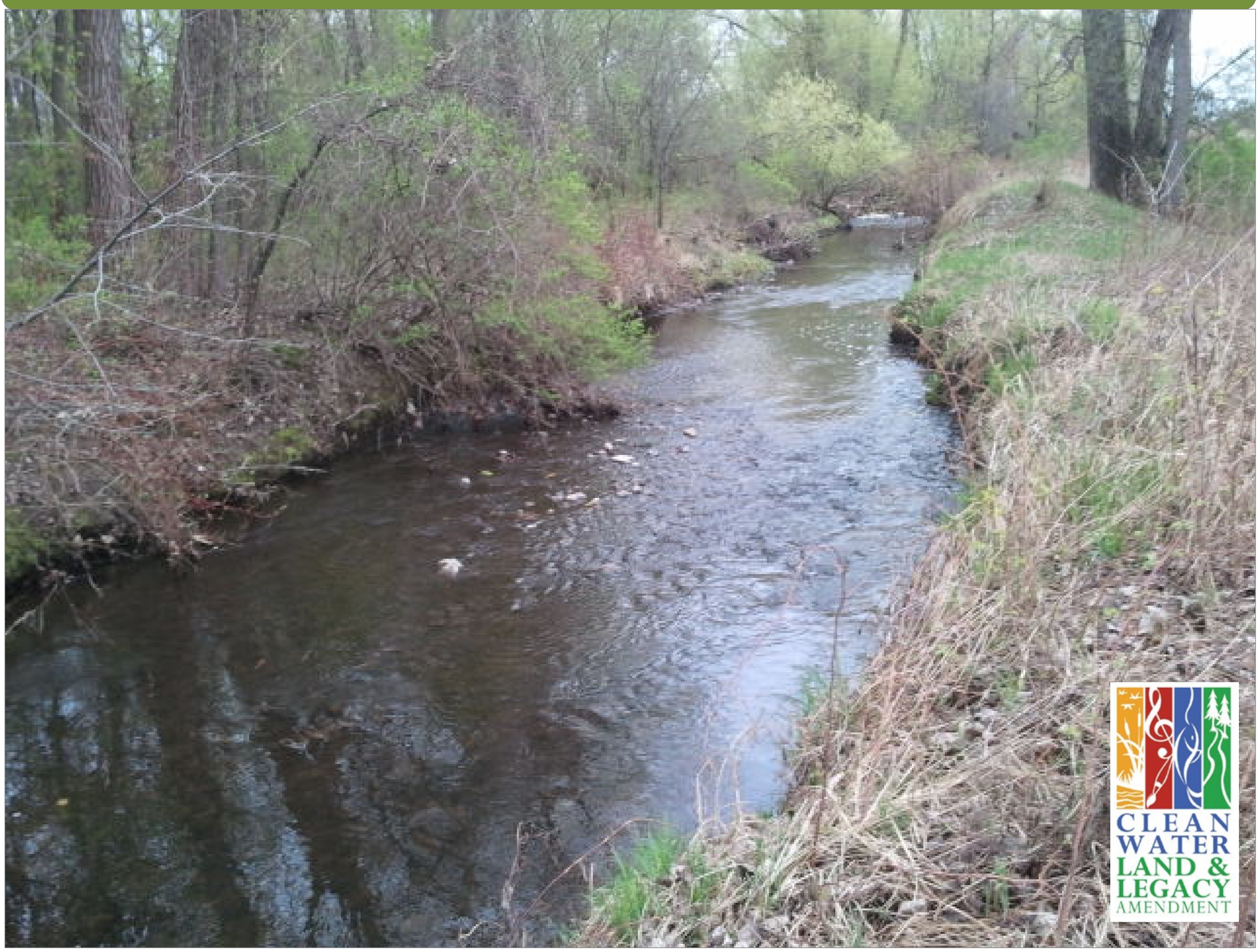
Battle Creek Stressor Identification Report

A study of local stressors limiting the biotic communities in the Battle Creek Watershed.



Prepared by Barr Engineering Company for Ramsey-Washington Metro Watershed District

Minnesota Pollution Control Agency

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Key Terms & Abbreviations

AUID	Assessment Unit Identification number
BOD	Biological Oxygen Demand
CADDIS	Causal Analysis/Diagnosis Decision Information System
CL	Confidence Limit
CS	Chronic Standard
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
FAV	Final Acute Value
F-IBI	Fish Index of Biological Integrity
HBI	Hilsenhoff Biotic Index
HUC	Hydrologic Unit Code
IBI	Index of Biological Integrity
M-IBI	Macroinvertebrate Index of Biological Integrity
MCES	Metropolitan Council Environmental Services
MPCA	Minnesota Pollution Control Agency
MS	Maximum Standard
MSHA	MPCA Stream Habitat Assessment
NE	No Evidence
NTU	Nephalometric Turbidity Unit
RWMWD	Ramsey Washington Metro Watershed District
SID	Stressor Identification
SOE	Strength of Evidence
TCMA	Twin Cities Metropolitan Area
TIV	Tolerance Indicator Value
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
USGS	United States Geological Survey
WOMP	Watershed Outlet Monitoring Program
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

This report summarizes stressor identification work in the Battle Creek Watershed.

Stressor identification (SID) 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 (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to fish and aquatic macroinvertebrates. SID 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 macroinvertebrates (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" for aquatic life use.

The purpose of SID is to explain the relationship between stressors and the degraded biological condition. 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.

Located in Ramsey and Washington Counties in the East metro area, the Battle Creek Watershed encompasses approximately 13 square miles. Battle Creek discharges to Pigs Eye Lake which is tributary to the Mississippi River.

In 2014, Battle Creek was placed on the draft MPCA 303(d) impaired waters list in need of a study for impaired biota due to low Fish Index of Biotic Integrity (F-IBI) score and low Macroinvertebrate Index of Biotic Integrity (M-IBI) score. This SID was initiated to find and evaluate factors, either natural or anthropogenic, which are likely responsible for the impaired condition of the fish and macroinvertebrate communities in Battle Creek.

Biological, chemical, and physical data from Battle Creek were analyzed to determine candidate causes for the biological impairments. After examining many candidate causes, the stressors listed in Table E.1 were identified as candidate causes of stress to aquatic life in Battle Creek.

Table E.1 Battle Creek biological stressors.

Stream Name	AUID	Biological Impairment	Candidate Causes						
			Excess Sediment	Specific Conductance and Chlorides	Dissolved Oxygen and BOD	Excess Total Phosphorus	Altered Habitat	Habitat Fragmentation	Metal Toxicity
Battle Creek	07010206-592	Fish	●	○	●*	◐	○	◐	○
		Macroinvertebrates	●	●	○	○	◐	○	○

● = probable primary stressor; ◐ = probable secondary stressor; ○ = inconclusive stressor

●* = probable station-specific primary stressor (e.g., DO impairment immediately downstream of detention areas)

1. Introduction

1.1. Monitoring and Assessment

Water quality and biological monitoring in Battle Creek have been ongoing since 1977. Monitoring activities by the Ramsey Washington Metro Watershed District (RWMWD) and the MPCA have increased in rigor and intensity since 2010, and have included biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2010, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages and potential causes of impairment (Figure 1.1).

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

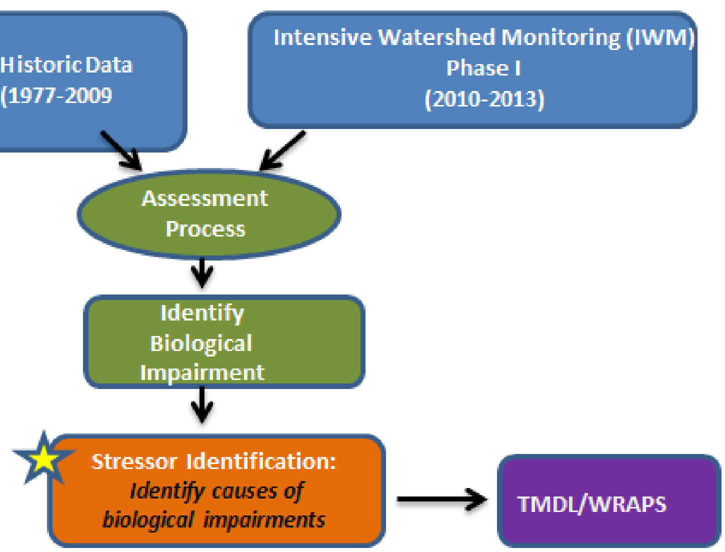


Figure 1.1 Process map of Intensive Watershed Monitoring, Assessment, Stressor Identification, and TMDL processes.

1.2. Stressor Identification Process

The RWMWD and the MPCA follow the United States Environmental Protection Agency's (EPA's) process of identifying stressors that cause biological impairment, which has been used to develop the MPCA's guidance to stressor identification (Cormier et al. 2000; MPCA 2008). The EPA has also developed an updated, interactive web-based tool, the Causal Analysis/Diagnosis Decision Information System (CADDIS; EPA 2010). This system provides an enormous amount of information designed to guide and assist investigators through the process of SID. Additional information on the SID process using CADDIS can be found here: http://www.epa.gov/caddis/.

SID is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act. SID draws upon a broad variety of disciplines and applications, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. A conceptual model showing the steps in the SID process is shown in Figure 1.2. Through a review of available data, stressor scenarios are developed that aim to characterize the biological impairment, the cause, and the sources/pathways of the various stressors.

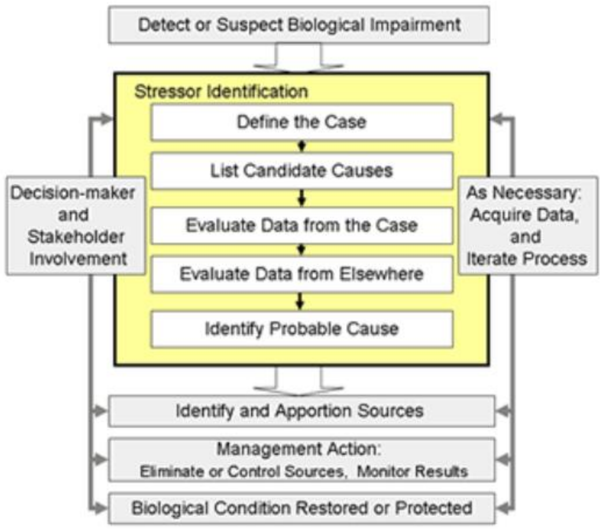


Figure 1.2 Conceptual model of Stressor Identification process (Cormier et al. 2000).

Strength of evidence (SOE) analysis is used to evaluate the data for candidate causes of stress to biological communities. The relationship between stressor and biological response are evaluated by considering the degree to which the available evidence supports or weakens the case for a candidate cause. Typically, much of the information used in the SOE analysis is from the study watershed (i.e., data from the case). However, evidence from other case studies and the scientific literature is also used in the SID process (i.e., data from elsewhere).

Developed by the EPA, a standard scoring system is used to tabulate the results of the SOE analysis for the available evidence (Appendix A). A narrative description of how the scores were obtained from the evidence should be discussed as well. The SOE table allows for organization of all of the evidence, provides a checklist to ensure each type has been carefully evaluated, and offers transparency to the determination process.

The existence of multiple lines of evidence that support or weaken the case for a candidate cause generally increases confidence in the decision for a candidate cause. The scoring scale for evaluating each type of evidence in support of or against a stressor is shown in Appendix A. Additionally; confidence in the results depends on the quantity and quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s) causing impairment. Additional detail on the various types of evidence and interpretation of findings can be found here: http://www.epa.gov/caddis/si_step_scores.html.

1.3 Common Stream Stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry, and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired water body. Table 1.1 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 1.1 Common stream stressors to biology (i.e., fish and macroinvertebrates).

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

1.4 Report Format

This SID report follows a format to first summarize candidate causes of stress to the biological communities in Battle Creek. Within Section 3 there is information about how the stressors relate broadly to the Battle Creek water quality standards and general effects on biology. Section 4 is organized by candidate causes and watershed, discusses the available water quality data and relationship to fish and macroinvertebrate metrics in more detail. Section 5 provides a summary of probable stressors that were determined to be causing stress to the biological communities in Battle Creek.

2. Overview of the Battle Creek Watershed

2.1 Background

The watershed tributary to Battle Creek totals 13.19 square miles (Figure 2.1). The tributary watershed includes the creek's direct watershed, which is divided into two subwatersheds, Battle Creek Watershed (4.56 square miles) and Mississippi River Bottomlands (1.87 square miles). Also included in the tributary watershed are two upstream indirect watersheds, Tanner's Lake Watershed (2.71 square miles) and Battle Creek Lake Watershed (4.05 square miles). The outflow from Tanner's Lake flows into Battle Creek Lake. Battle Creek originates at the outlet from Battle Creek Lake. The creek then flows west and discharges into Pig's Eye Lake located within the Mississippi River Bottomlands subwatershed.

2.1.1 Subwatersheds

The Tanner's Lake subwatershed is primarily located in the city of Oakdale, with a small portion of the subwatershed located within the cities of Landfall, Woodbury, and Maplewood. Most of the Tanner's Lake subwatershed is located in Washington County, with a small portion of the far western side located in Ramsey County. The Tanner's Lake subwatershed is nearly fully developed. Land use within the subwatershed is predominantly low-density residential (45%). Parkland and wetlands make up about 20% of the subwatershed and are mostly located adjacent to Tanner's Lake. There is one large area of high-density residential (mobile home park) that is located in the city of Landfall, next to Tanner's Lake.

The Tanner's Lake subwatershed drains into Tanner's Lake through a series of wetlands and detention ponds, connected primarily by storm sewers and drainage ditches. An off-line alum treatment facility treats a substantial portion of the discharge from the northern two-thirds of the subwatershed which enters Tanner's Lake via a stream. Up to 5 cfs from the stream is diverted to the alum treatment facility, treated, and then returned to the stream. The stream waters (i.e., both treated and untreated waters) discharge into a wetland directly north of Tanner's Lake, which then flows into the lake. The lake discharges into Battle Creek Lake through an outlet structure under I-94.

The Battle Creek Lake subwatershed is located in the cities of Oakdale, Landfall, and Woodbury which are located in Washington County. The Battle Creek Lake subwatershed is developed primarily with low-density residential and some commercial land use. There are significant undeveloped areas bordering the lake, and there are two large wetland areas, one in the southern portion, and the other in the northeastern portion of the subwatershed. Based on future land use projections, most of the undeveloped areas will be converted to commercial/industrial development and some additional high-density residential units.

The Battle Creek Lake subwatershed drains into Battle Creek Lake through a series of wetlands and detention ponds, which are connected primarily by storm sewers and drainage ditches. The subwatershed also receives incoming flows from the Tanner's Lake subwatershed. Battle Creek Lake discharges to the west to Battle Creek.

The Battle Creek subwatershed includes portions of Maplewood, St. Paul, and Woodbury. The majority of the subwatershed is located in Ramsey County, with a small portion on the eastern side in Washington County. Battle Creek is a perennial stream that originates at the outlet from Battle Creek

Lake in Woodbury. The creek then flows west and discharges into Pigs Eye Lake (Mississippi River Bottomlands subwatershed). Along Battle Creek in St. Paul, there is a well-maintained regional park with facilities for hiking and bicycling.

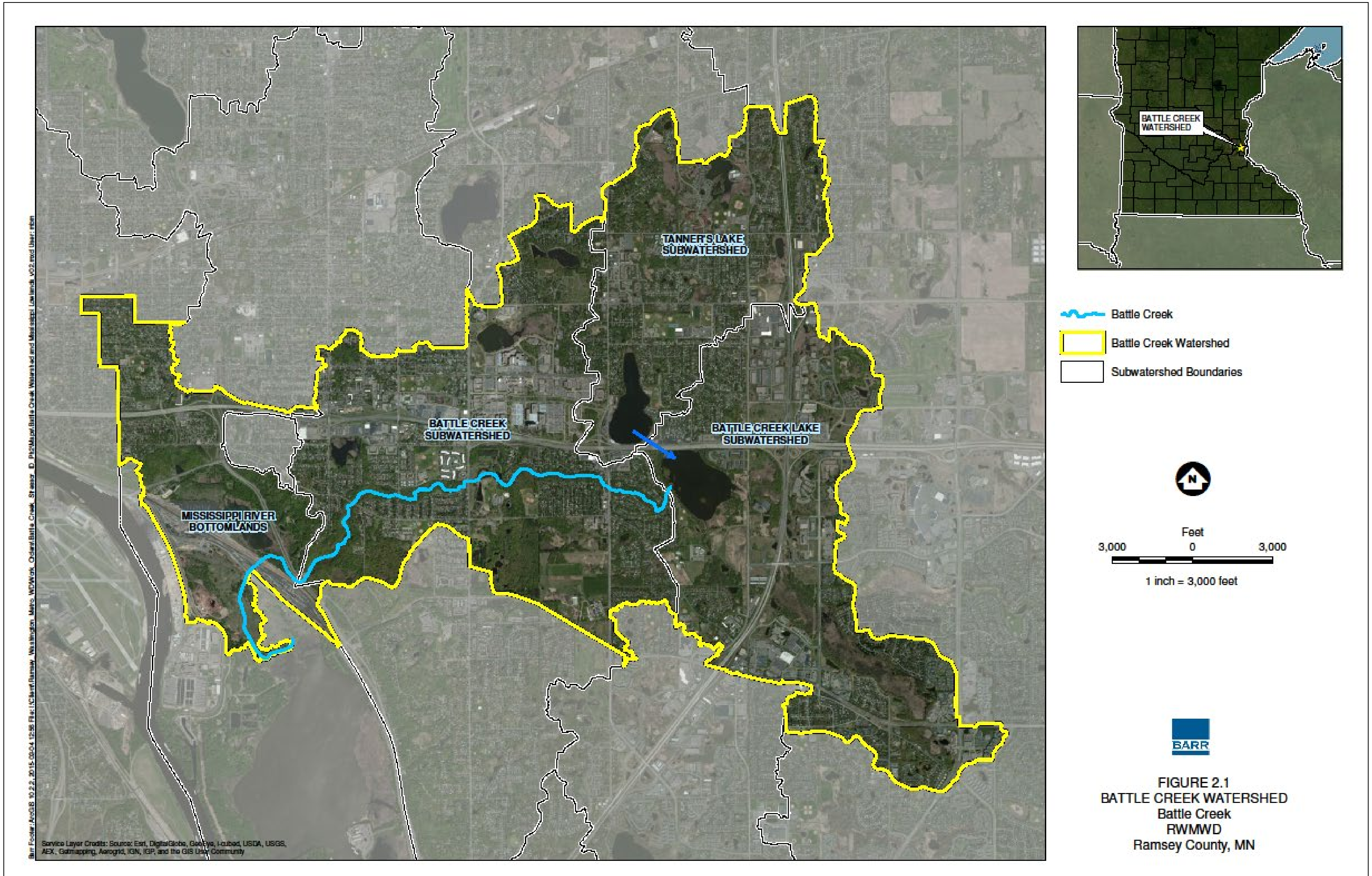


Figure 2.1 Battle Creek Watershed.

About 30% of the Battle Creek subwatershed is undeveloped or parkland, with the majority of that land consisting of the Battle Creek Regional Park. Of the developed portion of the subwatershed, the majority of the land use is low-residential. Approximately 10% of the subwatershed consists of the 3M industrial complex.

The Mississippi River Bottomlands subwatershed is located in St. Paul and is located entirely within Ramsey County. The subwatershed lies within the floodplain of the Mississippi River. Since most of the Mississippi River Bottomlands subwatershed lies within the floodplain, the land is suitable only for open space or development not subject to significant flood damage.

2.2 Monitoring Overview

Water quality and biological monitoring of Battle Creek began in 1977. The RWMWD monitored Battle Creek for water quality during 1977 through 1990, for fish during 1978 through 1979, and for macroinvertebrates during 1978 through 1988. Water quality monitoring did not occur during 1991 through 1995, but has occurred annually since 1996. The RWMWD, in partnership with the Metropolitan Council Environmental Services (MCES), began the Watershed Outlet Monitoring Program (WOMP) in 1996 and has continued this program through the present.

Battle Creek was further assessed for fish and macroinvertebrates during 2000 through 2012. The United States Geological Survey (USGS) assessed Battle Creek for fish during 1997 through 1998. The Minnesota Department of Natural Resources assessed Battle Creek for fish during 1999. The MPCA assessed Battle Creek for fish during 2000, for macroinvertebrates during 2000 and 2004, and assessed Battle Creek for both fish and macroinvertebrates during 2010 and 2012. The 2010 and 2012 assessment results were compared with State criteria to determine that Battle Creek was impaired for both fish and macroinvertebrates. Fish and macroinvertebrate monitoring dates and location are summarized below in Table 2.1 and Table 2.2. The locations of biological monitoring stations along Battle Creek are shown in Figure 2.2.

To assess the cause of biological impairment, the MPCA conducted continuous dissolved oxygen (DO) monitoring of Battle Creek during a portion of the summer of 2012 to evaluate diurnal oxygen changes. To further assess the cause of biological impairment, RWMWD conducted a longitudinal water quality monitoring program on Battle Creek during 2012 and 2013. The monitoring program included the collection of monthly field measurements/grab samples as well as synoptic DO surveys.

Table 2.1 Battle Creek fish sample dates and locations.

Sample Date	MPCA Station ID (organized upstream → downstream)					
	12UM148*	97UM008	99UM076	04UM011	99UM075	00UM071
10/11/1978		X		X	X	
9/19/1979		X		X	X	
9/23/1997		X				
8/18/1998		X				
6/14/1999			X		X	
8/21/2000						X
6/17/2010		X				
7/13/2010		X				
7/23/2012	X	X				
7/31/2012					X	

***** Only two (2) fish (two yellow bullhead) were observed during the 7/23/2012 fish survey at station 12UM148. For this reason, results from station 12UM148 will not be included in most summary table and figures throughout.

Table 2.2 Battle Creek macroinvertebrate sample dates and locations.

Sample Date	MPCA Station ID (organized upstream → downstream)			
	97UM008	04UM011	99UM075	00UM071
10/11/1978	X	X	X	
9/19/1979	X	X	X	
10/6/1980	X	X	X	
9/6/1983	X		X	
9/17/1984	X		X	
9/29/1985	X		X	
9/18/1986	X		X	
9/18/1987	X		X	
9/15/1988	X		X	
9/11/2000				X
9/2/2004		X		
8/23/2010	X			
8/13/2012			X	

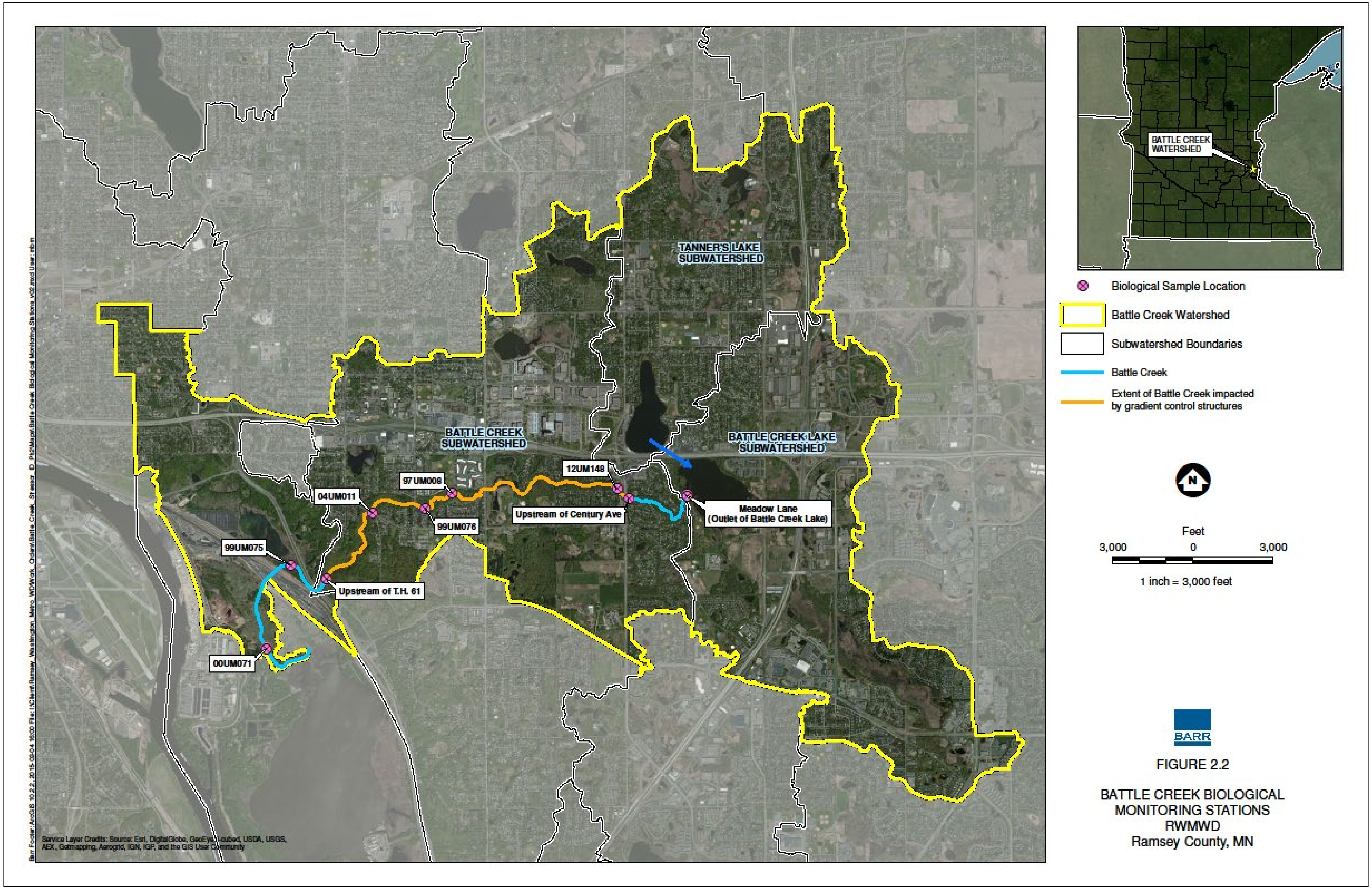


Figure 2.2 Battle Creek biological monitoring stations.

2.3 Summary of Biological Impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrates communities and related habitat conditions at sites throughout a watershed. The resulting information is used to develop an IBI. The IBI scores can then be compared to a range of thresholds.

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

Battle Creek is currently impaired for a lack of biological assemblage and for chloride. (Table 2.3)

Table 2.3 Battle Creek impairments.

			Impairments	
Stream Name	**AUID #**	**Reach Description**	**Biological**	**Water Quality**
Battle Creek	07010206-592	Battle Creek Lake to Pigs Eye Lake	Fish and Macroinvertebrates	Chloride

The fish and macroinvertebrate impairment thresholds and CLs are shown by class for sites in the Battle Creek watershed in Table 2.4 and Table 2.5. Each IBI is comprised of a fish or macroinvertebrate metric that is based on community structure and function and produces a metric score scaled to 100 points. The number of metrics that make up an IBI will determine the metric score scale. For example, an IBI with 8 metrics would have a scale from 0 to 12.5 and an IBI with 10 metrics would have a scale from 0-10.

As shown in Table 2.4, stations along Battle Creek fall in to one of two fish IBI (F-IBI) classes: *Southern Headwaters* and *Southern Streams*. The Southern Headwaters and Southern Streams classes cover identical geographic areas, with the difference being that Southern Headwaters have drainage areas less than 30 square miles, and Southern Streams have watershed areas greater than 30 square miles. The watershed area of the most downstream station along Battle Creek (station 00UM071) is just large enough to fall in to the Southern Streams classification. The F-IBI threshold and upper and lower CLs for Southern Headwaters and Southern Streams are shown below in Table 2.4.

Table 2.4 Fish classes with respective F-IBI thresholds and upper/lower CLs found in the Battle Creek watershed.

Class	Class Name	F-IBI Thresholds	Upper CL	Lower CL
3	Southern Headwaters	51	58	44
2	Southern Streams	45	54	36

Similar to the F-IBI classification, stations along Battle Creek fall in to one of two macroinvertebrate IBI (M-IBI) classes: *Southern Forest Streams (Riffle/Run Habitats)* and *Southern Forest Streams (Glide/Pool Habitats)*. These two classes cover the same geographic area (Eastern broadleaf forest ecological province and streams in the HUC07030005). Additionally, both classes have the same drainage area criteria (less than 500 square miles). As suggested by the class names, the difference in station classification is based on stream morphology, with the *Southern Streams (Riffle/Run Habitats)* class describing sections of the stream where water is fast moving / turbulent, and the *Southern Streams (Glide/Pool Habitats)* class describing portions that are slow moving / pooling (see Table 2.5).

Table 2.5 Macroinvertebrate classes with respective IBI thresholds and upper/ lower CLs found in the Battle Creek watershed.

Class	Class Name	M-IBI Thresholds	Upper CL	Lower CL
5	Southern Streams (Riffle/Run)	35.9	48.5	23.3
6	Southern Streams (Glide/Pool)	46.8	60.4	33.2

The purpose of SID is to interpret the data collected during the biological monitoring and assessment process. Trends in the IBI scores can help to identify causal factors for biological impairments. The assessment process to determine causal factors is a SOE approach that takes biological response into account along with water chemistry, physical, and exposure indicators. The F-IBI and M-IBI scores are shown in Table 2.6.

Each reported IBI value is color coded by its relationship to the IBI threshold and CL values. As can be seen, all F-IBI scores were below the lower CL and all M-IBI scores were below the M-IBI threshold, indicating Battle Creek is impaired for a lack of biological assemblage. While IBI scores are helpful in determining the general ecological health of the stream at a specific location on a specific date, further analysis will be required to help pinpoint the cause and severity of ecological stress to the system (see Section 4).

Table 2.6 F-IBI and M-IBI scores by biological station within AUID.

Fish IBI Summary			
Station	**Date**	**Fish Class**	**F-IBI**
97UM008	8/18/1998	3	**16 (R)**[2]
97UM008	9/23/1997	3	**21 (R)**
97UM008	6/17/2010	3	**33 (R)**
97UM008	7/13/2010	3	**28 (R)**
97UM008	7/23/2012	3	**6 (R)**
99UM076	6/14/1999	3	**42 (R)**
99UM075	6/14/1999	3	**23 (R)**
99UM075	7/31/2012	3	**39 (R)**
00UM071	8/21/2000	2	**30 (R)**

Macroinvertebrate IBI Summary			
Station	**Date**	**MI[1] Class**	**M-IBI**
97UM008	8/23/2010	5	**28 (O)**
04UM011	9/2/2004	6	**9 (R)**
99UM075	8/13/2012	5	**25 (O)**
00UM071	9/11/2000	6	**34 (O)**

[1] MI = Macroinvertebrate
[2] Color coding in table: Red (R) – value is ≤ lower CL; Orange (O) – value is ≤ IBI threshold.

3. Possible Stressors to Biological Communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found at, http://www.epa.gov/caddis/si_step2_stressorlist_popup.html. This comprehensive list serves two purposes. First, it can serve as a checklist for investigators to consider all possible options for impairment in the watershed of interest. Second, it can be used to identify potential stressors that can be eliminated from further evaluation. In some cases, the data may be inconclusive and limit the ability to confidently determine if a stressor is causing impairment to aquatic life. It is imperative to document if a candidate cause was suspected, but there was not enough information to make a scientific determination of whether or not it is causing harm to aquatic life. In this case, management decisions can include modification of sampling plans and future evaluation of the inconclusive case. Alternatively, there may be enough information to conclude that a candidate cause is not causing biological impairment and therefore can be eliminated. The inconclusive or eliminated causes will be discussed in more detail in the following section.

3.1 Eliminated Causes

3.1.1 Temperature

Temperature was eliminated as a candidate cause of impairment because Battle Creek temperature data indicate warmer temperatures that can stress aquatic life have not been observed in Battle Creek. Battle Creek temperature data consists of monthly point measurements recorded from the 1977 through 1991 point temperature measurements recorded during the 2012 and 2013 synoptic water quality surveys, and 13 days of continuous temperature sampling recorded in July of 2012 (July 19, 2012 through July 31, 2012). Over the period of record, the maximum temperature observed was 83°F (July 23, 2012). Of the 57 synoptic survey measurements completed in September and October of 2012, none exceeded 70°F and only four exceeded 60°F. The maximum temperature observed during the 2013 survey was 78°F (August 29, 2013 at Meadow Lane). Although difficult to assess due to a lack continuous, annual temperature monitoring data, because no single point measurement of temperature on Battle Creek has exceeded the MPCA's maximum daily average temperature of 86°F, it is unlikely that temperature is a stressor to aquatic life in Battle Creek.

3.1.2 Metals: Total Nickel and Total Chromium

Total nickel and total chromium were eliminated as candidate causes of impairment because Battle Creek total nickel and total chromium values have met the MPCA standard throughout the period of record (2000 through 2013). Nickle concentration varied from 0.4 to 44 µg/L, while chromium concentrations ranged from 0.1 to 14 µg/L. Of the 346 samples of nickel and chromium, none exceeded the MPCA's chronic standard (CS), maximum standard (MS), or final acute value (FAV) (Minn. R. 7050.0222, subp. 4, for Class 2B streams, see Appendix B).

3.1.3 Nitrates

Nitrates have been eliminated as a candidate cause of impairment in Battle Creek. During the period of record (2000 through 2013), there were no exceedances of either the MPCA's draft chronic (4.9 mg/L) or acute (41 mg/L) nitrate water quality standards were recorded at station 99UM075. Of the 436 samples, the maximum and average nitrate concentrations were 1.1 mg/L and 0.3 mg/L, respectively.

3.2 Inconclusive Causes

3.2.1 pH

Additional information is needed to determine if pH is a candidate stressor. Although pH data have generally met the MPCA standard, 4 out of 52 synoptic pH measurements performed on Battle Creek during the summer of 2013 did not meet the MPCA standard for Class 2B (6.5 ≤ pH ≤ 9.0; Minn. R. 7050.0222, subp. 4). As shown in Table 3.1, all Battle Creek pH data collected during September and October of 2012 met the MPCA standard for pH. The four violations recorded occurred during the 2013 synoptic survey at the outlet of Battle Creek Lake (see Table 3.2). The pH of Battle Creek Lake has been monitored most years since 2002. Review of the Battle Creek Lake pH dataset shows that pH measurements greater than 9.0 in the first 2-meters of depth are common during the growing season (June-September) of most years. High pH measurements within the lake during the growing season are likely attributed to elevated primary production (eutrophication), driven by excess nutrient loading. Elevated pH in Battle Creek Lake did not occur in September or October of 2012 (during the synoptic survey); but violations of the pH standard were observed at June through August of 2013, potentially explaining why pH violations were recorded at the Meadow Lane monitoring station during these months.

The biological impacts of elevated pH are not specific enough to be considered symptomatic (EPA CADDIS, http://www.epa.gov/caddis/ssr_ph_wtl.html). Non-specific biological impacts compounded with the fact that no macroinvertebrate or fish samples have been collected from the Meadow Lane station (the only station where elevated pH has been observed) makes it difficult to determine if elevated pH is impacting aquatic species within Battle Creek. Yellow perch and stoneflies (Plecoptera) may be sensitive to elevated pH, and have been used as indicator species of elevated pH stress in previous SID reports (MPCA 2014d). No stoneflies have been observed in Battle Creek, and the only three Yellow Perch that have been observed in Battle Creek were found downstream of McKnight Basin. The absence of stoneflies and spatial distribution of Yellow Perch, however, should be considered very weak evidence of stress related to elevated pH, as both are sensitive to a wide range of other stressors, such as TSS, low DO, and metal toxicity.

Because modern pH data is limited to the 2012 and 2013 synoptic surveys, pH violations were only recorded at the Meadow Land monitoring station at the outlet of Battle Creek Lake, and no biological surveys have been collected at or near the Meadow Lane; is it unclear (a) the extent to which pH is a stressor to the biological community immediately downstream of Battle Creek Lake, and (b) whether or not pH is a stressor at any other stations along Battle Creek. For this reason, it is recommended that pH be considered an inconclusive cause until additional pH monitoring data is collected.

Table 3.1 2012 Battle Creek pH summary from synoptic survey.

Location Stations organized from upstream to downstream	**pH (Standard Units)**						
	AM	PM	AM	PM	AM	PM	AM
	9/20/2012	9/20/2012	9/26/2012	9/26/2012	10/10/2012	10/10/2012	10/25/2012
Meadow Lane (outlet of Battle Creek Lake)	7.2	8.3	7.4	7.9	6.7	7.6	6.9
12UM148	6.9	7.4	7.3	7.4	6.9	7.2	7.5
Crestview Drive (upstream of McKnight Basin)	7.7	8.0	7.8	7.9	7.4	8.0	7.7
97UM008	7.0	7.2	7.1	7.2	7.4	7.7	7.2
99UM076	7.5	7.8	7.6	7.8	7.7	7.9	7.4
04UM011	7.6	8.0	7.7	8.1	7.8	8.1	7.7
Upstream of Highway 61	7.7	8.7	7.9	8.0	8.0	8.0	7.9
99UM075	7.8	8.0	7.9	8.0	7.9	7.9	8.0
MPCA Standard	6.5 ≤ pH ≤ 9.0						

Table 3.2 2013 Battle Creek pH summary from synoptic survey.

