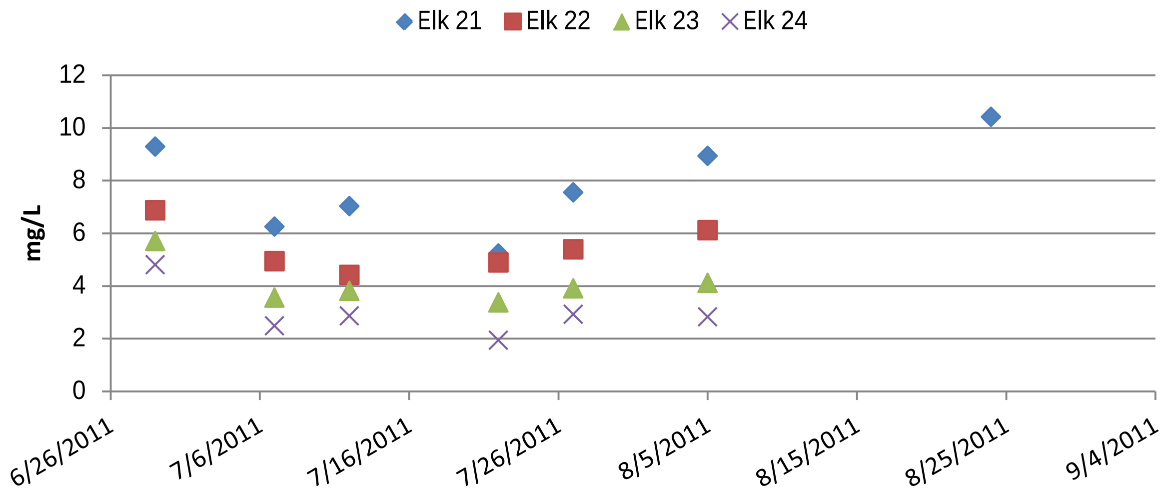


Figure 75: Early morning DO readings in Elk River below Big Elk Lake

Individual fish numbers were ranked according to Meador and Carlisle weighted mean DO TIVs. The individual fish were assigned a TIV value and placed into quartiles to represent the percent of individuals that are sensitive to low DO concentrations. Quartile 1 and 2 are fish that are the most tolerant to low DO, approximately 40 percent of each sample was tolerant to low DO levels (Figure 76). Northern redbelly dace and blacknose shiner make up the majority of the NA quartile and are both categorized as a sensitive fish species and blacknose shiner is also an intolerant species. Sampling in 2009 at sites 09UM014 and 09UM016 had 199 and 142 blacknose shiners counted. It is unclear if blacknose shiner is tolerant to low DO, however in Freshwater Fishes of Canada (Scott, 1973) it is noted that the species is intolerant of turbidity. Site 09UM016 is below the snake river AUID which is channelized. The low DO readings at Elk24 and the fish species present indicate that the effects of the Snake River AUID are negatively affecting this AUID. This data is inconclusive to determine if low DO is affecting the fish population. No long term deployment of sondes occurred in this 11 HUC as the synoptic data was strong enough evidence to show that low DO is a stressor to the aquatic community.

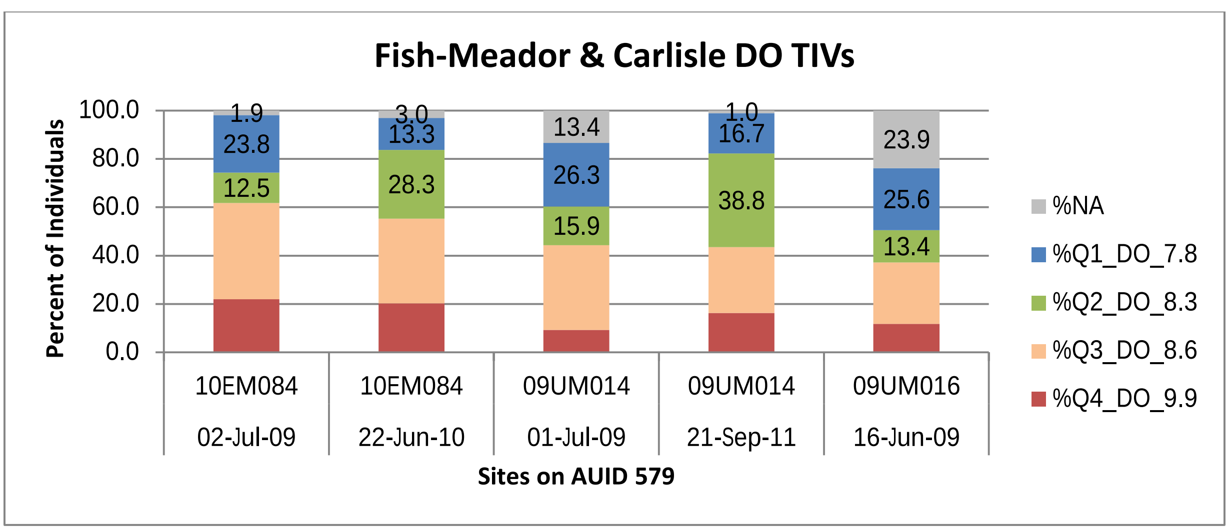


Figure 76: Percent individuals by biological site sampled in Lower Elk River, for each quartile based on DO weighted averages (Meador and Carlisle, 2007)

Conclusion

The two main stressors to the biotic community in the lower Elk River are elevated TP which in part causes low DO concentrations in the lower portion particularly below Big Elk Lake, and bedded sediment causing a lack of habitat. These stressors are all related to the large percentage of land (56 percent) that is currently farmed for row crops or utilized as pasture for cattle or horse operations, and 10 percent of the land is developed. Bank erosion is causing fine sediment to accumulate on the stream bed and fill pools and riffles. This is leading to 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.

Clearwater River 11 HUC (07010203730)

Clearwater River 11 HUC (07010203730) lies in the southwest side of the Mississippi St. Cloud watershed. This subwatershed starts at Clear Lake about three miles southwest of Watkins, and flows east-northeast into Clearwater Lake (Figure 77). Clearwater River flows into the Mississippi River in the town of Clearwater. Historically, this area was dominated by deciduous forest, with areas of "grassland/herbaceous" along the riparian corridor of the river. Current land-use is a mixture of agricultural (45 percent cultivated land, 19.1 percent range land) and natural areas (16.5 percent of the area remains forest and 4.4 percent wetlands) with 6.7 percent of the watershed being developed (Figure 78).

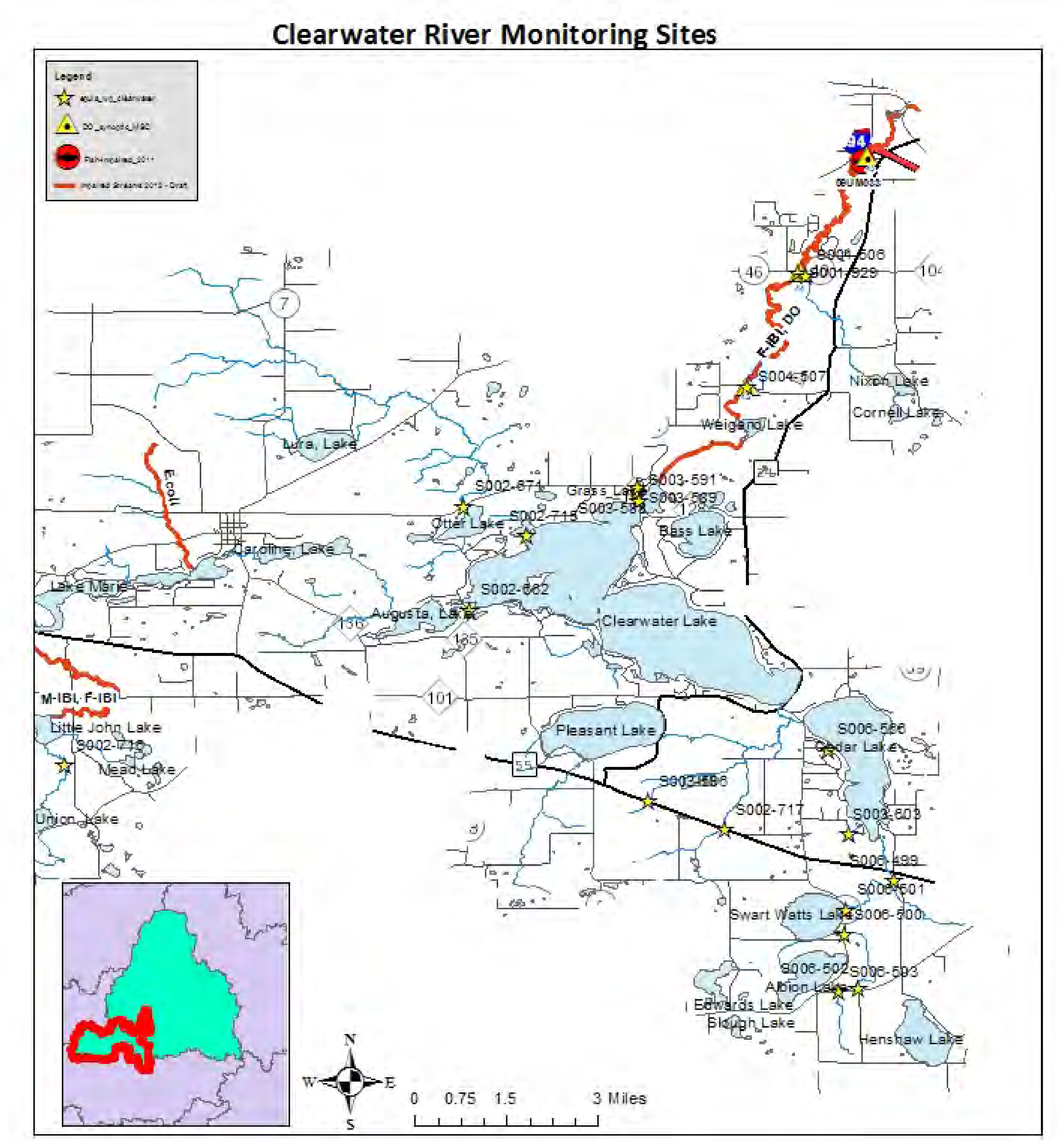


Figure 77: Clearwater River 11 digit HUC (07010203730) with sampling locations

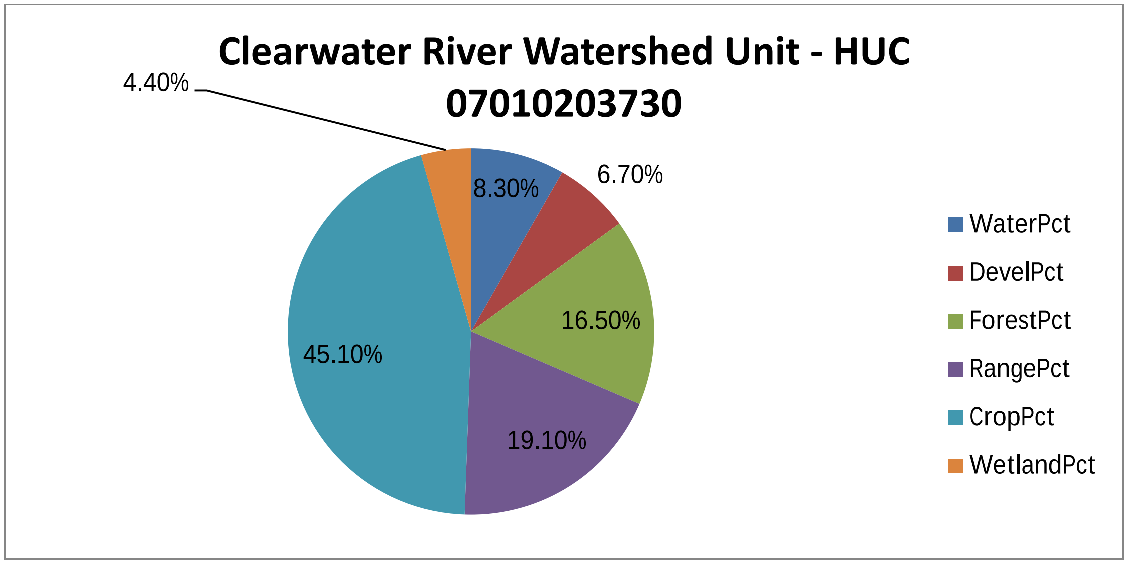


Figure 78: Clearwater River land use percentages

There are 198 registered feedlots located along the river corridor or its tributaries in this 11 HUC (Figure 79). There may be smaller unregistered pasturing operations that are in this HUC that may be contributing to nutrient levels and bank failure due to animal access and trampling.

