Mississippi River-Lake Pepin Tributaries Biotic Stressor Identification

A study of local stressors limiting the biotic communities

Minnesota Pollution Control Agency

July 2013

Legislative Charge

Minn. Statutes § 116.011 Annual Pollution Report

A goal of the Pollution Control Agency is to reduce the amount of pollution that is emitted in the state. By April 1 of each year, the MPCA shall report the best estimate of the agency of the total volume of water and air pollution that was emitted in the state the previous calendar year for which data are available. The agency shall report its findings for both water and air pollution, etc., etc.

HIST: 1995 c 247 art 1 s 36; 2001 c 187 s 3

Authors

Tiffany Schauls (MPCA)

Contributors / acknowledgements

Kim Laing (MPCA)
Justin Watkins (MPCA)
Jenna Roebuck (MPCA)
Katherine Logan (MPCA)
Khalil Ahmad (MPCA)
Mike Koschak (MPCA)
Beau Kennedy (Goodhue Soil and Water Conservation District)
Dan Spence (Minnesota Department of Natural Resources)
Nick Proulx (Minnesota Department of Natural Resources)
Dave Tollefson (Minnesota Department of Agriculture)

Editing and Graphic Design

Administrative staff: Barb Olafson
Cover Photos: Tiffany Schauls

MPCA is reducing printing and mailing costs by using the Internet to distribute reports and information to wider audience. Visit our website for more information.

MPCA reports are printed on 100 percent post-consumer recycled content paper manufactured without chlorine or chlorine derivatives.

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

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 | www.pca.state.mn.us | 651-296-6300
Toll free 800-657-3864 | TTY 651-282-5332

This report is available in alternative formats upon request, and online at www.pca.state.mn.us

Document number: wq-ws3-07040001d

Contents

Figures

Tables

Executive Summary

This report summarizes stressor identification work in the Mississippi River-Lake Pepin Watershed.

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

Over the past few years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of rivers and streams. The basic approach is to look at fish and aquatic invertebrates (mostly insects), and related habitat conditions, at sites throughout a major watershed. The resulting information is used to produce an index of biological integrity (IBI). IBI scores can then be compared to standards. Segments of streams and rivers with low IBI scores are deemed "impaired."

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

The Mississippi River-Lake Pepin Watershed encompasses 205,747 acres that drain several small, coldwater streams in bedrock-dominated bluff country in southeast Minnesota. The vast majority of streams in this watershed are in fair or good biological health. These watershed areas are candidates for protection strategies to ensure their continued health.

The MPCA did find two streams of concern: Gilbert and Hay Creeks, which are both designated trout streams. The MPCA also found bacteria (E. coli) levels to be a concern throughout streams in the watershed.

Gilbert Creek is a small direct tributary to Lake Pepin near Lake City. While the creek meets the standards for invertebrates, its low fish IBI score indicates impairment for aquatic life. After examining several candidate causes for the impairment, with several different methods, the MPCA and local partners identified two probable stressors in Gilbert Creek:

- lack of physical habitat
- habitat loss due to bedded sediment

Hay Creek is currently listed by the MPCA as impaired by turbidity for aquatic life. More data are currently being collected for turbidity in order to determine if this listing is accurate. Aquatic life (fish and invertebrates) are doing well throughout this watershed, and the MPCA does not believe that turbidity related to sediment is a stressor at this time.

Aquatic recreation impairments for bacteria (E. coli) were found extensively throughout the Mississippi River-Lake Pepin Watershed, including Gilbert Creek. The Stressor Identification process does not address the bacteria pollutant directly, but is still an important indicator because of the relationship of E. coli to other pollutants, such as sediment and nutrients, that can have an impact on aquatic life. Those impacts may not be evident now, but could be seen in the future.

Introduction

Stressor Identification Process

The Stressor Identification Process (SID) is used in this report to weigh evidence for or against various candidate causes of biological impairment (Cormier et al., 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 1). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s).

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

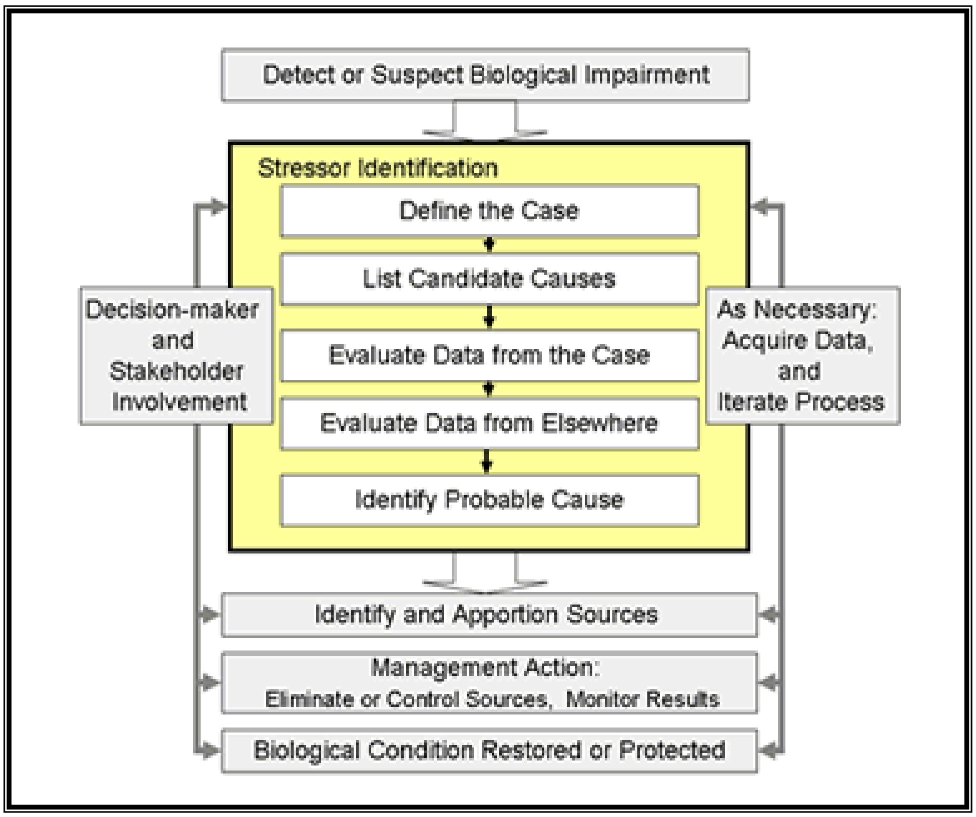


Figure 1: Conceptual model of stressor identification (SID) process

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

Elements of Stream Health

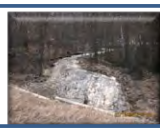
The elements of a healthy stream consist of five main components: stream connections, hydrology, stream channel assessment, water chemistry, and stream biology. The following flowchart shows the five components of a healthy stream. If one or more of the components are unbalanced, the stream ecosystem fails to function properly and is listed as an impaired water body (Figure 2).

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

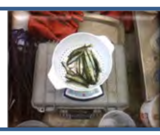
Hydrology
Examples: stream flow and runoff



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.

Common Stream Stressors to Biology (Fish, Macroinvertebrates)

Table 1: The Stream Health component along with the associated stressor(s) and their link to biological health

Stream Health	Examples of Stressor(s)	Link to Biology
Stream Connections	**<u>Loss of Connectivity</u>** · 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	**<u>Flow Alteration</u>** **<u>Lack of Physical Habitat</u>** **<u>Sediment (suspended or bedded)</u>** · Channelization · Peak discharge (flashy) · Lack of baseflow · 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	**<u>Lack of Physical Habitat</u>** **<u>Sediment (suspended or bedded)</u>** · Loss of dimension/pattern/profile · Bank erosion from instability · Loss of riffles due to accumulation of fine sediment · Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.
Water Chemistry	**<u>Low Dissolved Oxygen Concentrations</u>** **<u>Elevated levels of nutrients</u>** · Increased nutrients from human influence · Widely variable dissolved oxygen levels during the daily cycle · Increased algal and/or periphyton growth in stream · Increased nonpoint pollution from urban and agricultural practices · Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream Biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

Mississippi River-Lake Pepin Watershed

The Mississippi River-Lake Pepin Watershed includes 205,747 acres that drain several small, coldwater streams in bedrock-dominated bluff country. The largest of these streams is Wells Creek (45,954 acres), which winds through 18 miles of bluff lands and joins the Mississippi near Old Frontenac, southeast of Red Wing. Hay Creek is a popular trout stream (30,405 acres) that flows from south to north, joining the Cannon River bottoms at Red Wing. Four other named streams are all designated trout waters, and drain directly to the Mississippi River: Bullard Creek, Gilbert Creek, Miller Creek, and Second Creek.

Figure 2: Photo of Mississippi River-Lake Pepin, Frontenac State Park (T. Schauls)

The Mississippi River-Lake Pepin watershed consists of forests, bluff lands, and cultivated lands. The top of the watershed is rolling cropland interspersed by many small tributaries that drop steeply through forested valleys with scattered goat prairies atop cliffs. The tributaries form the named streams, which drain directly into the Mississippi River.

At 70 percent, agriculture is the primary land use in the watershed (land use data from 2001). Approximately 10 percent of the land is in grass. Corn and soybeans make up more than half the tilled acreage of the area, with barley, oats, and pasture land present. Forage production is strong because of the large number of dairy cows in the region. Of the grassland, 90 percent is in pasture and a small percentage (<10 percent) is in a management intensive rotational grazing system. Most of the remaining acreage is deciduous forest. Frontenac State Park, Lake Pepin, and the coldwater fisheries are important natural resources to the region (Figure 3).

The MPCA completed the biological monitoring component of intensive watershed monitoring in the Mississippi River-Lake Pepin during the summer of 2008. A total of 15 biological monitoring sites were established across the watershed and sampled. These sites were located near the outlets of most minor HUC-14 watersheds.

The Mississippi River-Lake Pepin Watershed was assessed in 2011 for aquatic recreation, aquatic consumption and aquatic life beneficial uses. Based on this investigation, the MPCA found one biological impairment in the Gilbert Creek Watershed (Figure 4).

This report connects the biological community to the stressor(s) causing the impairments. Stressors are those factors that negatively impact the biological community. Stressors can interact with each other and can be additive to the stress on the biota. The Mississippi River-Lake Pepin assessment report is available with additional background information about the watershed and the detailed results of recent monitoring and assessment online at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/mississippi-river-lake-pepin.html.

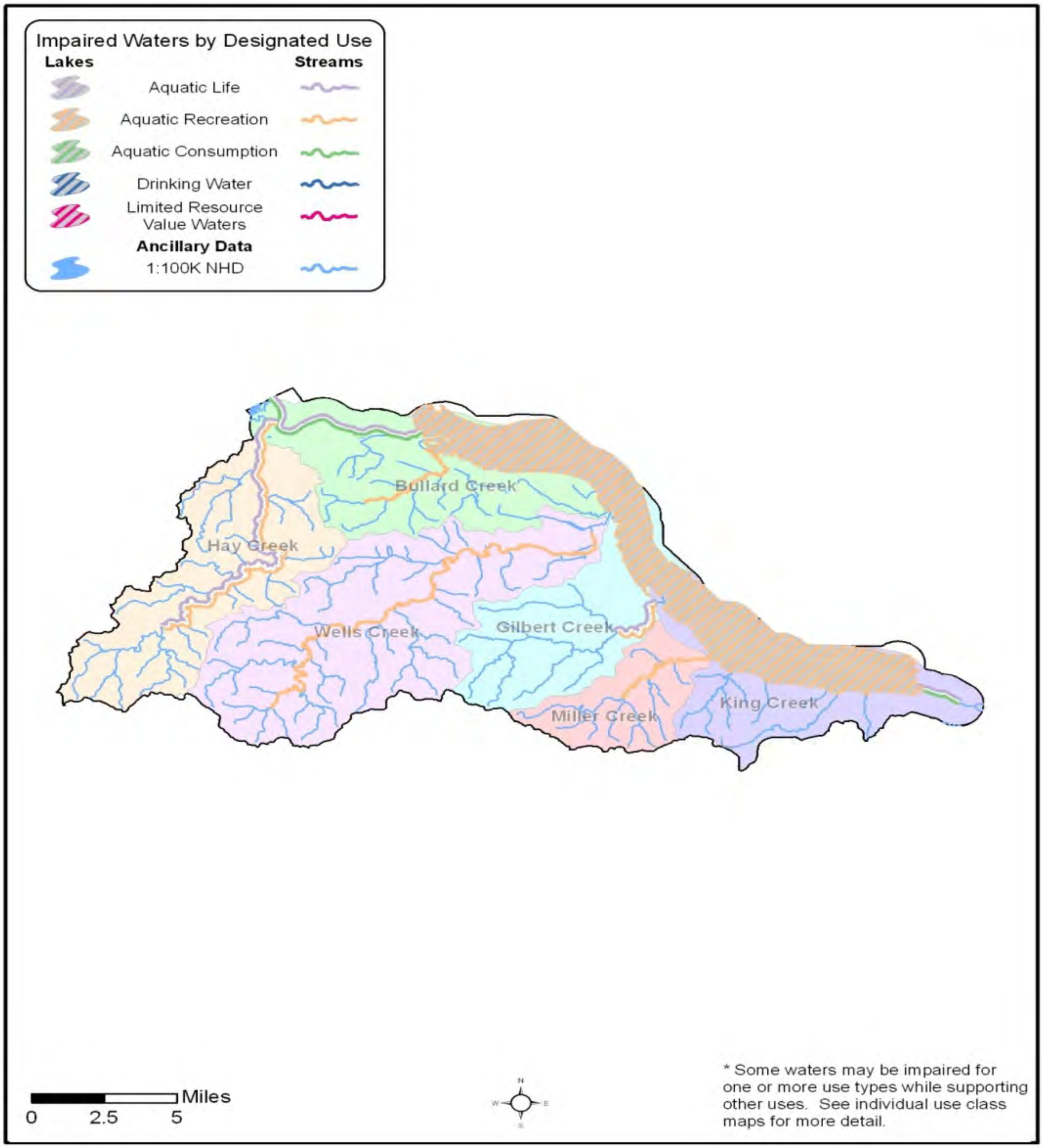


Figure 3: Mississippi River-Lake Pepin Impaired Waters (Mississippi River Lake Pepin Monitoring and Assessment Report)

Gilbert Creek

The Gilbert Creek HUC-11 Watershed unit is located in southern Goodhue and northern Wabasha Counties in the middle portion of the Mississippi River-Lake Pepin Watershed. There are multiple unnamed tributaries and a larger tributary (Sugarloaf Creek) that flow into Gilbert Creek. Cropland (35 percent), forest (26 percent), and rangeland (23 percent) are the predominant land uses in this watershed (NLCD, 2001). Gilbert Creek starts in northern Wabasha County and flows northeast into Lake Pepin just north of Lake City. Biological station 08LM130 located on Gilbert Creek at CSAH 5, one mile northwest of Lake City, represents the outlet of Gilbert Creek. The impairment in the watershed is based on data collected at this site (red line on map, below, Figure 5).