Location Stations organized from upstream to downstream	**pH (Standard Units)**										
	3/23/2013	3/28/2013	4/25/2013	5/29/2013	6/27/2013	7/25/2013	Morning 8/15/2013	Afternoon 8/15/2013	8/29/2013	9/24/2013	10/22/2013
Meadow Lane (outlet of Battle Creek Lake)	6.2	6.7	7.1	8.7	8.7	9.1	9.2	9.8	8.0	7.8	7.8
12UM148							8.0	8.1			
Crestview Drive (upstream of McKnight Basin)							7.8	8.2			
97UM008	7.0	7.2	7.6	7.9	8.1	7.4	7.4	7.6	8.1	6.9	7.4
99UM076							7.7	8.0			
04UM011	7.4	7.7	7.7	8.0	8.1	7.9	7.8	8.3	8.2	7.8	7.7
Upstream of Highway 61							7.1	8.4			
99UM075	7.9	7.9	8.0	8.1	8.1	7.9	6.9	8.4	8.2	8.0	8.0
MPCA Standard	6.5 ≤ pH ≤ 9.0										

3.2.2 Altered Hydrology

Additional information is needed to determine if altered hydrology (i.e., stream flow, stream discharge) is a candidate stressor. The 1981-1982 Battle Creek restoration project (described in more detail in Section 4.6.1) significantly altered the geomorphology of the stream. Gradient control structures lowered stream slope in many areas, and a high flow diversion system was installed. The project achieved the goal of greatly minimizing stream bank erosion and stabilizing the creek, but lower average flows and stream gradient lead to siltation. Eventually, increased siltation reduced stream gradient and flow rates to the point that vegetation could establish in the stream channel, further reducing flow. To address this issue, stream dredging and vegetation removal was completed of the winters of 1991 and 1992. Currently, vegetation and sediment are removed from the stream as needed by Ramsey County Parks. A 2012 survey photo survey by RWMWD staff (see Section 4.6) found little evidence of siltation or instream vegetation problems. Due to limited flow monitoring data (described below), it is difficult to determine what impacts the 1981-1982 restoration project has had on hydrology, and whether or not altered hydrology is a candidate stressor to aquatic communities.

Flow data has historically been monitored at station 99UM075 (the Battle Creek WOMP station). During the period from 1996 to 2013, less than 2% of flow measurements were below detection (< 0.1 cfs), and less than 3% were greater than 30 cfs. On average, flow at station 99UM075 was greater than 6 cfs. However, during the synoptic water quality survey performed by RWMWD staff in 2012, it was noted that there was no or very little flow at the sampling location near Century Avenue during two of the four total visits to that sampling site. Because Century Avenue is the most upstream of all the Battle Creek sampling locations, it is possible that low flow or no flow would be more likely to occur at this site when Battle Creek Lake drops below its outlet elevation.

To assess how flow regimes and hydrologic conditions may be impacting macroinvertebrates along Battle Creek, the behavioral traits of collected macroinvertebrates was analyzed (Figure 3.1). The "swimmer" and "burrower" behavior classification types are best suited for standing or slowing moving water, as slow moving water requires less physiological effort for swimming type macroinvertebrates, and siltation associated with slower moving water provides more habitat for burrowers (MPCA 2014c). The "clinger" classification group is best suited for high flow or "flashy" stream environments, as clingers possess physiological and morphological adaptations which allow them to attach to fixed substrates and avoid being carried downstream.

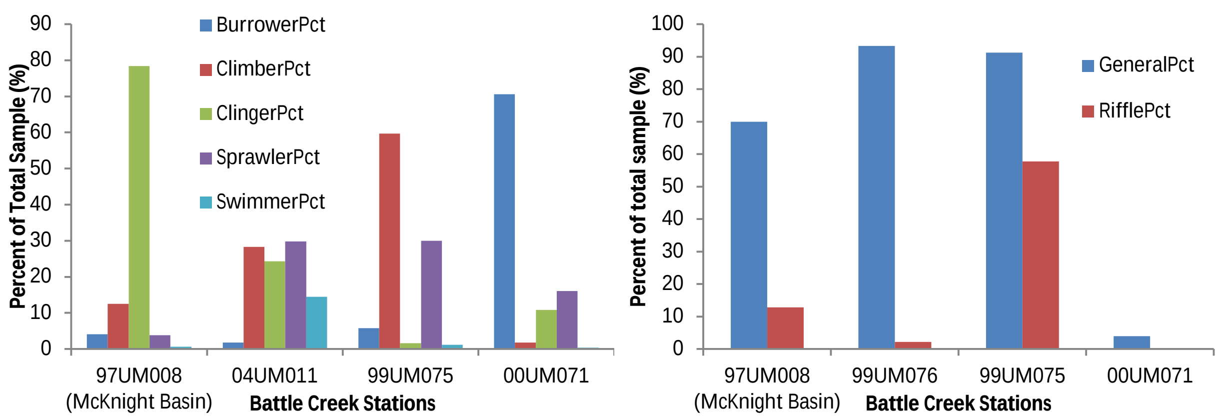


Figure 3.1 Behavior classification of macroinvertebrates (left) and fish (right) at Battle Creek stations.

As can be seen, clinger type macroinvertebrates dominate the population downstream of McKnight basin (station 97UM008), whereas burrower types are more abundant at the most downstream station near Pigs Eye Lake (station 00UM071). This shift in behavioral classification suggests that high or flashy flows may be more common just downstream of McKnight basin, and that lower, more consistent flow rates are more common as the stream gradient decreases near Pigs Eye Lake. If altered hydrology was leading to flashy, inconsistent flow rates throughout Battle Creek, it would be expected that clinger type macroinvertebrates would be the predominant behavioral type at a majority of sampled stations. The analysis of macroinvertebrate behavioral classification in Figure 3.1 does not, however, help to determine if altered hydrology may be impacting stations upstream of station 97UM008, as all macroinvertebrate samples were taken from stations downstream of McKnight Basin.

A similar analysis was performed on the distribution of generalist and riffle dwelling fish species along Battle Creek (Figure 3.1). Generalist fish species can be predictors of altered hydrology, due to their short life cycles and high tolerance to stream degradation (MPCA 2014c). Riffle dwelling fish species prefer rapidly moving water, so it is expected that they would be found in higher abundance near stations that routinely experience high flow. Generalist fish species were found in high abundance (>70% relative abundance) at all stations with the exception of station 00UM071, near Pigs Eye Lake. Because generalist fish species are tolerant to many stressors, this is not definitive evidence that stations near station 97UM008 are impacted by altered hydrology. Riffle dwelling fish were only found in significant numbers at station 99UM076. Similar to the analysis of macroinvertebrate behavioral classification, analysis of the spatial distribution of fish species does not help to determine if altered hydrology is impacting biological stations upstream of McKnight Basin (station 97U008).

Due to a lack of upstream biological monitoring and limited stream flow monitoring data, we are unable to analyze spatial difference in flow condition, and are unable to make a determination of whether or not stream flow (i.e., altered hydrology) is a candidate stressor until more stream flow and biological data are collected.

3.2.3 Ions other than Chloride

Chloride is the only ion which has been measured as part of water quality monitoring efforts on Battle Creek. Chloride has been found to be closely correlated to specific conductance in Battle Creek (see Section 3.3.2), but this finding does not preclude the possibility that other ions are also contributing to specific conductance. For this reason, all impact of all ions other than chloride (those associated with dissolved salts, alkalis, sulfides, carbonate compounds, etc.) is inconclusive. Additional data collection is needed to determine the impact of other constituent ions.

3.3 Summary of Candidate Causes in the Battle Creek Watershed

The initial list of candidate/potential causes was narrowed down after the initial data evaluation/data analysis resulting in seven for final analysis in this report:

- Excess sediment
- Specific conductance and chloride
  DO and biological oxygen demand (BOD)

- Excess total phosphorus (TP)
- Altered habitat
- Habitat fragmentation
- Metal toxicity (cadmium, copper, lead and zinc)

3.3.1 Candidate Cause: Excess Sediment

Increases in suspended sediment and turbidity, which is a measure of water clarity affected by sediment, algae, and organic matter, 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 important natural processes for all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat in addition to the direct harm to aquatic organisms (Cormier 2007).

3.3.1.1 Water Quality Standards

The water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2B waters, including Battle Creek.

Sediment is considered a possible stressor because turbidity levels in Battle Creek have exceeded the Class 2B Standard of Minn. R. ch. 7050, which is a maximum of 25 Nephalometric Turbidity Units (NTU) (Minn. R. ch. 7050.0222). Additional information about water quality standards in Minnesota (Minn. R. ch. 7050) can be found here: https://www.revisor.mn.gov/rules/?id=7050.

Total suspended solids (TSS) standards for rivers and streams were adopted at the June 24, 2014, MPCA Citizen Board meeting. The standard that is applicable to Battle Creek, located in the Central River Nutrient Region, is 30 mg/L. Additional information about the TSS water quality standard in Minnesota (Minn. R. ch. 7050) can be found here: http://www.pca.state.mn.us/index.php/view-document.html?gid=21204.

3.3.1.2 Types of Data

Point measurements

Sediment data were collected from Battle Creek during 1977 through 1990 and from 1996 through 2013. Monthly samples for TSS and turbidity were collected from two Battle Creek locations annually during the growing season from 1977 through 1990. The WOMP monitoring program has collected TSS data from 1996 through 2013 and turbidity data from 2000 through 2013.

Synoptic Longitudinal Profile

Monthly TSS samples were collected from selected locations along Battle Creek during September and October of 2012 and March through October of 2013 to assess longitudinal variability in TSS.

3.3.1.3 Sources and Causal Pathways Model

A conceptual model of sources and causal pathways for sediment impairment in Battle Creek is shown in Figure 3.2. In this conceptual model, sediments are the direct cause of biological impairments, but the behavior of sediments can be understood only in context with the hydrology, geology, and geomorphology of Battle Creek. The relationship between suspended and deposited sediments is dynamic and the relative importance of each "type" within Battle Creek will vary with factors such as soil types, stream gradient, and water velocity or discharge. For example, suspended sediment can settle and become silt, covering and embedding gravels under low flow conditions. During storms, flows increase and the force of the water is stronger and the sediments can once again become suspended. When the flow lessens again, sediments are deposited, changing the type of substrate, filling interstitial spaces, and covering plants, animals, and substrate with sediment (Cormier 2007).

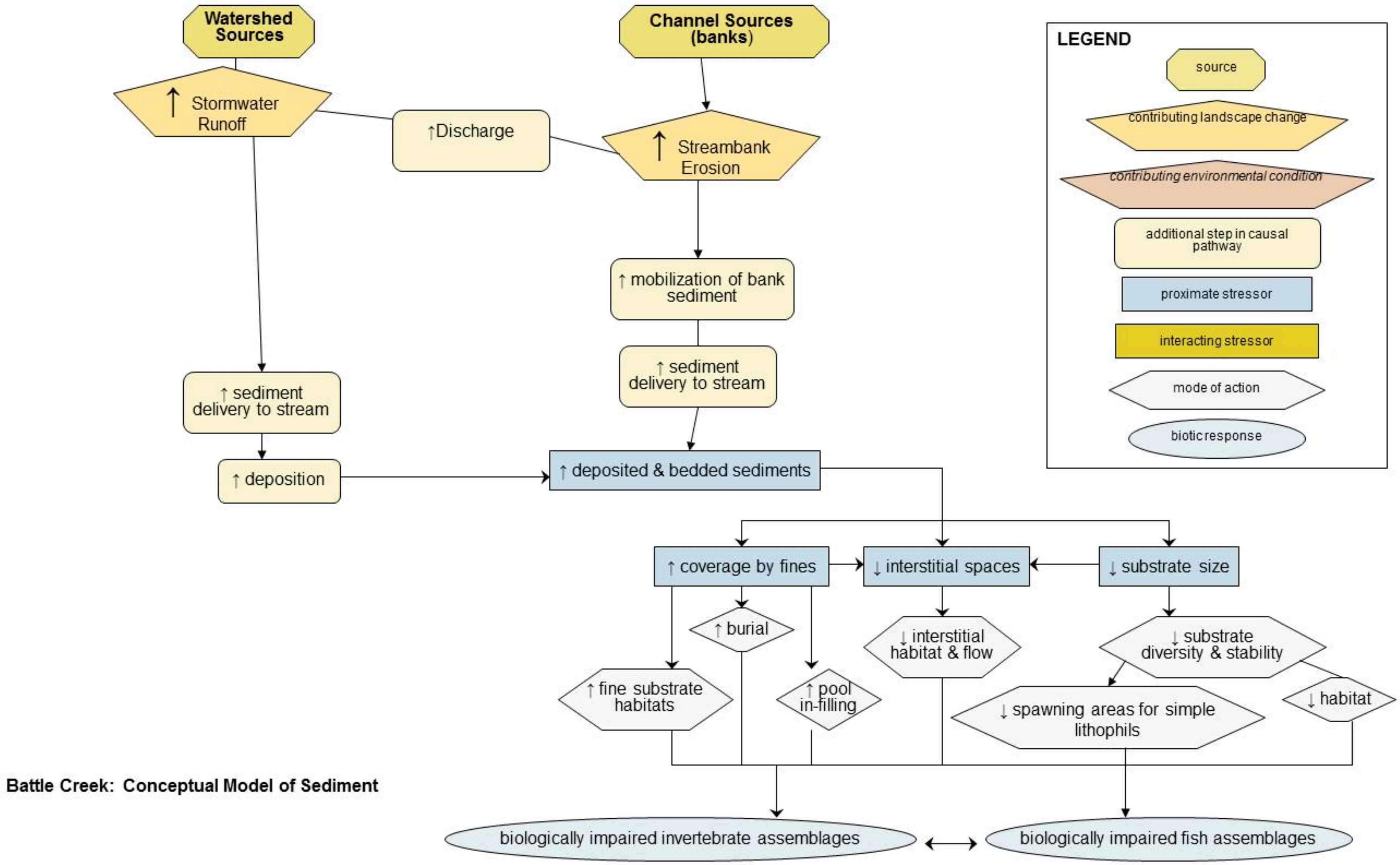


Figure 3.2 Conceptual model of suspended sediment for Battle Creek.

3.3.2 Candidate Cause: Specific Conductance and Chloride

Specific conductance is a measure of the ability of water to conduct an electric current, and serves as a quantitative measure of ionic strength. Specific conductance is a measure of all ionic species within a waterbody, but in Battle Creek has been shown to be highly correlated with chloride concentrations (Figure 3.3). The statistically significant correlation ($r(85) = 0.79$; $p < 0.001$) between specific conductance and chloride concentration is likely attributed to the widespread use of chloride containing deicing products (NaCl, $MgCl_2$, $CaCl_2$, etc.) within the watershed. For this reason, chloride concentration is related to specific conductance and overall ionic strength throughout.

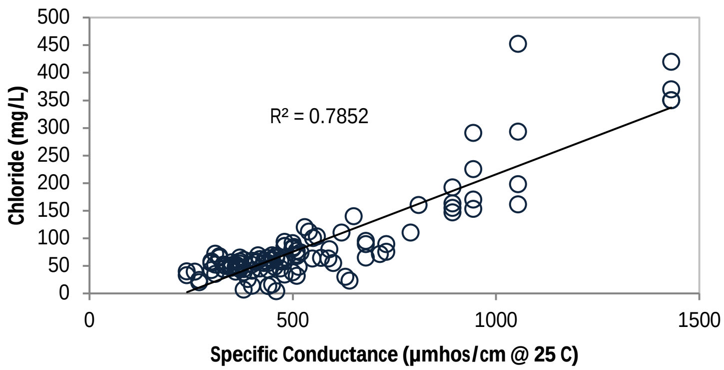


Figure 3.3 Relationship between specific conductance and chloride concentration.

3.3.2.1 Water Quality Standards

Ionic strength is considered a possible stressor because specific conductance and chloride levels in Battle Creek have exceeded the Class 2B Standard of [Minn. R. ch. 7050](). The specific conductance standard applicable to Battle Creek is a maximum of 1,000 µmhos/cm@25 C. The MPCA has adopted the [EPA recommended water quality criteria for chloride](). The allowable chloride concentration to protect for chronic 2B uses is 230 mg/L and the maximum (acute) is 860 mg/L. Two or more exceedances of the chronic criterion within a 3-year period or one exceedance of the acute criterion is considered an impairment.

3.3.2.2 Types of Data

Point measurements

Monthly samples for specific conductance and chloride were collected from two Battle Creek locations annually during the growing season from 1977 through 1990. The WOMP monitoring program has collected chloride data during 2001 through 2013.

Synoptic Longitudinal Profile

Specific conductance was measured and chloride samples were collected monthly from selected locations along Battle Creek during September and October of 2012 and March through October of 2013 to assess longitudinal variability.

3.3.2.3 Sources and Causal Pathways Model

Geologic and natural sources of ions or human activities can contribute to changes in the ion content of streams. The natural background of chloride in the Twin Cities Metropolitan Area (TCMA) has been estimated to be 18 mg/L (Stefan et al., 2008). Reviewing the chloride concentrations presented in Figure 3.3, it is clear that human activities have significantly increased chloride concentration in Battle Creek. The primarily source of anthropogenic chloride ions delivered to stream ecosystems in the Midwest is chloride containing deicer salt application for ice control on hard surfaces. A 2009 study of the TCMA found that 42% of road salt was applied by municipal sources, 23% by county agencies, 23% by the Minnesota Department of Transportation (MnDOT), and 12% by commercial sources (Wenck 2009). The same study also found a statistically significant ($P < 0.05$) between chloride concentration and specific conductance in TCMA streams and lakes.

Chloride is a conservative pollutant; meaning that it does not change form over time and cannot easily be removed once introduced into a waterbody. In the early 1990s Minnesota public works departments switched from a sand-salt mixture for deicing applications to pure salt. Since the mid-1990s median chloride concentrations observed in TCMA streams have steadily increased, and in 2010, the MPCA more than doubled the number of TCMA waterbodies listed as impaired for chloride.

A conceptual model of sources and causal pathways for ionic strength impairment in Battle Creek is shown in Figure 3.4. As shown in the conceptual model, the ionic strength and chloride concentration in Battle Creek is related to stormwater drainage and proximity to highways, roads, and other hard surfaces where chloride-containing deicing products are applied. Chloride and elevated specific conductance impact stream ecology mainly by increasing osmotic stress on aquatic organisms (i.e., negatively impacting osmotic regulation), but can also increase the toxicity and mobility of other contaminants and additives, such as cyanide.

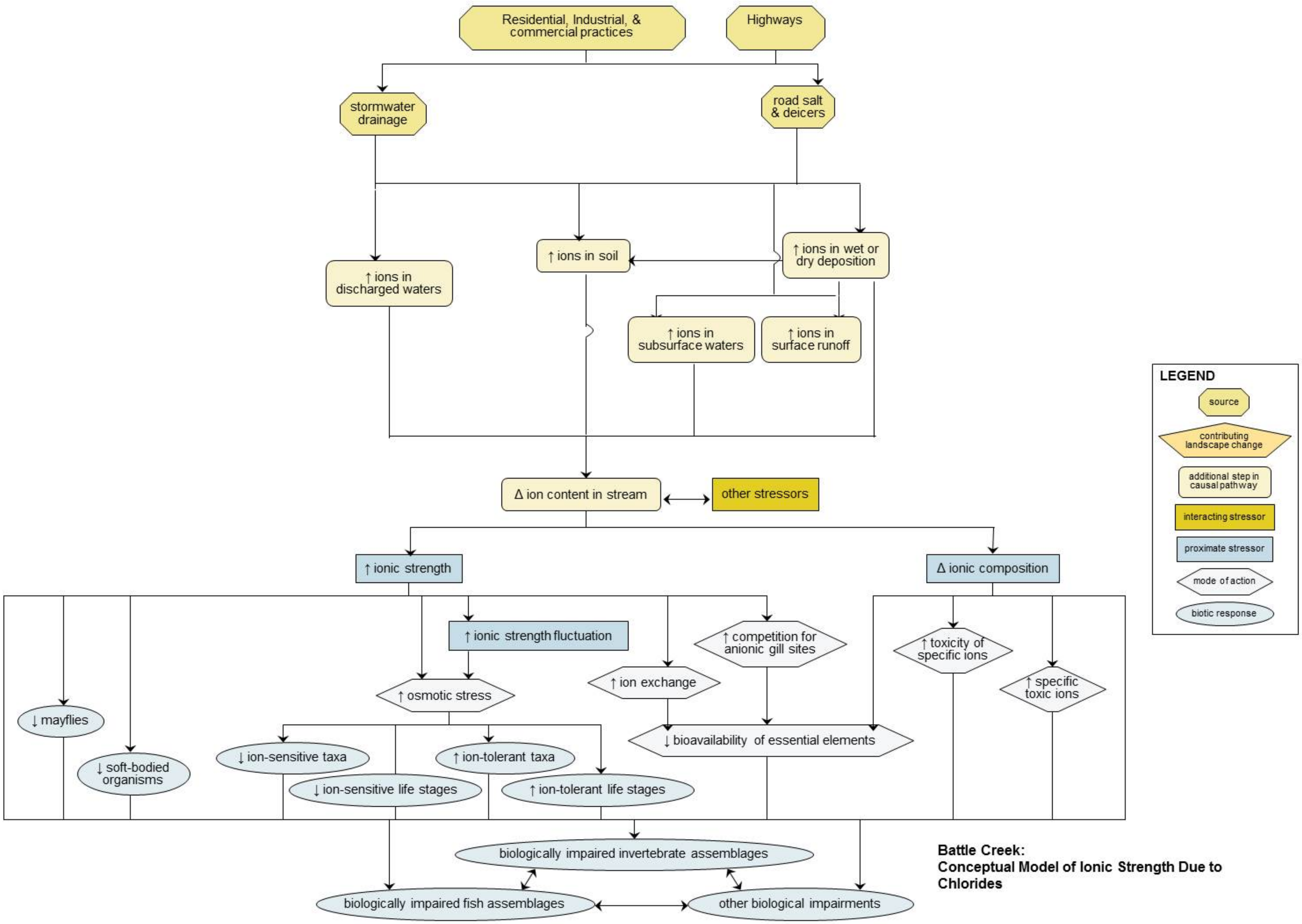


Figure 3.4 Conceptual model of ionic strength for Battle Creek.

3.3.3 Candidate Cause: Dissolved Oxygen and Biochemical Oxygen Demand

Aerobic aquatic life requires oxygen for survival, and most are dependent upon oxygen dissolved in the water column. The DO concentrations are normally sufficient to maintain healthy biotic assemblages in unpolluted, free-flowing streams, but low or extremely high DO levels can impair or kill fishes and macroinvertebrates. In addition, large fluctuations in DO levels over relatively short periods of time (e.g., daily) can stress aquatic organisms.

3.3.3.1 Water Quality Standards

In Class 2B streams, including Battle Creek, the Minnesota standard for DO is 5.0 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 for the Determination of Impairment* (MPCA 2009):

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

Additional information about water quality standards in Minnesota (Minn. R. ch. 7050) can be found here: https://www.revisor.mn.gov/rules/?id=7050.

According to the MPCA's *Minnesota Nutrient Criteria Development for Rivers* (MPCA 2013a), the BOD eutrophication criteria for streams in Minnesota ranges from 1.5 mg BOD/L to 3.0 mg/L. For streams in the Central River Nutrient Region (including Battle Creek), the criteria is that BOD should remain below 2.0 mg/L (≤ 2.0 mg BOD/mL).

3.3.3.2 Types of Data

Point measurements

Instantaneous DO data are available from Battle Creek and can be used as an initial screening for low DO. These measurements represent discrete point samples, usually conducted in conjunction with surface water quality sample collection utilizing a YSI 600 XLM V2 meter. Because DO concentrations can vary significantly as a result of changing flow conditions and time of sampling, instantaneous measurements need to be used with caution and are not completely representative of the DO regime at a given site.

In addition to DO data, instantaneous point measurements of BOD were also collected. The WOMP monitoring program has collected BOD data from 1996 through 2013.

Diurnal and synoptic longitudinal profile sampling of DO have been completed on Battle Creek, and are described below. BOD was not measured using either of these sampling strategies.

Diurnal (Continuous)

A Yellow Springs Instrument (YSI) sonde was employed by the MPCA in late summer of 2012 to capture diurnal fluctuations over the course of a number of diurnal patterns at station 97UM008. This information was then used to look at the diurnal flux of DO along with patterns of DO fluctuation. Hieskary et al. (2010) observed several strong negative relationships between fish and macroinvertebrate metrics and DO flux. Their study found that a diurnal (24 hour) DO flux over 4.5 mg/L reduced macroinvertebrate taxa richness and the relative abundance of sensitive fish species in a population.

Synoptic Longitudinal Profile

Instantaneous DO measurements were completed at selected locations along Battle Creek during early morning (around sunrise) and afternoon on selected sampling dates during 2012 and 2013 to assess longitudinal variability in DO as well as diurnal changes.

3.3.3.3 Sources and Causal Pathways Model

A conceptual model of sources and causal pathways for DO and BOD impairment in Battle Creek is shown in Figure 3.5. As shown in the conceptual model, causal factors of low DO in Battle Creek include (1) increased BOD and respiration in conjunction with no photosynthesis at night reduces oxygen levels in the stream; (2) reduced precipitation results in reduced flow which in turn results in increased stream temperatures in summer and reduced oxygen solubility in Battle Creek; and (3) Battle Creek Lake and McKnight Basin reduce discharges to Battle Creek which in turn results in reduced stream aeration during low flows. In addition, reduced oxygen in Battle Creek Lake and McKnight Basin discharge waters lowers oxygen levels in Battle Creek.

Human activities can significantly affect DO concentrations in streams, most notably by increasing chemical or BOD. Urbanization and agricultural land use alterations within a watershed can increase the nutrient and organic matter loading (e.g., yard waste, animal waste, fertilizer, etc.) to a stream. The amount of DO required by the aerobic biological assemblage in a steam to break down this organic material is referred to as biochemical oxygen demand, or BOD. As organic waste loading to a stream increases, BOD increase, and in response, cellular respiration increases. The increase in cellular respiration decreases DO in the stream until either the organic matter is broken down, or DO is lowered to the point where aerobic respiration is no longer a favorable metabolic reaction.

In addition to increasing BOD, human activities can negatively impact DO concentration in a stream by reducing the potential for oxygenation. Impoundments upstream of a location may discharge low oxygen water downstream, but releases also may increase turbulence and oxygenate water. Urbanization of a stream's watershed affects DO by increasing water temperature. Loss of riparian cover and addition of warm effluents (e.g., stormwater runoff) contributes to increased water temperatures. DO saturation occurs at lower concentrations in warm versus cold water. Hence, urbanization contributes to decreased DO concentrations.

In most streams, 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 DO decrease. Increased water temperatures also raise the DO needs for many species of fish (Raleigh et al. 1986). Low DO can be an issue in streams with slow currants, excessive temperatures, high BOD, and/or high groundwater seepage (Hansen 1975).

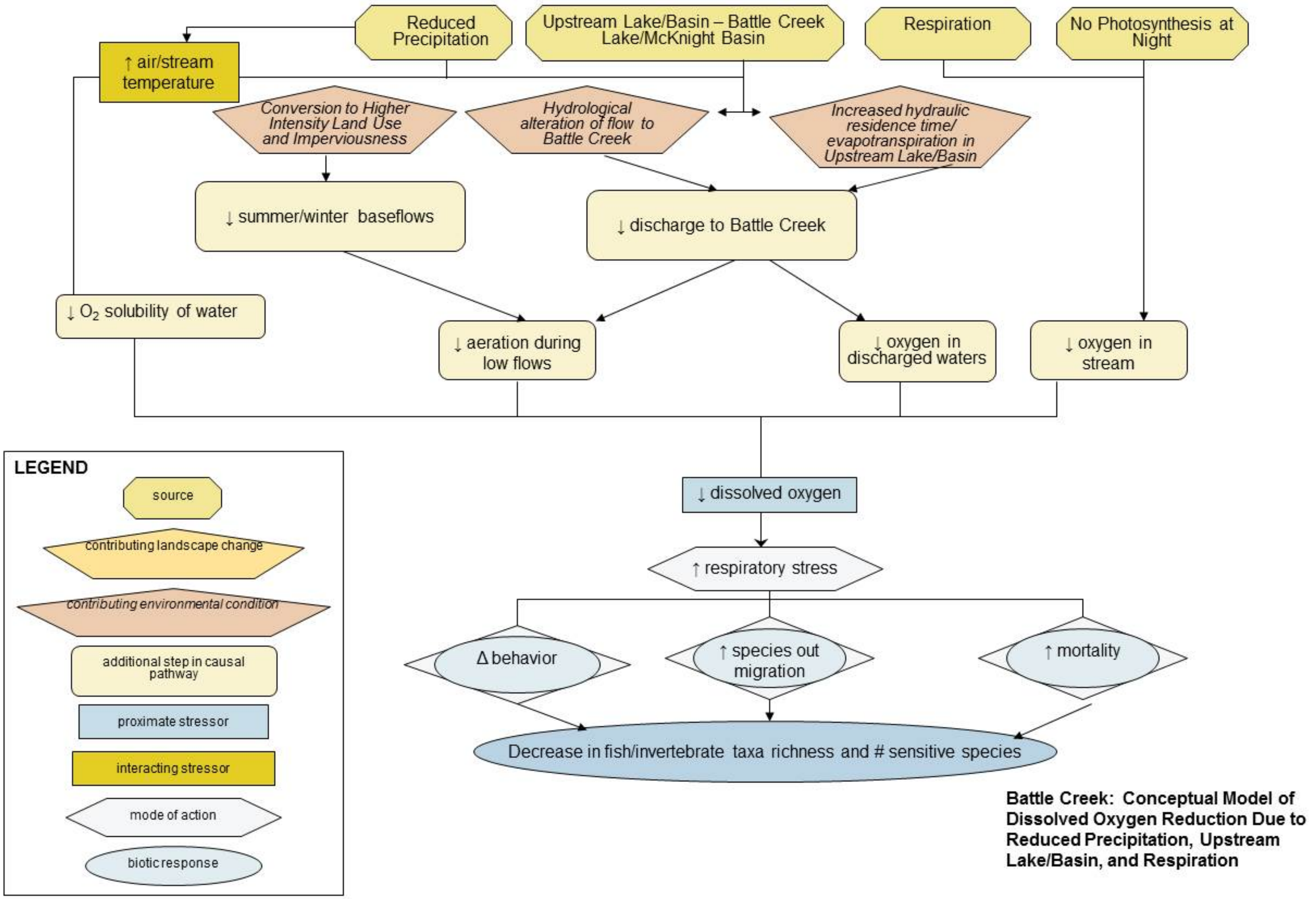


Figure 3.5 Conceptual model of DO reduction in Battle Creek.

3.3.4 Candidate Cause: Total Phosphorus

Phosphorus is an essential nutrient for aquatic life and plant growth, but excess phosphorus can negatively impact stream ecology in a number of ways. Primarily, excess phosphorus stresses aquatic ecosystems by causing excessive growth of algae, periphyton, and submerged aquatic vegetation. Senescence and decomposition of blooms of plant and microbial life can lead to increased turbidity and DO concentrations. Additionally, increased photosynthetic activity can increase fluctuations in diurnal DO levels, further stressing oxygen sensitive species.

3.3.4.1 Water Quality Standards

According to the MPCA's *Minnesota Nutrient Criteria Development for Rivers* (MPCA 2013a), the TP eutrophication criteria for streams in Minnesota ranges from 50 µg TP/L to 150 µg TP/L. For streams in the Central River Nutrient Region (including Battle Creek), the criteria is that TP should remain below 100 µg TP/L (≤100 µg TP/L).

3.3.4.2 Types of Data

Point Measurements

Monthly samples for TP were collected from two Battle Creek locations annually during the growing season from 1977 through 1990. The WOMP monitoring program has collected TP data from 2000 through 2013.

3.3.4.3 Sources and Causal Pathways

A conceptual model of sources and causal pathways for TP in Battle Creek is shown in Figure 3.6. As shown in the conceptual model, causal factors of elevated TP in Battle Creek include (1) urbanization in the watershed; and (2) increased channel incision and erosion.

Algae and aquatic plants require nitrogen (N) and phosphorus (P) for photosynthesis. The availability of these nutrients often drives ecosystem productivity and determines trophic status. However, excessive amounts of P and N can have several negative effects on aquatic communities. The N and P conceptual diagram depicts relationships between human activities and processes that increase nutrient levels in surface waters, and the effect of nutrient enrichment on aquatic communities. Note that nutrient enrichment itself is not shown as a proximate stressor, but affects processes and states that lead to proximate stressors, such as changes in DO levels or alteration of food resources, that have direct impacts on aquatic invertebrates and fish.

Nutrients naturally occur in soils and vegetation and move throughout watersheds in regular cycles, but excess nutrient loadings to streams can adversely impact aquatic biota. Many human activities (e.g., agricultural practices, residential and commercial development) lead to land cover alteration, with subsequent increases in surface runoff and watershed erosion; this land cover alteration can increase the mobilization of P bound to watershed soils, ultimately increasing nutrient delivery to streams. Decreases in vegetation and floodplain connectivity also may reduce P uptake and their retention on the floodplain, further increasing delivery to streams.

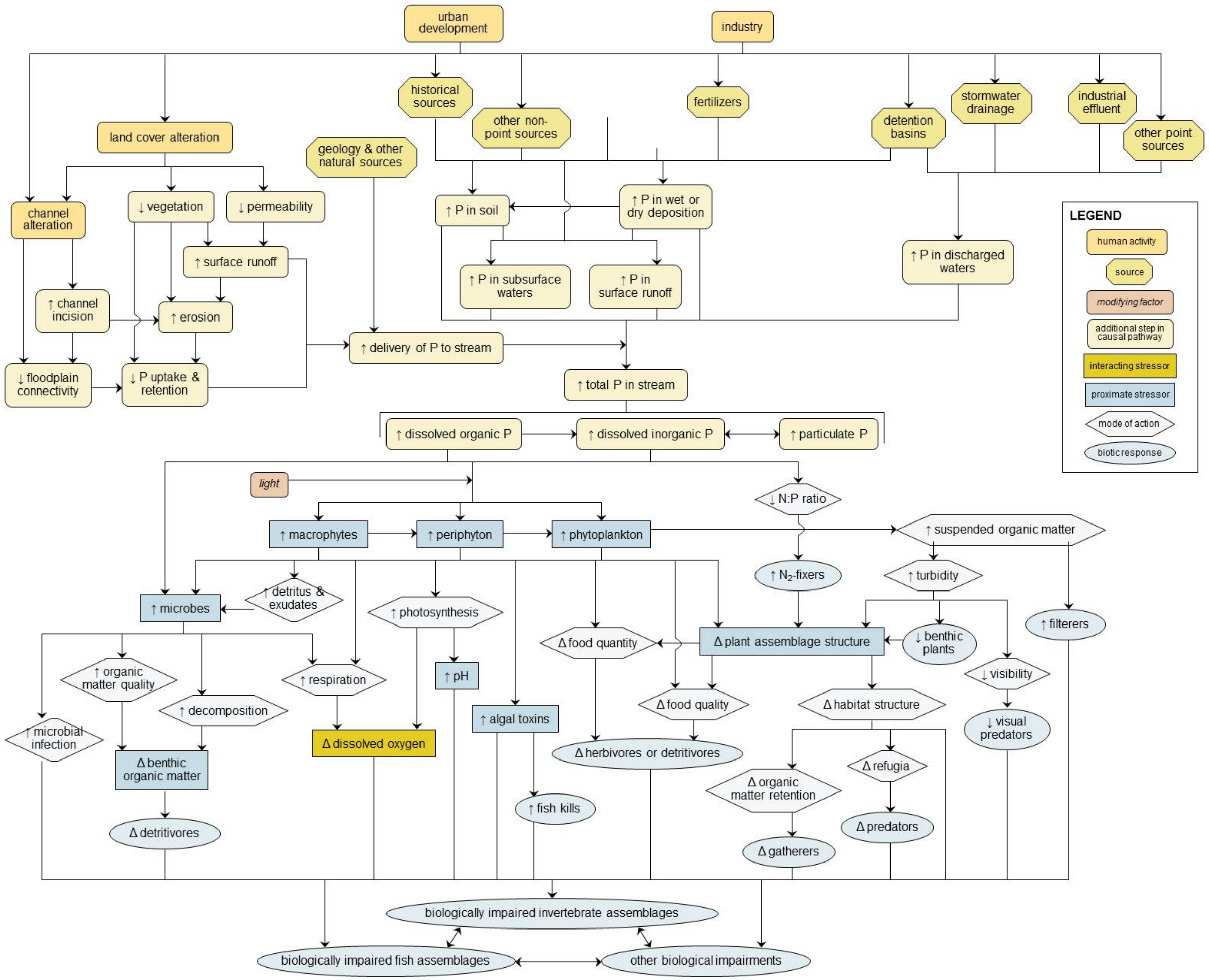


Figure 3.6 Conceptual model of total phosphorus for Battle Creek.

3.3.5 Candidate Cause: Altered Habitat

Whereas many of the candidate causes relate to physiochemical properties of a stream (e.g., water chemistry, water clarity, water quantity, etc.), altered habitat as a candidate cause evaluates whether or not the structural attributes of habitat (stream gradient, habitat complexity, vegetation cover, channel substrate, channel-riparian interactions, etc.) are impacting biological communities (EPA 2012).

3.3.5.1 Water Quality Standards

There are currently no applicable standards for altered habitat or habitat degradation.

3.3.5.2 Types of Data

MPCA stream habitat assessment data

Five MPCA stream habitat assessment (MSHA) surveys have been performed on Battle Creek. The MPCA-developed MSHA scoring process is a method of quantitatively assessing the quality of instream habitat within a river reach. The river reach selected is evaluated based on four scoring categories: land use, riparian zone, instream zone, and channel morphology. The maximum score possible is 100, with lower scores delimited into the qualification categories of “good,” “fair,” and “poor” overall habitat quality. The MSHA scoring can be used to evaluate longitudinal changes in habitat quality, as well as to help categorically diagnose which aspects of habitat degradation are most responsible for ecological stress.

Quantitative substrate measurements

Quantitative measurements of stream substrate were recorded during three of the five MSHA surveys. Embeddedness was measured as the “degree to which coarse substrates area surrounded by or covered with fine sediments throughout the reach” (MPCA 2014a). An embeddedness rating of 0% indicates that very little or no fine sediment was found surrounding course substrates. A rating of 100% indicates that coarse substrates are completely covered by fine sediment. In the field, the measurement of embeddedness is a visual assessment (i.e., the degree of embeddedness is not physically measured, but is visually evaluated by the field technician). In addition, the mean depth of fines (sediment ≤ 2.0 mm in diameter) was recorded during the same three surveys.