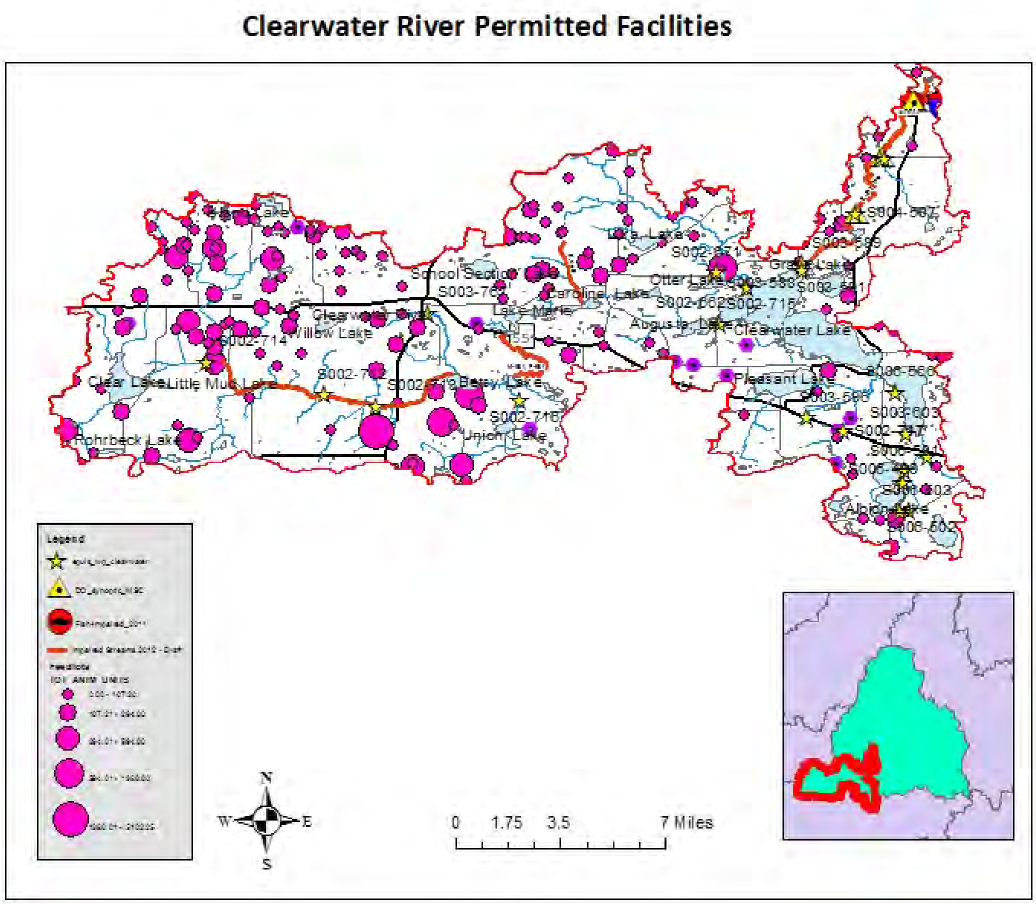


Figure 79: Feedlot density in the Clearwater River 11 HUC (07010203730)

Nutrients

Evidence of causal pathways-DO flux, chlorophyll-a, and oxygen demand

Nutrient enrichment, chlorophyll-a concentrations, and measures of BOD are all factors in the dissolved oxygen balance of streams.

Total Phosphorus (TP) data was collected 40 times from 2007-2010 at EQuIS site S004-508, the downstream end of the 11HUC near biological monitoring site 09UM003. TP data was also collected at various locations upstream from this station. Average TP data are below the proposed River criteria of 0.1 mg/L during all sampling years (Figure 80). The TP values were collected during various flow levels. There are several lakes upstream of this sampling location which can buffer the river as phosphorus that is attached to sediment particles settles out in the lakes. Elevated TP concentrations do not appear to be a stressor within this watershed below the chain of lakes. However, site S003-413 which is above the chain of lakes has very high nutrient concentrations along with high daily DO flux (Table 18). This area of the Clearwater River watershed has an existing TMDL for DO which is located here http://www.pca.state.mn.us/index.php/view-document.html?gid=14980.

Table 18: Comparison of total phosphorus statistics for Clearwater River sampling points

EQuIS Site Name	TP (minimum) mg/L	TP (maximum) mg/L	TP (average) mg/L
S004-508 (below lake chain)	0.009	0.057	0.0257
S003-413 (CSAH 15) above lake chain	0.041	1.74	0.302

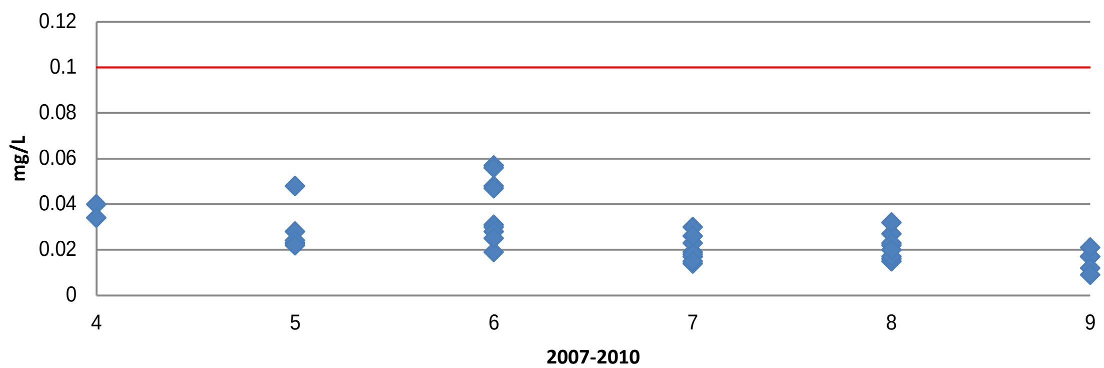


Figure 80: TP values by month collected from Clearwater River EQuIS site S004-508

Chlorophyll-a

There were 25 samples collected for Chl-a analysis from 2007 to 2010. The minimum value was 1 µg/L, the maximum value was 21µg/L, and the average chl-a concentration was 3.9µg/L. This reach of river is located 0.8 miles SW of Clearwater, Minnesota. The site is located below Clearwater Lake and upstream from a dam located on the Clearwater River on CR 75 just SW of the city of Clearwater. The chl-a concentrations are indicative of what is coming out of Clearwater Lake. There were four periphyton samples collected in 2009 in the Clearwater River. These four samples were collected by scraping rocks to collect attached algae and diatoms, and analyzed for Chl-a concentrations. Concentrations ranged from 3010 µg/L in June to 1180 µg/L in August, 2009. This data was collected to determine whether an overabundance of periphyton grows on the stream bottom here.

Dissolved oxygen flux

No sondes for recording continuous oxygen levels were deployed during 2011 at this monitoring location. The synoptic data collected indicated an impairment.

Sediment: total suspended solids and bedded sediment

Total suspended solids

TSS data was collected from 2007 through 2010. The minimum value was below detection, the maximum concentration was 36 mg/L, and the average was 4.6 mg/L. The draft TSS standard for the Clearwater River has been set at 30 mg/L, not to be exceeded in more than 10 percent of samples (collected April-September) within a 10-year data window. There is not enough evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the Clearwater River watershed. Sampling site S004-508 is located below the Clearwater lake outlet and there are two additional impoundments that the river flows through. Any upstream contributions of TSS would be settled out by the time the Clearwater River flows past sampling location S004-508. Figure 81 shows the location of the Clearwater lake outlet and the location of the Clearwater River dam at CR75. Land use in this downstream section is still heavily dominated by row crop agriculture, however the TSS sample results suggest that there is not a significant amount of suspended sediment entering the river in this downstream area. Figure 82 shows the individual fish samples separated into quartiles based on weighted mean suspended sediment TIVs developed by Meador and Carlisle,2007. Quartiles 3 and 4 are the fish most tolerant to TSS. The fish samples are dominated by less tolerant fish species. Therefore, TSS is not believed to be a stressor.

Bedded sediment

Riparian grazing/bank erosion

Rangeland and pasture are common landscape features throughout the Clearwater River watershed. Most of these areas are operated for cattle grazing but several small horse farms were noted during reconnaissance trips on the river. It is common to place pastures along streams to give animal's free access to water. In some areas, the riparian corridor along the Clearwater River has been cleared for pasture and heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect stream banks and provide shading. Exposure of these altered areas to weathering, trampling, and sheer stress from high flow events is increasing the quantity and severity of bank erosion.

Strength of evidence summary for bedded sediment

Bedded sediment is likely a stressor to fish and macroinvertebrate assemblages in the Clearwater River. Substrate embeddedness levels were very high (>70 percent) at site 09UM003, the D_{50} for particle size was 3 mm, which is coarse sand, and the response from biota indicated a cause and effect relationship (increased abundance of benthic insectivore taxa as we move downstream(Figure 83)). Macroinvertebrate samples were analyzed using fine sediment TIVs based on US EPA document EPA/600/P-04/116F. Figure 84 displays the individual macroinvertebrate percentage based on tolerance to fine sediment. Quartiles 1 and 2 are the most tolerant to fine sediment or embeddedness. There are very few individuals in quartiles 3 and 4 which are least sensitive to embeddedness. This evidence suggests that the macroinvertebrate community is impacted by fine sediment at both sites.

Figure 81: Clearwater River reach below Clearwater Lake outlet and the Mississippi River. This reach has a dam located at CR75 which prohibits fish passage and controls channel hydraulics

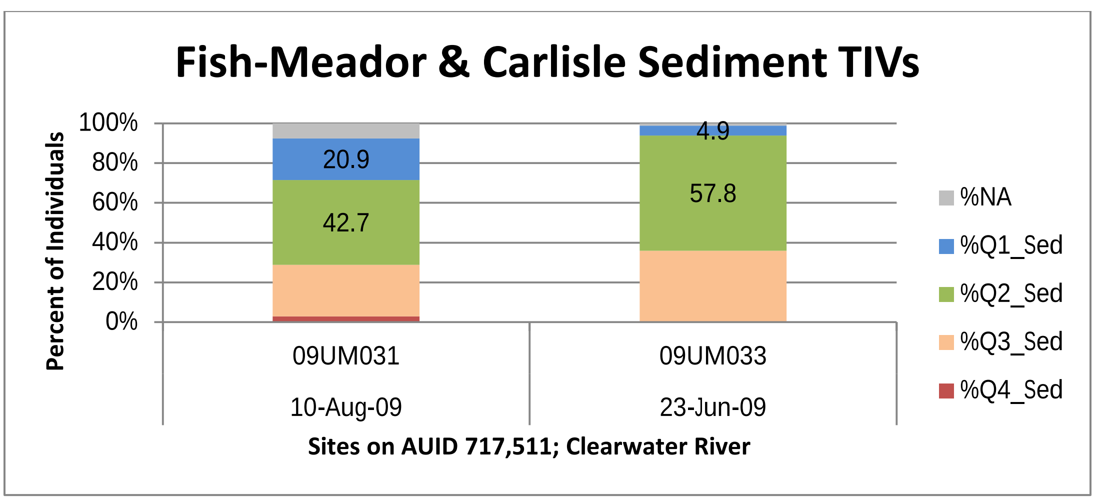


Figure 82: Percent individuals by biological site sampled in Clearwater River, for each quartile based on suspended sediment weighted averages (Meador and Carlisle, 2007)

