Grove Creek
Stressor Identification Report

A study of local stressors causing degraded fish and aquatic macroinvertebrate communities in a tributary to the North Fork Crow River

Minnesota Pollution Control Agency

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Executive Summary

This report summarizes the key causes, or “stressors,” contributing to impaired fish and aquatic macroinvertebrate communities in Grove Creek, a small tributary to the North Fork Crow River located in west central Minnesota.

Initially, a comprehensive review of existing biological, chemical, and physical data was performed to create a list of candidate causes for the impairments. The initial list of candidate causes was narrowed down after additional data analysis, leaving five candidate causes for the final analysis included in this report. The candidate causes evaluated in this report are listed below, along with a brief summary of their impact in this watershed. From the list of candidate causes, three were diagnosed as probable causes for biological impairments: loss of habitat due to excess deposited and bedded sediment, low dissolved oxygen (DO), and elevated turbidity/total suspended solids (TSS).

1. **Turbidity / total suspended solids** **Status: Diagnosed as probable cause**
   Turbidity and TSS concentrations were above current and draft thresholds for protecting aquatic life, particularly in the lower reaches of Grove Creek. Biological effects linked to this stressor include reduced collector-filterer macroinvertebrates and a fish community comprised of species that are tolerant of high turbidity levels and elevated TSS concentrations.

2. **Excess deposited and bedded sediments** **Status: Diagnosed as probable cause**
   Stream substrate material of Grove Creek is dominated by fines (silt/clay/sand) and the available coarse substrate is often highly embedded by fines. Biological effects linked to this stressor include; low richness/abundance of fish that use coarse substrates for spawning and low clinger macroinvertebrate taxa richness at sites with highly embedded substrates.

3. **Toxicity or stress from:**
   a. **Elevated nitrate-N concentrations** **Status: Remain a candidate stressor**
      Nitrate-N concentrations exceed 4.9 mg/L (value of the draft chronic standard) on occasion in the Grove Creek. It is unclear whether the duration of exposure to elevated nitrate-N concentrations is long enough to cause stress to aquatic life. Biological responses to nitrate were difficult to evaluate due to confounding stressors. Nitrate should remain a candidate cause to be re-evaluated when Minnesota’s nitrate standards to protect aquatic life are finalized.

   b. **Pesticides (herbicides, insecticides, fungicides)** **Status: Remain a candidate stressor**
      Several common pesticides were detected in Grove Creek. However, concentrations were generally low and did not exceed established water quality standards. At this time, pesticide toxicity does not appear to be a major stressor in the watershed, although additional monitoring is recommended due to the rate of pesticide application in the watershed.

4. **Low dissolved oxygen concentrations** **Status: Diagnosed as probable cause**
   Low, and highly fluctuating DO concentrations are common occurrences in most reaches of Grove Creek. Biological effects linked to low DO included low fish abundance, lack of sensitive fish and macroinvertebrate taxa, and biological assemblages dominated by tolerant species.

1.0 Background Information on Watershed and Impairments

Location and scale of impaired reach

Assessments completed between the years of 2002 and 2006 resulted in four tributary streams to the North Fork Crow / Crow River being listed as impaired due to impaired biotic communities. Grove Creek, a warm water tributary in the south central region of the watershed near Grove City, Minnesota was one of the streams listed for failing to meet indices of biological integrity (IBI) criteria for fish and aquatic macroinvertebrates. The details of this impairment listing, as well as information on water quality-based impairments in Grove Creek, are summarized in Table 1.

Table 1: **Tributaries to the North Fork Crow / Crow River with biota impairments**

			Impairments	
Stream Name	**AUID #**	**Reach Description**	**Biological**	**Water Quality***
Grove Creek	07010204-514	Unnamed Cr to N Fk Crow R	Fish IBI / Invertebrate IBI	DO, T

* DO = Low Dissolved Oxygen   T = Turbidity

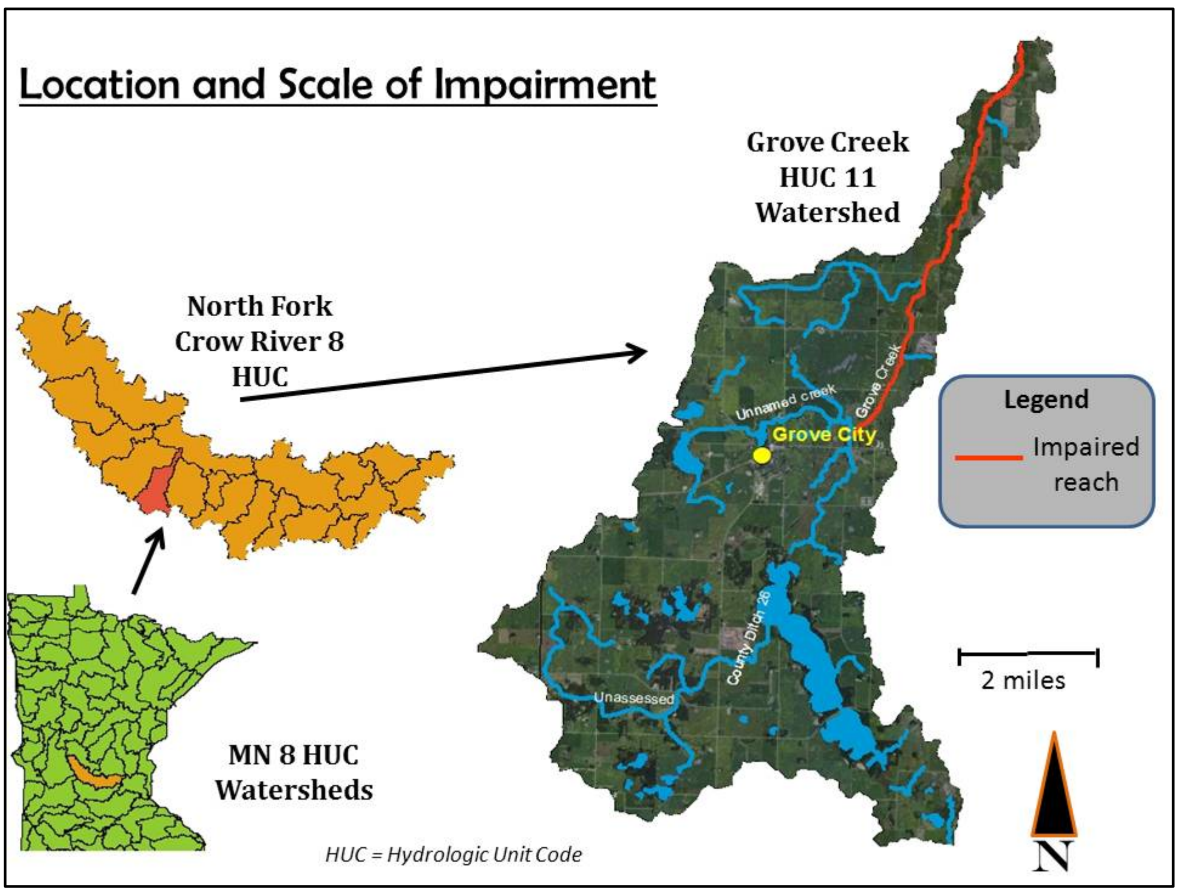


Figure 1: Location of North Fork Crow River tributaries with biological impairment

Watershed information

Grove Creek is a third-order (Strahler) tributary of the North Fork Crow River with a drainage area of 51.2 mi^2 and a slope of about 4.48 ft/mile (USGS Streamstats). The surface area of the watershed is about 10% covered by lakes and ponds. Long Lake (771 acres) is located near the headwaters of Grove Creek and contributes to the chemical and hydrological character of the creek. Cultivated cropland is the dominant land-cover type in the watershed (70%), followed by pasture/hay land (8%). The largest city in the watershed is Grove City, with a population of 635 (2010 census).

Much of Grove Creek was channelized prior to the 1930s, especially in the upper half of the watershed. However, based on aerial photos taken in 1939, it appears that much of the stream downstream from 570th Avenue (just downstream of site GC-5 on map) remained in natural channel and was never channelized. For additional information on this watershed, refer to the MPCA's Watershed Assessment [North Fork Crow River Watershed Assessment Report](#).

The biological and water chemistry monitoring sites used in this report are shown in Figure 1. The site codes listed under "map ID" will be used throughout this report.

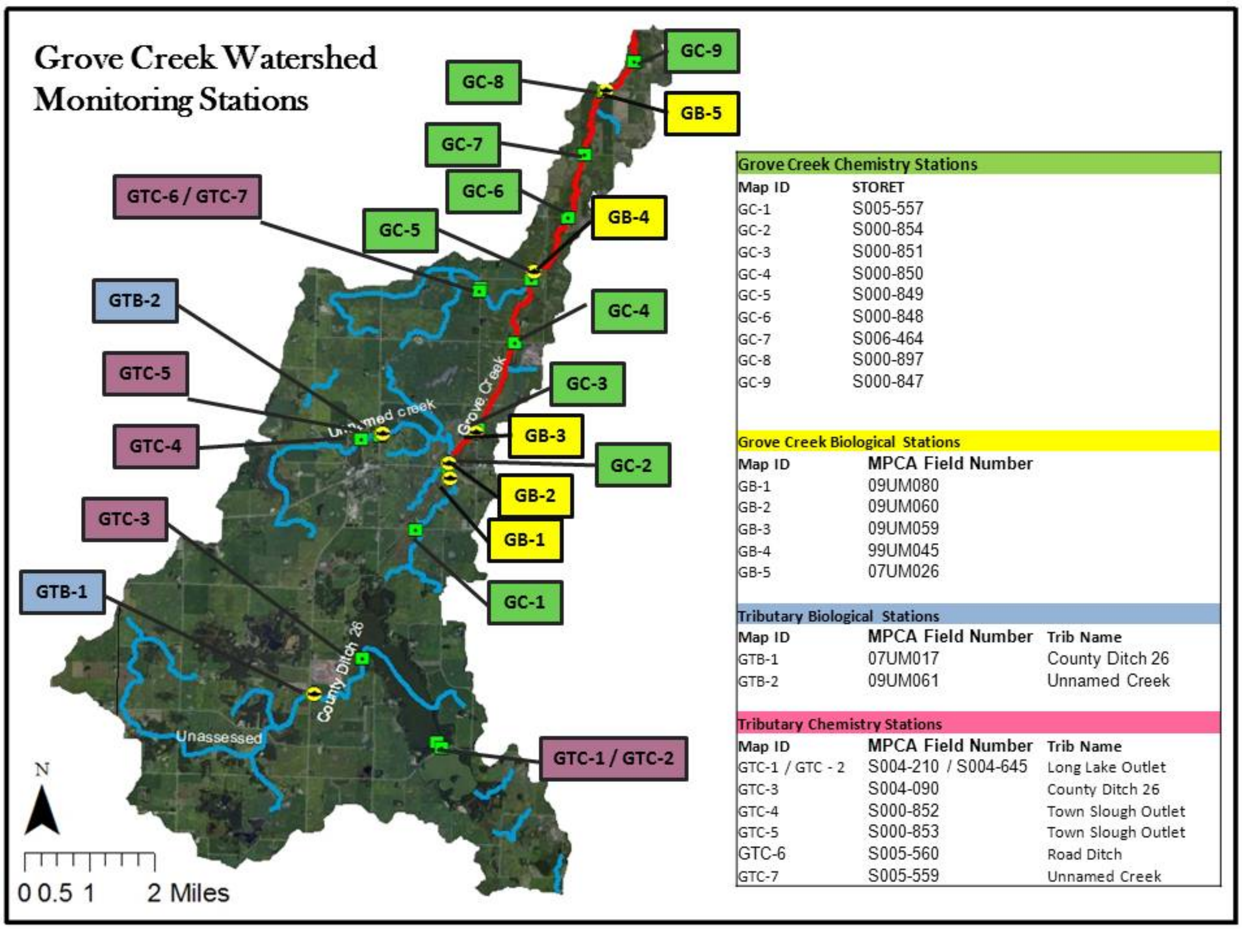


Figure 2: Biological and water chemistry monitoring stations on Grove Creek and major tributaries.

1.1 Fish IBI impairment

There are a total of seven biological monitoring stations in the watershed, five of which are located on the mainstem of the Grove Creek. The other two stations are located on tributary streams that have been extensively channelized. Station information and a summary of monitoring results, including drainage area, sinuosity, gradient, fish IBI class and associated standards, can be found in Figures 3 and 4 on the following page. Tributary data will not be discussed in detail in this report given that there are no current impairments listed for the tributary streams. However, data from tributary streams will be incorporated into the report as needed to support the analysis of stressors on the mainstem of Grove Creek.

In general, fish IBI scores for Grove Creek were well below established impairment thresholds at all stations. The exception is site GB-5, which recorded one fish IBI score within the lower confidence limit of the standard. The two visits to this station produced IBI scores which are somewhat discrepant; 18.0 / 100 in June of 2007, and 32/100 in July 2009. The latter score is above the lower confidence interval (26.0) for Class 5 fish stations.

Biological monitoring stations in the Grove Creek watershed fall into two fish IBI classes as determined by the statewide fish IBI developed by MPCA. The majority of the stations are Class 6 (Northern Headwaters Streams), but site GB-5 is classified as a Class 5 (Northern Streams) site with a drainage area of just over 50 square miles (Table 2). A set of biological metrics related to the life history traits of various fish species are used to calculate overall IBI score. Metrics generally focus on trophic status, reproductive traits, sensitivity to disturbance, community structure, and physical condition. The metrics used vary by fish class. A complete list of metrics used for each fish class can be found in Appendix B.

Table 2: Key criteria for Class 5 and 6 fish classes in the statewide fish IBI developed by MPCA.

Fish IBI Class	Class Name	Drainage Area	Gradient
6	Northern Headwaters	< 50 sq mi	> 0.50 m/km
5	Northern Streams	> 50 sq mi	not specified

Site #	FieldNum (MPCA)	Drain Area (SqMi)	Sinuosity	Gradient (ft/mile)	Fish Class	FishIBI	Fish IBI Standard	Upper C.L. / Lower C.L
GB-1	09UM080	31.1	1.34	4.395	6	22	50	59 / 41
GB-2	09UM060	31.9	1.32	4.329	6	23	50	59 / 41
GB-3	09UM059	39.1	1.16	3.804	6	14	50	59 / 41
GB-4	99UM045	47.5	1.05	3.444	6	18, 28	50	59 / 41
GB-5	07UM026	50.3	1.65	5.412	5	18, 32	35	44 / 26

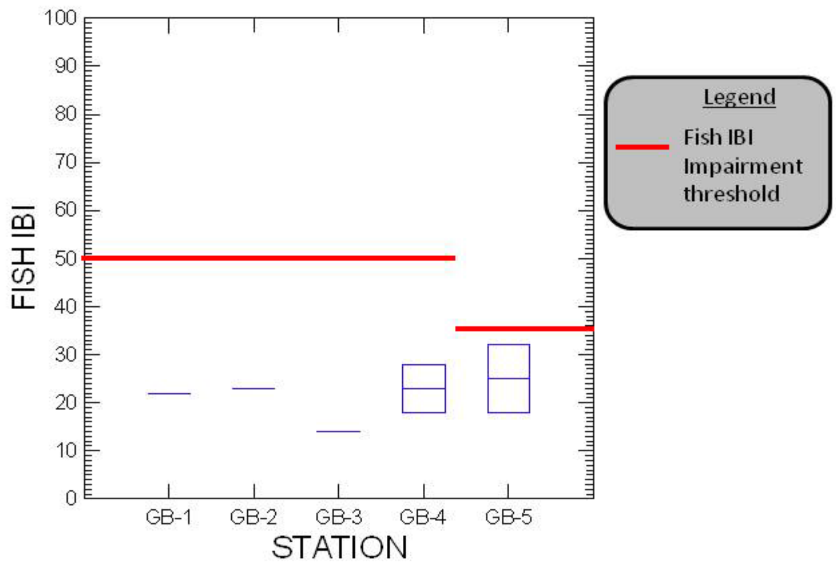


Figure 3: Fish IBI results for stations located on the mainstem of Grove Creek. Stations are arranged from upstream (left) to downstream (right)

Site #	FieldNum (MPCA)	Drainage (Sq Mi)	Sinuosity	Gradient (ft/mile)	Fish Class	Fish IBI	Fish IBI Standard	Upper C.L. / Lower C.L
GTB-1	07UM017	14.05	1.2	1.34	6	0	50	59/41
GTB-2	09UM061	4.47	1.18	6.56	6	11	50	59/41

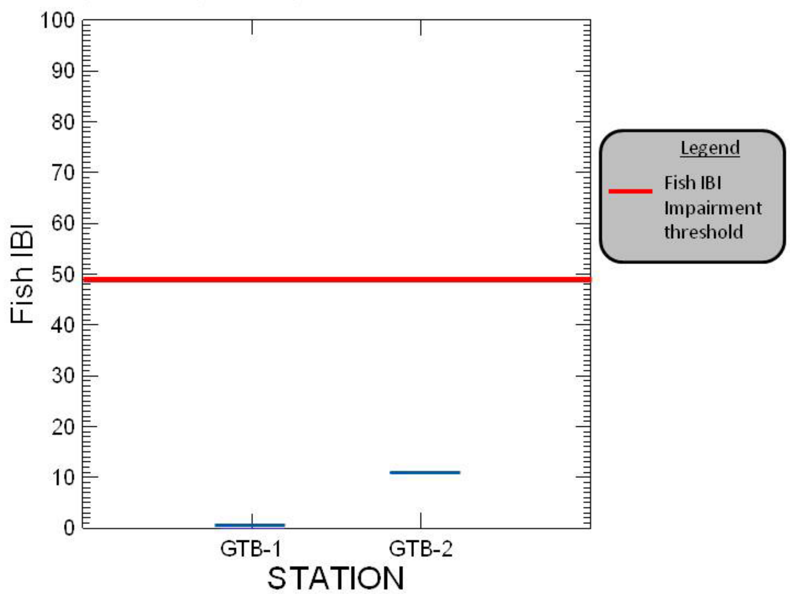


Figure 4: Fish IBI results for biological monitoring stations located on tributary streams to Grove Creek

Fish metric scores were evaluated for both Class 5 and Class 6 sites to determine which metric(s) were contributing to the low overall IBI scores. Figure 5 shows metric scores on a 0-10 scale, with the dashed green line indicating the “target score” for each metric. The target score is derived by taking the IBI impairment threshold (e.g. 35 for Class 5 sites) divided by the total number of metrics (35 ÷ 10 = 3.5). There is no individual standard for each metric, but using a target score provides one method of identifying problem metrics for a stream or individual monitoring site.

The metric results reveal several symptoms of impairment that are shared across many biological stations on Grove Creek. First, sensitive and/or pollution intolerant fish species were rare to non-existent at most sites. These species are typically the first to disappear when streams are altered from their natural state by some form of disturbance. Another trend throughout the creek was a lack of simple lithophilic spawning fish (simple lithophils). Fish with this reproductive trait broadcast eggs across gravel or coarse sand substrate. A lack of simple lithophils in a stream can suggest a lack of suitable substrate, which can be both a natural occurrence (e.g. low gradient streams in sand or clay dominated geology), or caused by an introduction of excess fine sediments through streambank/streambed erosion or overland runoff.

Pioneer and short-lived fish species were common in Grove Creek, which resulted in poor scores in several metrics related to fish community structure. “Short-lived” in this case means fish that reach sexual maturity before age 3. An abundance of pioneer and short-lived fish species can be indicators of an aquatic environment that is unstable and frequently disturbed by pulse-type stressors (e.g. low DO or flow alteration).

