North Fork Crow River Watershed Biotic Stressor Identification Report

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

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 the North Fork Crow River (NF Crow), a warm-water river located in west central Minnesota. Initially, a comprehensive review of existing biological, chemical, and physical data was performed to create a broad list of candidate causes for the impairments. The candidate causes evaluated in this report are listed below, along with a brief summary of their impact in this watershed.

1. **Loss of habitat due to stream channelization**

   This stressor appears to be a major contributor to biological impairments in the headwaters of the NF Crow and a several-mile reach immediately downstream of Lake Koronis. The channelized condition of the stream channel is likely responsible for degraded aquatic and riparian habitats observed in those areas.

2. **Elevated concentrations of total suspended solids**

   Total suspended solids (TSS) appears to be a significant stressor to aquatic life in the lower half of the NF Crow and Lower Crow River. From about Kingston, MN downstream to the Mississippi River, TSS concentrations are frequently above water quality standards to protect aquatic life.

3. **Loss of habitat due to fine sediment deposition**

   Increased deposition of fine sediment on the streambed is likely a stressor in the NF Crow and Lower Crow River, especially in the channelized stream reach downstream of Lake Koronis.

4. **Toxicity or stress from:**

   a. **Elevated nitrate-N concentrations**

      Nitrate-N concentrations exceed 4.9 mg/L (value of the chronic standard) on occasion in the North Fork and Lower Crow River system. It is unclear whether the **duration** of exposure to elevated nitrate-N concentrations is long enough to cause stress to aquatic life. Based on available data, nitrate-N may be a stressor in the NF Crow from the headwaters to Lake Koronis.

   b. **Pesticides (herbicides, insecticides, fungicides)**

      Several common pesticides were detected in surface waters of the NF Crow and Lower Crow River. However, concentrations were generally low and did not exceed established water quality standards. Additional sampling is recommended to further evaluate this potential stressor.

   c. **Chloride**

      Available chloride data shows concentrations are below state water quality standards. Chloride toxicity is not an unlikely stressor in the watershed.

5. **Low dissolved oxygen concentrations / dissolved oxygen flux**

   Low dissolved oxygen (DO) concentrations and high DO fluctuation are likely stressing fish and macroinvertebrate communities in the Lower NF Crow and Lower Crow River.

6. **Loss of connectivity (impoundments)**

   The carp control dam at the outlet of Lake Koronis limits fish passage between the lake and the portion of the NF Crow below the dam. The dam, as well as water quality problems in Lake Koronis and Rice Lake, is likely to be negatively impacting biota inhabiting downstream reaches of the NF Crow.

1.0 Introduction

1.1 Process overview / North Fork Crow River watershed impairments

Water quality and biological monitoring in the NF Crow watershed has been active for several decades. As part of the MPCA's new Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2007-2010. The data collected during this period, as well as historic data obtained prior to 2007, were used to identify stream reaches that lacked healthy fish and macroinvertebrate assemblages (Figure 1). Fish and macroinvertebrate data were collected at most biological monitoring stations, and were assessed independently, making it is possible for a given stream reach to be impaired for one or both of these biological indicators.

The result of this assessment monitoring effort was the listing of select NF Crow watershed streams as "impaired" for aquatic life. (Table 1, Figure 2).The biologically impaired stream reaches in the watershed include the entire NF Crow and Crow River mainstem, and numerous tributary streams (Figure 1).

NF Crow watershed streams that are not listed as impaired are either not yet assessed (lacking monitoring data) or are showing good to exceptional biological integrity based on current data. For a complete report on the condition of NF Crow watershed streams and lakes, see the Phase I IWM report at the following link (http://www.pca.state.mn.us/index.php/view-document.html?gid=17110).

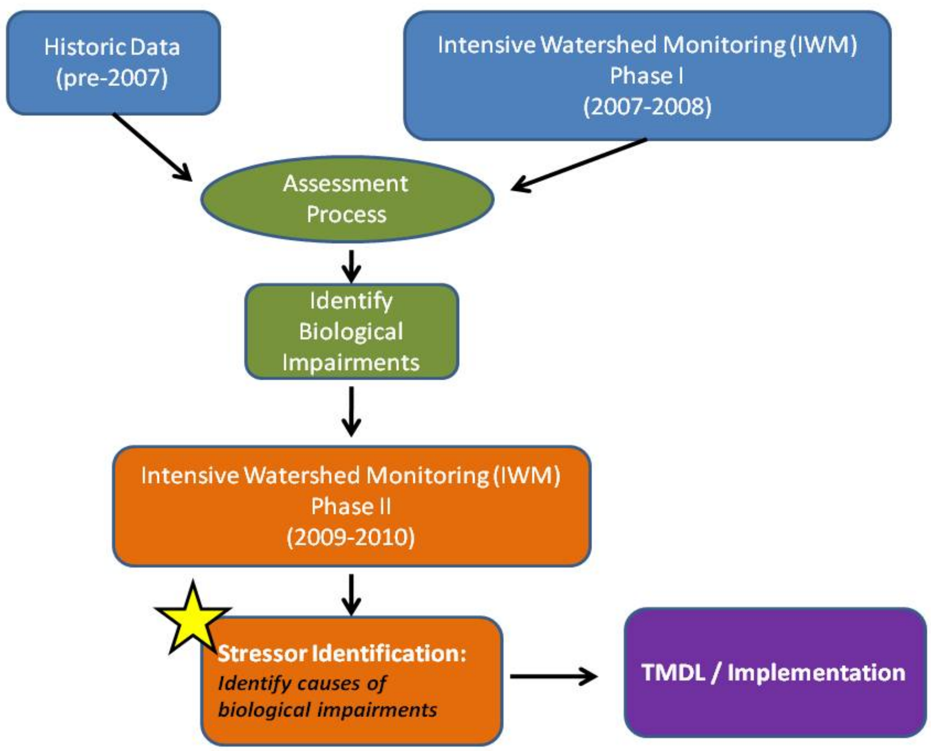


Figure 1: Process map of IWM, assessment, and Stressor ID/TMDL processes for the NF Crow watershed

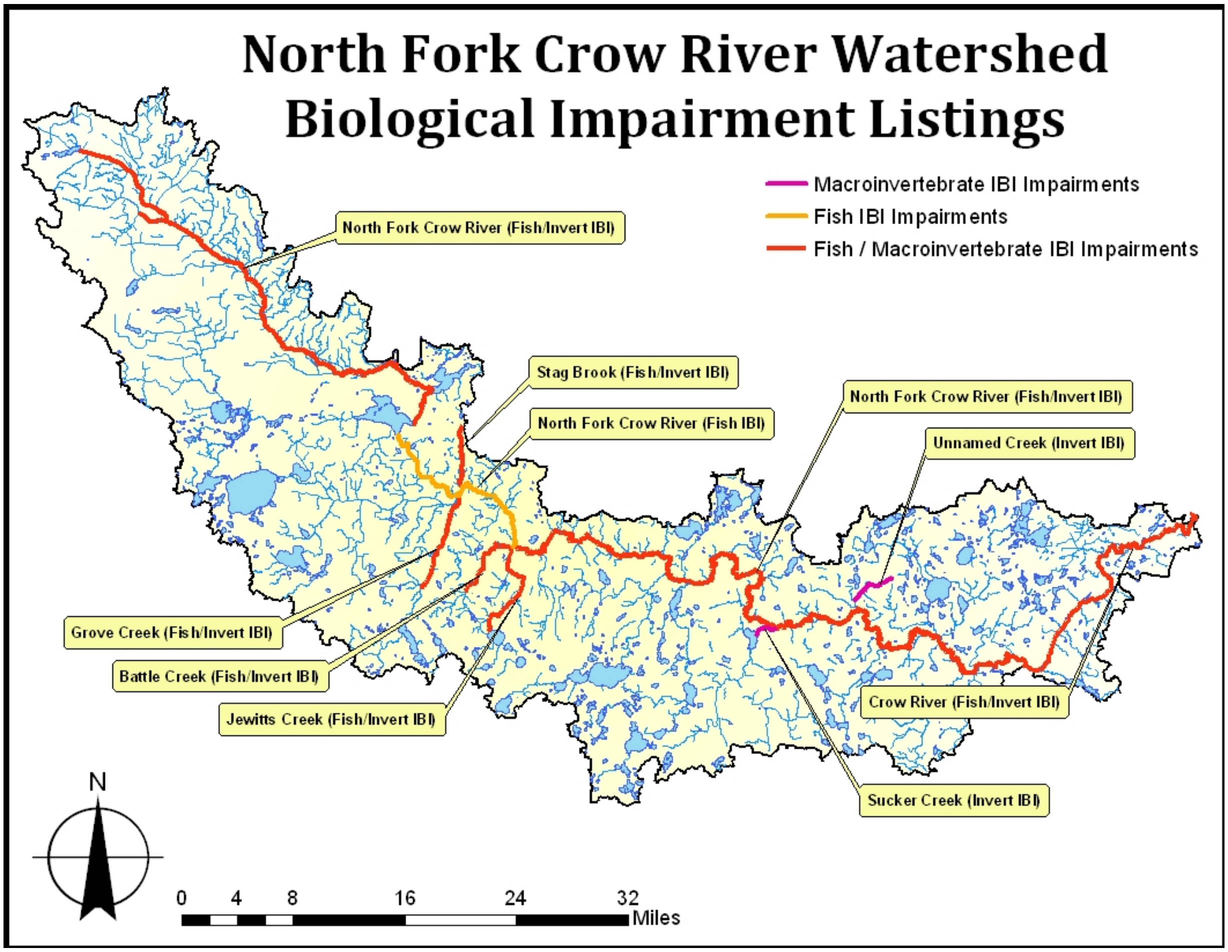


Figure 2: Location of biological impairments in the NF Crow watershed

Table 1: Summary of stream reaches with biological impairments in the NF Crow watershed. Water quality impairments for each stream reach are provided as well.

			Impairments	
Stream Name	**AUID #**	**Reach Description**	**Biological**	**Water Quality***
NF Crow River	07010204-508	Headwaters to Lk Koronis	Fish IBI / Invertebrate IBI	none
NF Crow River	07010204-504	Lk Koronis to M Fk Crow R	Fish IBI	Hg
NF Crow River	07010204-507	M Fk Crow R to Jewitts Cr	Fish IBI	none
NF Crow River	07010204-506	Jewitts Cr to Washington Cr	Fish IBI / Invertebrate IBI	none
NF Crow River	07010204-556	Meeker/Wright Co. line to Mill Cr	Fish IBI / Invertebrate IBI	none
NF Crow River	07010204-503	Mill Cr to S Fk Crow R	Fish IBI / Invertebrate IBI	DO, T, Hg
Crow River	07010204-502	S Fk Crow R to Mississippi R	Fish IBI / Invertebrate IBI	DO, T
Grove Creek	07010204-514	Unnamed Cr to N Fk Crow R	Fish IBI / Invertebrate IBI	DO, T
Battle Creek	07010204-552	T120 R31W S32, south line to Jewitts Cr	Fish IBI / Invertebrate IBI	none
Jewitts Creek	07010204-585	Headwaters to N Fk Crow R	Fish IBI / Invertebrate IBI	Cl, A
Sucker Creek	07010204-682	Cokato Lk to N Fk Crow R	Invertebrate IBI	none
Unnamed Cr	07010204-543	Unnamed cr to Unnamed cr	Invertebrate IBI	none

1.2 Organization framework of stressor identification

The stressor identification process (SID) is used in this report to weigh evidence for or against various candidate causes of biological impairment (see Cormier et al., 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 3). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s).

SID draws upon a broad variety of disciplines, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. Strength of evidence (SOE) analysis is used to develop cases in support of, or against various candidate causes. The scoring scale for evaluating each type of evidence in support or against a stressor is displayed in Appendix B. Typically, the majority of the information used in the SOE analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon in the SID process.