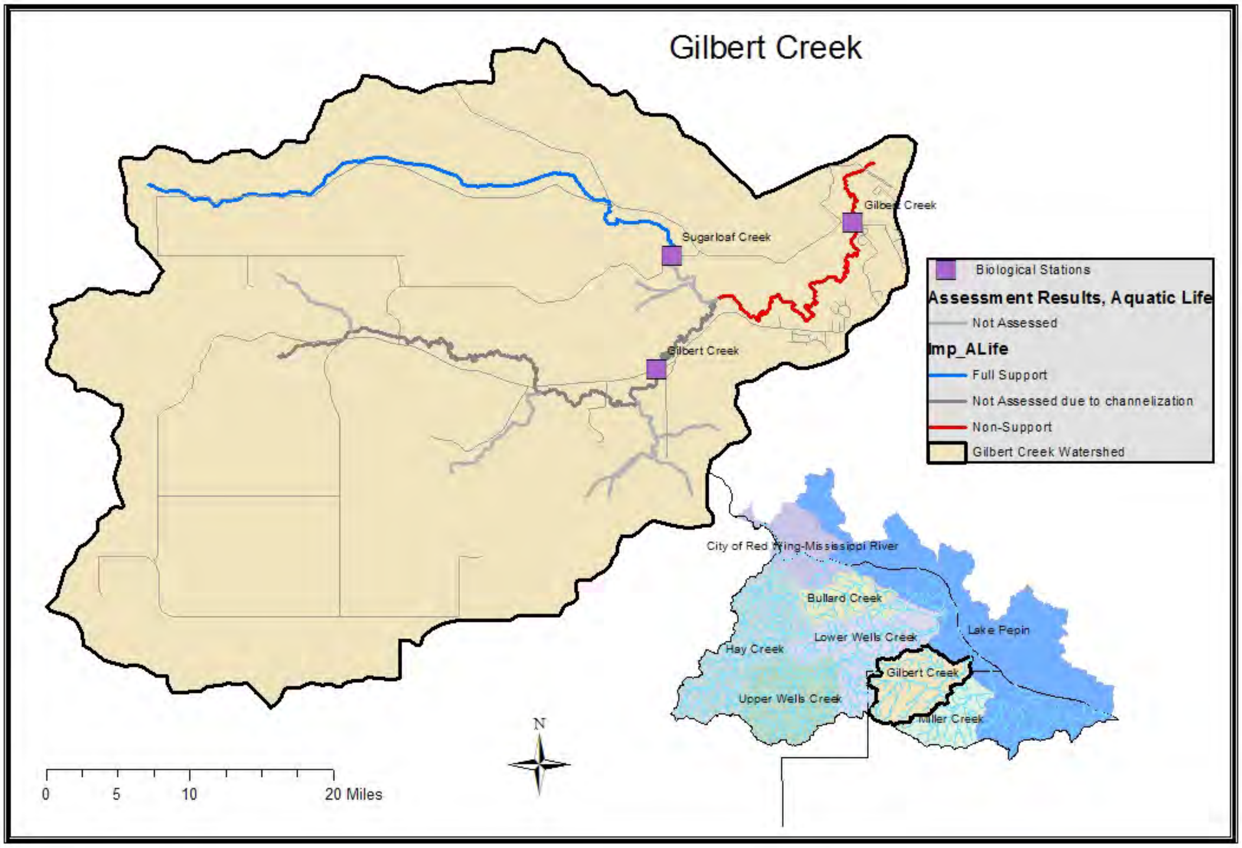


Figure 4: Map of Gilbert Creek Watershed

Stream assessment results

The MPCA surveyed three biological stations in the Gilbert Creek Watershed; Upper Gilbert Creek, Lower Gilbert Creek, and Sugarloaf Creek (Table 1). Table 1 includes the reaches with biological impairments.

Table 2: Summary of biological impairments in the Mississippi River-Lake Pepin

AUID (Assessment Unit ID)	Station ID	Name	Sq. Mi	InvertClass	Threshold	InvertIBI	FishClass	Threshold	FishIBI
07040001-530, Gilbert Creek, Sugarloaf Cr to T112 R12W S31, east line	08LM130	Gilbert Creek	24.07	Southern Coldwater	46.1	**53.96**	Southern Coldwater	45	**42**

The invertebrate community was meeting standards at station 08MN130 in Gilbert Creek. The fish IBI on Gilbert Creek station 08LM130 (Lower Gilbert Creek) was 42, below the threshold of 45 for streams of the southern coldwater class (45). The site also has a poor habitat score and is lacking quality habitat (deep pools) and course substrates. During the assessment process, the IBI score, as well as other factors, were used to determine official impairment.

Station 08LM138, in the upper part of the Gilbert Creek Watershed, was not able to be assessed at this time due to channelization. However, the fish community and invertebrate community at station 08LM138 appear to be healthy. This site is near a Minnesota Department of Natural Resources (DNR) easement and monitoring station, which has shown consistent populations of trout and reproducing trout. Therefore, the main stressors to the Gilbert Creek Watershed seem to be restricted to the lower portion, near 08LM130.

Use classification (coldwater/warmwater) questions are one of the complications in this watershed, and will continually be considered. For example, Sugarloaf Creek is currently classified warmwater. There was insufficient information at the time of assessment to recommend a change to coldwater, but there is documentation of a large spring input downstream of the site, which would favor coldwater conditions. Currently, this site meets warmwater thresholds for fish and inverts, but would likely fail coldwater thresholds. Temperature data for this site was collected in 2011, and can be found in the temperature section of this document.

Fish impairments in Gilbert Creek

In 2008, the biological stations sampled on Gilbert Creek differed in some metric scores, leading to differences in the IBI score. Figure 6 shows the metric scores for each of the stations, with the maximum score possible and the average metric score needed to have an IBI score above the threshold. The metric CWSensitivePct_10DrgArea, the percentage of coldwater sensitive individuals (adjusted for drainage area), are low for both stations. The coldwater sensitive species present in the watershed include brown trout, brook trout, slimy sculpin, and longnose dace; however, their presence is less than would be expected in Gilbert Creek at both stations. Descriptions of the biological metrics are included in Figure 7.

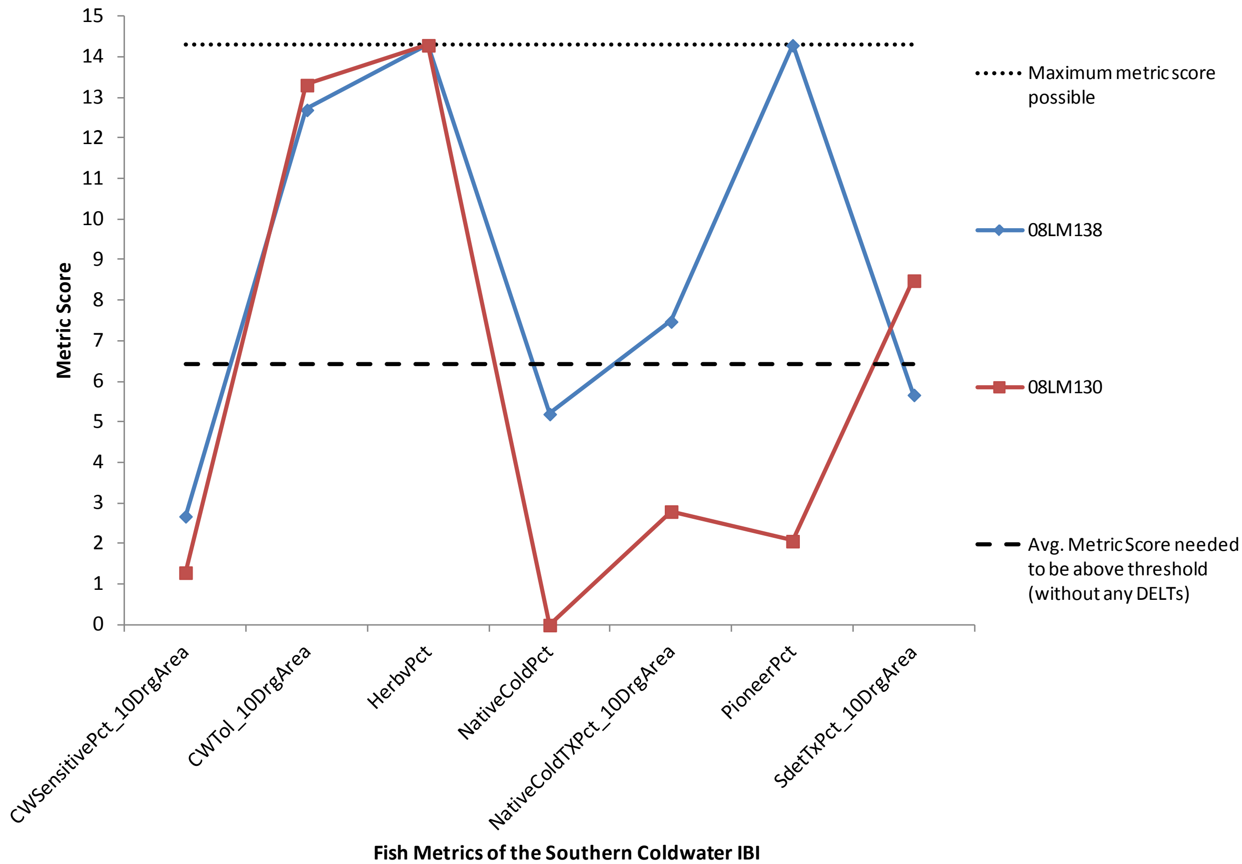


Figure 5: Fish metrics of the southern coldwater IBI in stations 08LM138 (Upper) and 08LM130 (Lower) in Gilbert Creek

Table 3: Biological metrics included in the Southern Coldwater Fish IBI

MetricName	Category	Response	Metric Description
CWSensitivePct_10DrgArea	tolerance	positive	Relative abundance (%) of individuals that are sensitive in coldwater streams (scoring adjusted for drainage area)
CWTol_10DrgArea	tolerance	negative	Taxa richness of tolerant species in coldwater streams (scoring adjusted for drainage area)
NativeColdTXPct_10DrgArea	habitat	positive	Relative abundance (%) of taxa that are native coldwater species (scoring adjusted for drainage area)
NativeColdPct	habitat	positive	Relative abundance (%) of individuals that are native coldwater species
HerbvPct	trophic	negative	Relative abundance (%) of individuals that are herbivorous
SdetTXPct_10DrgArea	trophic	negative	Relative abundance (%) of taxa that are detritivorous (scoring adjusted for drainage area)
PioneerPct	life history	negative	Relative abundance (%) of individuals that are pioneer species
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with Deformities, Eroded fins, Lesions, or Tumors

Three metrics greatly differed between the two stations: NativeColdPct, NativeColdTXPct_10 DrgArea, and PioneerPct. The metric NativeColdPct is the percent of individuals that are native coldwater species, and the metric NativeColdTXPct_10 DrgArea is the percent of taxa that are native coldwater species (adjusted for drainage area). The percent individuals that are pioneer species are measured by the metric PioneerPct.

Both the individuals and taxa percentage of native coldwater species are reduced in the downstream site 08LM130. The species included in these metrics and found in the watershed are: brook trout and slimy sculpin. Two slimy sculpin were found in Sugarloaf Creek in 2008. Sculpin were not found in Gilbert Creek by the MPCA in 2008 (nor does any DNR survey indicate sculpin in lower Gilbert Creek). Lower station 08LM130 had no native coldwater species, whereas upper station 08LM138 had three brook trout, which elevated the metric score for both native coldwater metrics.

Upper station 08LM138 did have a 10-point deduction of the IBI score because of the presence of four lesions present on white suckers. Lower station 08LM130 did not have any DELTs (abnormalities), which led to no deductions.

One of the greatest differences between the two sites in Gilbert Creek was the percentage of individuals of pioneer species. Creek chub were the pioneer species found at lower 08LM130 and were the most abundant with 47 percent, in 2008. In 2011, no creek chub were present, according to data from the DNR. Creek chub are responsible for the low metric score for Pioneers. Station 08LM138 (Upper Gilbert Creek) had no pioneer species. "Pioneering species predominate in unstable environments that have been affected by temporal desiccation or anthropogenic stressors, and are the first to reinvade sections of headwater streams following periods of desiccation" (Barbour et al., 1999).