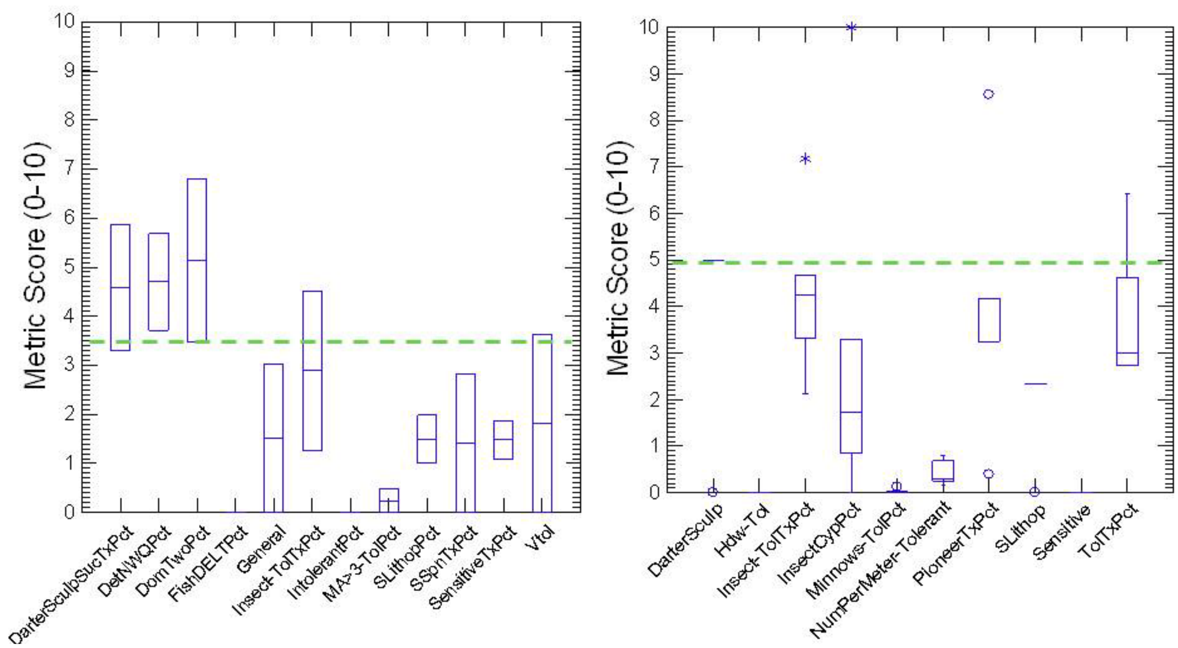


Figure 5: Fish IBI metric scores for Class 5 (right) and Class 6 (left) stations. Dashed green line represents a target score for each metric, or the score needed in each metric to surpass the fish IBI impairment threshold.

1.2 Macroinvertebrate IBI impairment

Macroinvertebrates were sampled at five monitoring stations along the mainstem of Grove Creek. Unlike the fish sampling effort, no tributary streams were sampled for macroinvertebrates. Station information and results, including drainage area, sinuosity, gradient, macroinvertebrate IBI class and associated standards, can be found in Figure 6 on the next page.

Macroinvertebrate IBI (MIBI) scores for the five stations were scattered slightly above and below the impairment threshold. All scores fell within the upper and lower confidence limits of the impairment threshold. Based on these results, Grove Creek macroinvertebrate populations are in better relative condition than the fish community, as F-IBI scores fell well below the lower confidence interval at most monitoring locations.

All five Grove Creek biological monitoring stations were assessed in the Prairie Streams Glide-Pool MIBI class. Sites within this class have watershed areas less than 500 square miles, and are representative of the Eastern Broadleaf Forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces. The metrics used in this MIBI class are listed and definite in Appendix B.

Figure 7 shows MIBI metric scores on a 0-10 scale, with the dashed green line indicating the “target score” for each metric. Box-plots for several of the MIBI metrics show a wide gap between maximum and minimum values. These include *Collector-FiltererPct, PredatorCh,* and *TricopteraChTxPct.* The variability in these metric scores is suggestive of localized stressors or differences in habitat characteristics that are suppressing certain taxa at some sites and not others. The poor metric scores at all sites for *Intolerant2Ch* and *TrichwoHydroPct* metrics reveal an overall lack of sensitive macroinvertebrate taxa and non-hydrophychid caddisfly individuals in the creek.

FieldNum	Drainage Area (Sq. mi)	Sinuosity	Gradient (ft/mile)	MIBI Class	MIBI Score*	MIBI Standard	Upper C.L. / Lower C.L.
GB-1	31.17	1.34	4.40	7	42.90	38.3	51.9 / 24.7
GB-2	31.91	1.32	4.37	7	32.95	38.3	51.9 / 24.7
GB-3	39.12	1.16	2.85	7	30.86	38.3	51.9 / 24.7
GB-4	47.51	1.05	1.07	7	45.16 / 33.07	38.3	51.9 / 24.7
GB-5	50.37	1.65	1.48	7	25.19 / 33.25	38.3	51.9 / 24.7

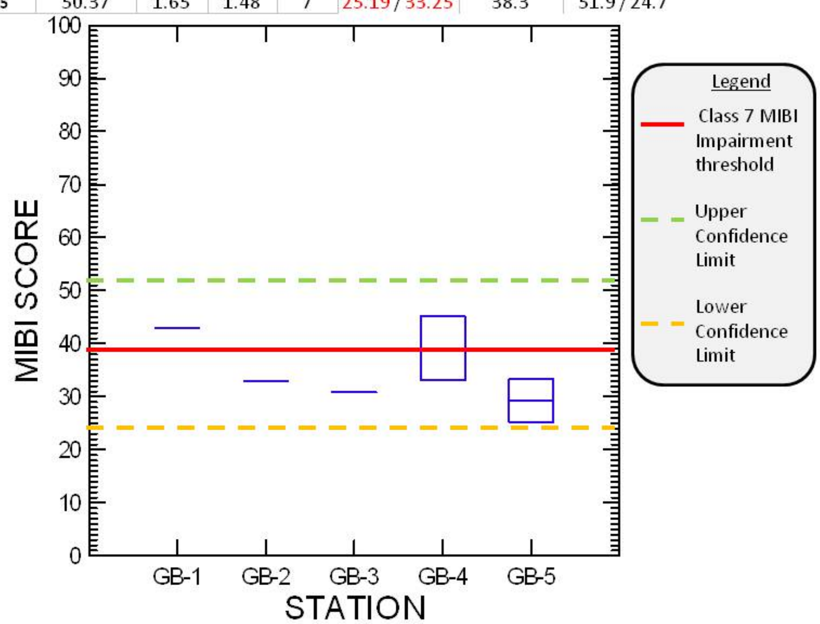


Figure 6: Macroinvertebrate monitoring stations, IBI results, and impairment threshold.

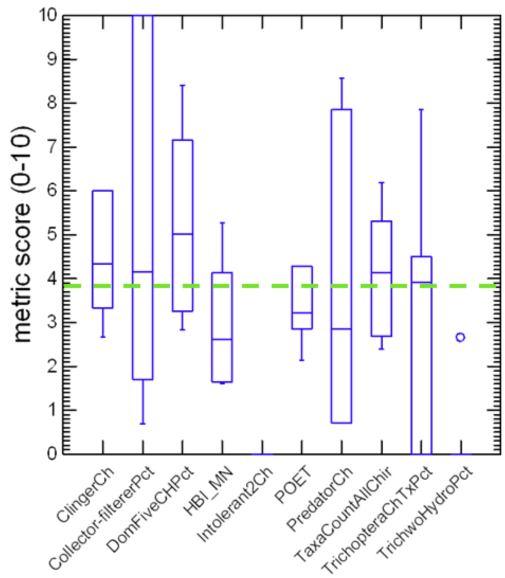


Figure 7: Composite MIBI metric scores for all Grove Creek monitoring stations.

2.0 Candidate Causes/Stressor ID Reconnaissance Results

In addition to the biological impairments, Grove Creek is currently listed on the Federal 303(d) list of impaired waters for several water quality parameters -- low DO (first listed in 2004), turbidity (2010), and *E. coli* bacteria (2010). Low DO and turbidity are considered candidate causes for biological impairments as well, and will be further evaluated to see if there are strong connections between these documented impairments and biological effects. The *E. coli* impairment listing is considered an "aquatic recreation" listing, and does not have a strong or direct linkage to the biotic impairments. Therefore, the *E. coli* impairment will not be specifically addressed in this report.

Stressor ID reconnaissance (SIDR) tables were completed for the Grove Creek watershed in order to generate a list of candidate causes for the IBI impairments. The SIDR is process comprehensive evaluation of watershed characteristics and available physical, chemical, and hydrological data. In general, the SIDR focuses on five major watershed components; water chemistry, biology, hydrology, geomorphology, and connectivity. The results of the SIDR were used to develop a list of candidate causes for stream impairments and establish causal pathways between stressor sources and negative impacts to the streams of the watershed. The completed SIDR tables are included in Appendix A.

The SIDR screening process resulted in six candidate causes for the biological impairments observed in Grove Creek. Three of the candidate causes are water quality-based stressors; elevated turbidity/total suspend solids (TSS) concentrations; low DO and DO flux; and nitrate (NO3) toxicity. The other candidate cause is loss of habitat due to excess fine sediment deposition, which is related to physical stream processes and geomorphology. In some cases, several of these stressors may be confounding or linked through various watershed processes (e.g. streamflow alteration may be linked to sediment stressor).

The candidate causes for Grove Creek impairments, as well as some of the probable sources and pathways related to each stressor, are listed in Table 3. These tables were developed using the SIDR protocols and establish working hypothesis for each stressor that will be tested in the causal analysis section of this report. Using available data and knowledge of the watershed and ecological processes, each candidate stressor, source, and pathway was evaluated and ranked in terms of the likelihood of that stressor playing a prominent role in the observed impairments. The SIDR tables in Appendix A classify each source and pathway as either a direct ("D") contributor or indirect ("I"). An example of a "direct" source and pathway would be an increase in nitrate concentration from a point-source discharge. An example of an "indirect" source and pathway would be nutrient rich runoff from an agricultural field entering the stream, causing an increase in primary production and diurnal DO fluctuation.

Table 3: List of candidate causes developed from Stressor Identification Reconnaissance (SIDR) methodology.

Candidate Stressor	Summary of Stressor Identification Desktop Reconnaissance
Turbidity / Total Suspended Solids	§ **Turbidity and TSS concentrations exceed WQ standards to protect aquatic life** Sources & Pathways o Runoff from agricultural fields o Stream channel processes -- Bank / bed erosion o Grove City WWTP discharge o Runoff from urban/residential areas o Grazing and rangeland o Runoff from gravel/dirt roads
Dissolved Oxygen	§ **Low dissolved oxygen / dissolved oxygen fluctuation** Sources & Pathways o Increase in primary production from nutrient enrichment § Nutrient Inputs: · Runoff from agricultural fields · Grove City WWTP effluent · Grazing and rangeland · Riparian wetlands o Streamflow Modifications (Increased frequency of low flows / velocity) § Channelization / ditching § Agricultural drainage tile
Nitrate Toxicity	§ **NO2+NO3 concentrations above aquatic life protection targets** Sources & Pathways o Runoff from agricultural fields and tile lines o Grove City WWTP effluent
Stream Channel Instability / Excess Deposited and Bedded Sediment (DBS)	§ **Direct de-stabilization of channel (e.g. ditch clean-out)** § **Streambed / streambank scouring & excess sediment deposition** Sources & Pathways o Intensive agriculture land-use o Channelization / ditching o Municipal wastewater discharge o Grazing and rangeland o Road crossings / culverts

3.0 Evaluation of Candidate Causes

In this section, candidate causes for impairment will be evaluated using existing data from Grove Creek, as well as established stressor-response relationships that have been observed in scientific literature and similar case-studies. Analyses conducted during this step combine measures of the biological response (e.g., fish abundance or invertebrate taxonomic richness) with direct measures of proximate stressors (e.g., toxicant concentrations or percent embeddedness values), or measures of other steps linking sources, candidate causes, and biological effects. For example, if low levels of DO constitute the candidate cause, data from the case may include actual DO measurements at the impaired and reference sites; evidence that organisms intolerant of low DO have declined at the impaired site; and/or measurements of increased organic matter (one potential step in the causal pathway) at the impaired site (from EPA CADDIS website).

3.1 Excess deposited and bedded sediment

Physical habitat degradation was identified as a candidate cause for biological impairments based on general field observations and available habitat data. Quality habitat for fish and macroinvertebrate life in Grove Creek appears to be limited by the presence of channelization, stream channel instability, and highly altered riparian corridors within the watershed. The cumulative effects of these disturbances have led to several proximate stressors that are negatively influencing aquatic life: (1) Excess fine sediment and substrate embeddedness, (2) reduced riffle/pool habitat; (3) a reduction in habitat complexity and cover.

Channelization and ditching in the Grove Creek watershed

The mainstem of Grove Creek, along with many of its tributary streams, has been significantly channelized for the purpose of agricultural drainage. While ditches can provide important drainage and flood control functions in agricultural landscapes, ecological services are often lost when previously natural channels become modified for these purposes (Allan, 1995).

The stream channel at biological monitoring stations GB-1, GB-2, GB-3, and GB-4 were channelized sometime prior to 1939. Since then, a small amount of natural re-meandering has occurred at these sites, but they still lack the stream features and habitat heterogeneity that is typically observed in unmodified, natural channels. At the time of the biological surveys GB-3 and GB-4 had sinuosity measurements of 1.16 and 1.05, respectively. A sinuosity of 1.00 represents a completely straightened stretch of stream. Point-bar formation was evident at stations GB-1 and GB-2, which have developed a slightly meandering pattern and have sinuosity of 1.32 and 1.34.

There is no evidence available to suggest that the stream channel at station GB-5 was ever channelized or modified. Aerial photos from the 1930s show GB-5 as a natural channel. Sinuosity at GB-5 was measured as 1.65 during the time of biological monitoring in 2007. According to Applied River Morphology (Rosgen, 1996), sinuosity between 1.2 – 1.5 is considered “moderate,” sinuosity below 1.2 is considered “low”, and above 1.5 is considered “highly sinuous.”

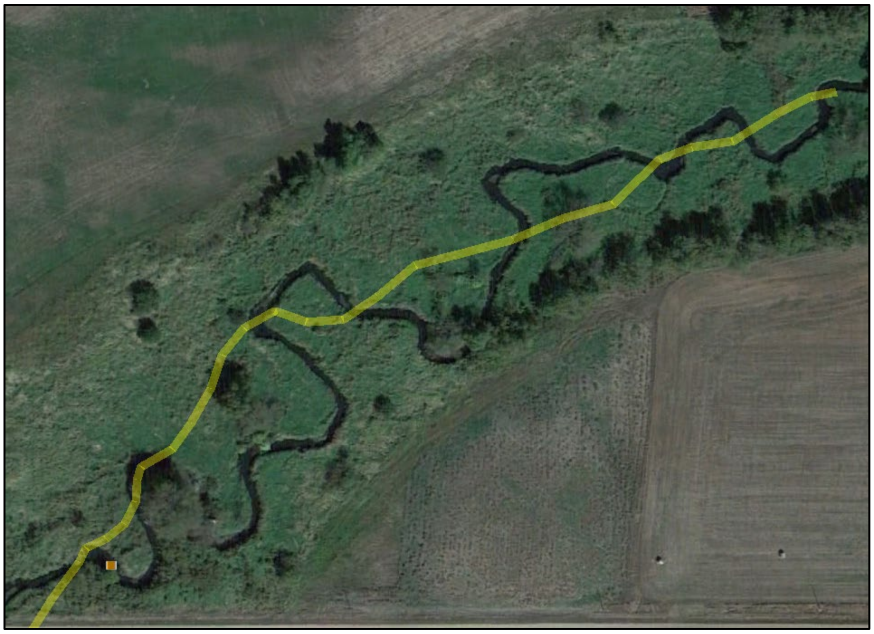


Figure 8: Biological monitoring site GB-3 stream channel (yellow lie – sinuosity of 1.05) superimposed on top of biological monitoring site GB-5 (sinuosity of 1.65).

Numerous studies suggest that the channelization of rivers and streams can degrade aquatic habitat and change species composition. Schlosser (1982) compared the trophic structure, reproductive success, and growth rate in fishes from a natural and modified (ditched) stream in central Illinois. The study found that the ditched stream experienced a loss of pool habitat, increased organic substrates, and a shift in trophic structure to omnivores and herbivores instead of insectivores and piscivores. In a study conducted in the east-central Indiana cornbelt region, Lau et al (2006) found that channelized streams had lower quality fish assemblages when compared to natural streams, and that a reduction in riffle and pool habitats associated with channelization was the most significant factor affecting the fish assemblage.

Figure 9 provides a comparison of relevant habit parameters from channelized vs. natural channel biological monitoring sites on Grove Creek. Habitat measurements from all channelized and natural channel sites were averaged and compared for this analysis. Similar to the results of the Illinois study, pool habitat seems to be reduced at channelized monitoring sites (-14% compared to natural channel sites in Grove Creek (Figure 9). In addition, the channelized sites contained a higher percentage of fine substrate, less riffle habitat, fewer habitat features, and lower overall scores on the Minnesota Stream Habitat Assessment (MSHA).

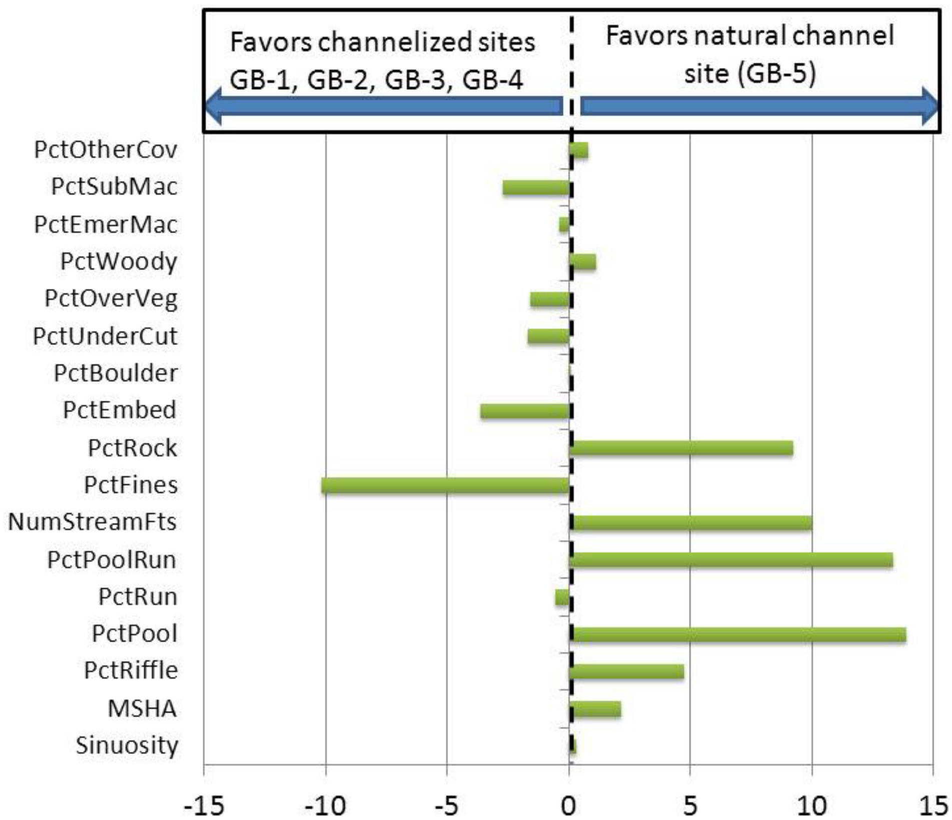


Figure 9: A comparison of relevant habit parameters from channelized vs. natural channel biological monitoring sites on Grove Creek.

A major channel modification was identified approximately 1 mile east of Grove City, Minnesota during aerial photo analysis and stream reconnaissance (Figure 10). The creek in this area is channelized into multiple channels, causing a severe backwater effect and a high rate of sediment deposition. During a reconnaissance trip to this reach, an abundance of common carp was observed, along with very low DO concentrations and elevated turbidity (likely from carp stirring up bottom sediments). The stream channel in this area has widened to a point where streamflow and sediment transport are significantly altered, leaving very little suitable habitat for fish and macroinvertebrates. A perched culvert was also identified at the upstream end of this impacted reach. The culvert was perched severely enough to completely eliminate fish passage.