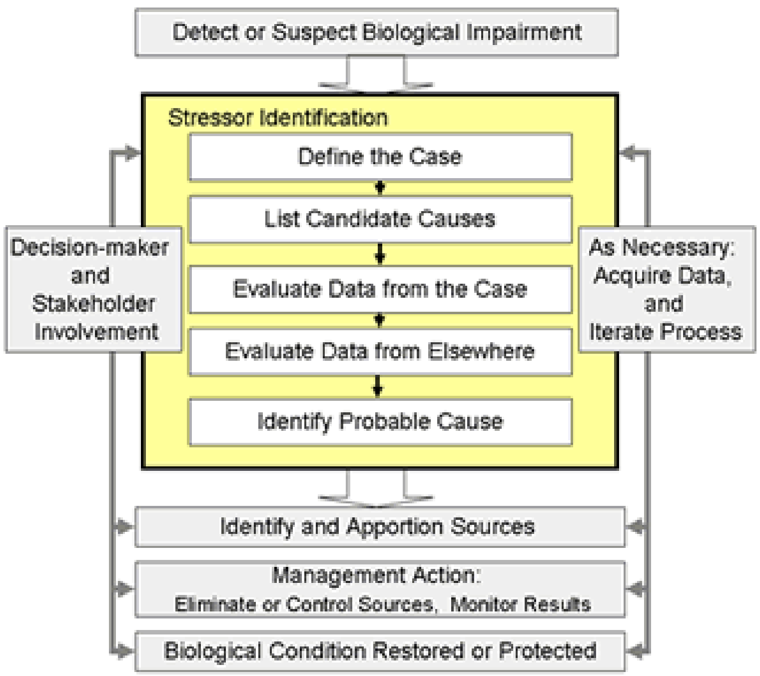


Figure 3: Conceptual model of SID process

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

Strength of evidence scoring

The relationships between stressor and biological response are evaluated by considering the degree to which the available evidence supports or weakens the case for a candidate cause. A standard set of scores recommended by the U.S. Environmental Protection Agency (EPA) were used to tabulate scores for each candidate cause. These scores are described in Table 1.1. For additional information on the scoring process, visit the EPA CADDIS website on scoring (http://www.epa.gov/caddis/si_step_scores.html).

Table 1.1: Strength of evidence scoring criteria

Score	Interpretation
+ + +	This finding *convincingly supports* the case for the candidate cause
+ +	This finding *strongly supports* the case for the candidate cause, but is not convincing due to potential confounding
+	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because coincidence and errors may be responsible.
0	This finding *neither supports nor weakens* the case for the candidate cause
-	This finding *somewhat weakens* the case for the candidate cause, but is not strongly weakening because coincidence and errors may be responsible
- -	This finding *strongly weakens* the case for the candidate cause, but is not convincing because the exposure or the mechanism may have been missed
- - -	This finding *convincingly weakens* the candidate cause
NE	No evidence of this type available

2.0 North Fork Crow River - Crow River watershed zones

The NF Crow originates from Grove Lake and a series of wetlands in eastern Pope County and flows southeasterly 148 river miles to the city of Rockford, where it joins the South Fork Crow River. From this confluence downstream, it becomes the Crow River, flowing northeasterly 26 miles to the Mississippi River near the town of Dayton. Along its course, the NF Crow flows through several lakes and impounded reservoirs, some of which are quite large in size (e.g. Lake Koronis – 2,970 acres). Several of the lakes in the watershed are in violation of state water quality standards and have the potential to alter river conditions and affect the distribution of fish and other aquatic life.

In all, the watershed drains approximately 950,000 acres and includes portions of eight counties. The size and complexity of the NF Crow watershed makes it difficult to evaluate potential stressors without further stratifying the NF Crow drainage into smaller sections. Although there may be some consistent chemical and physical stressors found throughout, some stressors are likely acting locally and are driven by characteristics specific to a certain region of the watershed. For the purpose of investigating biological impairments in this report, the NF Crow watershed was stratified into four zones based on geomorphological, geological, and agro-ecoregion (University of Minnesota) boundaries. Hydrological factors such as drainage area and rate of channelization were also considered in breaking down the watershed into more manageable sections. The map in Figure 4 shows the locations of each watershed zone and the name given to it.

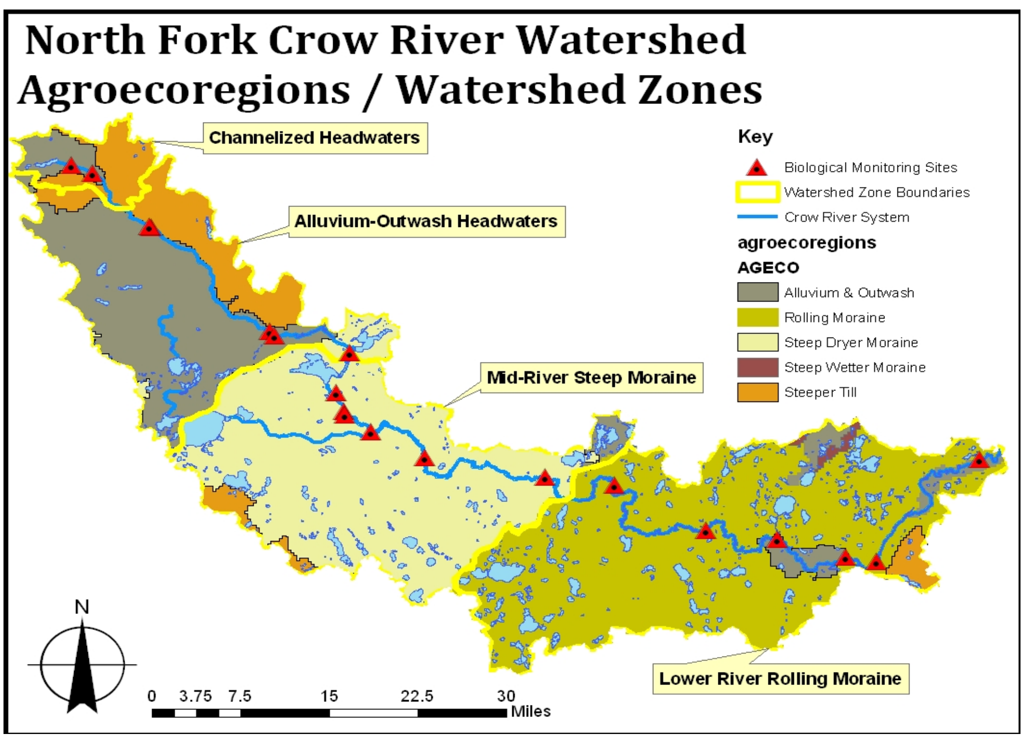


Figure 4: Map showing agroecoregions and "watershed zones" in the NF Crow watershed.

The biological criteria used to evaluate fish and macroinvertebrate populations in the NF Crow watershed are closely correlated with the watershed zones that were established. The index of biological integrity (IBI) criteria developed by the Minnesota Pollution Control Agency (MPCA) separates monitoring sites into classes based on drainage area, stream gradient, and geographical location. Table 2 shows all of the biological monitoring sites located on the NF Crow and Lower Crow River, along with the fish/invertebrate classifications as assigned by the MPCA. As shown in the table, there is a high level of correlation between these classes and the watershed zones, especially within the fish classes.

Table 2: List of NF Crow / Crow River biological monitoring sites, biological classifications, and corresponding watershed zone

Site ID	County / Nearest Town	Fish Class	Invert Class	Watershed Zone
00UM081	Wright Co. / 4 mi. S. of Elk River	4	2	Lower River Rolling Moraine
00UM080	Wright Co. / Rockford	4	2	Lower River Rolling Moraine
07UM046	Wright Co. / 3 mi. W of Rockford	4	2	Lower River Rolling Moraine
07UM055	Wright Co. / 5.5 mi. N of Montrose	4	2	Lower River Rolling Moraine
07UM050	Wright Co. / Highland	4	2	Lower River Rolling Moraine
07UM059	Wright Co. / 1 mi. S of French Lake	4	2	Lower River Rolling Moraine
07UM013	Meeker Co. / Kingston	4	2	Mid-River Steep Moraine
07UM021	Meeker Co. / 8 mi. N of Litchfield	4	2	Mid-River Steep Moraine
07UM029	Meeker Co. / Manannah	5	5	Mid-River Steep Moraine
07UM074	Meeker Co. / 3 mi. NW of Manannah	5	7	Mid-River Steep Moraine
00UM056	Meeker Co. / 1/2 mile E on C.R.	5	7	Mid-River Steep Moraine
09UM058	Meeker Co. / 4 mi SE of Paynesville	5	7	Mid-River Steep Moraine
07UM035	Stearns Co. / 2.5 mi. SE of Paynesville	5	6	Alluvium-Outwash Headwaters
96UM004	Kandiyohi Co. / 2.5 mi. W of Paynesville	5	n/a*	Alluvium-Outwash Headwaters
07UM009	Kandiyohi Co. / 3.5 mi. West of Paynesville	5	n/a*	Alluvium-Outwash Headwaters
99UM050	Stearns Co. / 5.7 mi E of Brooten	5	7	Alluvium-Outwash Headwaters
07UM003	Stearns Co. / 5.7 mi E of Brooten	5	5	Alluvium-Outwash Headwaters
07UM032	Stearns Co. / 5.9 mi N of Brooten	6	7	Channelized Headwaters
07UM084	Stearns Co. / 6.1 mi N of Brooten	6	7	Channelized Headwaters

* station not sampled for macroinvertebrates

The following pages provide a brief description of the land-use and natural background characteristics of each watershed zone. In addition, potential stressors and their sources are presented to introduce some apparent concerns and how they vary by watershed zone.

2.1 Channelized Headwaters zone

The Channelized Headwaters (CHH) watershed zone of the NF Crow encompasses the extreme headwaters reaches of the river in portions of Pope and Stearns counties (Figure 5). The mainstem of the NF Crow and most of the tributaries in this zone are entirely channelized due to agricultural ditching. Historically, this area was dominated by tallgrass prairie, with areas of “wet prairie” along the riparian corridor of the river. Current land-use is predominantly agricultural (63% cultivated land). Only 2% of the area remains grassland and 5% in wetlands (Figure 5). Cattle grazing operations are fairly common in this watershed zone and several reaches of the river have riparian corridors that have been impacted by this land use.

Center pivot irrigation is a common feature of the landscape in this watershed zone. The agricultural fields near the towns of Brooten and Belgrade are some of the most heavily irrigated in the state and region. The MPCA and Minnesota Department of Natural Resources (MDNR) are currently studying the rate and timing of irrigation pumping in this area and its effect on water table elevation and streamflow. The potential stressors related to this land-use will need to be incorporated into stressor identification work as more information becomes available.

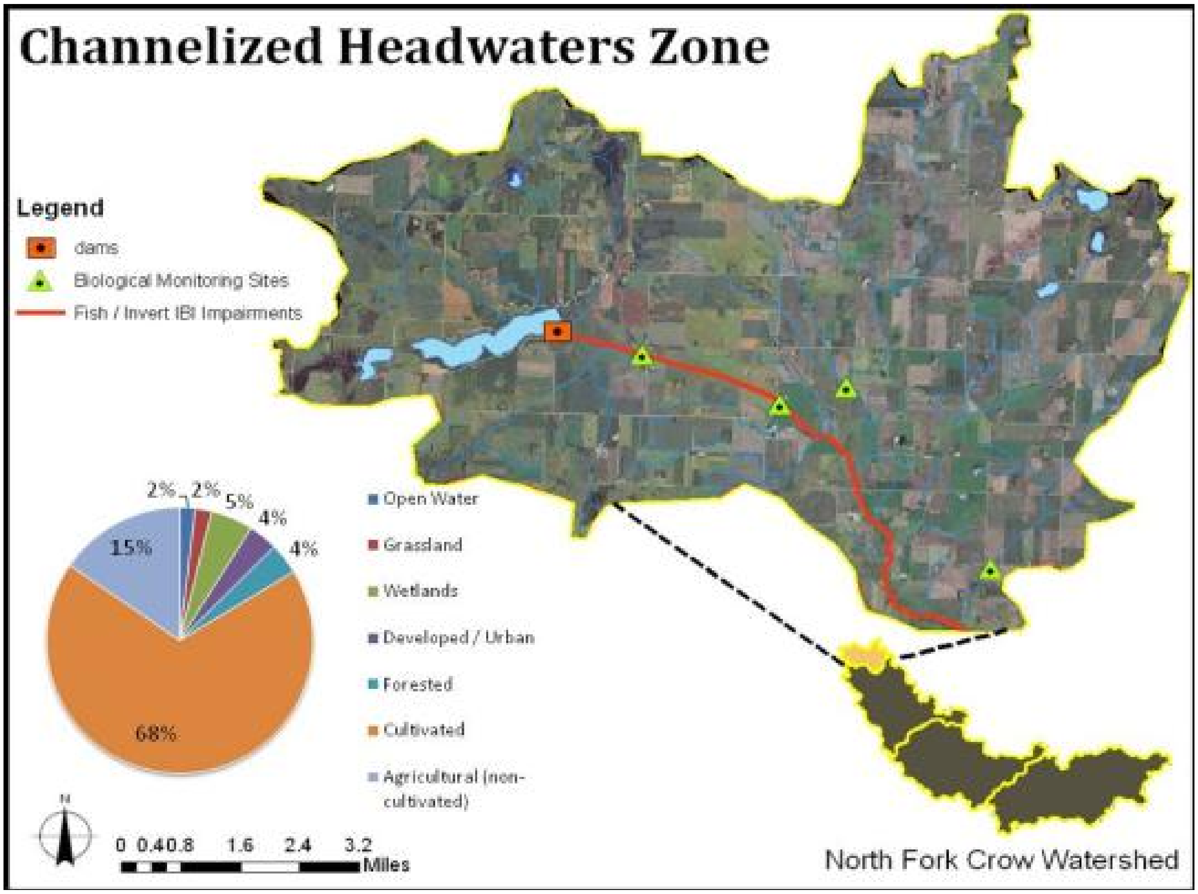


Figure 5: Location of CHH watershed zone and local land-cover.