Lower station 08LM130 had a low number of fish, 34, in 2008, but the DNR reported an even lower number of fish surveyed, 13, in 2011. To contrast, in 2011, 374 fish were captured near upper station 08LM138 by the DNR. There is a minimal abundance of fish in the lower 08LM130 reach and the fish present are not what is expected of a coldwater stream. In comparison, the next-door watershed Miller Creek had 82 fish surveyed at station 08LM131. It also lacked high scores in the native coldwater metrics, but it had no pioneer species and was comprised of mostly brown trout (92 percent), which are sensitive to water quality conditions.

The DNR initiated stocking of Gilbert Creek in 1982. At that time, it did not have any success. Brook and brown trout are reproducing naturally after 2005 and 2006 stockings of brook trout. In 2008, two brown trout were found in lower 08LM130. In 2011, DNR found one brown trout and two brook trout near lower station 08LM130. In 2001, 13 brown trout were found by DNR. Brook trout have been found as far up as 6.9 miles upstream of the confluence with the Mississippi River.

In 2012, Lower Gilbert Creek-08LM130 was resampled for fish. The IBI score was 50 compared to 42 in 2008. The site was sampled on July 31, 2012, and only 13 total fish were sampled compared to 34 in 2008. Both years showed similar results: few trout and no other coldwater species. The majority of species sampled were warmwater.

Stressor list for Gilbert Creek and supporting data

Table 4: Candidate Stressors for Gilbert Creek

Candidate Stressors Found	Other Candidate Stressors Examined (found to not be affecting aquatic life at this time)
· Physical Habitat · Bedded Sediment	· Temperature · Pesticides · Flow Alteration · Dissolved Oxygen · Nitrate and Nitrite · Connectivity

This list is based on all the information and data collected during monitoring and stressor ID process. In the following sections of the report, each candidate stressor is examined and data are presented as to which stressors were found to be affecting fish in Gilbert Creek. Overall, two candidate stressors exist: physical habitat and bedded sediment. These two stressors are related, as the lack of physical habitat is partially due to the bedded sediment issue. Other candidate causes and data are presented to show why and how those stressors are not affecting aquatic life. Further details on each candidate cause and how it impacts biology, along with our current standards, can be found in the appendix.

Physical habitat in Gilbert Creek

Habitat is variable throughout the Mississippi River-Lake Pepin Watershed and is vital in understanding the biological communities. Throughout the Mississippi River-Lake Pepin Watershed, qualitative habitat was measured with the Minnesota Stream Habitat Assessment (MSHA). The MSHA is useful in describing the aspects of habitat needed to obtain an optimal biological community. It includes five subcategories: land use, riparian zone, substrate, cover, and channel morphology.

Table 5: Minnesota Stream Habitat Assessment (MSHA) results for the Gilbert Creek 11 HUC

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
1	08LM139	Sugarloaf Creek	1.5	8.5	13.7	15	21	59.7	Fair
1	08LM130	Gilbert Creek (Lower)	2.5	10.5	13.1	2	16	44.1	Poor
1	08LM138	Gilbert Creek (Upper)	5	10	13.2	15	22	65.2	Fair
Average Habitat Results: *Gilbert Creek 11 HUC*			**3**	**9.7**	**13.3**	**10.7**	**19.7**	**56.3**	**Fair**

Qualitative habitat ratings:
Good: MSHA score above the median of the least-disturbed sites (MSHA>66)
Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)
Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Fish cover is a limiting factor in lower Gilbert Creek (08LM130), as demonstrated by the MSHA measurements and DNR observation. Multiple DNR reports confirm that fish cover and habitat are limiting in this part of the stream. "The lower end of Gilbert is a sandy bottom with high eroding banks. There are very few deep pools or fast riffles. This reach is poor trout habitat due to lack of cover and poor substrates." (DNR Stream Assessment Report, February 2012)

As defined by the MSHA: cover for fish consists of objects or features dense enough to provide complete or partial shelter from the stream current or concealment from predators or prey. In order to be considered cover, the water depth must be at least 10 cm where the cover type occurs. Types of cover include: undercut banks, overhanging vegetation, deep pools, logs and woody debris, boulders, root wads, and macrophytes.

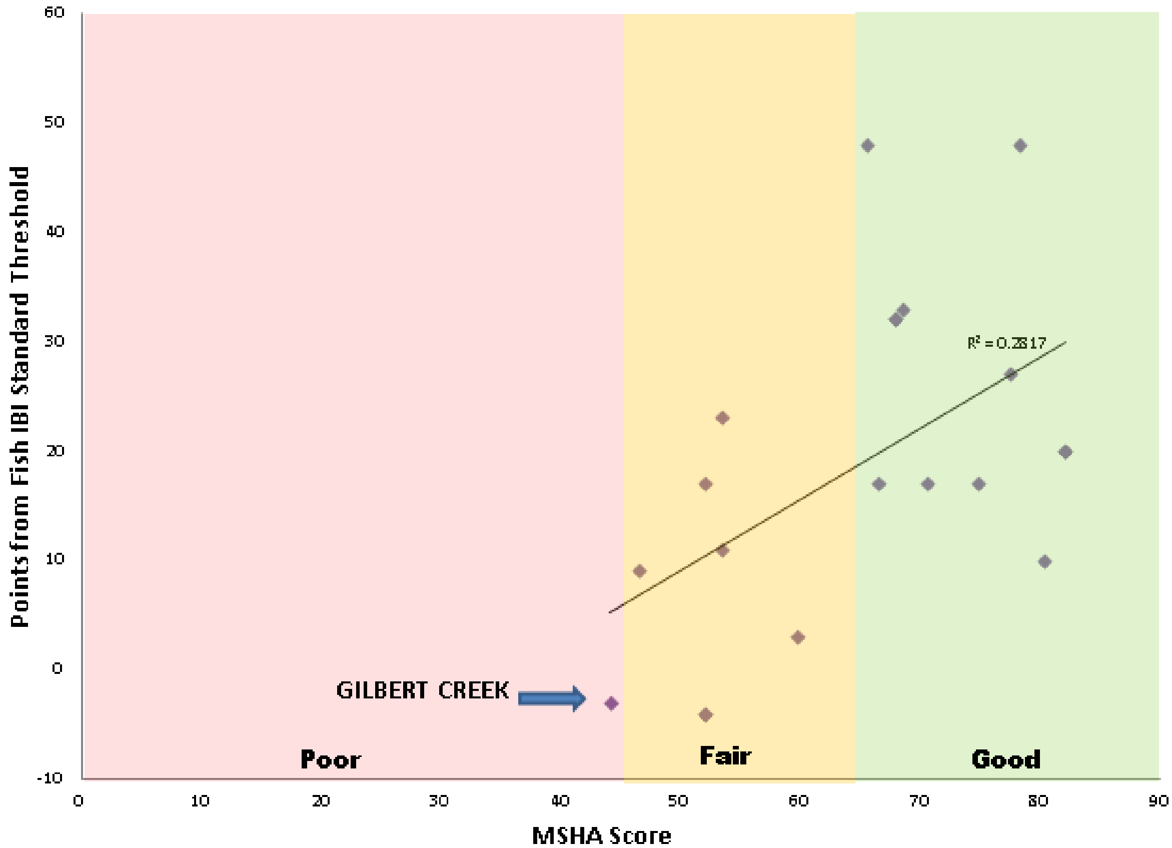


Figure 6: MSHA scores and points above or below fish IBI threshold for all natural channel sites in the Mississippi-Red Wing Watershed

The IBI scores in the Mississippi River-Lake Pepin watershed have a limited positive relationship with the total MSHA score (Figure 8). In comparison to the rest of the watershed, Gilbert Creek had the lowest fish IBI score combined with MSHA. In fact, lower Gilbert Creek-08LM130 was the only site in the Mississippi-Red Wing watershed that received a “poor” MSHA rating. It also has one of the lowest fish IBI scores in the watershed. The IBI is comprised of numerous metrics that measure biotic response to various stresses including, but not limited to, habitat.

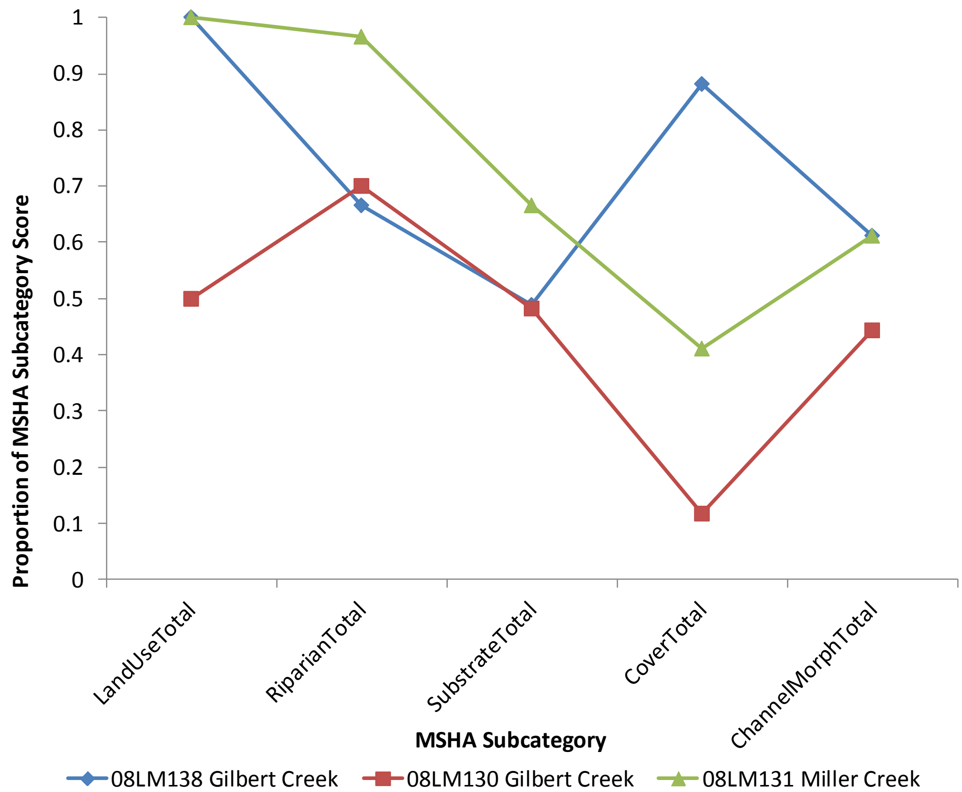


Figure 7: MSHA Subcategory Scores for Gilbert Creek and Miller Creek sites

Figure 9 above demonstrates the difference in MSHA components for both Gilbert Creek sites, as well as neighboring watershed, Miller Creek. Miller Creek is not impaired for fish or invertebrates. Figure 10 below demonstrates the "weight" of each portion of the MSHA, to the total score.

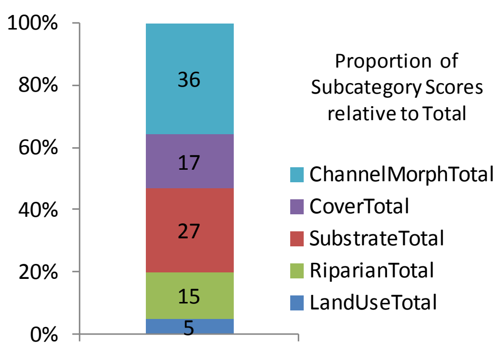


Figure 8: MSHA Subcategory Scores

To read additional information about the effects of physical habitat on aquatic life, see the appendix.

Deposited and bedded sediment in Gilbert Creek

As discussed in the previous section on habitat, deposited and bedded sediment appear to be adversely affecting the fish community. Sand is the dominant substrate in the lower portion of the watershed, which includes the fish impaired site, lower 08LM130. Overall water depth and pool development were essentially non-existent. Figure 11 below shows trees leaning towards the over-widened channel. This channel over-widening is allowing sediment to deposit and preventing pools and other important stream morphological features to develop. The channel is storing sediment in this location which is affecting the habitat quality for fish. Invertebrates can also become affected by excess bedded sediment. However, at this site, invertebrates have sufficient habitat provided by woody debris, so the population is less affected. In fact, during invertebrate sampling woody debris were the only habitat found to be sampled. Riffles are expected types of habitat in coldwater trout streams, but were not found at this site.