3.3.5.3 Sources and Causal Pathways Model

A conceptual model of sources and causal pathways for altered habitat is shown in Figure 3.7. As outlined in the conceptual model, changes in land use and urbanization within a watershed can lead to alterations of channel morphology and ultimately to degradation of habitat availability and quality. Altered hydrology cause by urbanization can lead to channelization, which has been shown in numerous studies to negatively impact biotic communities (Lau et al. 2006). Geomorphic changes, including channelization and widening, and increased watershed sediment loading can lead to loss of cover, loss of pool depth due to sedimentation, and loss of interstitial habitat due to embeddedness (Aadland et al. 2005 as cited by MPCA 2014b).

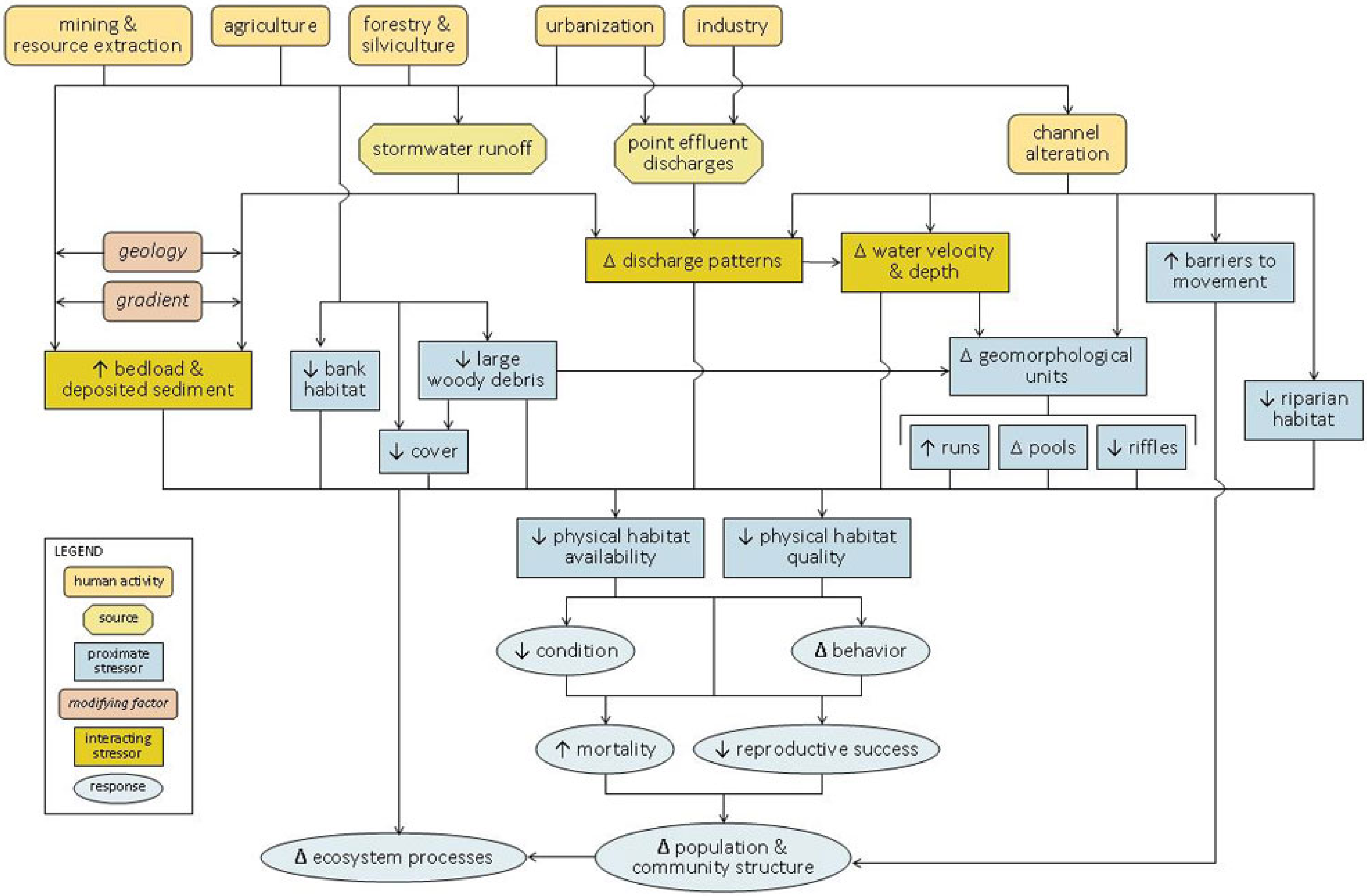


Figure 3.7 Conceptual model of altered habitat for Battle Creek.

3.3.6 Candidate Cause: Habitat Fragmentation

Creating barriers to movement can adversely affect aquatic organisms. Waterfalls and drop structures prevent the passage of fish and macroinvertebrates between upstream and downstream reaches of the stream. Habitat fragmentation is a candidate stressor due to the presence of 29 check dam and step weir structures installed along the length of Battle Creek during the 1981-1982 Battle Creek restoration project (described in greater detail in Section 4.7). The extent of Battle Creek impacted by gradient control structures is shown on Figure 2.2.

3.3.6.1 Water Quality Standards

There are currently no applicable standards for habitat fragmentation.

3.3.6.2 Types of Data

There are no quantitative measurements of habitat fragmentation. The position of sheet pile check dams and other gradient control structures was compared to the assemblage of fish species to determine the magnitude and extent of habitat fragmentation along the stream channel.

3.3.6.1 Sources and Causal Pathways Model

A conceptual model of sources and causal pathways for habitat fragmentation in Battle Creek is shown in Figure 3.8. Drop structures and waterfalls cause habitat fragmentation which isolates biota. Such fragmentation may increase mortality due to isolation from food sources and prevent replenishment of the species when disease or other stressors eliminate individual biota species.

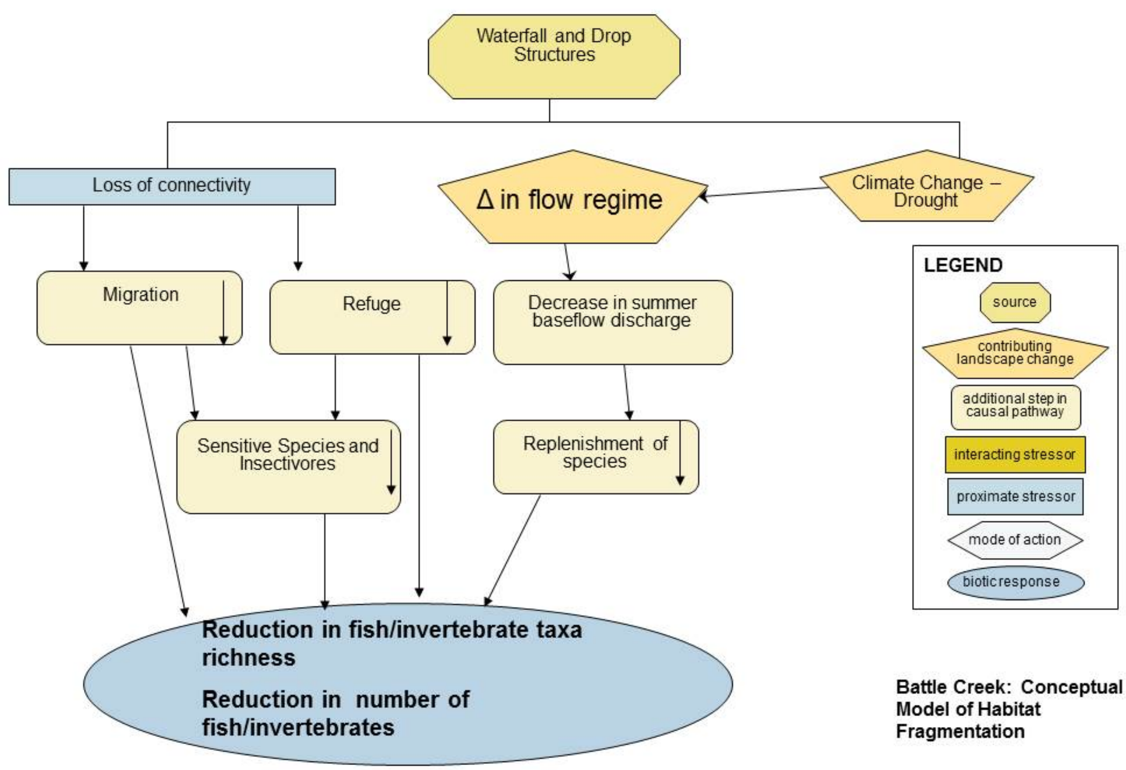


Figure 3.8 Conceptual Model of habitat fragmentation in Battle Creek.

3.3.7 Candidate Cause: Metals (Zinc, Cadmium, Copper, and Lead)

Human activities redistribute and concentrate metals in areas that are not naturally metals-enriched; when these metals are released into the air, water, and soil, they also can reach surface waters. If these metals are biologically available at toxic concentrations, they can contribute to biological impairment of aquatic communities (Shaw-Allen et al. 2007).

Four metals species are candidate causes of biological impairment in Battle Creek: zinc, cadmium, copper, and lead. Due to the commonality between these four metals, discussions of water quality standards, types of data, and sources and causal pathways have been grouped, below. However, each of the four metals species is a candidate cause of the biological impairment of Battle Creek.

3.3.7.1 Water Quality Standards

High concentrations of metals are considered a possible stressor because zinc, cadmium, copper, and lead concentrations in Battle Creek have failed to meet Class 2B Standards of Minn. R. ch. 7050. Metals standards are influenced by hardness and vary with hardness concentrations (Minn. R. ch. 7050.0222). Metals are more toxic in soft water (lower hardness) than in hard water (higher hardness) because they are more soluble in soft water and it is known that the dissolved forms of heavy metals are the active toxic agents. Hence, hardness concentrations in Battle Creek were used to determine Class 2B metals standards during each sample event.

Additional information about water quality standards in Minnesota (Minn. R. ch. 7050) can be found here: https://www.revisor.mn.gov/rules/?id=7050

3.3.7.2 Types of Data

Point measurements

The WOMP monitoring program has collected metals data during 2000 through 2013.

Synoptic Longitudinal Profile

Metals samples were collected monthly from selected locations along Battle Creek during September and October of 2012 and March through October of 2013 to assess longitudinal variability.

3.3.7.3 Sources and Causal Pathways Model

A conceptual model of sources and causal pathways for metals impairment in Battle Creek is shown in Figure 3.9. Metals enter surface waters, such as Battle Creek, by non-point sources. Non-point sources include atmospheric emissions and land uses which contaminate soils with metals. Urban development is a contributing factor because it results in reduced water transpiration due to de-vegetation and reduced infiltration due to the increased impervious surface cover (compacted soil, roofs, parking lots, and roads. These reductions increase the volume and velocity of stormwater runoff entering surface waters. Accelerated flow can incise channels, reducing bank stability and increasing bank and channel erosion. Stormwater turbulence can re-suspend sediments, which may allow sediment associated metals to partition into the water column, or transport contaminated sediment into previously uncontaminated areas (Shaw-Allen et al. 2007).

Metals entering the atmosphere from tailpipe and stack emissions are precipitated onto land or directly onto water. Episodic, pulsed exposures occur when metals precipitated onto land are washed into surface waters during storms. Smaller runoff events may result from activities such as washing cars or watering lawns and landscaping. The severity of episodic exposures is related to the amount of dry deposition built up in the period between events, saturation levels of non-impervious areas, and the volume of water discharged. The highest levels occur early in the runoff period, or in the "first flush." Metal mobility can be increased by acid rain or soils with acid-forming parent material, fertilizers, tailings, or other amendments. More gradual releases occur over periods of snowmelt which can contribute metals to both soil moisture and direct runoff (Shaw-Allen et al. 2007).

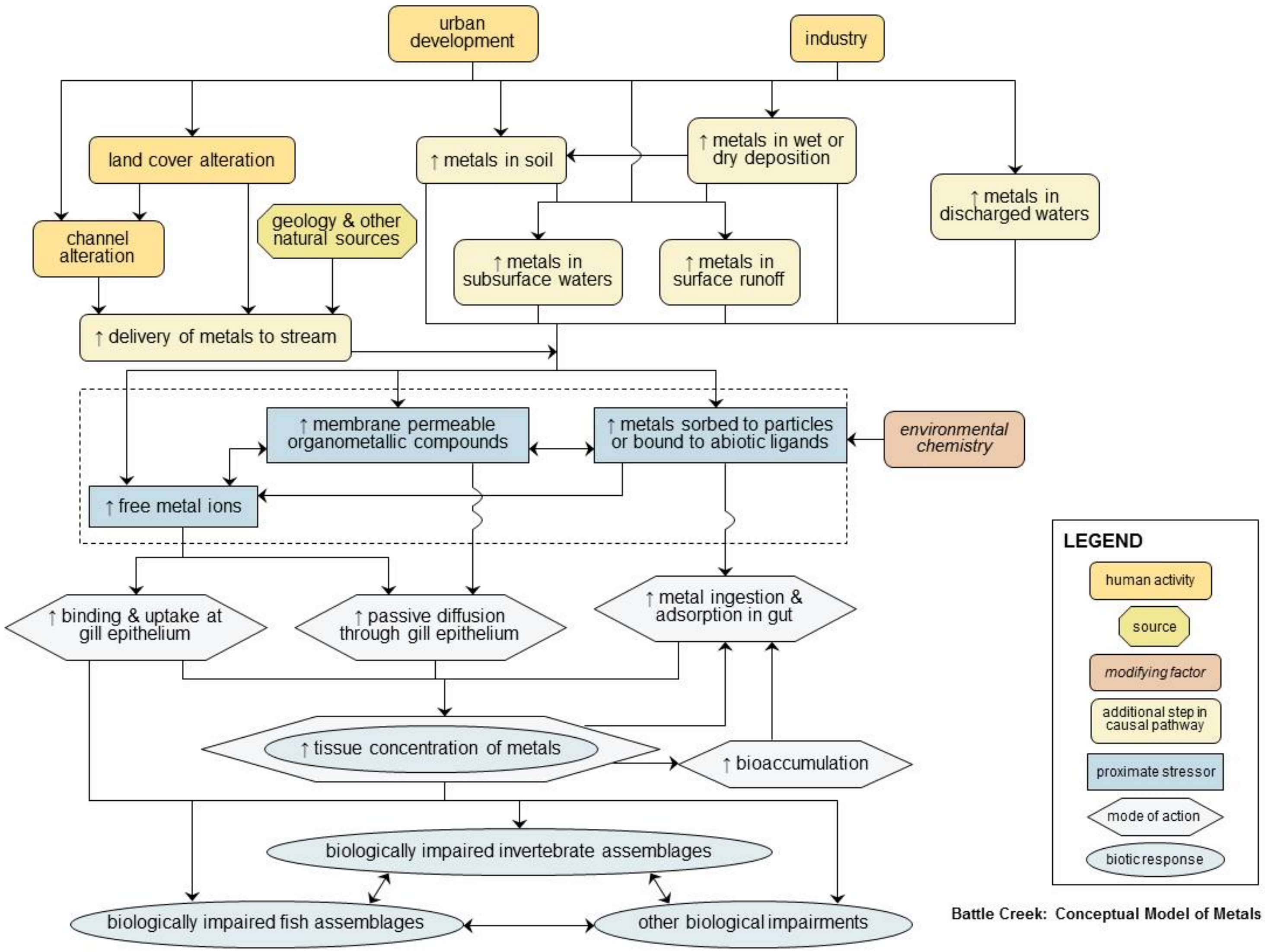


Figure 3.9 Conceptual model of metal toxicity in Battle Creek.

4. Evaluation of Candidate Causes

As discussed in Section 3, each of the identified candidate causes can degrade the biological integrity of a stream ecosystem in a number of ways. To evaluate general biological impairment within Battle Creek, data from biological surveys were used to produce an IBI for the macroinvertebrate and fish and communities sampled at stations along Battle Creek.

To evaluate the impact of each individual candidate cause, water quality data was compared to stressor-specific biological analytical techniques, such as biological metric analysis and tolerance indicator value (TIV) analysis. Whereas the IBI rating is a measure of the general, non-specific stress within a river ecosystem, biological metric analysis can be used to determine if a specific stressor, such as elevated TSS or low DO, is impacting a sensitive subset of the ecosystem. Typically, TIVs are assigned by evaluating the relationship of the probability of occurrence of a given species or taxon to the magnitude of an environmental stressor. The magnitude of stress at which a species or taxon is most likely to be observed is defined as the TIV for that species or taxon, for that environmental stressor. At the end of each candidate cause subsection, results from the casual analysis are presented in a SOE table. In Section 5, SOE tables are compared to determine which candidate causes are most related to biological impairment.

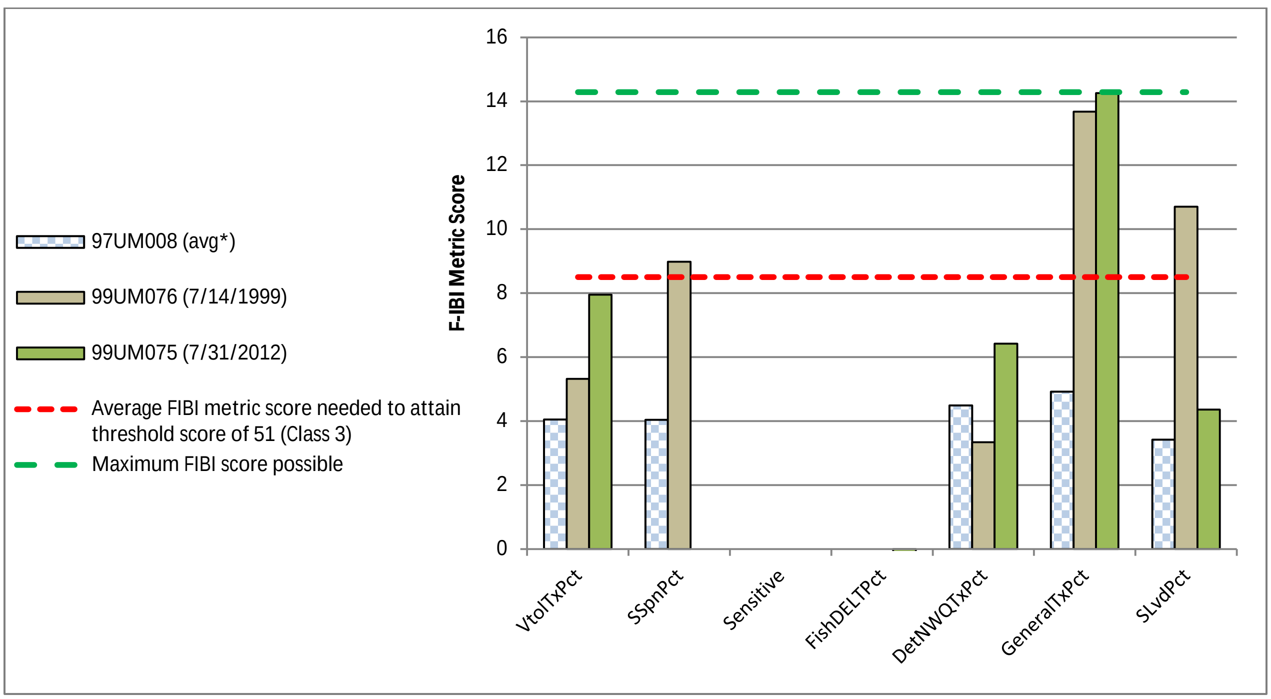
4.1. Biological Impairment

4.1.1 Fish Community

As outlined in Section 2.3, Battle Creek is currently listed as impaired for biological assemblage based on below-threshold F-IBI and M-IBI scores (see Table 2.6). Figure 4.1 shows the individual biological metric scores for stations classified as *Southern Headwaters* (F-IBI Class 3), and Figure 4.2 shows metric score for station 00UM071, classified as a *Southern Stream* (F-IBI Class 2). Descriptions of the biological metrics related to F-IBI scores can be found in Table 4.1.

Table 4.1 Descriptions of biological metrics used to generate F-IBI Class 2 and Class 3 scores.

Metric Name	Category	Response	Metric Description
Fish: Class 2 - Southern Streams			
BenInsect-TolTXPct	trophic	positive	Relative abundance (%) of taxa that are benthic insectivores (excludes tolerant species)
DetNWQTXPct	trophic	negative	Relative abundance (%) of taxa that are detritivorous
MA<2Pct	reproductive	negative	Relative abundance (%) of early-maturing individuals (female mature age <=2 years)
SensitiveTXPct	tolerance	positive	Relative abundance (%) of taxa that are sensitive
SLvd	life history	negative	Taxa richness of short-lived species
TolTXPct	tolerance	negative	Relative abundance (%) of taxa that are tolerant
TolPct	tolerance	negative	Relative abundance (%) of individuals that are tolerant
DomTwoPct	dominance	negative	Combined relative abundance of two most abundant taxa
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with Deformities, Eroded fins, Lesions, or Tumors
Fish: Class 3 - Southern Headwaters			
DetNWQTXPct	trophic	negative	Relative abundance (%) of taxa that are detritivorous
GeneralTXPct	trophic	negative	Relative abundance (%) of taxa that are generalist feeders
Sensitive	tolerance	positive	Taxa richness of sensitive species
SLvdPct	life history	negative	Relative abundance (%) of individuals that are short-lived
SSpnPct	reproductive	negative	Relative abundance (%) of individuals that are serial spawners (multiple times per year)
VtolTXPct	tolerance	negative	Relative abundance (%) of taxa that are very tolerant
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with Deformities, Eroded fins, Lesions, or Tumors



* Metric scores shown for station 97UM008 represent the average value of five fish surveys at that station from 9/23/1997 to 7/23/2012. Additionally, the 7/23/2012 station 12UM148 FIBI metric scores are not shown in this figure, as the site produced an FIBI score of 0.

Figure 4.1 Individual biological metric scores for Southern Headwater stations (F-IBI Class 3).

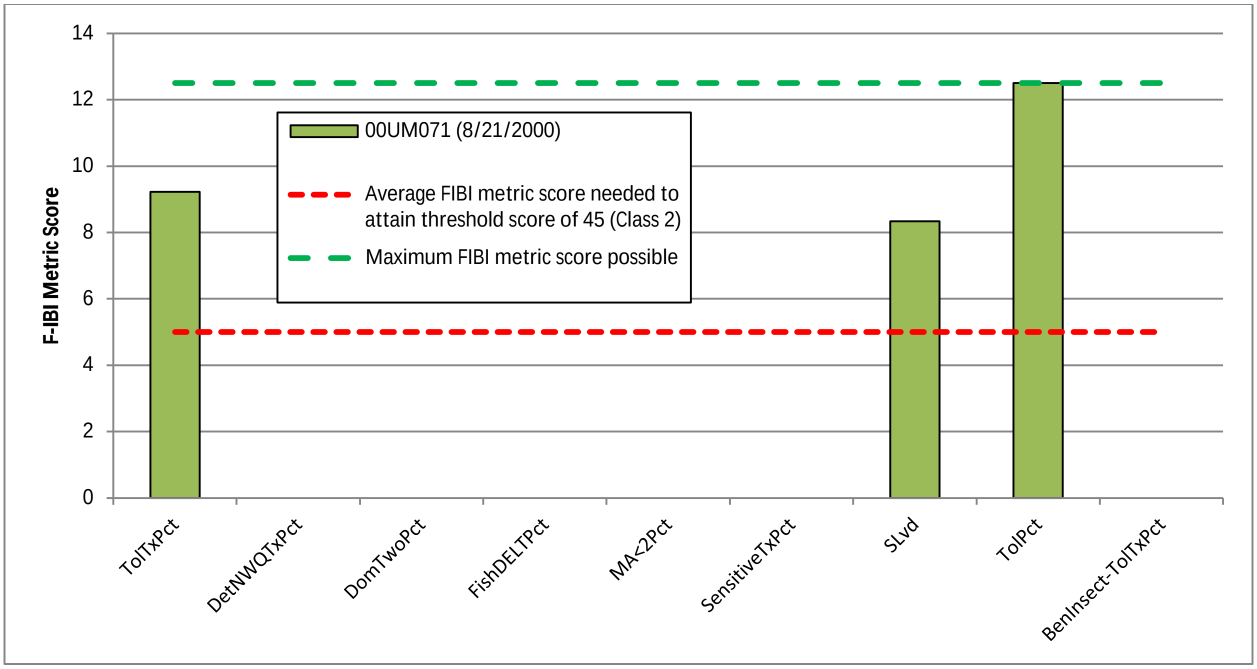


Figure 4.2 Individual biological metric scores for Southern Stream station (F-IBI Class 2).

A trend that is common in the scores for both F-IBI stream classifications is that more tolerant biological metrics (*VtolTxPct*, *GeneralTxPct*, and *TolPct*) score higher than more sensitive metrics (*BenInsect-TolTxPct* and *Sensitive*). This finding indicates that sustained ecological stress has allowed tolerant species to thrive, at the expense of less-tolerant species. This decrease in ecological diversity is the major contributing factor to the low F-IBI scores shown in Table 2.4. From Figure 4.1, there does not appear to be a clear longitudinal trend in F-IBI biological metrics.

While a few of the individual biological metrics in Figure 4.1 and Figure 4.2 are weakly associated with a particular stressor (e.g., *BenInsect-TolTxPct* may be related to embeddedness and habitat degradation), the majority are related to general ecological stress. For this reason, it is difficult from the F-IBI analysis alone to make a determination of which candidate causes are most responsible for ecological stress.

4.1.2 Macroinvertebrate Community

Individual biological metric scores for the two Battle Creek M-IBI classifications, *Southern Stream (Riffle/Run Habitats)* (M-IBI Class 5) and *Southern Forests (Glide/Pool Habitats)* (M-IBI Class 6), are shown in Figure 4.3 and Figure 4.4, respectively. Descriptions of M-IBI biological metrics are shown in Table 4.2.

Table 4.2 Descriptions of biological metrics used to generate F-IBI Class 2 and Class 3 scores.

Metric Name	Category	Response	Metric Description
Macroinvertebrate: Class 5 - Southern Streams (Riffle/Run Habitats)			
ClingerChTxPct	Habitat	Decrease	Relative percentage of taxa adapted to cling to substrate in swift flowing water
DomFiveChPct	Composition	Increase	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)
HBI_MN	Tolerance	Increase	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart
InsectTxPct	Composition	Decrease	Relative percentage of insect taxa
Odonata	Richness	Decrease	Taxa richness of Odonata
Plecoptera	Richness	Decrease	Taxa richness of Plecoptera
PredatorCh	Trophic	Decrease	Taxa richness of predators
Tolerant2ChTxPct	Tolerance	Increase	Relative percentage of taxa with tolerance values equal to or greater than 6, using MN TVs
Trichoptera	Richness	Decrease	Taxa richness of Trichoptera
Macroinvertebrate: Class 6 - Southern Forest Streams (Glide/Pool Habitats)			
ClingerCh	Habitat	Decrease	Taxa richness of clinger taxa
Collector-filtererPct	Trophic	Decrease	Relative abundance (%) of collector-filterer individuals in a subsample
DomFiveChPct	Composition	Increase	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)
HBI_MN	Tolerance	Increase	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart
Intolerant2Ch	Tolerance	Decrease	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs
POET	Richness	Decrease	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)
PredatorCh	Trophic	Decrease	Taxa richness of predators
TaxaCountAllChir	Richness	Decrease	Total taxa richness of macroinvertebrates
TrichopteraChTxPct	Composition	Decrease	Relative percentage of taxa belonging to Trichoptera
TrichwoHydroPct	Composition	Decrease	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample

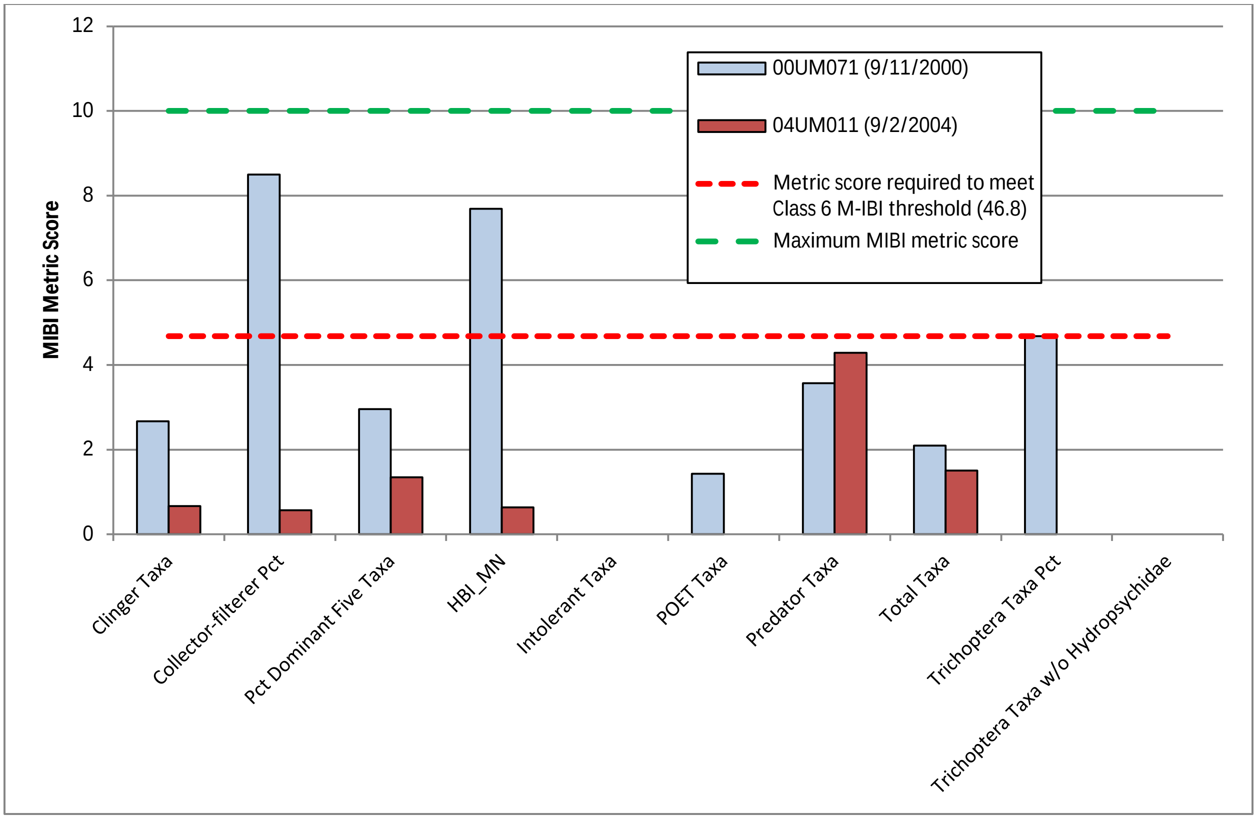


Figure 4.3 **Individual biological metric scores for Southern Streams (Riffle/Run Habitats) stations (M-IBI Class 5).**

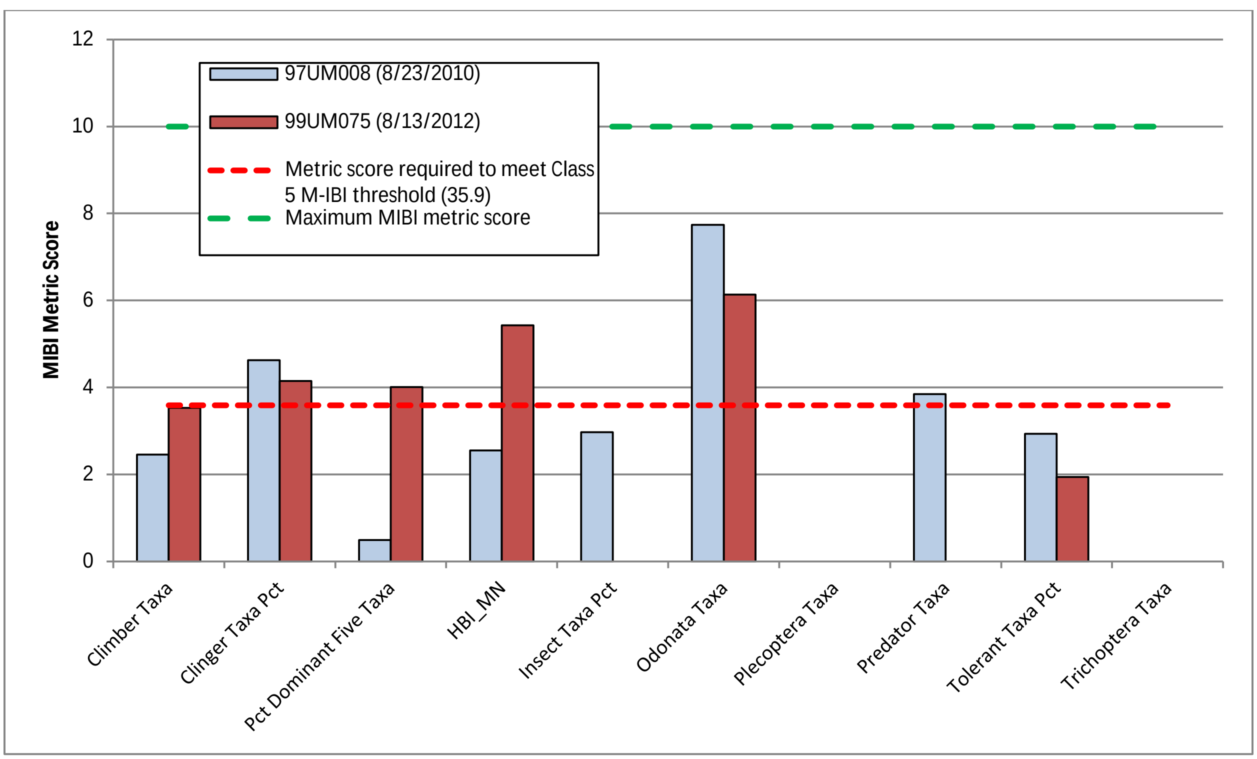


Figure 4.4 **Individual biological metric scores for Southern Forests (Glide/Pool Habitats) stations (M-IBI Class 6).**

The overall M-IBI score as well as the individual biological metric scores are similar between the two M-IBI Class 5 stations. This result is evidence that a similar level of ecological stress may exist from station 97UM008 (downstream of McKnight Basin) downstream to station 99UM075 (Battle Creek WOMP station). This evidence, however, is contradicted by the biological metric scores of M-IBI Class 6 stations, which found a much higher level of stress at station O4UM011 than station 00UM071. Station 04UM011 is between stations 97UM008 and 99UM075, while station 00UM071 is the furthest downstream of all Battle Creek stations, very near to Pigs Eye Lake. From this dataset, it is difficult to determine if longitudinal differences in the biological integrity of macroinvertebrates exist.

Similar to the F-IBI biological analysis, very few of the M-IBI Class 5 and Class 6 biological metrics can be related to a particular candidate cause. *Collector-Filterers* can be related to turbidity, and *Clingers* can be related to stress caused by altered hydrology, but the majority of individual metrics are either related to several stressors (e.g., *Plecoptera* and *Trichoptera*) or are indicators of general ecosystem stress (e.g., *InsectTxPct* and *InsectTxPct*). For this reason, M-IBI scores are less useful for determining the root causes, and are more helpful for measuring the magnitude of ecological stress within the macroinvertebrate community.

In the following subsections, water quality data and biological analytical techniques specific to each candidate cause identified in Section 3 will be evaluated to determine which are most related to the ecological stress observed in the fish and macroinvertebrate communities in Battle Creek.

4.2 Candidate Cause #1: Excess Sediment

4.2.1 Overview of Sediment in the Battle Creek Watershed

Excess sediment is a candidate cause of biological impairment of Battle Creek. Battle Creek TSS and turbidity levels have frequently exceeded the MPCA standard for Central Region streams (30 mg/L and 25 NTU, respectively) during the period of record (Figure 4.5 and Figure 4.6). As can be seen in Figure 4.5, exceedances of the MPCA standard for TSS at station 99UM075 are common. In the period from 2000 to 2013, 46% of all TSS samples collected at the station (201 of 434 total samples) exceeded 30 mg/L, and 12% (50 of 434 samples) were at least five times greater than the MPCA standard. Exceedances of the MPCA turbidity standard for Class 2B streams at station 99UM075 were also quite common, with 9% (40 of 434) samples exceeding 25 NTU (Figure 4.6). As shown in Figure 4.7, TSS concentrations at station 99UM075 were found to be highly correlated with turbidity measurements, suggesting that suspended solid loading is the primary cause of instream turbidity.

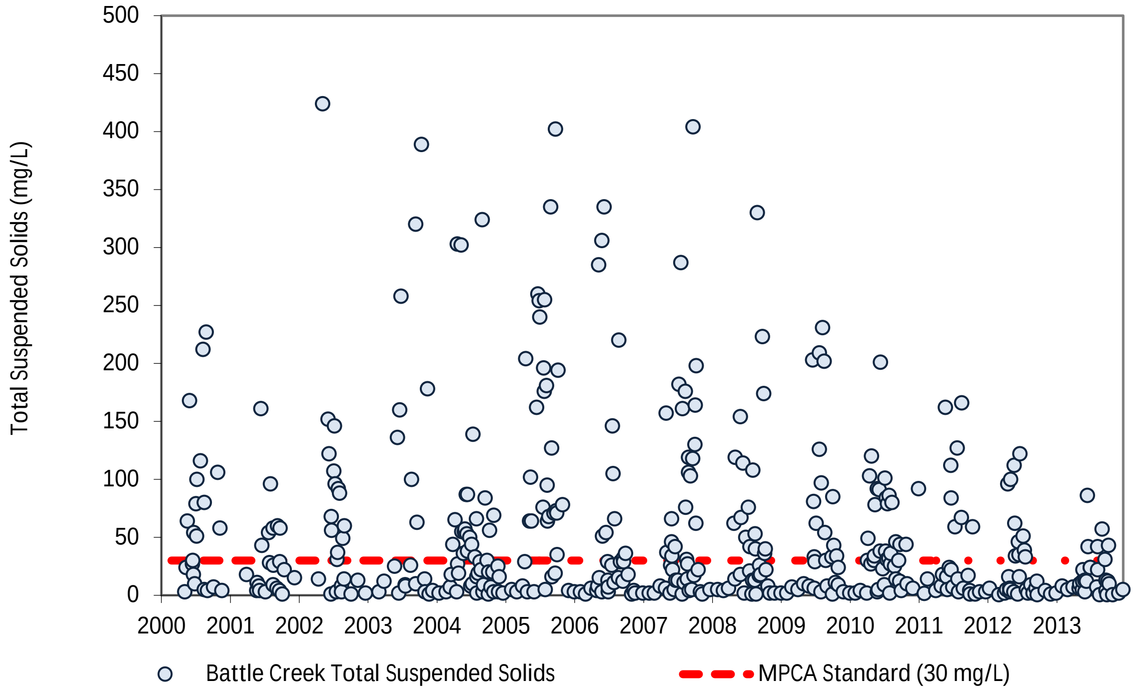


Figure 4.5 Total Suspended Solids at station 99UM075, 1996-2013.