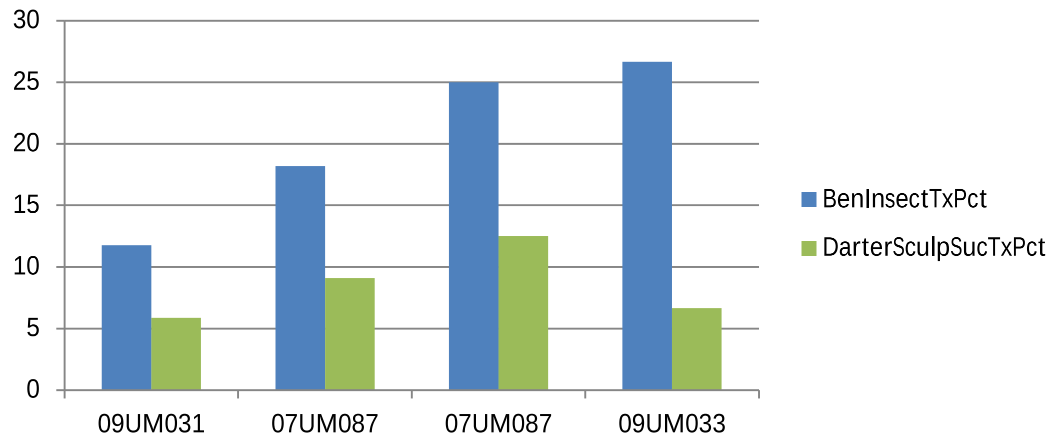


Figure 83: Percentage of fish taxa that are benthic insectivore feeding groups and sensitive taxa such as darters, suckers, and sculpin

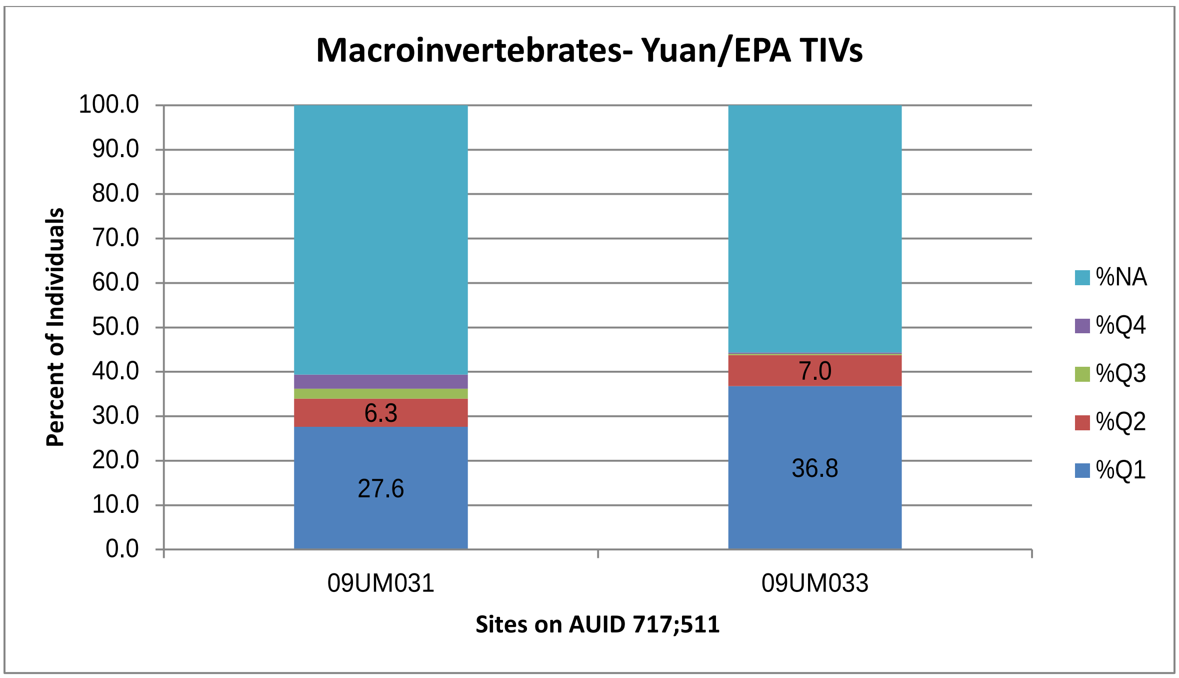


Figure 84: Percent of macroinvertebrate individuals sampled by site in Clearwater River, for each quartile based on fine sediments as a stressor (Yuan/EPA 2006). NA is not assigned a weighted mean value. Q1 and Q2 are the most tolerant to fine sediment.

Dissolved oxygen

Early morning longitudinal DO readings were collected in the summer of 2011 in the Clearwater River at three locations. DO concentrations were routinely below 5 mg/L, which indicates that low DO was a stressor to aquatic life in 2011 (Figure 85). DO data was also collected at site S004-508 from 2007 to 2010 (Figure 86). Data collected later in the day shows an elevated DO concentration, which indicates that there is likely a high daily DO flux driven by elevated periphyton and/or macrophyte growth in the stream. During the day the elevated periphyton growth will elevate the DO concentrations to super saturation levels. Generally these super saturation levels will be above 14 mg/L.

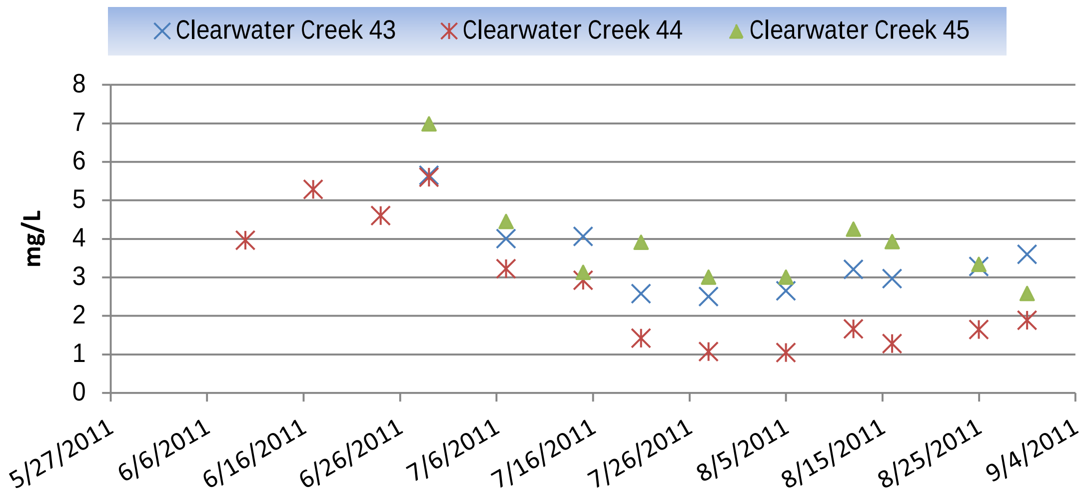


Figure 85: Early morning DO readings pre 9 am for Clearwater River downstream of Clearwater Lake

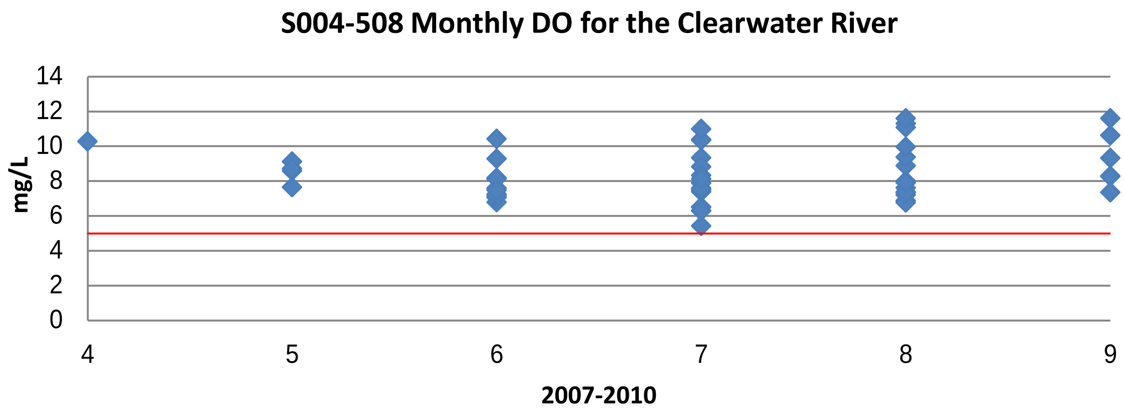


Figure 86: Clearwater River DO data from late morning through midafternoon collected from 2007-2010. High daily maximum DO concentrations indicate a potential for a large daily DO flux, possibly caused by elevated Peryphyton growth in channel.

The individual fish data was compared to Meador and Carlisle weighted mean DO TIVs to determine the percent of the sample that are tolerant to low levels of DO. Figure 87 shows that around 45 percent of the fish sample is sensitive to low DO levels. Quartiles 1 and 2 are the most tolerant to low DO. This may suggest that the stream fish community is adapted to tolerate low DO concentrations.

Nitrate toxicity

Review of the Nitrate data that was collected at site S004-508 reveals that Nitrate levels are slightly elevated, however they do not exceed 4.9 mg/L and are often below 0.4 mg/L. The current data set suggests that levels of nitrate toxic to fish or invertebrates are not occurring here.

Connectivity

The lower section of the Clearwater River is disconnected from the Mississippi River by a dam located at CR75 just northwest of the city of Clearwater (Figure 81). The dam discharges flow with very high velocity and has a drop structure that would impede fish passage. Figure 88 below shows the two dam structures located on the Clearwater River.

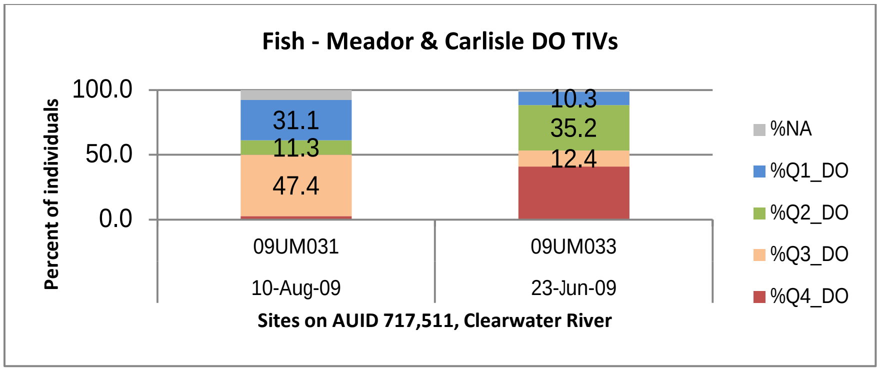


Figure 87: Percent individuals by biological site sampled in Clearwater River, for each quartile based on dissolved oxygen weighted averages (Meador and Carlisle, 2007). Quartile 1 and 2 are most tolerant to low oxygen concentrations.

Dam at CR75 nr City of Clearwater   Dam at Co. Hwy 7 just south of City of Fairhaven

Figure 88: Dams located along the Clearwater River that prevent fish passage

Farther upstream at the Lake Maria outlet there is a dam located at County Highway 7 which would also prevent fish passage. Both of these dams would impede fish migration and cause a potential for a lack of repopulation of the river reaches. There currently is no connection of the Clearwater River to the Mississippi River.

Conclusion

The main stressors to the biotic community in the Clearwater River are bedded sediment, low DO concentrations, and connectivity. Because of the two dams located near the mouth of Mississippi River and farther upstream near Fairhaven, there is limited recruitment possibility for fish. The fish communities within the river corridor can migrate and reproduce, however when a community is lost due to extreme current during extreme flow events or historical pollutant issues, there is no possibility for upstream migration and repopulation. The low DO and bedded sediment stressors are all related to the large percentage of land (65 percent) that is currently farmed for row crops or utilized as pasture for cattle or horse operations, and the seven percent of the land which is developed.

Otsego (Unnamed Creek) 11 HUC (07010203790)

Unnamed Creek 11 HUC (07010203790) lies in the southeast corner of the Mississippi St. Cloud watershed, starting two miles east of the city of Monticello and flowing northeast into the Mississippi River, 0.5 miles south of Otsego, Minnesota (Figure 90). Historically, this area was dominated by deciduous forest, with areas of "emergent herbaceous wetland" along the riparian corridor of the river. Current land-use is a mixture of agricultural (50.3 percent cultivated land, 27 percent range land) and natural areas (3.9 percent of the area remains forest and 4.7 percent wetlands) with 12.1 percent of the watershed being developed (Figure 91).