Figure 9: Picture of lower Gilbert Creek-08LM130; mid-channel bar indicative of excess sediment and channel aggredation due to over-widened channel

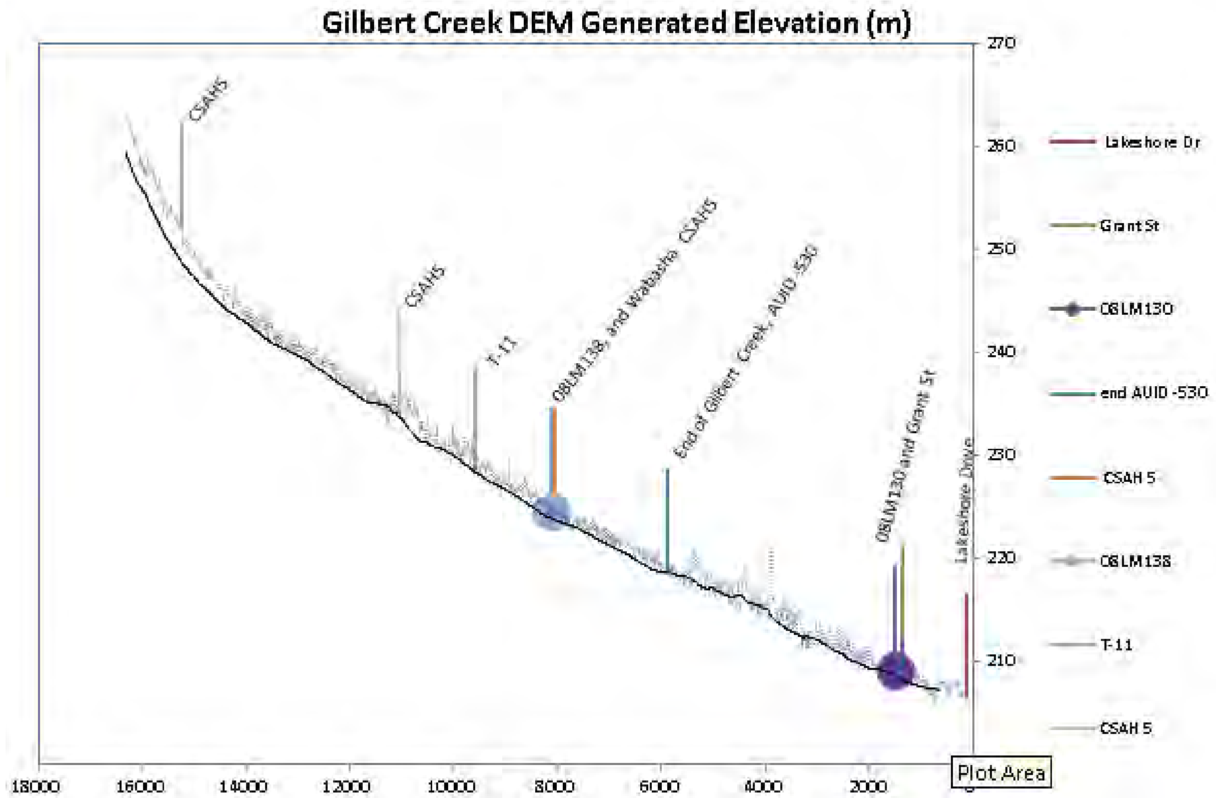


Figure 10: Elevation Profile of Gilbert Creek Watershed

An elevation profile shows the elevation changes along a stream channel. It is likely that the lower portion of Gilbert Creek is being controlled by Lake Pepin (downstream) and results in sediment aggradation that is seen in lower Gilbert Creek-08LM130. Figure 12 shows a difference in stream slope between the two biological stations, 08LM138 and 08LM130. The sediment aggradation that occurs at 08LM130 can be partially explained by the change in overall stream slope. Stream slope is important for sediment transport capacity, meaning if slope decreases, so does the streams ability to move sediment. This is seen at lower 08LM130, where the pools and riffles are filled in, and sediment covers habitat.

Figure 13 to the right shows that the product of sediment load and sediment size is proportional to the product of stream slope and discharge—or stream power. A change in any one of these variables causes a rapid physical adjustment in the stream channel.

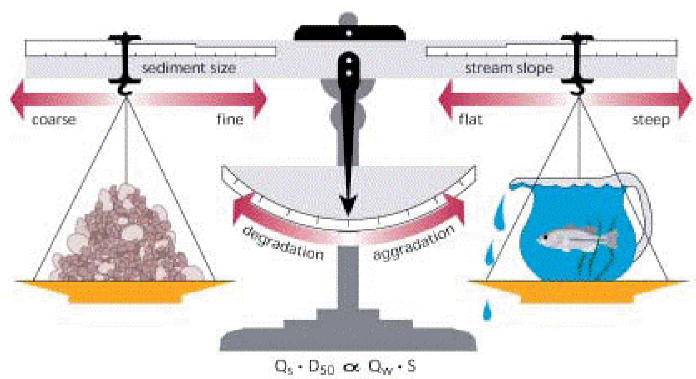


Figure 11: Generalized relationship of stream stability (Rosgen)

The stream elevation profile of neighboring watershed Miller Creek (Figure 14) shows similar stream slope changes. Like Gilbert Creek, the lower portion of Miller Creek also loses stream slope, but the biological station is located farther upstream to avoid those slope/excess sediment/habitat issues. Based on this data, there appears to be a knick point near CSAH 9, potentially caused by that road crossing. Knick points are locations of very active erosion due to changes in slope and stream power. Knick points tend to migrate upstream if allowed. The MPCA did not formally collect stability data on Miller Creek, but general observations noted some instability occurring throughout the watershed.

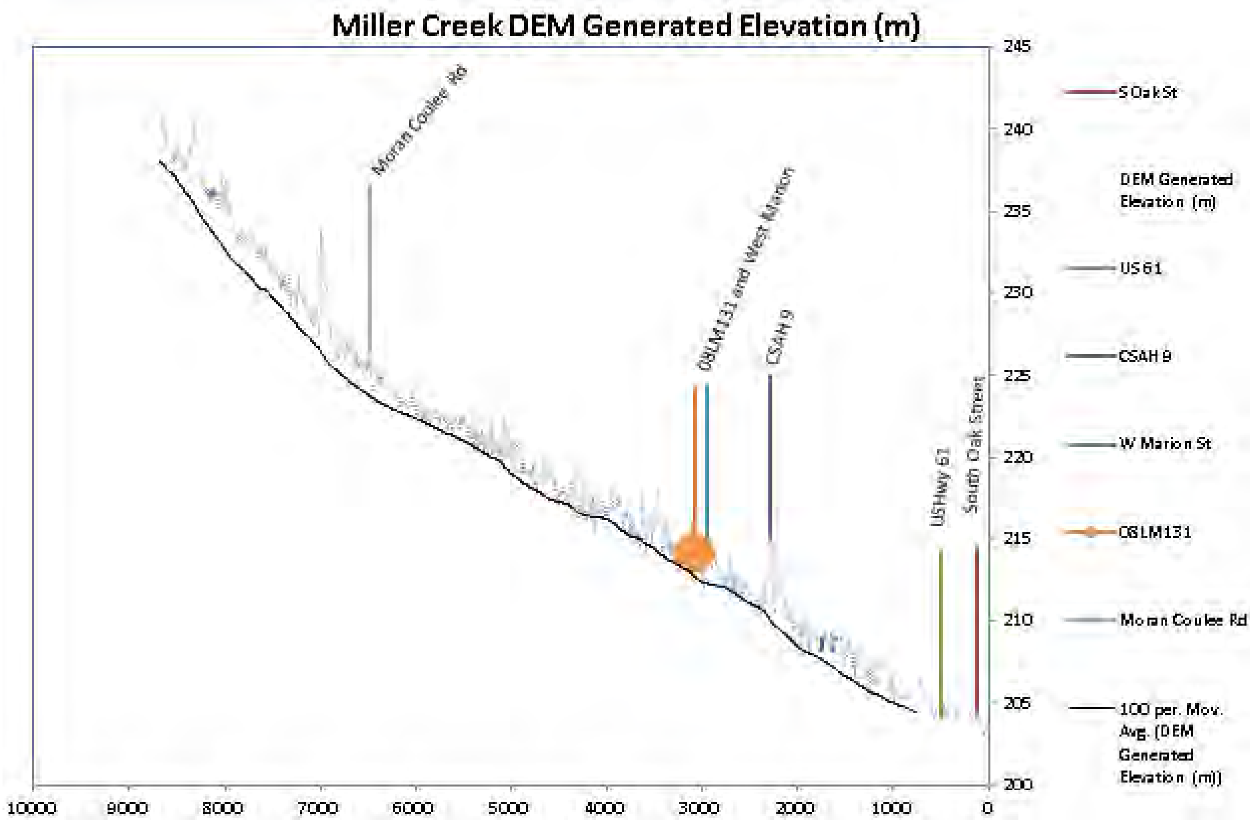


Figure 12: Miller Creek Elevation Profile

Figure 13: Sediment plumes in Lower Gilbert Creek below biological station, 08LM130 (Google, 2012)

Sediment plumes found in the reach downstream of lower 08LM130 are indicative of poor substrate in this area. Shifting sand dominates this reach of the river and provides little habitat niches for fish to find refuge from competitors and temperature.

Erosion and sediment are not a new phenomenon in this watershed or others in the Mississippi River-Lake Pepin watershed. DNR surveys on Gilbert Creek pointed out that in 1946, “The banks are generally herbaceous but frequent steeply cut and exposed banks of sandy loam show considerable erosion.” (DNR Summary of Gilbert Creek-Nursery Creek; August 25, 1946)

“Most of the riparian corridor is vegetated by successional trees, which shade out any understory and thus allow severe bank erosion. Sloping and stabilizing stream banks would be helpful in some areas, and most effective if the riparian vegetation were replaced with grasses and long lived (not successional) hardwoods.” (DNR Stream Population Assessment, 2001)

Urban runoff and agricultural runoff are present in the Gilbert Creek watershed. Land use in the valley is agricultural, but an increasing portion is becoming urbanized as Lake City expands. As a result, stormwater runoff from urban areas in lower Gilbert Creek is increasing.

Figure 14: Picture of station 08LM130 on June 25, 2008

Total suspended solids (TSS) were elevated during monitoring season 2008; however, flow conditions during this year were atypical. In 2008, this watershed and surrounding area received on average 4-5 inches of rain in the month of June alone (Minnesota State Climatology). On the day of fish sample, June 25, 2008, TSS concentrations were 26 mg/L (milligrams per liter) at lower Gilbert Creek-08LM130 indicating that flows were still elevated slightly from recent rains (Figure 16).

As a result, Gilbert Creek-08LM130 was resampled for fish on July 31, 2012. The IBI score was 50 compared to 42 in 2008. Only 13 total fish were sampled in 2012 compared to 34 in 2008. Both years showed similar results -- few trout and no other coldwater species. The majority of species sampled were warmwater. These results confirm that the elevated flow regime in 2008 had little to no affect on the fish sample in 2008, and the results are representative of the fish community present.

Suspended sediment measurements can also be important indicators regarding how much sediment is deposited in the stream channel. The data points for TSS on Gilbert Creek were limited to 2008. Transparency tube measurements can help indicate how often and to what extent sediment effects a stream. Gilbert Creek has multiple transparency tube measurements, over a number of years (Figure 17).

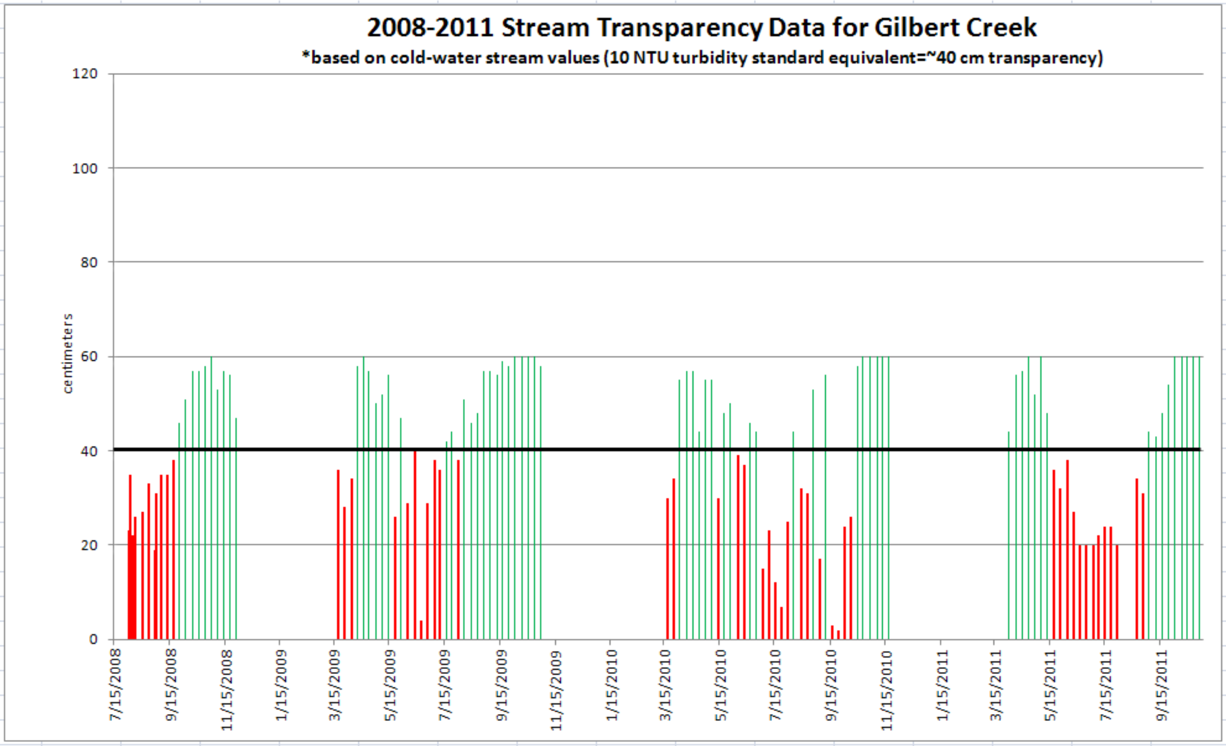


Figure 15: 2008-2011 Transparency Data for Gilbert Creek

The transparency data above were collected near the 08LM130 biological monitoring site for 2008-2011 (Citizen Stream Monitoring Data). This data show how often the stream sees turbid conditions. Red bars indicate data that are likely failing to meet the turbidity standard, while green bars indicate data that are likely meeting the turbidity standard. For the purposes of this graph, the turbidity equivalent to transparency was estimated to be around 40 cm (i.e., 10 NTU=40 cm). This estimate is based on paired data found throughout the state and a turbidity standard of 10 NTU for coldwater streams.

As seen on this graph, each year has different season rainfall patterns, land use/land cover impacts, etc. All of these factors impact the sediment delivery in the stream. For example, spring can be a vulnerable time for streams regarding sediment delivery and movement. Crops are not protecting soil and therefore, runoff can deliver sediment to the stream quickly, which results in stream bank failure.

To read additional information about the effects of bedded sediment on aquatic life, see the appendix.

Temperature in Gilbert Creek

A continuous temperature logger was deployed at lower Gilbert Creek-08LM130 from late June through early September 2011 (Figure 18). This time period is most important to consider when determining if the stream is responding to the warm summer air temperatures. In the case of Gilbert Creek, temperature shows a similar pattern to other coldwater streams in southeast Minnesota. The maximum temperature and ranges of temperatures found in the creek are appropriate.