2.2 Alluvium Outwash Headwaters

The Alluvium Outwash Headwaters (AOH) watershed zone of the NF Crow begins near the confluence with Sedan Brook near the town of Brooten, MN and extends downstream to Lake Koronis near Paynesville, MN (Figure 5). The mainstem of the NF Crow returns to a natural stream channel in this watershed zone, although a significant amount of channelization is still evident in tributary streams. The lack of channelization of the mainstem is the most significant difference between this watershed zone and the channelized headwaters region immediately upstream, although stream gradient also increases in the AOH and more coarse substrates are evident in the stream channel and banks.

The dominant land-uses in this watershed zone are agricultural, consisting primarily of cultivated cropland (53%) and pasture/hay operations (13%) (Figure 6). Some of the rangeland used to pasture cattle and other livestock in this watershed zone is within the riparian corridor of the river, which appears to be impacting stream channel stability and overall habitat quality. This potential stressor will be discussed further in Section 5 of this report.

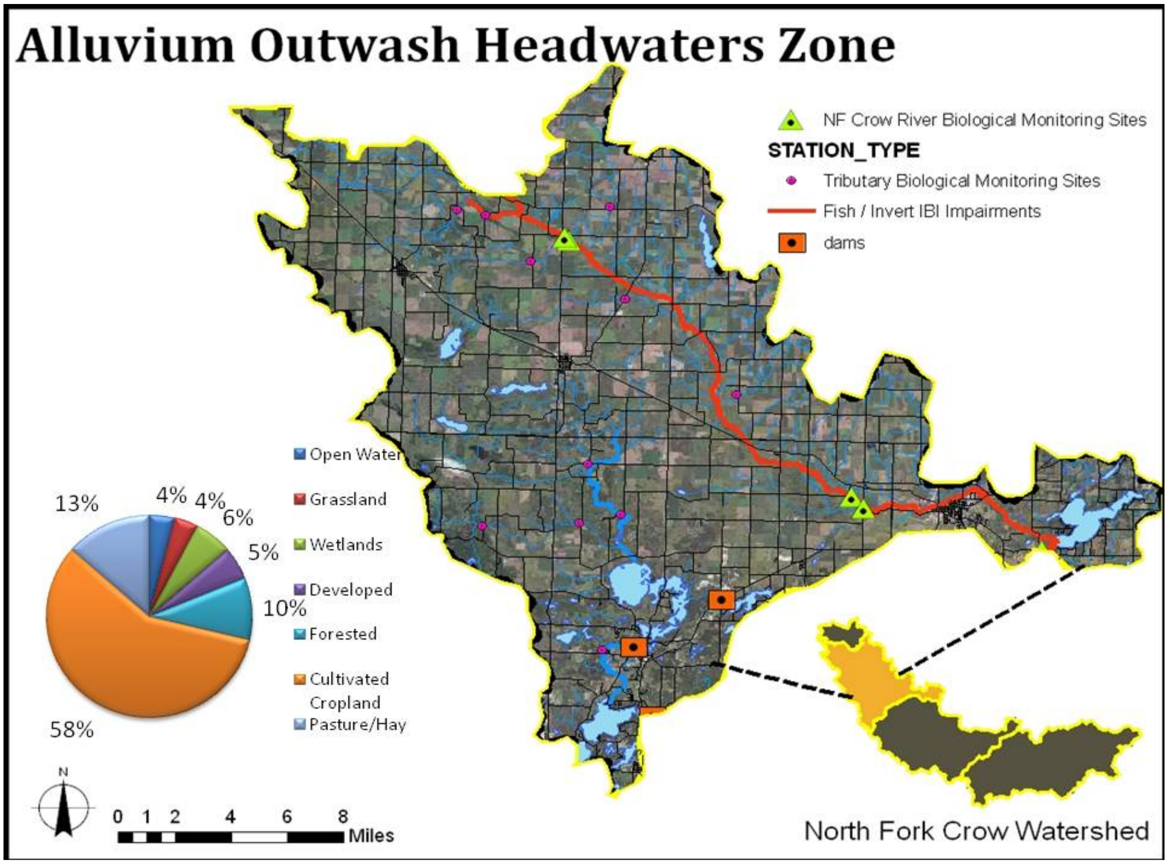


Figure 6: Location of the AOH watershed zone

2.3 Mid-River Moraine

The Mid-River Moraine (MRM) watershed zone begins at the outlet of Lake Koronis, and extends downstream a few river miles beyond Kingston, MN. Just downstream of Lake Koronis, the NF Crow is channelized for approximately three river miles, but returns to a natural channel for the remainder of its length. The downstream boundary of this watershed zone is the dividing line between two agroecoregions -- the Steeper Dryer Moraine that is found in the mid-reaches of the river, and the Rolling Moraine that is prominent in the lower watershed.

Several significant tributaries enter the NF Crow in this watershed zone, including the Middle Fork Crow River, Grove Creek, and Jewitts Creek. Several of these tributaries, especially Jewitts Creek and Grove Creek, are impaired waters and have historically carried high sediment and nutrient loads. As with most areas of the NF Crow watershed, agricultural land-uses are prominent in this area. Over 70% of the land area in this watershed zone is in agricultural production, most of which is cultivated cropland (Figure 7).

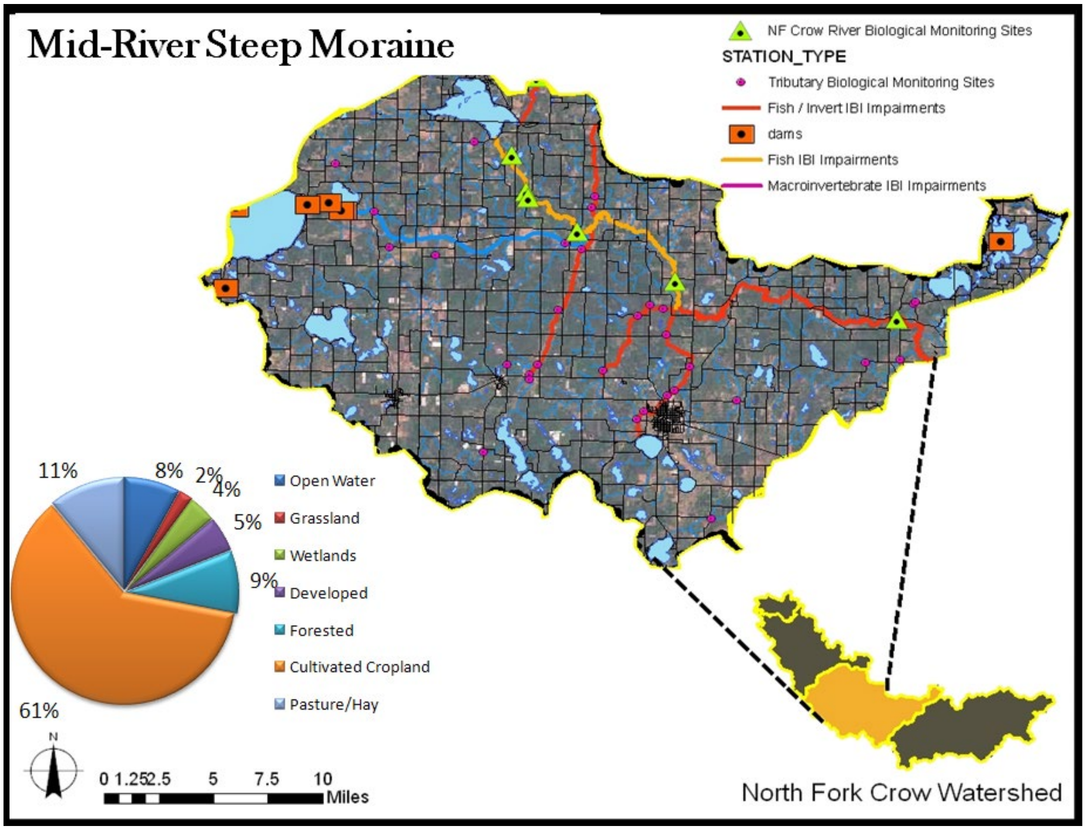


Figure 7: Location of MRM watershed zone

2.4 Lower River Rolling Moraine

The Lower River Rolling Moraine (LRRM) watershed zone encompasses the last 90 river miles of the NF Crow/ Lower Crow River before its confluence with the Mississippi River. The South Fork Crow and North Fork Crow converge at Rockford, MN to form the Crow River. A significant number of lake outlet tributaries enter the river within this watershed zone, including Sucker Creek, Mill Creek, and French Creek.

The land-use in this watershed zone is still highly agricultural, but the total land area in row crops (48%) is lower than the other watershed zones upstream (Figure 8). Overall, the amount of developed land is still relatively low (8%), but it is the most developed of the four watershed zones. The river flows through several growing cities (e.g. St. Michael, Rockford) and near several major highways in this section of the watershed, which introduces the possibility of stressors related to urban and residential land-uses.

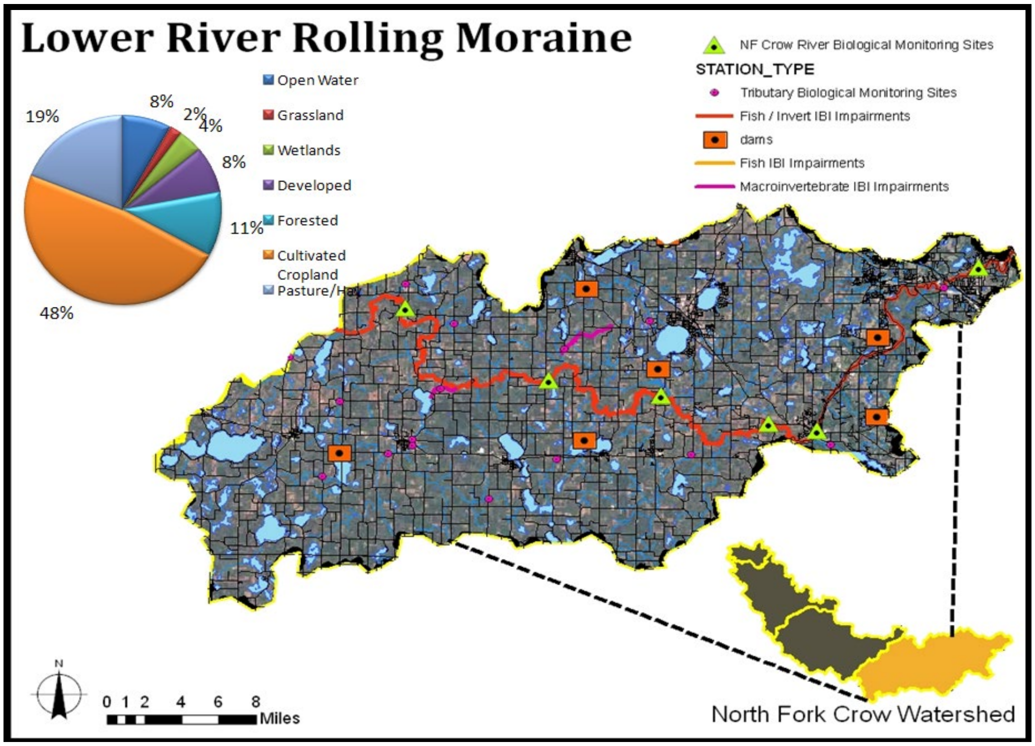


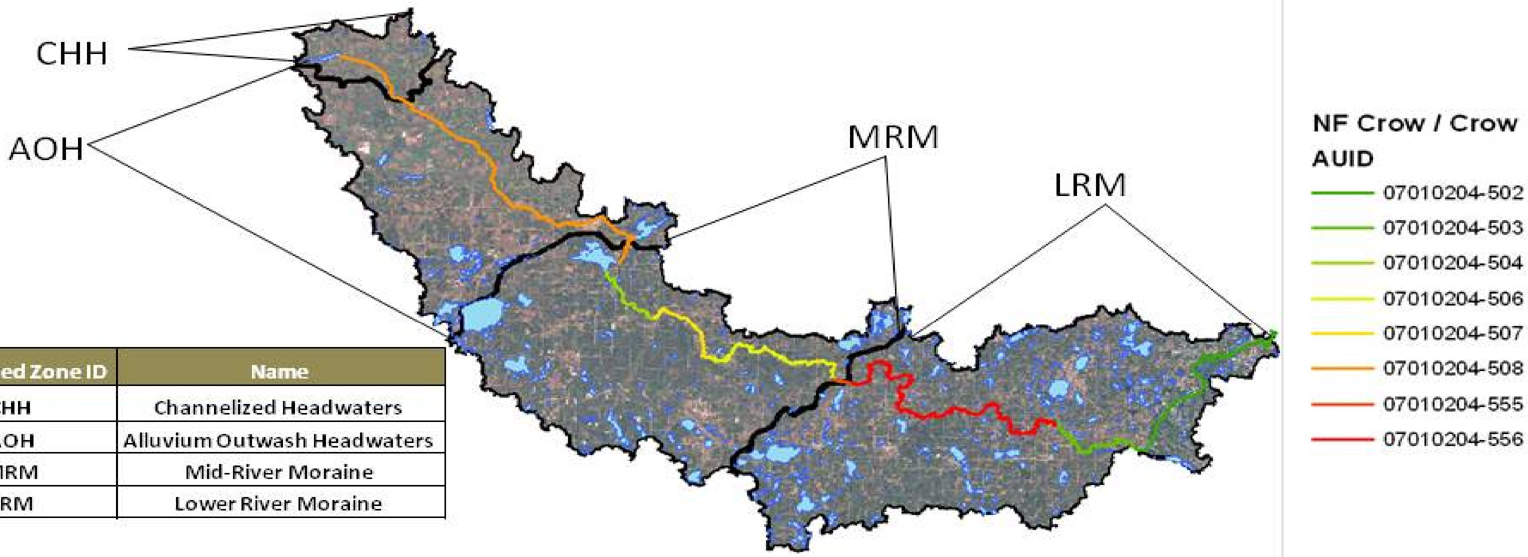
Figure 8: Location of LRRM watershed zone