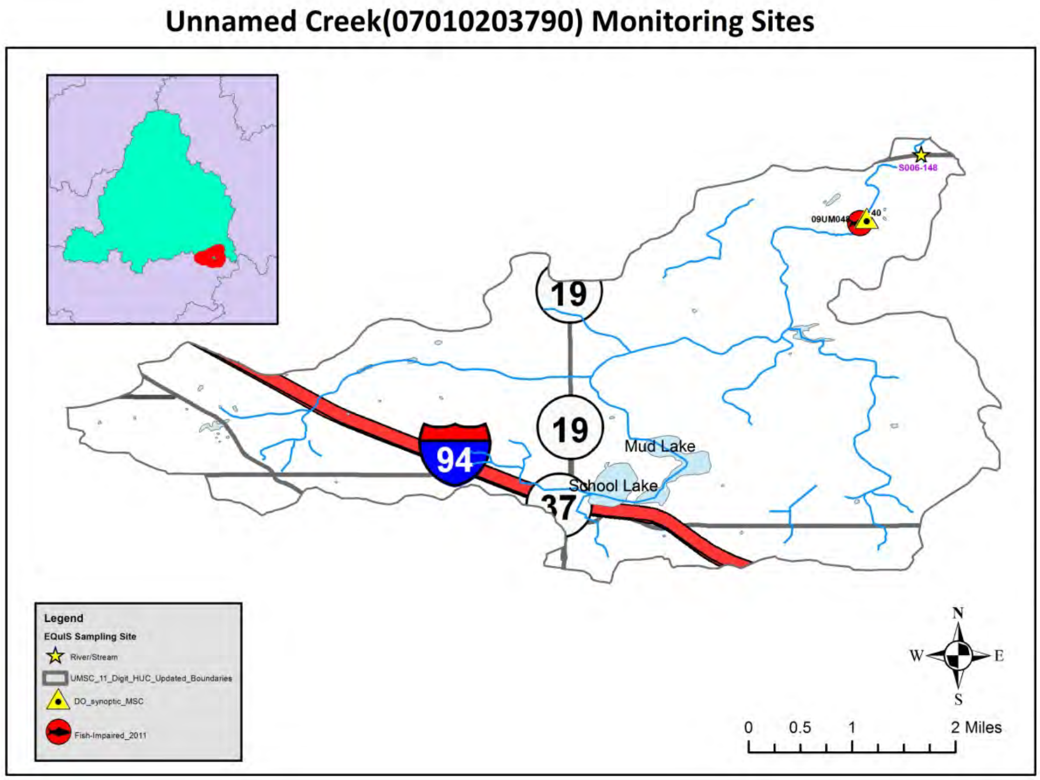


Figure 89: Unnamed Creek 11 digit HUC (07010203790) with sampling locations

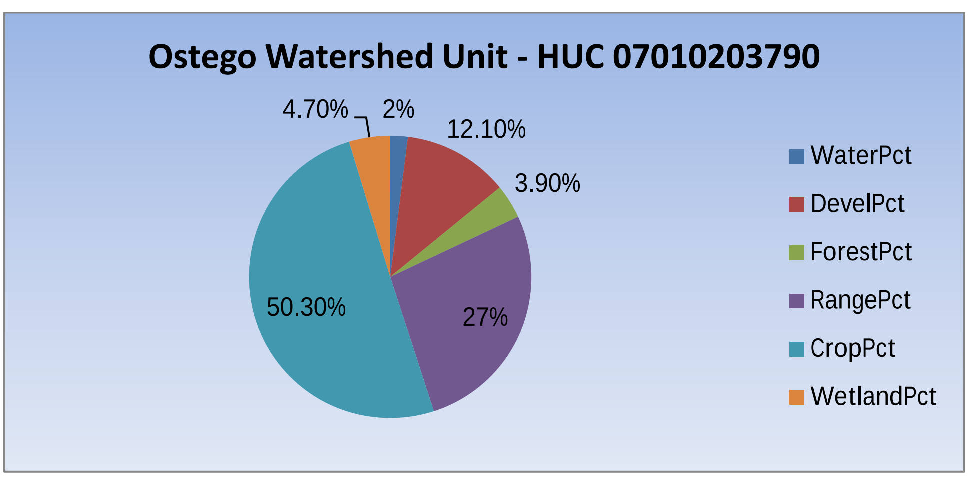


Figure 90: Unnamed Creek land use percentages

There are 11 registered feedlots located in this 11 HUC (Figure 92). There may be smaller unregistered pasturing operations that are in this HUC that may be contributing to nutrient levels and stream bank failure due to animal access and trampling.

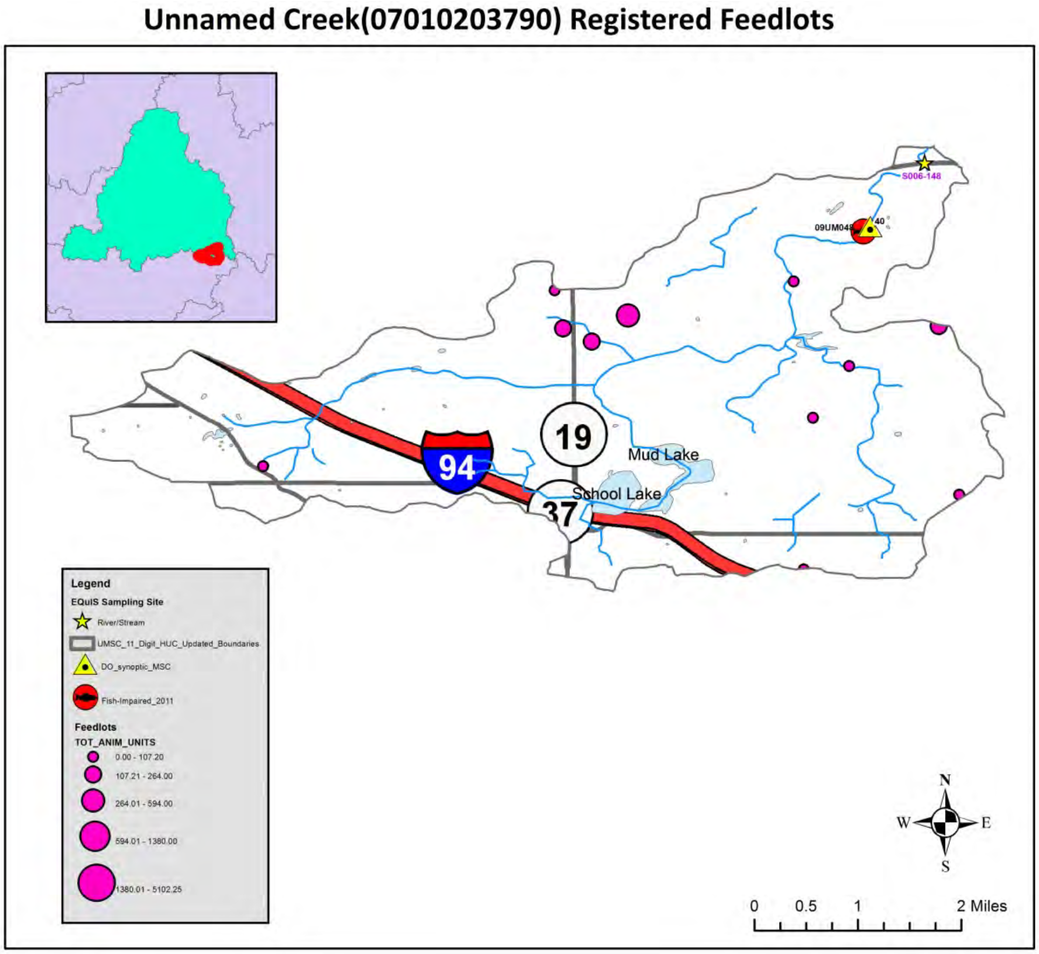


Figure 91: Feedlot density in the Otsego (Unnamed Creek) 11 HUC

Biological impairments

The most downstream section of Unnamed Creek (AUID 07010203-528) is listed for aquatic life impairment (Figure 92), with both fish and macroinvertebrate IBI scores being well below the threshold. AUID 07010203-528 is described as Unnamed Creek from T121 R23W S19, south line Mississippi River. Biological sampling was conducted at site 09UM048 for biological integrity. This site scored low in the MSHA metric fish cover. There was a lack of pools (10 percent) and riffles (five percent) available for various fish species. Observed biological communities within this watershed were represented by species typical of poor quality conditions. During the 2009 fish visit to 09UM048 (AUID 528) zero fish were collected. The aquatic macroinvertebrate community from this location was limited to 18 genera, all of which are adapted to tolerate periods of low DO concentrations. The sample was dominated by *Oligochaeta, Hirudinea*, and *Chironomus*.

Habitat conditions ranged from poor to fair, with station 09UM048 receiving a fair score, likely a result of the forested riparian corridor and slightly better channel morphology. It is important to note that roughly 40 percent of the assessed AUID (528) is channelized stream, and therefore the fair habitat scores and unfavorable biological communities are likely a result of diminished habitat complexity due to channelization and the observed land use practices within this watershed unit.

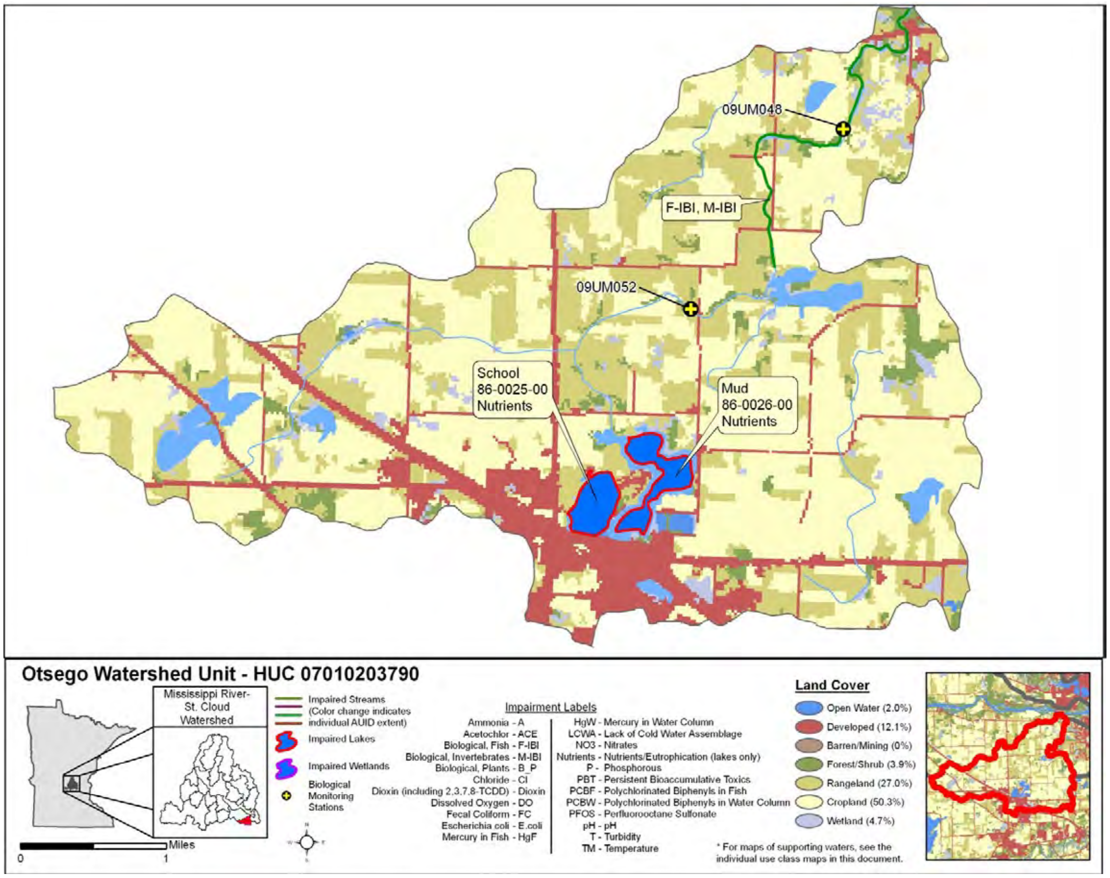


Figure 92: Currently listed impaired waters by parameter with land use characteristics for the Otsego Watershed Unit

Nutrients

There was one water quality sample collected at the biological sampling location 09UM048 on June 5, 2009. This sample had a TP result of 0.842 mg/L which is well above the proposed TP standard of 0.1 mg/L TP. There also was an elevated ammonia sample collected at this same time (2.63 mg/L). This level of ammonia may be toxic to fish and invertebrates. A number of miles upstream from this location, the Albertville WWTP discharges treated wastewater into Mud Lake, which is located at the headwaters of Unnamed Creek just north of the city of Albertville. The station ID is MN0050954-SD-2 and is located at Lat/Lon: 45.2419/-93.6499. Water quality data has been collected from the WWTP discharge from 1998 through 2012. There is no downstream water chemistry data collected in this AUID for nutrients. The available nutrient data from this 11 HUC comes from the discharge permit data from the Albertville WWTP (Figure 93). The data suggests that the TP removal efficiency has improved over time, as monthly average TP concentrations have generally decreased over time. The downstream water bodies from the WWTP are School Lake (86-0025-00) and Mud lake (86-0026-00), and both of these lakes are listed on the TMDL list for excessive nutrients (Figure 92). Both lakes are classified as shallow lakes and have a high degree of residential development that also contributes to the excessive nutrient levels. The mean TP and Chl-a concentrations for Hunters (Mud) Lake are 0.521 mg/L and 150 µg/L respectively. With Unnamed Creek flowing out of Mud Lake, we can assume that the creek concentrations at the headwaters are the same as the Mud Lake concentrations.