"The optimal range of water temperatures for brown trout is consistently reported as 12-18°C. A laboratory study by Coutant (1975) found that the tolerance range for brown trout was 18-20°C and the resistance ranges 20-22°C. This confirms Gardner and Leetham's (1914) observation that adult trout mortality is high above 20°C and complete above 25°C." (Bell, 2006)

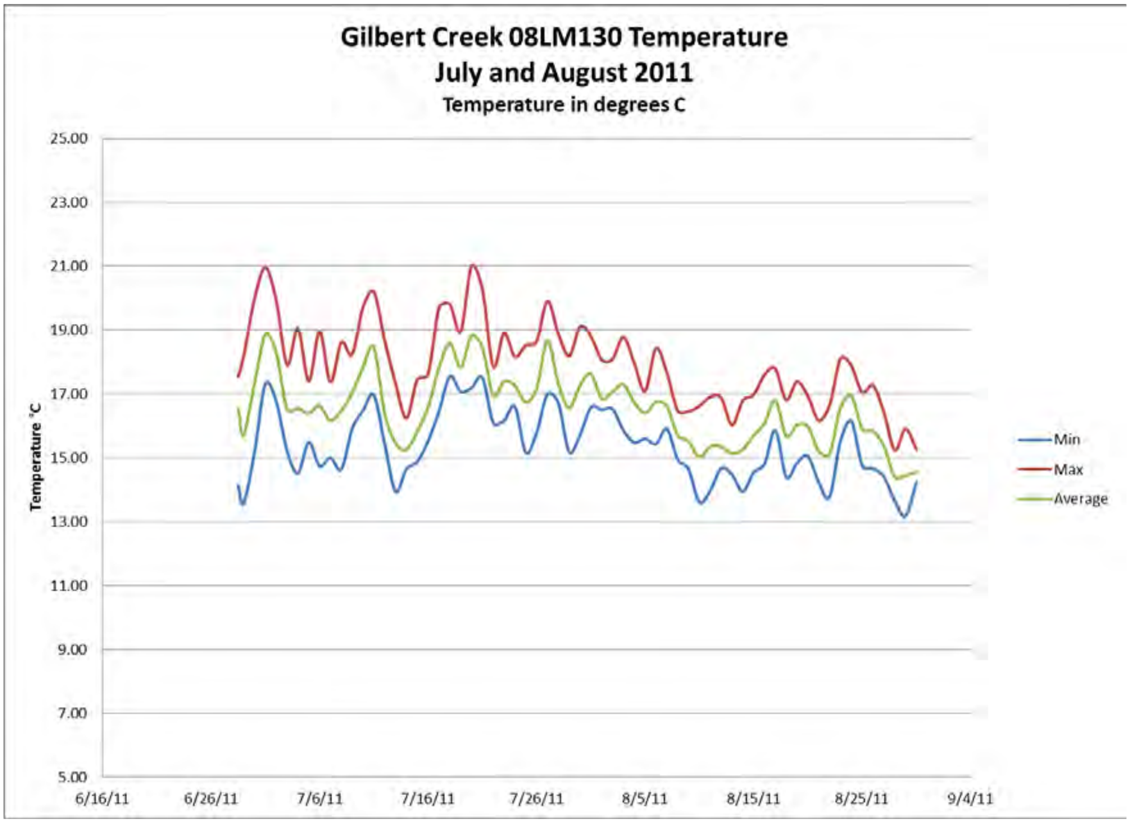


Figure 16: Temperature data collected for Gilbert Creek, July and August 2011

Due to a healthy coldwater invertebrate community, the MPCA believes that temperature is not a limiting factor for trout and other coldwater species in Gilbert Creek at this time. However, as development expands, and stormwater inputs increase throughout the watershed, this might be a stressor to continue to evaluate.

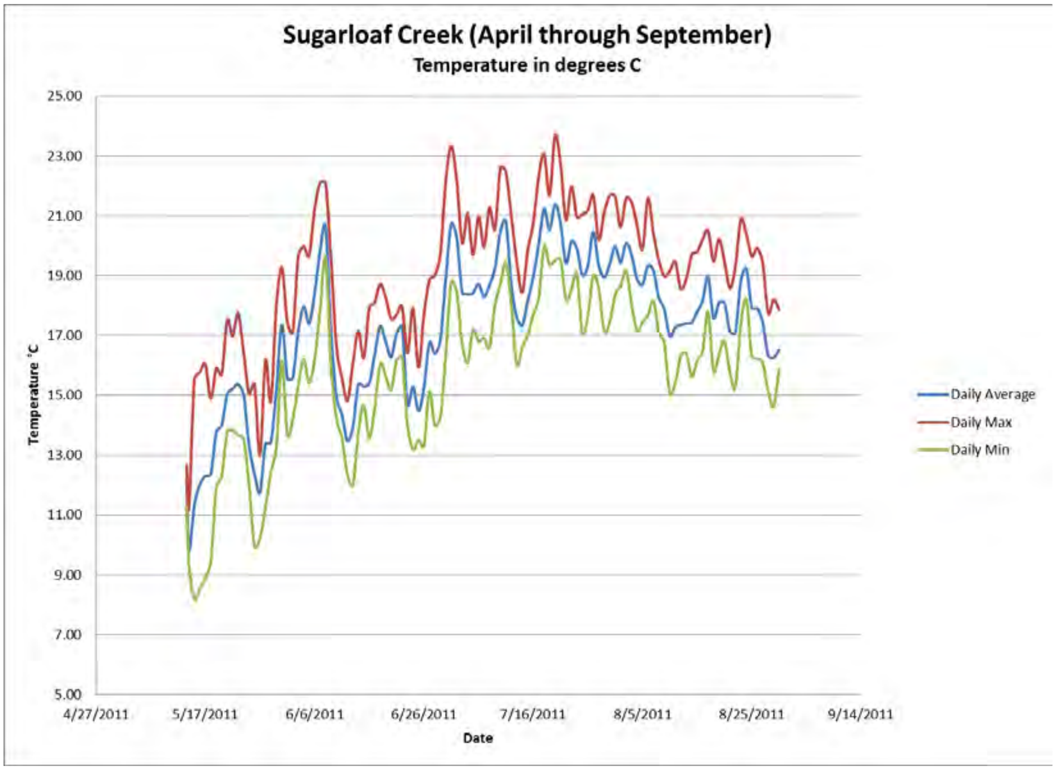


Figure 17: Temperature data collected from Sugarloaf Creek in 2011 (May-September)

In comparison, Figure 19 shows temperature data from Sugarloaf Creek, a warmwater tributary to Gilbert Creek. Sugarloaf Creek temperatures are much more characteristic of a warmwater system. The data appear less thermally buffered by cold spring water. This is evidenced by a larger range of temperatures, and the influence air temperature has on the stream. After some additional data collection, it appears that Sugarloaf Creek transitions to coldwater just downstream of the biological sampling station, where a large spring input begins. It is uncertain at this time if the small upper portion of Sugarloaf Creek is a degraded coldwater system, or truly warmwater. Due to these uncertainties, the decision was to assess the site using warmwater thresholds.

Flow alteration in Gilbert Creek

Flow alteration can become a stressor to streams when the hydrologic regime is disrupted, such as baseflow decreases or increases. In many parts of the state, flow alteration becomes apparent when the watershed is dominated with tile drainage, or the landscape has changed in a way that alters water storage on the land, such as drained wetlands. Tile drainage is present in the upper portion of the watershed, but it is fairly minimal since the watershed is not dominated by row crop agriculture. Gilbert Creek's base flow is sustained by multiple springs in the watershed.

Streams will naturally change course over time. In an effort to understand changes in Gilbert Creek, the 1855 public land survey map was digitized and overlaid with the NHD (National Hydrography Dataset) flow lines (Figure 20). One difference between the 1855 public land survey map (in black), and the NHD flowline (in blue), is that the NHD dataset includes perennial and intermittent streams. It appears the stream has lost some sinuosity over time, which can be natural or result from anthropogenic influence. While there is a noticeable difference in some areas of Gilbert Creek, it is difficult to conclude that the flow has been altered to result in this stream channel change.

It is unclear how small changes in hydrologic regime can affect the biological community directly. In many cases, it is more likely noticeable with other stressors, such as sediment. The connection and relationship is something that is unknown at this time and still being developed. Overall, it does not appear that the natural hydrologic regime has been dramatically altered in Gilbert Creek and, therefore, flow alteration is not a likely stressor at this time.

To read additional information about the effects of flow alteration on aquatic life, see the appendix.

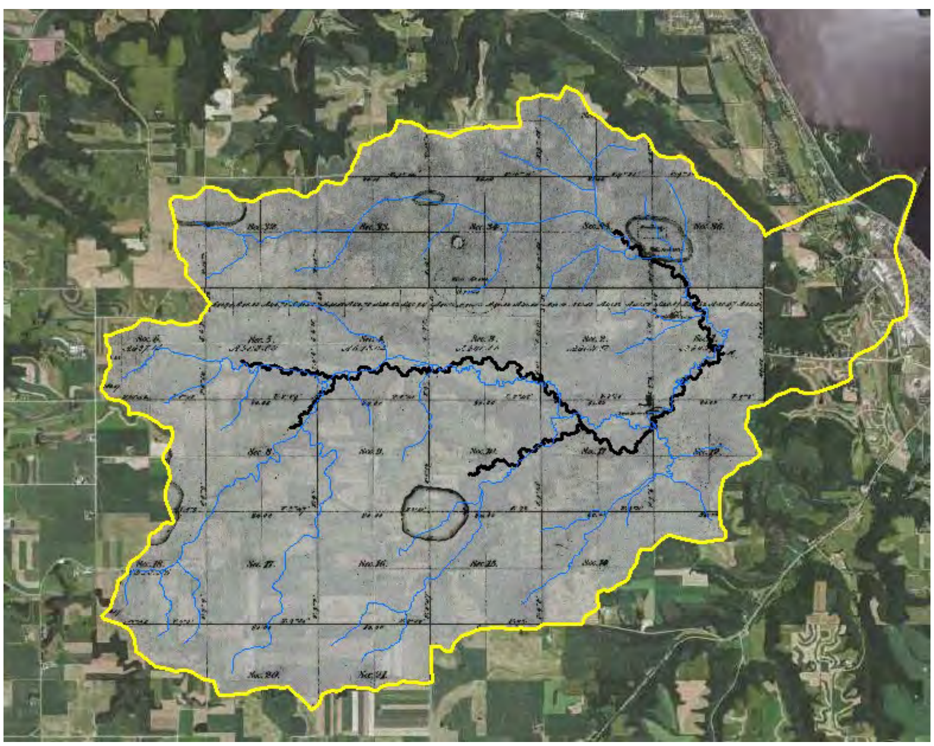


Figure 18: Gilbert Creek comparison (1855 Public Land Survey in Black; NHD flowline (perennial and intermittent) in Blue)

Connectivity (longitudinal) in Gilbert Creek

Gilbert Creek has two biological stations, which show different fish communities. Therefore, it was important to look further into longitudinal connectivity, which refers to the free flow of water downstream and passage of fish upstream.

Dams are a common connectivity concern, but are not present in Gilbert Creek. However, improperly designed or poorly maintained culverts also have the potential to disrupt stream flow, temperature, and sediment delivery in streams. They can disrupt stream habitat and the ability for fish to migrate upstream and spawn.

For example, “perched” culverts have affected fish migration in other southeast Minnesota trout streams. Perched culverts can occur when the outlet of a culvert becomes “perched” above the level of the stream. Perched culverts are a serious barrier to fish movement. Anecdotal information from DNR fisheries staff suggests they have not seen any perched culverts currently on any reaches of Gilbert Creek.

DNR reports do indicate that beaver dams are common in Gilbert Creek, which can also limit fish migration. However, fish movement does not appear to be an issue in Gilbert Creek due to the presence of migratory fish throughout the creek (upstream and downstream reaches). Other types of connectivity (i.e., lateral connectivity: channel to floodplain) were not examined in this report due to lack of information.

To read additional information about the effects of connectivity on aquatic life, see the appendix.

Pesticides in Gilbert Creek

Pesticides (including herbicides, fungicides, and insecticides) are considered as potential stressors in Gilbert Creek due to the surrounding land use. Twelve pesticide compounds or pesticide breakdown products were detected in a sample collected on July 27, 2011, in Gilbert Creek. All of the detections were well below applicable MPCA water quality standards or EPA aquatic life benchmark reference values. Based on these sample results, it was concluded that pesticides are currently not likely a stressor. The MPCA assumes that pesticides have minimal impact to aquatic life in Gilbert Creek at this time because pesticide detection levels in the sample were less than one percent of their lowest reference value, exept for one circumstance (2-4-D at 1.4 percent of reference value). Pesticides will continue to be examined as potential stressors in Gilbert Creek.

Additional monitoring is recommended to further understand the presence of pesticides in Gilbert Creek and the potential impact to fish, invertebrates and other aquatic biota. Since the impairment is for fish and not invertebrates on Gilbert Creek, it is assumed that this stressor has a minimal impact to aquatic life at this time. However, pesticides are not something that should be ruled out as a threat to aquatic life given the local land use activities. Targeted storm flow monitoring during the peak pesticide runoff period (spring and early summer) would improve confidence in the ability to diagnose or refute pesticide toxicity as a stressor in this watershed for herbicides applied early in the growing season. Also, one sample may not determine the full range of possible pesticide detections found in the system. Given these current gaps in the pesticide data, it is difficult to rule out pesticide toxicity as a possible stressor to aquatic life. However, additional pesticide monitoring at other streams in the region has not resulted in pesticides being identified as a stressor to aquatic life.