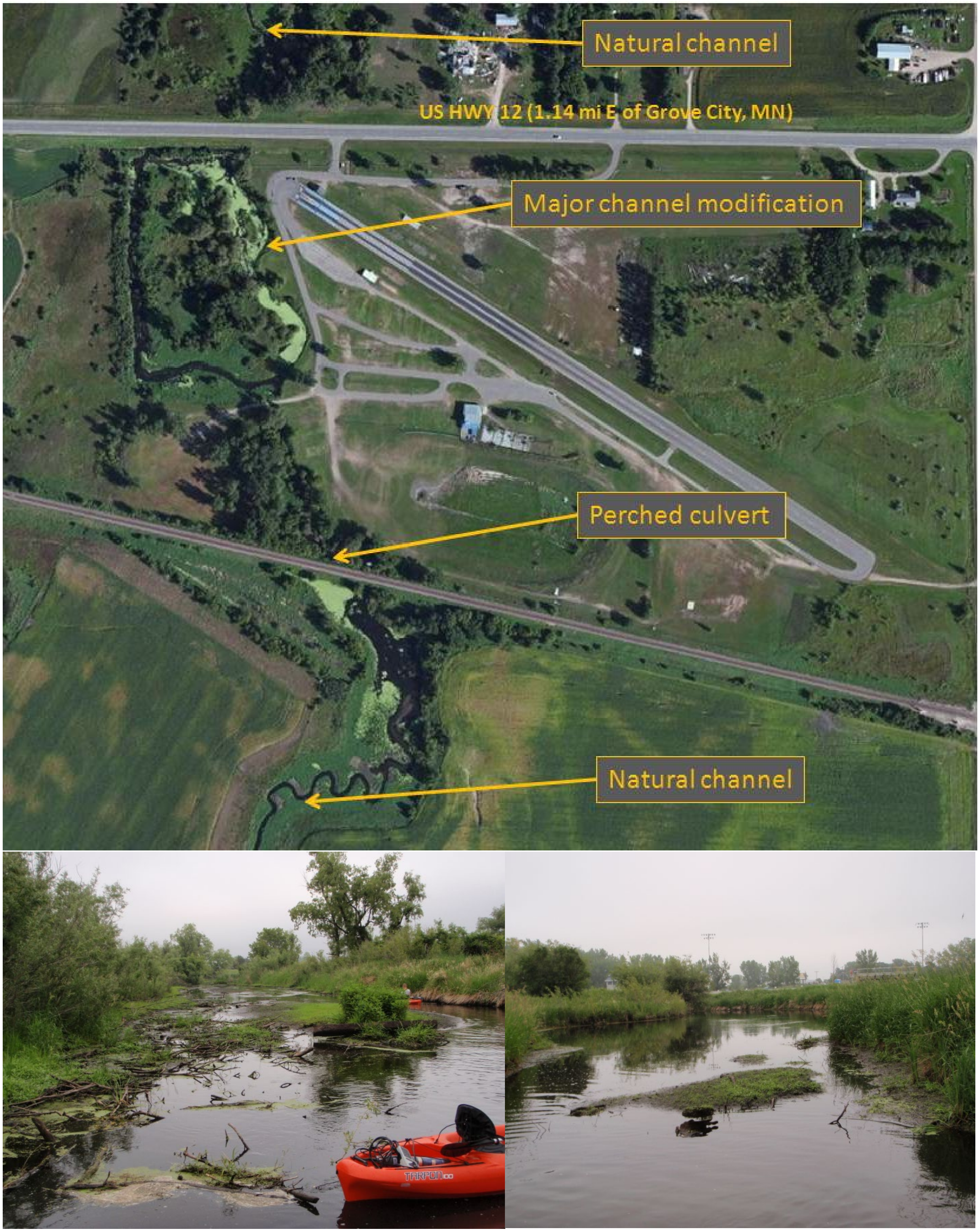


Figure 10: Area of major stream channel alterations upstream of US HWY 12, 1 mile east of Grove City, MN.

Stream channel instability in the Grove Creek watershed

A stable stream channel has the ability to maintain its dimension, pattern, and profile over time without aggrading or degrading. River form and fluvial processes are not static, and therefore streams are constantly adjusting to fluctuations in precipitation and runoff, erosional and depositional processes, topography, and other features of the watershed that are ever changing. To achieve stability, a stream channel must be able to effectively transport its sediment load associated without unnaturally high rates of scour and deposition (Rosgen, 1996).

Channel instability can occur when sediment inputs (bank erosion, overland runoff, etc.) exceed the transport capacity of a stream. Watershed reconnaissance and water quality monitoring efforts conducted within the Grove Creek watershed revealed a variety sediment sources that may be contributing significant sediment loads. Overland runoff is common in the watershed during snowmelt and extreme rain events, particularly when the crops are not established in the fields (Figure 11). The runoff from the field pictured in Figure 11 had a turbidity concentration of 508.9 nephelometric turbidity units (NTU).

Figure 11: Overland runoff from cultivated cropland observed in March, 2008.

Pfankuch channel stability index (PSI) assessments (Pfankuch 1979) were conducted at all of the biological monitoring sites on the mainstem of Grove Creek. The results indicate that streambank and/or in-channel process, such as bank erosion and streambed scour/deposition, also contribute to sediment imbalances. PSI results collected at biological monitoring stations are summarized in Table 4, and specific metrics related to bank erosion and substrate condition are shown in Figures 12-14. PSI scores pertaining to the upper bank area were generally in the fair to good range. The upper bank assessments deal primarily with landform slope, mass wasting, debris jam potential, and vegetative bank protection. Aside from some areas of mass wasting, most of the other metrics were not problematic, as scores were in the good to fair range for this category.

PSI scores for the lower bank and stream bottom are more indicative of channel instability and benthic habitat degradation, especially in the mid to lower reaches of Grove Creek. Sites GB-1, GB-2, and GB-4 are exceptions, as the lower bank metrics received an overall rating of either “good” or “fair” at these sites. PSI ratings for stream bottom stability and substrate quality were rated as “poor” at the three downstream-most sites.

Table 4: (PSI) scores for metrics related to streambanks and bottom substrate, as well as overall scores and stability ratings for the reach.

Station	Upper Banks (out of 40)	Lower Banks	Stream Bottom	*Overall Score (out of 152)*	*Overall Rating*
GB-1	25 (fair)	31 (fair)	36 (good)	*92*	*FAIR*
GB-2	15 (good)	27 (fair)	45 (fair)	*87*	*FAIR*
GB-3	20 (good)	39 (poor)	56 (poor)	*121*	*POOR*
GB-4	13 (good)	28 (fair)	49 (poor)	*90*	*FAIR*
GB-5	28 (fair)	39 (poor)	52 (poor)	*123*	*POOR*

Specific PSI metrics were further evaluated to determine the various factors that were contributing to channel instability at each site. Below is a summary of those scores and photos depicting observations from the sites that were assessed.

Mass wasting

Areas of active mass wasting were observed with some regularity in the mid to lower reaches of Grove Creek, especially at sites GB-5 and GB-3. Mass wasting was observed most frequently in areas where steep bank angles and reed canary grass were present (Figure 12).

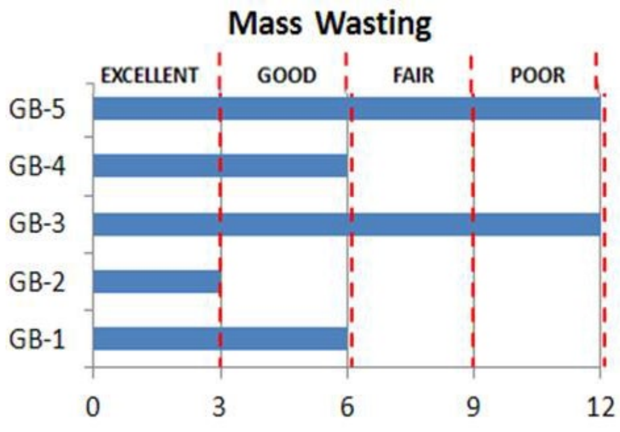


Figure 12: Mass wasting of a streambank at GB at station GB-3. Graph shows PSI metric scores 0-12 (3 = Excellent; 6 = Good; 9 = Fair; 12 = Poor).

Cutting (bank erosion) and deposition

Excessive bank erosion or cutting of streambanks, along with extensive sediment deposition on inside bends or mid-channel bars can be an indicator of channel instability. Bank erosion was observed throughout the length of Grove Creek, with significant erosion and deposition rates observed at GB-5, and to a somewhat lesser extent, station GB-4.

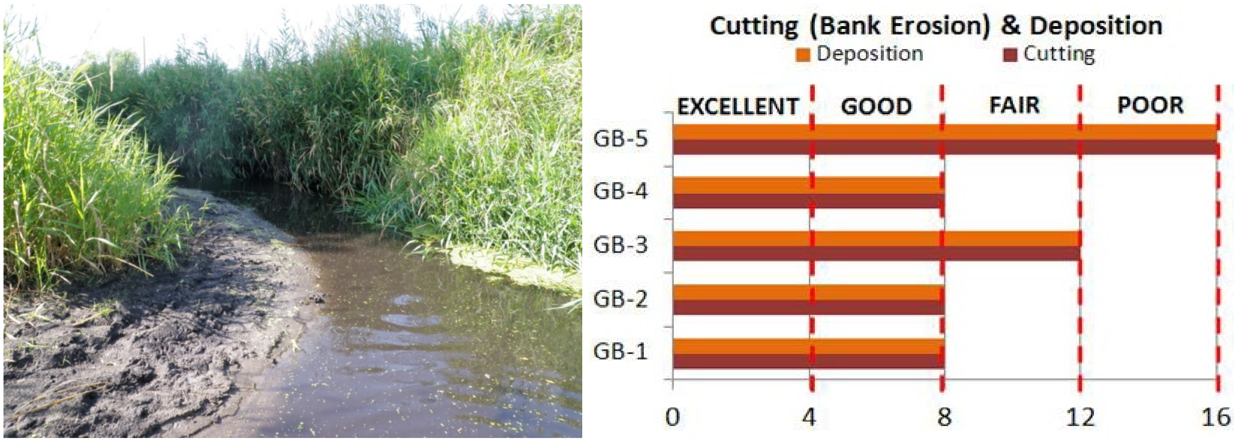


Figure 13: Example of accelerated point bar development from excess sediment deposition at station GB-5. Graph shows PSI metric scores (4 = Excellent, 16 = poor)

Bed scour and deposition, substrate

The substrate material observed at most biological monitoring stations was dominated by fines (silt / sand) and small gravel. Several sites had poor PSI metric scores in metrics related to particle size distribution, percent stable substrates, and scour and deposition rates (Figure 14). These results suggest that bottom substrate material is prone to be mobilized all year-round, but particularly during high flow events. Much of the bed material that becomes mobilized is scoured from riffles, runs, or areas where the stream channel is more constricted. Deposition tends to occur in pool and glide habitats where current velocity is lower.

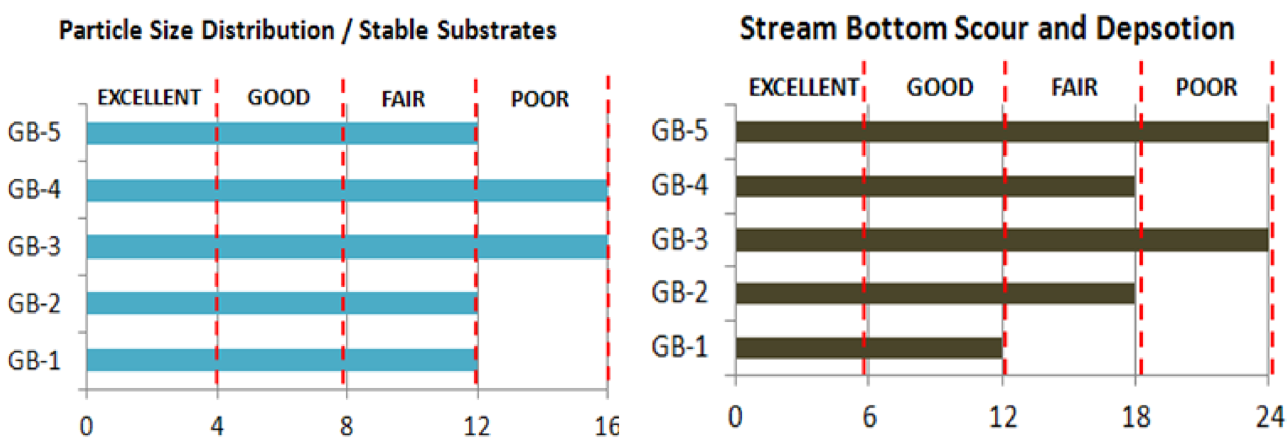


Figure 14: PSI metric scores related to substrate composition, stability, and scour and deposition rates/patterns.

Impacts of deposited and bedded sediment on habitat/aquatic life

Excess deposited/bedded fine sediment (DBS) upon benthic habitat has been proven to negatively impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction. Aquatic macroinvertebrates are generally affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman and Ligon, 1988); (2) increase in drift (avoidance) due to sediment deposition or substrate instability (Rosenberg and Wiens 1978); and

(3) changes in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman 1988) and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton 1985; Gray and Ward 1982).

Percent fine substrates

The amount of fine sediment present in a stream is influenced by a combination of anthropogenic disturbance (e.g. changes in land-use) and natural background factors (e.g. local geology and soils). Figure 15 shows box-plot quartiles of percent fine substrate at Class 5 and 6 sites by Level III ecoregion in Minnesota. Sites in the Western Corn Belt Plains ecoregion (WCBP) and Northern Central Hardwood Forests ecoregrion (NCHF) have a median value for percent- fines of 72% and 67% respectively. Grove Creek monitoring stations GB-4 and GB-3 (100% fines) are located on the upper hinge, or maximum value of the box-plot for their respective ecoregions. Stations GB-2 and GB-5 are in the 3rd quartile, and GB-1 plots in the 2nd quartile of the WCBP plot. Based on these figures, it can be concluded that Grove Creek monitoring stations generally have higher amounts of fine sediment as substrate than other sites with comparable natural background conditions.

The abundance of fine substrate appears to have a general negative effect on fish IBI scores at Class 5 and 6 monitoring stations, although the results can be highly variable. The median percent fines for sites with fish IBI scores below the impairment threshold was just below 80%, while median value for sites with “passing” fish IBI scores was 43% (Figure 15). The range of percent fine substrate observed at sites with passing fish IBI scores is 0% - 100%, with a 75th percentile value above 80%. This is an indication that percent fines near 80% may not be a significant indicator of stream impairment if other habitat conditions are suitable.

Embeddedness of coarse substrates

Highly embedded coarse substrates reduce spawning habitat and interstitial spaces for the fish and macroinvertebrate taxa which depend on these microhabitats. Substrate embeddedness shows similar trends across Minnesota ecoregions for Class 5 and 6 fish IBI sites. Median percent substrate embeddedness values are highest in the WCBP ecoregion (62%) and show fewer sites with low percent embeddedness than all of the other ecoregions. None of the stations in the WCBP had embeddedness values lower than 45% (Figure 15).

Several biological monitoring stations on Grove Creek had coarse substrates that were highly embedded. Sites GB-1 and GB-2 fall between the median and 75th percentile for Class 5 and 6 stations in the WCBP ecoregion for percent embeddness. GB-5, with coarse substrates over 97% embedded falls at the very upper end of the plot for the NCHF ecoregion (Figure 15). The other three stations (not plotted on the graph) did not have any exposed coarse substrates at the time of sampling, so embeddedness measures do not apply. These stations may have embeddness values of 100% if fine material has completely covered any coarse substrates that would have been present.

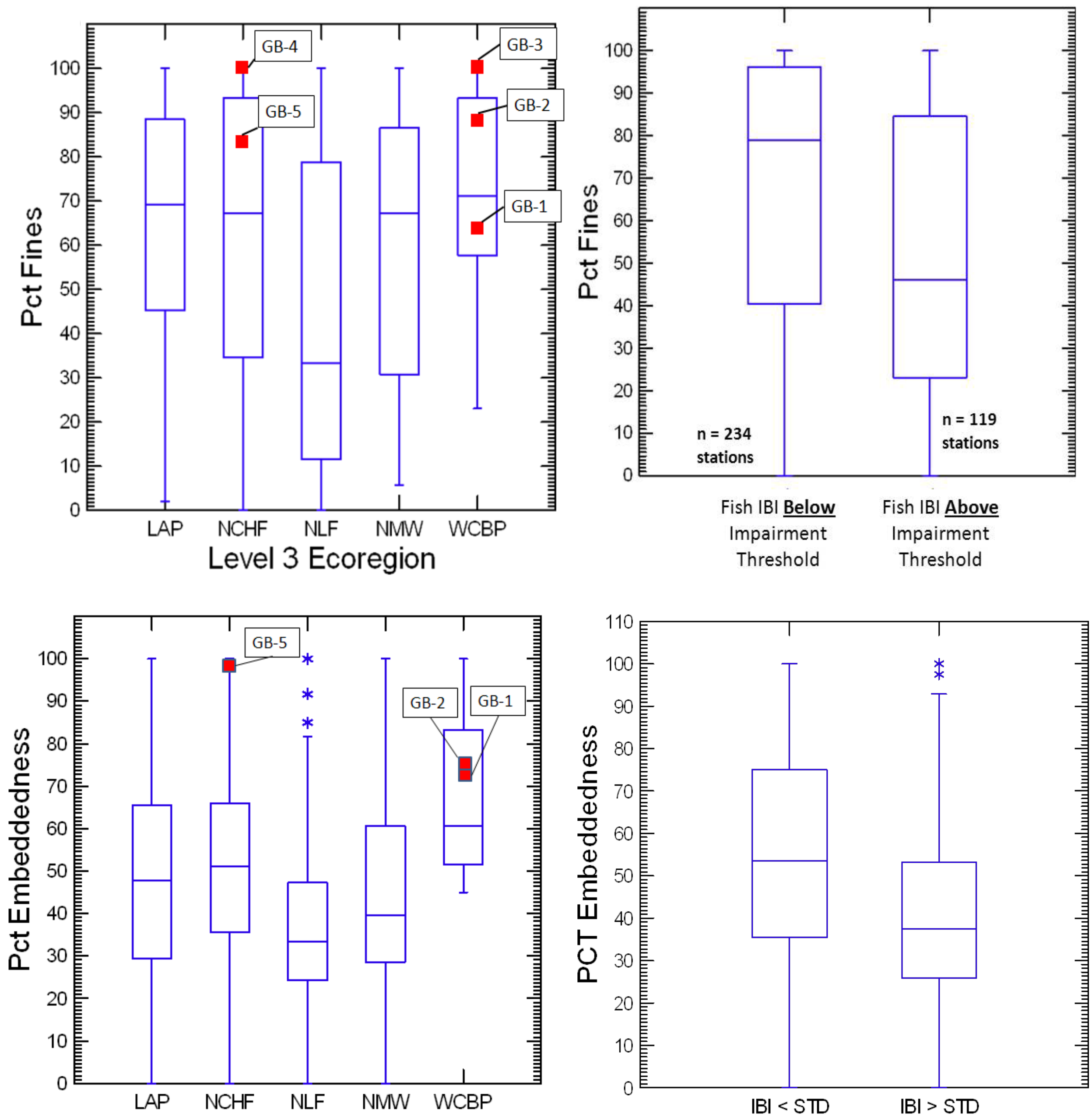


Figure 15: (Left) Percent fines / substrate embeddedness at Class 5 and 6 fish IBI classes, partitioned by Level III ecoregion. Grove Creek sites are represented by red squares. (Right) Box-plot distributions of percent fine substrate / embeddedness at Class 5 and 6 fish IBI sites above and below fish IBI standard.

Reduction in simple lithophils

Simple lithophilic spawning fish (i.e. fish that utilize gravel substrates for spawning) occur in low numbers at all Grove Creek monitoring stations. Every station scored below the target score in metrics related to measures of simple lithophil abundance or taxa richness (Figure 16). Spatial correlations between substrate conditions and metric scores are not all that responsive when looking at Grove Creek monitoring sites alone. Stations with a lower percentage of fine substrates (e.g. GB-1 and GB-2) have similar metric scores to stations with 100% fines or nearly 100% embeddedness (Figure 16). There may be several reasons for the lack of response; (1) stressors other than excess fine sediment are likely involved in limiting the diversity and abundance of simple lithophils at some or all sites, and/or (2) percent fines and embeddedness values are high enough at all locations to effectively limit fish with this reproductive trait.

Figure 17 provides a larger scale analysis of percent embeddedness values and metric scores for simple lithophilic spawning fish. This box-plot shows percent embeddedness values partitioned by a range of metric scores for simple lithophils. The plot only includes data from Class 5 and 6 stations in order to provide a better benchmark for Grove Creek. Median percent embeddedness for metric scores in the range of 4.0 – 5.9 is 47%. The lowest embeddedness observed in Grove Creek was 74% at GB-1, a value that is above the 75th percentile for a metric score of 4.0-5.9. These observations suggest that it is unlikely for a site to score well in simple lithophil metrics with embeddedness values as high as those seen in Grove Creek.