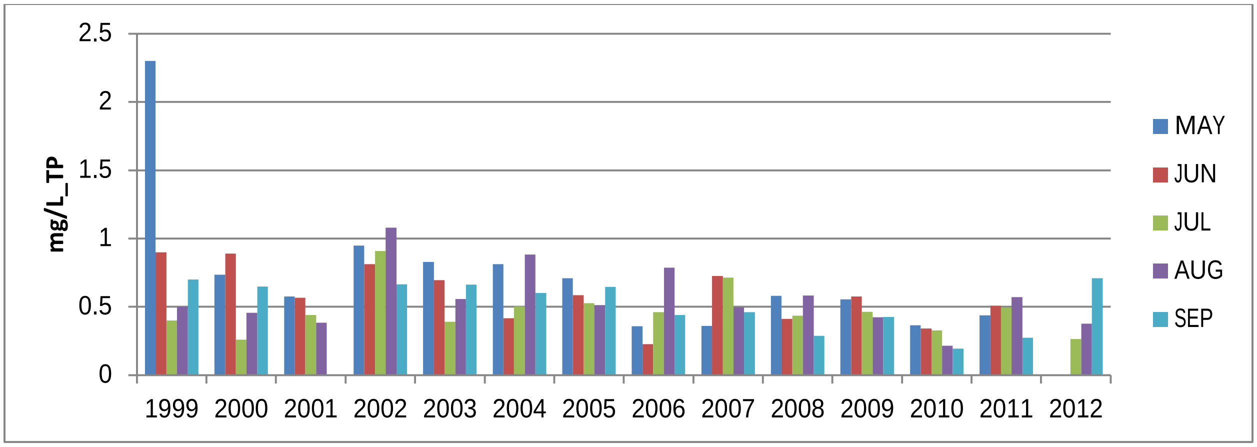


Figure 93: Monthly average TP discharge values over time collected from Albertville WWTP (MN0050954-SD-2)

Unnamed Creek flows north for 2.6 miles before entering and flowing through another unassessed lake (86-0351-00). This lake 11.3 acres in size, has a significant drainage ditch coming in from the southwest and has row crop agriculture as the predominant riparian land use. Figure 94 shows the most recent aerial photograph along with the various and diverse land use types within this 11 HUC. To the southwest near the city of Albertville there is a major expansion of residential development. North of the city limits of Albertville the land use is predominately row crop agriculture along with animal pasturing operations.

Unnamed Creek(07010203790) Road crossing and Areas of Interest

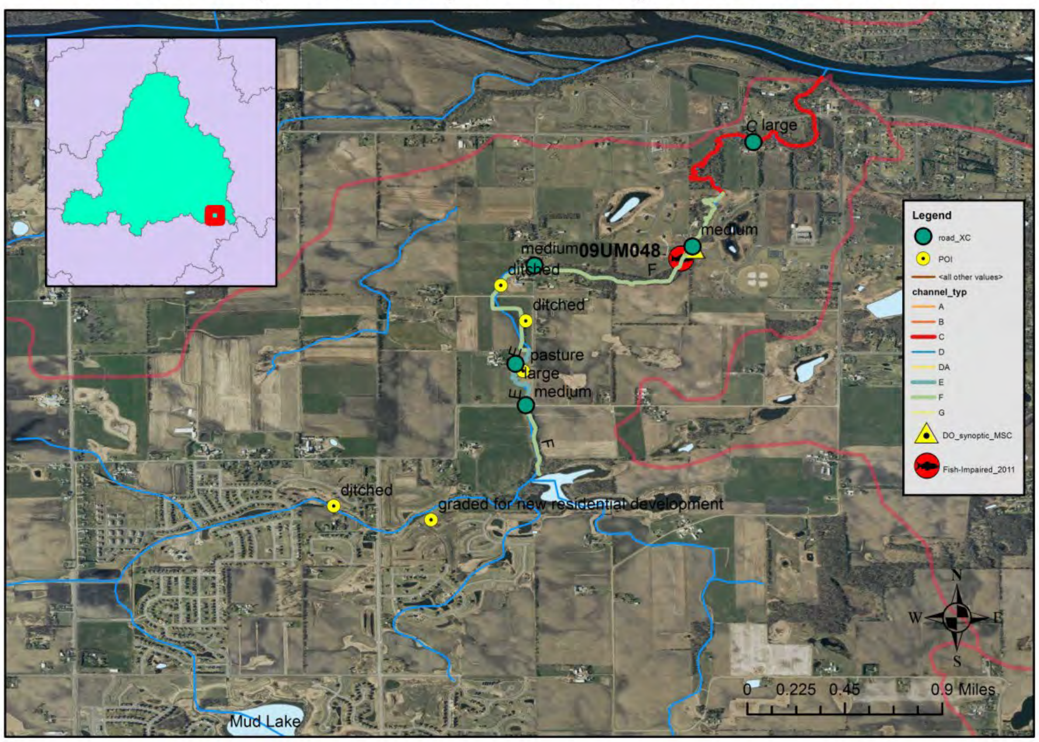


Figure 94: Current land use practices in the Unnamed Creek Watershed. Note the newer residential areas to the southwest along with the intensive agricultural land use in the north and eastern sections of the watershed.

Dissolved oxygen flux

One continuous-recording sonde was deployed during 2011 at this monitoring location from July 22 through August 9th, 2011 (Figure 95). After August 2nd it appeared that the DO probe started to malfunction, so DO data thereafter should be disregarded. Review of the daily flux of DO data collected from the YSI sonde indicates a DO daily flux of less than three mg/L, which is good. This indicates that the stream DO is not driven by abnormal macrophyte or periphyton growth. During field visits there was virtually no instream plant growth documented. During the continuous data collection there are a number of observations for DO that are below the five mg/L standard. The continuous DO readings occasionally dropped below four mg/L during the early morning hours.

Sampling location 09UM048 recorded 0 fish during sampling. There were 18 individual macroinvertebrates collected at 09UM048 during 2009. All of these individuals are tolerant to low DO concentrations.

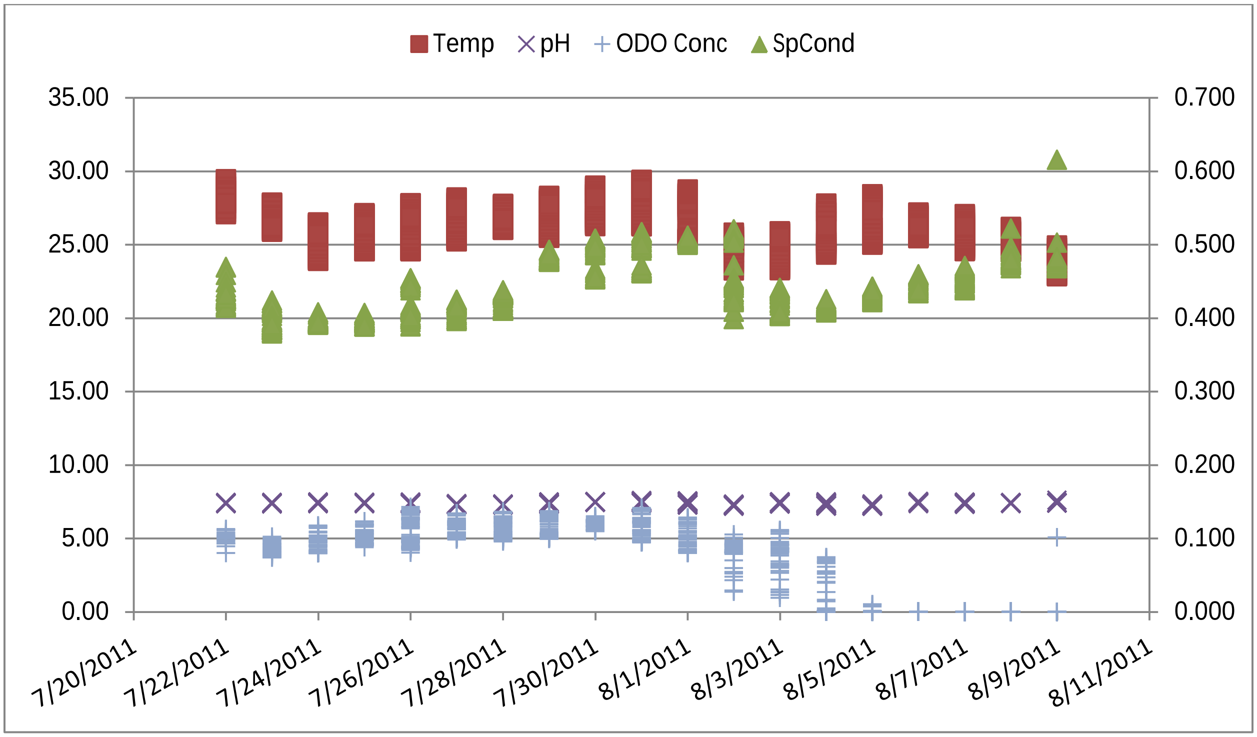


Figure 95: Continuous sonde data from biological monitoring site 09UM048. This site is located at Naber Avenue NE and operates more like a drainage ditch that a stream. The daily DO flux is below three mg/L however there are periods of low DO for every sampling day.

Due to the fact that there are no fish and very low DO tolerant macroinvertebrates at this site, it is suspected that daily DO minimums is a stressor to the aquatic community.

Dissolved oxygen

Early morning longitudinal DO readings were collected in the summer of 2011 in Unnamed Creek at one location (Site 40, which is located at Naber Ave NE crossing) and concentrations were below five mg/L, which indicates that low DO was a stressor to aquatic life in 2011 (Figure 96). Review of the monthly minimum DO discharge records from Albertville WWTP (Figure 97) indicate that the stream does not re-aerate as it makes it way downstream to the Mississippi River. The slope of the channel in the upstream reaches is flat (low gradient). There are virtually no riffles in the upstream section which would re-aerate the stream.