The chart below reports the detected pesticide compounds, and concentration, from the sample collected on July 27, 2011. A total of 118 different pesticides compounds, including degradates, were analyzed. Twelve pesticide compounds were detected including six herbicides, one fungicide, and five pesticide breakdown compounds. All detections were well below applicable water quality reference values. ***Only*** pesticide compounds that were detected in the sample collected on July 27, 2011, are presented in Figure 21.

To read about the effects of pesticides on aquatic life in general, see the appendix.

Table 6: Pesticide detections in Gilbert Creek Sample, 7/27/2011

Gilbert Creek Pesticide Detections (Sample on July 27, 2011)					
Pesticide and info	**Gilbert Creek Result (µg/L)**	**MPCA Class 2A Chronic Standard (µg/L)**	**MPCA Max Standard (µg/L)**	**EPA Acute Value Aquatic Life BenchMark (µg/L)**	**EPA Chronic Value Aquatic Life Benchmark (µg/L)**
Azoxystrobin; fungicide applied on both agriculture and non-ag setting for disease control and plant health benefits	**0.0141**	na	na	130 (i)	44(i)
Desethylatrazine; degradation product of the parent herbicide atrazine, used to control weeds in agricultural settings	**0.06**	na	na	Na	1,000 (n)
2,4-D; herbicide and secondary plant growth regulator, used to control broadleaf weeds in agricultural settings	**0.177**	70 H	na	12,075 (f)	13.1 (v)
Acetochlor ESA; degradation product of the parent herbicide acetochlor, used as a herbicide on corn	**0.151**	na	na	>62,500 (i)	9,900 (n)
Acetochlor OXA; degradation product of the parent herbcide acetochlor, used as a herbicide on corn	**0.137**	na	na	Na	na
Hydroxyatrazine; degradation product of the parent herbicide atrazine, used to control weeds in various agricultural crops	**0.0853**	na	na	>1,500 (f)	>10,000 (n)
Imazethapyr; herbicide applied to feed crops	**0.00965**	na	na	>55,000 (f) (i)	8.10 (v)
MCPA; herbicide widely used in both agricultural and non-crop (turf/lawn care) areas	**0.008**	na	na	90 (i)	20 (v)
Metolachlor ESA; degradation product of the parent herbicide metolachlor, widely used in both agricultural and non-crop areas	**0.0561**	na	na	24,000 (f)	>95,100 (v)
The following were found at trace amounts					
Acetochlor; used as a herbicide on corn fields	**P (<0.05)**	3.6 T	86 T	Na	na
Atrazine; widely used herbicide on broadleaf and grassy weeds	**P (<0.05)**	3.4 H; 10 T	323 T	Na	na
Metolachlor; widely used herbicide for general weed control	**P (<0.07)**	23 T	271 T	Na	na

Key to Value Types and Symbols in Surface Water Reference Values

– – For some analytes, reference values have not been identified or evaluated.

na – not applicable

(f) – USEPA/OPP benchmark value for fish.

(i) – USEPA/OPP benchmark value for invertebrates.

(n) – USEPA/OPP benchmark value for nonvascular plants

(v) – USEPA/OPP benchmark value for vascular plants.

H – "H" Chronic Standard values are human health-based and protective for an exposure duration of 30 days.

T – "T" Chronic Standard values are toxicity-based for aquatic organisms and protective for exposure duration of 4 days.

Nitrate and nitrite in Gilbert Creek

Gilbert Creek was sampled 11 times in the summer of 2008 for nitrate. The ranges of nitrate sample results were 1.7-2.5 mg/L. This concentration is relatively low given the average nitrate concentrations found in the region. Many studies suggest that invertebrates are typically more sensitive to elevated nitrate concentrations than fish. Since invertebrates appear to be fairly healthy, it is not believed that nitrate is affecting aquatic life at this time.

Nitrate-nitrogen concentrations in southeast Minnesota's trout streams show a strong linear relationship to row crop land use. A linear regression showed a slope of 0.16, suggesting that the average baseflow nitrate concentration in the trout stream watersheds of southeast Minnesota can be approximated by multiplying a watershed's row crop percentage by 0.16 (Watkins, et al.). Gilbert Creek (to 08LM130) has 28 percent row crop land use, which correlates well to the low nitrate concentrations. The strong correlation between nitrate-nitrogen concentrations in streams and watershed row crop percentage suggests that, in general, nitrogen application over a span of decades has impacted the condition of the underlying aquifers that are the source of these streams' baseflow (Watkins, et al.).

By maintaining or decreasing the percentage of row crops in the watershed, the MPCA believes the nitrate level would stay at or near current levels as well.

Figure 22 below shows nitrate concentration comparisons throughout watersheds of southeast Minnesota. The Mississippi River-Lake Pepin Watershed, which includes Gilbert Creek, is represented in Green. Overall, sites in this area are less than 40 percent row crop agriculture, and have a range of nitrate concentrations from 2-8 mg/L. Gilbert Creek is on the low end of that, and the low end compared to the majority of trout streams in southeast Minnesota.

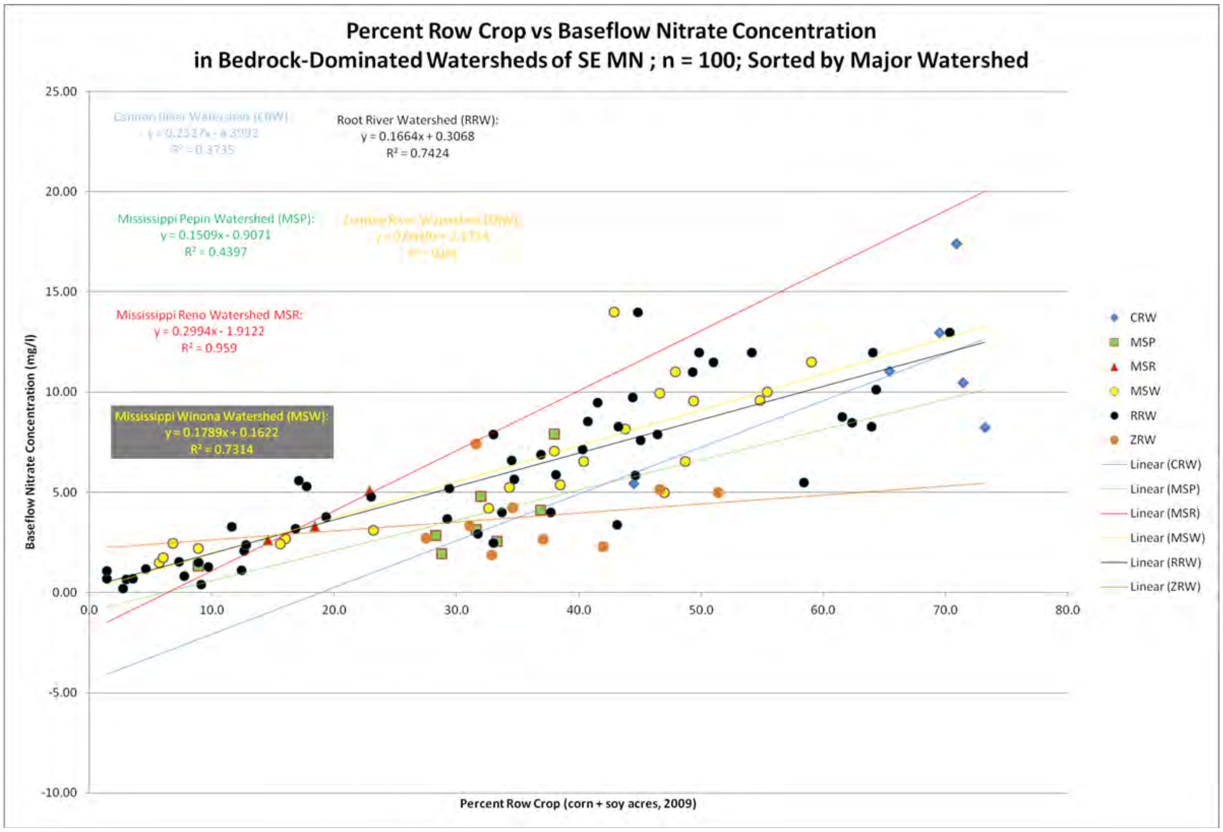


Figure 19: Nitrate vs. Row Crop in southeastern Minnesota (Watkins et al.)

Currently, the MPCA does not have a proposed nitrate standard for aquatic life. Minnesota's current standard is 10 mg/L for drinking water protection only.

To read additional information about the effects of nitrate levels on aquatic life, see the appendix.

Dissolved oxygen in Gilbert Creek

Gilbert Creek did not have any low dissolved oxygen (DO) measurements (i.e., below the minimum standard of 7 mg/L for coldwater streams). Grab samples taken in 2008 and 2009, during the summer months, showed a dissolved oxygen range from 9.2 to 11.1 mg/L. Also, a continuous multi-parameter sonde was deployed from August 3, 2011, to August 18, 2011, and showed a range of 8.9 mg/L to 10.3 mg/L and an average concentration of 9.69 mg/L for dissolved oxygen. During this time, the flow was very low and air temperatures were warm. These are prime conditions for low dissolved oxygen.

The ranges found are very normal for coldwater systems and are not low enough to cause concern. The average daily flux, which was found to be 2 mg/L or less, is also a good sign that the oxygen dynamics in this location are not a threat to aquatic life. When a daily dissolved oxygen flux of greater than 5 mg/L is found, it becomes a concern. Due to the combination of grab sample data and continuous data, dissolved oxygen was not identified as a stressor to aquatic life in Gilbert Creek at this time.

To read additional information about the effects of dissolved oxygen levels on aquatic life, see the appendix.

Strength of Evidence

The Evidence of each potential stressor, and the quantity and quality of each type of evidence is evaluated. The consistency and credibility of the evidence is also evaluated. Gilbert Creek was scored and summarized in Table 3. For more information on scoring, see EPA's CADDIS Summary Table of Scores.

Table 7: Strength of Evidence Table for Stressors in Gilbert Creek

GILBERT CREEK								
Types of Evidence	**Scores of Candidate Causes**							
	Low Dissolved Oxygen	**Pesticides**	**High Nitrate**	**Lack of Connectivity**	**Lack of Habitat**	**Deposited and Bedded Sediment**	**Temperature**	**Altered Hydrology**
Spatial/temporal co-occurrence	---	0	R	R	+	+	---	---
Temporal sequence	---	0	R	R	+	+	---	0
Field evidence of stressor-response	-	--	--	--	++	++	--	+
Causal pathway	+	+	+	+	++	+	+	+
Evidence of exposure, biological mechanism	0	--	--	0	++	++	--	0
Field experiments /manipulation of exposure	NE	NE	NE	NE	NE	NE	NE	NE
Laboratory analysis of site media	NE	0	NE	NE	NE	NE	NE	NE
Verified or tested predictions	-	NE	-	NE	+++	+++	-	0
Symptoms	0	---	---	---	D	D	0	0
Evidence using data from other systems								
Mechanistically plausible cause	+	+	+	+	+	+	+	+
Stressor-response in other lab studies	+	+	+	NA	NE	+	+	NE
Stressor-response in other field studies	+	+	+	+	+	+	+	+
Stressor-response in ecological	NE	NE	NE	NA	NE	NE	NE	NE

models								
Manipulation experiments at other sites	NE	NE	NE	NA	NE	NE	NE	NE
Analogous stressors	NE	NA	NE	NA	NA	NE	NE	NE
Multiple lines of evidence								
Consistency of evidence	---	-	---	---	+++	+++	---	-
Explanatory power of evidence	-	-	-	-	++	++	-	-

Table 8: Values used to score evidence in the Stressor Identification process developed by EPA

Rank	Meaning	Caveat
+++	*Convincingly supports*	*but other possible factors*
++	*Strongly supports*	*but potential confounding factors*
+	*Some support*	*but association is not necessarily causal*
0	*Neither supports nor weakens*	*(ambiguous evidence)*
-	*Somewhat weakens support*	*but association does not necessarily reject as a cause*
--	*Strongly weakens*	*but exposure or mechanism possible missed*
---	*Convincingly weakens*	*but other possible factors*
R	*Refutes*	*findings refute the case unequivocally*
NE	*No evidence available*	
NA	*Evidence not applicable*	
D	*Evidence is diagnostic of cause*	

Table 9: Strength of Evidence Scores for various types of evidence used in Stressor ID analysis

Types of Evidence	Possible values, high to low
Evidence using data from case	
Spatial / temporal co-occurrence	+, 0, ---, R
Evidence of exposure, biological mechanism	++, +, 0, --, R
Causal pathway	++, +, 0, -, ---
Field evidence of stressor-response	++, +, 0, -, --
Field experiments / manipulation of exposure	+++, 0, ---, R
Laboratory analysis of site media	++, +, 0, -
Temporal sequence	+, 0, ---, R
Verified or tested predictions	+++, +, 0, -, ---, R
Symptoms	D, +, 0, ---, R
Evidence using data from other systems	
Mechanistically plausible cause	+, 0, --
Stressor-response relationships in other field studies	++, +, 0, -, --
Stressor-response relationships in other lab studies	++, +, 0, -, --
Stressor-response relationships in ecological models	+, 0, -
Manipulation of exposure experiments at other sites	+++, +, 0, --
Analogous stressors	++, +, -, --
Multiple lines of evidence	
Consistency of evidence	+++, +, 0, -, --
Explanatory power of evidence	++, 0, -

Recommendations and conclusions for Gilbert Creek

Lack of suitable habitat in Gilbert Creek is the main stressor affecting the fish community of Gilbert Creek. There are few riffles, deep pools, and cover for fish in the lower reaches of the watershed. The stream channel is over widened with diminishing gradient near Lake Pepin. As a result, bedded sediment is being deposited contributing to poor habitat condition, including filling-in of pools.