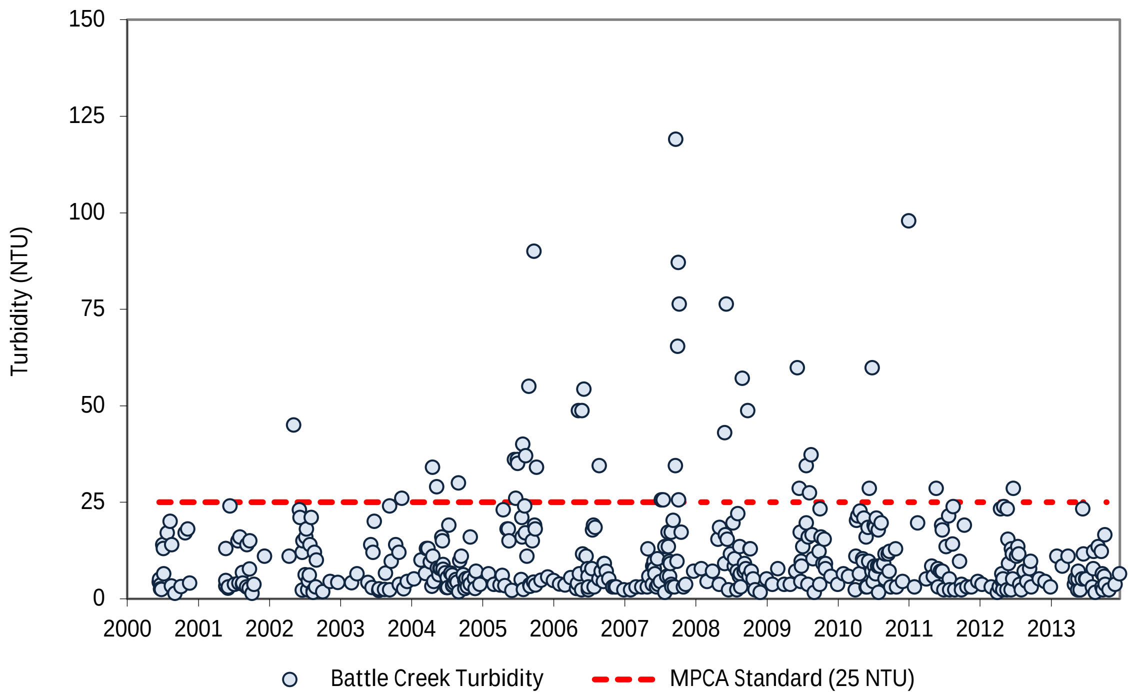


Figure 4.6 Turbidity at station 99UM075, 2000-2013.

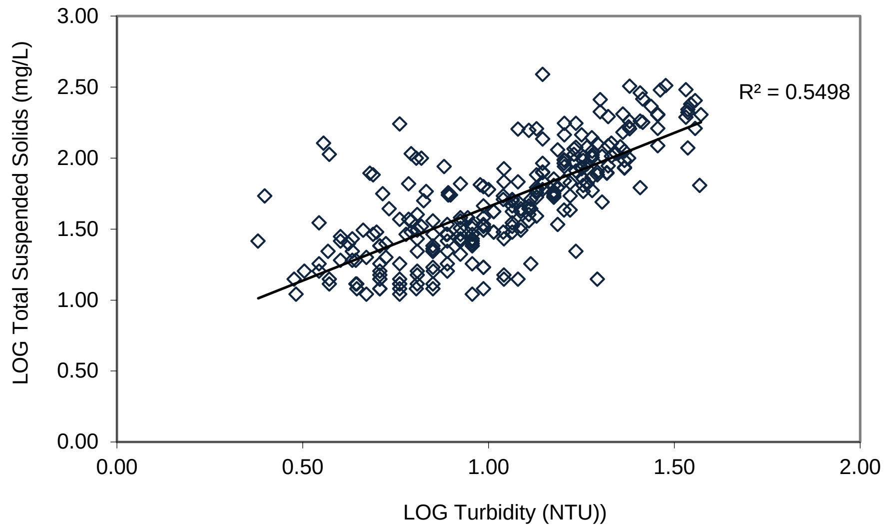


Figure 4.7 Relationship between suspended solids and turbidity at station 99UM075.

To determine if a relationship between flow rate and TSS concentration exists at station 99UM075, TSS measurements were correlated with flow in Table 4.3 and Figure 4.8. As shown in Figure 4.8, TSS concentrations are strongly correlated with stream flow, with high flows generating higher TSS concentrations on average, and lower flows producing lower TSS concentrations. Table 4.3 shows that a majority of samples taken at *high flow* and *moist conditions* exceeded the MPCA standard for TSS, while only 8% of samples taken at the *low flow* condition exceeded the standard. Only at *dry conditions* and *low flows* does the average TSS concentration in the stream drop below the MPCA standard.

Table 4.3 Total suspended solids and flow duration intervals at station 99UM075.

Flow condition	High Flows	Moist Conditions	Mid-range Flows	Dry Conditions	Low Flows
Flow duration interval	0-10%	10-40%	40-60%	60-90%	90-100%
Average TSS concentration (mg/L)	98	67	32	27	10
Percentage of samples exceeding MPCA TSS standard (30 mg TSS/L)	72%	49%	37%	24%	8%

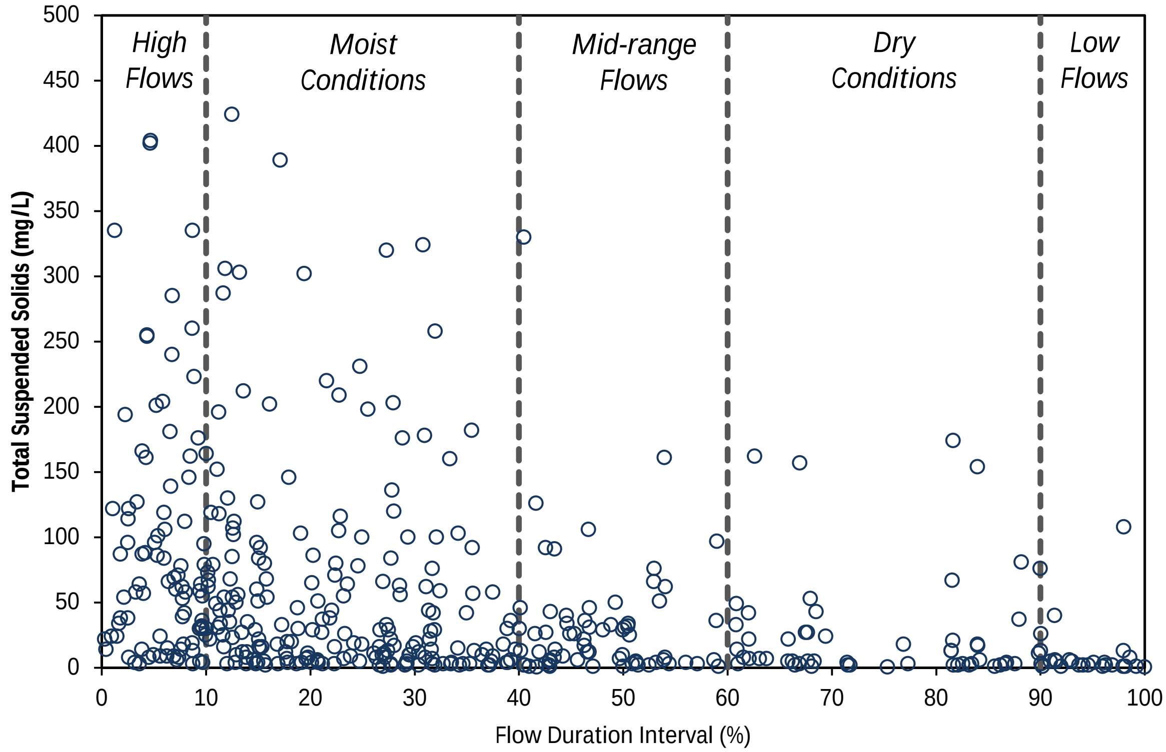


Figure 4.8 Total Suspended Solids water quality duration curve at station 99UM075.

In addition to being correlated to flow, Table 4.4 shows that TSS concentrations in Battle Creek are also seasonally dependent. As can be seen, the majority of standard exceedances occur in the late spring and early summer (the growing season). Elevated TSS concentrations during the growing season are typically caused by: (a) higher sediment delivery associated with higher stream flows; and (b) elevated primary production within the stream system.

Table 4.4 Seasonal variation in total suspended solids concentration at station 99UM075.

Month	TSS Sample Count	Average Percent Volatile Suspended Solids (VSS/TSS, %)	Percentage of samples exceeding MPCA TSS standard (30 mg TSS/L)
January	10	55%	0%
February	11	64%	0%
March	13	50%	8%
April	28	37%	36%
May	50	29%	54%
June	69	33%	59%
July	65	29%	65%
August	64	27%	58%
September	53	38%	43%
October	42	44%	40%
November	17	58%	12%
December	12	57%	8%

To help access the source of elevated TSS concentration within Battle Creek, Table 4.4 also shows the average percentage of TSS comprised of volatile suspended solids (VSS). VSS is the measure of solids within a sample that combust at 500°C. Because the majority of volatile solids within a sample are organic in nature, the percentage of the TSS which are volatile can serve as an estimate of how much of the sample is organic compared to inorganic. From Table 4.4, it can be seen that samples taken in months with higher percentage of samples exceeding the MPCA TSS standard typically have a lower average percent VSS. The inverse relationship between percent standard exceedance and average percent VSS points to the conclusion that, while increased primary production during the growing season likely does contribute to elevated TSS concentration, higher sediment delivery associated with greater precipitation and higher stream flow is the primary cause of TSS standard exceedances during the growing season.

Longitudinal surveys conducted during 2012 and 2013, shown in Table 4.5, found relatively low levels of TSS. Only 3 of 52 total samples exceeded the MPCA TSS standard (highlighted in red in Table 4.5). The greatest exceedance recorded at the outlet of Battle Creek Lake (140 mg/L) occurred during a low flow condition at station 99UM075. For this reason, it is likely that there was low outflow from Battle Creek Lake on this sampling date, and that the elevated TSS observed was caused by algae suspended in the outflow from Battle Creek Lake. From the 13 samples collected at 4 different sites over a 2-year period, it is difficult to identify any longitudinal trends in TSS concentration. From the more robust dataset collected at station 99UM075, it is clear that TSS concentrations exceeding the MPCA standard are common at downstream portions of the stream. More data will need to be collected to determine the extent to which this degraded condition propagates upstream.

Table 4.5 Summary of TSS measurements from 2012 and 2013 synoptic surveys.

Upstream → *Downstream*

		Total Suspended Solids (mg/L)			
Date	Flow Condition at WOMP Station	Meadow Lane (at the outlet from Battle Creek Lake)	97UM008	04UM011	99UM075
9/20/2012	Mid-Range Flows	ND	ND	ND	ND
9/26/2012	Mid-Range Flows	6.1	10.5	ND	ND
10/10/2012	Moist Conditions	6.8	9.4	11.4	ND
3/23/2013	Dry Conditions	7.5	12	7.5	7
3/28/2013	Mid-Range Flows	48	15	12	9
4/25/2013	High Flows	ND	5.5	14	12
5/29/2013	High Flows	1.5	4.5	5	4.5
6/27/2013	High Flows	2	3.5	14	14
7/25/2013	Dry Conditions	4	3.5	2	ND
8/15/2013	Dry Conditions	13	16	5	3.5
8/29/2013	Moist Conditions	26	36	9.5	8
9/24/2013	Low Flows	140	6	1.5	ND
10/22/2013	Mid-Range Flows	2.5	6.5	3	4.5

ND = not detectable (below laboratory detection limits).

4.2.2 Stressor Pathway

As shown in Figure 3.2, excess sediment is introduced to a stream system through watershed sources (i.e., stormwater runoff) and local channel erosion. Anthropogenic activities can increase watershed sources of sediment and accelerate channel erosion in a number of ways. Watershed development can increase direct sources of sediment from active constructions sites and large impervious surfaces such as roads and parking lots. Additionally, development within a watershed often decreases runoff detention and infiltration, leading to increased rates of sediment detachment and delivery to waterbodies. Decreased infiltration and detention also leads to higher total runoff volumes and higher peak runoff intensities, leading to increased potential for channel erosion and degradation.

High suspended sediment loadings to Battle Creek from watershed runoff can adversely affect biota by four main pathways: (1) impairment of filter feeding, by filter clogging or reduction of food quality; (2) reduction of light penetration and visibility in the stream, which may alter interactions between visually-cued predators and prey, as well as reduce photosynthesis and growth by submerged aquatic plants, phytoplankton, and periphyton; (3) physical abrasion by sediments, which may scour food sources (e.g., algae) or directly abrade exposed surfaces (e.g., gills) of fishes and invertebrates; and (4) increased heat absorption, leading to increased water temperatures (Cormier 2007).

4.2.3 Biological Response to Excess Suspended Sediment

As discussed in Section 4.2.2, suspended solids can impair biological communities in a number of ways. In order to assess whether elevated TSS concentrations are adversely affecting the biological assemblage within Battle Creek, sensitive species and biological metrics sensitive to elevated TSS concentrations were evaluated. This evaluation is referred to throughout as a biological metric analysis. Whereas the IBI rating is a measure of the general, non-specific stress within a river ecosystem, biological metric analysis can be used to determine if a specific stressor, such as elevated TSS or low DO, is impacting a sensitive subset of the ecosystem. A second method to evaluate biological response to stressors is based on the TIV, which is a measure of the sensitivity of an individual species or taxon to an environmental stressor (TSS, DO, chloride, etc.). Typically, TIVs are assigned by evaluating the relationship of the probability of occurrence of a given species or taxon to the magnitude of an environmental stressor. The magnitude of stress at which a species or taxon is most likely to be observed is defined as the TIV for that species or taxon, for that environmental stressor.

4.2.3.1 Biological Metric Analysis

In the MPCA's *Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids* (MPCA 2011), six fish metrics and three macroinvertebrate metrics were identified as having a statistically significant biological response to TSS concentrations in the *Central* River Nutrient Region of Minnesota (Table 4.6). These nine biological metrics were evaluated within Battle Creek and compared to state average values to help determine if elevated TSS concentrations are responsible for degrading the biological community.

From 1997 to the present, eight fish surveys and four macroinvertebrate surveys have been conducted on Battle Creek. Biological metric data from each of these surveys are compared to state average values in Table 4.7 and Table 4.8. Sample values highlighted in red are meant to indicate stress in relation to the average Minnesota station in the same stream class. If the expected response is that the biological metric *decreases* in response to stress, the value is highlighted in red if the sample is *lower* than the state average. Conversely, if the metric is expected to *increase* in response to stress, the value is highlighted if the sample is *higher* than the state average.

From the fish biological metric data shown in Table 4.7, it can be seen that no fish classified as intolerant or sensitive were observed in any of the eight completed surveys. Although both metrics were identified as having a statistically significant relationship to TSS concentration, their absence can indicate a more general ecological stress as both metrics are also related to other stressors, such as DO and phosphorus. A metric more uniquely associated with stress caused by elevated TSS concentrations is percent non-tolerant Percidae (Percfm-TolPct). Percidae are a family of perciforms consisting of species such as walleye, perch, and darters. Because these benthic carnivores are sight-feeders, reduced visibility caused by suspended solids can reduce hunting efficiency. Additionally, many of their benthic prey sources may also be negatively impacted by suspended solids and related sedimentation. The low relative abundance of Percidae across all stations and dates is strong evidence that elevated TSS concentration may be negatively impacting the biological community.

The macroinvertebrate biological metric data presented in Table 4.8 is less compelling than the fish metric data, as all three macroinvertebrate metrics identified as being statistically related to TSS concentrations are also related to other stressors, and are more indicative of general ecosystem stress. That being said, the low relative abundance of long lived species and the fact that no intolerant macroinvertebrates were observed does indicate that the macroinvertebrate community is under stress, potentially due to elevated TSS concentrations in the stream.

Table 4.6 TSS sensitive biological metrics, Central River Nutrient Region of Minnesota.

Group	**Metric** *(Metric Description)*	Response to TSS Stress	Description[1]
Fish	**CarnPct** *(Percent Carnivorous)*	Decrease	As adults, carnivorous fish species feed largely on fish, other vertebrates, and large invertebrates (e.g., crayfish). These species include many sport fish (e.g., bass, pike, walleye, and trout) (Barbour et al. 1999).
Fish	**Centr-TolPct** *(Percent non-tolerant Centrarchidae)*	Decrease	Fish species in the family Centrarchidae. These species are sight feeders which can be negatively impacted by increased turbidity. Species classified as tolerant are not included in this metric.
Fish	**IntolerantPct** *(Percent Intolerant)*	Decrease	Intolerant species are those that are known to be sensitive to environmental degradation. They are often the first species to disappear following a disturbance. Their presence in a stream is an indication of a high quality resource.
Fish	**LLvdPct** *(Percent Long Lived Species)*	Decrease	Long lived species typically have long life histories and as a result require more time to recover from disturbance.
Fish	**Percfm-TolPct** *(Percent non-tolerant Percidae)*	Decrease	Fish species in the family Percidae which includes walleye, perch, and darters. Species classified as tolerant are not included in this metric.
Fish	**SensitivePct** *(Percent Sensitive)*	Decrease	Sensitive species are susceptible to environmental degradation and often decline in abundance and richness following disturbance. They are not as susceptible as intolerant taxa but their presence in a stream is an indication of a high quality resource.
MI[2]	**IntolerantPct** *(Percent Intolerant)*	Decrease	Taxa with tolerance values less than or equal to 2 (Hilsenhoff 1987). Intolerant species are those that are known to be sensitive to environmental degradation and often decline in abundance and richness following disturbance. Their presence in a stream is an indication of a high quality resource.
MI[2]	**LongLivedPct** *(Percent Long Lived Species)*	Decrease	Long lived species typically have long life histories and as a result require more time to recover from disturbance.
MI[2]	**OdonataPct** *(Percent Odonata)*	Decrease	Odonata, or dragon and damselflies, are a diverse group of organisms that display a wide array of sensitivities and life histories. They exploit most aquatic microhabitats, and their diversity is considered a good indicator of aquatic health (Chirhart 2003 as cited by MPCA, 2011).

[1] Metric descriptions from the referenced MPCA technical document (MPCA, 2011)
[2] MI = Macroinvertebrate

Table 4.7 Battle Creek fish biological metric data related to TSS.

TSS Relevant Bio Metrics										
Station	Date	Fish Class	FIBI Threshold	FIBI	CarnPct	Centr-TolPct	IntolerantPct	LLvdPct	Percfm-TolPct	SensitivePct
97UM008	9/23/1997	3	51	21	3.1	1.5	0.0	0.0	1.5	0.0
	8/18/1998	3	51	16	11.0	0.0	0.0	0.0	0.0	0.0
	6/17/2010	3	51	33	1.3	0.7	0.0	1.3	1.3	0.0
	7/13/2010	3	51	28	2.3	0.0	0.0	0.0	0.0	0.0
	7/23/2012	3	51	6	18.2	4.5	0.0	13.6	4.5	0.0
99UM076	6/14/1999	3	51	42	4.4	2.2	0.0	2.2	4.4	0.0
99UM075	7/31/2012	3	51	39	92.3	7.7	0.0	11.0	7.7	0.0
Average: All Minnesota Stations, Fish Class = 3					27.2	1.0	1.1	4.9	8.3	3.9
00UM071	8/21/2000	2	45	30	0.3	4.6	0.0	5.0	4.6	0.0
Average: All Minnesota Stations, Fish Class = 2					21.2	2.3	1.4	10.5	12.1	7.0
Expected response with increased stress					D	D	D	D	D	D

Table 4.8 Battle Creek macroinvertebrate biological metric data related to TSS.

TSS Relevant Bio Metrics							
Station	Date	MI Class	MIBI Threshold	MIBI	IntolerantPct	LongLivedPct	OdonataPct
97UM008	8/23/2010	5	35.9	28	0.0	4.1	4.7
99UM075	8/13/2012	5	35.9	25	0.0	19.1	20.0
Average: All Minnesota Stations, Invert Class = 5					6.9	6.9	1.8
04UM011	9/2/2004	6	46.8	9	0.0	0.0	13.2
00UM071	9/11/2000	6	46.8	34	0.0	0.4	0.7
Average: All Minnesota Stations, Invert Class = 6					3.0	4.9	3.5
Expected response with increased stress					D	D	D

In addition to the three macroinvertebrate biological metrics that were identified being related to TSS concentrations in the *Central* nutrient region of Minnesota, several studies (Arruda et al. 1983; Lemley 1982) and Minnesota stressor ID reports (MPCA 2013b; MPCA 2014c) have noted that the relative abundance of collector-filters and collector-gathers is related to TSS stress. Specifically, as TSS concentrations rise, the relative abundance of collector-filters should fall, and the abundance of collector-gatherers should rise. As TSS concentration rise, antennae and physical nets used by filter feeders become clogged or otherwise impaired by sediment. The reduced feeding efficiency of filterers causes the relative abundance of both functional feeding groups to shift, as described above. As can be seen in Figure 4.9, the relative abundance of collector-gathers is greater than that of collector-filterers at all of the stations surveyed, with the exception of station 97UM008. Station 97UM008 is located just downstream of McKnight Basin, a wet pond located just east of McKnight Road North. It is likely that some of the sediment load within Battle Creek settles out as the stream passes through McKnight Basin, causing TSS concentrations at station 97UM008 to be, on average, lower than stations immediately upstream and downstream. Because sustained TSS monitoring efforts have occurred only at station 99UM075, a direct relationship between TSS concentrations and functional feeding groups cannot be made, however this still serves as compelling evidence that TSS concentrations may be impacting the macroinvertebrate community in the downstream sections of Battle Creek.

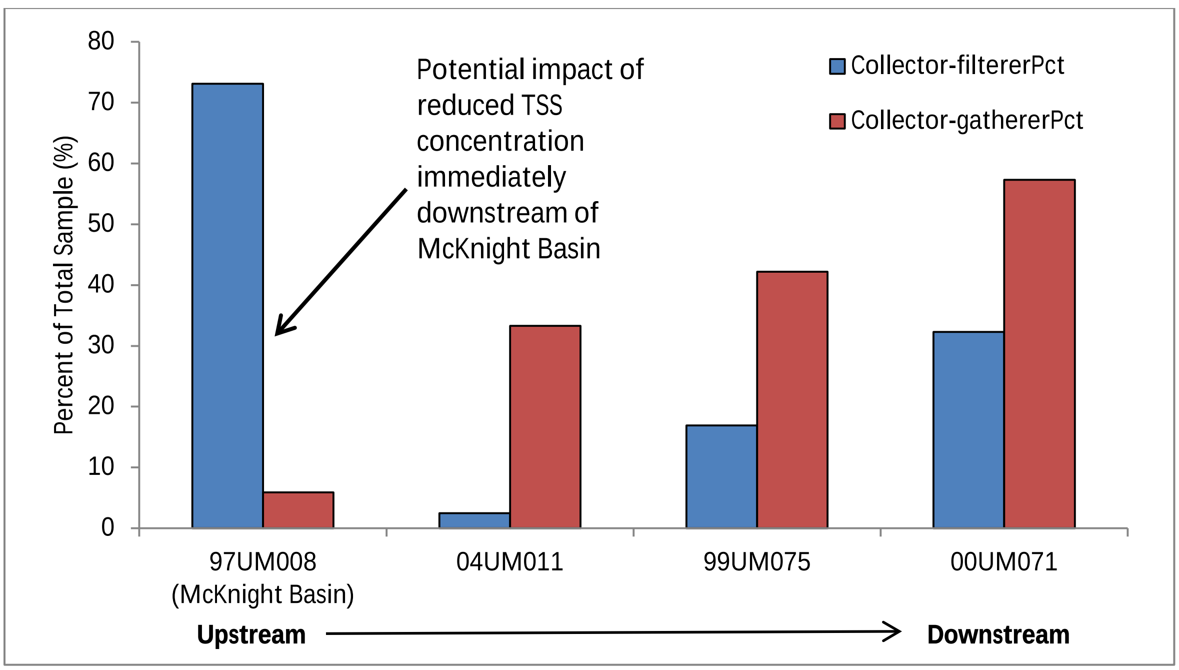


Figure 4.9 Relative abundance of functional feeding groups at Battle Creek monitoring stations.

Although the results of the biological metric analysis provides evidence that TSS may be a primary stressor to the biological community within Battle Creek, it is difficult to assess the magnitude of biological stress or spatial differences in biological stress from these results alone.

4.2.3.2 Tolerance Indicator Value Analysis

To help assess (a) the overall TSS tolerance of the fish and macroinvertebrate communities within Battle Creek; and (b) longitudinal and temporal changes in biological stress; a TIV analysis was performed using Minnesota based TIV.

In this analysis, the relative TSS tolerance of the assemblage of fish and macroinvertebrates observed in Battle Creek was compared to other streams within the Twin Cities 8-Digit Hydrologic Unit Code (Twin Cities HUC-8). All fish species and macroinvertebrate taxa observed during biological surveys within the Twin Cities HUC-8 were divided into four quartiles, with species and taxa groups falling within the forth quartile being more tolerant to TSS, and those in the first quartile being the least tolerant. Figure 4.10 shows the results of the quartile analysis performed on Twin Cities HUC-8 fish species. Species displayed in bold are those which have been observed in Battle Creek. The number in parentheses following each entry is the total number observed in the eight fish surveys performed on Battle Creek.

From the magnitude of counts shown in Figure 4.10, it can be seen that the majority of fish species observed fall into the second and third quartiles, with the two most common fish species (fathead minnow and emerald shiner) falling into the upper-most end of the third quartile. A figure similar to Figure 4.10 for macroinvertebrates is not presented, as there are over 200 unique macroinvertebrate taxa observed in the Twin Cities HUC-8. Instead, the quartile distribution the each of the macroinvertebrate and fish surveys is presented in Table 4.9, below.

1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
Common Name	TSS TIV	Common Name	TSS TIV	Common Name	TSS TIV	Common Name	TSS TIV
river darter	2.6	blackside darter	11.4	slenderhead darter	17.3	highfin carpsucker	31.8
burbot	5.3	**pumpkinseed (17)**	11.4	central stoneroller	17.7	**spotfin shiner (280)**	34.4
banded killifish	6.7	johnny darter	11.6	northern hogsucker	17.7	sand shiner	36.1
logperch	6.7	**bluegill (48)**	11.6	golden redhorse	18.3	blue sucker	36.8
longnose dace	7.1	**common shiner (2)**	12.0	bigmouth shiner	18.8	**common carp (8)**	42.5
mottled sculpin	7.7	**largemouth bass (7)**	12.1	channel shiner	18.9	quillback	43.4
smallmouth bass	7.7	fantail darter	12.2	shorthead redhorse	20.2	sauger	43.5
rock bass	7.7	**yellow bullhead (21)**	12.6	silver redhorse	20.2	gizzard shad	44.7
mimic shiner	8.3	northern pike	12.6	mooneye	21.2	bigmouth buffalo	45.7
blackchin shiner	8.9	tadpole madtom	13.2	**black bullhead (32)**	22.0	white bass	46.7
northern redbelly dace	9.9	brown bullhead	13.3	walleye	23.8	silver chub	46.8
yellow perch (3)	10.1	spottail shiner	13.8	trout-perch	23.9	smallmouth buffalo	48.2
blacknose dace	10.2	**golden shiner (7)**	14.0	stonecat	24.1	channel catfish	48.9
bowfin	10.3	**white sucker (105)**	14.2	**bluntnose minnow (2)**	24.5	orangespotted sunfish	49.6
hornyhead chub	10.4	hybrid sunfish	14.3	bullhead minnow	25.2	freshwater drum	50.9
blacknose shiner	10.8	Iowa darter	14.6	**green sunfish (72)**	25.9	flathead catfish	53.9
brook silverside	10.9	**black crappie (2)**	15.0	**fathead minnow (1146)**	27.8	river carpsucker	55.7
central mudminnow (117)	10.9	creek chub	16.0	**brassy minnow (1)**	28.0	white crappie	60.8
		brook stickleback (108)	16.6	**emerald shiner (661)**	30.7	black buffalo	66.8

Least Tolerant → **Most Tolerant**

* **Bold** entries indicate species which have been observed in Battle Creek. The number in parentheses after each entry is the total number of each species observed in the eight fish surveys preformed on Battle Creek.

Figure 4.10 Fish Species TSS TIV quartiles for the Twin Cities HUC-8.

Table 4.9 Battle Creek fish and macroinvertebrate TSS TIV quartiles.

FISH						
Station	Date	Twin Cities HUC-8 TSS TIV Quartiles				
		Q1	Q2	Q3	Q4	
12UM148*	7/23/2012	0%	100%	0%	0%	
97UM008	9/23/1997	8%	5%	87%	0%	*Upstream*
	8/18/1998	12%	20%	68%	0%	
	6/17/2010	3%	66%	31%	1%	
	7/13/2010	7%	52%	41%	0%	
	7/23/2012	36%	32%	23%	9%	
99UM076	6/14/1999	4%	60%	36%	0%	
99UM075	6/14/1999	2%	16%	81%	1%	
	7/31/2012	1%	22%	74%	3%	
00UM071	8/2/2000	0%	2%	68%	31%	*Downstream*
MACROINVERTEBRATES						
Station	Date	Twin Cities HUC-8 TSS TIV Quartiles				
		Q1	Q2	Q3	Q4	
97UM008	8/23/2010	0%	23%	34%	43%	*Upstream*
04UM011	9/2/2004	4%	33%	58%	5%	
99UM075	8/13/2012	5%	59%	25%	12%	
00UM071	9/11/2000	1%	51%	34%	13%	*Downstream*

* The station 12UM148, 7/23/2012 survey consisted of two (2) fish.

As can be seen in Table 4.9, the macroinvertebrate and fish communities in Battle Creek consistently skew towards the more tolerant quartiles of the Twin Cities HUC-8. It should also be noted that the quartile distribution of fish and macroinvertebrates are fairly similar, both skewing towards the second and third quartiles. When performing a TIV analysis on a non-primary stressor (i.e., a stressor that is not impacting the biological community), inconsistent results between populations (e.g., fish skew towards the forth quartile while macroinvertebrates skew towards the first) and between quartiles (e.g., large percentage in the first and forth quartiles, small percentage in the second and third) are more common. The consistency exhibited both between quartiles and between populations is good evidence that TSS concentrations are impacting the biological assemblage within Battle Creek.

The underrepresentation of quartile one (Q1) fish and macroinvertebrate species across all stations indicates that the consistent and sustained TSS stress observed at station 99UM075 may propagate further upstream. From Table 4.9, it can be seen that Q1 fish species are most abundant at station 97UM008. As previously mentioned, station 97UM008 is located immediately downstream of McKnight Basin, and for this reason may experience lower average TSS concentrations compared to stations located immediately upstream and downstream. This hypothesis is supported by the macroinvertebrate functional feeding groups observed at station 97UM008 compared to downstream stations, discussed previously (see Figure 4.9). When taken together, these findings support the conclusion that longitudinal differences in TSS stress occur along Battle Creek, and that gradient responses of the biological community to TSS stress are possible.

Another possible trend from Table 4.9 is that the quartile distribution for fish at station 97UM008 seems to be shifting towards more TSS sensitive quartiles over time. However, from monitoring data at station 99UM075 (downstream of station 99UM008), TSS concentrations appear very stable over the modern period of record (2000-2013), so it is unlikely that station 97UM008 could be shifting to a less-impaired state over the same period of time. In Figure 4.11, the quartile distributions observed at station 97UM008 are compared to TSS concentrations observed at station 99UM075 (note that this is only possible for the three dates shown, as TSS was not measured at station 99UM075 before 2000).

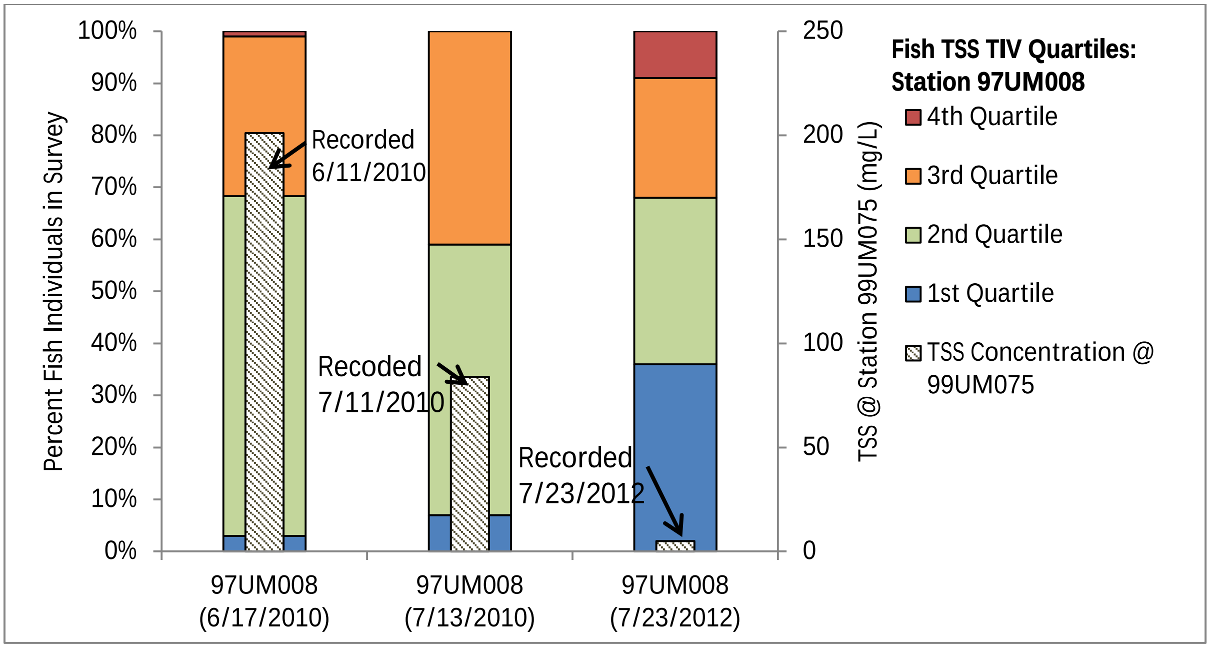


Figure 4.11 Comparison of fish TSS TIV quartiles to measured TSS concentrations.

As can be seen, the quartile distributions observed at station 97UM008 appear to correspond as expected to TSS concentrations observed at the downstream station 99UM075, with Q1 increasing proportionally to decreases in TSS concentration. This analysis may be impacted by differences in record dates and station, but assuming that TSS concentrations at station 97UM008 are proportional to concentrations observed at station 99UM075, this may serve as evidence of TSS stress and biological response co-occurrence.

4.2.4 Strength of Evidence

Table 4.10 presents the SOE scores for excess sediment as a candidate cause. Water quality measurements indicate that TSS and turbidity routinely exceed MPCA standards. Biological metric and TIV analysis indicate a clear response to this stress, with both the fish and macroinvertebrate communities being dominated by species and taxa highly tolerant to stress related to suspended sediment. Based on the analysis presented above and related SOE scoring, excess sediment has been identified as a primary stressor to the biological community within Battle Creek. For more information of SOE scoring, see Appendix A.

Table 4.10 **Strength of Evidence for excess sediment.**

Types of Evidence	**Candidate Cause:** Excess Sediment
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	+ +
Causal Pathway	+
Evidence of Exposure or Biological Mechanism	+
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	+
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	+
Stressor-Response Relationships from Other Field Studies	+ +
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	NE
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	+
Explanation of the Evidence	+ +

4.3 Candidate Cause #2: Specific Conductance and Chloride

4.3.1 Overview of Specific Conductance and Chloride in Battle Creek.

According to the MPCA's draft 2014 Impaired Waters List, Battle Creek was first listed as impaired for Chloride in 2008. Specific conductance and chloride monitoring of Battle Creek began in 1977. The historic dataset of specific conductance and chloride concentrations consists of growing season grab sample taken at two stations (97UM008 and 99UM075) each year from 1977 to 1990. The modern dataset consists of event-based monitoring at the Battle Creek WOMP station (station 99UM075, 2000-2013) and two synoptic surveys performed in 2012 and 2013. As discussed in Section 3.3.2, specific conductance is highly correlated with chloride concentration in Battle Creek (see Figure 3.3). Exceedances of MPCA standards for specific conductance and chloride concentration are outlined in Table 4.11.

Table 4.11 **Specific conductance and chloride MPCA standard exceedance summary.**

	Specific Conductance		Chloride	
	Historic Dataset (1977-1997)	Modern Dataset (2000-2013)	Historic Dataset (1977-1990)	Modern Dataset (2000-2013)
Number of Measurements	102	107	145	454
Number of Samples Exceeding MPCA Standard[1]	0	38	0	63
Percent of Samples Exceeding Standard (%)	0%	36%	0%	14%

[1] Number of samples exceeding the MPCA standard for chloride concentration (≥230 mg/L) or specific conductance (≥ 1000 µmhos/cm @258 C).