2.5 Alignment of watershed zones, AUIDs, and biological impairments

Figure 9 shows the location of impaired Assessment Unit Identification numbers (AUIDs) and their associated impairments in relation to the watershed zones that were established in this report. The AUID 07010204-508 was split between two watershed zones due to channelization in the upper portion of this AUID. The channelized portion of the AUID is located in the CHH watershed zone, while the natural channel segment is located in the AOH watershed zone.

Candidate causes for biological impairments (i.e. "stressors") will be initially evaluated by watershed zones, but will also be partitioned out by AUID later in the report in order to stay consistent with the 303(d) reporting and TMDL process. The purpose of using watershed zones instead of AUIDs throughout the report is to simplify data analysis by grouping similar stream reaches based on drainage area, underlying geology, land-use, and biological expectations.

Watershed zones, stream AUIDs, and impairment listings



Watershed Zone ID	Name
CHH	Channelized Headwaters
AOH	Alluvium Outwash Headwaters
MRM	Mid-River Moraine
LRM	Lower River Moraine

AUID	Watershed Zone ID	REACH_NAME	REACH DESCRIPTION	River Miles	Biota Impairments (Aquatic Life)	Other Impairments
07010204-508 (channelized portion)	CHH	Crow River, North Fork	Headwaters (Grove Lk 61-0023-00) to Lk Koronis	51.59	Fish IBI / Macroinvertebrate IBI	None
07010204-508 (natural channel portion)	AOH	Crow River, North Fork	Headwaters (Grove Lk 61-0023-00) to Lk Koronis	51.59	Fish IBI / Macroinvertebrate IBI	None
07010204-504	MRM	Crow River, North Fork	Lk Koronis to M Fk Crow R	8.70	Fish IBI	Hg
07010204-507	MRM	Crow River, North Fork	M Fk Crow R to Jewitts Cr	10.94	Fish IBI	None
07010204-506	MRM	Crow River, North Fork	Jewitts Cr to Washington Cr	22.28	Fish IBI / Macroinvertebrate IBI	None
07010204-555	MRM	Crow River, North Fork	Washington Cr to Meeker/Wright County line	2.21	none	None
07010204-556	LRM	Crow River, North Fork	Meeker/Wright County line to Mill Cr	47.69	Fish IBI / Macroinvertebrate IBI	None
07010204-503	LRM	Crow River, North Fork	Mill Cr to S Fk Crow R	13.66	Fish IBI / Macroinvertebrate IBI	DO, T, Hg
07010204-502	LRM	Crow River	S Fk Crow R to Mississippi R	24.98	Fish IBI / Macroinvertebrate IBI	DO, T

* DO = Dissolved Oxygen; T = Turbidity; Hg = mercury (water column)

Figure 9: Location of impaired AUIDs in relation to the four watershed zones established for SID analysis

3.0 Characterization of biological impairments

3.1 North Fork Crow River fish IBI impairments

The entire length (148 river miles) of the NF Crow is listed as impaired for failing to meet fish Index of Biological Integrity (IBI) criteria established by MPCA. Although the entire river is considered impaired, the nature and severity of the fish impairments differ from one region of the watershed to another. This section provides an overview of the available fish IBI data, and highlights some of the key components of the fish communities that are lacking or causing low IBI scores. Discussion of these results will provide some context for the Stressor Identification portion of the report. For a complete overview of NF Crow watershed fish and macroinvertebrate IBI data, refer to Phase 1 report (http://www.pca.state.mn.us/index.php/view-document.html?gid=17110).

A total of 19 fish monitoring stations are located on the mainstem of the NF Crow and Lower Crow River. These sites are divided into three classes based on drainage area and stream gradient (table 3). Of the 19 sites on the mainstem of the river, 47% are Class 5, 42% are Class 4, and 11% Class 6. For more information on the various fish and macroinvertebrate classes, refer to Appendix A.

Table 3: NF Crow / Lower Crow River fish IBI classes based on the MPCA biological assessment protocols.

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
4	Northern Rivers	> 500 sq mi	not specified

Individual metric scores can be used to further evaluate the fish IBI results and identify “problem metrics” or apparent deficiencies in the observed fish assemblage. For example, the Class 4 fish IBI consists of nine individual metrics that pertain to overall fish condition, trophic and reproductive function, and sensitivity to disturbance. The following paragraphs will also discuss some metric scores in attempt to further define the nature of biological impairments. A complete list of metrics used in the Class 4 fish IBI can be found in Appendix A.

Northern rivers (Class 4) fish results

The Class 4 fish IBI sites are located in the lower half of the watershed and have drainage areas exceeding 500 mi^2. Class 4 stations in this watershed are all located on the NF Crow and Crow River mainstem. Figure 10 shows the location of these sites and the corresponding IBI scores with standard deviation (for sites with multiple visits). On average, IBI scores for all Class 4 sites fall below the impairment threshold score of 32. The two downstream most sites (00UM080 and 00UM081) are the exception in that each of these sites recorded a fish IBI score above the threshold during one of three visits to each site. The majority of the Class 4 stations achieved fish IBI scores within or close to the lower confidence interval of the impairment threshold, indicating that these sites are not severely impaired. Sites 07UM013 and 07UM021, the two upstream-most Class 4 sites appear to have a more degraded fish assemblage based on the overall IBI scores.

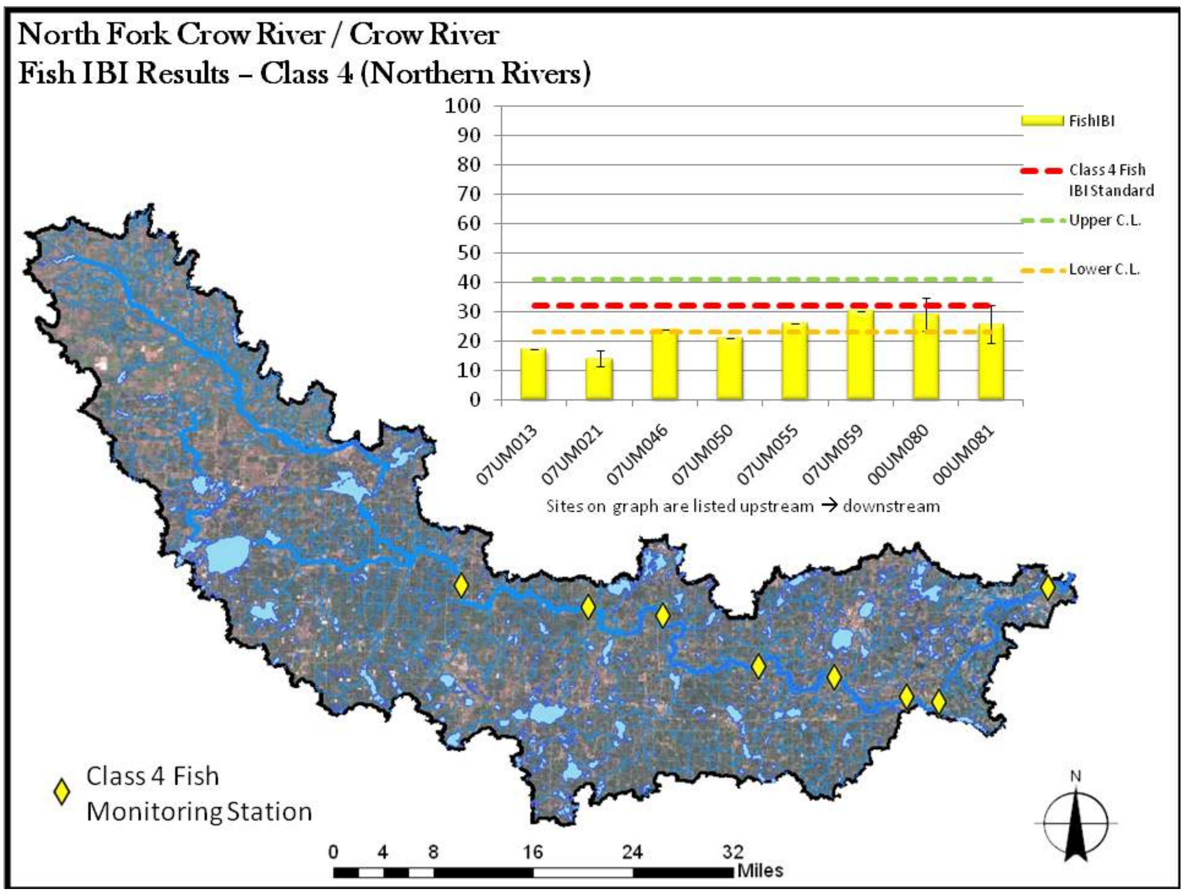


Figure 10: Class 4 (northern rivers) fish IBI stations and results

Several metrics related to trophic traits appear to be problematic for the Class 4 sites of the NF Crow watershed. Specifically, these sites support few benthic insectivore species (i.e. redhorse spp., darter spp.) and as a result receive very low scores in that metric. There are also an abundance of detritivorous fish species in this reach of the river such as the common carp, sand shiner, white sucker, and fathead minnow. These species are considered highly adaptable to disturbance because they can rely on a variety of food sources.

Low metric scores from fish tolerance metrics are also a concern. In general, Class 4 fish stations scored low in the metric VtolTXPct which indicates that a high proportion of the fish taxa observed at these sites are classified as "very tolerant." Examples of very tolerant taxa include common carp, green sunfish, and bluntnose minnow. All of the sites in this area of the watershed show a high proportion of tolerant fish species. This may be indicative of a widespread stressor that is common to numerous sites in the Lower NF Crow/Crow River.

Several Class 4 fish sites scored low in the percent simple lithophilic spawner (SLithopTXPct), indicating that there may be a lack of suitable gravel substrate for these species. The scores for this metric were highly variable in the Lower NF Crow/Crow River. The percent simple lithophils observed was extremely low at stations 07UM021 and 07UM050, but fairly high percentages of these fish were observed at other Class 4 sites (e.g. 07UM055 and 07UM046). Excess sediment deposition on the streambed is often correlated with decreases in percent simple lithophils. This stressor is evaluated as a potential candidate cause for impairment in section 5.

Northern streams (Class 5) fish results

The Class 5 fish IBI stations are located in the middle to upper reaches of the NF Crow. Figure 11 shows the locations of these sites and the corresponding IBI scores with standard deviation (for sites with multiple visits). Several stations further up in the watershed meet the established fish IBI criteria, and several others in this region of the watershed produced fish IBI scores within the confidence interval. However, even the highest scoring sites may be showing signs of impairment, as none of the Class 5 stations scored above the upper confidence interval of the fish IBI (Figure 11).