Even though habitat for fish is being affected, the invertebrates appear somewhat healthy. This is due to woody debris in the stream channel that functions as their primary habitat. However, this lack of habitat variety for invertebrates could eventually negatively affect them as well. Riffles and overhanging vegetation are other examples of common habitat for invertebrates that are not present in lower Gilbert Creek. The invertebrate IBI scores are above the impairment threshold, but not by much.

Having two indicators for aquatic life (fish and invertebrates) has helped eliminate many probable stressors. This is due to the fact that invertebrates are typically more sensitive to fish when exposed to many stressors.

The upstream reach of Gilbert Creek was not assessed due to stream channelization at the site. However, using the same IBI threshold as the lower Gilbert Creek site, the upstream site meets biological standards for fish and invertebrates. This is strong evidence that indicates aquatic life is mainly affected in the lower reaches of Gilbert Creek.

Sugarloaf Creek is an important tributary to Gilbert Creek. Currently, the biological station on Sugarloaf Creek is classified as warmwater. It meets biological thresholds for a warmwater stream. However, even though Sugarloaf Creek is a small tributary, there is evidence that shows part of the tributary is actually coldwater (downstream of the current biological monitoring location). In the future, it may be beneficial to consider assessing a site on the true coldwater reach of Sugarloaf Creek.

With additional time and resources, it would be useful to collect additional pesticide samples or samples for heavy metals and toxics given the land use in the area. Also, using bedload to characterize sediment delivery would be useful for understanding bedded sediment impacts to habitat and aquatic life.

The next step on the process will be a TMDL report for the Mississippi River-Lake Pepin Watershed. This will address the new impairments in the watershed, including the biological impairment on Gilbert Creek. Recommendations for best management practices and implementation will be included in the TMDL. At this time, lack of physical habitat is the primary stressor to the fish impairment. It will be important to work with the local DNR staff that manage this stream for trout, and see how the MPCA and DNR goals for this stream can work together.

Protection in the Mississippi River-Lake Pepin Watershed

Based on the MPCA's current assessment of aquatic life, many areas in the Mississippi River-Lake Pepin watershed are doing well biologically. However, it is important to take into consideration areas that may need some extra support to help sustain a high functioning aquatic environment, or to help the threatened aquatic environment.

For the purposes of this report, protection has been broken into two categories; 1) Exceptional, very good biological condition; and 2) Vulnerable biologically.

1) **Exceptional: The watersheds with the highest IBI scores are as follows:**

Both Fish and invertebrates (30 points or more above the coldwater thresholds)

- Handshaw Coulee

Fish only (30 points or more above the coldwater threshold of 45)

- Bullard Creek
- Tributary to Wells Creek
- Trout Brook

Inverts only (30 points or more above the coldwater threshold of 46.1)

- Hay Creek (both 08LM128 and 04LM132)

2) **Vulnerable: The watersheds that are *near impairment* thresholds include:**

Both fish and invertebrates (within 10 points of impairment threshold)

- Wells Creek (08LM136)

Fish only (within 10 points of impairment threshold)

- Sugarloaf Creek
- Hay Creek (10EM111)

Invertebrates only (within 10 points of impairment threshold)

- Miller Creek
- Tributary to Wells Creek
- Gilbert Creek
- Bullard Creek
- Hay Creek (08LM133)

Appendix
Candidate Cause: Dissolved Oxygen

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

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

Minnesota water quality standards

In Class 2B streams (warmwater), the Minnesota standard for dissolved oxygen is 5.0 mg/L as a daily minimum. In Class 2A streams (coldwater), the standard for dissolved oxygen is 7.0 mg/L as a daily minimum. Additional stipulations have been recently added to this standard. The following is from the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2009):

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

Sources and Causal pathways

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

Candidate Cause: Flow Alteration

Increasing surface water runoff and seasonal variability in stream flow have the potential for both indirect and direct effects on fish populations (Schlosser, 1990). Indirect effects include alteration in habitat suitability, nutrient cycling, production processes, and food availability. Direct effects include decreased survival of early life stages and potentially lethal temperature and oxygen stress on adult fish (Bell, 2006).

Increased flows may directly impair the biological community or may contribute to additional stressors. Increased channel shear stresses, associated with increased flows, often cause increased scouring and bank destabilization. With these stresses added to the stream, the fish and invertebrate community may be influenced by the negative changes in habitat and sediment.

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

Across the conterminous United States, Carlisle et al. found a strong correlation between diminished streamflow and impaired biological communities (2010). Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to a decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space, and when flows are reduced beyond normal baseflow, competition for resources increases. Pollutant concentrations often increase when flows are lower than normal, making it more difficult for populations to maintain a healthy diversity. Often tolerant individuals that can outcompete in limiting situations will thrive. Low flows of prolonged duration tend to lead to invertebrate and fish communities that have preference for standing water or are comprised of generalist species (CADDIS, 2011).

When baseflows are reduced, fish communities respond with an increase in nest guarding species than simple nesters (Carlisle et al., 2010). This adaptation increases the reproductive ability for nest guarders by protecting from predators and providing "continuous movement of water over the eggs, and to keep the nest free from sediment" (Becker, 1983). Active swimmers, such as the green sunfish, contend better under low velocity conditions (Carlisle et al., 2010). Streamlined species have bodies that allow fish to reduce drag under high velocities (Blake, 1983). Similarly, the invertebrate communities exhibit changes with increasing swimming species and decreasing taxa with slow crawling rates. EPA's CADDIS lists the response of low flow alteration with reduced total stream productivity, elimination of large fish, changes in taxonomic composition of fish communities, fewer species of migratory fish, fewer fish per unit area, and a greater concentration of some aquatic organisms (potentially benefiting predators).

Minnesota water quality standards

There is not a specific standard regarding the alteration of maximum peak flows. The standard for minimum streamflow, according to Minn. Stat. § 7050.0210, subp. 7 is:

> *Point and nonpoint sources of water pollution shall be controlled so that the water quality standards will be maintained at all stream flows that are equal to or greater than the* $7Q_{10}$ [the lowest streamflow for 7 consecutive days that occurs on average once every 10 years] *for the critical month or months, unless another flow condition is specifically stated as applicable in this chapter*.

Sources and Causal pathways

The causes and potential sources for altered flow are modeled at EPA's CADDIS Flow Alteration. webpage.

Candidate Cause: Connectivity (longitudinal)

Connectivity in river ecosystems refers to how waterbodies and waterways are linked to each other on the landscape and how matter, energy, and organisms move throughout the system (Pringle, 2003). 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 more than 800 dams on streams and rivers for a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

Dams, both human-made and natural, can cause changes in flow, sediment, habitat and chemical characteristics of a waterbody. They can alter the hydrologic (longitudinal) connectivity, which may obstruct the movement of migratory fish causing a change in the population and community structure. The stream environment is also altered by a dam to a predominately lentic surrounding (Mitchell and Cunjak, 2007).

In many cases, connectivity becomes an issue with culverts. This is especially important in coldwater trout fisheries where migration to upstream reaches for spawning is important. When a culvert becomes raised (or perched) above the stream level, this limits the ability of fish to migrate throughout the stream. A similar phenomenon can occur naturally with beaver dams, which can also be barriers to fish migration.

Minnesota water quality standards

There is no applicable water quality standard for connectivity impacts.

Sources and Causal pathways

The conceptual model for connectivity as a candidate stressor is found in Figure 25:

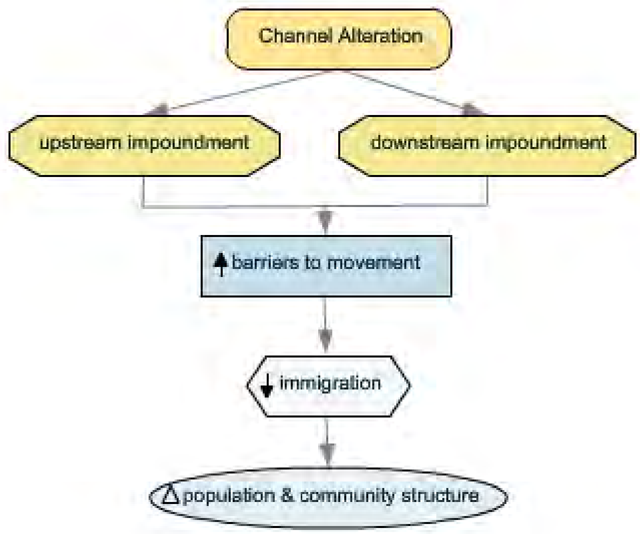


Figure 20: Conceptual Model for Connectivity

Candidate Cause: Temperature

Temperature is a major factor in determining invertebrate and fish species composition in streams. Increases in temperature due to altered watersheds can lead directly to extirpation of coldwater assemblages. Warmer water impacts organisms indirectly due to the relationship with lower dissolved oxygen and directly through changes in growth and reproduction, egg mortality, disease rates, and direct mortality. Macroinvertebrate species have well-known tolerances to thermal changes, and community composition of invertebrates is useful in tracking the effects of increasing temperature. Fish assemblages, likewise, change with temperature, and coldwater adapted species either leave, are unable to reproduce, or die in warmer regimes.

Fish can suffer adverse effects due to increases in temperature (Raleigh et al., 1986). When temperatures rise near 21°C, other fish can have a competitive advantage over trout for the food supply (Behnke, 1992). The temperature at which fish continue to feed and gain weight is considered their functional feeding temperatures. The limits for brown trout growth at 4 – 19.5 °C (Elliot and Elliot, 1995); however, for egg development, brown trout need temperatures between 0 and 15 °C (Elliot, 1981). According to Bell 2006, brown trout may be physiologically stressed in the thermal window of 19-22°C. These temperatures are near the upper metabolic limit for trout and may affect the ability to maintain normal physical function and ability to gain weight.

Brook trout functional feeding temperatures are between 12.7°C and 18.3° (Raleigh, 1982). They can briefly tolerate temperatures near 22.2°C, but temperatures of 23.8°C for a few hours are generally lethal (Flick, 1991). Juvenile brook trout density is negatively correlated with July mean water temperatures (Hinz and Wiley, 1997). Growth and distribution of juvenile brook trout is highly dependent on temperature (McCormick et al., 1972).

Minnesota water quality standards

The state standard for temperature in Class 2A streams is "no material increase" (7050.0222 Specific Water Quality Standards for Class 2 Waters of the State; Aquatic Life and Recreation).

Sources and Causal pathways

The conceptual model for Temperature as a candidate stressor is modeled at EPA's CADDIS Temperature webpage.

Candidate Cause: Nutrients (nitrate-nitrite)

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

In Minnesota coldwater streams specifically, there appears to be some biological response trends to elevated nitrate concentrations. The data on coldwater streams indicate that when concentrations exceed 12 mg/L, it becomes fairly rare for streams to meet standards for invertebrates. It appears the invertebrates are more sensitive to the nitrate concentrations (likely due to smaller size), as fish do not show the same response in terms of impairment. It is unknown what concentrations affect reproduction and other important parts of the life cycle. In general, when concentrations are below ~4 mg/L, it is much more common for invertebrates to meet standards.

At this time, it is difficult to understand exactly what concentrations are detrimental to fish and invertebrates, as they appear to have a different tolerance and response. Many factors can contribute to a biological response including, but not limited, to timing, duration, and flux of nitrate concentrations. There are efforts underway to help understand these issues.

Minnesota water quality standards

Streams classified as Class 1 waters (i.e., coldwater) of the state, designated for domestic consumption (drinking water), in Minnesota have a nitrate-N (nitrate plus nitrite) water quality standard of 10 mg/L. Minnesota currently does not have a nitrate standard for other waters of the state except for class 1. Currently, the state has a draft standard for nitrate, but it is subject to change as research continues.

Sources and Causal pathways model for nitrate and nitrite

Nitrogen is commonly applied as a crop fertilizer. It is likely that various forms of nitrogen including nitrate and ammonia are being applied to the cropland throughout the watershed. The specific timing and rate of nitrogen fertilizer application is unknown, but nitrogen isotopes could assist in the source identification of excess nitrate in future monitoring. Nitrogen pathways can be different depending on geology and hydrology of the watershed. When water moves quickly through the soil profile (as in the case of karst watersheds and heavily tiled watersheds) nitrate transport can become large. Figure 26 shows how nitrogen can affect fish and invertebrates.

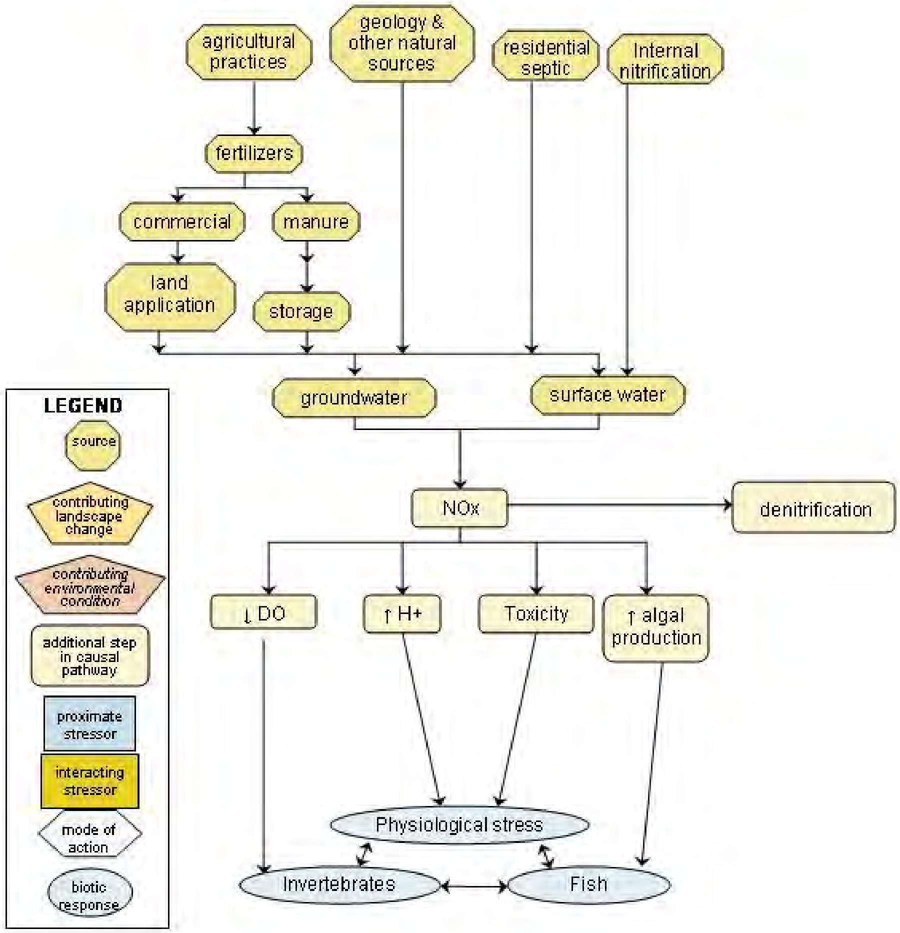


Figure 21: Conceptual model for nitrate stressor on the biotic community

Candidate Cause: Deposited and Bedded Sediment

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairment in the United States (EPA, 2003). Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat and/or direct harm to aquatic organisms. As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (i.e., abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (i.e., loss of visibility, increase in sediment oxygen demand). Elevated turbidity levels and total suspended solids (TSS) concentrations can reduce the penetration of sunlight and can thwart photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

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

Minnesota water quality standards

There are no Minnesota standards for deposited and bedded sediment; however, suspended sediment related to turbidity is very closely related.