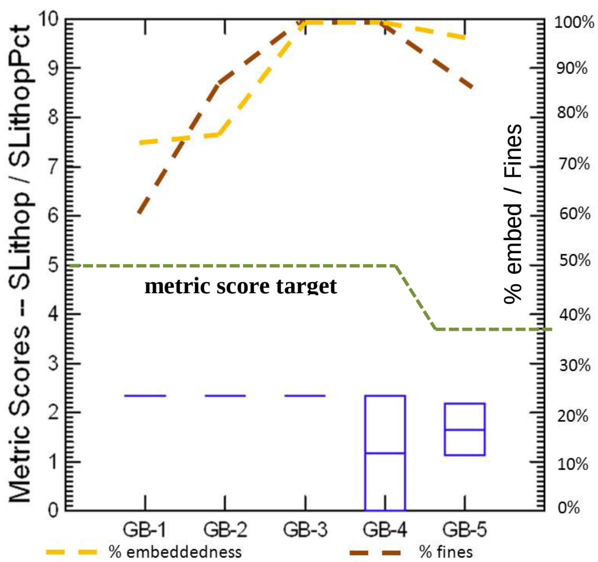


Figure 16: Metric scores for simple lithophilic spawning fish with percent fines and percent substrate embeddedness

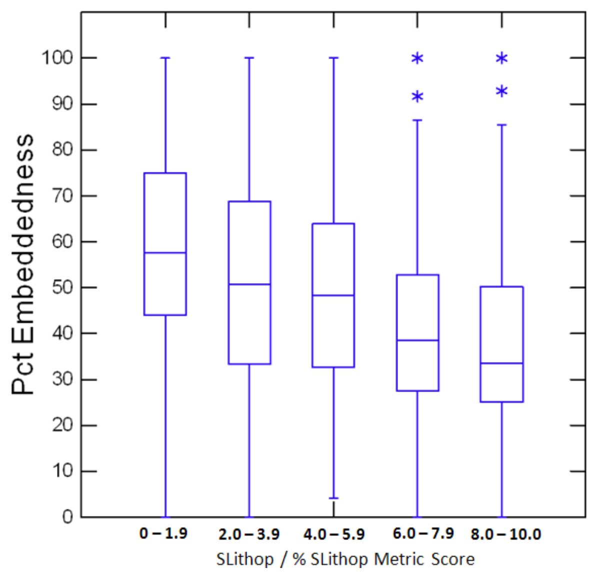


Figure 17: Percent embeddedness values partitioned by metric score range for simple lithophils

Reduction in "clinger" macroinvertebrate taxa

"Clinger" macroinvertebrate taxa typically dwell in swift water and attach themselves to the surfaces of coarse substrates or woody debris. They are particularly dependent on the interstitial spaces created by gaps in overlapping coarse material (large gravels, cobbles, boulders, etc.). Increases in DBS are detrimental to these habitat types, and have been shown to significantly limit "clinger" macroinvertebrate densities and richness (Rabeni et al., 2005).

Observations of DBS and clinger taxa richness at Grove Creek monitoring stations show a fairly consistent negative relationship. Metric scores are relatively high (> 4.0) at sites GB-1 and GB-2, but drop several points as percent fine substrate increases at GB-3 and GB-4. *ClingerCH* metric scores at GB-5 are variable, but the lower range of the data from that site indicates that Clinger taxa richness can be limited by fine substrate and embeddedness.

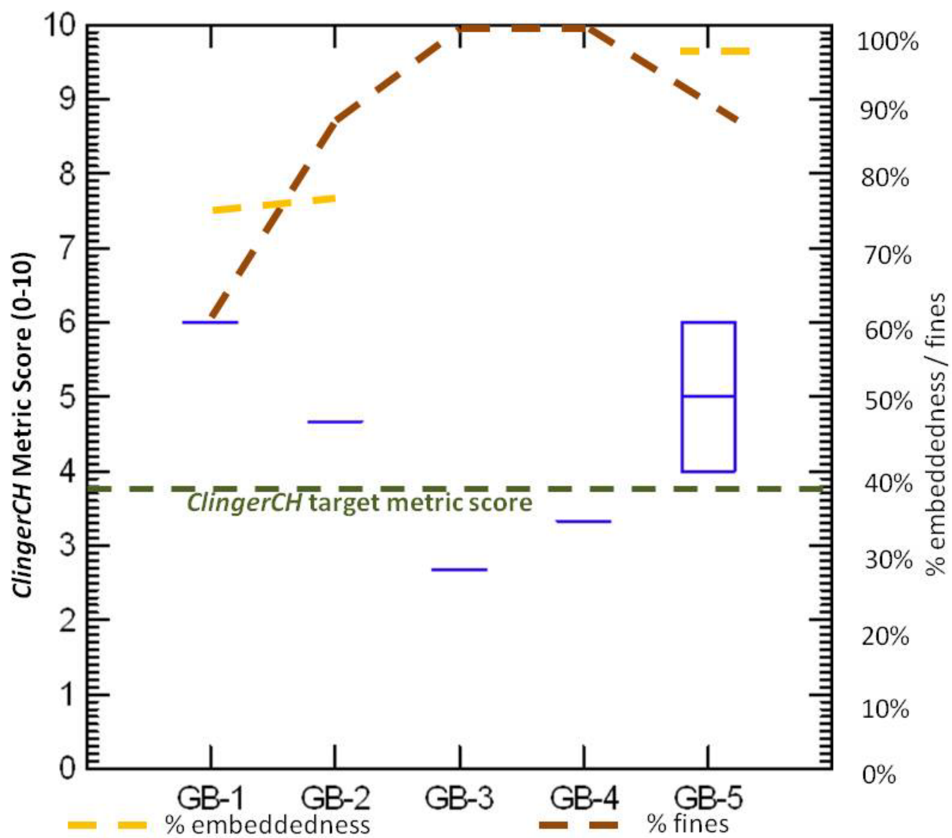


Figure 17: Clinger macroinvertebrate taxa richness metric score (*ClingerCH*) and percent fines / substrate embeddedness at Grove Creek monitoring stations

Effects of DBS on benthic insectivorous fish

Metrics pertaining to benthic insectivorous fish are not included in the IBI scoring for Class 5 and 6 stations. However, this trophic group is important to consider when evaluating increases in DBS as a stressor. Benthic insectivores are fish species that prey on insect life that occupy benthic (stream bottom) habitats. The abundance and richness of fish species with this trophic trait has been shown to decrease as the percentage of fine sediment increases (Berkman and Rabeni, 1987). For reference, Table 5 shows a breakdown of benthic insectivore relative abundance at biological monitoring stations comparable to those located on Grove Creek.

Table 5: Average, median, and percentiles for benthic insectivore metric values (not scores) at Class 5 and 6 biological monitoring stations.

	Percent of fish community as benthic insectivores (*including* tolerant species)	Percent of fish community as benthic insectivores (*excluding* tolerant species)
# stations	536	536
25th percentile	2.15	1.98
Average	20.02	19.16
Median	13.31	12.09
75th percentile	32.02	31.00

Benthic insectivores made up a very low percentage of the fish community at sites GB-1, GB-2, and GB-3 (Figure 18). The relative abundance of fish with this trophic trait was highly variable at sites GB-4 and GB-5. The variability observed at these is the result of fluctuating populations of bigmouth shiner (*Notropis dorsalis*). Bigmouth shiners are often found in sand-dominated streams and may not be as impacted by deposited sediments as other benthic insectivores. These fish are also classified as a "tolerant" species in Minnesota streams, which means they are less sensitive to a wide range of disturbances.

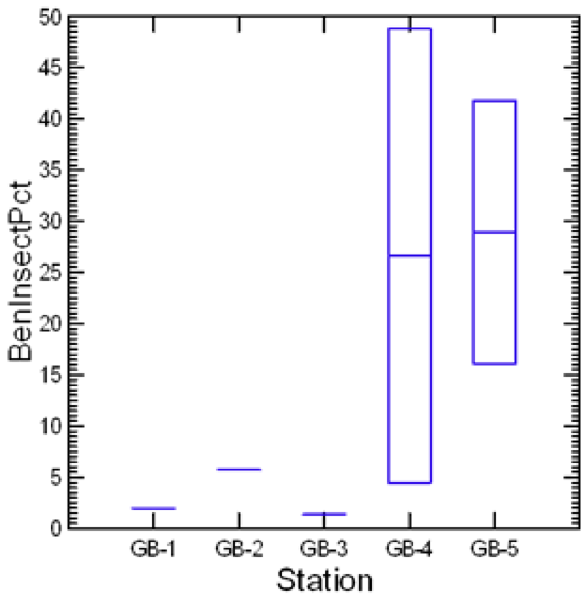


Figure 18: Percent of the fish community consisting of benthic insectivores (including tolerant species) at Grove Creek monitoring stations

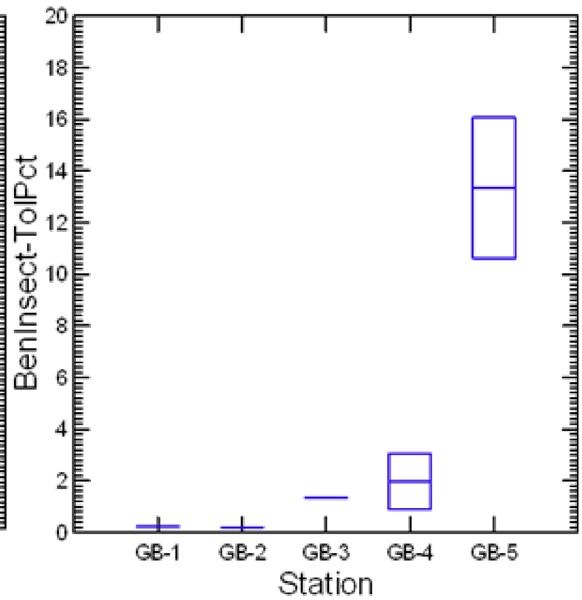


Figure 19: Percent of the fish community consisting of benthic insectivores (excluding tolerant species) at Grove Creek monitoring stations

The graph on the right in Figure 17 represents the relative percentage of benthic insectivores excluding tolerant species. The relative abundance of benthic insectivores drops considerably at site GB-4, and to a lesser extent at GB-5, when tolerant species (bigmouth shiner) are not counted. Three species of benthic insectivores in addition to the bigmouth shiner were recorded at GB-5; johnny darter (*Ethestoma nigrum*), blackside darter (*Percina maculata)*, and tadpole madtom (*Noturus gyrinus*). The presence of these species gives GB-5 the highest percentage of benthic insectivores when tolerant species are excluded.

On average, benthic insectivorous fish account for around 20% of fish species sampled at Class 5 and 6 monitoring stations, regardless of whether or not tolerant species are included. The fish community at the majority of Grove Creek monitoring stations was comprised of less than 5% benthic insectivores. Excluding tolerant species, benthic insectivore relative abundance exceeded 2% at only two of five stations (Figure 19).

Summary of stressor and strength of evidence

The evidence available to diagnose deposited and bedded sediments as a stressor is fairly strong and consistent. The biological metrics most affected by this stressor responded in predictable ways to the presence of this stressor in Grove Creek (low percent simple lithophils, reduced clinger macroinvertebrate taxa richness, and low percent benthic insevtivorous fish).

Evaluating DBS as a stressor in this particular stream is somewhat difficult considering that there is not a suitable reference site within the watershed that is not impacted by this stressor. However, comparisons made to other stations of the same IBI class support the diagnosis of DBS as a stressor in the Grove Creek watershed.

Table 6: Strength of evidence (SOE) scoring for deposited and bedded sediments as a cause for biological impairments in Grove Creek.

STRENGTH OF EVIDENCE (SOE) TABLE	Fish Impairment	Invertebrate Impairment
Evidence from Grove Creek Data		
Spatial/temporal co-occurrence	+ / 0	+
Temporal sequence	0	0
Causal pathway	++	++
Evidence of exposure, biological mechanism	+	++
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	+	+
Symptoms	+	+
Evidence using data from other watersheds / Scientific Literature		
Mechanistically plausible cause	+	+
Stressor-response in other lab studies	0	0
Stressor-response in other field studies	+	+
Stressor-response in ecological models	NE	NE
Manipulation experiments at other sites	NE	NE
Analogous stressors	++	++
Multiple lines of evidence		
Consistency of evidence	+	+++
Explanatory power of evidence	+	+

3.2 Low dissolved oxygen

Grove Creek (AUID 07010204-514) was listed as impaired in 2004 for failing to meet the Class 2B (warmwater stream) Dissolved oxygen (DO) standard. Extensive monitoring efforts have been conducted over the past several years to evaluate the nature, extent, and sources of this impairment. Recently, a total maximum daily load (TMDL) was completed for this impairment and implementation strategies to improve the DO regime of the creek are in the planning stages. The completed TMDL can be found here http://www.pca.state.mn.us/index.php/view-document.html?gid=19565.

Low DO concentrations are considered a likely stressor to aquatic life and a contributing factor to the low fish and invertebrate IBI scores in this system. This section will provide a brief overview of the available DO data and explore linkages between low DO and biological response. For a more thorough analysis of DO data, including a summary of all monitoring and modeling efforts related to this parameter, refer to the Grove Creek DO TMDL [Grove Creek DO TMDL](#).

Dissolved oxygen as a stressor to aquatic life

Dissolved oxygen refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1991). DO concentrations change seasonally and daily in response to shifts in ambient air and water temperature, along with various chemical, physical, and biological processes within the water column. If DO concentrations become limited or fluctuate dramatically, aerobic aquatic life can experience reduced growth or fatality (Allan, 1995). Many species of fish avoid areas where DO concentrations are below 5 mg/L (Raleigh et al., 1986).

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

The Class 2B water quality standard for DO in Minnesota is 5 mg/L as a daily minimum. Additional stipulations have been recently added to this standard. The following is from the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters* (MPCA, 2009):

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

Types of dissolved oxygen data

1. Instantaneous measurements
   Instantaneous DO data is available throughout the watershed and can be used as an initial screening for low DO. These measurements represent discrete point samples, which are usually collected in conjunction with surface water sample collection.

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.

A total of 173 instantaneous DO readings are available for Grove Creek. These readings were collected at seven monitoring stations along the mainstem between the months of February and November, spanning the years 1981 – 2010. The instantaneous DO data is summarized by monitoring site in Table 7. Station GC-2 is near the headwaters of the creek and GC-9 is just upstream of the confluence with the North Fork Crow River. Minimum DO concentrations observed at all sites were well below the 5 mg/L target for supporting aquatic life. DO concentrations below 1.5 mg/L were recorded at six out of the eight stations.

All monitoring sites had sub-5 mg/L DO with high enough frequency to violate the DO standard, although the sample size was only sufficient to evaluate site GC-9 (must have 10 or more observations). The high percentage of observations below 5 mg/L, along with the extremely low minimum concentrations (< 1 mg/L), suggest that the magnitude and duration of stress from low DO concentrations are considerably high.

Observations of low DO are most common during the months of July, August, and September (Figure 20). The lowest DO concentrations recorded occurred during July and August at sites located near the headwaters and middle sections of Grove Creek (GC-2 and GC-5). Two observations from GC-2 were around 1 mg/L, and a concentration of less than 1 mg/L was recorded at GC-5 in August.

Table 7: Summary of instantaneous DO readings for the mainstem of Grove Creek, including number of violations and percent observations in violation of the 5 mg/L DO standard.

	Monitoring Station (upstream à downstream)							
	GC-2	**GC-3**	**GC-4**	**GC-5**	**GC-6**	**GC-7**	**GC-8**	**GC-9**
# obs.	10	11	9	10	10	6	20	96
Avg (mg/L)	4.42	5.19	4.51	5.24	4.99	3.84	6.19	8.07
Median (mg/L)	5.01	5.60	5.70	4.02	4.87	2.94	6.31	8.40
25^{th} Pct (mg/L)	3.38	3.23	2.80	2.67	2.56	2.12	4.61	6.42
75^{th} Pct (mg/L)	5.98	6.71	6.30	6.52	7.40	5.77	7.53	9.64
Minimum (mg/L)	1.01	0.72	0.73	0.84	1.28	0.90	3.06	1.97
Maximum (mg/L)	6.64	9.60	6.54	11.90	9.40	7.69	10.33	14.90
# Obs below 5 mg/L	5	3	4	6	5	4	7	13
% Obs below 5 mg/L	***50%***	***27%***	***44%***	***60%***	***50%***	***67%***	***35%***	***14%***
% Obs below 5 mg/L (May – Sept Only)	***44%***	***44%***	***44%***	***75%***	***56%***	***67%***	***37%***	***16%***

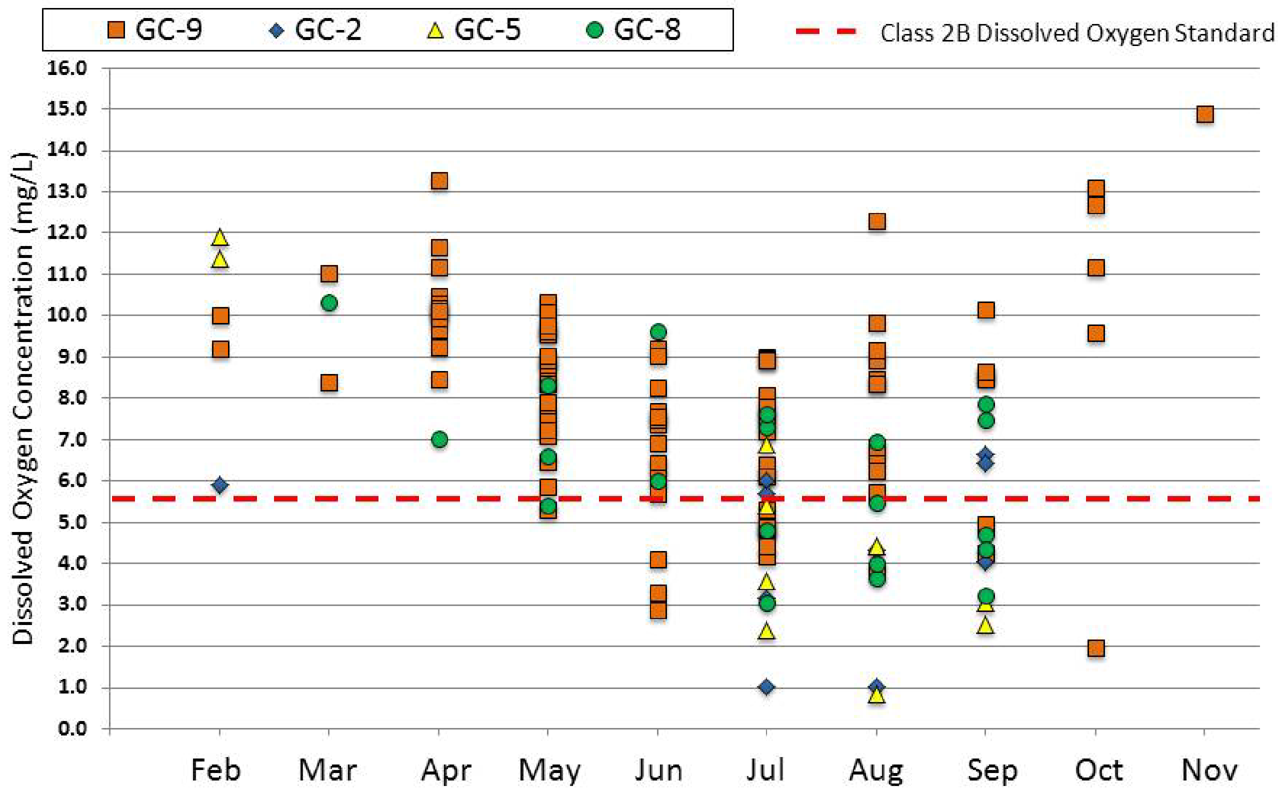


Figure 20: Grove Creek instantaneous DO readings displayed by monitoring site and month

2. Longitudinal (synoptic) dissolved oxygen surveys

A series of longitudinal synoptic DO surveys were conducted during the months of July, August, and September in 2010. A synoptic monitoring approach aims to gather data across a large spatial scale and minimal temporal scale. In terms of DO, the objective was to sample a large number of sites from upstream to downstream under comparable ambient conditions. Dissolved oxygen readings were taken at pre-determined sites in late afternoon/evening and early morning in attempt to capture the peak and trough of the diurnal fluctuation.

Results from the longitudinal surveys are shown in Figure 21. Dissolved oxygen concentrations general increased from upstream to downstream, although this trend was reversed to some degree during the September survey. DO concentrations below 5 mg/L were regularly observed during both AM and PM sampling at sites in the headwaters and upper reaches of Grove Creek (e.g. sites GC-1 through GC-4). Several of these stations are located in reaches of the creek that have extensive riparian wetlands and relatively little flow during the summer months.

DO concentrations well below 5 mg/L were regularly observed at sites in the lower reaches of the creek (e.g. GC-6 through GC-9) during early morning hours, but afternoon/evening readings were generally well above 5 mg/L, with the exception of the September survey.

DO flux was highest in the lower reaches of Grove Creek (GC5 – GC-9). DO flux greater than 4.5 mg/L was observed at GC-4, GC-5, GC-6, and GC-7 during July and August surveys. DO flux was greatest during the July and August surveys and decreased substantially during the final survey in late September. Fluctuations of this magnitude can be considered a potential stressor to aquatic life and/or an indicator of nutrient enrichment.