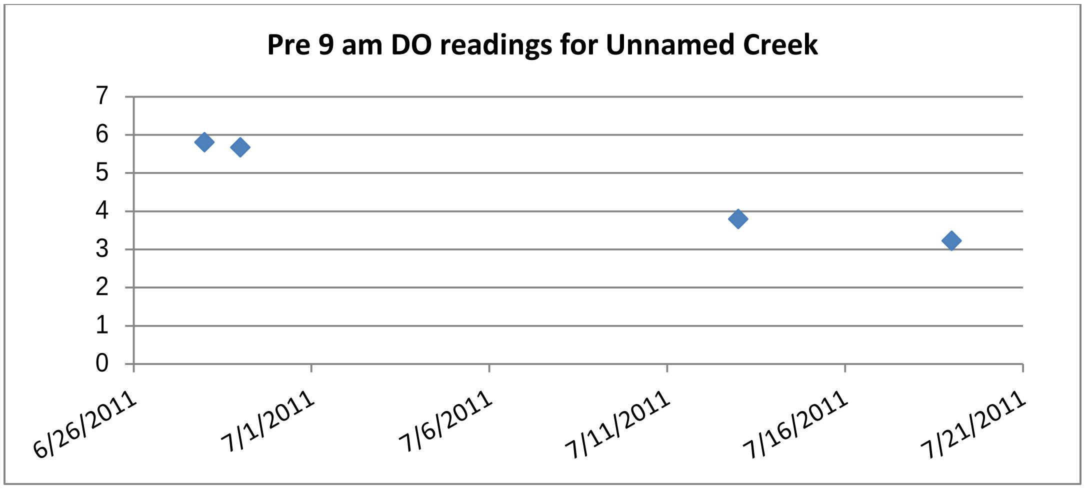


Figure 96: Early morning DO readings pre 9 am for Unnamed Creek just below biological site 09UM048

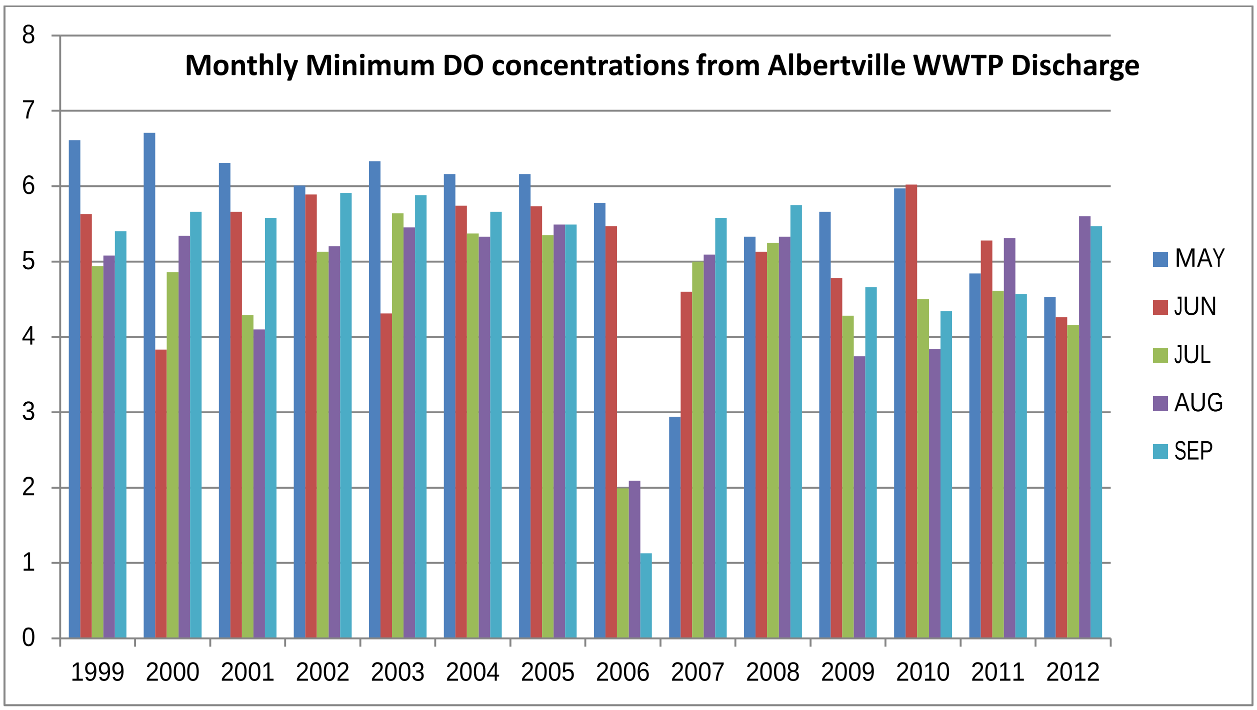


Figure 97: Monthly discharge data for DO from the Albertville WWTP. Review of the July 2011. DO data is higher at the Albertville WWTP than during the instantaneous readings or the continuous readings shown in Figure 98.

Sediment: total suspended solids and bedded sediment

Total suspended solids

There is no data to evaluate TSS as a candidate cause for biological impairments in the lower section of the Unnamed Creek watershed. However, during collection of sonde data, it was noted that the stream was brown during high flow events (Figure 98-99). This indicates that TSS is a potential stressor.

Bedded sediment

Bedded sediment is a problem within the sampling location at 09UM048. Sampling for substrate particle size was conducted at two locations during 2011. The first location was downstream of Naber Avenue and the second location was upstream of Naber Avenue near the biological monitoring site 09UM048. Substrate sampling along with channel dimension, pattern and profile surveying was conducted on 8/9/2011. The downstream location had a D50 particle size of 0.35 mm. The substrate at this location is 20 percent silt, 67 percent sand and 13 percent gravel. Figure 98 below shows a picture of the failing banks at this location. The channel banks are eroding due to the channel incision and suspected altered hydrology caused from, upstream channelization and additional stormwater runoff volume and flow rate. Bank failure is increasing the amount of sediment entering the stream.

Figure 98: View of downstream stream section below the Nabor Avenue culvert. This site has a double culver, one box and one arch culvert. The arch culvert is filled with sand and only carries flow during high flow events.

Bank failure is caused by two main variables; flow and bank stability. The flow in Unnamed Creek has been altered by increased stormwater runoff from residential and agricultural practices. Peak discharge is higher than historical peak discharge and the slope of the channel increases shear stress on the banks. The vegetation along the banks has also been altered. There are areas on the bank that are dominated by reed canary grass, which is shallow rooted and does not provide bank protection. Other bank surfaces have turf grass or are virtually void of any vegetative protection. The water surface slope at this site is 0.006. This high slope causes downstream bank failure which is causing a significant amount of sediment transport and deposition downstream. Table 19 below lists the channel dimensions and channel type based on Rosgen (1996) Classification. The channel downstream of the road culvert at Nabor Avenue is steeper than the upstream section. The downstream section is also more incised keeping a higher volume of water within the channel before it reaches its floodplain. This is causing higher shear stress on the banks along with increased rates of erosion on the downstream section. The ability to move fairly large particles (102 mm or 4 in.) during bank full discharge has caused an environment that is unstable, and thus makes colonization by macroinvertebrates difficult.

Table 19. Unnamed Creek summary of channel dimensions and calculations using Rivermorph 5.0

Location	Wbkf (ft)	Dbkf (ft)	Abkf (ft^2)	Slope (water)	D50 (mm)	Channel Type	Shear Stress (lb/sq ft)	Movable particle (mm) (Schields Curve)	Entrenchment Ratio
DS of Nabor Ave	13.4	1.82	24.4	0.006	0.35	B	0.59	35.1-102.8	1.94
US of Nabor Ave	17.21	2.17	37.3	0.0028	0.31	E	0.32	17.3-35.0	2.77

The upstream channel is slightly flatter in slope. This section of channel is also experiencing a high rate of bank failure along with a noticeable amount of sediment export. Figure 99 displays some areas of bank failure which are typical in this stream reach.

Figure 99: Typical bank condition on Unnamed Creek upstream from Nabor Avenue. Note the debris on culvert. Storm flows are cleaning out the channel moving any beneficial woody debris downstream. Note the brown color of stream on right photo.

The altered hydrology and increased peak discharges, along with the extent of exposed bank material is allowing this area to experience a high degree of erosion and sedimentation within the bank full width. There is a general lack of habitat in the surveyed reach. There are no deep pools and no riffles. The entire length of the long profile is run (Figure 100). The channel is devoid of woody debris. Woody debris helps with channel diversity, causing scour pools, flow refuge during high flow events, and invertebrate substrate. The woody debris that enters the stream is currently passed through due to high stream velocities during storms. Without woody debris or adequate bank vegetation the stream banks are vulnerable to erosion. During high flows the channel is cutting away at the banks and causing turbidity issues within the stream. Many of the photos taken during field sampling events show that the stream is turbid. There appears to be a significant supply of fine sediment coming in from the exposed banks.

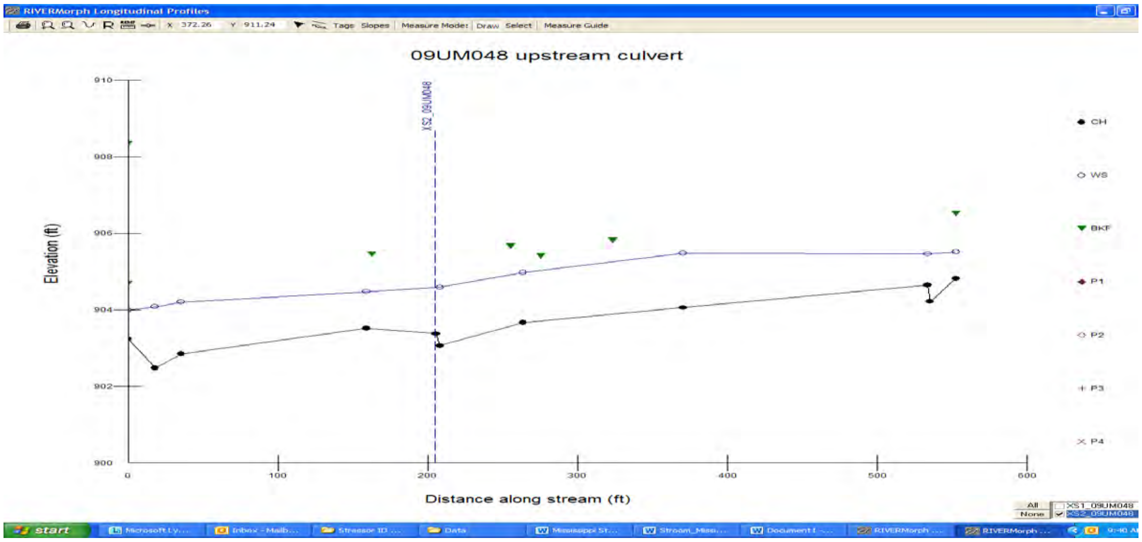


Figure 100: Channel features at 09UM048, upstream of Nabor Avenue. Channel survey shows no pools or riffles of adequate depth. Minimal habitat features in the reach, virtually all run.

Connectivity/altered hydrology

Unnamed Creek is channelized from Mud Lake downstream to unnamed lake. Below this location there are sections of stream that are channelized or were historically channelized. There are seven road crossings downstream of MDNR lake 86-0351-00 that have culverts. Three of the culverts have large scour holes on the downstream side. Such scour holes indicate a culvert that is either undersized or improperly installed, creating increased water velocity at the outlet of the culvert that results in scouring away of bed material. These same three culverts are located on private driveways and should be investigated further. These culverts are probably causing fish passage issues. There are also areas that have no riparian buffer and areas of intensive residential and agricultural land use, all of which are increasing flow rates and altering the delivery pattern of water to the stream. The widening channels and raw banks suggest that the stream channel is going through a period of hydrologic adjustment. The channel is trying to accept the new bankfull flow regime, which is higher than when the landscape was unaltered. The discharge from the Albertville WWTP along with discharge from the various stormwater systems and ditches throughout the southern end of the watershed would all contribute to a change in how water historically was being delivered to Unnamed Creek.

Summary of biological metrics

There were no fish sampled at this location during the 2009 site visit, which is a rare occurrence in the monitoring program. The macroinvertebrates collected reveal a limited community, both in terms of abundance and diversity, one that was dominated by insects that are burrowers. The burrowers naturally utilize fine sediment and are known to survive in areas that have DO problems. They do not require hard substrates such as rock or wood as habitat. There were also a high percentage of collector gatherer groups of insects. The collector-gatherer percent was 77.7 percent and the collector-filterer group percentage was 0 percent. The latter again require hard, stable substrate to attach themselves and/or their filtering nets onto. The invert metric Legless revealed that 97.5 percent of the sample was represented by legless (limited mobility) macroinvertebrates. This is further evidence of a lack of hard substrates, as these taxa do not cling to objects. The lack of clinging invertebrates may also relate to flashy stream flows of increased velocity and scouring ability (attached organisms are torn away and flushed from their living sites). The fish and macroinvertebrates samples indicate a hostile environment for biological communities, one that lacks a diversity of habitat features required for a diverse, thriving community of organisms.