As can be seen in Table 4.11, no exceedances of specific conductance or chloride standards were recorded in the historic dataset, while exceedances in the modern dataset are common. Although this data suggests that specific conductance and chloride concentrations are increasing over the period of record, there could be several explanations for this trend including difference in data collection protocol, weather patterns, changes in development, and changes in winter maintenance practices.

Table 4.12 shows the average monthly specific conductance and chloride concentrations recorded over the historic and modern datasets. As can be seen, concentrations are much higher over the winter months. This trend is very likely caused by the use of chloride containing deicers. Because measurements in the historic dataset were typically recorded during growing season (June through September), elevated winter concentrations (including potential standard-exceedances) was not recorded. However, from the results shown in Table 4.12, it appears that growing season specific conductance and chloride concentrations have increased significantly. Figure 4.12 shows the growing season specific conductance and chloride concentrations for each year data was recorded at station 99UM075. As can be seen, both specific conductance and chloride concentration increase steadily over the period of record, and the upward trajectory extends through the modern dataset. It should be noted that average growing season chloride concentrations remain below the CS throughout the period of record, and that CS exceedances are uncommon during the growing season.

Table 4.12 Monthly average specific conductance and chloride concentrations at station 99UM075.

	Monthly Average Specific Conductance (µmhos/cm @258 C)	
Month	Historic Dataset (1977-1990)	Modern Dataset (2000-2013)
Jan	--	--
Feb	--	--
Mar	--	1965
Apr	--	957
May	496	984
June	467	714
July	460	738
Aug	411	991
Sept	469	719
Oct	535	815
Nov	--	--
Dec	--	--

	Monthly Average Chloride Concentration (mg/L)	
Month	Historic Dataset (1977-1990)	Modern Dataset (2000-2013)
Jan	--	855
Feb	--	763
Mar	--	250
Apr	--	180
May	57	153
June	51	120
July	53	107
Aug	45	106
Sept	44	117
Oct	42	109
Nov	--	198
Dec	78	563

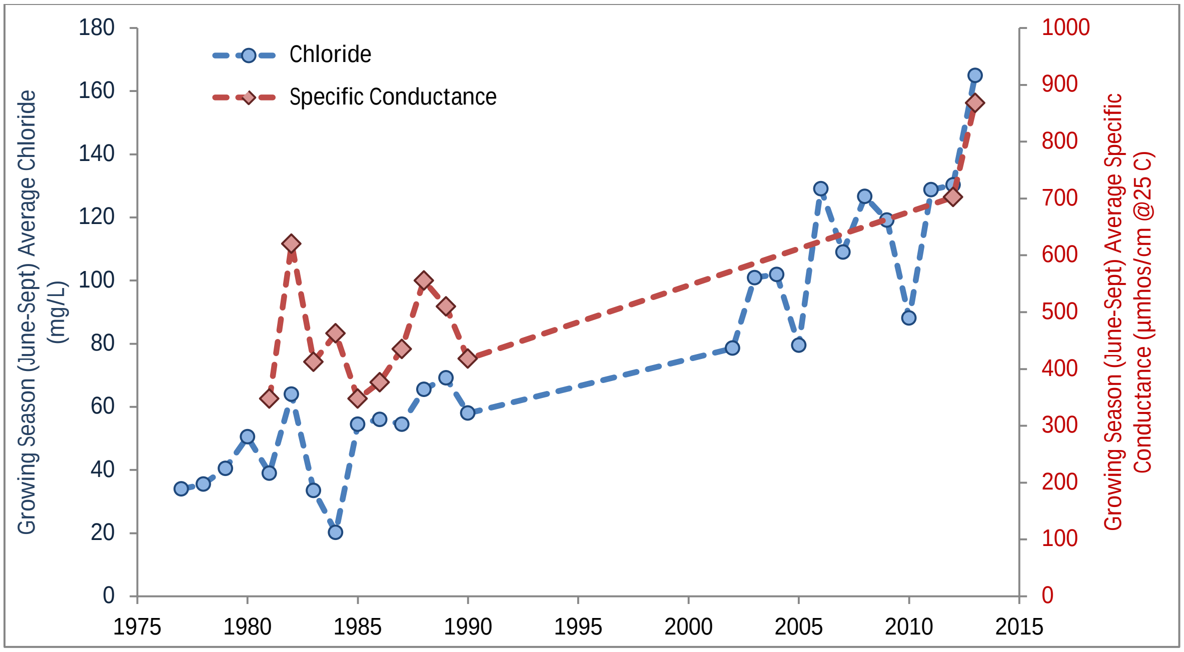


Figure 4.12 Average growing season specific conductance and chloride concentration at station 99UM075.

4.3.2 Stressor Pathway

A conceptual model of sources and causal pathways for ionic strength and chloride impairment in Battle Creek is shown in Figure 3.4. As can be seen, although natural sources of ions (e.g., soil deposition) impart a background concentration of chloride concentration and specific conductance to a stream, impairment is associated with anthropogenic sources of ions. As discussed in Section 3.3.2.3, deicers used on impervious surfaces within a watershed are primary source of chloride concentration and specific conductance impairment of streams in the Midwest.

Elevated ionic strength or large fluctuations in ionic strength over relatively short periods may affect freshwater biota via several modes of action including osmotic stress, increased competition for gill binding sites, and increased ion exchange (Ziegler et al. 2007). The exact mechanism by which elevated chloride concentrations affect stream biota is not well understood, but it is likely related to osmotic and ionic regulation (http://www.epa.gov/caddis/ssr_ion4s.html).

Documented biological responses to ionic strength-related proximate stressors include increased abundance of certain ion-tolerant taxa (including amphipods, decapods, and isopods) and decreased abundance of certain ion-sensitive taxa such as mayflies and soft-bodied organisms. However biological responses frequently are site- and species-specific and do not apply to all situations (Ziegler et al. 2007).

Common mechanisms by which changes in ionic composition may adversely impact biota include increased concentration of toxic ions or changes in the toxicity of specific ions. These compositional changes have been associated with decreased bioavailability of essential elements (e.g., magnesium) and with changes in biotic assemblages (Ziegler et al. 2007).

4.3.3 Biological Response to Specific Conductance and Chloride

Sustained osmotic stress caused by high specific conductance and chloride concentrations can have a degrading effect on biological communities. In order to determine if specific conductance and chloride concentrations within Battle Creek are negatively impacting the biological community, species and biological metrics sensitive to ionic strength and chloride concentration were evaluated (MPCA 2010; MPCA 2014d; Piscart et al. 2005; Echols et al. 2009). Among these sources, the most commonly cited biological responses to stress related to ionic strength are a reduction in the mayfly population (Ephemeroptera), and an overall reduction in the taxa diversity of the macroinvertebrate community. No biological metrics related to the fish community were found to be uniquely related to or predictive of chloride concentration or specific conductance. A biological metric analysis comparing Ephemeroptera and macroinvertebrate taxa count observed in Battle Creek surveys to state average values is shown below in Table 4.13.

Table 4.13 Battle Creek macroinvertebrate biological metric data related to ionic strength.

Ionic Strength Relevant Bio Metrics					Ephemeroptera	EphemeropteraPct	TaxaCount
Station	Date	MI Class	MIBI Threshold	MIBI			
97UM008	8/23/2010	5	35.9	28	2.0	0.6	17.0
99UM075	8/13/2012	5	35.9	25	1.0	14.5	16.0
Average: All Minnesota Stations, Invert Class = 5					3.9	19.9	23.8
04UM011	9/2/2004	6	46.8	9	0.0	0.0	19.0
00UM071	9/11/2000	6	46.8	34	0.0	0.0	17.0
Average: All Minnesota Stations, Invert Class = 6					2.6	12.2	21.5
Expected response with increased stress					D	D	D

As can be seen, Ephemeroptera taxa counts and overall macroinvertebrate taxa diversity are low when compared to other macroinvertebrate Class 5 and Class 6 streams throughout Minnesota. All four of the macroinvertebrate surveys shown in Table 4.13 were collected in August and September, when specific conductance and chloride concentrations are typically at their seasonal lowest. The fact that the biological metrics analyzed are lower than state average values even during the late summer may indicate that baseline concentrations of specific conductance and chloride may be reaching concentrations sufficient to degrade the macroinvertebrate community year-round.

Because Ephemeroptera have been shown to be sensitive to many stressors, such as TSS (MPCA 2014c) and metals (Kaputska et al. 2004), below-average taxa count and relative abundance cannot not be exclusively related specific conductance and chloride. However, because specific conductance and chloride concentrations have *increased* over the period of record, while other related candidate causes have remained fairly unchanged, changes in the Ephemeroptera population over time may be more uniquely associated with specific conductance and chloride than other potentially related candidate causes.

To see if rising specific conductance and chloride concentrations have had an impact on the macroinvertebrate community, the total and relative abundance of Ephemeroptera recorded in 24 historic biological surveys performed on Battle Creek (1978 to 1988) was compared to the four surveys completed from 2000 to 2012 (Figure 4.13). As can be seen, there appears to be a decrease in the total count and relative abundance of Ephemeroptera over the period of record. Ephemeroptera are relatively sensitive to stress, and as an order are used as indicators of many contaminants and stressors. The *decreasing* trend in the total count and relative abundance of Ephemeroptera observed in Battle Creek, however, can be more confidently associated with ionic strength, as specific conductance and chloride concentration are the only stressors identified as candidate causes that are clearly *increasing* in magnitude. All other stressors evaluated exhibit little to no change in magnitude over the period of record, and thus could not explain this apparent shift in the macroinvertebrate community. The apparent trend in the Ephemeroptera population, however, cannot be cited as definitive evidence that chloride concentrations are impacting macroinvertebrate community as (a) the modern dataset is fairly small (only four data points); and (b) low Ephemeroptera total counts and relative abundance have occurred in the historic dataset. That being said, the apparent trend in the Ephemeroptera population raises concern that increasing specific conductance and chloride concentrations may be impacting the macroinvertebrate community.

There is limited available data linking shifts in the biotic assemblage of fish to chloride concentration and/or specific conductance. Helms et al. (2009) found that sunfish are tolerant of high concentrations of total dissolved solid, but because individual fish species counts were only available for the modern dataset (1997 through 2013), historic trends in the Battle Creek sunfish population could not be evaluated.

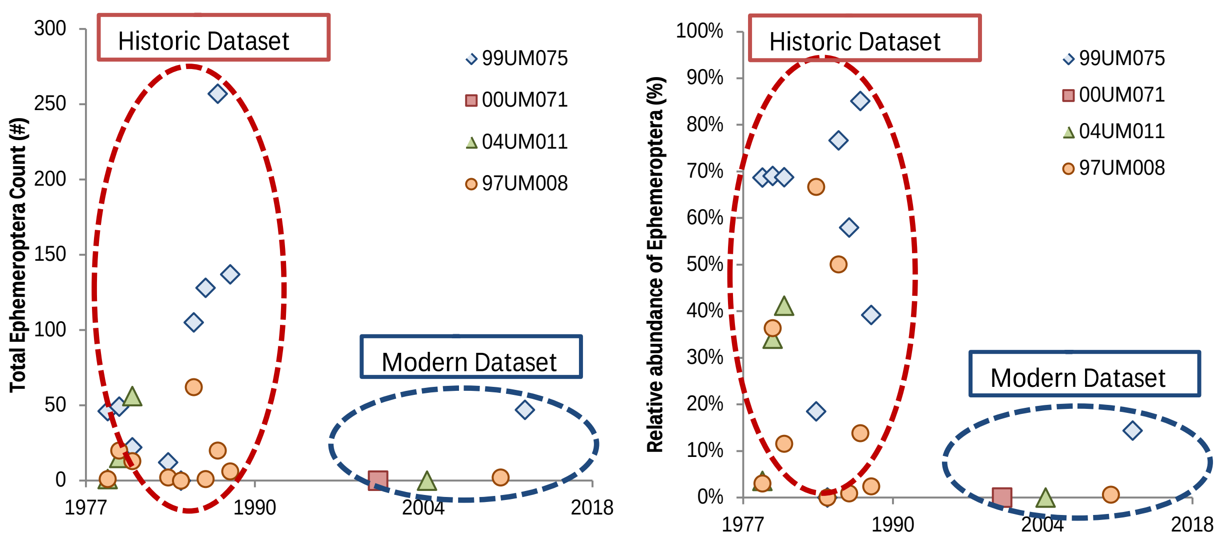


Figure 4.13 Relative abundance and total count of Ephemeroptera in Battle Creek biological surveys.

4.3.4 Strength of Evidence

Table 4.14 presents the SOE scores for specific conductance and chloride. Specific conductance and chloride concentrations have steadily increased over the period of record, to the point where exceedances of MPCA standards for both contaminants are now commonplace. Historic analysis shows that the macroinvertebrate community appears to be responding to increased stress, experiencing an apparent decrease in the relative abundance of mayfly (Ephemeroptera) species. Although the impact of ionic strength on biological communities can be difficult to assess due to interactions with proximate stressors, specific conductance and chloride has been identified as a potential primary stressors due to the apparent response of the macroinvertebrate community to the observed increases in specific conductance and chloride concentrations. For more information of SOE scoring, see Appendix A.

Table 4.14 Strength of Evidence for specific conductance and chloride.

Types of Evidence	**Candidate Cause:** Specific Conductance and Chloride
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	+
Stressor-Response Relationship from the Field	+
Causal Pathway	NE
Evidence of Exposure or Biological Mechanism	+
Manipulation of Exposure	**+ + +**
Laboratory Tests of Site Media	NE
Verified Predictions	+
Symptoms	+
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	NE
Stressor-Response Relationships from Other Field Studies	**+ +**
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	NE
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	+
Explanation of the Evidence	**+ +**

4.4 Candidate Cause #3: Dissolved Oxygen and BOD

4.4.1 Overview of Dissolved Oxygen in Battle Creek

DO concentrations in Battle Creek have not been extensively monitored. The modern (post-2000) DO data set consists of two synoptic surveys, one performed in 2012 and one performed in 2013, and 12 days of continuous DO monitoring completed by the MPCA in the late summer of 2012 (July 19, 2012 through July 31, 2012). Results from the synoptic surveys are shown below in Table 4.15. Values lower than the MPCA DO standard (≤ 5 mg DO/L) are highlighted in red. Stations are organized from most upstream to most downstream.

Although data from the synoptic surveys is limited, consisting of only 108 total measurements, it can be seen that exceedances of the MPCA DO standard are common (18 total exceedances, 17%). Of all early morning measurements (taken before 9:00 am), 25% were below the standard (10 of 40 early morning measurements). Diel DO flux recorded at each of the stations routinely met the MPCA standard of less than or equal to 3.5 mg DO/L, with the exception of the Meadow Lane measurements collected on August 15, 2013.

A trend that is common between both synoptic surveys is that DO concentrations are often lowest at the outlet of upstream waterbodies. The majority of below-standard measurements occur at the Meadow Lane monitoring site (downstream of Battle Creek Lake) and station 97UM008 (downstream of McKnight Basin). This apparent trend may be attributed to: (a) low dissolved-oxygen content in outflows from upstream waterbodies caused by eutrophication; or (b) attenuation in stream flow caused by upstream waterbodies. All samples collected during the 2012 synoptic survey occurred during mid-range to moist flow conditions at station 99UM075, making it less likely that low DO concentrations at station 97UM008 during this survey were due to low outflow from McKnight Basin. Data from MPCA water quality monitoring at Battle Creek Lake station 82-0091-00-201 shows that below 5 mg DO/L measurements are relatively common during the growing season, although no below-standard measurements were observed during the growing season of 2012.

Without flow monitoring data upstream of station 99UM075 and with limited DO data from upstream stations and detention areas, the cause of low DO concentrations immediately downstream of detention areas cannot be determined. For this reason, expanded flow and DO monitoring is recommended (see Section 5.2).

Table 4.15 2012 and 2013 Battle Creek DO synoptic surveys.

Most Upstream → **Most Downstream**

			Dissolved Oxygen (mg/L)							
Date	**Pre-9 AM?**	**Flow Condition at 99UM075**	Meadow Lane (at the outlet from Battle Creek Lake)	12UM148	Crestview Drive (upstream of McKnight Basin)	97UM008 (downstream of McKnight Basin)	99UM076	04UM011	Upstream of Highway 61	99UM075 (WOMP Station)
2012 Synoptic Survey										
9/20/2012	Yes	Mid-range Flows	7.4	4.9	6.8	3.7	8.1	8.0	8.7	8.7
9/20/2012	No	Mid-range Flows	8.1	6.3	8.3	4.2	9.3	12.0	9.0	9.1
9/26/2012	Yes	Mid-range Flows	4.9	6.2	7.6	4.8	9.0	9.2	10.0	9.3
9/26/2012	No	Mid-range Flows	6.4	6.4	9.0	4.5	9.9	13.0	9.6	9.2
10/10/2012	Yes	Moist Conditions	1.7	2.1	3.7	11.4	9.0	9.8	10.8	8.6
10/10/2012	No	Moist Conditions	4.1	5.0	12.9	11.2	11.1	12.4	11.2	11.3
10/25/2012	Yes	Mid-range Flows	1.3	11.1	11.6	9.6	9.8	11.0	10.9	11.6
2013 Synoptic Survey										
3/23/2013	No	Dry Conditions	1.6			12.4		14.4		14.1
3/28/2013	No	Mid-range Flows	0.7			12.1		14.2		13.9
4/25/2013	No	High Flows	11.7			13.9		13.7		13.2
5/29/2013	No	High Flows	12.0			10.0		10.3		10.2
6/27/2013	No	High Flows	10.4			8.0		8.6		8.3
7/25/2013	No	Dry Conditions	7.5			7.2		9.1		9.0
8/15/2013	Yes	Dry Conditions	3.5	8.8	8.5	7.2	9.1	9.3	9.4	9.3
8/15/2013	No	Dry Conditions	11.3	8.9	10.8	7.6	9.2	10.5	10.4	9.9
8/29/2013	No	Moist Conditions	1.8			5.2		6.5		6.2
9/24/2013	No	Low Flows	2.7			0.4		8.9		9.4
10/22/2013	No	Mid-range Flows	12.2			11.2		12.7		12.7

The results of the July 2012 continuous DO monitoring conducted at station 97UM008 (immediately downstream of McKnight Basin) are shown in Figure 4.14. In addition to DO values, flow monitored downstream at station 99UM075 is shown on the secondary axis.

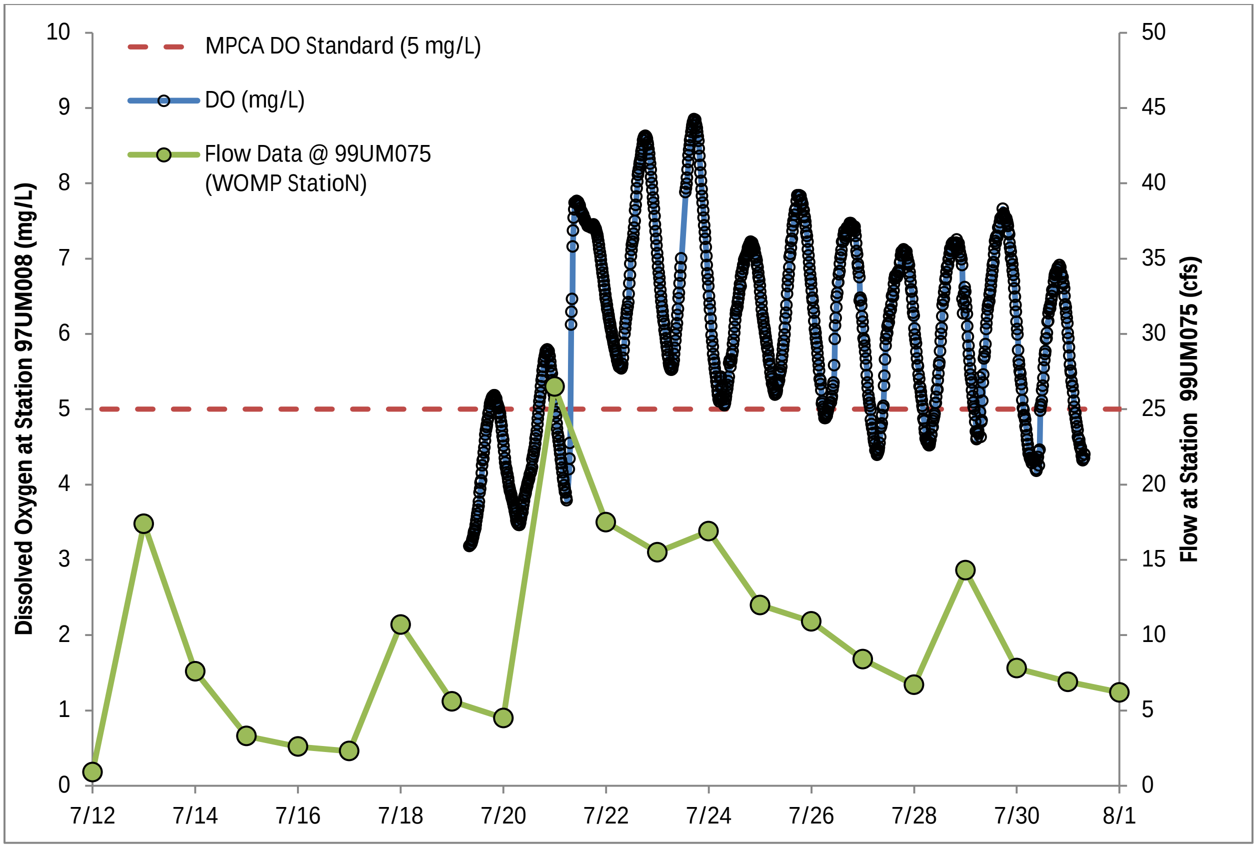


Figure 4.14 Continuous DO monitoring at station 97UM008.

As can be seen, DO concentration drops below the MPCA standard many times over the 12-day monitoring period. In addition, the diel DO flux exceeded the MPCA standard of 3.5 mg DO/L on a few occasions. Perhaps most concerning is the period from the 7/19 to 7/21, in which DO concentrations only rose above the MPCA standard during the peak of the diurnal swing. When compared to the flow rate monitored downstream at station 99UM075, it appears that the increase in DO concentrations observed on 7/21 coincides with an increase in total stream flow. This is potential evidence that DO concentrations, particularly downstream of detention areas (e.g., McKnight Basin), may be impacted by stream flow. It is possible that McKnight Basin had little or no discharge in the period from 7/19 to 7/21, leading to the low DO concentrations at station 97UM008 observed during this period.

Evidence from the synoptic surveys and continuous DO monitoring suggests that Battle Creek is potentially impaired for DO, particularly at downstream stations. Battle Creek is currently not listed for DO impairment, as a formal assessment has not yet been conducted.

4.4.2 Overview of BOD in Battle Creek

BOD recorded at station 99UM075 from the period of 2000-2012 routinely exceeded the MPCA standard of 2 mg BOD/L (52 of 145 total measurements, 36%). Although the summer (June through September) average concentration of the entire BOD dataset is below the MPCA standard (1.6 mg BOD/L), exceedances are quite common especially during the spring months (see Table 4.16).

The Flow duration analysis of BOD concentrations at 99UM075 (Figure 4.15) show that exceedances are most common during high flows, but are not as related to flow regime as other stressors (e.g., TSS). Seasonal analysis shows that exceedances are most common during late winter and early spring (Table 4.16). This trend is likely explained by mobilization of accumulated biomass during spring runoff events.

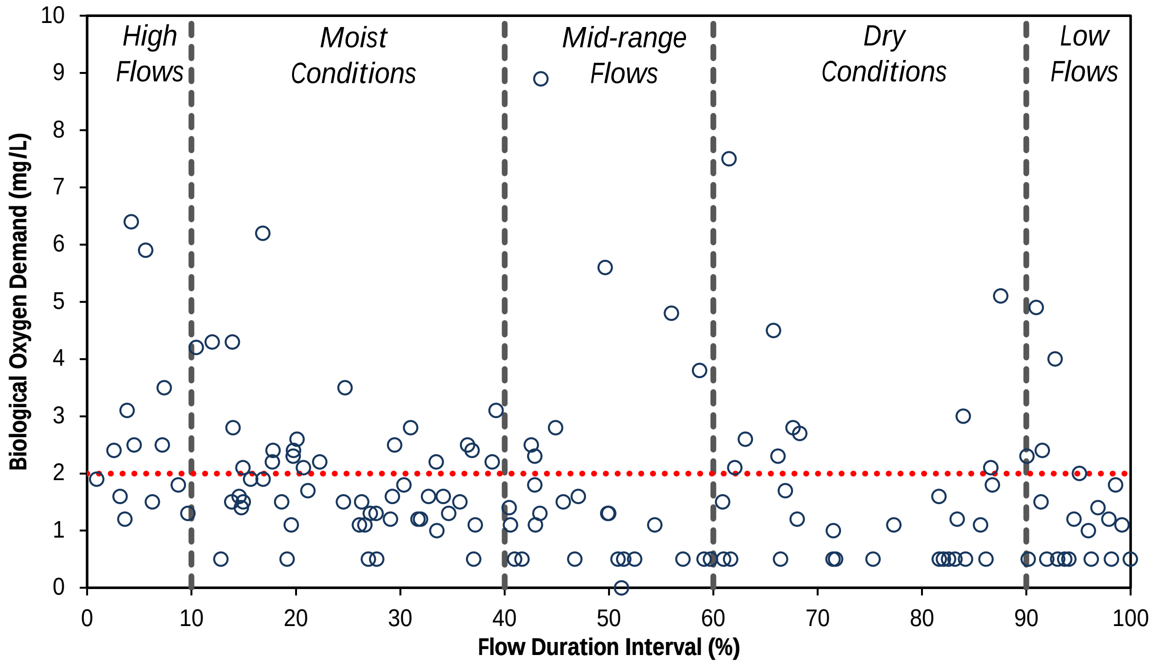


Figure 4.15 Biological oxygen demand water quality duration curve at station 99UM075.

Unfortunately, there is little ability to draw correlation between DO concentrations and BOD, as BOD has only been recorded at station 99UM075. Only four points from the DO synoptic survey correlate with same-day BOD measurements at this station. There is no clear relationship between BOD and DO in this small dataset, though this may be explained by inconsistent sampling time between the four matching DO measurements (three were collected in post-9 AM, one pre-9 AM). From the DO synoptic survey results (Table 4.15), the seasonal trend observed in BOD concentrations is not reflected in the seasonal DO concentrations recorded at station 99UM075. In fact, DO concentrations appear to be their seasonal *highest* in the early spring, when BOD standard exceedances are most common. This trend in DO concentrations is likely explained by increased DO solubility at cooler temperatures, and helps illustrate the fact that many factors other than BOD can impact DO concentration. Referring to Table 4.16, it can be seen that average monthly BOD concentrations may still be elevated during summer months, but are generally lowest when DO concentrations are at their lowest. For this reason, it can be assumed that elevated BOD concentrations could contribute to DO impairment in Battle Creek, but lower DO levels are likely coinciding with higher water temperatures and increased sediment oxygen demand.

Table 4.16 Seasonal variation in biological oxygen demand at station 99UM075.

Month	BOD Sample Count	Percentage of samples exceeding MPCA BOD standard (2.0 mg/L)	Monthly Average BOD Concentration (mg/L)
January	10	30%	2.0
February	11	45%	2.2
March	12	75%	3.3
April	11	73%	2.5
May	13	62%	4.1
June	14	29%	2.0
July	11	18%	1.5
August	14	29%	1.7
September	12	17%	1.4
October	12	33%	2.0
November	13	8%	1.0
December	12	17%	2.0

4.4.3 Stressor Pathway

As shown in Figure 3.5, DO concentrations in a stream are impacted by a range of anthropogenic factors, seasonal and climactic conditions, in-stream primary production, watershed hydrology and hydraulic features, and stream morphology. Changes in agricultural and urban land use, hydraulic impoundments (such as dams and in-stream detention) and point source discharges high in BOD are examples of anthropogenic factors which most commonly negatively impact DO concentrations in steams.

If DO concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan 1995). Some macroinvertebrates that are intolerant to low levels of DO include mayflies, stoneflies, and caddisflies (Marcy, 2007). Many species of fish avoid areas where DO concentrations are below 5 mg/L (Raleigh et al. 1986). Additionally, fish growth rates can be significantly affected by low DO levels (Doudoroff, P., and Warren 1965).

4.4.4 Biological Response to Low Dissolved Oxygen

4.4.4.1 Biological Metric Analysis

Sufficient and relatively stable DO concentrations are required for aerobic aquatic life to thrive. In order to determine if DO concentrations within Battle Creek are negatively impacting the aerobic biological community, species and biological metrics sensitive to DO concentration were evaluated. In the MPCA's *Minnesota Nutrient Criteria Development for Rivers* (MPCA 2013a), four fish metrics and three macroinvertebrate metrics were identified as having a statistically significant biological response to either DO flux or BOD concentrations based on statewide analysis as well as analysis limited to the *Central* River Nutrient Region of Minnesota. In addition to these seven biological metrics, several metrics related to low DO stress noted by other Minnesota stressor ID reports (MPCA 2013c; MPCA 2014c) were also included in this analysis. All metrics analyzed are described in Table 4.17, and the results of the fish and macroinvertebrate biological metric analysis are shown in Table 4.18 and Table 4.19, respectively.

Table 4.17 DO sensitive biological metrics.

Group	Metric	Response to DO Stress	Description
Fish	**SensitivePct**	Decrease	Percent of total count identified as sensitive.
Fish	**NumPerMeter**	Decrease	Number of fish per meter
Fish	**MA>3Pct**	Decrease	Percent of late maturing fish
Fish	**TolPct**	Increase	Percent of total count identified as tolerant.
Fish	**IntolerantPct**	Decrease	Percent of total count identified as intolerant.
Fish	**SLithopPct**	Decrease	Percent of total count identified as simple lithophils.
Macroinvertebrate	**EPT**	Decrease	Number of EPT taxa identified
Macroinvertebrate	**TaxaCountAllChir**	Decrease	Total taxa richness of macroinvertebrates.
Macroinvertebrate	**Collector-Gatherer**	Decrease	Taxa richness of collector-gatherers.
Macroinvertebrate	**Intolerant**	Decrease	Taxa richness of intolerant taxa.
Macroinvertebrate	**HBI_MN**	Increase	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart

Table 4.18 Battle Creek fish biological metric data related to DO.

Dissolved Oxygen Relevant Bio Metrics					**SensitivePct**	**NumPerMeter**	**MA>3Pct**	**TolPct**	**IntolerantPct**	**SLithopPct**
Station	Date	Fish Class	FIBI Threshold	FIBI						
12UM148*	7/23/2012	3	51	0	0.0	0.0	0.0	0.0	0.0	0.0
97UM008	9/23/1997	3	51	21	0.0	5.0	0.2	98.1	0.0	0.2
	8/18/1998	3	51	16	0.0	1.0	18.8	98.4	0.0	18.8
	6/17/2010	3	51	33	0.0	1.0	16.3	97.4	0.0	15.7
	7/13/2010	3	51	28	0.0	0.3	20.5	95.5	0.0	20.5
	7/23/2012	3	51	6	0.0	0.1	9.1	77.3	0.0	9.1
99UM076	6/14/1999	3	51	42	0.0	0.3	60.0	95.6	0.0	57.8
99UM075	7/31/2012	3	51	39	0.0	0.6	5.5	80.2	0.0	2.2
Average: All Minnesota Stations, Fish Class = 3					3.9	1.7	10.7	82.6	1.1	24.5
00UM071	8/21/2000	2	45	30	0.0	1.3	0.0	4.0	0.0	0.0
Average: All Minnesota Stations, Fish Class = 2					7.0	2.0	15.8	67.1	1.4	26.2
Expected response with increased stress					D	D	D	I	D	D

* Station 12UM148 was included in this analysis, as abundance-based biological metrics (NumPerMeter) were included in this analysis.

Table 4.19 Battle Creek macroinvertebrate biological metric data related to DO.

Dissolved Oxygen Relevant Bio Metrics					**EPTPct**	**TaxaCountAllChir**	**Intolerant**	**Collector-Gatherer**	**HBI_MN**
Station	Date	MI Class	MIBI Threshold	MIBI					
97UM008	8/23/2010	5	35.9	28	54.7	25.0	0.0	4.0	7.5
99UM075	8/13/2012	5	35.9	25	20.0	26.0	0.0	6.0	6.5
Average: All Minnesota Stations, Invert Class = 5					37.6	36.4	3.0	7.8	7.5
04UM011	9/2/2004	6	46.8	9	0.0	24.0	0.0	5.0	8.7
00UM071	9/11/2000	6	46.8	34	1.8	26.0	0.0	4.0	6.5
Average: All Minnesota Stations, Invert Class = 6					18.1	34.8	1.5	7.6	7.6
Expected response with increased stress					D	D	D	D	I

As can be seen, nearly all of the biological metrics sampled over the various sample dates and stations point to DO stress when compared to state average metric values. The response sensitive and intolerant species and overall taxa richness is commonly cited by other stressor ID reports as being highly related to DO stress (MPCA 2013c; MPCA 2014b; MPCA 2014c). Table 4.18 and Table 4.19 show that no species or taxa identified as sensitive or intolerant have been observed in Battle Creek. Additionally, the overall taxa richness of macroinvertebrates and fish number per meter are low when compared to average class values of all Minnesota stations. Notably, the Minnesota based HBI values of three of four macroinvertebrate surveys were below state average values. Because high HBI values are indicative of elevated stress related to organic pollution and low DO, the results of surveys along Battle Creek may indicate that stress observed in the macroinvertebrate community is less directly related to elevated BOD and low DO.

4.4.4.1 Tolerance Indicator Value Analysis

To help better understand the overall tolerance of the fish and macroinvertebrate community in Battle Creek to DO stress, a TIV analysis was performed. Similar to the TSS TIV analysis performed in Section 4.2.3, all fish species and macroinvertebrate taxa observed during biological surveys within the Twin Cities HUC-8 were divided into four tolerance quartiles. The assemblage of fish and macroinvertebrates observed in Battle Creek was then compared to these quartiles to assess the overall tolerance of the community, as it compares to other streams within the Twin Cities HUC-8. The quartile distribution for each of the macroinvertebrate and fish surveys performed on Battle Creek is presented in Table 4.20.

Table 4.20 Battle Creek fish and macroinvertebrate DO TIV quartiles.

FISH						
		Twin Cities HUC-8 DO TIV Quartiles				
Station	Date	Q1	Q2	Q3	Q4	
12UM148*	7/23/2012	0%	0%	0%	100%	
97UM008	9/23/1997	0%	0%	0%	100%	*Upstream*
	8/18/1998	0%	19%	1%	80%	
	6/17/2010	0%	16%	1%	84%	
	7/13/2010	0%	20%	0%	80%	
	7/23/2012	0%	9%	5%	86%	
99UM076	6/14/1999	0%	58%	2%	40%	
99UM075	6/14/1999	0%	25%	18%	58%	
	7/31/2012	0%	2%	73%	25%	
00UM071	8/2/2000	0%	66%	32%	1%	*Downstream*
MACROINVERTEBRATES						
		Twin Cities HUC-8 DO TIV Quartiles				
Station	Date	Q1	Q2	Q3	Q4	
97UM008	8/23/2010	38%	55%	3%	5%	*Upstream*
04UM011	9/2/2004	0%	46%	8%	45%	
99UM075	8/13/2012	94%	66%	3%	2%	
00UM071	9/11/2000	24%	8%	70%	8%	*Downstream*

* The station 12UM148, 7/23/2012 survey consisted of two (2) fish.

As can be seen, the general quartile distribution of the fish community is very different than that of the macroinvertebrate community. In the majority of surveys, the fish community tends to skew towards the fourth, most tolerant quartile, while the macroinvertebrate community appears to skew more towards the first and second quartiles. Additionally, it is apparent that significant inter-quartile inconsistencies occur in both datasets. For example, the fish community appears to typically have more representation in the second and forth quartiles, and less in the third. As discussed in Section 4.2.3, inconsistent results between populations and between quartiles are more common when performing a TIV analysis on a non-primary stressor.

That being said, from the TIV analysis it appears that DO may be an important, sometimes controlling, secondary stressor. Fish surveys performed at station 97UM008 all clearly skew towards the fourth quartile, while surveys performed at stations further downstream skew more towards the second and third quartiles. This difference in quartile distribution is supported by results of the synoptic water quality surveys presented in Section 4.4.1, which found that below-standard DO concentrations are much more common at station 97UM008 (immediately downstream of McKnight Basin) than at stations further downstream. It is also notable that the two fish observed during the station 12UM148 survey (two yellow bullhead) fall into the forth quartile for DO tolerance. In fact, yellow bullhead had the lowest DO TIV value of all species observed in Battle Creek (i.e., yellow bullhead were the most tolerant to low DO of all species observed in Battle Creek). The results of this survey indicate that low DO may be a significant problem in stations upstream of McKnight Basin, but due to the small sample size of this survey and a lack of replicate results (no other biological surveys were performed at stations upstream of McKnight Basin), the impact of low DO and BOD at upstream station remains unclear. For this reason, it is recommended that DO monitoring efforts be extended to include upstream stations (see recommendations in Table 5.2).

4.4.5 Strength of Evidence

Table 4.21 presents the SOE scores for DO and BOD as a candidate cause. DO concentrations in Battle Creek have not been extensively monitored, but the limited water quality available suggests that Battle Creek may be impaired for DO, particularly at locations immediately downstream of Battle Creek Lake and McKnight Basin. BOD data has only been recorded at one station and cannot be correlated to DO, but routine exceedances of BOD standards suggest that BOD is likely contributing to DO stress observed in Battle Creek. TIV analysis supports this conclusion that impairment may be localized to stations downstream of detention areas, finding the fish population immediately downstream of McKnight Basin to be significantly more tolerant to DO stress than populations surveyed further downstream. Although available water quality and TIV analysis data suggests that stations immediately downstream of detention areas may be impaired for DO, limited DO monitoring data and lack of flow monitoring data upstream of station 99UM075 makes it difficult to assess: (a) the cause of and extent of DO stress; and (b) how far DO stress propagates downstream of detention areas.