The longitudinal DO readings from September were influenced by a precipitation event that brought the stream to bankfull stage (Figure 22). The increase in flow caused several changes in the DO regime of the creek. First of all, DO flux was significantly lower at all sites. Little to no change in DO concentration was observed between AM and PM samples in the headwaters reaches during the September sampling event. Sites in the lower reaches had slightly higher DO flux, but still much lower than August and July. In addition, minimum and maximum values at several locations changed considerably from mid-summer low flow measurements. Sites GC-2 through GC-4 near the headwaters experienced a sharp increase in DO concentration compared to July/August measurements. The opposite effect was observed further downstream, as sites GC-5 through GC-9 had lower evening DO concentrations than those observed in July and August.

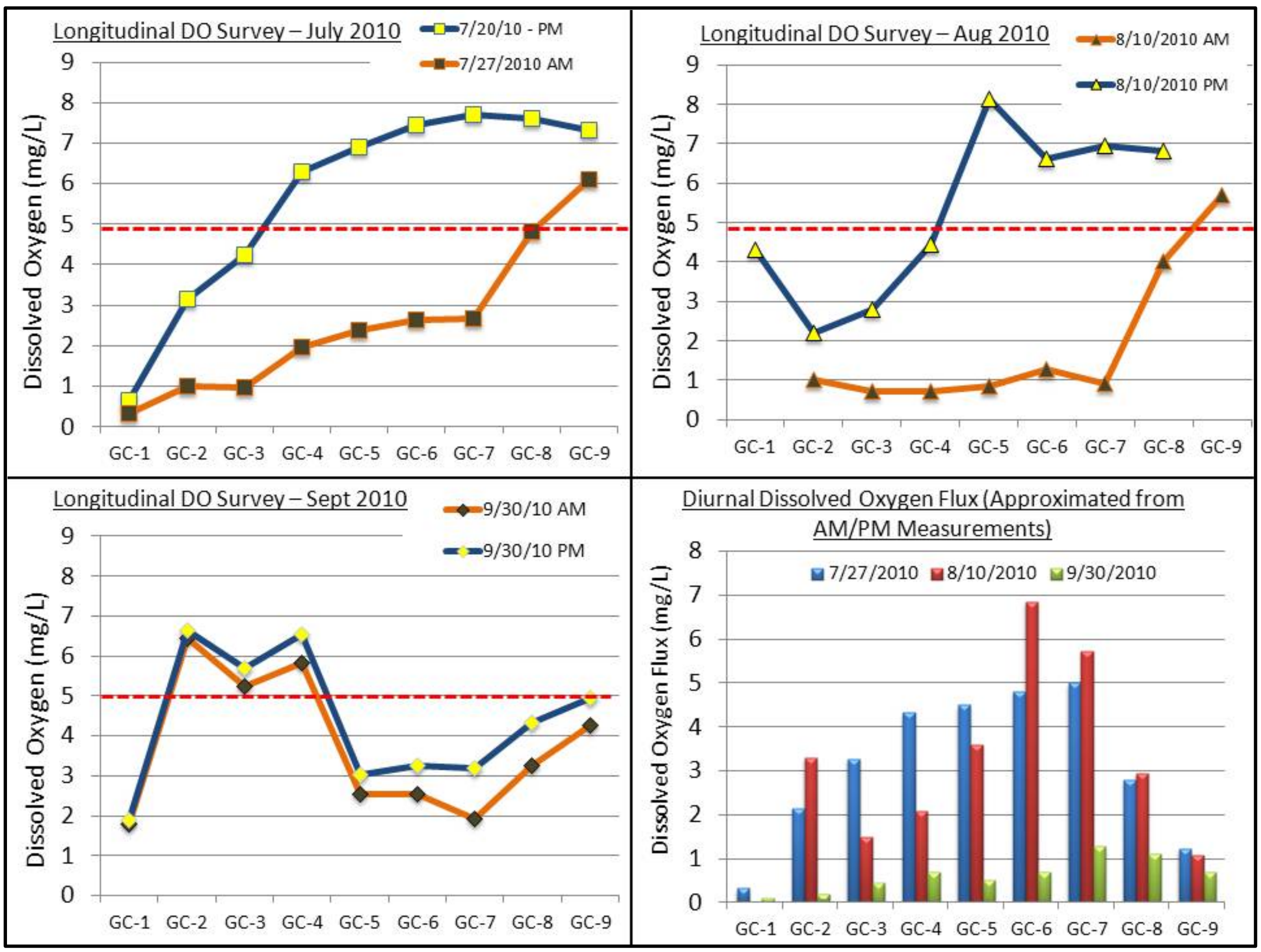


Figure 21: Results of synoptic longitudinal DO monitoring on Grove Creek, completed July – Sept 2010.

Figure 22: Monitoring stations GC-7 (left) and GC-5 (right) at bankfull discharge. Photos taken during longitudinal DO survey, September 30, 2010.

Dissolved oxygen and biological response

Low, and/or highly fluctuating DO concentrations have been observed throughout the length of Grove Creek. Sites in the headwaters and middle-reaches of the creek appear to be more DO-limited than the lower-reaches, but there is sufficient data to suggest that low DO is a systemic stressor that is likely impacting biological integrity at all monitoring sites.

Table 8 provides an overview of some of the typical biological responses, or symptoms, seen in streams with low DO. These biological metrics are known to respond to DO stress, or other stressors, in a predictable fashion. The predicted response is listed next to each biological metric in the table, as well as a summary of available data and whether or not the predicted response was validated by data from the case.

In all cases, the predicted biological response to low DO was validated using available data from Grove Creek. However, many of these same responses can be attributed to other candidate stressors (e.g. turbidity) that may impact the same sensitive fish and macroinvertebrate species. The fish and invert community present in Grove Creek is not entirely dominated by species that would indicate a severely limited DO regime (e.g. central mudminnow). Instead, there is a general lack of sensitive species that are intolerant of marginal habitat conditions.

Summary and strength of evidence

There is a fair amount of evidence in the form of biological and water chemistry data to diagnose DO as a stressor in Grove Creek. However, due to the systemic nature of low DO and poor fish and macroinvertebrate IBI scores, it is difficult to isolate the effects of low DO from other confounding stressors. The fish and macroinvertebrate species present in the creek are not indicative of severely low DO environment, yet the lack of sensitive fish and invertebrate taxa coupled with numerous observations of very low DO concentrations provides solid evidence to diagnose.

As previously mentioned, Grove Creek is currently listed as impaired for low DO based on the available data for that parameter. A TMDL is being developed in response to that impairment listing, which will evaluate sources and pathways that are contributing to low DO levels. The findings of this stressor identification report support the impairment listing for low DO.

Table 8: Compilation of various fish and macroinvertebrate metrics known to respond in a predictable manner in streams with DO deficiencies. Symptoms and responses from Grove Creek biota are also discussed for each metric.

Metric / Biological Attribute	Predicted Response	Observations from Grove Creek	Validated Prediction?
Lack of sensitive fish and macroinvertebrate taxa	Decrease	No sensitive fish species were recorded at sites GB-1 through GB-4, while GB-5 did contain a small percentage of sensitive species in the population. This observation may be due in part to a slightly more suitable DO regime at monitoring station GB-5. Intolerant macroinvertebrate taxa were not found in high numbers at any of the biological monitoring sites. All stations scored a 0 out of 10 for the metric *Intolerant2Ch,* which is based on taxa richness of macroinvertebrates with tolerance values less than or equal to 2.0 using Minnesota tolerance indicator values developed by MPCA.	**YES**
Tolerant Fish / Invertebrate Taxa	Increase	Tolerant fish taxa were observed in relatively high proportions compared to non-tolerant or sensitive taxa. Tolerant fish taxa were particular dominant in the middle reaches of Grove Creek at sites GB-2 and GB-3, which had the lowest mid-summer DO concentrations in during 2010 longitudinal surveys.	**YES**
Fish Abundance	Decrease	Fish abundance measures were low. Metric scores for *NumPerMeter-Tolerant* for sites GB-1, GB-2, GB-3, and GB-4 averaged 0.44 out of a possible 10.0. This metric provides a measure for the number of fish per meter of stream sampled, excluding tolerant species.	**YES**
Serial Spawning Fish	Increase	The metric SSpnTxPct was used in IBI scoring at site GB-5 to evaluate the relative abundance (%) of fish taxa that are serial spawners. Fish with this reproductive trait are capable of spawning numerous times throughout the year, and as a result, their populations are less susceptible to pulse stressors like low DO. Over ¼ of the fish taxa at GB-5 were serial spawners, resulting in very low metric scores for SSpnTxPct over the two sampling events (0/10 and 2.8/10).	**YES**
Late Maturing Fish (female mature age > 3 years)	Decrease	The metric MA>3-TolPct was used in IBI scoring at site GB-5 to evaluate the relative abundance (%) of individuals with a female mature age > or = 3 years, excluding tolerant taxa. Two sampling visits resulted in scores 0 / 10 and 0.48 / 10 in this metric. These results indicate a significant lack of species that have a higher age of sexual maturity and require a more stable DO regime.	**YES**
EPT Taxa	Decrease	The invertebrate metric *POET* was used to evaluate Plecoptera (stonefly), Odonata (dragonfly), Ephemeroptera (mayfly), and Trichoptera (caddisfly) taxa richness. *POET* metric scores were relatively low at all stations, but were particularly low at GB-1, GB-3, and GB-4.	**YES**
Macroinvertebrate Taxa Richness	Decrease	The invertebrate metric *TaxaCountAllChir* was used to evaluate macroinvertebrate taxa richness (excluding chironomids). Taxa richness generally increased from upstream to downstream. Richness at GB-4 and GB-5 could be considered fair to good based on metric scores, while the upstream sites (GB-1 through GB-3) showed relatively poor taxa richness. This trend generally mirrors that of DO based on longitudinal DO sampling.	**YES**

Table 9: Strength of evidence scoring for low DO concentrations as a cause for biological impairments in Grove Creek.

STRENGTH OF EVIDENCE (SOE) TABLE	Fish Impairment	Invertebrate Impairment
Evidence from Grove Creek Data		
Spatial/temporal co-occurrence	+	+
Temporal sequence	0	0
Causal pathway	+	+
Evidence of exposure, biological mechanism	+	+
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	+	+
Symptoms	+	+
Evidence using data from other watersheds / Scientific Literature		
Mechanistically plausible cause	NE	NE
Stressor-response in other lab studies	+	NE
Stressor-response in other field studies	++	++
Stressor-response in ecological models	NE	NE
Manipulation experiments at other sites	NE	NE
Analogous stressors	++	++
Multiple lines of evidence		
Consistency of evidence	+++	+++
Explanatory power of evidence	+	+

3.3 Turbidity and total suspended solids

Grove Creek (AUID 07010204-514) was added to the state impaired waters list in 2010 for failing to meet the Class 2B (warmwater stream) turbidity standard. Due to this impairment listing, a TMDL will be developed to address the elevated turbidity concentrations in Grove Creek. The following section of this Stressor Identification report will evaluate the linkages between elevated turbidity/total suspended solids (TSS) and biological impairments.

Turbidity / TSS targets

Currently, Minnesota is working towards the development of a TSS standard that will replace the water quality standard for turbidity. The specific criteria of the turbidity standard and draft TSS standard are outlined in Table 10. Unlike the turbidity standard which is uniformly applied to all warmwater streams in Minnesota, the TSS impairment threshold varies across three regions of the state that were delineated for development of river nutrient criteria. Grove Creek is located on the border of the Central River Nutrient Region and the Southern River Nutrient Region. The impairment threshold concentrations for both of these regions are listed in Table 10. The majority of the Grove Creek watershed falls within the boundary of the Southern Nutrient Region, so that standard is probably a more accurate standard to apply when evaluating the data.

Table 10: Water quality standards for turbidity and total suspended solids (draft standard) applicable to the Grove Creek watershed.

Parameter	Target (Impairment Threshold)	Specifics of WQ Standard
Turbidity	25 NTU (Class 2B – warmwater streams)	Minimum of 20 independent observations; at least three observations and 10% of total observations must be in violation
TSS	Central River Nutrient Region = 30 mg/L Southern River Nutrient Region = 65 mg/L	Target concentrations can be exceeded for no more than 10% of the appropriately collected samples over a ten year data window; the assessment season is April through September

Grove Creek turbidity / TSS data

Turbidity data from 1981 – 2006, covering 132 discrete measurements, is summarized in Table 11. Turbidity readings above the Class 2B standard of 25 NTU were observed only at the two monitoring sites furthest downstream (GC-8 and GC-9). The rate at which these two stations violate the turbidity standard is sufficient to list the AUID as “impaired” for turbidity. Relatively small data sample sizes for turbidity are available for upstream monitoring station, but the existing data shows considerably lower turbidity levels at those sites, with maximum concentrations well below 25 NTU.

Turbidity levels in Grove Creek exceed the 25 NTU standard most frequently during the month of June (Figure 23). Observations from March, April, and May also show elevated turbidity levels, most likely coinciding with snowmelt runoff events and rain events prior to crop establishment. There are no recorded violations of the turbidity standard for the period of July-October.

Table 11: Summary of instantaneous turbidity readings for the mainstem of Grove Creek, including number of violations and percent observations in violation of the 25 NTU standard.

	Monitoring Station (upstream à downstream)							
	GC-2	**GC-3**	**GC-4**	**GC-5**	**GC-6**	**GC-7**	**GC-8**	**GC-9**
# obs.	8	9	7	8	8	6	21	64
Avg (NTU)	1.9	3.4	2.7	2.3	1.5	0.6	26.2	12.1
Median (NTU)	1.2	2.6	0.2	1.4	0.6	0.0	7.4	8.5
25th Pct (NTU)	0.5	0.0	0.0	0.0	0.0	0.0	3.3	5.0
75th Pct (NTU)	3.4	5.9	6.0	4.6	2.2	0.8	27.3	16.9
Minimum (NTU)	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Maximum (NTU)	4.7	9.5	6.9	6.0	5.4	2.9	110.0	55.1
# Obs above 25 (NTU)	0	0	0	0	0	0	6	7
% Obs above 25 mg/L	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**29%**	**11%**
% Obs below 5 mg/L (April – Sept Only)	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	***30%***	***12%***

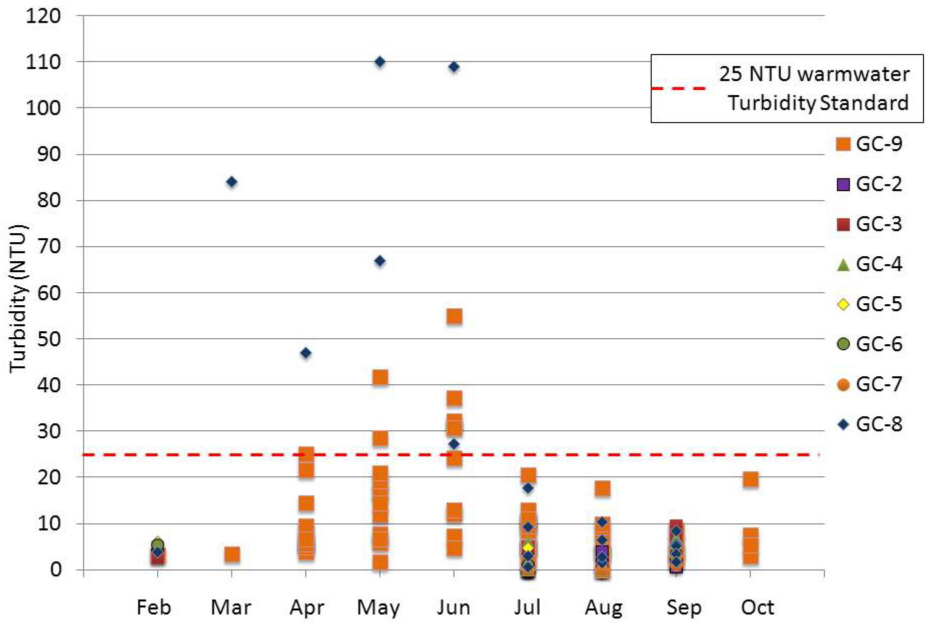


Figure 23: Turbidity readings from Grove Creek by monitoring site and month.

TSS data collected during the period of 1981 – 2009 is summarized in Table 12. Overall, a total of 94 TSS samples were collected at six stations. Almost all of the available TSS data (87 of 94 samples) is from sites GC-8 and GC-9 which are located near the mouth of Grove Creek. TSS concentrations at GC-9 were found to be above southern region TSS threshold 10% of the time (7 of 73 samples) and above central region TSS threshold 32% of the time (23 of 73 samples). A much smaller sample size exists for station GC-8; there were no exceedences of the southern region TSS standard at this station.

TSS follows the same seasonal trends as turbidity. Concentrations are frequently above the draft regional TSS standards in May and June, and rarely exceed these thresholds during late summer and fall months (Figure 23).

Table 12: Summary of instantaneous TSS concentrations for the mainstem of Grove Creek, including number of violations and percent observations in violation of the 25 NTU standard.

		Monitoring Station (upstream à downstream)				
	GC-2	**GC-3**	**GC-4**	**GC-5**	**GC-8**	**GC-9**
# obs.	2	2	1	2	14	73
Avg (mg/L)	9.3	10.3	--	19	21.0	28.4
Median (mg/L)	--	--		--	7.8	22.0
25th Pct (mg/L)	--	--		--	5.1	9.0
75th Pct (mg/L)	--	--		--	34.3	37.0
Minimum (mg/L)	7.6	5.6	29	16	3.6	2.0
Maximum (mg/L)	11	15	29	22	62.0	166.0
# Obs above 30 mg/L	0	0	0	0	4	23
% Obs above 30 mg/L	0%	0%	0%	0%	29%	32%
# Obs above 65 mg/L	0	0	0	0	0	7
% Obs above 65 mg/L	**0%**	**0%**	**0%**	**0%**	**0%**	**10%**

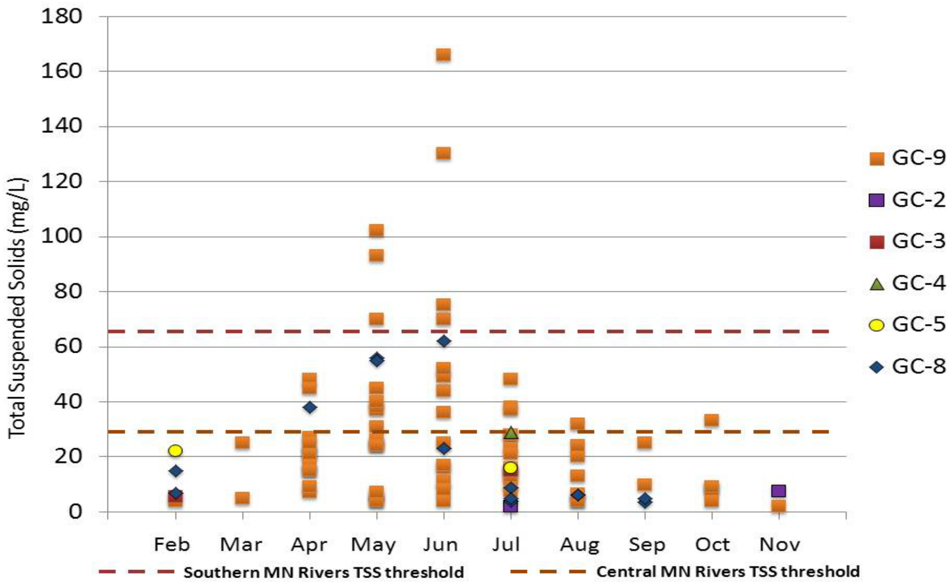


Figure 23: Grove Creek TSS concentrations by month and monitoring station.

Biological response to turbidity / TSS

Increases in suspended sediment and turbidity within aquatic systems are now considered one of the greatest causes of water quality and biological impairment in the United States (U.S. EPA, 2003). Although sediment delivery and transport are an important natural process in all stream systems, sediment imbalance (either excess sediment or lack of sediment) can result in the loss of habitat and/or direct physical or physiological harm to aquatic organisms. As described in a review by Waters (1995), excess suspended sediments cause harm to aquatic life through two major pathways: (1) direct, physical effects on biota (e.g. abrasion of gills, suppression of photosynthesis, avoidance behaviors); and (2) indirect effects (e.g. loss of visibility, increase in sediment oxygen demand).