Conclusion

The main stressors to the biotic community in the Unnamed Creek watershed are low DO concentrations, excess sediment supply due to bank failure, lack of habitat variability and a loss of connectivity/altered hydrology. During high flow conditions there is unnaturally high sediment input due to bank scouring and/or failure. The stream bed is mainly composed of fine material. The increased discharge should not allow for the buildup of fine material in the thalweg but the channel may be scoured down to the parent material that is stable enough to withstand the high velocity and shear stress in the channel.

Silver Creek 11 HUC (07010203750)

Silver Creek 11 HUC (07010203750) lies in the northeast side of the Mississippi St. Cloud watershed. This watershed area starts south of Highway 55 near the city of Maple Lake and flows north east into the Mississippi River, one mile east of Hasty, Minnesota (Figure 101). Historically, this area was dominated by deciduous forest, with areas of “emergent herbaceous wetland” along the riparian corridor of the river. Current land-use is a mixture of agricultural (44 percent cultivated land, 19 percent range land) and natural areas (17.8 percent of the area remains forest and 6.1 percent wetlands) with 6.7 percent of the watershed being developed (Figure 102).

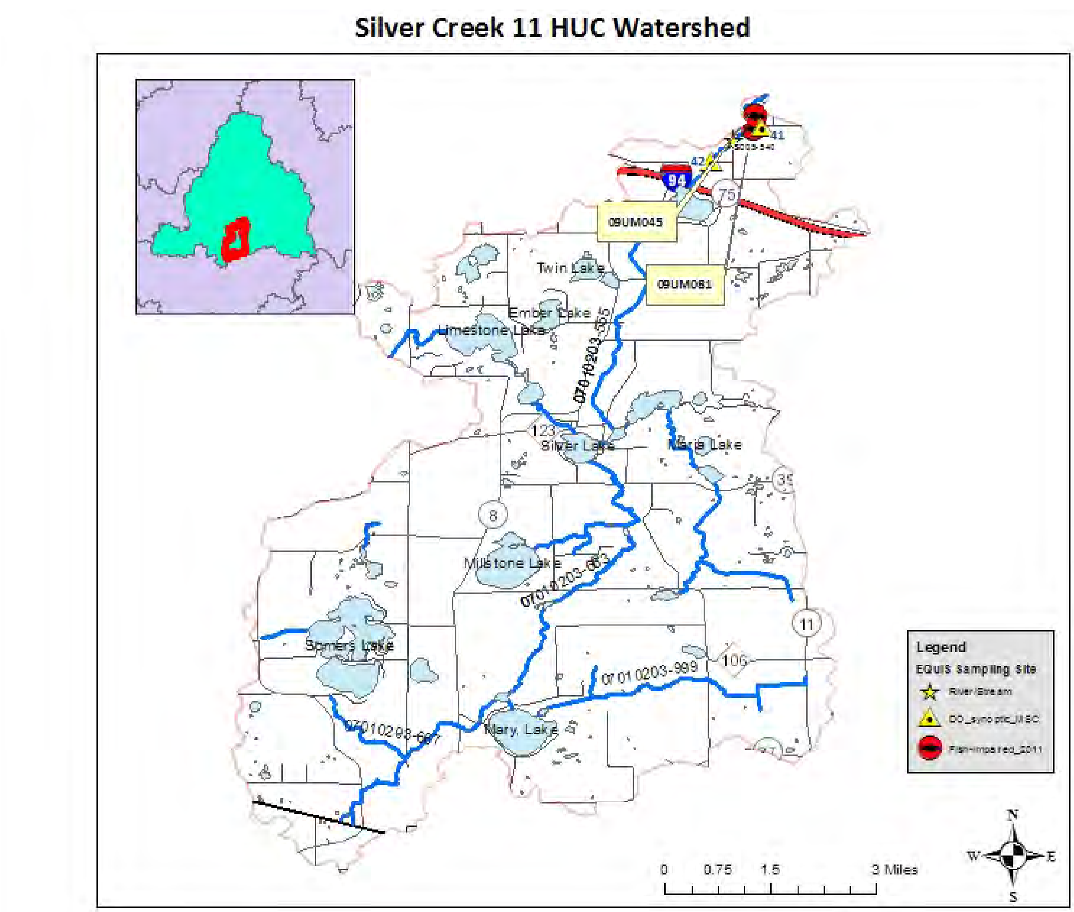


Figure 101: Silver Creek 11 digit HUC (07010203750) with sampling locations

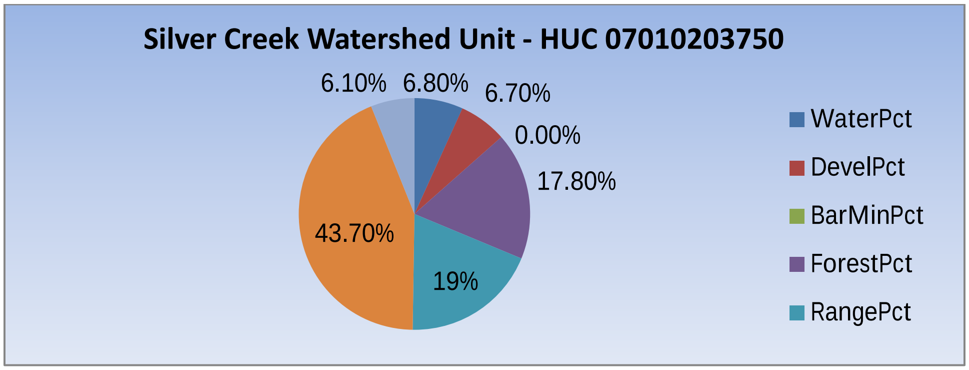


Figure 102: Silver Creek land use percentages

There are 35 registered feedlots located in this 11 HUC (Figure 103). There may be smaller unregistered pasturing operations that are in this HUC that may be contributing to nutrient levels and bank failure due to animal access and trampling.

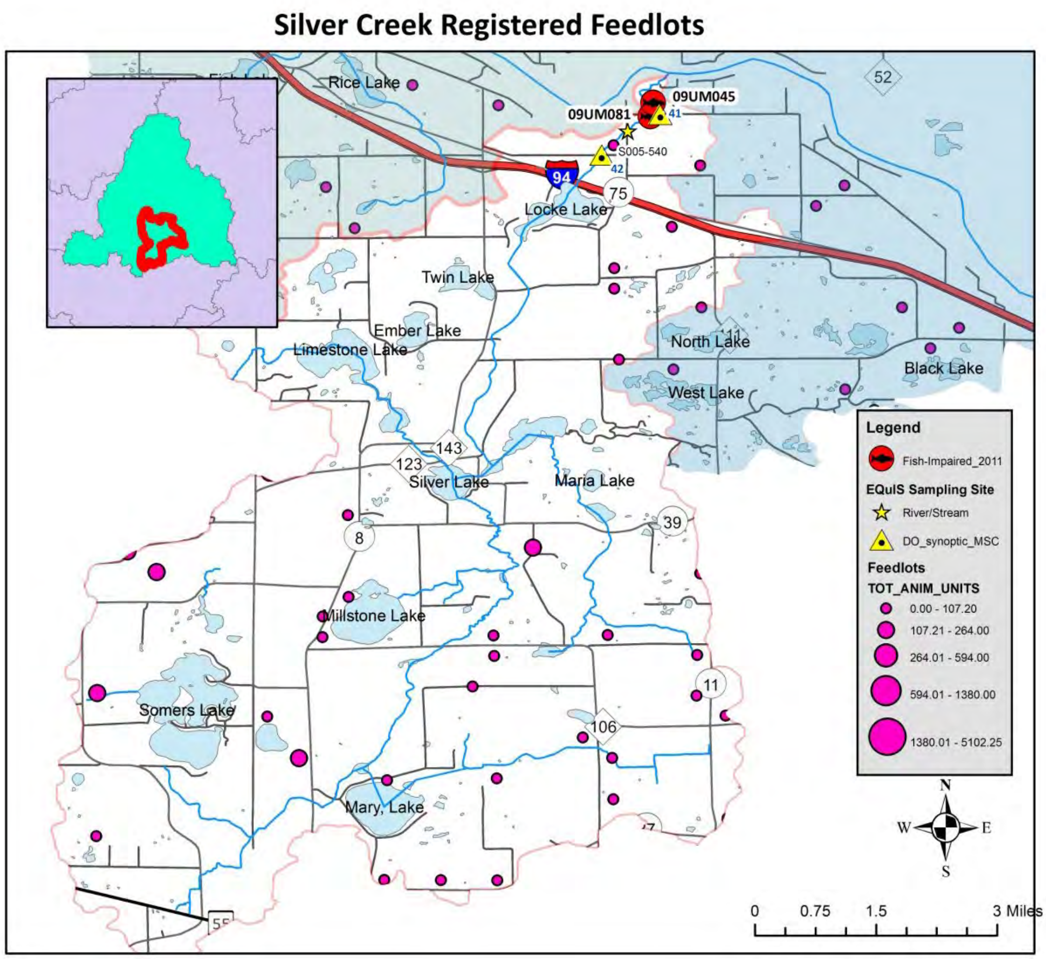
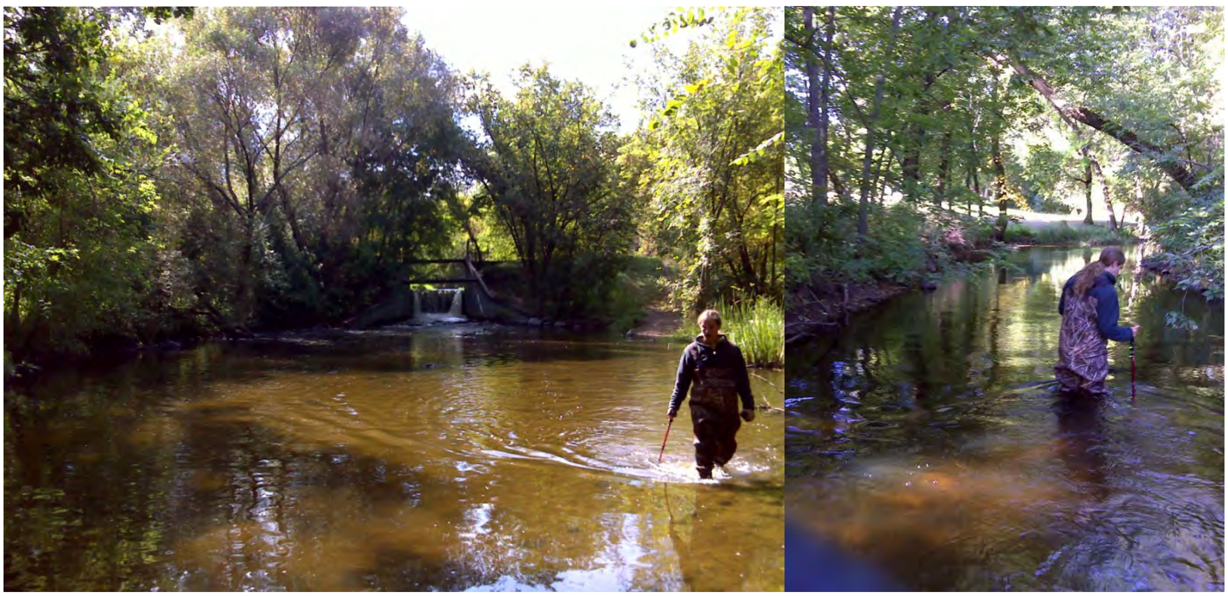


Figure 103: Feedlot density in the Silver Creek 11 HUC (07010203750)

Biological impairments

The segment of Silver Creek below Locke Lake is listed for Aquatic Life and Aquatic Recreation impairments. AUID 07010203-557 is non-supporting for fish, macroinvertebrates and DO. This reach also exceeds eco region expectations for E. coli bacteria levels. This reach is 1.98 miles long and includes sampling locations 09UM045 and 09UM081, both of which are biologically impaired. Both sites scored low in the MSHA metric fish cover. This indicates that there is a lack of important habitat available for various fish species. There is a dam located on this AUID between the two fish sampling locations, located approximately 0.4 miles downstream from Curtis Road, which acts as a fish barrier. The site above the dam 09UM045 scored very low for the fish IBI. This reach is dominated by sand and the stream channel is aggrading due to the downstream dam. Figure 104 below shows the dam. The approximate height of the dam is 5.5 feet.



looking upstream to dam on Silver Creek **09UM045 above dam**

Figure 104: Photos from Silver Creek both above and below the dam near Curtis Road

The photo above right is representative of the channel above the dam. The site here (09UM045) had 5 species of fish in the sample. The IBI score was 17 which is well below the score that determines the reach is supporting the aquatic life use for fish. The downstream site (09UM081) had 10 species present and an IBI score of 28. This location has a direct connection to the Mississippi River, which may explain the additional species present vs. upstream of the barrier. Even with this connection, the habitat characteristics are not very suitable, there are no undercut banks and the channel is in a state of change due to the amount of bed material that is scoured below the dam. The dam has a deep scour pool on the downstream side and the substrate material is moving downstream to the Mississippi River causing a constant change in channel condition. The deposition of bed material from the scour is causing bed aggradation.