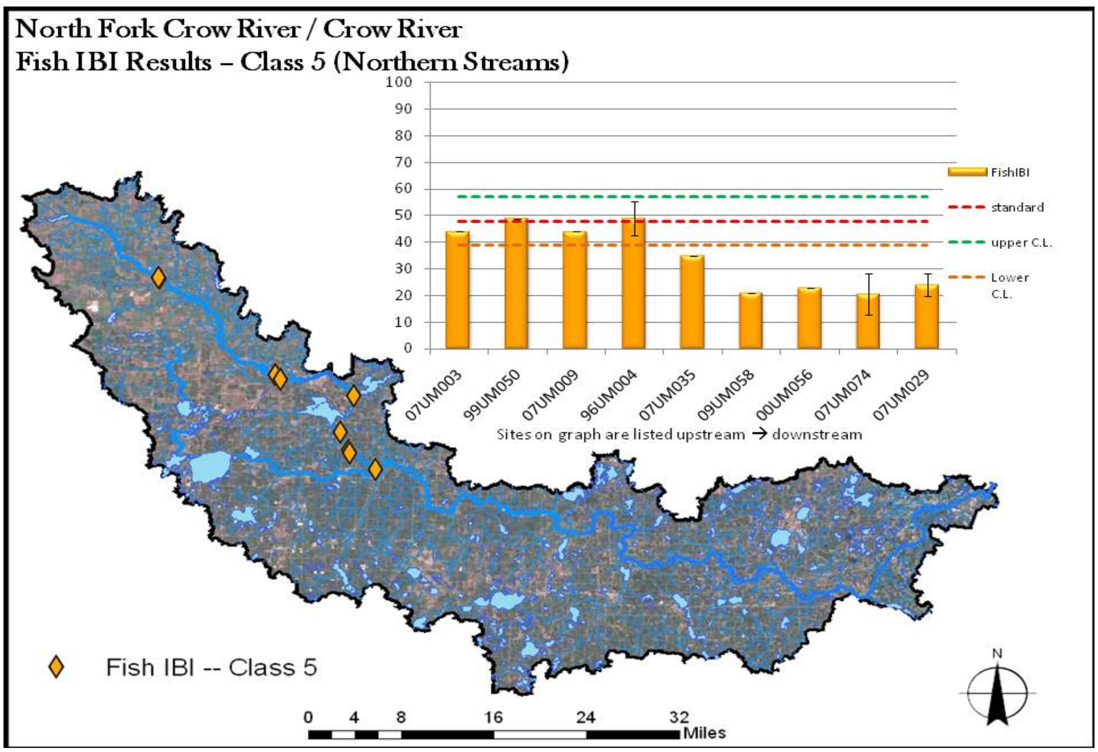


Figure 11: Class 5 (northern streams) fish IBI sites and IBI scores (w/ standard deviation)

Downstream of Rice Lake, fish IBI scores on the NF Crow are more indicative of severe impairment Figure 11). The potential effects of Rice Lake and Lake Koronis on fish IBI scores will be explored in the stressor identification section of this report. The dam located at the outlet of Lake Koronis must also be considered as a potential stressor, as such structures have been found to block fish passage and alter sediment transport, water quality, and flow regime.

Low fish IBI scores downstream of Lake Koronis are driven by poor scores in several metrics related to trophic structure and reproduction. Sites downstream of Koronis scored poorly in the metric *DetNWQPct*, which is based on the relative abundance of detritivorous fish (Figure 12). The fish assemblages at all four of the sites below Lake Koronis consisted of over 50% detritivorous individuals. The abundance of detritivores below the lake may be indicative of nutrient imbalance, physical habitat degradation, low benthic productivity, and/or several other potential stressors that result in a more simplistic trophic structure.

Scores for the reproductive metric *SLithopPct* show a similar pattern. The percentage fish that are simple lithophilic spawners decreases markedly downstream of the Rice Lake / Lake Koronis complex (Figure 12). This apparent shift in reproductive approach will be more closely examined during the stressor identification process.

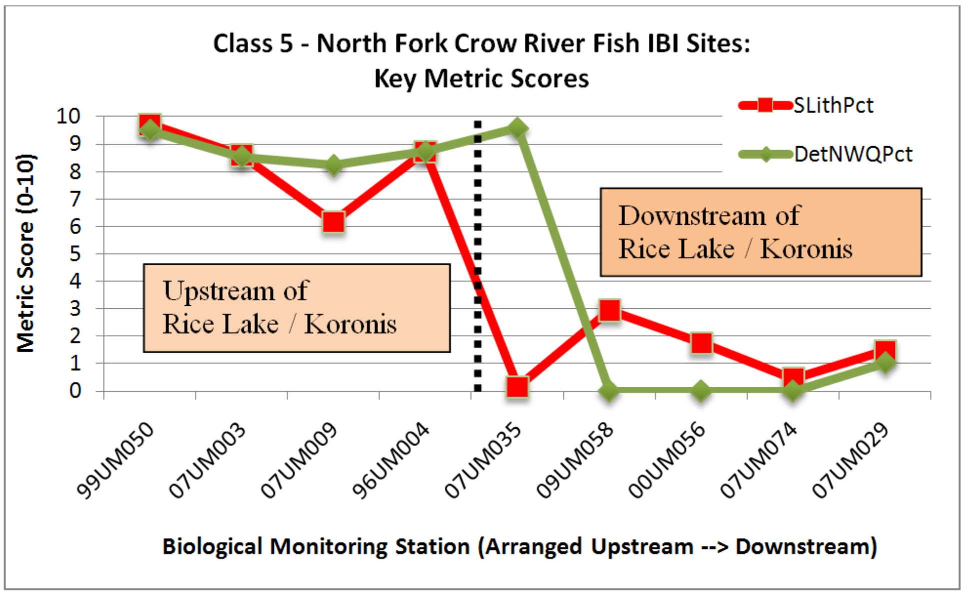


Figure 12: Metric scores for % simple lithophils and % detritivorous fish at Class 5 fish monitoring sites

Another reproduction-related metric that appears to be contributing to low IBI scores in this region of the watershed deals with the fecundity of the fish species present at a site. The metric *MA>3-TolPct* measures the relative abundance (%) of individuals with a female maturity age at or above 3 years, excluding tolerant taxa. A greater abundance of fish species with this reproductive trait suggests a high level of stability in fish assemblage and the surrounding environment. Very few species that qualify for this metric were found at the monitoring sites in this region of the watershed.

Northern headwaters (Class 6) fish results

The Class 6 fish IBI stations are located in the extreme headwaters of the NF Crow system. Most of the mainstem and tributaries are channelized in this region of the watershed, including the two biological monitoring stations. Figure 13 shows the location of the monitoring sites and respective IBI scores. Currently, there are no fish IBI criteria available for channelized streams. The fish IBI standard shown on the graph in Figure 13 was developed for northern headwaters streams with natural stream channels. Until separate IBI criteria are developed for channelized streams, the IBI metrics corresponding to the fish class of each station will be used to obtain an estimate of impairment status.

The combination of a low drainage area, extensive ditching, and a highly agricultural landscape appears to be limiting biological integrity in the extreme headwaters of the NF Crow. The fish communities at these sites displayed a lack of sensitive taxa, low overall fish abundance, and were dominated by species that are tolerant of degraded chemical and physical habitat conditions (e.g. central mudminnow, fathead minnow, white sucker). Many of the fish species present were omnivores and very few benthic insectivores were observed. These observations are an indicator that benthic habitat quality may be poor in these stream reaches.

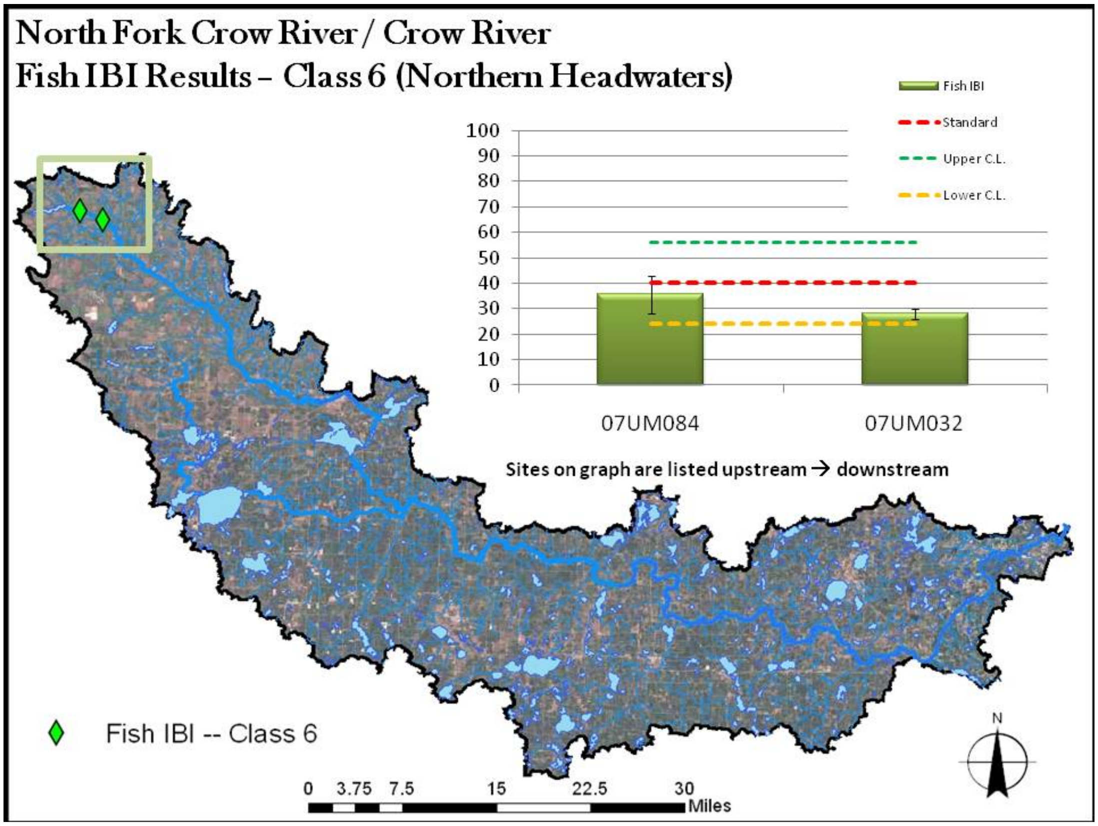


Figure 13: Location of Class 6 fish IBI sites in the NF Crow watershed

3.2 North Fork Crow River macroinvertebrate IBI impairments

A significant portion of the NF Crow mainstem is listed as impaired for failing to meet established IBI criteria for aquatic macroinvertebrates. As with the fish stations, the macroinvertebrate monitoring sites and results are separated into several classes due to differences in drainage area, channel morphology, and other natural background variables (see Table 4). The following sections provide an overview of the macroinvertebrate impairment and some of the specific metrics contributing to the low IBI scores.

Macroinvertebrate sampling was performed according to MPCA protocols, which can be found through the following link (http://www.pca.state.mn.us/index.php/view-document.html?gid=6094). Macroinvertebrate data used in this report were collected between 2000 – 2009. The majority of the sites were sampled during Phase 1 IWM in 2007.

Table 4: Macroinvertebrate IBI classifications of stations located on the NF Crow/ Crow River mainstem

M-IBI IBI Class	Class Name	Drainage Area	Description
2	Prairie Forest Rivers	>500 mi^2	Sites in Minnesota that are representative of the Eastern Broadleaf forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces
5	Southern Streams (Riffle/Run Habitats)	<500 mi^2	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.
6	Southern Forest Streams (Glide/Pool Habitats)	<500 mi^2	Sites within this class have watershed characteristics representative of Eastern broadleaf forest ecological province, as well as streams in HUC 07030005
7	Prairie Streams (Glide/Pool Habitats)	<500 mi^2	Sites in Minnesota that are representative of the Prairie Parklands and Tall Aspen Parklands ecological provinces

Class 2 macroinvertebrate results

Class 2 macroinvertebrate stations are located in the lower half of the watershed as shown in Figure 14. All of the Class 2 sites are located on the mainstem of the NF Crow or Crow River. Macroinvertebrate IBI (M-IBI) scores appear to decrease moving from upstream to downstream, with the most severe impairments occurring in the reach containing sites 07UM055, 07UM046, and 00UM080 near river miles 45 through 25. Several of the Class 2 sites score above the M-IBI impairment threshold but within the upper confidence limit, indicating that these sites are only marginally meeting the established criteria.