Reduction in collector-filterer macroinvertebrate taxa

Macroinvertebrates taxa that belong to the functional feeding group “collector-filterers” obtain their food by collecting fine particulate organic matter from the water column using a variety of intricate filters. The abundance of organisms belonging to this functional feeding group can decrease with increasing turbidity levels and/or elevated TSS concentrations. Increases in suspended particles, particularly inorganic sediment, can interfere with the collection of food or damage filters designed to trap organic particles.

Collector-filterer taxa were evaluated as part of the macroinvertebrate IBI scoring for Grove Creek using the metric *Collector-filtererPct*, which measures the relative abundance of these organisms in a sub-sample. Biological monitoring stations in the headwaters and middle-reaches of Grove Creek scored well in this metric, but a sharp decline in metric scores was observed starting at site GB-4 and continuing on to site GB-5 (Figure 24). The low metric scores for *Collector-filtererPct* at GB-5 are spatially co-located with chemistry site GC-8, which frequently has turbidity/TSS values above established thresholds for protecting aquatic life GC8.

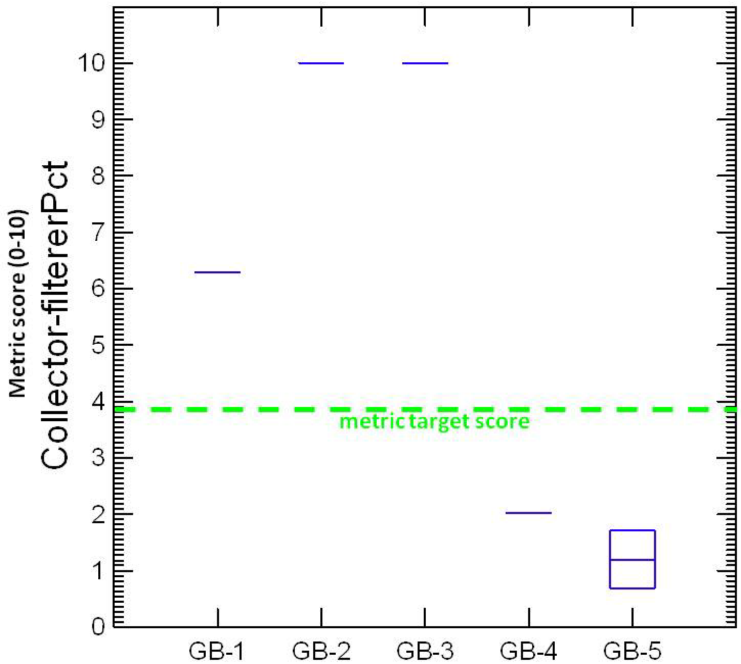


Figure 24: Metric scores for *Collector-filtererPct*, which measures the relative abundance of these organisms in a sub-sample.

Spatial co-occurrence relationships are harder to evaluate for the other biological monitoring sites due to weaker chemistry data sets at those sites. For example, the other site with low collector-filterer MIBI metric scores (GB-4) is co-located with chemistry site GC-5 which has only eight turbidity readings, all of which were collected in 2010. The vast majority of turbidity and TSS data available for monitoring sites other than GC-8 / GC-9 was collected during the summer of 2010, a year that saw lower than normal turbidity concentrations at all Grove Creek monitoring sites, even those that had high turbidity readings in other monitoring years.

There is a very obvious decline in collector-filterer macroinvertebrates in the lower reaches of Grove Creek. Additional turbidity/TSS sampling, especially with a longitudinal or synoptic design, would clarify spatial co-occurrence relationships between this stressor and biological effect.

Fish community and suspended sediment / turbidity

Meador and Carlisle (2007) derived tolerance indicator values (TIVs) for common fish species of the U.S.). The species identified during biological sampling of Grove Creek were compared with the TIVs, and quartered for comparison (Table 13). The first quartile species are more sensitive to suspended sediment while the fourth quartile species are less sensitive to suspended sediment. Several species present in Grove Creek fish did not have TIV data available.

None of the fish species collected in Grove Creek fall into the 1st quartile (most sensitive) for suspended sediment. Species in the 2nd quartile were observed during five of eight sampling events, but were completely absent from GB-3, and made up a very small percentage of the population (1.0% or less) at all stations with the exception of GB-5 (Figure 25). Species in the 3rd quartile for tolerance to suspended sediment were present at all monitoring stations during all sampling events, and made up a large proportion of the assemblage at GB-5 during both visits.

Species in the 4th quartile (most tolerant) were dominant at most monitoring stations. The exceptions to this are station GB-5 (July 2007 sampling event) and GB-3. In both of these instances, the majority of the fish sampled were central mudminnow which is not included in the TIV analysis for suspended sediment in Meador and Carlisle (2007). Central mudminnow are highly tolerant to many forms of disturbance, including sediment. It is likely that this species would fall into a TIV quartile that is tolerant of suspended sediment (3rd or 4th quartile).

Table 13: Fish species present in Grove Creek separated by quartiles based on weighted averages (WA) for suspended sediment (Meador and Carlisle, 2007).

1st Quartile	2nd Quartile		3rd Quartile		4th Quartile	
	CommonName	***TIV***	***CommonName***	***TIV***	***CommonName***	***TIV***
No 1st Quartile fish species observed in Grove Creek	blacknose dace	36	black crappie	56	bigmouth shiner	77
	brown bullhead	26	blackside darter	67	black bullhead	76
	golden shiner	30	bluntnose minnow	48	common carp	93
	largemouth bass	31	common shiner	38	fathead minnow	106
	tadpole madtom	34	creek chub	46	sand shiner	111
			green sunfish	62		
			horneyhead chub	64		
			johnny darter	56		
			northern pike	48		
			spotfin shiner	65		
			white sucker	62		

No tolerance data available:
brassy minnow, brook stickleback, central mudminnow, hybrid sunfish

Sensitive to Suspended Sediment → Less Sensitive to Suspended Sediment

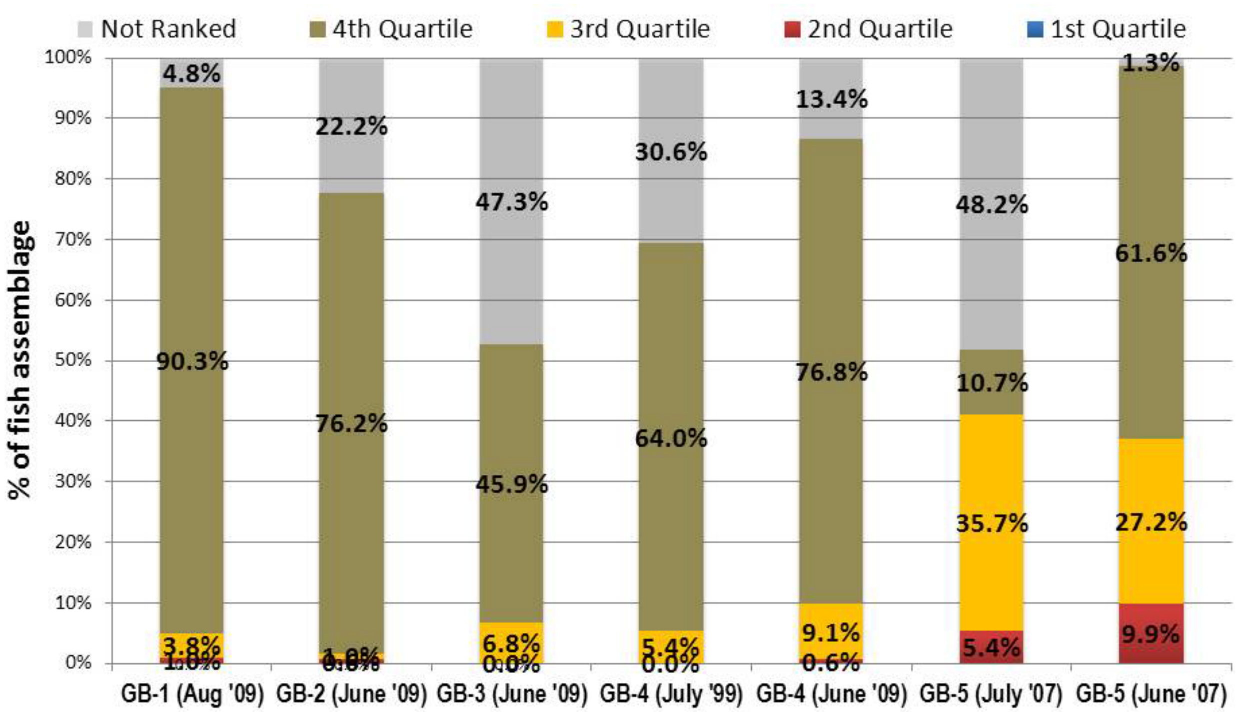


Figure 25: Percent individuals by biological site for each quartile based on suspended sediment weighted averages from Meador and Carlisle, 2007.

Summary and strength of evidence

Turbidity and TSS concentrations in Grove Creek both exceed existing and draft criteria established to protect aquatic life. Biological metric data from the case follow some of the typical trends seen in streams with turbidity/TSS problems; lack of sensitive species, decrease in collector-filterer macroinvertebrates, and low taxa richness for species that are typically not found in turbid streams.

Grove Creek is currently listed as impaired for high turbidity levels based on the available data for that parameter. A TMDL is being developed to in response to that impairment listing, which will evaluate sources and pathways that are contributing to the problem. The findings of this stressor identification report support the impairment listing for turbidity and there are several indicators that this stressor is linked to low fish and invertebrate scores in the watershed.

Table 13: Strength of evidence scoring for elevated turbidity and total suspended solids concentrations as a cause for biological impairments in Grove Creek.

STRENGTH OF EVIDENCE (SOE) TABLE	Fish Impairment	Invertebrate Impairment
Evidence from Grove Creek Data		
Spatial/temporal co-occurrence	0	+
Temporal sequence	0	0
Causal pathway	+	+
Evidence of exposure, biological mechanism	++	+
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	+	+
Symptoms	0	0
Evidence using data from other watersheds / Scientific Literature		
Mechanistically plausible cause	+	+
Stressor-response in other lab studies	+	NE
Stressor-response in other field studies	+	+
Stressor-response in ecological models	NE	NE
Manipulation experiments at other sites	NE	NE
Analogous stressors	++	+
Multiple lines of evidence		
Consistency of evidence	+++	+
Explanatory power of evidence	++	++

3.4 Nitrate toxicity

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

Water samples analyzed for nitrate-N were collected throughout the watershed for purposes of assessment and stressor identification. Nitrate-N is comprised of both nitrate (NO3-) and nitrite (NO2-). Sample results are reported as a concentration of NO2+NO3, but typically water samples contain a small proportion of nitrite relative to nitrate due to the instability of nitrite, which quickly oxidizes to nitrate. For the purposes of this report, “nitrate” will be used to refer to concentrations of NO2+NO3.

The difficulty in applying current knowledge of nitrate toxicity to Minnesota waters is that most of the research has been focused on species that are either not native to North America, or coldwater (salmonid) fish species. Currently, MPCA is working on the development of a nitrate-N standard to protect aquatic life. The draft nitrate standard under development by MPCA (4.9 mg/L chronic; 41 mg/L acute) incorporates toxicology data from a number of studies that have used aquatic organisms commonly found in Minnesota.

Due to the difficulties in isolating nitrate toxicity effects on individual species or biological metrics at this time, this stressor will remain a listed as a candidate cause for impairment (neither diagnosed nor refuted) until a water quality standard is in place. In this report, the MPCA’s draft targets will be used to evaluate the potential for nitrate toxicity as a cause for impairment. When a standard is available, this stressor can be re-visited and a more definitive diagnosis can be made.

Sources of nitrate-N

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

Elevated nitrate concentrations in surface water have been linked to a variety of sources and pathways. Anthropogenic alterations of the landscape, namely increases in agricultural land-use, have raised ambient nitrate concentrations in some watersheds to levels that can be toxic to some fish and macroinvertebrates (Lewis and Morris, 1986; Jensen, 2003). In addition to agricultural sources, elevated NO2 and NO3 concentrations have also been linked to effluent from facilities producing metals, dyes, and celluloids (Kimlinger, 1975), as well as effluent from wastewater treatment plants (Alleman, 1978).

Nitrate-N found in streams of the Grove Creek watershed originate from both point and non-point sources. Given the abundance of cultivated cropland in the watershed, a likely non-point source of nitrate is runoff of from agricultural fields that receive chemical or organic fertilizers. Lefebvre et al. (2007) determined that fertilizer application and land-cover were the two major determinants of nitrate signatures observed in surface water and that nitrate signatures in surface waters increased with fertilization intensity. A sample of field runoff entering a Grove Creek tributary taken during a 2008 snowmelt had a NO2+NO3 concentration of 9.4 mg/L (Figure 26). With land-cover in the watershed being 70% cultivated cropland, the probability of runoff events contributing to high nitrate concentrations in streams is very high.

Figure 26: Runoff from cultivated cropland during March 2008 snowmelt event.

The Grove City wastewater treatment plant (WWTP) is the lone point source for nitrate in the watershed. This facility discharges to a tributary of Grove Creek just north of Grove City. The current discharge permit for this facility does not require the monitoring of effluent for nitrate concentration. However, nitrate-nitrite concentrations of the effluent have been monitored on occasion. Calendar month averages for effluent nitrate concentration are available for September 2011, April 2012, and September 2012, and are displayed in Table 14.

Table 14: Available nitrite-nitrate concentrations and discharge rates for the Grove City WWTP.

Month/Year	Calendar Month Average NO2+NO3 (mg/L)	Discharge - Calendar Month Avg (cfs)
September 2011	10.1	0.0905
April 2012	14.1	0.0736
September 2012	15.5	0.0372

Results from grab samples taken at the time of biological monitoring show an increase in nitrate concentration downstream of the Grove City WWTP discharge point. Figure 27 shows monitoring sites and nitrate concentrations for grab samples from June 17-18, 2009. Nitrate concentration increased from 0.75 mg/L to 2.1 mg/L between sites GB-2 and GB-3, with the Town Slough Outlet (WWTP discharge tributary entering Grove Creek in between those sites. The monitoring station on Town Slough Outlet had a concentration of 3.1 mg/L. Nitrate concentration was below 0.05 mg/L at site GB-4, which indicates that WWTP effluent did have a localized effect on nitrate levels, but the effects were not observed 2.5 miles downstream. These samples only represent one scenario under specific flow conditions and discharge rates from the WWTP, and the effects of the WWTP on nitrate concentrations are likely to vary considerably depending on those variables.

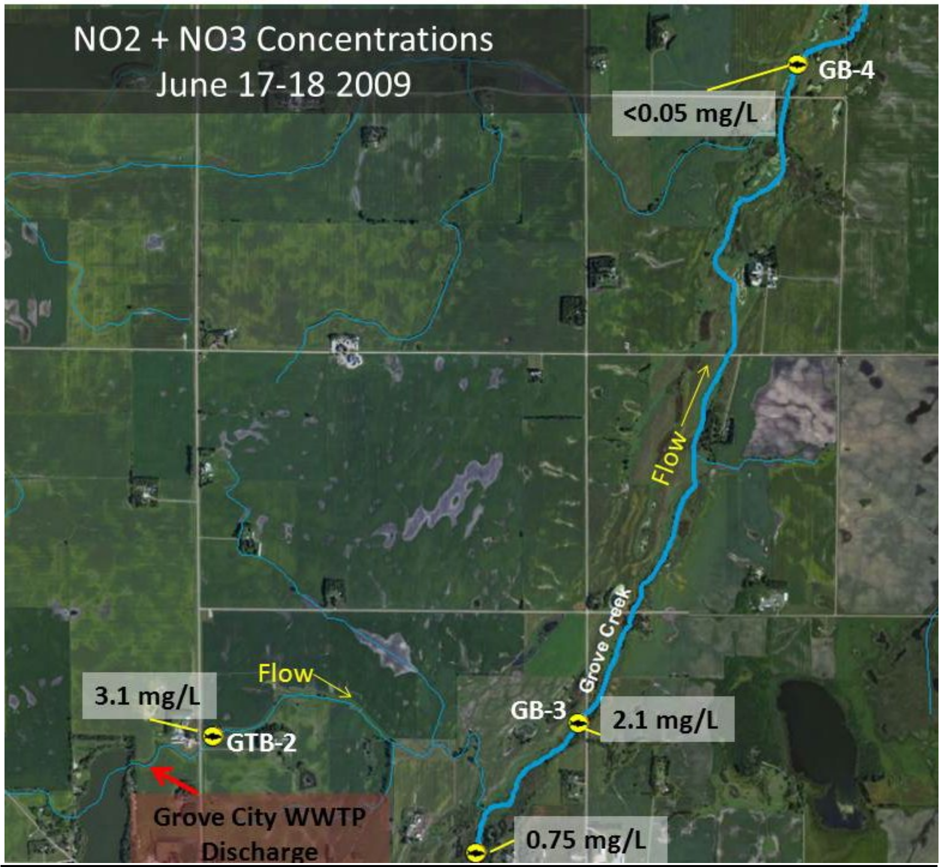


Figure 27: Map showing nitrate concentrations in Grove Creek and Town Slough Outlet on June 17-18. Note increase in nitrate concentration downstream of Town Slough Outlet tributary.

Grove Creek nitrate-N data

Existing nitrate-N data for Grove Creek is displayed by monitoring station and month in Figure 26. The figure includes data from 2001 through 2010, which excludes some older monitoring results from 1981 and 1982. All results from the early 1980's were below the draft chronic standard (n=12, Avg = 1.13 mg/L, Max = 2.23 mg/L). Available data from 2001-2010 show some exceedences of the draft chronic standard during spring and early summer months. These instantaneous sampling points do not reveal any information regarding the duration of time that the draft standard was exceeded, which is an important factor in determining whether a chronic standard was violated. The draft chronic standard for nitrate has a duration component where the chronic concentration (4.9 mg/L) must be exceeded for 96 hours or longer.

All of the samples that exceed or nearly exceed the chronic standard were collected at GC-8 or GC-9, although the other monitoring sites are not represented by large data sets. Additional data collection for nitrate is strongly recommended to improve spatial coverage of the data and address the duration component of the chronic standard.

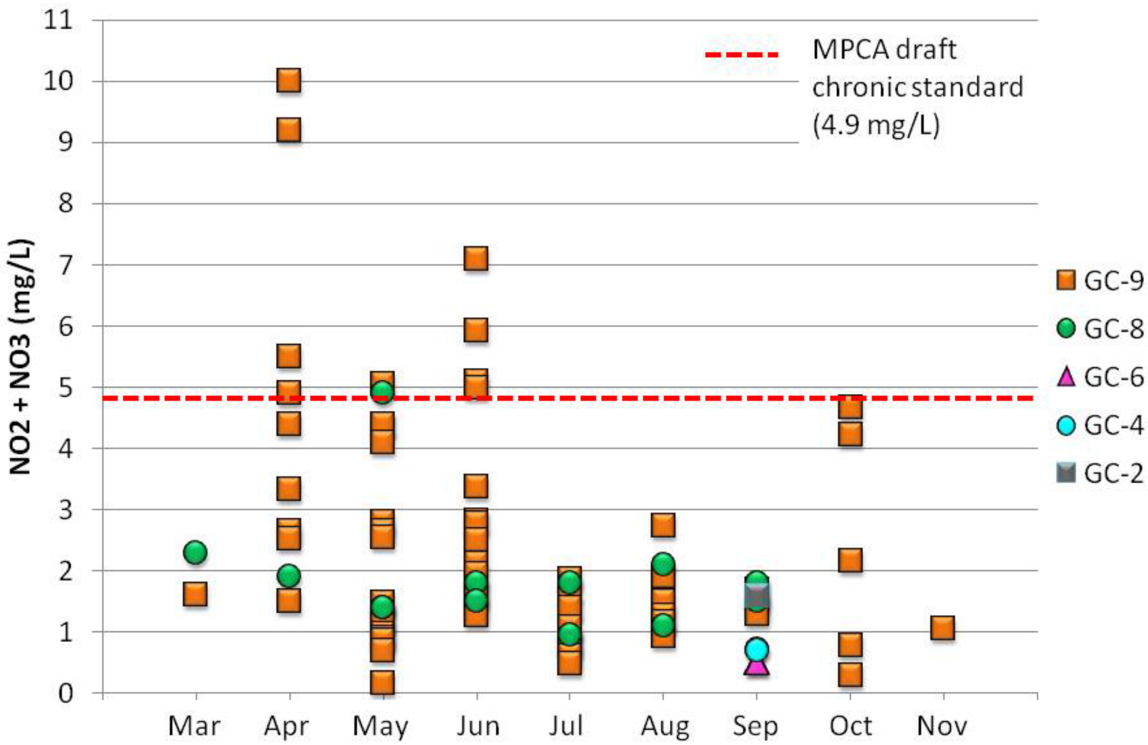


Figure 26: Grab sampling results for NO2+NO3 by monitoring site and month. Graph includes monitoring data from 2001-2010.