Based on the analysis presented above and related SOE scoring, low DO has been identified as potential primary stressor to fish immediately downstream of detention areas, and as a secondary stressor at stations not impacted by in-stream detention. For more information of SOE scoring, see Appendix A.

Table 4.21 Strength of Evidence for low dissolved oxygen.

Types of Evidence	**Candidate Cause:** Dissolved Oxygen and BOD
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	0
Causal Pathway	+
Evidence of Exposure or Biological Mechanism	NE
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	+
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	+
Stressor-Response Relationships from Other Field Studies	**+ +**
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	NE
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	0
Explanation of the Evidence	**+ +**

4.5 Candidate Cause #4: Excess Total Phosphorus

4.5.1 Overview of Total Phosphorus in Battle Creek.

TP measured in Battle Creek has routinely exceeded the eutrophication criteria concentration for streams in the Central River Nutrient Region (0.10 mg TP/L; MPCA, 2013a) over the period of record. The historic (1977 through 1990) and modern (2012 through 2013) TP datasets are shown in Figure 4.16. As can be seen, the magnitude of TP concentrations does not appear to change over the monitoring period. The percentage of eutrophication standard exceedances is greater in the modern dataset than the historic datasets, but this trend is likely explained by differences in sampling protocol (grab sampling in the historic dataset, event-based sampling in the modern dataset), as average TP concentration has not increased (Table 4.22). From the historic dataset, it appears there is little difference in longitudinal TP concentrations from station 97UM008 downstream to station 99UM075.

Table 4.22 **Battle Creek total phosphorus eutrophication criteria exceedance.**

	Historic (1977-1990)		Modern (2000-2013)
Station	97UM008	99UM075	99UM075
Number of Measurements	73	72	432
Number of Samples Exceeding Eutrophication Criteria[1]	21	25	276
Percent of Samples Exceeding Standard (%)	29%	35%	64%
Average TP Concentration (mg/L)	0.14	0.21	0.18
Summer (June-Sept) Average TP Concentration (mg/L)	0.16	0.24	0.19

[1] Total phosphorus eutrophication criteria for Central River Nutrient Region (0.1 mg TP/L)

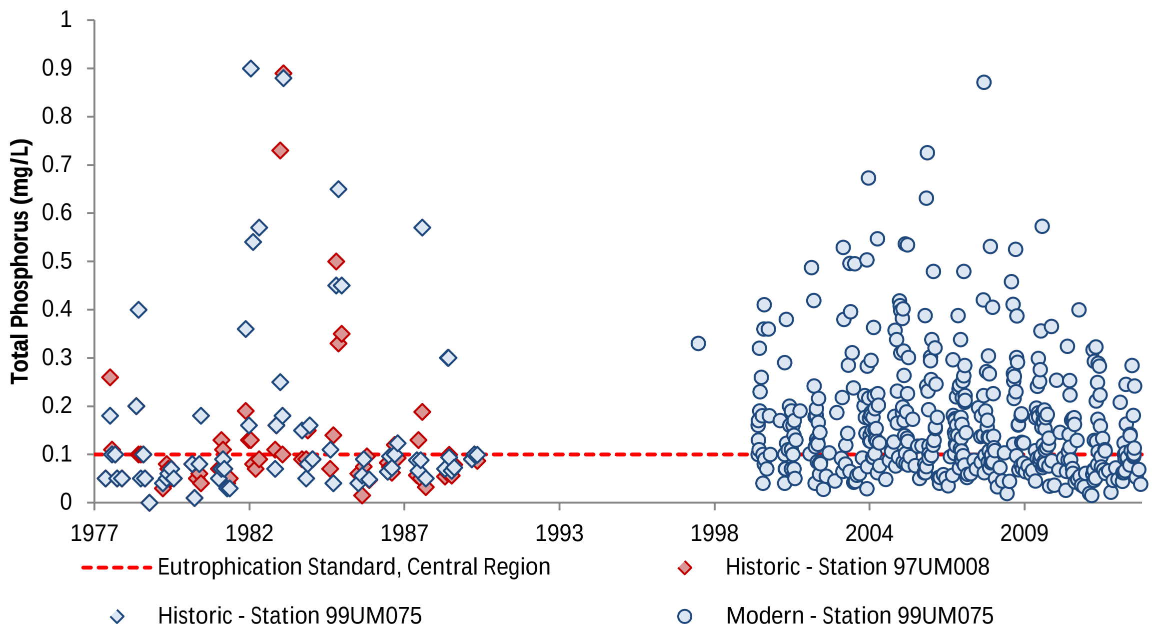


Figure 4.16 Battle Creek measured total phosphorus concentrations.

TP concentrations in Battle Creek are highly correlated with TSS (Figure 4.17). Additionally flow duration and seasonal analysis of TP concentration at station 99UM075 produced results similar to those presented for TSS in Figure 4.8 and Table 4.4, showing that the majority of eutrophication criteria exceedances occur at high flows during the growing season. Based on the correlation between TSS delivery and TP concentration, it can be assumed that elevated phosphorus concentrations at station 99UM075 are driven mainly by inorganic particulate phosphorus associated with sediment delivery.

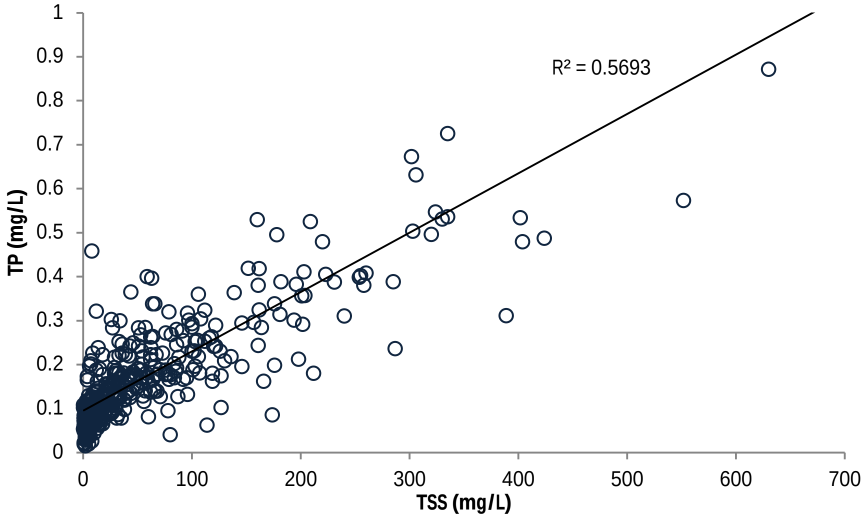


Figure 4.17 Total phosphorus compared to total and volatile suspended solids at station 99UM075.

Excessive phosphorus loading can lead to increased plant and algal growth. Although not currently listed as impaired for nutrients, elevated phosphorus concentrations have been observed in Battle Creek Lake (the headwaters of Battle Creek). In the past 10 years, growing season average phosphorus concentrations in Battle Creek Lake have remained close to or slightly higher than the MPCA shallow lake criteria of 60 µg TP/L. Visual evidence of excessive algal growth in Battle Creek Lake was observed in an August, 2012, survey of Battle Creek. Additionally, and filamentous algal blooms were observed near step-weir structures downstream of station 04UM011 (Figure 4.18).

Figure 4.18 Excessive macrophyte and algal growth near outlet of Battle Creek Lake and downstream of station 04UM011.

4.5.2 Stressor Pathway

A conceptual model of sources and causal pathways for TP in Battle Creek is shown in Figure 3.6. As can be seen, the major anthropogenic sources of TP to Battle Creek are associated with urban development. As discussed in Section 4.2.2, urban development can increase sediment delivery to a stream by increasing watershed sediment mobilization and delivery, as well increasing in-channel erosion. Particulate phosphorus associated with soil is mobilized when increases runoff (associated with urban development) erodes soils and widens channels. Therefore, as sediment delivery to a stream increases, so does TP. Another major anthropogenic source of TP is fertilizer. Although there is very little agricultural area within the Battle Creek watershed, the application of phosphorus-containing fertilizer to residential lawns is another potential source of TP to the stream.

Phosphorus is an essential nutrient and is not a proximate stressor to aquatic life. However, excessive phosphorus loading to a waterbody can lead to accelerated primary production (a process known as *eutrophication*). Changes in the growth rate species composition caused by eutrophication can have proximate effects on the fish and macroinvertebrate community by: (a) altering food resources; (b) altering habitat structures; and (c) allowing for growth of toxic algae and bacteria (EPA 2010). Additionally, excessive phytoplankton and algal growth can increase turbidity, reducing feeding efficiency of sight feeding and filtering fish and macroinvertebrate taxa groups, as well as degrading benthic habitat. Eutrophication can also impact the chemical composition of a waterbody. In particular, increased photosynthesis during the day and respiration at night (decomposition of accumulated biomass) can lead to large fluctuations in DO and pH. As discussed in previous sections (Section 4.4 and Section 3.2.1), fluctuations in DO and pH impart stress on fish and macroinvertebrate communities, reducing both diversity and abundance.

4.5.3 Biological Response to Excess Total Phosphorus

As discussed in Section 4.5.2, excessive TP loading can impact the physical and chemical characteristics of a waterbody. Because phosphorus loading and eutrophication indirectly impact several proximate stressors (DO concentration, pH concentration, altered habitat, etc.), the biological impact of excessive TP loading can be varied and compounding with other stressors. To evaluate the impact of excessive TP loading within Battle Creek, biological metrics identified as being statistically related to TP concentration in the *Central* Nutrient Region of Minnesota were evaluated (MPCA 2013a). The 12 biological metrics analyzed are described in Table 4.23, and the results of the fish and macroinvertebrate biological metric analysis are shown in Table 4.24 and Table 4.25, respectively.

Table 4.23 TP sensitive biological metrics.

Group	**Metric**	Response to TP Stress	Description
Fish	DarterPct	Decrease	Percent of total count identified as darters
Fish	IntolerantPct	Decrease	Percent of total count identified as intolerant.
Fish	SensitivePct	Decrease	Percent of total count identified as sensitive.
Fish	SLithopPct	Decrease	Percent of total count identified as simple lithophils.
Fish	TolPct	Increase	Percent of total count identified as tolerant.
Fish	CountofTaxa	Decrease	Total number of taxa groups identified
Macroinvertebrate	EPT	Decrease	Number of EPT taxa identified
Macroinvertebrate	Collector-filterer	Decrease	Number of Collector-filterer taxa identified
Macroinvertebrate	Collector-Gatherer	Decrease	Number of Collector-gatherer taxa identified
Macroinvertebrate	Intolerant	Decrease	Number of intolerant taxa identified
Macroinvertebrate	TolerantPct	Increase	Percent of total count identified as tolerant
Macroinvertebrate	TaxaCountAllChir	Decrease	Total taxa richness of macroinvertebrates.

Table 4.24 Battle Creek fish biological metric data related to total phosphorus.

Phosphorus Relevant Bio Metrics										
Station	Date	Fish Class	FIBI Threshold	FIBI	DarterPct	IntolerantPct	SensitivePct	SLithopPct	TolPct	CountofTaxa
12UM148	7/23/2012	3	51	0	0.0	0.0	0.0	0.0	0.0	1.0
97UM008	9/23/1997	3	51	21	0.0	0.0	0.0	0.2	98.1	7.0
	8/18/1998	3	51	16	0.0	0.0	0.0	18.8	98.4	6.0
	6/17/2010	3	51	33	0.0	0.0	0.0	15.7	97.4	8.0
	7/13/2010	3	51	28	0.0	0.0	0.0	20.5	95.5	6.0
	7/23/2012	3	51	6	0.0	0.0	0.0	9.1	77.3	6.0
99UM076	6/14/1999	3	51	42	0.0	0.0	0.0	57.8	95.6	5.0
99UM075	7/31/2012	3	51	39	0.0	0.0	0.0	2.2	80.2	7.0
Average: All Minnesota Stations, Fish Class = 3					6.6	1.1	3.9	24.5	82.6	9.0
00UM071	8/21/2000	2	45	30	0.0	0.0	0.0	0.0	4.0	7.0
Average: All Minnesota Stations, Fish Class = 2					8.0	1.4	7.0	26.2	67.1	15.3
Expected response with increased stress					D	D	D	D	I	D

* Station 12UM148 was included in this analysis, as abundance-based biological metric(s) (CountofTaxa) were included in this analysis.

Table 4.25 Battle Creek macroinvertebrate biological metric data related to total phosphorus.

Phosphorus Relevant Bio Metrics										
Station	Date	MI Class	MIBI Threshold	MIBI	EPT	Collector-filterer	Collector-Gatherer	Intolerant	TolerantPct	TaxaCountAllChir
97UM008	8/23/2010	5	35.9	28	4.0	3.0	4.0	0.0	39.7	25.0
99UM075	8/13/2012	5	35.9	25	3.0	2.0	6.0	0.0	28.9	26.0
Average: All Minnesota Stations, Invert Class = 5					8.3	3.8	7.8	3.0	57.6	36.4
04UM011	9/2/2004	6	46.8	9	0.0	1.0	5.0	0.0	97.9	24.0
00UM071	9/11/2000	6	46.8	34	2.0	4.0	4.0	0.0	86.7	26.0
Average: All Minnesota Stations, Invert Class = 6					5.2	2.5	7.6	1.5	74.9	34.8
Expected response with increased stress					D	D	D	D	I	D

Many of the 12 biological metrics analyzed are likely statistically related to TP concentration due to the impact of TP or other proximate stressors, such as turbidity, DO, and habitat degradation. For example, the feeding efficiency of collector-filterers and the sight-feeding taxa group of darters is negatively affected by turbidity (Section 4.2.3.1). Taxa richness and the prevalence of taxa groups defined as intolerant are highly related to DO stress (Section 4.4.4.1). Simple lithophilic species (SlithopPct) require clean gravel or cobble for spawning, are good indicators of stress related to habitat degradation related to embeddedness (Section 4.6.3). Taken as a whole, the biological metrics presented in Table 4.24 and

Table 4.25 all appear to indicate the macroinvertebrate and fish communities are responding to the stress related to excessive phosphorus loading, but due to the indirect impact phosphorus loading on several proximate stressors, it is difficult to determine causality from these results alone (e.g., are the metrics related to turbidity negatively impacted by turbidity related to excessive phosphorus loading and primary production, or turbidity from excessive sediment loading to the stream?).

A biological metric that may be more directly related to excessive TP loading and primary production is the relative abundance of detritivorous and planktivorous fish species (*DetPlnkPct*) (MPCA 2014c). Increased primary production related to excessive nutrient loading can shift the fish assemblage toward species that feed primarily on particulate organic material (Miranda 2008). As can be seen in Figure 4.19, the relative abundance of detritivorous and planktivorous fish species was found to be greater than state average values at all but one of the biological surveys performed on Battle Creek. TSS concentrations measured at station 99UM075 on July 31, 2012, were atypically low (~2 mg/L), which might explain the low relative abundance of detritivorous and planktivorous fish species recorded during this survey.

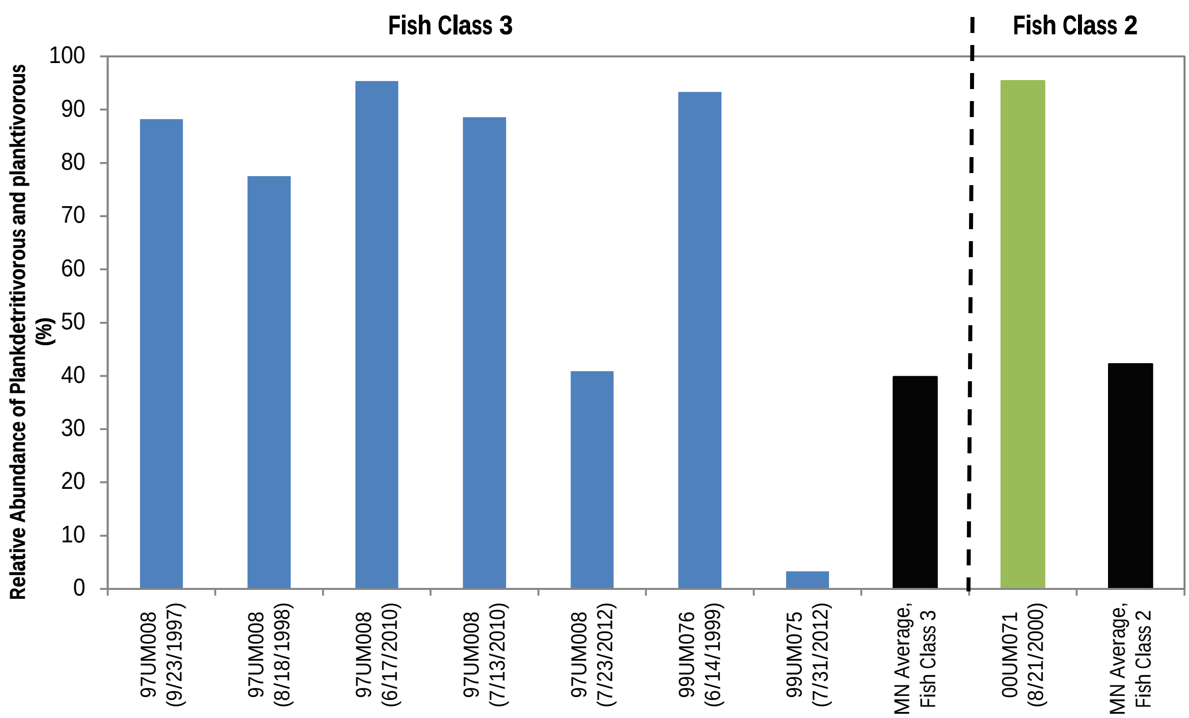


Figure 4.19 Relative abundance of detritivorous and planktivorous fish species.

4.5.4 Strength of Evidence

Table 4.26 presents the SOE scores for excess TP. Phosphorus concentrations in exceedance of the eutrophication standard for the *Central* River Nutrient Region are common in Battle Creek, and phosphorus loading has been shown to be highly correlated with TSS loading. Biological metric analysis indicates that fish and macroinvertebrate populations may be responding to elevated phosphorus concentrations, but the direct relationship between phosphorus loading and several proximate stressors also identified as candidate causes (low DO, excess sediment, altered habitat) make causality specific to phosphorus loading difficult to determine. Based on the analysis presented above and related SOE scoring, excess phosphorus has been identified as a likely secondary stressor to the biological community within Battle Creek. For more information of SOE scoring, see Appendix A.

Table 4.26 Strength of Evidence for excess total phosphorus.

Types of Evidence	**Candidate Cause:** Excess Total Phosphorus
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	0
Causal Pathway	+
Evidence of Exposure or Biological Mechanism	NE
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	0
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	NE
Stressor-Response Relationships from Other Field Studies	+
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	NE
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	+
Explanation of the Evidence	0

4.6 Candidate Cause #5: Altered Habitat

4.6.1 Overview of Altered Habitat in Battle Creek.

Watershed urbanization has had significant impacts on the geomorphology of Battle Creek. To resolve routine flooding issues and address major erosion issues within the channel (Figure 4.20), a large restoration project was completed on Battle Creek in 1982. The project, funded by the newly formed RWMWD, included the installation of several sheet pile drop structures and step weir structures, a major flood detention basin (McKnight Basin), and a flood-flow diversion structure which routes high flows into an underground pipe. Major re-grading and ravine restoration was also completed at this time. More information about the project can be found on the RWMWD's project web-portal (http://www.rwmwd.org/).

Figure 4.20 Severe pre-Battle Creek Project bank erosion (left) and regrading efforts during construction (right).

Since completion of the project, bank erosion and channelization have been significantly reduced. Further ravine stabilization was implemented in an upper reach of Battle Creek in the 1990s, but has not been needed elsewhere, and maintenance has been limited to routine repair of flood-diversion infrastructure and sediment removal in upstream detention areas. Although channel stabilization has significantly improved since completion of the 1982 project, it is important to understand how constructed gradient control and in-stream detention may be impacting the biological community.

As outlined in Section 3.3.5, five MSHA surveys have been performed on Battle Creek. Surveys were conducted at four stations over the period of 2000 to 2012. MSHA scores ranged from 76 ("good" condition) to 38 ("poor" condition), with the majority of surveys finding "fair" to "good" instream habitat (Table 4.27). As can be seen, there does not appear to be any clear trends in the rating categories (i.e., no consistently high-scoring or low-scoring categories). The MSHA survey performed at station 00UM071, the furthest downstream station, is noteworthy as being the only survey to produce a "poor" qualitative habitat rating. From Table 4.27, it can be seen that the substrate score of this survey is particularly low. Review of the assessment worksheet for this survey (Appendix C) shows that the low score in this category is attributed mainly to lack of substrate diversity. Substrate at this site consisted entirely of clay sediment, with no coarse substrate observed at the site. Although the most downstream sampling location did produce the worst MSHA score, there does not appear to be a clear longitudinal trend in any of the MSHA scoring categories. In general, the magnitude of MSHA scores suggests that habitat stress is not severe.

Table 4.27 Battle Creek MSHA survey data.

	Station	Date	Land Use Score (0-5)	Riparian Zone Score (0-15)	Instream Zone Score		Channel Morph. Score (0-36)	Total MSHA Score (0-100)	MSHA Rating[1]
					Substrate (0-27)	Fish Cover (0-17)			
Upstream	12UM148	7/23/2012	2	9	18	8	20	**57**	**Fair**
↓	97UM008	7/13/2010	2	11	20	11	32	**76**	**Good**
		7/23/2012	2	11	15	9	19	**56**	**Fair**
	99UM075	7/31/2012	3	14	21	14	24	**76**	**Good**
Downstream	00UM071	8/21/2000	3	8	6	7	14	**38**	**Poor**

[1] MSHA qualitative habitat rating (MSHA > 66 is "good," 45 < MSHA <66 is "fair," and MSHA < 45 is "poor").

Table 4.28 Battle Creek substrate metrics.

Station	Date	**Total**	Embed. Rating	Percent	Depth of

			MSHA Score (0-100)		Fines (%)	Fines (cm)
Upstream	12UM148	7/23/2012	**57**	25-50% (Moderate)	37	1.9
	97UM008	7/13/2010	**76**	5-25% (light)	--	--
	97UM008	7/23/2012	**56**	25-50% (Moderate)	58	3.5
	99UM075	7/31/2012	**76**	5-25% (light)	--	--
Downstream	00UM071	8/21/2000	**38**	No Coarse Substrate	94	18.9

Quantitative measurements of substrate were recorded during three of the five MSHA surveys. Although qualitative MSHA embeddedness ratings typically ranged from “moderate” (25-50% embedded) to “light” (5-25% embedded), the percent of fines and depth of fines appears to increase moving upstream to downstream (Table 4.28). The increase in fines at downstream stations can likely be attributed to reduced longitudinal stream gradient. The overall gradient of Battle Creek decreases from Battle Creek Lake downstream to Pigs Eye Lake. Reduced slope at downstream stations causes the average particle size of the bed load to shift towards finer particles, leading to accumulation of fines.

Since the 1981-1982 restoration project, the channel has remained relatively stable. During a 2012 survey, only relatively minor channel widening and bank erosion was observed (Figure 4.21).

Figure 4.21 Minor channel widening and bank erosion in Battle Creek (8/16/2012).

4.6.2 Stressor Pathway

Altered habitat as a candidate cause refers to any and all changes to the structural attributes of habitat (stream gradient, habitat complexity, vegetation cover, channel substrate, channel-riparian interactions, etc.) that may have negative impacts on aquatic life. The geomorphology of a stream system is naturally in constant flux, changing in shape and form to balance the impacts of degradation and aggradation (Rosgen 1996), dictated by local geology and climate (Leopold et al. 1994). Changes to channel morphology, however, can be accelerated by changes to land use and urbanization (Klein 1979). Increased impervious area, loss of riparian buffer, and urban encroachment can increase the volume and energy of stream inflows, leading to channel widening, bank erosion, gradient change, and channelization. These accelerated geomorphological changes can negatively impact habitat quality and diversity by: (a) reducing riparian cover; (b) reducing pool depth and pool frequency; and (c) reducing interstitial habitat due to embeddedness (Aadland et al. 2005 as cited by MPCA 2014b).

Deposited sediment and embeddedness may lead to biological impairment by three main pathways: (1) increased coverage by fine particles, which can alter benthic habitats (e.g., increasing fine substrate habitats favored by burrowing insects) and bury relatively sessile taxa and life stages (e.g., fish eggs);

(2) clogging of interstitial spaces, leading to reduced interstitial flows and habitats; and (3) reduction of substrate size, leading to reduced substrate diversity and stability. Deposited sediments can have indirect effects by reducing oxygen levels either with restricted flow through streambed substrates or by oxygen consumption by bacterial respiration, especially when sediments contain a high concentration of organic matter (Cormier 2007).

4.6.3 Biological Response to Altered Habitat

Due to the wide range of impacts degraded habitat can have on the biological assemblage, several studies have found a relationship between the overall IBI score for the fish and macroinvertebrates and MSHA scores (MPCA 2014b; MPCA 2014c). MSHA surveys were performed during four (4) of the fish biological surveys performed on Battle Creek. MSHA and F-IBI scores are compared in Figure 4.22. As can be seen, there appears to be little correlation between scores in this small dataset. Based on only three correlated points, this is insufficient evidence to conclude that F-IBI score are not related to MSHA scores, but the fact that the second-highest F-IBI score was recorded during the survey with the lowest MSHA score suggests that there may not be a strong relationship between the fish community and MSHA habitat scores. The relationship between M-IBI and MSHA score could not be evaluated, as MSHA score were not recorded during any macroinvertebrate surveys.

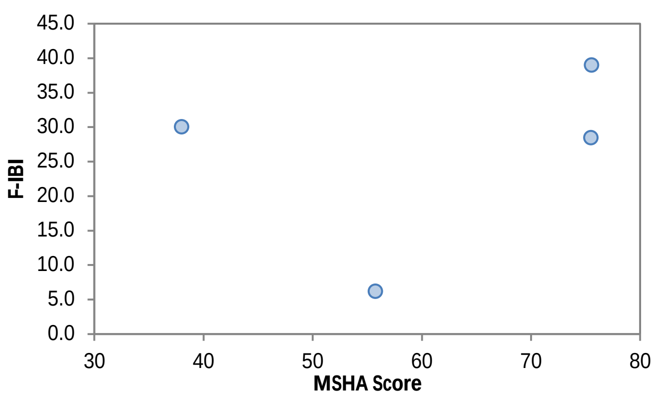


Figure 4.22 Fish IBI and MSHA score relationship.

Because there is limited ability to compare fish and macroinvertebrate biological metrics to MSHA scores, biological metrics identified as being sensitive to altered habitat were evaluated and compared to state average values for each macroinvertebrate and fish classification within Battle Creek. Biological metrics identified and evaluated are described in Table 4.29. Biological metric analysis results for the fish and macroinvertebrate communities are shown in Table 4.30 and Table 4.31, respectively.

Table 4.29 Biological metrics sensitive to altered habitat.

Group	**Metric**	Response to Habitat Stress	Description
Fish	BenInsectPct	Decrease	Percent of total count identified as benthic insectivours
Fish	CompLithPct	Decrease	Percent of total count identified as complex lithophils.
Fish	SLithopPct	Decrease	Percent of total count identified as simple lithophils.
Macroinvertebrate	ClingerPct	Decrease	Percent of total count identified as clingers
Macroinvertebrate	SprawlerPct	Decrease	Percent of total count identified as sprawling
Macroinvertebrate	BurrowerPct	Increase	Percent of total count identified as burrowing

Table 4.30 Battle Creek fish biological metric data related to altered habitat.

Habitat Relevant Bio Metrics					BenInsectPct	CompLithPct	SLithopPct
Station	Date	Fish Class	FIBI Threshold	FIBI			
97UM008	9/23/1997	3	51	21	0.0	8.2	0.2
	8/18/1998	3	51	16	0.0	11.5	18.8
	6/17/2010	3	51	33	0.0	2.0	15.7
	7/13/2010	3	51	28	0.0	6.8	20.5
	7/23/2012	3	51	6	0.0	36.4	9.1
99UM076	6/14/1999	3	51	42	0.0	2.2	57.8
99UM075	7/31/2012	3	51	39	0.0	1.1	2.2
Average: All Minnesota Stations, Fish Class = 3					10.0	41.9	24.5
00UM071	8/21/2000	2	45	30	0.0	0.0	0.0
Average: All Minnesota Stations, Fish Class = 2					14.8	31.8	26.2
Expected response with increased stress					D	D	D

Table 4.31 Battle Creek macroinvertebrate biological metric data related to altered habitat.

Habitat Relevant Bio Metrics					ClingerPct	SprawlerPct	BurrowerPct
Station	Date	MI Class	MIBI Threshold	MIBI			
97UM008	8/23/2010	5	35.9	28	78.4	3.8	4.1
99UM075	8/13/2012	5	35.9	25	24.3	29.8	1.8
Average: All Minnesota Stations, Invert Class = 5					43.3	16.8	3.0
04UM011	9/2/2004	6	46.8	9	1.6	30.0	5.8
00UM071	9/11/2000	6	46.8	34	10.8	16.1	70.6
Average: All Minnesota Stations, Invert Class = 6					26.9	23.2	14.9
Expected response with increased stress					D	D	I

All three fish biological metrics analyzed in Table 4.30 are impacted by the effects of altered habitat on instream substrate. Simple and complex lithophils require clean gravel or cobble for successful spawning (MPCA 2013a). Similarly, benthic insectivores rely on coarse and diverse substrate material, conducive to benthic macroinvertebrates, to feed and reproduce. As shown in Table 4.28, the depth of fines and percent of substrate material composed as fines appears to increase from upstream to downstream. For this reason, it is not surprising that the relative abundance of complex and simple lithophils appears to decrease from upstream to downstream stations. It should also be noted that none of the four fish biological metrics analyzed registered positive values at station 00UM071, which produced the worst MSHA total score and substrate score and where no course substrate was observed.

Similar to the fish biological metrics analyzed the relative abundance of clinger and sprawling macroinvertebrate taxa generally decreases in response to embeddedness and siltation. Sources of habitat for clinger taxa are reduced when substrate (plants, rocks, stable substrate) becomes covered by fine organic or inorganic material. Similarly, sprawling taxa are reduced when interstitial space between coarse gravel, cobble, or boulder substrata becomes embedded by fine substrates. Conversely, the relative abundance of burrowers is expected to increase proportional to the degree of siltation, as burrowing macroinvertebrates require fine, unconsolidated substrate. As shown in Figure 4.23, the relative abundance clingers and spawlers tends to decrease from upstream to downstream, while the relative abundance of burrower increases. The shift in behavioral macroinvertebrate groups corroborates the finding of the MSHA surveys that embeddedness and the depth of fine substrate increases from station 97UM008 downstream to station 00UM071.

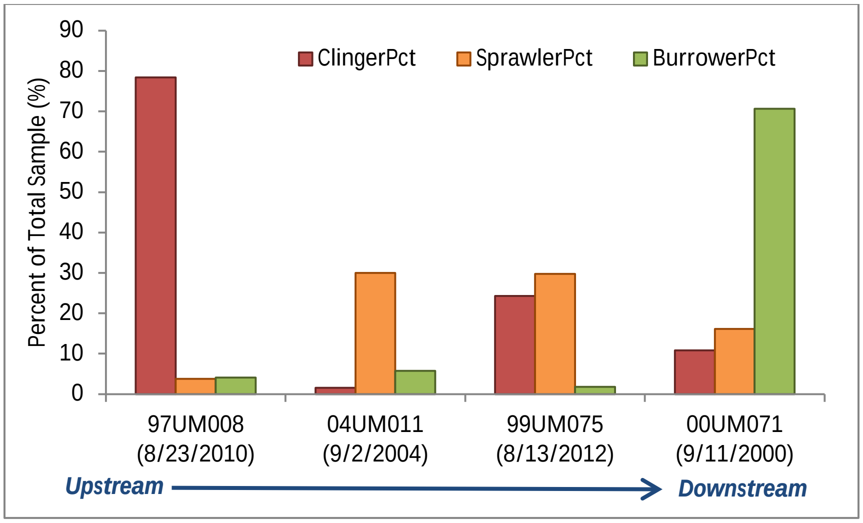


Figure 4.23 Macroinvertebrate biological metrics related to altered habitat.

4.6.4 Strength of Evidence

Table 4.32 presents the SOE scores for altered habitat. Habitat condition along Battle Creek has not been extensively monitored. Data from five MSHA surveys suggest that habitat condition is “fair” to “good” at all stations aside from station 00UM071, the most downstream biological monitoring station, which exhibits poor habitat quality due primarily to lack of substrate diversity. Quantitative substrate data suggests that siltation and depth of fines increase from upstream to downstream stations, although this trend is somewhat contradicted by qualitative MSHA embeddedness ratings. Excess sediment loading has been identified as a primary stressor (Section 4.2.4), and may explain poor substrate quality related to siltation and embeddedness at downstream stations.

Biological metrics analysis suggests that fish and macroinvertebrates may be displaying a longitudinal response to habitat degradation. The presence of taxa sensitive to siltation and embeddedness appears to decrease from upstream to downstream stations. Although this finding supports the hypothesis that siltation increases at downstream stations, this trend is drawn from a small dataset, and may be impacted by differences in sampling date in addition to differences in sampling location. Based on the analysis presented above and related SOE scoring, altered habitat has been identified as a potential secondary stressor to the biological community within Battle Creek. For more information of SOE scoring, see Appendix A.

Table 4.32 Strength of evidence for altered habitat.

Types of Evidence	Candidate Cause: Altered Habitat
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	0
Causal Pathway	+
Evidence of Exposure or Biological Mechanism	+
Manipulation of Exposure	0
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	+
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	NE
Stressor-Response Relationships from Other Field Studies	+
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	NE
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	+
Explanation of the Evidence	0

4.7 Candidate Cause #6: Habitat Fragmentation

4.7.1 Overview of Habitat Fragmentation in Battle Creek.

As discussed in Section 4.6.1, many gradient control structures were installed along the length of Battle Creek during the 1981-1982 Battle Creek restoration project. Beginning at Century Avenue North (just east of station 12UM148) a total of 23 drop structures and 6 step-weir structures were installed. Examples of gradient control structures are shown in Figure 4.24. The majority of drop structures installed are sheet pile check dams, ranging in depth from 3- to 5-feet above the streambed. The 6 step-weir "waterfall" structures were installed between East Upper Afton Road and Highway 61. Each waterfall structure lowers the bed elevation of Battle Creek by 7 feet. The height of gradient control structures along Battle Creek eliminates the potential for upstream movement of fish and most macroinvertebrate species between many biological survey stations. The extent of Battle Creek impacted by gradient control structures is shown in Figure 2.2.

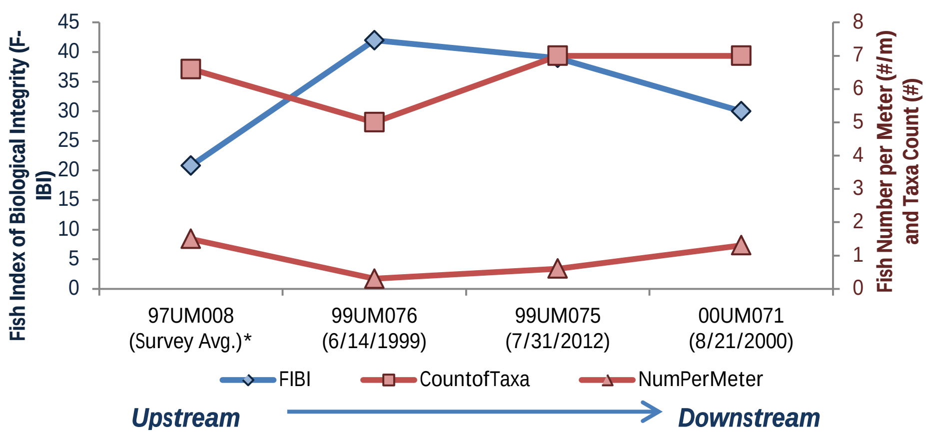
Figure 4.24 Examples of drop structures and step-weir structures along Battle Creek.

4.7.2 Stressor Pathway

In Battle Creek, habitat fragmentation is caused by gradient control structures installed during the 1981-1982 Battle Creek restoration project. Disruption of longitudinal connectivity can negatively impact aquatic communities in several ways. Instream structures can limit or reduce upstream migration, which can lead to changes in community structure (Brooker 1981 as cited by MPCA 2014b). These structures can also impact the physiochemical properties of the stream by altering water temperature, sediment transport and stream flow, and can affect upstream primary production and nutrient cycling (Cumming 2004).

4.7.3 Biological Response to Habitat Fragmentation

To evaluate the impact of habitat fragmentation on the fish and macroinvertebrate communities within Battle Creek, longitudinal trends in F-IBI and M-IBI scores were evaluated. Additionally, biological metrics related to taxa richness and abundance were evaluated to determine if significant spatial differences in fish and macroinvertebrate populations exist. Longitudinal analysis of F-IBI score and fish biological metrics are shown in Figure 4.25.



* Average of five biological surveys from station 97UM008 (9/23/1997, 8/18/1998, 6/17/2010, 7/13/2010, and 7/31/2012)

Figure 4.25 Longitudinal analysis of F-IBI and fish biological metrics.

Although there are no gradient control structures between the two most downstream stations (stations 00UM071 and 99UM075), gradient control structures completely halt upstream movement of fish populations between stations 99UM075, 99UM076 and 97UM008. As can be seen in Figure 4.25, fish abundance and diversity (fish number per meter and taxa count, respectively) do not appear to exhibit a clear longitudinal trend between stations 99UM008 and 00UM071, which suggests that fish populations are not being negatively impacted by habitat fragmentation between McKnight Basin (station 97UM008) and Pigs Eye Lake (station 00UM071). Similarly, F-IBI scores do not appear to exhibit a longitudinal trend, and do not appear to be negatively impacted by habitat fragmentation.