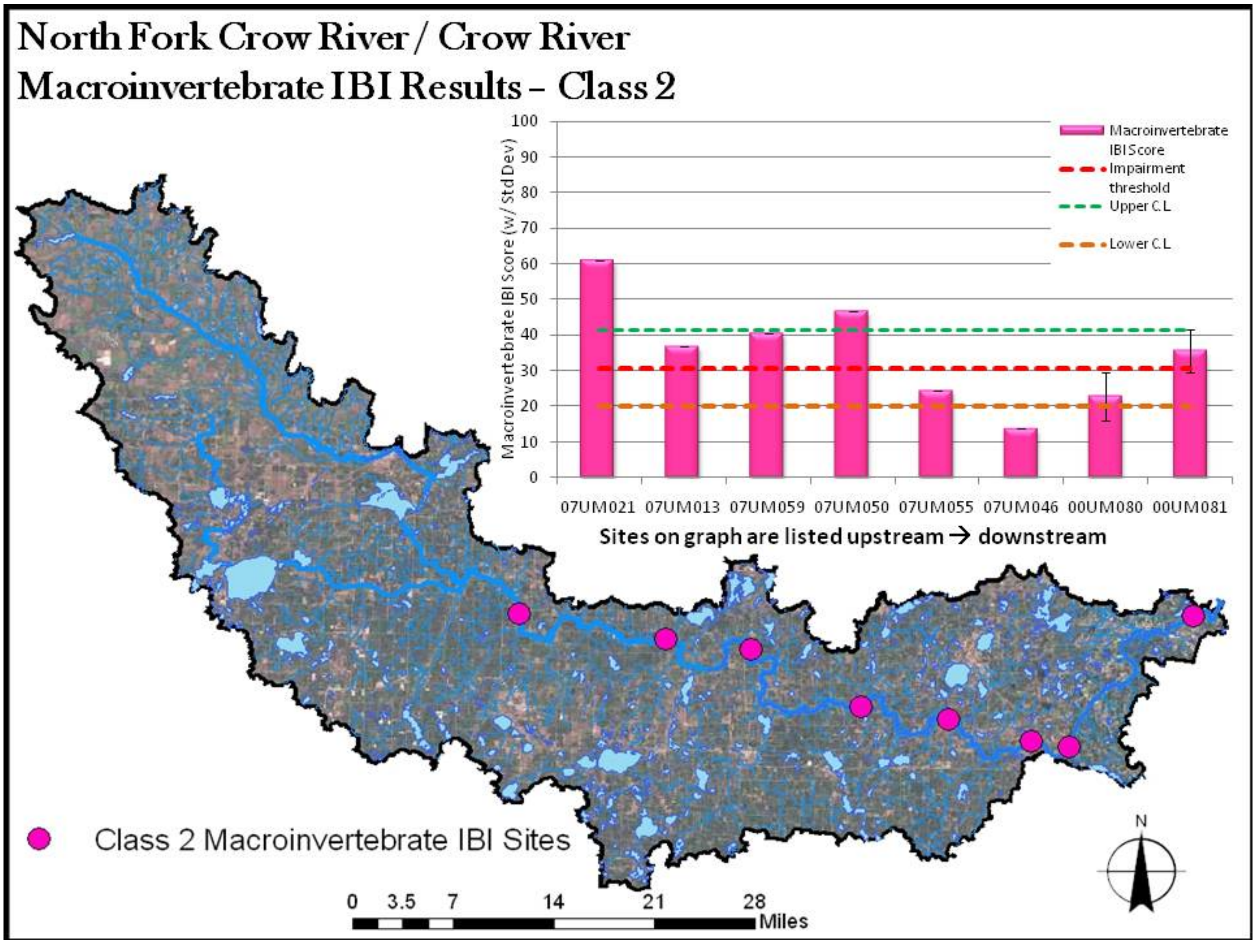


Figure 14: Location of Class 2 macroinvertebrate sites and IBI scores (w/ standard deviation)

Site 07UM021 north of Litchfield appears to support a high quality macroinvertebrate assemblage in comparison to the rest of the class 2 stations (Figure 14). In comparison to this high scoring site, downstream stations with lower IBI scores have lower taxa richness and fewer sensitive species. In addition, certain orders of macroinvertebrates that represent healthy stream habitat, such as Odonata (dragonflies and damselflies) and Trichoptera (caddisflies) are less abundant in the lower reaches of the NF Crow / Lower Crow River when compared to 07UM021.

Class 7 macroinvertebrate results

All of the Class 7 macroinvertebrate stations in the watershed are channelized to some degree. Sites 07UM084 and 07UM032 in the extreme headwaters of the watershed are both located within trapezoidal channels. The M-IBI scores at these sites indicate impairment (Figure 15). The other three Class 7 stations are located in a three-mile stretch of channelized river below Lake Koronis. Despite poor habitat from channelization and large amounts of deposited sediment, these sites show slightly higher M-IBI scores in comparison to other Class 7 sites.

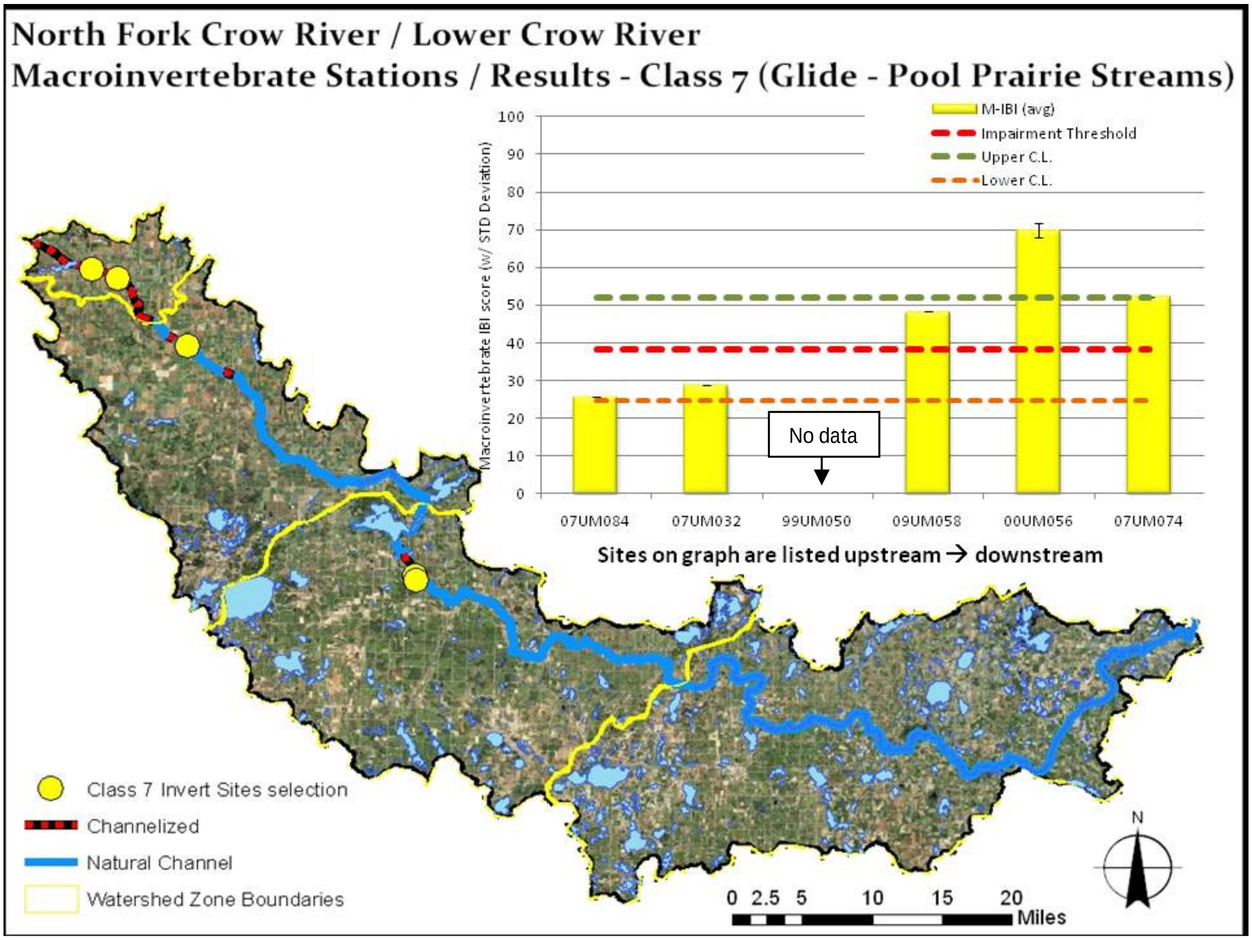


Figure 15: Location of Class 7 macroinvertebrate monitoring stations and average IBI scores (w/ standard deviation).

Several indicators of a degraded macroinvertebrate assemblage are evident across all of the Class 6 sites. Metric results show a general lack of sensitive invertebrate taxa in these reaches of the river, as well as an abundance of invertebrate taxa that are collector-filterer feeders. The latter is a potential indicator that these stream reaches contain higher than normal amounts of organic particulate matter. Stations 07UM084 and 07UM032 scored extremely low in caddisfly-related metrics and lacked intolerant macroinvertebrate species.

Class 5 and 6 macroinvertebrate results

Class 5 (Riffle –Run Southern Streams) and Class 6 (Glide-Pool Southern Forest Streams) sites are relatively uncommon on NF Crow/Lower Crow River, with one station of each class. Both of these stations are in the vicinity of Lake Koronis in the MRM watershed zone (Figure 16). M-IBI scores for both sites are below the impairment threshold, but within the confidence limit.

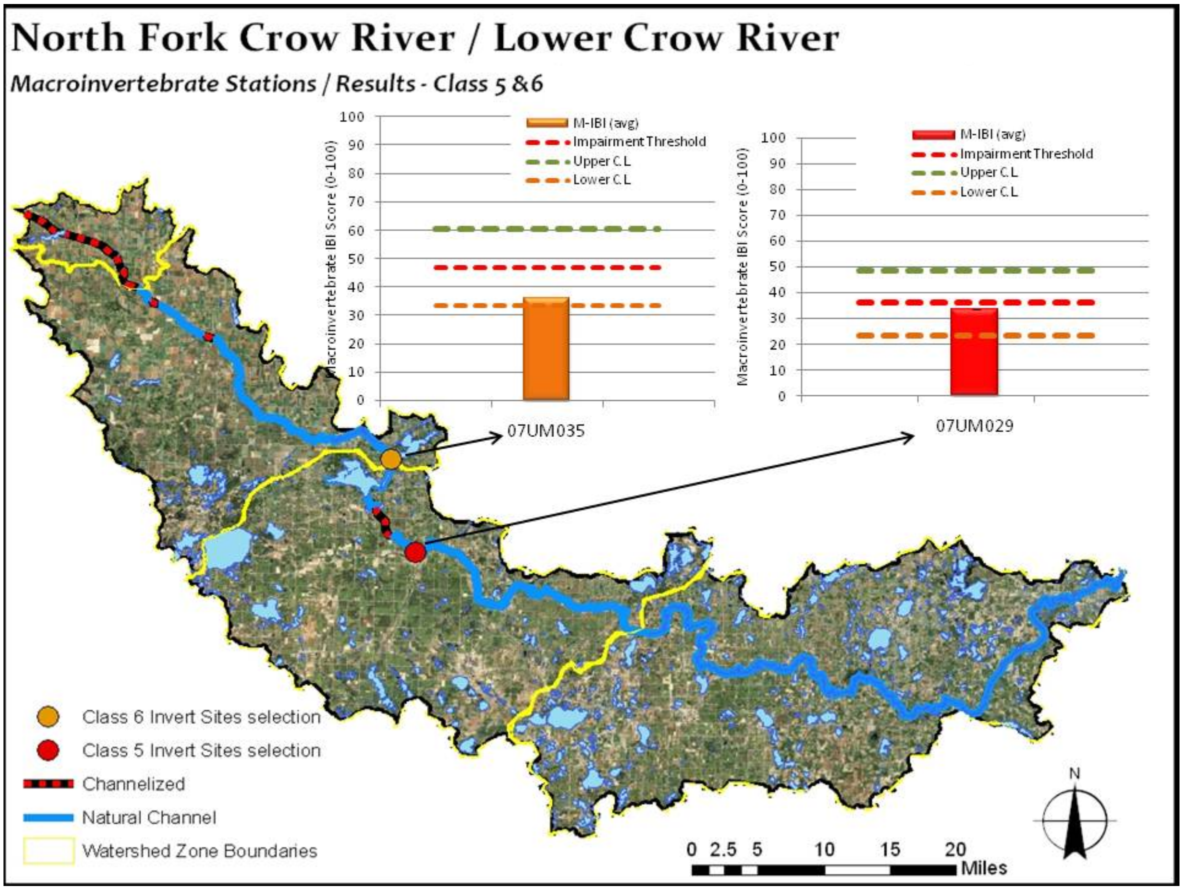


Figure 16: Location of Class 5 and Class 6 macroinvertebrate monitoring stations and IBI results.