The water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2b waters. For Class 2a waters, the standard is 10 NTUs. Turbidity is a measure of reduced transparency that can increase due to suspended particles such as sediment, algae, and organic matter.

A strong correlation exists between the measurements of TSS concentration and turbidity. In 2010, the MPCA released draft TSS standards for public comment (Markus). The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The draft TSS standard for the southeast "central" region of Minnesota is 30 mg/L for 2B waters, and 10 mg/L for 2A (coldwater) streams. For assessment, this concentration is not to be exceeded in more than 10 percent of samples within a 10-year data window.

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

For the purposes of stressor identification, transparency tube measurements, and TSS are used along with habitat evaluations and biological response. Using these tools, inferences can be made regarding the effects of suspended solids on fish and invertebrate populations.

Sources and Causal pathways

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

Candidate Cause: Physical Habitat

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. This section will focus on the physical habitat structure including geomorphic characteristics and vegetative features (Griffith et al., 2010).

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

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

Minnesota water quality standards

There currently is no applicable standard for lack of habitat for biotic communities.

Sources and Causal pathways

The causes and potential sources for lack of habitat are modeled at EPA's CADDIS Physical Habitat webpage. Many riparian areas along the Mississippi River-Lake Pepin Watershed and tributaries are influenced by cattle and row crop agriculture; this, in turn, decreases riparian and bank vegetation. Along with altered hydrology, the alteration of habitat caused by channelization has numerous pathways of influence affecting the biological community.

Candidate Cause: Pesticides

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

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).

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, such as 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 (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 EPA website on insecticides and causal analysis located at http://www.epa.gov/caddis/ssr_ins_int.html.

The MDA annually collects samples from various surface water bodies throughout the state and analyzes those samples for the presence of pesticides and degradates. The MDA attempts to capture the influence of different land uses on surface water resources. Out of the 100-plus pesticides this program analyzed, three have been named a "surface water pesticide of concern" -- acetochlor, atrazine, and chlorpyrifos. Detection frequency and detection maximums can vary among years for individual pesticides. When detection maximums reach certain thresholds, the MDA may focus monitoring and response efforts in the location of the detection. To understand more about the MDA surface water monitoring program, visit: http://www.mda.state.mn.us/chemicals/pesticides/maace.aspx.

Minnesota water quality standards

Since 1985, 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 Chapter 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 4**.

Table 10. Summary of MPCA surface water standards associated with target pesticides analytes

	Chronic[1] and Maximum[2] Standards (µg/L)		
Pesticide Analyte	**Class 2A[3]**	**Class 2B[4]**	**Maximum Standard[4]**
Acetochlor	3.6	3.6	86
Alachlor	59	59	800
Atrazine	10	10	323
Chlorpyrifos	0.041	0.041	0.083
Metolachlor	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 4 days
[2] Maximum standard value for aquatic life & recreation as defined in Minn. R. ch. 7050. Values are the same for all classes of surfacewaters.
[3] State water classification for coldwater streams and all recreation.
[4] State water classification for cool and warmwater streams and all recreation.

Sources and Causal pathways

For the background and to see the Conceptual Model for herbicides, follow this link: http://www.epa.gov/caddis/ssr_herb_int.html.

Summary of biological assessments in the Mississippi River Lake Pepin Watershed

AUID	Station ID	Name	DA Sq. Mi	Invert Class	Threshold	InvertIBI	FishClass	Threshold2	FishIBI
07040001-537, Trout Brook, T113 R15W S35, south line to Hay Cr	08LM132	Trout Brook	6.21	9	46.1	**59.45**	10	45	**93**
07040001-518, Hay Creek, T111 R15W S4, west line to Mississippi R	08LM128	Hay Creek	46.03	9	46.1	**89.96**	10	45	**56**
07040001-518, Hay Creek, T111 R15W S4, west line to Mississippi R	10EM111	Hay Creek	23.78	9	46.1	*	10	45	**54**
07040001-518, Hay Creek, T111 R15W S4, west line to Mississippi R	04LM089	Hay Creek	16.36	9	46.1	**60.49**	10	45	**72**
07040001-518, Hay Creek, T111 R15W S4, west line to Mississippi R	04LM132	Hay Creek	33.46	9	46.1	**79.07**	10	45	**62**
07040001-518, Hay Creek, T111 R15W S4, west line to Mississippi R	08LM133	Hay Creek	20.12	9	46.1	**46.49**	10	45	**62**
07040001-526, Bullard Creek, T112 R14W S10, west line to T113 R4W S36, north line	08LM129	Bullard Creek	11.2	9	46.1	**53.34**	10	45	**78**
07040001-708, Wells Creek, Headwaters to Hwy 61	08LM127	Wells Creek	67.89	9	46.1	**55.91**	10	45	**41**
07040001-708, Wells Creek, Headwaters to Hwy 61	08LM127	Wells Creek	67.89	9	46.1	**65.22**			
07040001-708, Wells Creek, Headwaters to Hwy 61	08LM135	Wells Creek	45.87	9	46.1	**32.53**	10	45	**65**
07040001-708, Wells Creek, Headwaters to Hwy 61	08LM135	Wells Creek	45.87	9	46.1	**59.93**			
07040001-708, Wells Creek, Headwaters to Hwy 61	04LM007	Wells Creek	64.68	9	46.1	**74.29**	10	45	**63**
07040001-708, Wells Creek, Headwaters to Hwy 61	04LM031	Wells Creek	41.09	9	46.1	**53.47**	10	45	**68**
07040001-708, Wells Creek, Headwaters to Hwy 61	08LM136	Wells Creek	33.36	9	46.1	**52.66**	10	45	**55**
07040001-708, Wells Creek, Headwaters to Hwy 61	04LM070	Wells Creek	55.92	9	46.1	**71.41**	10	45	**62**
07040001-700, Unnamed creek, Unnamed cr to Wells Cr	08LM134	Trib. to Wells Creek	6.4	9	46.1	**52.3**	10	45	**93**
07040001-662, Sugarloaf Creek, Headwaters to T112 R13W S36, south line	08LM139	Sugarloaf Creek	6.35	6	46.8	**60.65**	3	51	**54**
07040001-530, Gilbert Creek, Sugarloaf Cr to T112 R12W S31, east line	08LM130	Gilbert Creek	24.07	9	46.1	**53.96**	10	45	**42**
07040001-534, Miller Creek, Boston Coulee to Mississippi R	08LM131	Miller Creek	14.66	9	46.1	**56.59**	10	45	**62**
07040001-553, Handshaw Coulee (Second Creek), T111 R12W S15, south line to Mississippi R	04LM138	Handshaw Coulee	5.1	9	46.1	**82.48**	10	45	**77**
07040001-553, Handshaw Coulee (Second Creek), T111 R12W S15, south line to Mississippi R	04LM138	Handshaw Coulee	5.1	9	46.1	**61.75**			

Literature Cited

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Becker, G. C. 1983. Fishes of Wisconsin. Univ. Wisconsin Press, Madison. 1052 pp.

Behnke, R. J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6; Bethesda, Maryland.

Bell, John M., "The Assessment of Thermal Impacts on Habitat Selection, Growth, Reproduction and Mortality in Brown Trout (*Salmo trutta L*): A Review of the Literature," Applied Ecological Services Inc., September 2006, 23 pp

Blake, R. W. 1983. Fish Locomotion. London: Cambridge University Press.

Camargo, J. A.; Alonso, A.; Salamanca, A. 2005. Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. Chemosphere, 58**,** 1255.

Carlisle D.M., Wolock D.M. and M.R. Meador. 2010. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Front Ecol Environ 2010; doi:10.1890/100053.

Cormier, S., Norton S., Suter G., and D. Reed-Judkins. 2000. Stressor Identification Guidance Document. U.S. Environmental Protection Agency, Washington, DC, EPA/822/B-00/025, 2000.

Davis, J. 1975. Minimal Dissolved Oxygen Requirements of Aquatic Life with Emphasis on Canadian Species: A Review. Journal of the Fisheries Research Board of Canada, p 2295-2331.

Doudoroff, P. and C. E. Warren. 1965. Dissolved oxygen requirements of fishes. Biological Problems in Water Pollution: Transactions of the 1962 seminar. Cincinatti, Ohio. Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Health Service Publication, 999-WP-25.

Elliott, J. M.; Elliott, J. A. 1995. The effect of the rate of temperature increase on the critical thermal maximum for parr of Atlantic salmon and brown trout. Journal of Fish Biology, 47**,** 917.

EPA, CADDIS. 2009. http://cfpub.epa.gov/caddis/.

Flick, W. A. 1991. Brook trout. Pages 196-207 in J. Stohlz and J. Schnell, editors. *The* wildlife series: Trout. Stackpole Books. Harrisburg, Pennsylvania.

Grabda, E.; Einszporn-Orecka, T.; Felinska, C.; Zbanysek, R. 1974. Experimental methemoglobinemia in trout. *Acta Ichthyol. Piscat*., 4, 43.

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

Griffith, M.B., B. Rashleigh, and K. Schofield. 2010. Physical Habitat. In USEPA, Causal Analysis/Diagnosis Decision Information System (CADDIS). http://www.epa.gov/caddis/ssr_phab_int.html

Hansen, E. A. 1975. Some effects of groundwater on brook trout redds. Trans. Am. Fish. Soc. 104(1):100-110

Hinz, L. C., Jr., and M. J. Wiley. 1997. Growth and production of juvenile trout in Michigan streams: influence of temperature*.* Michigan Department of Natural Resources, Fisheries research Report No. 2041.

Marcy, SM. 2007. Dissolved Oxygen: Detailed Conceptual Model Narrative. In USEPA, Causal Analysis/Diagnosis Decision Information System (CADDIS). http://www.epa.gov/caddis/pdf/conceptual_model/Dissolved_oxygen_detailed_narrative_pdf

McCormick, J. H.; Hokansen, K. E. F.; Jones, B. R. 1972. Effects of temperature on growth and survival of young brook trout, Salvelinus fontinalis. Journal of the Fisheries Research Board of Canada, **29,** 1107.

Mitchell, S.C. and Cunjak, R.A.,2007. Stream flow, salmon and beaver dams: roles in the construction of stream fish communities within an anadromous salmon dominated stream. Journal of Animal Ecology. Nov;76(6):1062-74.

DNR 2012. Gilbert Creek Stream Assessment Report. Section of Fisheries, Minnesota Department of Natural Resources. Lake City, Minnesota.

DNR 1946. Summary of Gilbert Creek-Nursery Creek. Section of Fisheries, Minnesota Department of Natural Resources. Lake City, Minnesota.

MDNR 2001. Gilbert Creek Stream Population Assessment. Section of Fisheries, Minnesota Department of Natural Resources. Lake City, Minnesota.

DNR 2001. Gilbert Creek Stream Management Plan. Section of Fisheries, Minnesota Department of Natural Resources. Lake City, Minnesota.

MPCA and MSUM. 2009. State of the Minnesota River, Summary of Surface Water Quality Monitoring 2000-2008. http://mrbdc.wrc.mnsu.edu/reports/basin/state_08/2008_fullreport1109.pdf

Nebeker, A., Dominguez, S., Chapman, G., Onjukka, S., & Stevens, D. (1991). Effects of low dissolved oxygen on survival, growth and reproduction of Daphnia, Hyalella and Gammarus. *Environmental Toxicology and Chemistry* , Pages 373 - 379.

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

Poff, N. L., and J. D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76:606–627.

Pringle, C.M., 2003. What is Hydrologic Connectivity and Why is it Ecologically Important? Hydrological Processes 17:2685-2689.

Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout. Biological Report 82 (10.124). U.S. Fish and Wildlife Service. 65 pp.

Schlosser, I. 1990. Environmental variation, life history attributes, and community structure in stream fishes: Implications for environmental management and assessment. Environmental Management 14(5):621-628.

Waters, T. 1995. *Sediment in Streams: Sources, Biological Effects, and Control.* Bethesda, Maryland: American Fisheries Society.

Watkins, et al., "The Relationship of Nitrate-Nitrogen Concentrations in Trout Streams to Row Crop Lane Use in Karstland Watersheds of Southeast Minnesota," Geological Society of America *Abstracts with Programs*, Vol. 43, No. 5, p. 285