Model output for nitrate-N

A Hydrological Simulation Program - FORTRAN (HSPF) model was developed for streams and rivers of the North Fork Crow River watershed to simulate watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale Agricultural Runoff Model and Non-Point Source models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed.

HSPF model output simulating nitrate-N concentrations in Grove Creek was provided for the years 2000-2010. Mean daily nitrate-N concentrations were arranged into a concentration exceedence curve to determine how frequently a given daily average nitrate concentration is exceeded. A total of 3,653 mean daily nitrate results were simulated by the HSPF model. The concentration exceedence curve based on the modeled results is shown in Figure 27. Based on the curve, the draft chronic nitrate standard of 4.9 mg/L was only exceeded 0.33% of the time as a daily average. This may be an indication that the higher nitrate concentrations observed in Grove Creek are short in duration and may not present a chronic stress to aquatic life.

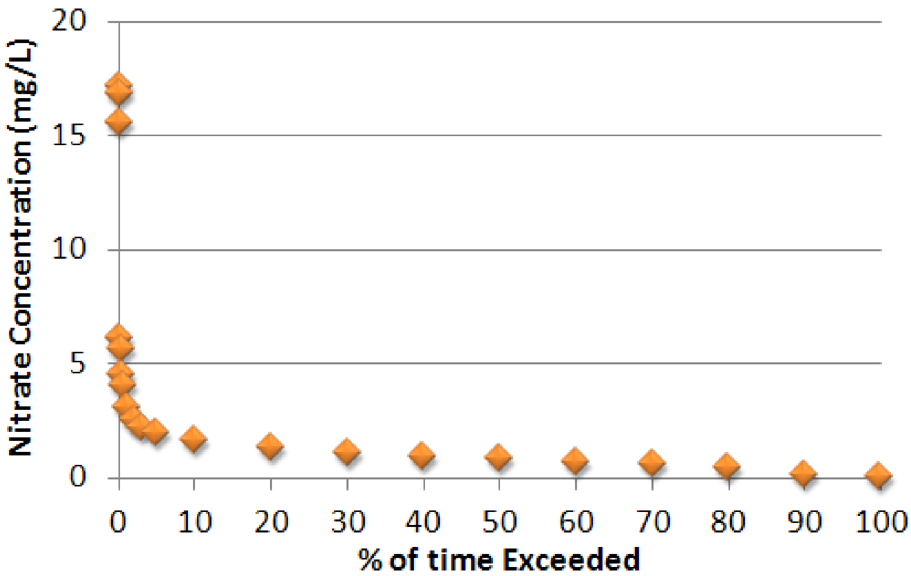


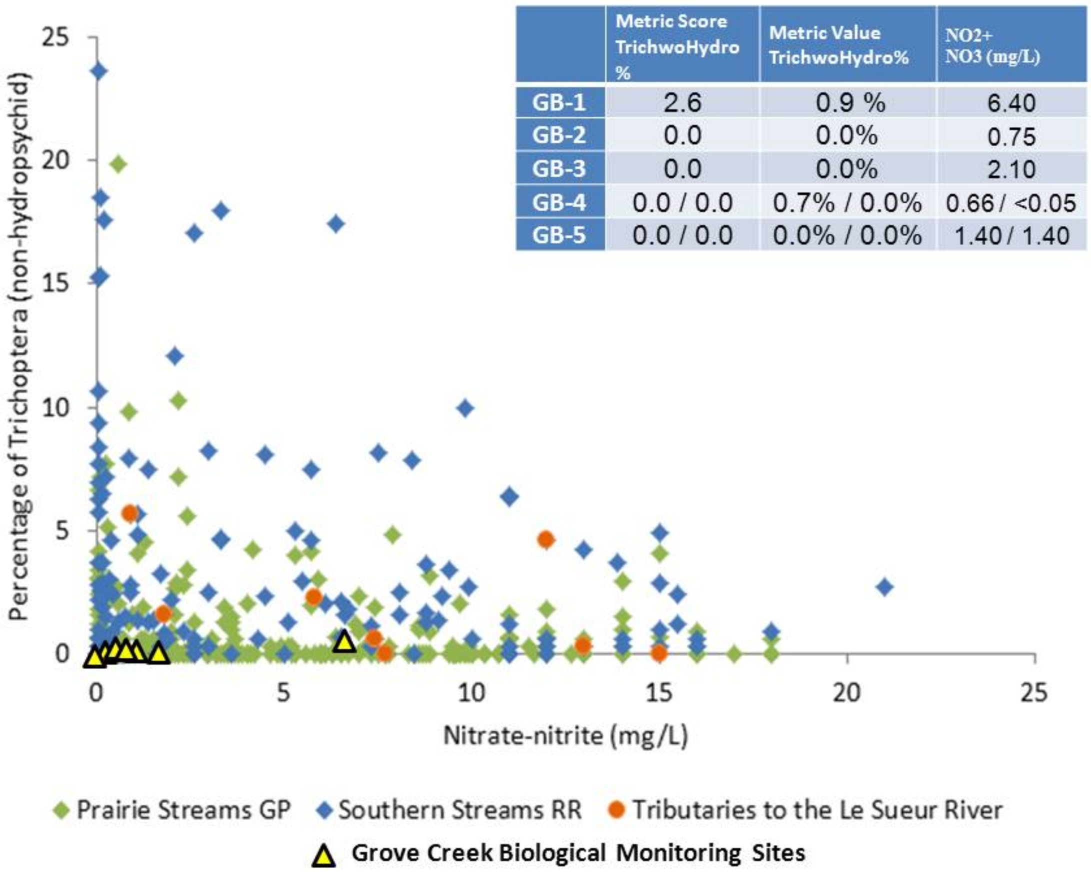
Figure 27: Concentration exceedence curve for nitrate based on mean daily nitrate concentrations simulated by HSPF modeling.

Biological response to nitrate-N

As previously mentioned, certain species of caddisflies, amphipods, and salmonid fishes seem to be the most sensitive to nitrate toxicity (Camargo and Alonso, 2006). Less is known about the effects of nitrate on non-salmonid warmwater and coolwater fish species. This section will evaluate the relationships between nitrate and various biological metrics in Grove Creek.

Tricoptera (caddisfly) richness

Several tricoperta (Caddisfly) metrics have shown negative relationships to nitrate concentration in streams and rivers of Minnesota. Laing (2012) created the scatter-plot in Figure 27 showing a fairly strong negative correlation between non-hydropsychid Caddisfly taxa and increasing nitrate-nitrite concentrations for several biological monitoring classes. Grove Creek monitoring sites are shown on the plot, and are also included in the Prairie Streams Glide-Pool grouping. This plot is based on one-time grab samples for nitrate taken during fish sampling, so the nitrate concentrations represented may not be applicable to all flow regimes.



	Metric Score TrichwoHydro %	Metric Value TrichwoHydro%	NO2+ NO3 (mg/L)
GB-1	2.6	0.9 %	6.40
GB-2	0.0	0.0%	0.75
GB-3	0.0	0.0%	2.10
GB-4	0.0 / 0.0	0.7% / 0.0%	0.66 / <0.05
GB-5	0.0 / 0.0	0.0% / 0.0%	1.40 / 1.40

Figure 27: Scatter-plot showing relative abundance of non-hydropsychid caddisfly individuals and co-located grab samples for nitrite-nitrate nitrogen. Adapted from Laing (2012).

Grove Creek sites show very low relative abundance (%) non-hydropsychid Caddisfly taxa at all sites, but these sites also had comparatively low nitrate concentrations at the time of fish sampling (Figure 27). Site GB-1 in the headwaters of Grove Creek had much higher nitrate concentrations (6.4 mg/L) than the other stations at the time of sample collection. This station also had the highest relative abundance of non-hydropsychid Caddisfly individuals, although the percent was still very low (0.92 %). Although this scatter-plot shows a clear negative relationship between nitrate concentrations and non-hydropsychid caddisfly abundance on a larger scale, data from Grove Creek is less conclusive.

The macroinvertebrate IBI metric *TricopteraChTxPct* measures the relative abundance (%) of tricoptera (caddisfly) taxa in the invertebrate population. Scores for this metric decrease steadily from headwaters site GB-1 downstream, with sharper decreases in metric scores evident at GB-4 and GB-5. These stations are downstream of two sizeable tributaries. One of these tributaries named “Town Slough Outlet” originates in a small lake and serves as the discharge point for the WWTP of Grove City, Minnesota. Monitoring data from this tributary shows relatively high nitrate concentrations at times (9.1 mg/L on 2/10/82), although the other six measurements of nitrate from this tributary are much lower, ranging from 0.45 mg/L to 3.5 mg/L. The other tributary drains an area of intensive row crop agriculture and is known to carry high nitrate concentrations, at least during spring runoff conditions (6.4 mg/L on 3/23/2009).

Regular inputs of nitrate from the WWTP and unnamed tributary may produce a chronic stress effect at sites GB-4 and GB-5, limiting the relative abundance of caddisfly taxa observed at these stations. However, existing chemistry and biological monitoring data is not robust enough to isolate nitrate concentrations as the main cause of decreasing scores in this caddisfly-based metric. There may be other confounding stressors that are increasing in intensity in the same reach.

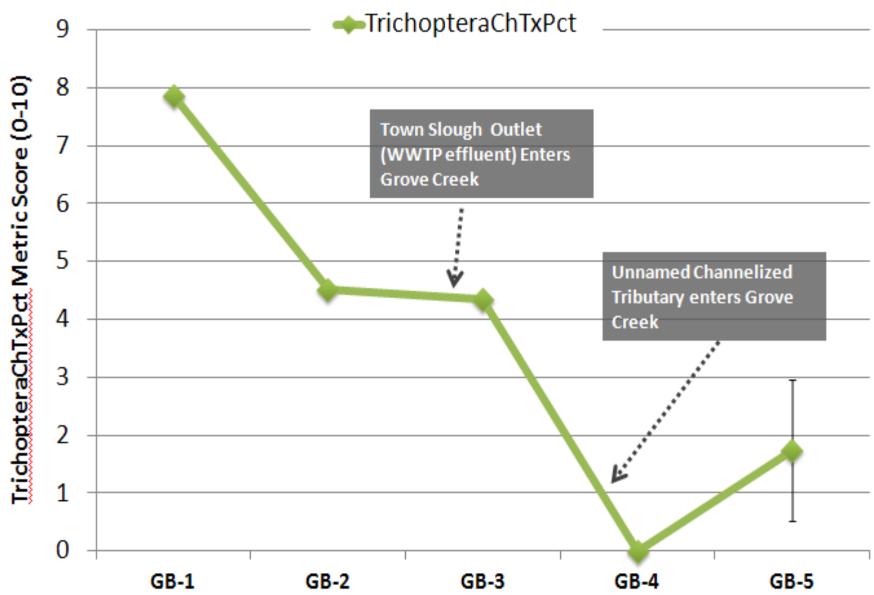


Figure 28: Metric scores related to relative abundance of caddisfly taxa arranged from upstream (left) to downstream (right). Possible sources of nitrate-N are shown in relation to biological monitoring sites.

Fish sensitivity to nitrate

Meador and Carlisle (2007) derived TIVs for common fish species of the United States. Available nitrate TIVs for fish species were quartered into four classes, with the 1st quartile representing species with TIVs most sensitive to nitrate, and the 4th quartile including species that have the highest TIVs for nitrate. Fish species collected in Grove Creek are displayed in Table 15 by quartile with TIVs values for nitrate concentration. Only one individual in the first quartile (golden shiner) was observed in Grove Creek (station GB-1). The vast majority of fish taxa observed were in the 3rd and 4th quartiles for nitrate TIVs, indicating that the fish population is relatively tolerant of higher nitrate concentrations. Seventy-nine percent of the total fish sampled fall into the 4th quartile (least sensitive) for nitrate sensitivity according to the TIVs developed in Meador and Carlisle (2007).

Table 15: Fish species present in Grove Creek separated by quartiles based on weighted averages (WA) for nitrate concentration (Meador and Carlisle, 2007)

1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
		CommonName	*TIV*	*CommonName*	*TIV*	*CommonName*	*TIV*
golden shiner	0.44	tadpole madtom	0.68	black crappie	0.98	blackside darter	1.74
		yellow perch	0.7	brown bullhead	0.99	spotfin shiner	1.81
		hornyhead chub	0.87	northern pike	1.03	bluntnose minnow	1.96
				johnny darter	1.04	blacknose dace	2.44
				largemouth bass	1.15	common carp	2.45
				creek chub	1.21	sand shiner	2.46
				common shiner	1.28	fathead minnow	2.57
				green sunfish	1.42	white sucker	2.6
						black bullhead	2.61
						bigmouth shiner	3.45
						blackside darter	1.74

No tolerance data available:
brassy minnow, brook stickleback, central mudminnow, hybrid sunfish

Sensitive to Suspended Sediment → Less Sensitive to Suspended Sediment

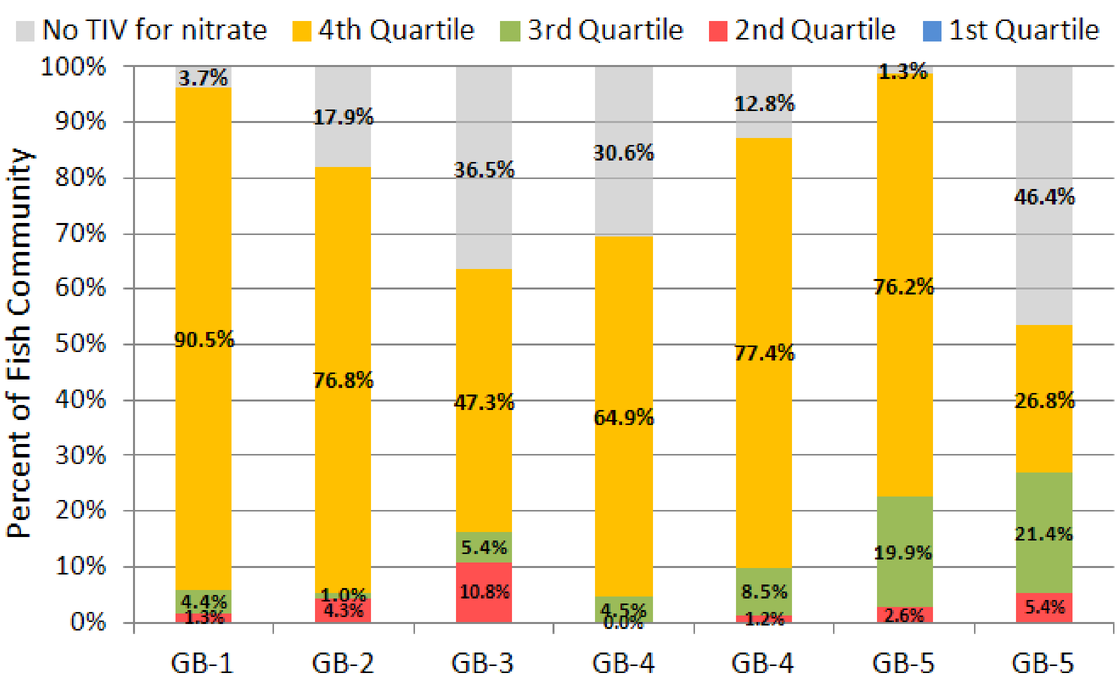


Figure 29: Percentage of fish individuals that fall within established quartiles for nitrate-N tolerance indicator values (TIVs) from Meador and Carlisle, 2007.

There are no clear spatial relationships between nitrate sources and fish with high or low TIVs for nitrate. Fish species with higher TIVs for nitrate make up a lower percentage of the fish community at site GB-3, which is just downstream of the tributary carrying the WWTP effluent, compared to sites upstream. Station GB-3 also had the highest percentage of 2nd quartile individuals of any site sampled. There does appear to be an increase in 4th quartile (more tolerant to nitrate) species starting at GB-4 and continuing downstream to GB-5, although the relative abundance of these species is variable at GB-5. It is difficult to say whether or not the increase in nitrate-tolerant species at these sites is due to increased nitrate concentrations or some other stressor (e.g. turbidity, DO) that may also provide a competitive advantage for species that are more generally tolerant.

Summary and conclusions

Nitrate concentrations in Grove Creek are higher than natural background conditions due to WWTP effluent discharge and intensive agricultural land-uses in the watershed. The draft water quality standard for chronic nitrate toxicity (4.9 mg/L) was exceeded in 11% (9 of 85) of sampling events to date. The maximum concentration recorded in the creek (10 mg/L) is well below the proposed nitrate acute toxicity standard of 41 mg/L. If nitrate toxicity is a stressor in this stream, the effects would be chronic in nature.

Although there is some indication that nitrate-sensitive fish and macroinvertebrate are absent or occur in low numbers, the biological data alone is not sufficient to refute or diagnose nitrate toxicity as a cause of impairment. There is no clear indication that these biological responses are the result of stress from elevated nitrate and not other stressors that are better documented by larger data sets and/or existing water quality standards (e.g. turbidity and DO).

There is not sufficient evidence to diagnose or refute this stressor at this time. Nitrate toxicity should remain a candidate stressor for Grove Creek, and further analysis should take place when the nitrate toxicity standards for Minnesota are finalized. Additional monitoring should also be conducted to satisfy the duration component of the proposed chronic standard.

Table 16: Strength of evidence scoring for nitrate toxicity as a cause for biological impairments in Grove Creek.

STRENGTH OF EVIDENCE (SOE) TABLE	Fish Impairment	Invertebrate Impairment
Evidence from Grove Creek Data		
Spatial/temporal co-occurrence	0	0
Temporal sequence	NE	NE
Causal pathway	+	+
Evidence of exposure, biological mechanism	0	0
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	NE	NE
Symptoms	0	0
Evidence using data from other watersheds / Scientific Literature		
Mechanistically plausible cause	0	0
Stressor-response in other lab studies	NE	NE
Stressor-response in other field studies	NE	NE
Stressor-response in ecological models	NE	NE
Manipulation experiments at other sites	NE	NE
Analogous stressors	+	+
Multiple lines of evidence		
Consistency of evidence	0	0
Explanatory power of evidence	0	0

3.5 Toxicity from insecticides and herbicides

Toxicity from insecticides and herbicides was included as a candidate cause for impairment due to the intensive agricultural land-use in the Grove Creek watershed. Insecticides are designed to be lethal to insects, so they pose a particular risk to aquatic insects, but they also affect other aquatic invertebrates and fish. Herbicides have relatively low toxicity to fish and invertebrates, therefore, acute toxicity is likely only when they are deliberately or accidentally applied directly to water bodies. Direct applications may result in direct toxicity to non-target plants and animals or indirect effects due to the death and decomposition of plants.

Pesticide reference values and standards (text from MDA, 2010)

Water quality reference values and standards are used by MDA's monitoring program to help guide water monitoring activities. These reference values come from several state and federal agency sources. The development of surface and groundwater reference values is an ongoing process and new values are continually being developed over time.

"The Minnesota Pollution Control Agency (MPCA) has developed toxicity-based (for aquatic life) or human health-based enforceable chronic standards for pollutants detected in surface water. The toxicity-based standard is designed to be protective of aquatic life exposure, and is typically based on exposure duration of four days. The human health-based standard (protective for drinking water plus fish consumption) is based on exposure duration of 30 days. For the most current MPCA water quality rules see Chapter 7050: Standards for Protection of Waters of the State (www.revisor.leg.state.mn.us/rules/?id=7050)." A summary of MPCA's chronic and maximum standard values for common pesticides used in Minnesota are shown in Table 17.

Table 17: Summary of MPCA surface water standards associated with target pesticide analytes

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

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

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

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

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

Grove Creek pesticide data

Limited data is available for evaluating pesticides as a stressor to aquatic life in Grove Creek. Site GC-9, located at the mouth of the creek, was sampled once on August 19, 2010, as part of a monitoring effort to gather initial data on impaired streams in the greater North Fork Crow River watershed. Results are displayed in Table 18 for Grove Creek site GC-9 and neighboring tributaries to the North Fork Crow River with similar land-uses.

No violations of current pesticide water quality standards were observed from the single sampling event in 2010. Atrazine and desethylatrazine (degenerate of atrazine) were detected in Grove Creek at levels below quantification limit. Degenerates of the herbicides acetochlor, metolachlor, alochlor, and dimethenamid were also detected in quantities below the quantification limit.

Table 18: Results of pesticide samples collected August 2010 on tributaries to North Fork Crow River. Results are only shown for pesticides and degenerates with applicable state water quality standards.