Site 07UM029 is located in a relatively high gradient reach and offers more riffle, run, and pool habitat than most of the other sites in the NF Crow watershed. A large number of clinger macroinvertebrate taxa are present in this reach, which is probably a reflection of the numerous riffles and exposed coarse substrate observed at this site. This station falls below the impairment threshold due to low scores in metrics related to low Plecoptera (stonefly) taxa richness and an abundance of taxa that are tolerant of organic pollution.

Site 07UM035 is located within a low-gradient flowage that connects Rice Lake to Lake Koronis. This reach has wetland qualities and is dominated by fine organic substrates and aquatic macrophytes. The low M-IBI score at this site is the result of low overall taxa richness, very few intolerant species, and a lack of collector-filterer taxa.

3.3 General symptoms/indicators of biological impairments

Biological impairments in the NF Crow/Lower Crow River watershed can be characterized by watershed-wide and local biological indicators of stress. Some of these biological responses are fairly general (e.g. ↑ very tolerant taxa) and can be indicative of a wide range of potential stressors. On the other hand, biological responses that deal with a specific taxonomic order (e.g. Trichoptera) or life history traits (e.g. simple lithophilic spawning fish) can be more suggestive of specific stressors.

Each of the biological responses shown in Figure 17 will be tested against a set of candidate stressors to identify the most probable cause of impairment. The symptoms of biological impairment shown in Figure 17 were used to develop the initial list of candidate stressors that will be discussed in the *Causal Analysis / Strength of Evidence* section of this report.

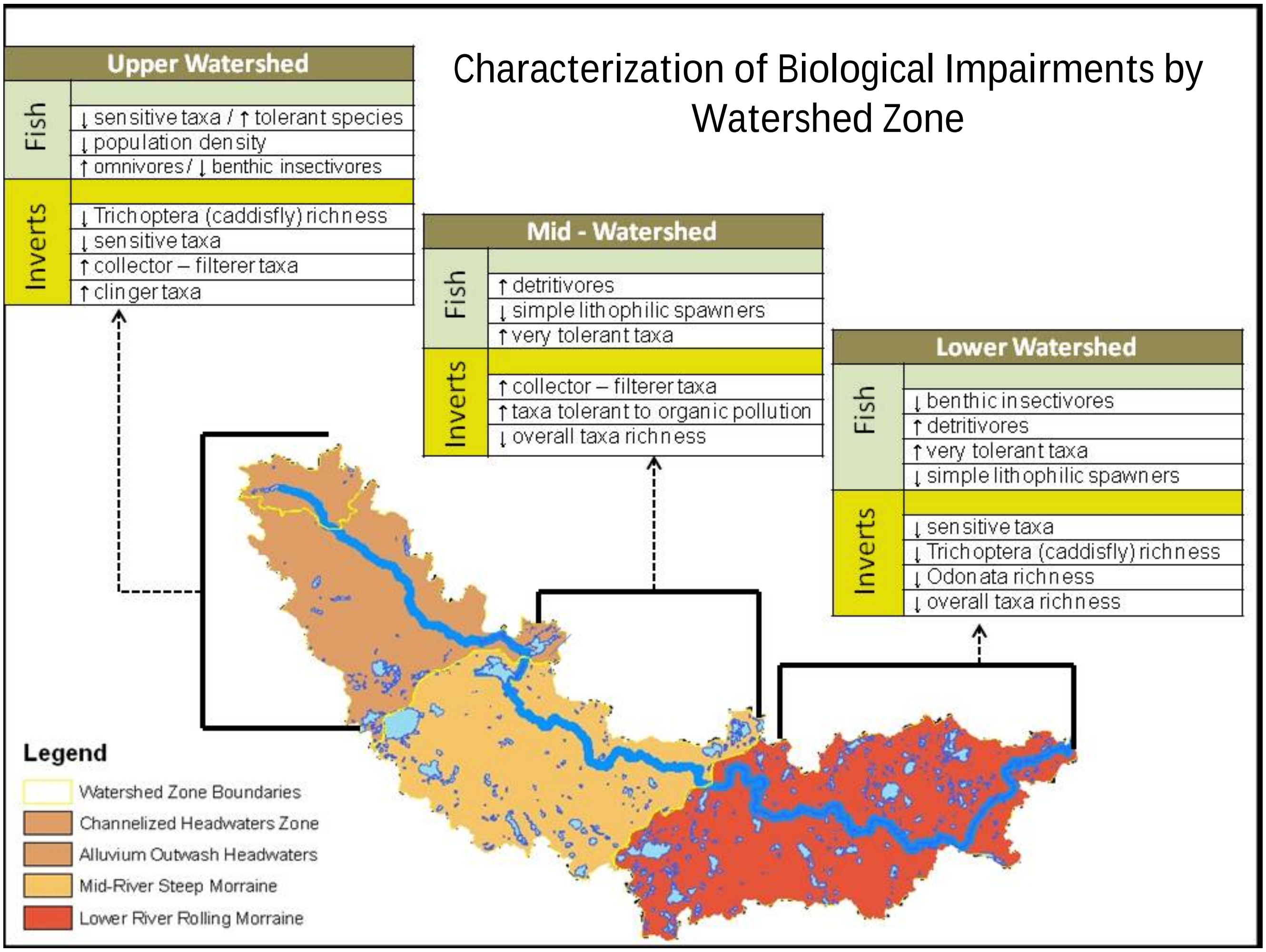


Figure 17: Summary of biological impairment symptoms by watershed zone

4.0 Candidate causes for biological impairment

Nine candidate causes were selected as potential drivers of biological impairments in the NF Crow/ Lower Crow River mainstem. These candidate causes were chosen after consideration of a broad set of "common candidate causes" developed by the EPA. Due to the large size of the study watershed, potential candidate causes were evaluated using a rapid screening assessment of the biological, water chemistry, land-use, and physical habitat data from each of the watershed zones described in Section 2.

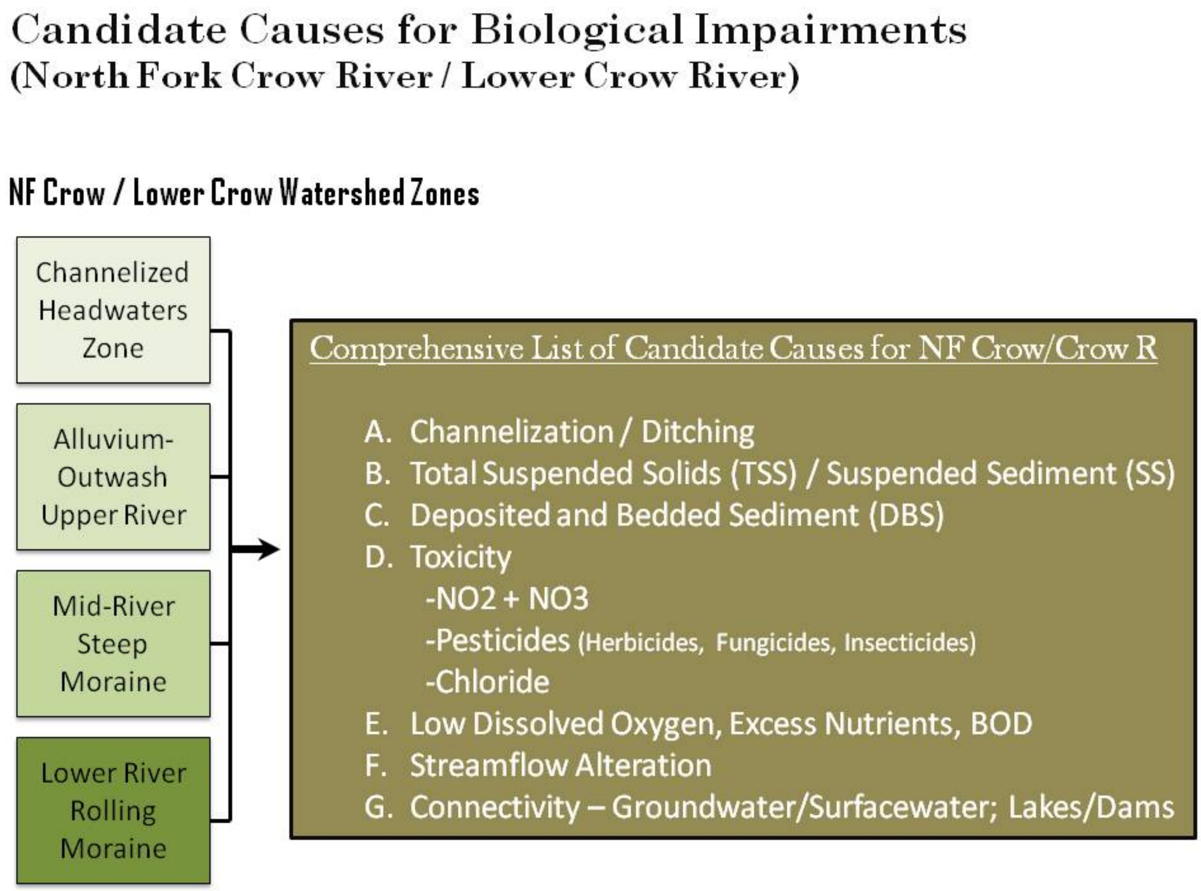


Figure 18: List of candidate causes for biological impairment in the NF Crow/Lower Crow River system

4.1 Ditching/channelization

Drainage ditches are a common feature of Minnesota watersheds dominated by agricultural land-uses. There is an estimated 27,000 miles of drainage ditches in the state, many of which have been in place since the turn of the 20th century. In the NF Crow watershed alone there are 15 county ditch systems consisting of approximately 100 miles of total ditch length. There are also many miles of private ditch networks in the watershed and a buried tile system containing 11,280 feet of underground drainage tile. Due to the prevalence of agricultural ditching in the NF Crow watershed, it was identified as a potential cause of fish and invertebrate impairments.

Ditches can provide important drainage and flood control functions in agricultural landscapes, but ecological services are often lost when previously natural channels become modified for these purposes (Allan, 1995). 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 addition, Schlosser (1982) observed a temporally variable physical environment and unstable autotrophic energy base in the channelized stream that varied between years and seasons. On the contrary, the natural stream in his study maintained a stable biomass, diverse trophic structure, and well-rounded age-structure in the fish community.

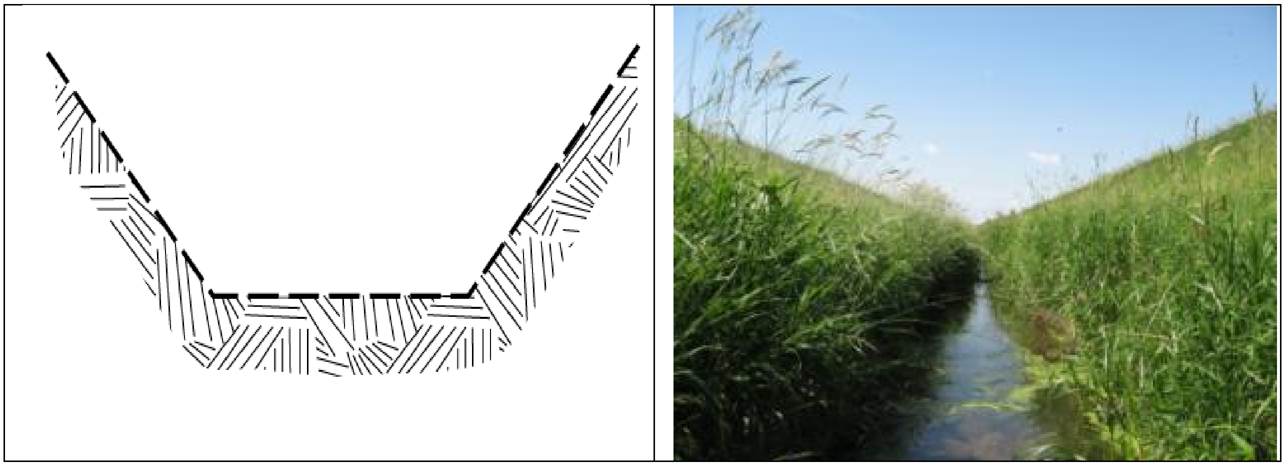


Figure 19: Cross-section of trapezoidal ditch design (left) and an example of this ditch design in NF Crow watershed (right).

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

Numerous studies have found conventional trapezoidal ditches to be inferior to natural streams in terms of sediment transport capacity and channel stability over time (Urban and Rhoads, 2004; Landwehr and Roads, 2003). Typical drainage ditch construction consists of a trapezoidal channel cross-section (see Figure 18 on previous page) designed to carry their maximum anticipated flow when filled to 80% of their design depth (Christner er al, 2004). The return interval for this discharge is typically greater than 50-years. In other words, conventional ditches are designed to handle low frequency, high-magnitude flood events. This design may not support adequate water depth and velocities for transporting sediment and maintaining stream facets (e.g. glide, riffle, run, pool) during more frequent, lower magnitude high flow events. The result can be excess sedimentation of the stream bed as particles become immobile and aggrade over time.