Nutrients

Nutrient enrichment, Chl-a concentrations, and measures of BOD are all factors in the DO balance of streams. TP data was collected from 2009 and 2011 at EQuIS site S005-540. This site is located at Curtis Avenue near the downstream end of the 11 HUC near biological monitoring site 09UM045. TP concentrations were above the proposed criterion of 0.1 mg/L twice during the sampling record in 2011 (Figure 105). Both values were collected during late summer in 2011 during a period of above normal flow. During the early summer months of 2011, this area experienced above average rainfall, and upstream wetland complexes were full of water and discharged continuously for a longer period than normal. Elevated TP concentrations do not appear to be a main stressor within this watershed. However, Locke Lake which is just upstream of the AUID is impaired for nutrients, due to high TP and Chl-a concentration. Lake phosphorus standards are lower than for streams.

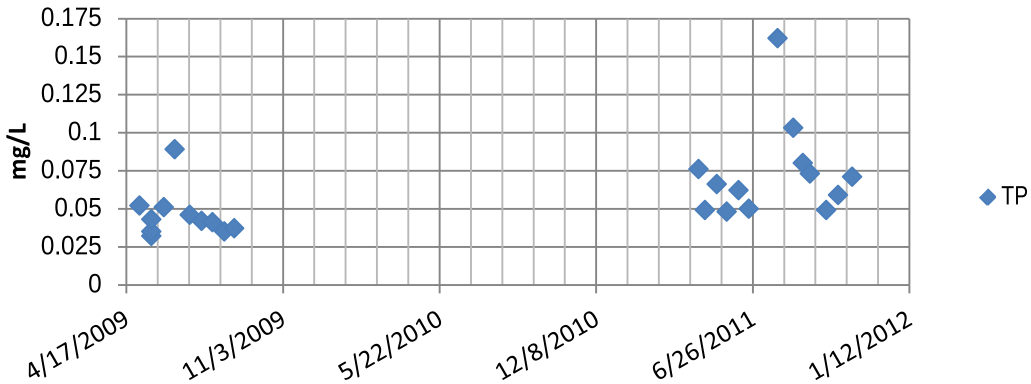


Figure 105: TP values over time collected from Silver Creek EQuIS site S005-540

Chlorophyll-a

No samples were collected for Chl-a in Silver Creek. During field data collection it was noted that submerged aquatic plant and periphyton growth increased as we moved downstream toward the dam located below Curtis Avenue. This impoundment slows down the river flow and creates favorable conditions for plants to grow and for the export of algal biomass downstream.

Dissolved oxygen

Early morning longitudinal DO readings were collected in the summer of 2011 in Silver creek at two locations and often were well below five mg/L (Figure 106), which indicates that low DO was a stressor to aquatic life in 2011.

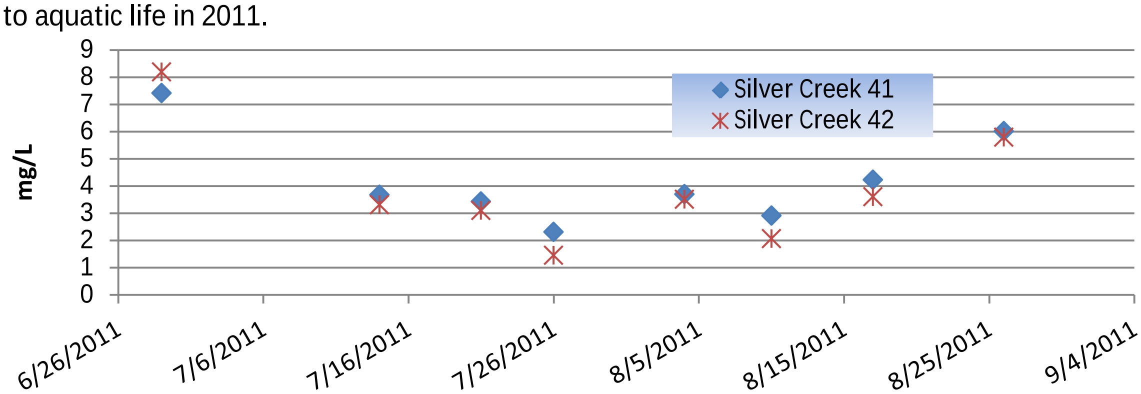


Figure 106: Pre-9am DO readings in Silver Creek downstream of Locke Lake

The low DO observed is supported by reviewing the biological metrics that would be associated with low DO. The fish communities from the two sampling locations have low percentages of sensitive fish. Sampling location 09UM045 recorded 0 percent of the sample as sensitive fish and site 99UM081 had 2.4 percent sensitive fish species. The 2009 fish sampling event at site 09UM045 which is above the dam was dominated by two species; Spotfin Shiner and Bluntnose Minnow. Both of these fish species are tolerant to low levels of DO and can survive short term intervals of DO below the five mg/L standard. The 2009 fish sampling event at site 09UM081 was slightly more diverse, with 10 species recorded, including a single burbot as the lone sensitive species. The sample at 09UM081 was dominated by young of year white suckers. There were no macroinvertebrate samples collected at either of these sites during 2009.

It is suspected that low DO concentrations along with high daily DO flux is a stressor to the aquatic community.

Sediment: total suspended solids and bedded sediment

Total suspended solids

There is not currently sufficient sample size to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the lower section of the Silver Creek watershed. Available data suggests that TSS is not an issue in the Silver Creek watershed. The proposed standard is 30 mg/L for this watershed and measurements were well below, ranging from 1.2 to 12 mg/L with an average of 4.7 mg/L.

Bedded sediment

Bedded sediment is in excess at sampling location 09UM045. The substrate at this location is 37 percent sand and 53 percent small gravel. The particle size D_{50} was 4.57 mm. This is caused by a reduced gradient in this stretch of stream resulting from human activity. The dam located downstream of Curtis Avenue is 5.5 feet higher than the lower section of Silver Creek below the dam. This backs up water and allows for the settling of small material on the stream bed. Despite the presence of some suitable gravel habitat in this reach, the dam blocks fish migration and recruitment from the Mississippi River. Downstream of the dam at site 09UM081, the particle size D_{50} is much larger at 10.31 mm. This area has better gravel substrate, however the high velocity and relatively sediment-free water coming over the dam has a tendency to scour below the dam and redistribute the coarser material downstream. This area has mid-channel bar deposition, a sign of excess sediment movement, and it appears that the stream bed is in a state of flux. There is strong evidence showing that the dam located below Curtis Avenue is causing bedded sediment issues that are potentially adversely affecting the stream biota.

Nitrate toxicity

Nitrate data collected at site S005-540 reveals that levels are elevated, but do not exceed 4.9 mg/L and are often below 0.6 mg/L. It is not likely that nitrate is present at levels toxic to aquatic life.

Connectivity/altered hydrology

Silver Creek is disconnected from the Mississippi River via a dam located on Silver Creek just downstream of Curtis Avenue. The elevation of the dam is approximately 5.5 feet higher than the downstream channel bed. This dam affects the movement of fish and also impacts the slope of Silver Creek above the dam to Locke Lake

The slope change caused by the dam at Curtis Avenue has caused a change in the hydrology of the lower section of Silver Creek. With the dam creating a flatter slope above and a gradient change downstream.

Figure 108 below shows the 1963 aerial photo versus the 2010 color image, revealing the change in water level from the dam has caused a substantial amount of scour within the stream corridor below the dam. It also appears there is evidence of historical channelization above the Curtis Avenue road crossing. The channel appears to be widening both above and below the dam. In the 1963 photo there is very little riparian buffer and the channel appears straightened. The dam is causing streambed aggradation above the dam and scour and unstable substrate below the dam.

Summary biological metrics

Review of the biological data suggests that both sampling locations in Silver Creek have a very poor fish community. Above the dam at (09UM045), there are no fish species that require three years of age to reach reproductive potential. This can indicate that the stream does not support fish throughout the year and there are no resident fish populations.

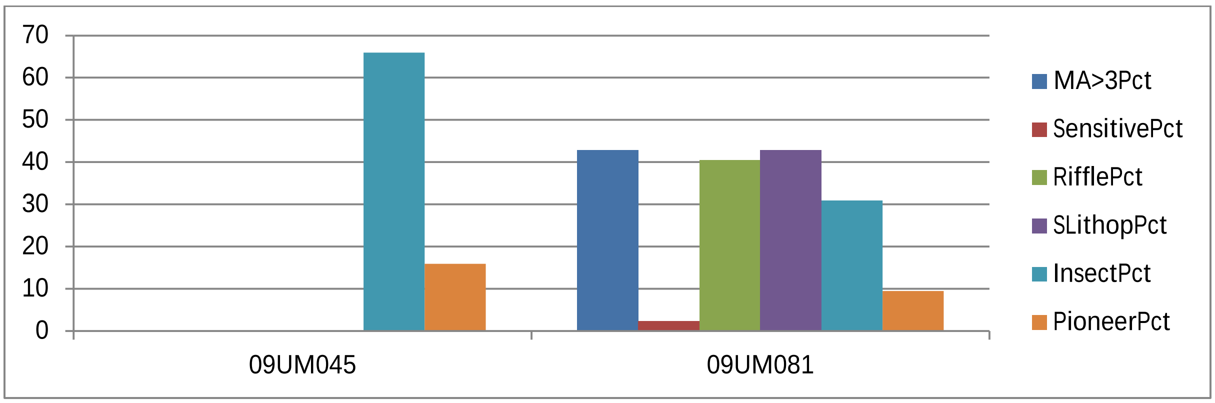


Figure 107: Silver Creek fish metrics for feeding and reproductive groups of fish

The above metrics (Figure 107) reveal that the two sites are different in many of the fish reproductive and trophic metrics. This can be explained by the presence of the dam between the two sites, in conjunction with the lower site having connection to the fish reservoir provided by the Mississippi River. The only metrics that are higher above the dam are pioneering species percent and insectivore feeding species percent. The presence of the dam along with limited habitat available such as undercut banks, gravel –cobble substrate, and the presence of pool and riffle complexes all limit the ability of fish to move and find habitat appropriate to their needs.

Conclusion

The main stressors to the biotic community in the Silver creek Watershed are low DO concentrations and loss of connectivity/altered hydrology. The stream channel of Silver Creek is disconnected from the Mississippi River by a dam located just downstream of Curtis Avenue. This dam has altered the stream channel slope both above and below the dam causing stream bed aggradation above the dam and stream bed degradation below the dam. During high and low flow conditions there appears to be a large DO daily flux. Locke Lake which lies immediately above this reach is listed as impaired for nutrients. This causes excessive algal growth to form in the lake and it is transported downstream the creek where the algae can die back and consume DO. Further investigation is needed to determine if the DO flux could be corrected by reducing nutrient inputs and restoring the water quality in Locke Lake along with restoration of the historical channel by removal of the dam.

Photo taken from http://maps.dnr.state.mn.us/landview/historical_airphotos/projects/wp/y1963/wp_2dd_234.jpg.

Figure 108: Comparison of location of dam in 1963 before installation and in 2010 after several years of dam being in place

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