	Grove Creek (GC-9) S000-897*	Jewitts Creek S000-294*	Battle Creek S006-443*
Herbicide			
Acetochlor (ug/L)	ND	ND	ND
Alachlor (ug/L)	ND	ND	ND
Atrazine (ug/L)	**P**	**0.05**	ND
- Deisopropylatrazine (ug/L)	ND	ND	ND
- Desethylatrazine (ug/L)	**P**	ND	ND
Dimethenamid (ug/L)	ND	**P**	ND
Metolachlor (ug/L)	ND	**P**	ND
Prometon (ug/L)	ND	ND	ND
Propazine (ug/L)	ND	ND	ND
Insecticide			
Chlorpyrifos (ug/L)	ND	ND	ND
Fungicide			
Propiconazole (ug/L)	ND	ND	ND
Tetraconazole (ug/L)	ND	ND	ND

The available monitoring results may be indicator that pesticides are not present at harmful concentrations in Grove Creek during mid-summer low flow periods. However, the data set for Grove Creek needs to be expanded upon to include monitoring results from months when pesticide application rates and potential for runoff into waterways are high. There is not enough data available at this time to refute or diagnose pesticide toxicity as a stressor.

Table 19: Strength of evidence scoring for pesticide toxicity as a cause for biological impairments in Grove Creek.

STRENGTH OF EVIDENCE (SOE) TABLE	Fish Impairment	Invertebrate Impairment
Evidence from Grove Creek Data		
Spatial/temporal co-occurrence	0	0
Temporal sequence	NE	NE
Causal pathway	0	0
Evidence of exposure, biological mechanism	0	0
Field experiments /manipulation of exposure	NE	NE
Laboratory analysis of site media	NE	NE
Verified or tested predictions	NE	NE
Symptoms	0	0
Evidence using data from other watersheds / Scientific Literature		
Mechanistically plausible cause	0	0
Stressor-response in other lab studies	NE	NE
Stressor-response in other field studies	NE	NE
Stressor-response in ecological models	NE	NE
Manipulation experiments at other sites	NE	NE
Analogous stressors	NE	NE
Multiple lines of evidence		
Consistency of evidence	0	0
Explanatory power of evidence	0	0

4.0 Probable Causes for Impairment

There is strong and consistent evidence available to diagnose deposited and bedded sediments, low DO, and elevated turbidity/TSS concentrations as probable causes of biological impairment in Grove Creek. The evidence for nitrate toxicity and pesticide toxicity was not sufficient to diagnose or refute these stressors, so they remain candidate causes for impairment that should be evaluated when available data improves and/or aquatic life standards are available (in the case of nitrate).

Table 20: Strength of evidence scoring for the five candidate causes evaluated for Grove Creek biological impairments

	Deposited & Bedded Sediments	Low Dissolved Oxygen	Turbidity / TSS	Nitrate Toxicity	Pesticide Toxicity
Consistency of evidence	+++	+++	+	0	0
Explanatory power of evidence	++	++	++	0	0

Appendix A – Stressor Identification Desktop Reconnaissance Results

		STREAMFLOW / STREAM POWER				LANDCOVER ALTERATION		RIPARIAN	CHANNEL STABILITY					CONNECTIVITY	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Land Uses (SOURCES)	Streamflow changes (magnitude/ timing/ duration)	Surface/ sub-surface slope hydrology	Clear water discharge	Stream power change (energy distribution)	Surface disturbance (% bare ground/ compaction)	Loss of stream buffers, surface filters, ground cover	Riparian vegetation change (composition/ density)	Direct channel impacts that destabilize channel	Altered dimension, pattern and profile	Excess sediment deposition/ supply (agradation)	Streambed scour / channel incision (degradation)	Large woody debris in channel	Floodplain encroachment channel confinement	Loss of connectivity (fish passage, nutrient cycling, etc.)
A	Urban development	I / L	I / L	X	I / L	D / L	X	X	X	D / M	X	X	X	X	X
B	Idustrial Wastewater	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C	Agricultural	D & I / H	D & I / H	X	D / H	D / H	D / H	D / H	X	D & I / H	D & I / H	I / M	I / L	D / L	D / M
D	Channelization / Ditching	D / H	D / H	X	D / H	X	D / H	D / H	D / H	D / H	D & I / H	D / M	D & I / M	D / L	D / M
E	Municipal Wastewater	D / M	X	D / M	D / L	X	X	X	X	I / M	I / M	I / L	X	X	X
F	Flood control, dredging, levees	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G	Reservoir storage, hydropower	X	X	X	X	X	X	X	X	X	X	X	X	X	X
H	Diversions, depletions (-) Imported (+)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
I	Grazing	I / L	I / L	X	I / L	D / L	D / L	D / L	D / L	D & I / M	D & I / L	D & I / L	D & I / L	X	X
J	Road Crossings/ Culverts	X	X	X	D / L	X	X	X	D / L	D & I / L	D & I / L	D / L	I / L	D / L	D / L
K	Mining	X	X	X	X	X	X	X	X	X	X	X	X	X	X
L	In-channel mining	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		Streamflow alteration is considered a candidate stressor due to the presence of WWTP discharge, landcover alterations, sub-surface drain tiling, and channelization.	Sub-surface drain tile is likely used in many of the cultivated agricultural fields in the watershed. The presence of tile can alter the hydrograph as less water is retained during snowmelt and rain events.	Clear water discharges in the watershed include Grove City WWTP and many miles of sub-surface agricultural drainage tile	Stream power changes have likely occurred as the result of surface disturbance and sub-surface drainage tiling.	Around 75% of Grove Creek's watershed is cultivated cropland. During non-growing seasons these cultivated fields are prone to accelerated surface run-off, which is usually linked to flashy hydrographs and water quality degradation	63% of the land within 250 m buffer of Grove Creek is cultivated cropland, another 14% is pasture. Historically, most of the buffer consisted of prairie grasslands	63% of the land within 250 m buffer of Grove Creek is cultivated cropland, another 14% is pasture. Historically, most of the buffer consisted of prairie grasslands	More than 70% of Grove Creek is currently channelized, or was channelized in the past. All biological monitoring sites except GB-5 were ditched at some point, and are in some phase of re-meandering naturally.	More than 50% of Grove Creek is currently channelized, or was channelized in the past. Biological sites GB-4 and GB-3 are ditched. Significant channel alterations have occurred near the Grove City racetrack, just downstream of 09UM080. This area is now full of fine sediment and carp.	Biological sites GB-4, GB-3, GB-5, and GB-2 all have over 80% fine substrate (sand/silt). Available coarse substrate appears to be highly embedded at sites where it is present (GB-5 - 100% / 95% embedded, GB-2 = 75% embedded, GB-1 = 73% embedded). Avg depth of deposited fines is quite high at several sites (e.g. 26.12 cm at GB-2; 24.85 cm at GB-4)	Sites GB-5 and GB-3 received "poor" scores for scour and depsotion during Pfankuch stability surveys. Sites GB-4 and GB-2 received "fair" scores, while GB-1 received a score rated as "good."	Large woody debris is not a widespread issue on Grove Creek because much of the riparian corridor is herbaceous (reed canary grass). Site GB-5 had some larger debris obstructions due to the forested nature of the riparian corridor at this site.	In some cases, agricultural fields encroach on the floodplain of Grove Creek. The floodplain near the Grove City racetrack is also altered/encroached upon.	A few undersized culverts were noted during kayak surveys. The channel alterations adjacent to the Grove Creek racetrack reduce connectivity of the stream, and appear to have an impact on fish community structure (increase in carp) as well as nutrient/sediment transport.

D = Direct potential impact

I = Indirect potential impact

X= disturbance and effects not present in sub-watershed

O = lack of data (data gap)

H = High probability Stressor

L = Low probability Stressor

M = Medium probility stressor

Land Uses (SOURCES)	Increased TSS / Turbidity	Increased Nutrient Loading	Low Dissolved Oxygen	Δ Stream Temperature	high / low pH	Chloride Toxicity	Toxicity (Metals)	Toxicity (Nitrate/Nitrite, Ammonia)	Toxicity (Pesticides)
	Potential Impacts (STRESSORS OR PATHWAYS)								
Urban development	I / L	D & I / L	X	X	X	X	X	X	X
Point Source Discharge	D / M	D / H	D & I / M	X	X	X	X	D / H	D / L
Logging	X	X	X	X	X	X	X	X	X
Agricultural field runoff	D / H	X	I / M	X	X	X	X	D / H	D / M
Channelization	I / M	I / L	D & I / M	X	X	X	X	X	I / L
Fires or other natural disturbance	X	X	X	X	X	X	X	X	X
Flood control, clearing, veg. removal, dredging, levees	X	X	X	X	X	X	X	X	X
Stream Channel Processes (bank / bed erostion)	D / H	X	X	X	X	X	X	X	X
Diversions, depletions (-) Imported (+)	X	X	D & I / M	X	X	X	X	X	X
Grazing	D & I / L	D & I / L	D & I / L	X	X	X	X	D / L	D / L
Roads (runoff from gravel or paved roads, road de-icing)	D & I / L	I / L	X	X	X	X	X	X	X
Mining	X	X	X	X	X	X	X	X	X
Wetlands	X	D / L	D & I / M	X	X	X	X	X	X
D = Direct potential impact I = Indirect potential impact X= disturbance and effects not present in sub-watershed O = lack of data (data gap) H = High probability Stressor L = Low probability Stressor M = Medium probility stressor	**Turbidity --** Elevated turbidity concentrations (> 25 NTU) at GC-8 and GC-3 during the spring and early summer months. **TSS --** Similar to turbidity -- GC-8 and GC-3 show high concentrations (40-180 mg/L) during spring and early summer	**Phosphorous --** Concentrations of total phosphorous (TP) are well above established river nutrient criteria for the region (0.1 mg/L). Mid-summer TP ranges from 0.2 to 0.6 mg/L.	Low dissolved oxygen concentrations (below 5 mg/L) observed regularly at all Grove Creek biological monitoring sites, especially during the months of July-Sept. DO flux appears to be excessive in some cases as well, with DO maximums above 12 mg/L at GC-9.	Summer maximums appear to be in the range of 25-30 C. Since Grove Creek is a warmwater stream, stream temperature is not a likely stressor.	Almost all pH readings collected on Grove Creek are within the acceptable range of 6.5 - 8.5. One violation of the pH standard was recored at station GC-2 (ph = 8.85), but this reading appears to be an outlier or the result of measurement error. Change in pH is not considered a candidate cause for impairment.	Chloride concentrations are well below established standard of 230 mg/L set to protect aquatic life. 66 chloride samples have been collected on Grove Creek (max = 37 mg/L; Avg = 20.6 mg/L)	Limited metals data exists for Grove Creek. Available data is mostly from the early 1980's. **Arsenic** -- 1 sample @ GC-2 in July 1981 (3.6 ug/L) **Cadmium** -- 0.069 ug/L **Chromium --** 0.9 ug/L **Copper** -- 3.4 ug/L; **Lead** -- 1.2 ug/L; **Nickel** -- 1 ug/L; **Zinc** -- 2.5 mg/L. Based on this limited sampling int he early 80's, heavy metals are an unlikely stressor in the Grove Creek watershed.	**Ammonia** -- concentrations (both total and unionized) are below established standards to protocect aquatic life. **NO2+NO3** -- A good data set for nitrate-nitrite exists at GC-9. Concentrations of 10 mg/L have been observed in early spring, while most readings were in the range of 2-6 mg/L. Samples collected in June show concentrations as high as 7.5 mg/L, while most samples this time of year were around 2-4 mg/L.	No violations of current pesticide water quality standards were observed from the single sampling event in 2010. Atrazine and desethylatrazine (degenerate of atrazine) were detected in Grove Creek at levels below quantification limit. Degenerates of the herbicides acetochlor, metolachlor, alochlor, and dimethenamid were also detected in quantities below the quantification limit.

Appendix B – Fish and Macroinvertebrate IBI Classes of Grove Creek

Fish IBI Class 4 -- northern rivers

Classification criteria

Large warm/cool water rivers in northern Minnesota

Sites in northern Minnesota, excluding the Glacial Lake Agassiz Basin (GLAB) ecoregion, where watershed area is greater than 500 square miles (>350 square miles watershed area in the Red River Basin).

Examples
Rainy River, Mississippi River (above St. Anthony Falls), St. Croix River (above Taylors Falls), Red Lake River (outside of GLAB), St. Louis River, Crow Wing River, Crow River, Little Fork River, Big Fork River, Kettle River

Biocriteria

Upper confidence limit: 44
Impairment threshold: 35
Lower confidence limit: 26

Metric Name	Category	Response	Metric_Desc_tech
DetNWQPct	trophic	negative	relative abundance (%) of individuals that are detritivorous
ExoticPct	composition	negative	Relative abundance (%) of individuals that are exotic
Insect-TolPct	trophic	positive	Relative abundance (%) of individuals that are insectivorous (excludes tolerant species)
NestNoLithPct	reproductive	negative	Relative abundance (%) of individuals that are non-lithophilic nest-guarders
SLithopTXPct	reproductive	positive	Relative abundance (%) of taxa that are simple lithophilic spawners
SSpnTXPct	reproductive	negative	Relative abundance (%) of taxa that are serial spawners (multiple times per year)
VtolTXPct	tolerance	negative	Relative abundance (%) of taxa that are very tolerant
SensitivePct	tolerance	positive	Relative abundance (%) of individuals that are sensitive (scoring adjusted for gradient)
SensitiveTXPct	tolerance	positive	Relative abundance (%) of taxa that are sensitive (scoring adjusted for gradient)
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 IBI Class 5 -- northern streams

Classification criteria

Large warm/coolwater streams and small rivers in northern Minnesota

Sites in northern Minnesota, excluding the GLAB ecoregion, where watershed area is greater than 50 square miles but less than 500 square miles (>350 square miles watershed area in the Red River Basin).

Examples
Cloquet River, Elk River, Boy River, Rice Creek, Platte River, Stony River, Schoolcraft River, Ashley Creek, Sand Hill River

Biocriteria

Upper confidence limit: 59
Impairment threshold: 50
Lower confidence limit: 41

Metric Name	Category	Response	Metric_Desc_tech
DarterSculpSucTXPct	composition	positive	Relative abundance (%) of taxa that are darters, sculpins, and round-bodied suckers
DetNWQPct	trophic	negative	Relative abundance (%) of individuals that are detritivorous
General	trophic	negative	Taxa richness of generalist species
Insect-TolTXPct	trophic	positive	Relative abundance (%) of taxa that are insectivorous (excludes tolerant species)
IntolerantPct	tolerance	positive	Relative abundance (%) of individuals that are intolerant
MA>3-TolPct	reproductive	positive	Relative abundance (%) of individuals with a female mature age >=3 (excludes tolerant taxa)
SensitiveTXPct	tolerance	positive	Relative abundance (%) of taxa that are sensitive
SLithopPct	reproductive	positive	Relative abundance (%) of individuals that are simple lithophilic spawners
SSpnTXPct	reproductive	negative	Relative abundance (%) of taxa that are serial spawners (multiple times per year)
Vtol	tolerance	negative	Number of taxa that are very 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 IBI Class 6 -- northern headwaters

Classification criteria

Small, moderate to high-gradient warm/coolwater streams in northern Minnesota

Sites in northern Minnesota, excluding the GLAB ecoregion, where watershed area is less than 50 square miles and gradient is greater than 0.5 m/km.

Examples
Twelvemile Creek, Grove Creek, Flint Creek, Mayhew Creek, Tibbetts Brook, Shingle Creek, Little Ann River, Hardwood Creek, Barber Creek

Biocriteria

Upper confidence limit: 56
Impairment threshold: 40
Lower confidence limit: 24

Metric Name	Category	Response	Metric_Desc_tech
DarterSculp	richness	positive	Taxa richness of darter and sculpin species
Hdw-Tol	habitat	positive	Taxa richness of headwater species (excludes tolerant species)
InsectCypPct	trophic	positive	Relative abundance (%) of individuals that are insectivorous Cyprinids
Insect-TolTXPct	trophic	positive	Relative abundance (%) of taxa that are insectivorous (excludes tolerants)
Minnows-TolPct	composition	positive	Relative abundance (%) of individuals that are Cyprinids (excludes tolerant species)
NumPerMeter-Tolerant	composition	positive	Number of individuals per meter of stream sampled (excludes tolerant species)
PioneerTXPct	life history	negative	Relative abundance (%) of taxa that are pioneers
Sensitive	tolerance	positive	Taxa richness of sensitive species
SLithop	reproductive	positive	Taxa richness of simple lithophilic spawning species
TolTXPct	tolerance	negative	Relative abundance (%) of taxa that are tolerant
FishDELTPct	tolerance	negative	Relative abundance (%) of individuals with deformities, eroded fins, lesions, or tumors

Invertebrate Class 2 - prairie forest rivers

Classification citeria

Sites in Minnesota that are representative of the Eastern Broadleaf Forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces. Sites included in this class have watershed areas that exceed 500 square miles.

Examples

Blue Earth River, Bois de Sioux River, Buffalo River, Cannon River, Cedar River, Chippewa River, Crow River, Des Moines River, Minnesota River, Mississippi River, Ottertail River, Pomme de Terre River, Red Lake River, Red River, Redwood River, Root River, Roseau River, Sauk River, St. Croix River, Two Rivers, Wild Rice River, and Zumbro River

Biocriteria

Upper confidence limit: 41.5
Impairment threshold: 30.7
Lower confidence limit: 19.9

Metric Name	Category	Response	Metric Description
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
Intolerant2lessCh	Tolerance	Decrease	Taxa richness of macroinvertebrates with tolerance values less than or equal to 4, using MN TVs
Odonata	Richness	Decrease	Taxa richness of Odonata
PredatorCh	Richness	Decrease	Taxa richness of predators
TaxaCountAllChir	Richness	Decrease	Total taxa richness of macroinvertebrates
TrichwoHydroPct	Composition	Decrease	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample
VeryTolerant2Pct	Tolerance	Increase	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8; metric uses tolerance values developed for the HBI_MN metric

Invertebrate Class 5 – southern streams (riffle/run habitats)

Classification criteria

Sites within this class are representative of the Eastern Broadleaf Forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces, as well as streams in HUC 07030005. Sites included in this class have watershed areas less than 500 square miles.

Examples
Ashley Creek, Beaver Creek, Cedar River, Chippewa River, Clearwater River, Cobb River, Deer Creek, Elk River, Le Sueur River, Okabena Creek, Otter Creek, Pomme de Terre River, Redwood River, Rice Creek, Rock River, Root River, Wells Creek, Yellow Medicine River, and Zumbro River

Biocriteria

Upper confidence limit: 48.5
Impairment threshold: 35.9
Lower confidence limit: 23.3

Metric Name	Category	Response	Metric Description
ClimberCh	Habitat	Decrease	Taxa richness of climbers
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
Plecopotera	Richness	Decrease	Taxa richness of Plecoptera
PredatorCh	Richness	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

Invertebrate Class 6 – southern forest streams (glide/pool habitats)

Classification criteria

Sites within this class have watershed characteristics representative of Eastern Broadleaf Forest ecological province, as well as streams in HUC 07030005. Sites included in this class have watershed areas less than 500 square miles.

Examples

Battle Creek, Cedar River, Deer Creek, Elk River, Goose Creek, Le Sueur River, Little Cedar River (Middle Fork), Long Prairie River, Mill Creek, Money Creek, Otter Creek, Pine Creek, Rice Creek, Riceford Creek, Root River, Rush Creek, Shell Rock River, Sucker Creek, Sunrise River, and Wells Creek

Biocriteria

Upper confidence limit: 60.4
Impairment threshold: 46.8
Lower confidence limit: 33.2

Metric Name	Category	Response	Metric Description
ClimberCh	Habitat	Decrease	Taxa richness of climbers
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	Richness	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

Invertebrate Class 7 – prairie streams (glide/pool habitats)

Classification criteria

Sites in Minnesota that are representative of the Prairie Parklands and Tall Aspen Parklands ecological provinces. Sites included in this class have watershed areas less than 500 square miles.

Examples

Ashley Creek, Beaver Creek, Buffalo River, Crow River, Maple River, Marsh Creek, Middle River, Mud Creek, Pomme de Terre River, Rice Creek, Shakopee Creek, Snake River, Tamarac River, Two Rivers, Whiskey Creek, Wild Rice River (South Branch), and Yellow Medicine River

Biocriteria

Upper confidence limit: 51.9
Impairment threshold: 38.3
Lower confidence limit: 24.7

Metric Name	Category	Response	Metric Description
ClimberCh	Habitat	Decrease	Taxa richness of climbers
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	Richness	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