The impacts of habitat fragmentation on the fish community can more clearly be seen through analysis of the individual fish species counts at each biological station. As shown in Table 4.33, fathead minnow is the dominant species at stations 97UM008, 99UM076, and 99UM075. Emerald shiners and spotfin shiners are the two dominant species at station 00UM071 and have been observed at station 99UM075, but have never been observed at stations further upstream. Habitat fragmentation associated with the 1981-1982 Battle Creek project begins upstream of station 99UM075, which explains why upstream progress of emerald and spotfin shiners halts at this station. White suckers, a migratory fish species found in Battle Creek Lake, exhibit a spatial trend similar to fathead minnows (i.e., higher abundance at upstream stations, lower abundance at downstream stations.

Table 4.34 shows the fish class 2 and class 3 F-IBI metrics associated with fathead minnows, emerald shiners, spotfin shiners, and white suckers. As can be seen, the presence of all three fish species is associated only with biological metrics that are inversely related to F-IBI scoring. Because emerald shiners and spotfin shiners are associated with fewer biological metrics, upstream migration of these two species could marginally improve F-IBI scoring. It is unclear, however, how far upstream emerald and spotfin shiners would migrate if habitat fragmentation were removed. Both species thrive in deep lakes and rivers, which explains why they are predominantly found near Pigs Eye Lake.

Table 4.33 Relative abundance of fish species at biological survey stations.

	Relative abundance over all biological surveys (%)			
Station	97UM008	99UM076	99UM075	00UM071
Fathead Minnows	73%	36%	42%	1%
White Suckers	5%	58%	2%	0%
Emerald and Spotfin Shiners	0%	0%	18%	97%

Table 4.34 F-IBI fish class 2 and fish class 3 biological metrics associated with fathead minnows, emerald shiners, spotfin shiners, and white suckers.

			Species related to corresponding metrics			
F-IBI metric	Fish Class 2 or Fish Class 3?	Metric had *positive* or inverse relationship with F-IBI score?	Fathead Minnows	Emerald Shiner	Spotfin Shiner	White Sucker
DetNWQ	Fish Class 2 and 3	Inverse	X		X	X
SLvd	Fish Class 2 and 3	Inverse	X	X		
General	Fish Class 3	Inverse	X			X
MA<2	Fish Class 2	Inverse	X	X	X	
Tol	Fish Class 2	Inverse	X			X

Longitudinal analysis of M-IBI score and macroinvertebrate biological metrics associated with habitat fragmentation are shown in Figure 4.26. As can be seen, none of the metrics analyzed appear to exhibit a clear longitudinal trend. M-IBI scores were below threshold concentrations at all biological stations surveyed. The M-IBI score at station 04UM011 was particularly low, but because M-IBI scores upstream and downstream of this station are fairly similar, the low score is likely not associated with habitat fragmentation (stations immediately upstream and downstream are equally impacted by gradient control structures, see Figure 2.2). The overall macroinvertebrate taxa count (TaxaCountAllChir) mollusca taxa count was found to be relatively similar at all sites. Mollusca larva (*glochidia*) attach to the fills of fish for a period of time. For this reason, their distribution is closely related to movement of fish populations. Because taxa counts and M-IBI scores are fairly similar across all biological station surveyed, it is unlikely that habitat fragmentation is negatively impacting the macroinvertebrate community.

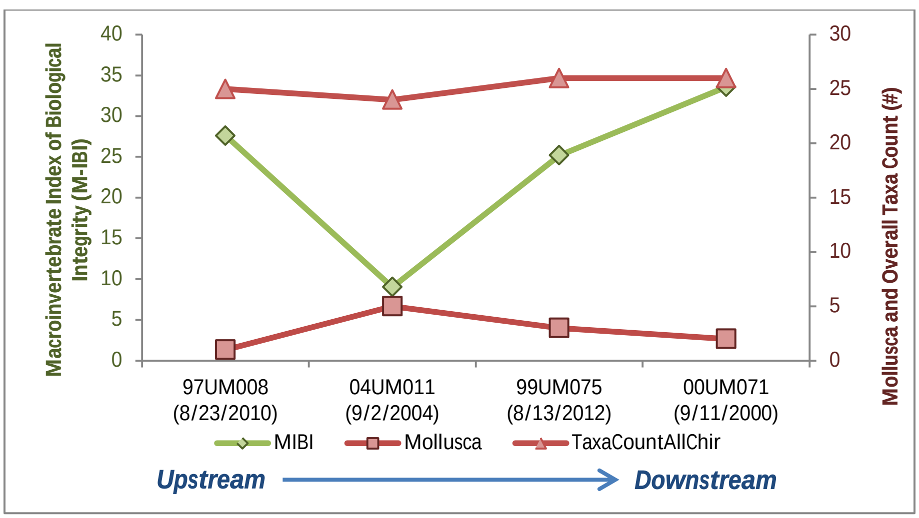


Figure 4.26 Longitudinal analysis of M-IBI and macroinvertebrate biological metrics.

4.7.4 Strength of Evidence

Table 4.35 presents the SOE scores for habitat fragmentation. As discussed in Section 4.7.1, gradient control structures installed during the 1981-1982 Battle Creek restoration project eliminated the potential for upstream movement of fish and most macroinvertebrate species between biological survey stations. From analysis of indices of biological integrity and biological metric analysis, it does not appear that habitat fragmentation is currently a primary stressor to the aquatic community. However, it may be the case that the biological condition of Battle Creek has been sufficiently degraded by other stressors that potential negative impacts of habitat fragmentation are overwhelmed or not currently assessable. Based on the analysis presented above and related SOE scoring, habitat fragmentation has been identified as a low priority, secondary stressor to the fish community within Battle Creek, and an inconclusive stressor to the macroinvertebrate community. For more information of SOE scoring, see Appendix A.

Table 4.35 Strength of evidence for habitat fragmentation.

Types of Evidence	**Candidate Cause:** Habitat Fragmentation
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	-
Causal Pathway	NE
Evidence of Exposure or Biological Mechanism	0
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	0
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	NE
Stressor-Response Relationships from Other Field Studies	+
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	+
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	0
Explanation of the Evidence	0

4.8 Candidate Cause #7: Metals (Cd, Cu, Pb, and Zn)

4.8.1 Overview of Metals in Battle Creek.

Beginning in 2000, concentrations of six heavy metal species has been tracked within Battle Creek: Pb, Cu, Cr, Cd, Ni, and Zn. Of the metals analyzed, Cd, Cu, Pb and Zn have failed to meet CSs, MS, or FAVs for Class 2B streams, pursuant to Minn. R. 7050.0222, subp. 4 (Appendix B). As outlined in Section 3.3.7.2, metal concentrations in Battle Creek have been recorded since 2000 as part of the WOMP monitoring program at station 99UM075, and were recorded during the 2012 and 2013 synoptic surveys. Because hardness (i.e., the sum of calcium and magnesium concentrations expressed as $CaCO_3$) was not recorded during the synoptic surveys, standard exceedances cannot be evaluated. For this reason, only metal concentrations recorded during event-based sampling at station 99UM075 will be discussed in this section. An additional caveat to the discussion of metal concentrations and standard exceedances presented in this section is that EPA "clean hands/dirty hands" sampling protocol was not followed. For this reason, it is possible that post-collection contamination of samples may have impacted metal concentrations reported. It is recommended that "clean hands/dirty hands" sampling protocol be followed during future sampling efforts.

Table 4.36 Metal standard exceedances at station 99UM075.

		Percent of Samples Exceeding Standard (%)		
Metal	Total Number of Samples	Chronic Standard (CS)	Maximum Standard (MS)	Final Acute Value (FAV)
Cadmium (Cd)	393	1%	0%	0%
Copper (Cu)	390	12%	3%	1%
Lead (Pb)	393	24%	0.3%	0%
Zinc (Zn)	400	2%	1%	0.2%

[1] Definitions of CS, MS, and FAV standard for each metal species can be found in Appendix B

Standard exceedances recorded during event-based sampling at station 99UM075 are outlined in Table 4.36. Only the metals Cd, Cu, Pb, and Zn are shown, as these were the only heavy metal species to exceed MPCA's CS, MS or FAV for Class 2B streams. The *Guidance Manual for assessing the Quality of Minnesota Surface Waters* (MPCA 2009), states that a water body is considered impaired if two or more exceedances of the CS occur within three years, or if one exceedance of the MS is recorded. Based on these criteria, Battle Creek could be listed as impaired for all four metals listed in Table 4.36. However, because "clean hands/dirty hands" sampling protocol was not followed, it is uncertain how much post-collection contamination has impacted metal measurements.

Lead concentrations observed at station 99UM075 are compared to MPCA standards in Figure 4.27. Additionally, Figure 4.28 shows the relationship between lead concentration and flow, and shows how lead concentrations are related to observed TSS concentrations. Figures similar to Figure 4.27 and Figure 4.28 for Cd, Cu, and Zn can be found in Appendix B.

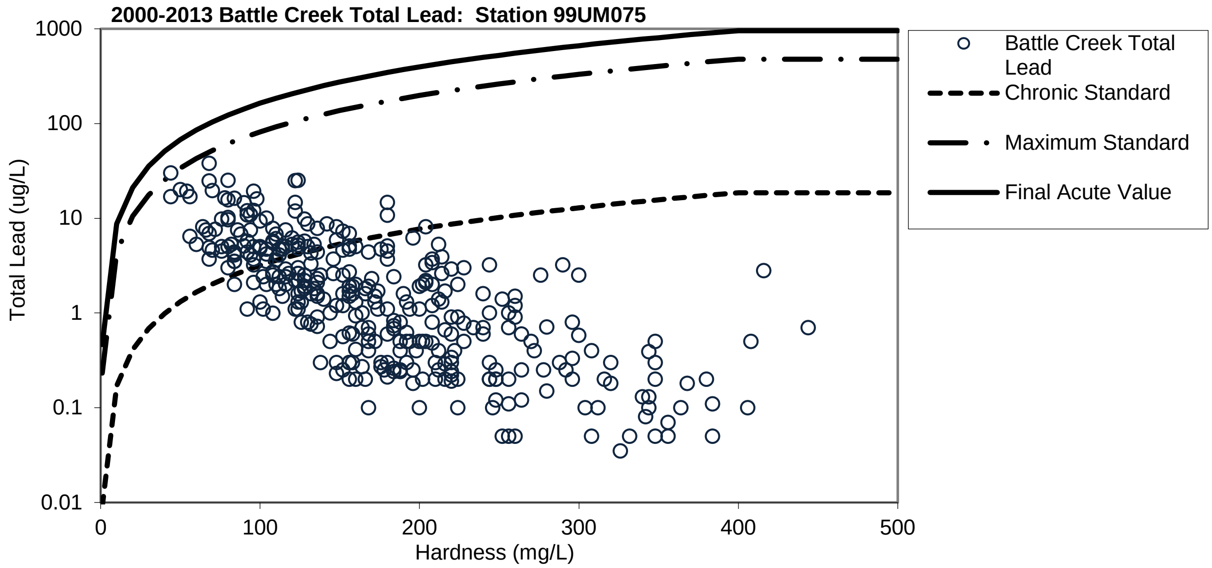


Figure 4.27 Total lead at station 99UM075, 2000-2013.

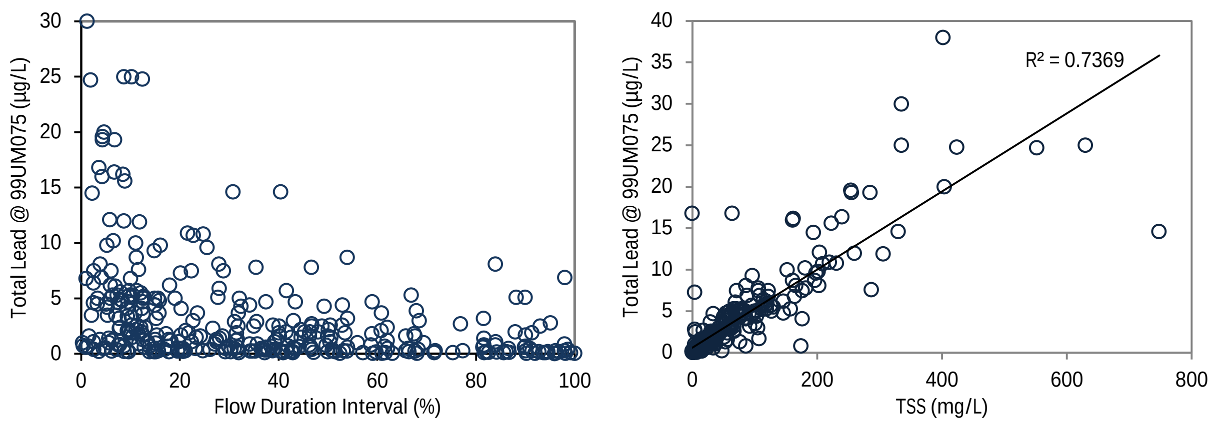


Figure 4.28 Total lead water quality duration curve (left) and relationship to TSS (right) at station 99UM075.

Figure 4.28 shows a water quality duration curve for total lead that appears similar to the water quality duration curve for TSS presented in Section 4.2.1 (see Figure 4.5), with higher total lead concentrations typically being associated with higher flows. The similarity in water quality duration curves is likely explained by the fact that TSS concentrations and total lead concentrations at station 99UM075 are highly correlated (Figure 4.28). The other three metals analyzed in this section (Cd, Cu, and Zn) are similarly related to TSS concentration (see Appendix B). The strong correlation between each of the metal species and TSS suggests that heavy metal delivery via sediment loading is the primary cause of elevated metal concentrations within Battle Creek.

Seasonal and annual metal standard exceedances are shown in Table 4.37 and Table 4.38. As can be seen, exceedances of the CS for Cd, Cu, Pb, and Zn are more common during the growing season (June-September), when sediment delivery is at its seasonal highest. Annual analysis shows that exceedances were particularly frequent in 2005. As can be seen, the average TSS concentration observed at station 99UM075 in 2005 was 110 mg/L, over three times the applicable MPCA standard of 30 mg TSS/L. Trends in annual and seasonal metal standard exceedances serves as further evidence that metal loading is highly associated with sediment loading in Battle Creek.

Table 4.37 Annual metal standard exceedances at station 99UM075.

Year	Average TSS Concentration (mg/L)	Total Lead (Pb)		Total Copper (Cu)		Total Cadmium (Cd)		Total Zinc (Zn)	
		Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)
2000	57	4	75%	4	25%	4	0%	5	20%
2001	33	21	29%	35	11%	34	0%	27	7%
2002	69	23	43%	36	14%	38	5%	30	0%
2003	86	1	0%	2	0%	2	0%	1	0%
2004	50	9	22%	17	0%	16	0%	9	0%
2005	110	28	71%	38	45%	39	5%	37	5%
2006	57	32	19%	32	13%	32	0%	52	4%
2007	69	42	31%	42	10%	42	0%	54	2%
2008	70	36	22%	36	8%	36	0%	36	0%
2009	77	31	29%	31	16%	31	0%	31	0%
2010	58	34	26%	34	6%	34	0%	34	3%
2011	37	24	13%	24	4%	24	0%	24	0%
2012	26	32	9%	32	0%	32	0%	32	0%
2013	19	29	3%	29	0%	29	3%	29	0%

Table 4.38 Seasonal metal standard exceedances at station 99UM075.

Month	Average TSS Concentration (mg/L)	Total Lead (Pb)		Total Copper (Cu)		Total Cadmium (Cd)		Total Zinc (Zn)	
		Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)	Number of Measurements	Percentage Exceeding Chronic Standard (%)
Jan	4	6	0%	6	0%	7	0%	7	0%
Feb	4	8	0%	9	0%	9	0%	10	0%
Mar	10	8	0%	8	0%	8	0%	9	0%
Apr	50	23	9%	25	8%	26	0%	26	0%
May	65	42	24%	46	11%	48	0%	52	6%
June	95	54	39%	63	27%	60	3%	65	3%
July	67	51	33%	60	12%	60	0%	57	0%
Aug	72	51	43%	57	16%	58	5%	58	3%
Sept	56	46	28%	50	8%	53	0%	51	4%
Oct	46	33	21%	41	5%	39	0%	37	0%
Nov	19	14	7%	16	0%	15	0%	17	0%
Dec	11	10	0%	11	0%	11	0%	12	0%

4.8.2 Stressor Pathway

As shown in Figure 3.9, elevated metal toxicity within Battle Creek is mainly attributed to urban development. Metals enter surface waters via non-point sources. Non-point sources include atmospheric emissions and land uses which contaminate soils with metals. Urban development is a contributing factor because it results in reduced water transpiration due to de-vegetation and reduced infiltration due to the increased impervious surface cover (compacted soil, roofs, parking lots, and roads. These reductions increase the volume and velocity of stormwater runoff entering surface waters. Accelerated flow can incise channels, reducing bank stability and increasing bank and channel erosion. Stormwater turbulence can re-suspend sediments, which may allow sediment associated metals to partition into the water column, or transport contaminated sediment into previously uncontaminated areas (Shaw-Allen, et al 2007).

Once in water, the bioavailability and toxicity of a metal is determined by its speciation, which is itself largely determined by several environmental parameters (e.g., pH, temperature, redox potential, ionic strength, presence of methylating microbes, and the availability of binding sites). Based on these parameters, free metal ions may precipitate as flocculates, form complexes with ligands (i.e., biotic or abiotic binding sites), become transformed to organometallic compounds (e.g., methylation in mercury), or sorb to solid particles (Shaw-Allen et al. 2007).

The physiological mechanisms of metal toxicity may translate into a broad spectrum of organism-level effects, ranging from altered behavior (avoidance of contaminated areas, increased susceptibility to predation or reduced success of predators) to outright lethality. Responses detectable in bio-surveys often are limited to increases in the relative abundance of metal-tolerant species, decreases in metal-sensitive species, and certain physical anomalies observed in fish. Examples of species often considered metal-tolerant include chironomids, caddisflies (tricoptera), small-bodied stoneflies (plecoptera), yellow perch, and central stonerollers; examples of metal-sensitive species include bivalves, mayflies, and salmonids. However, it should be kept in mind that biotic responses are both taxa- and metal-specific (Shaw-Allen et al. 2007).

4.8.3 Biological Response to Metals

To determine if elevated metal concentrations are impacting aquatic communities, biological metrics sensitive to metal toxicity were evaluated. As described in Section 4.8.2, elevated metal toxicity typically causes the relative abundance of metal-tolerant macroinvertebrate taxa, such as chironomidae, trichoptera, and plecoptera, to increase and the relative abundance of metal sensitive taxa, such as Ephemeroptera and mollusca, to decrease. Fish species typically identified as being tolerant (yellow perch, central stonerollers) or sensitive (salmonids) to metal toxicity have not been identified in large numbers in Battle Creek (only three yellow perch have been observed in all fish surveys), and for this reason will not be analyzed in this section. Descriptions of macroinvertebrate biological metrics sensitive to metal toxicity are described in Table 4.39, and results of the macroinvertebrate biological metric analysis are shown in Table 4.40.

Table 4.39 Metal sensitive macroinvertebrate biological metrics.

Group	Metric	Response to Metal Stress	Description
Macroinvertebrate	MolluscaPct	Decrease	Percent of total count identified as mollusca
Macroinvertebrate	EphemeropteraPct	Decrease	Percent of total count identified as ephemeroptera
Macroinvertebrate	PlecopteraPct	Increase	Percent of total count identified as plecoptera
Macroinvertebrate	TrichopteraPct	Increase	Percent of total count identified as tricoptera
Macroinvertebrate	ChironomidaeChPct	Increase	Percent of total count identified as chironomids

Table 4.40 Battle Creek macroinvertebrate biological metric data related to metal toxicity.

Metals Relevant Bio Metrics					MolluscaPct	EphemeropteraPct	PlecopteraPct	TrichopteraPct	ChironomidaeChPct
Station	Date	MI Class	MIBI Threshold	MIBI					
97UM008	8/23/2010	5	35.9	28	0.3	0.6	0	54.06	31.9
99UM075	8/13/2012	5	35.9	25	2.5	14.5	0	5.538	16.0
Average: All Minnesota Stations, Invert Class = 5					7.3	19.9	0.3	17.4	30.5
04UM011	9/2/2004	6	46.8	9	45.7	0.0	0	0	7.4
00UM071	9/11/2000	6	46.8	34	1.1	0.0	0	1.792	69.2
Average: All Minnesota Stations, Invert Class = 6					11.4	12.2	0.1	5.7	37.3
Expected response with increased stress					D	D	I	I	I

As can be seen, the relative abundance of metal-tolerant taxa groups does not appear to be consistently higher than the state average values from applicable invert stream classifications. The relative abundance of mollusca and Ephemeroptera does appear to be lower than state average values, but both metrics have been shown to be related to other stressors in Battle Creek (habitat fragmentation and chloride concentration, respectively). Each of the biological metrics in Table 4.40 was compared to monthly metal standard exceedances and average monthly metal concentrations, but no relationship could be identified. Based on the results of this analysis, there does not appear to be a clear relationship between metal toxicity and the macroinvertebrate community.

4.8.4 Strength of Evidence

Table 4.41 presents the SOE scores for metal toxicity. Several metal species (Cd, Cu, Pb, and Zn) have been found to exceed MPCA standards from chronic metal toxicity. However, because EPA "clean hands/dirty hands" sampling protocol was not followed, it is unclear to what extent post-collection contamination has impacted measured metal concentrations. Biological metrics analysis provides little evidence that macroinvertebrates are responding to elevated metal concentrations, although results may be impacted by other previously identified primary and secondary stressors, such as excess sediment, elevated phosphorus concentrations, and habitat fragmentation. Based on the analysis presented above and related SOE scoring, metal toxicity has been identified as a low priority, inconclusive stressor to the biological community within Battle Creek. For more information of SOE scoring, see Appendix A.

Table 4.41 Strength of evidence for metal toxicity.

Types of Evidence	Candidate Cause: Metal Toxicity
Evidence Using Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from the Field	0
Causal Pathway	0
Evidence of Exposure or Biological Mechanism	0
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	0
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	+
Stressor-Response Relationships from Laboratory Studies	+
Stressor-Response Relationships from Other Field Studies	+
Stressor-Response Relationships from Ecological Simulation Models	NE
Manipulation of Exposure at Other Sites	0
Analogous Stressors	NE
Evaluating Multiple Lines of Evidence	
Consistency of Evidence	-
Explanation of the Evidence	0

5. Conclusions and Recommendations

5.1 Summary of Probable Stressors

A summary of the probable primary, secondary, and inconclusive stressors to aquatic communities in Battle Creek is presented in Table 5.1. Identification of probable stressors is based on SOE scoring and related analysis, presented in Section 4. Of the seven candidate causes analyzed, biological impairment in Battle Creek was most strongly and consistently related to two probable primary stressors: (1) excess sediment; and (2) specific conductance and chloride. Excess sediment routinely exceeds MPCA water quality standards and was the only stressor found to have a degrading impact on both the fish and macroinvertebrate communities, based on biological metric analysis as well as TIV analysis. While specific conductance and chloride concentrations also routinely exceed MPCA standards, the grouped candidate cause was found to be clearly related to biological degradation only within the macroinvertebrate community. Low DO concentrations appear to be negatively impacting fish communities, particularly downstream of detention areas such as McKnight Basin, but due to limited DO and BOD data and the inconsistent response of the macroinvertebrate community, the grouped candidate cause of DO and BOD cannot be identified as a probable primary stressor.

Excess TP loading appears to be impacting the fish assemblage, but due to the direct relationship between phosphorus and other proximate stressors identified as candidate causes (e.g., DO and turbidity), it is difficult to assess how much of the response can be attributed to phosphorus loading. Altered habitat appears to be impacting the macroinvertebrate population in Battle Creek, particularly at downstream stations. The MSHA scoring and quantitative substrate measurements suggest that the response of the macroinvertebrate community can primarily be attributed to depth of fines and embeddedness, which increase from upstream to downstream. Habitat fragmentation appears to be restricting longitudinal fish movement, but the biological impact of this restriction is unclear due to compounding impacts of other, more primary stressors. Metal toxicity was not found to have unique, measureable impacts on either the fish or macroinvertebrate communities in Battle Creek.

Many of the candidate causes discussed above are interrelated, meaning that addressing one may indirectly impact another (e.g., reducing watershed sediment loading may reduce phosphorus and metal loading associated with sediment). For this reason, it is recommended that candidate causes identified as probable primary stressors be addressed with precedence over secondary and inconclusive stressors. Specific recommendations are discussed further in Section 5.2.

Table 5.1 Summary of probable stressors in the Battle Creek Watershed.

Stream Name	AUID	Biological Impairment	Candidate Causes: Excess Sediment	Specific Conductance and Chlorides	Dissolved Oxygen and BOD	Excess Total Phosphorus	Altered Habitat	Habitat Fragmentation	Metal Toxicity
Battle Creek	07010206-592	Fish	●	○	●*	◐	○	◐	○
		Macroinvertebrates	●	●	○	○	◐	○	○

● = probable primary stressor; ◐ = probable secondary stressor; ○ = inconclusive stressor

●* = probable station-specific primary stressor (e.g., DO impairment immediately downstream of detention areas)

5.2 Recommendations

Recommendations for each of the candidate causes discussed in Section 4 as well as inconclusive causes identified in Section 3.2 are presented in Table 5.2. As can be seen, it is recommended that a TMDL be created for sediment loading, and that Battle Creek be included in the Chloride TMDL for the TCMA being developed by the MPCA. Table 5.2 additionally outlines recommended management actions and monitoring efforts related to lower priority stressors and inclusive candidate causes.

Table 5.2 Recommendations to address biological impairment in Battle Creek.

Stressor	Priority	Recommendations
Candidate Causes		
Excess Sediment	High	· Create and implement TMDL for sediment loading (TSS loading). · TMDL should focus on watershed sediment loading, as well as sediment loading from the immediate stream channel.
Specific Conductance and Chloride	High	· Recommendation that Battle Creek be included in the Chloride TMDL for the TCMA being developed by the MPCA.
Dissolved Oxygen and BOD	Medium-High	· Increase longitudinal DO and BOD monitoring efforts along Battle Creek · Efforts should focus on determining (a) whether or not DO impairment is limited to stations immediately downstream of detention areas and (b) the source of DO impairment (BOD? TP? Temperature? In-stream detention? Low Flow? Chl-a? Etc.). · Consider (a) longitudinal deployment of continuous DO monitoring sensors and (b) additional pre-9 AM synoptic surveying efforts during the growing season. Simultaneous measurements of DO, BOD, TP, temperature, and flow will help determine potential sources of DO impairment.
Excess Total Phosphorus	Medium	· Continue longitudinal monitoring of TP concentrations. · TP monitoring should be conducted during TSS monitoring associated with sediment loading TMDL (to determine if reduced TSS loading also reduces TP loading).
Altered Habitat	Medium	· Continue MSHA surveying and request quantitative substrate measurements be taken during each survey. · Monitor survey results throughout sediment loading TMDL.
Habitat Fragmentation	Low	· Reassess biological metric impacts after other primary and secondary stressors addressed.
Metal Toxicity	Low	· Monitor concentrations of Cd, Cu, Pb, and Zn throughout sediment loading TMDL (to determine if reduced sediment loading reduces metal toxicity). · Reassess biological metric impacts after other primary and secondary stressors addressed.
Inconclusive Causes		
pH	Unknown	· Expand pH monitoring efforts along Battle Creek. · Include pH in event based sampling at station 99UM075 (WOMP station). · Include pH in future synoptic surveys (include pH flux monitoring).
Altered Hydrology	Unknown	· Continue flow monitoring at station 99UM075, and consider installing flow monitoring stations further upstream (potentially upstream and downstream of McKnight Basin). · Continue vegetation clearing and sediment removal maintenance efforts.

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Appendix A: Strength of Evidence (SOE) Scoring Methodology

Table A.1. Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Spatial/Temporal Co-occurrence		
The effect occurs where or when the candidate cause occurs, **OR** the effect does not occur where or when the candidate cause does not occur.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental.	+
It is uncertain whether the candidate cause and the effect co-occur.	This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous.	0
The effect does not occur where or when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur.	This finding *convincingly weakens* the case for the candidate cause, because causes must co-occur with their effects.	- - -
The effect does not occur where and when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause, because causes must co-occur with their effects.	R
Temporal Sequence		
The candidate cause occurred prior to the effect.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental.	+
The temporal relationship between the candidate cause and the effect is uncertain.	This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous.	0
The candidate cause occurs after the effect.	This finding *convincingly weakens* the case for the candidate cause, because causes cannot precede effects (note that this should be evaluated with caution when multiple sufficient causes are present).	- - -
The candidate cause occurs after the effect, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause, because effects cannot precede causes.	R
Stressor-Response Relationship from the Field		
A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, and the gradient is in the expected direction.	This finding *strongly supports* the case for the candidate cause, but is not convincing due to potential confounding.	+ +
A weak effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, **OR** a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, and the gradient is in the expected direction.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive due to potential confounding or random error.	+
An uncertain effect gradient is observed relative to exposure to the candidate cause.	This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous.	0
An inconsistent effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, **OR** a strong effect gradient is observed relative to exposure to the candidate cause, at non-spatially linked sites, but the gradient is not in the expected direction.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening due to potential confounding or random error.	-
A strong effect gradient is observed relative to exposure to the candidate cause, at spatially linked sites, but the relationship is not in the expected direction.	This finding *strongly weakens* the case for the candidate cause, but is not convincing due to potential confounding.	- -

Table A.1 (Continued). Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Causal Pathway		
Data show that all steps in at least one causal pathway are present.	This finding *strongly supports* the case for the candidate cause, because it is improbable that all steps occurred by chance; it is not convincing because these steps may not be sufficient to generate sufficient levels of the cause.	+ +
Data show that some steps in at least one causal pathway are present.	This finding *somewhat supports* the case for the candidate cause.	+
Data show that the presence of all steps in the causal pathway is uncertain.	This finding *neither supports nor weakens* the case for the candidate cause.	0
Data show that there is at least one missing step in each causal pathway.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because it may be due to temporal variability, problems in sampling or analysis, or unidentified alternative pathways.	-
Data show, with a high degree of certainty, that there is at least one missing step in each causal pathway.	This finding *convincingly weakens* the case for the candidate cause, assuming critical steps in each pathway are known, and are not found at the impaired site after a well-designed, well-performed, and sensitive study.	- - -
Evidence of Exposure or Biological Mechanism		
Data show that exposure or the biological mechanism is clear and consistently present.	This finding *strongly supports* the case for the candidate cause, but is not convincing because it does not establish that the level of exposure or mechanistic action was sufficient to cause the effect.	+ +
Data show that exposure or the biological mechanism is weak or inconsistently present.	This finding *somewhat supports* the case for the candidate cause.	+
Data show that exposure or the biological mechanism is uncertain.	This finding *neither supports nor weakens* the case for the candidate cause.	0
Data show that exposure or the biological mechanism is absent.	This finding *strongly weakens* the case for the candidate cause, but is not convincing because the exposure or the mechanism may have been missed.	- -
Data show that exposure or the biological mechanism is absent, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause.	R
Manipulation of Exposure		
The effect is eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect starts or increases when exposure to the candidate cause starts or increases.	This finding *strongly supports* the case for the candidate cause, but is not convincing because it may result from other factors (e.g., removal of more than one agent or other unintended effects of the manipulation).	+ + +
Changes in the effect after manipulation of the candidate cause are ambiguous.	This finding *neither supports nor weakens* the case for the candidate cause.	0
The effect is not eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect does not start or increase when exposure to the candidate cause starts or increases.	This finding *convincingly weakens* the case for the candidate cause, because such manipulations can avoid confounding. However, effects may continue if there are impediments to recolonization or if another sufficient cause is present.	- - -
The effect is not eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect does not start or increase when exposure to the candidate cause starts or increases, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause, given that data are based on a well-designed and well-performed study.	R

Table A.1 (Continued). Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Laboratory Tests of Site Media		
Laboratory tests with site media show clear biological effects that are closely related to the observed impairment.	This finding *convincingly supports* the case for the candidate cause.	+ + +
Laboratory tests with site media show ambiguous effects, **OR** clear effects that are not closely related to the observed impairment.	This finding *somewhat supports* the case for the candidate cause.	+
Laboratory tests with site media show uncertain effects.	This finding *neither supports nor weakens* the case for the candidate cause.	0
Laboratory tests with site media show no toxic effects that can be related to the observed impairment.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because test species, responses or conditions may be inappropriate relative to field conditions.	-
Verified Predictions		
Specific or multiple predictions of other effects of the candidate cause are confirmed.	This finding *convincingly supports* the case for the candidate cause, because predictions confirm a mechanistic understanding of the causal relationship, and verification of a predicted association is stronger evidence than associations explained after the fact.	+ + +
A general prediction of other effects of the candidate cause is confirmed.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because another cause may be responsible.	+
It is unclear whether predictions of other effects of the candidate cause are confirmed.	This finding *neither supports nor weakens* the case for the candidate cause.	0
A prediction of other effects of the candidate cause fails to be confirmed.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because other factors may mask or interfere with the predicted effect.	-
Multiple predictions of other effects of the candidate cause fail to be confirmed.	This finding *convincingly weakens* the case for the candidate cause.	- - -
Specific predictions of other effects of the candidate cause fail to be confirmed, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause.	R
Symptoms		
Symptoms or species occurrences observed at the site are diagnostic of the candidate cause.	This finding is sufficient to *diagnose* the candidate cause as the cause of the impairment, even without the support of other types of evidence.	D
Symptoms or species occurrences observed at the site include some but not all of a diagnostic set, **OR** symptoms or species occurrences observed at the site characterize the candidate cause and a few others.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because symptoms or species are indicative of multiple possible causes.	+
Symptoms or species occurrences observed at the site are ambiguous or occur with many causes.	This finding *neither supports nor weakens* the case for the candidate cause.	0
Symptoms or species occurrences observed at the site are contrary to the candidate cause.	This finding *convincingly weakens* the case for the candidate cause.	- - -
Symptoms or species occurrences observed at the site are indisputably contrary to the candidate cause.	This finding *refutes* the case for the candidate cause.	R

Table A.1 (Continued). Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Mechanistically Plausible Cause		
A plausible mechanism exists.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because levels of the agent may not be sufficient to cause the observed effect.	+
No mechanism is known.	This finding *neither supports nor weakens* the case for the candidate cause.	0
The candidate cause is mechanistically implausible.	This finding strongly weakens the case for the candidate cause, but is not convincing because the mechanism could be unknown.	- -
Stressor-Response Relationships from Other Field Studies		
The stressor-response relationship in the case agrees quantitatively with stressor-response relationships from other field studies.	This finding *strongly supports* the case for the candidate cause, but is not convincing because the correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and elsewhere.	+ +
The stressor-response relationship in the case agrees qualitatively with stressor -response relationships from other field studies.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the correspondence is only qualitative, and the degree of correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and elsewhere.	+
The agreement between the stressor-response relationship in the case and stressor-response relationships from other field studies is ambiguous.	This finding *neither supports nor weakens* the case for the candidate cause.	0
The stressor-response relationship in the case does not agree with stressor-response relationships from other field studies.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because there may be differences in organisms or conditions between the case and elsewhere.	-
There are large quantitative differences or clear qualitative differences between the stressor-response relationship in the case and the stressor-response relationships from other field studies.	This finding *strongly weakens* the case for the candidate cause, but is not convincing because there may be substantial and consistent differences in organisms or conditions between the case and elsewhere.	- -

Table A.1 (Continued). Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Stressor-Response Relationships from Laboratory Studies		
The observed relationship between exposure and effects in the case agrees quantitatively with stressor-response relationships in controlled laboratory experiments.	This finding *strongly supports* the case for the candidate cause, but is not convincing because the correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and the laboratory.	+ +
The observed relationship between exposure and effects in the case agrees qualitatively with stressor-response relationships in controlled laboratory experiments.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the correspondence is only qualitative, and the degree of correspondence could be coincidental due to confounding or differences in organisms or conditions between the case and the laboratory.	+
The agreement between the observed relationship between exposure and effects in the case and stressor-response relationships in controlled laboratory experiments is ambiguous.	This finding *neither supports nor weakens* the case for the candidate cause.	0
The observed relationship between exposure and effects in the case does not agree with stressor-response relationships in controlled laboratory experiments.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because there may be differences in organisms or conditions between the case and the laboratory.	-
The observed relationship between exposure and effects in the case does not even qualitatively agree with stressor-response relationships in controlled laboratory experiments, or the quantitative differences are very large.	This finding *strongly weakens* the case for the candidate cause, but is not convincing because there may be substantial and consistent differences in organisms or conditions between the case and the laboratory.	- -
Stressor-Response Relationships from Ecological Simulation Models		
The observed relationship between exposure and effects in the case agrees with the results of a simulation model.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because models may be adjusted to simulate the effects.	+
The results of simulation modeling are ambiguous.	This finding *neither supports nor weakens* the case for the candidate cause.	0
The observed relationship between exposure and effects in the case does not agree with the results of simulation modeling.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening, because it may be due to lack of correspondence between the model and site conditions.	-
Manipulation of Exposure at Other Sites		
At other sites, the effect is consistently eliminated or reduced when exposure to the candidate cause is eliminated or reduced, **OR** the effect is consistently starts or increases when exposure to the candidate cause starts or increases.	This finding *convincingly supports* the case for the candidate cause, because consistent results of manipulations at many sites are unlikely to be due to chance or irrelevant to the site being investigated.	+ + +
At other sites, the effect is eliminated or reduced at most sites when exposure to the candidate cause is eliminated or reduced, **OR** the effect starts or increases at most sites when exposure to the cause starts or increases.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because consistent results of manipulation at one or a few sites may be coincidental or irrelevant to the site being investigated.	+
Changes in the effect after manipulation of the candidate cause are ambiguous.	This finding *neither supports nor weakens* the case for the candidate cause.	0
At other sites, the effect is not consistently eliminated or reduced when exposure to the cause is eliminated or reduced, **OR** the effect does not consistently start or increase when exposure to the cause starts or increases.	This finding *strongly weakens* the case for the candidate cause, but is not convincing because failure to eliminate or induce effects at one or a few sites may be due to poorly conducted studies, or results may be irrelevant due to differences among sites.	- -

Table A.1 (Continued). Values used to score evidence in the Stressor Identification Process.

Finding	Interpretation	Score
Analogous Stressors		
Many similar agents at other sites consistently cause effects similar to the impairment.	This finding *strongly supports* the case for the candidate cause, but is not convincing because of potential differences among the agents or in conditions among the sites.	+ +
One or a few similar agents at other sites cause effects similar to the impairment.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because of potential differences among the agents or in conditions among the sites.	+
One or a few similar agents at other sites do not cause effects similar to the impairment.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because of potential differences among the agents or in conditions among the sites.	-
Many similar agents at other sites do not cause effects similar to the impairment.	This finding *strongly weakens* the case for the candidate cause, but is not convincing because of potential differences among the agents or in conditions among the sites.	- -
Consistency of Evidence		
All available types of evidence support the case for the candidate cause.	This finding *convincingly supports* the case for the candidate cause.	+ + +
All available types of evidence weaken the case for the candidate cause.	This finding *convincingly weakens* the candidate cause.	- - -
All available types of evidence support the case for the candidate cause, but few types are available.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because coincidence and errors may be responsible.	+
All available types of evidence weaken the case for the candidate cause, but few types are available.	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because coincidence and errors may be responsible.	-
The evidence is ambiguous or inadequate.	This finding *neither supports nor weakens* the case for the candidate cause.	0
Some available types of evidence support and some weaken the case for the candidate cause.	This finding *somewhat weakens* the case for the candidate cause, but is not convincing because a few inconsistencies may be explained.	-
Explanation of the Evidence		
There is a credible explanation for any negative inconsistencies or ambiguities in an otherwise positive body of evidence that could make the body of evidence consistently supporting.	This finding can save the case for a candidate cause that is weakened by inconsistent evidence; however, without evidence to support the explanation, the cause is barely strengthened.	+ +
There is no explanation for the inconsistencies or ambiguities in the evidence.	This finding neither strengthens nor weakens the case for a candidate cause.	0
There is a credible explanation for any positive inconsistencies or ambiguities in an otherwise negative body of evidence that could make the body of evidence consistently weakening.	This finding further weakens an inconsistent case; however, without evidence to support the explanation, the cause is barely weakened.	-

Appendix B: Metal Standards and Data

Table B.1 MPCA metal standards for Class 2B streams.

Metal	MPCA Standard (Minn. R. Pt. 7050.0222, subpart 4; Class 2B streams). Total metal concentration shall not exceed:	
	CS (µg/L)	MS (µg/L)
Cadmium (Cd), total	exp.(0.7852[ln(total hardness mg/L)]-3.490)	exp.(1.128[ln(total hardness mg/L)]-1.685)
Chromium (Cr), total	exp.(0.819[ln(total hardness mg/L)]+1.561)	exp.(0.819[ln(total hardness mg/L)]+3.688)
Copper (Cu), total	exp.(0.6200[ln(total hardness mg/L)]-0.570)	exp.(0.9422[ln(total hardness mg/L)]-1.464)
Lead (Pb), total	exp.(1.273[ln(total hardness mg/L)]-4.705)	exp.(1.273[ln(total hardness mg/L)]-1.460)
Nickel (Ni), total	exp.(0.846[ln(total hardness mg/L)]+1.1645)	exp.(0.846[ln(total hardness mg/L)]+3.3612)
Zinc (Zn), total	exp.(0.8473[ln(total hardness mg/L)]+0.7615)	exp.(0.8473[ln(total hardness mg/L)]+0.8604)
Metal	FAV (µg/L)	
Cadmium (Cd), total	exp.(1.128[ln(total hardness mg/L)]-0.9919)	
Chromium (Cr), total	exp.(0.819[ln(total hardness mg/L)]+4.380)	
Copper (Cu), total	exp.(0.9422[ln(total hardness mg/L)]-0.7703)	
Lead (Pb), total	exp.(1.273[ln(total hardness mg/L)]-0.7643)	
Nickel (Ni), total	exp.(0.846[ln(total hardness mg/l)]+4.0543)	
Zinc (Zn), total	exp.(0.8473[ln(total hardness mg/L)]+1.5536)	

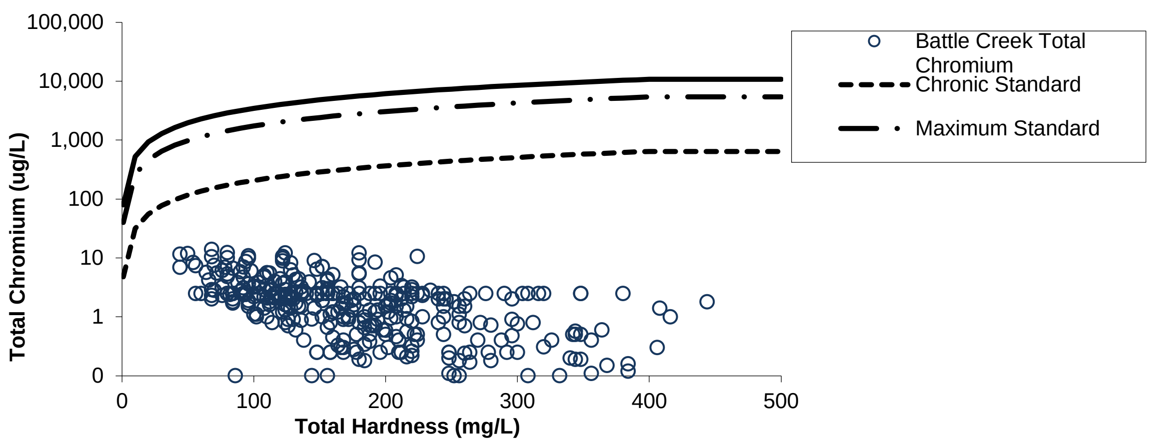


Figure B.1 Total chromium at station 99UM075, 2000-2013.

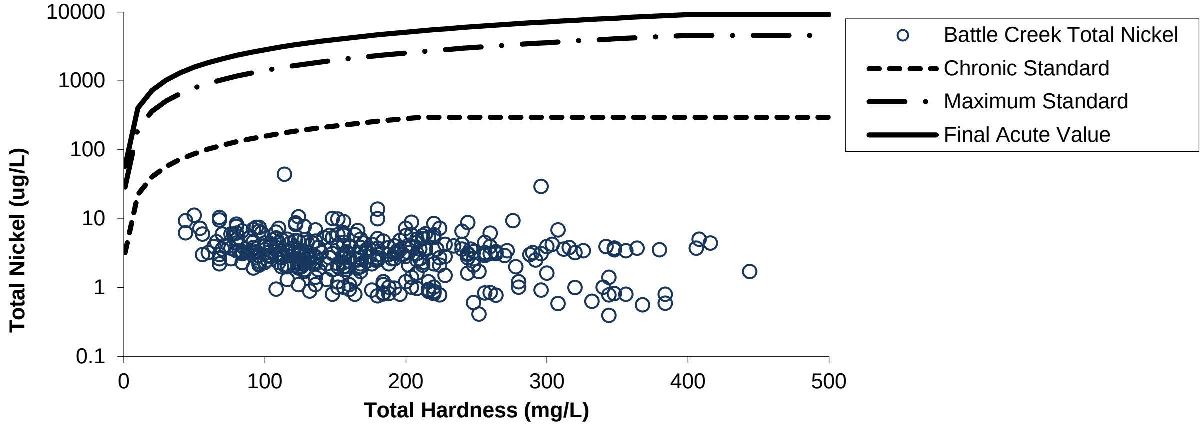
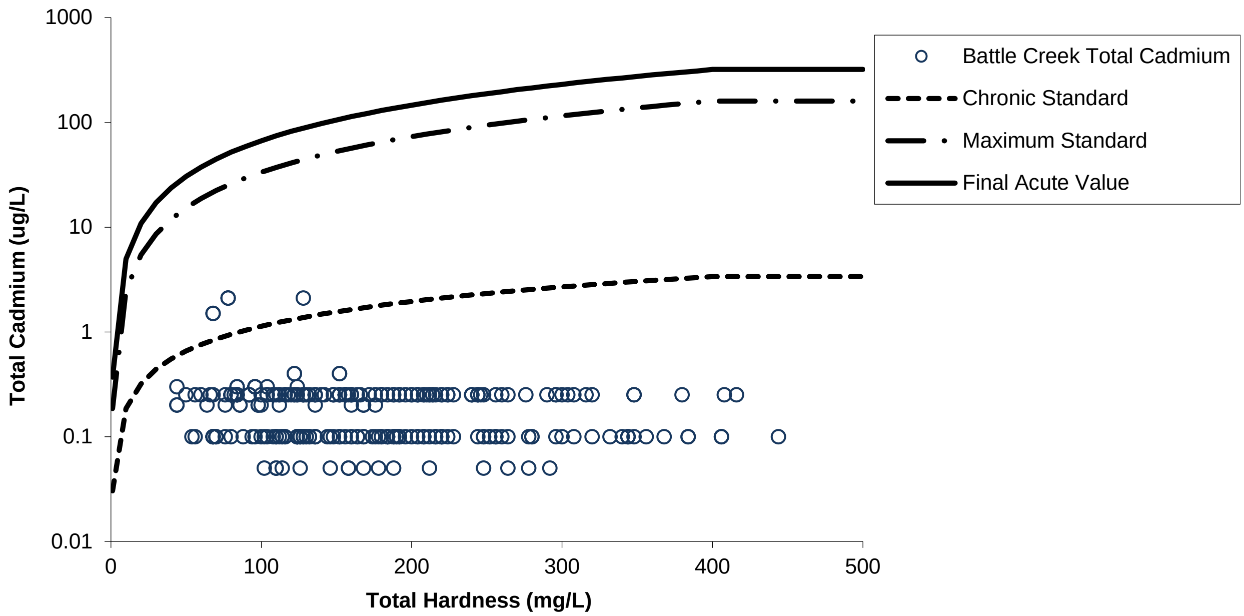


Figure B.2 Total nickel at station 99UM075, 2000-2013.



FigureB.3 Total cadmium at station 99UM075, 2000-2013.

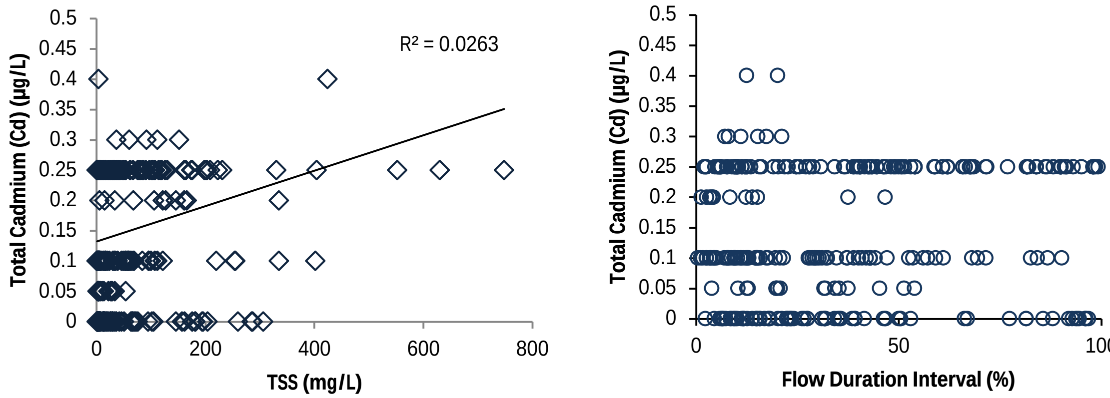


Figure B.4 Total cadmium water quality duration curve (left) and relationship to TSS (right) at station 99UM075.

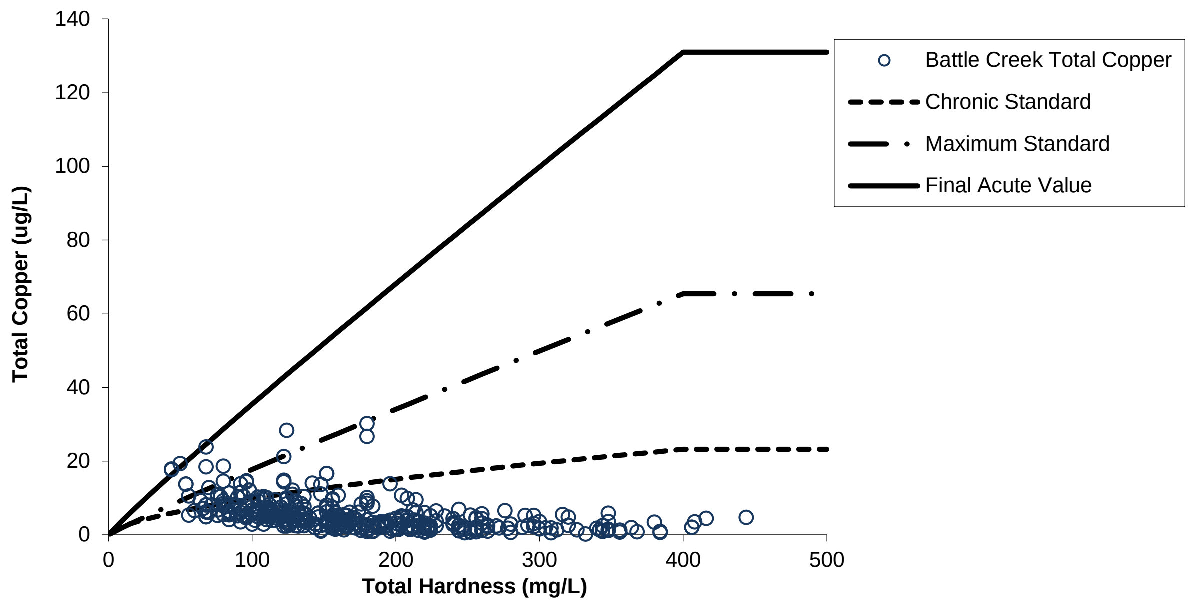


Figure B.5 Total copper at station 99UM075, 2000-2013.

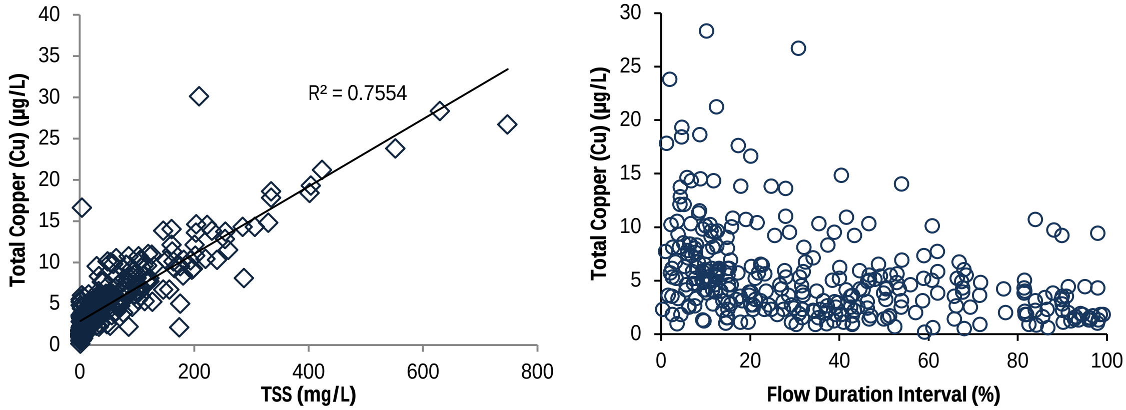


Figure B.6 **Total copper water quality duration curve (left) and relationship to TSS (right) at station 99UM075.**

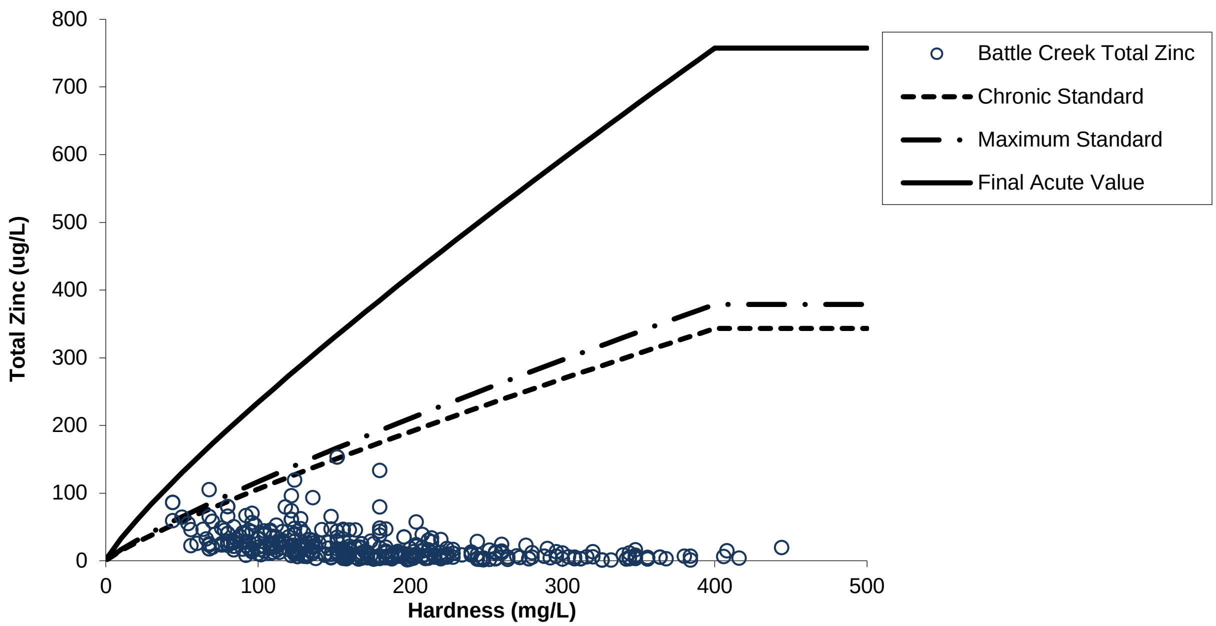
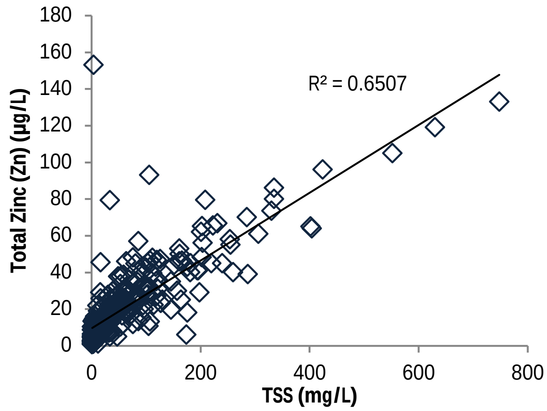


Figure B.7 **Total zinc at station 99UM075, 2000-2013.**



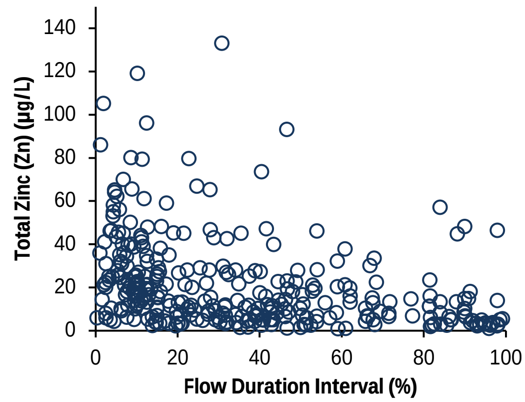


Figure B.8 Total zinc water quality duration curve (left) and relationship to TSS (right) at station 99UM075.

Appendix C: MSHA Assessment Worksheets

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream: Battle Creek
County: ______ Date: 8/21/2000
Field Number: ______ Person Scoring: ______
Site Location: 00UM071

MSHA SCORE Max = 100: 38 Poor

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☑	☑	Forest, Wetland, Prairie, Shrub	[5]	☐	☑	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☑	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use Max=5: 3

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300'	[5]
☐	☑	Wide	150'-300'	[4]
☑	☐	Moderate	30'-150'	[3]
☐	☐	Narrow	15'-30'	[2]
☐	☐	Very Narrow	3'-15'	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☐	☑	Little	5-25%	[4]
☑	☐	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☐	☐	Heavy	>75%	[5]
☐	☐	Substantial	50-75%	[4]
☑	☑	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian Max=15: 8

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder [10]	Cobble [9]	Gravel [8]	Sand [7]	Clay [5]	Bedrock [5]	Silt [2]	Muck [1]	Detritus [1]	Sludge [0]	Channel Type %
Pool	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0
Riffle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0
Run	☐	☐	☐	☐	☑	☐	☐	☐	☑	☐	100
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0

B. Embeddedness

- ☐ None [5]
- ☐ Light 25-50% [3]
- ☐ Moderate 50-75% [1]
- ☐ Severe 75-100% [-1]
- ☑ No coarse substrate [0]

C. Substrate Types

- ☐ >4 [2]
- ☑ <=4 [0]

D. Water Color

- ☐ Clear
- ☐ Stained
- Turbid: ☐ Brown ☐ Green ☐ Other

Substrate Max=27: 6

E. Cover Type (check all that apply)

- ☑ Undercut Banks [1]
- ☑ Overhanging Vegetation [1]
- ☐ Deep Pools [1]
- ☑ Logs or Woody Debris [1]
- ☐ Boulders [1]
- ☐ Rootwads [1]
- ☑ Macrophytes: [1]
  - ☑ Emergent
  - ☐ Floating Leaf
  - ☑ Submergent

F. Cover Amount (check one)

- ☐ Extensive >50% [10]
- ☐ Moderate 25-50% [7]
- ☑ Sparse 5-25% [3]
- ☐ Nearly Absent [0]
- ☐ Choking Vegetation only [-1]

Cover Max=17: 7

5. Channel Morphology

A. Depth Variability

- ☐ Greatest Depth >4X Shallow Depth [6]
- ☑ Greatest Depth 2-4X Shallow Depth [3]
- ☐ Greatest Depth <2X Shallow Depth [0]

B. Channel Stability

- ☐ High [9]
- ☑ Moderate/High [6]
- ☐ Moderate [3]
- ☐ Low [0]

C. Velocity Types (check all that apply)

- ☐ Torrential [-1]
- ☑ Fast [1]
- ☑ Moderate [1]
- ☑ Slow [1]
- ☐ Eddies [1]
- ☐ Intermittent [-2]
- ☐ Interstitial [-1]

D. Sinuosity

- ☐ Excellent [6]
- ☑ Good [4]
- ☑ Fair [2]
- ☐ Poor [0]

3

E. Pool Width/Riffle Width

- ☐ Pool Width > Riffle Width [2]
- ☐ Pool Width = Riffle Width [1]
- ☐ Pool Width < Riffle Width [0]
- ☑ No Riffle [0]

F. Channel Development

- ☐ Excellent [9]
- ☐ Good [6]
- ☑ Fair [3]
- ☐ Poor [0]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☐ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology Max=36: 14

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream Battle Creek

County ____ Date 7/13/10

Field Number ____ Person Scoring ____

Site Location 97UM008

MSHA SCORE

Max = 100 75.5

Good

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☐	☐	Forest, Wetland, Prairie, Shrub	[5]	☑	☑	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use 2 Max=5

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300'	[5]
☑	☐	Wide	150'-300'	[4]
☐	☐	Moderate	30'-150'	[3]
☐	☑	Narrow	15'-30'	[2]
☐	☐	Very Narrow	3'-15'	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☑	☑	Little	5-25%	[4]
☐	☐	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☐	☐	Heavy	>75%	[5]
☑	☑	Substantial	50-75%	[4]
☐	☐	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian 11 Max=15

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder [10]	Cobble [9]	Gravel [8]	Sand [7]	Clay [5]	Bedrock [5]	Silt [2]	Muck [1]	Detritus [1]	Sludge [0]	Channel Type %
Pool	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	15
Riffle	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	20
Run	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐	65
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0

B. Embeddedness

- ☐ None [5]
- ☑ Light 25-50% [3]
- ☐ Moderate 50-75% [1]
- ☐ Severe 75-100% [-1]
- ☐ No coarse substrate [0]

C. Substrate Types

- ☑ >4 [2]
- ☐ <=4 [0]

D. Water Color

- ☑ Clear
- ☐ Stained

Turbid
- ☐ Brown
- ☐ Green
- ☐ Other

Substrate 19.5 Max=27

E. Cover Type (check all that apply)

- ☐ Undercut Banks [1]
- ☑ Overhanging Vegetation [1]
- ☑ Deep Pools [1]
- ☑ Logs or Woody Debris [1]
- ☑ Boulders [1]
- ☐ Rootwads [1]
- ☐ Macrophytes: [1]
  - ☐ Emergent
  - ☐ Floating Leaf
  - ☐ Submergent

F. Cover Amount (check one)

- ☐ Extensive >50% [10]
- ☑ Moderate 25-50% [7]
- ☐ Sparse 5-25% [3]
- ☐ Nearly Absent [0]
- ☐ Choking Vegetation only [-1]

Cover 11 Max=17

5. Channel Morphology

A. Depth Variability

- ☑ Greatest Depth >4X Shallow Depth [6]
- ☐ Greatest Depth 2-4X Shallow Depth [3]
- ☐ Greatest Depth <2X Shallow Depth [0]

B. Channel Stability

- ☐ High [9]
- ☐ Moderate/High [6]
- ☑ Moderate [3]
- ☐ Low [0]

C. Velocity Types (check all that apply)

- ☐ Torrential [-1]
- ☑ Fast [1]
- ☑ Moderate [1]
- ☑ Slow [1]
- ☐ Eddies [1]
- ☐ Intermittent [-2]
- ☐ Interstitial [-1]

D. Sinuosity

- ☑ Excellent [6]
- ☐ Good [4]
- ☐ Fair [2]
- ☐ Poor [0]

E. Pool Width/Riffle Width

- ☑ Pool Width > Riffle Width [2]
- ☐ Pool Width = Riffle Width [1]
- ☐ Pool Width < Riffle Width [0]
- ☐ No Riffle [0]

F. Channel Development

- ☑ Excellent [9]
- ☐ Good [6]
- ☐ Fair [3]
- ☐ Poor [0]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☑ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology 32 Max=36

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream: Battle Creek

County: ______ Date: 7/23/2012

Field Number: ______ Person Scoring: ______

Site Location: 974M008

MSHA SCORE Max = 100: 55.75

Fair = 55.75

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☐	☐	Forest, Wetland, Prairie, Shrub	[5]	☑	☑	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use Max=5: 2

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300'	[5]
☐	☐	Wide	150'-300'	[4]
☑	☐	Moderate	30'-150'	[3]
☐	☑	Narrow	15'-30'	[2]
☐	☐	Very Narrow	3'-15'	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☑	☐	Little	5-25%	[4]
☐	☑	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☑	☑	Heavy	>75%	[5]
☐	☐	Substantial	50-75%	[4]
☐	☐	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian Max=15: 11

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder [10]	Cobble [9]	Gravel [8]	Sand [7]	Clay [5]	Bedrock [5]	Silt [2]	Muck [1]	Detritus [1]	Sludge [0]	Channel Type %
Pool	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	25
Riffle	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	10
Run	☐	☐	☐	☑	☑	☐	☐	☐	☐	☐	65
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

B. Embeddedness

- ☐ None [5]
- ☐ Light 25-50% [3]
- ☑ Moderate 50-75% [1]
- ☐ Severe 75-100% [-1]
- ☐ No coarse substrate [0]

C. Substrate Types

- ☑ >4 [2]
- ☐ <=4 [0]

D. Water Color

- ☐ Clear
- ☑ Stained
- Turbid
  - ☐ Brown
  - ☐ Green
  - ☐ Other

Substrate Max=27: 14.75

14.75

E. Cover Type (check all that apply)

- ☑ Undercut Banks [1]
- ☑ Overhanging Vegetation [1]
- ☑ Deep Pools [1]
- ☑ Logs or Woody Debris [1]
- ☑ Boulders [1]
- ☑ Rootwads [1]
- ☐ Macrophytes: [1]
  - ☐ Emergent
  - ☐ Floating Leaf
  - ☐ Submergent

F. Cover Amount (check one)

- ☐ Extensive >50% [10]
- ☐ Moderate 25-50% [7]
- ☑ Sparse 5-25% [3]
- ☐ Nearly Absent [0]
- ☐ Choking Vegetation only [-1]

Cover Max=17: 9

5. Channel Morphology

A. Depth Variability

- ☑ Greatest Depth >4X Shallow Depth [6]
- ☐ Greatest Depth 2-4X Shallow Depth [3]
- ☐ Greatest Depth <2X Shallow Depth [0]

B. Channel Stability

- ☐ High [9]
- ☐ Moderate/High [6]
- ☑ Moderate [3]
- ☐ Low [0]

C. Velocity Types (check all that apply)

- ☐ Torrential [-1]
- ☐ Fast [1]
- ☑ Moderate [1]
- ☑ Slow [1]
- ☑ Eddies [1]
- ☐ Intermittent [-2]
- ☐ Interstitial [-1]

D. Sinuosity

- ☐ Excellent [6]
- ☐ Good [4]
- ☑ Fair [2]
- ☐ Poor [0]

E. Pool Width/Riffle Width

- ☑ Pool Width > Riffle Width [2]
- ☐ Pool Width = Riffle Width [1]
- ☐ Pool Width < Riffle Width [0]
- ☐ No Riffle [0]

F. Channel Development

- ☐ Excellent [9]
- ☐ Good [6]
- ☑ Fair [3]
- ☐ Poor [0]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☑ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology Max=36: 19

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream: Battle Creek

County: ______ Date: 7/31/2012

Field Number: ______ Person Scoring: ______

Site Location: 99UM075

MSHA SCORE Max = 100: 75.55 Good

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☑	☑	Forest, Wetland, Prairie, Shrub	[5]	☑	☑	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use Max=5: 3

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☒	☒	Extensive	> 300'	[5]
☐	☐	Wide	150'-300'	[4]
☐	☐	Moderate	30'-150'	[3]
☐	☐	Narrow	15'-30'	[2]
☐	☐	Very Narrow	3'-15'	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☒	☒	Little	5-25%	[4]
☐	☐	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☒	☐	Heavy	>75%	[5]
☐	☒	Substantial	50-75%	[4]
☐	☐	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian Max=15: 13.5

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder [10]	Cobble [9]	Gravel [8]	Sand [7]	Clay [5]	Bedrock [5]	Silt [2]	Muck [1]	Detritus [1]	Sludge [0]	Channel Type %
Pool	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐	20
Riffle	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	25
Run	☐	☑	☐	☑	☐	☐	☐	☐	☐	☐	55
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0

B. Embeddedness

- ☐ None [5]
- ☒ Light 25-50% [3]
- ☐ Moderate 50-75% [1]
- ☐ Severe 75-100% [-1]
- ☐ No coarse substrate [0]

C. Substrate Types

- ☒ >4 [2]
- ☐ <=4 [0]

D. Water Color

- ☒ Clear
- ☐ Stained

Turbid
- ☐ Brown
- ☐ Green
- ☐ Other

Substrate Max=27: 21.05

21.05

E. Cover Type (check all that apply)

- ☒ Undercut Banks [1]
- ☒ Overhanging Vegetation [1]
- ☒ Deep Pools [1]
- ☒ Logs or Woody Debris [1]
- ☒ Boulders [1]
- ☒ Rootwads [1]
- ☒ Macrophytes: [1]
  - ☐ Emergent
  - ☐ Floating Leaf
  - ☒ Submergent

F. Cover Amount (check one)

- ☐ Extensive >50% [10]
- ☒ Moderate 25-50% [7]
- ☐ Sparse 5-25% [3]
- ☐ Nearly Absent [0]
- ☐ Choking Vegetation only [-1]

Cover Max=17: 14

5. Channel Morphology

A. Depth Variability

- ☒ Greatest Depth >4X Shallow Depth [6]
- ☐ Greatest Depth 2-4X Shallow Depth [3]
- ☐ Greatest Depth <2X Shallow Depth [0]

B. Channel Stability

- ☐ High [9]
- ☐ Moderate/High [6]
- ☒ Moderate [3]
- ☐ Low [0]

C. Velocity Types (check all that apply)

- ☐ Torrential [-1]
- ☒ Fast [1]
- ☒ Moderate [1]
- ☒ Slow [1]
- ☒ Eddies [1]
- ☐ Intermittent [-2]
- ☐ Interstitial [-1]

D. Sinuosity

- ☐ Excellent [6]
- ☐ Good [4]
- ☐ Fair [2]
- ☒ Poor [0]

E. Pool Width/Riffle Width

- ☒ Pool Width > Riffle Width [2]
- ☐ Pool Width = Riffle Width [1]
- ☐ Pool Width < Riffle Width [0]
- ☐ No Riffle [0]

F. Channel Development

- ☐ Excellent [9]
- ☒ Good [6]
- ☐ Fair [3]
- ☐ Poor [0]

G. Present Water Level

- ☐ Flood
- ☐ High
- ☒ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology Max=36: 24

Total = 75.55 = Good

MPCA STREAM HABITAT ASSESSMENT

(revised 3-07)

1. Stream Documentation

Stream: Battle Creek

County: ____ Date: 7/23/2012

Field Number: 12UM148 Person Scoring: ____

Site Location: ____

MSHA SCORE Max = 100: 57.2 FAIR

2. Surrounding Land Use (check the most predominant or check two and average scores) [L=left bank/R =right bank, facing downstream]

L	R			L	R		
☐	☐	Forest, Wetland, Prairie, Shrub	[5]	☑	☑	Residential/Park	[2]
☐	☐	Old Field/Hay Field	[3]	☐	☐	Urban/Industrial	[0]
☐	☐	Fenced Pasture	[2]	☐	☐	Open Pasture	[0]
☐	☐	Conservation Tillage, No Till	[2]	☐	☐	Row Crop	[0]

Land Use Max=5: 2

3. Riparian Zone (check the most predominant)

A. Riparian Width

L	R			
☐	☐	Extensive	> 300'	[5]
☑	☑	Wide	150'-300'	[4]
☐	☐	Moderate	30'-150'	[3]
☐	☐	Narrow	15'-30'	[2]
☐	☐	Very Narrow	3'-15'	[1]
☐	☐	None		[0]

B. Bank Erosion

L	R			
☐	☐	None		[5]
☐	☐	Little	5-25%	[4]
☑	☑	Moderate	25-50%	[3]
☐	☐	Heavy	50-75%	[1]
☐	☐	Severe	75-100%	[0]

C. Shade

L	R			
☐	☐	Heavy	>75%	[5]
☐	☐	Substantial	50-75%	[4]
☑	☑	Moderate	25-50%	[2]
☐	☐	Light	5-25%	[1]
☐	☐	None		[0]

Riparian Max=15: 9

4. Instream Zone

A. Substrate (check two for each channel type)

	Boulder [10]	Cobble [9]	Gravel [8]	Sand [7]	Clay [5]	Bedrock [5]	Silt [2]	Muck [1]	Detritus [1]	Sludge [0]	Channel Type %
Pool	☐	☐	☐	☑	☑	☐	☐	☐	☐	☐	10
Riffle	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐	25
Run	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐	65
Glide	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	0

B. Embeddedness

- ☐ None [5]
- ☑ Light 25-50% [3]
- ☐ Moderate 50-75% [1]
- ☐ Severe 75-100% [-1]
- ☐ No coarse substrate [0]

C. Substrate Types

- ☑ >4 [2]
- ☐ <=4 [0]

D. Water Color NOT RECORDED

- ☐ Clear
- ☑ Stained
- Turbid
  - ☐ Brown
  - ☐ Green
  - ☐ Other

Substrate Max=27: 18.2

E. Cover Type (check all that apply)

- ☑ Undercut Banks [1]
- ☑ Overhanging Vegetation [1]
- ☑ Deep Pools [1]
- ☑ Logs or Woody Debris [1]
- ☑ Boulders [1]
- ☐ Rootwads [1]
- ☐ Macrophytes: [1]
  - ☐ Emergent
  - ☐ Floating Leaf
  - ☐ Submergent

F. Cover Amount (check one)

- ☐ Extensive >50% [10]
- ☐ Moderate 25-50% [7]
- ☑ Sparse 5-25% [3]
- ☐ Nearly Absent [0]
- ☐ Choking Vegetation only [-1]

Cover Max=17: 8

5. Channel Morphology

A. Depth Variability

- ☐ Greatest Depth >4X Shallow Depth [6]
- ☑ Greatest Depth 2-4X Shallow Depth [3]
- ☐ Greatest Depth <2X Shallow Depth [0]

B. Channel Stability

- ☐ High [9]
- ☐ Moderate/High [6]
- ☐ Moderate [3]
- ☐ Low [0]
- ☑ [2]

C. Velocity Types (check all that apply)

- ☐ Torrential [-1]
- ☑ Fast [1]
- ☑ Moderate [1]
- ☑ Slow [1]
- ☑ Eddies [1]
- ☐ Intermittent [-2]
- ☐ Interstitial [-1]

D. Sinuosity

- ☐ Excellent [6]
- ☐ Good [4]
- ☐ Fair [2]
- ☐ Poor [0]
- ☑ [3]

E. Pool Width/Riffle Width

- ☐ Pool Width > Riffle Width [2]
- ☑ Pool Width = Riffle Width [1]
- ☐ Pool Width < Riffle Width [0]
- ☐ No Riffle [0]

F. Channel Development

- ☐ Excellent [9]
- ☐ Good [6]
- ☑ Fair [3]
- ☐ Poor [0]

G. Present Water Level

- ☑ [3]
- ☐ Flood
- ☐ High
- ☐ Normal
- ☐ Low
- ☐ Interstitial

Channel Morphology Max=36: 20