Sediment aggradation in drainage ditches is often dealt with through costly and ecologically destructive clean-out operations. In some instances, this sediment is merely pulled out of the stream channel and placed near or on the upper banks of the ditch, creating a more severely incised stream channel in the process (Figure 20). Ditch clean-out also removes aquatic and terrestrial vegetation which benefits channel stability, water quality, and aquatic habitat (Beeson and Doyle, 1995; Smiley and Dibble, 2005). The photos in Figure 20 were taken in June of 2009 near the confluence of a cleaned-out ditch and the NF Crow. At this site, the ditch cleanout extended right up to the confluence with the mainstem NF Crow (right photo).

Figure 20: Photos of 2009 clean-out of a ditch flowing into the NF Crow

Conceptual model

A conceptual model for stream channelization is shown in Figure 21 on the next page. This candidate cause for impairment can influence biota via numerous pathways involving water chemistry, channel geomorphology, and physical habitat changes.

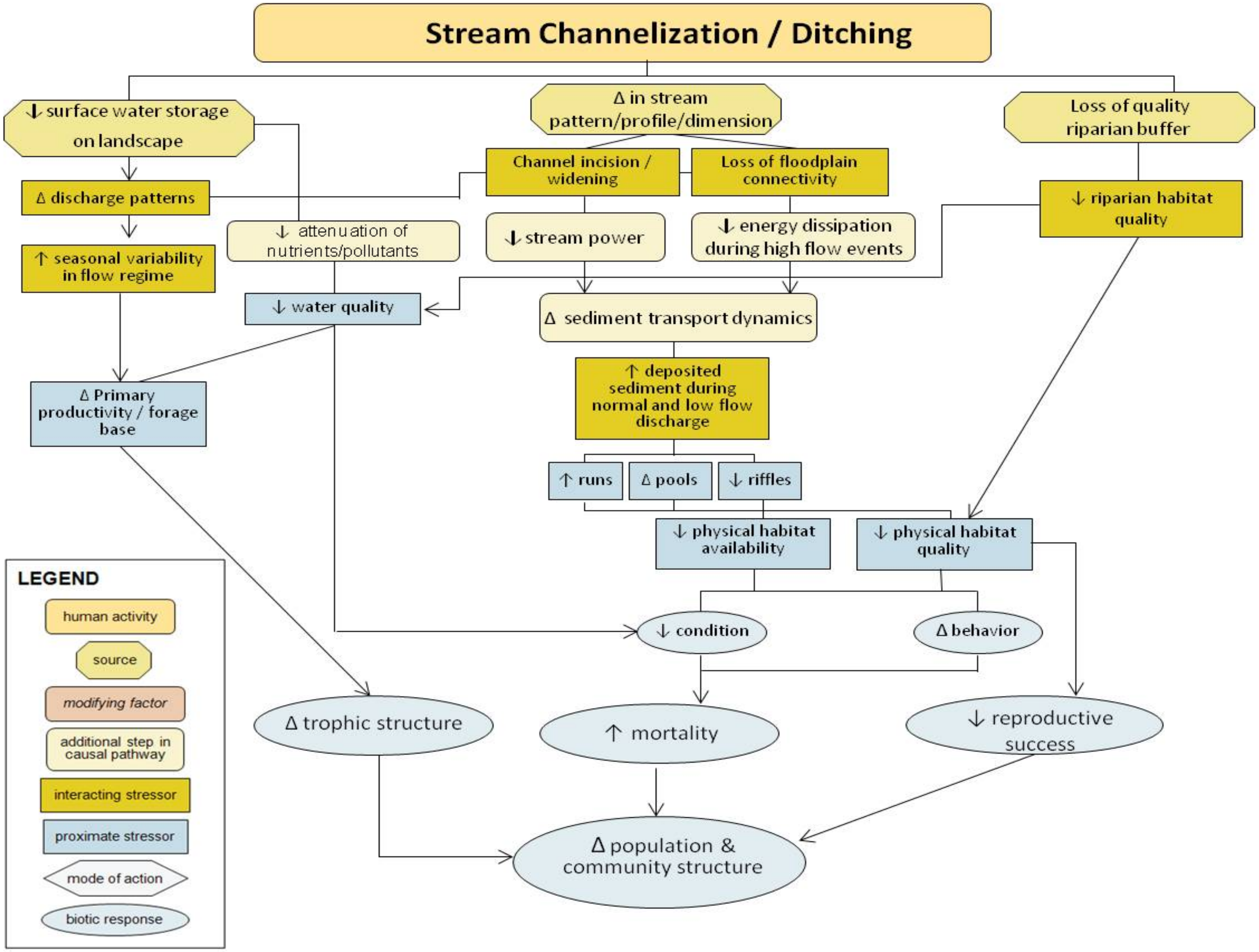


Figure 21: Conceptual model for stream channelization as a stressor in the NF Crow/Lower Crow River (Source: EPA CADDIS website)

Causal analysis

The North Fork of the Crow River is channelized in portions of the CHH and MRM watershed zones (Figure 22). Overall, a very small percentage of the river system is channelized, but the effects of channelization can impact natural channel reaches upstream and downstream. The photos in Figure 22 show some of the variable conditions of channelized stream reaches in the watershed. Ditches in the headwaters are generally not as deeply incised and lack healthy riparian buffers. The channelized reaches downstream of Lake Koronis are incised, and in most cases, are not connected to a floodplain. The ditches downstream of Koronis have a wooded riparian corridor, although many of those trees are falling into the river and creating debris jams due to erosion of the streambanks.

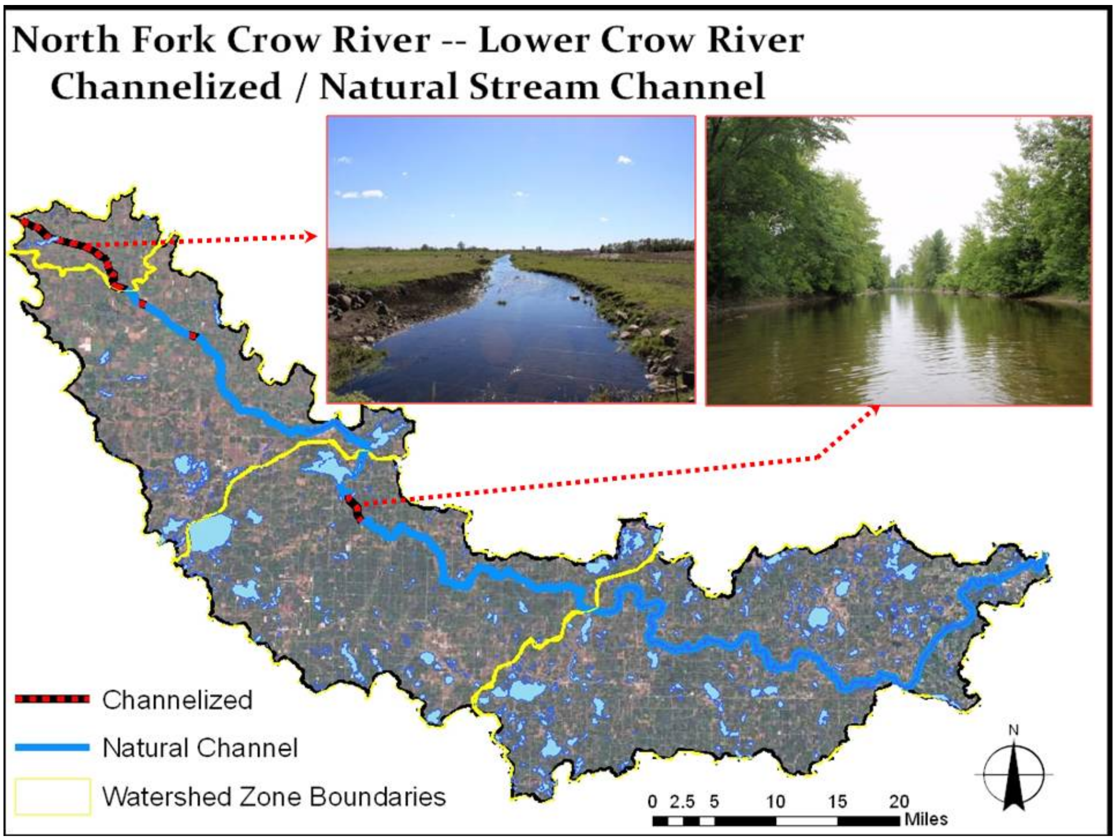


Figure 22: Location of channelized reaches on the mainstem NF Crow

Channelization and IBI scores

Five biological monitoring stations on the mainstem of the river are located within channelized reaches, compared to a total of 12 that are within natural stream channels. Table 5 summarizes fish IBI scores between channelized and natural channel monitoring sites. In general, fish impairments appear to be more severe (further below IBI threshold) in channelized reaches when compared to natural channel sites. The most substantial difference in fish IBI scores were observed between channelized and natural channel occurs within the Class 5 (northern streams) stations. The lowest scoring Class 5 stations are all downstream of Lake Koronis, and it appears that even natural channel sites downstream of Koronis are more severely impaired than those upstream of the lake (e.g. station 07UM029). Therefore, it is difficult to determine if the low fish IBI scores are related to channelization or some other stressor occurring in this area of the watershed. Across all fish IBI classes, natural channel sites were on average -8 points below IBI thresholds, while channelized sites were an average of -15.9 points below IBI thresholds (Table 5).

Table 5: Comparison of fish IBI Scores and impairment severity between channelized and natural channel monitoring sites in NF Crow / Crow River mainstem

Channel Type / Fish IBI Class	IBI Score (Average)	Avg. +/- to Fish IBI Threshold*	# Sites
Natural Channel (All Classes)	32	-8	12
Channelized (All Classes)	25.6	-15.9	5
Natural Channel (Class 4)	22	-10	6
Channelized (Class 4)	no data	no data	0
Natural Channel (Class 5)	**42**	**-6**	**6**
Channelized (Class 5)	**21.5**	**-26.5**	**3**
Natural Channel (Class 6)	no data	no data	0
Channelized (Class 6)	31.75	0	2

* value based on (SUM of difference between IBI score and IBI threshold for each site) / number of sites. Fish IBI scores for each station were compared to the threshold criteria established for its specific class

Average M-IBI scores were slightly higher at channelized sites compared to those within natural stream channels (Table 6). This trend is also true for the entire watershed including all of tributary monitoring stations, as average M-IBI in channelized reaches was 34.6 (n=33; max=75.1; min=7.49) compared to an average M-IBI score of 32.9 (n=42; max=75.9; min=4.2) at natural channel sites. It appears that there may be other stressors unrelated to channelization that are suppressing M-IBI scores across the NF Crow watershed.

Table 6: Comparison of macroinvertebrate IBI Scores and impairment severity between channelized and natural channel monitoring sites in NF Crow/Crow River mainstem

Channel Type / Fish IBI Class	IBI Score (Average)	Avg. +/- to Fish IBI Threshold*	# Sites
Natural Channel (All M-IBI Classes)	37.20	3.17	8
Channelized (All M-IBI Classes)	44.93	11.43	5
Natural Channel (Class 2)	41.78	11.01	6
Channelized (Class 2)	no data	no data	no data
Natural Channel (Class 5)	33.55	-2.30	1
Channelized (Class 5)	no data	no data	no data
Natural Channel (Class 6)	36.14	-10.66	1
Channelized (Class 6)	no data	no data	no data
Natural Channel (Class 7)	no data	no data	no data
Channelized (Class 7)	44.93	11.43	5

Effects of channelization on NF Crow River fish community

The conceptual model (Figure 21) for this candidate cause highlights changes in trophic characteristics, reproductive success, and community structure as potential biological effects resulting from stream channelization. A selection of fish metrics covering these traits along with their predicted response to stream channelization are shown in Table 7. Fish metric values were observed from a total of 10 sites in the upper half of the NF Crow watershed, which is where all of the channelization occurs in the watershed. Of the 10 sites used to investigate biological response to channelization, 5 were channelized and 5 are natural channel.

Table 7: Selection of fish metrics that may be responsive to stream channelization

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

Trophic response

The values for several fish trophic metrics were compared to investigate potential changes in trophic structure caused by stream channelization (Table 8 / Figure 25). The results suggest that channelized reaches of the NF Crow support fewer fish taxa that are benthic insectivores, and that a smaller portion of the overall fish community at channelized sites is composed of fish with this trophic trait. The abundance of omnivorous and detritivorous fish appears to increase within channelized reaches, suggesting that the food base in these locations is less dependent on productive benthic habitat (Table 8). The presence of piscivore fishes did not seem to differ substantially between natural channel sites and ditches.

Reproductive metrics

The relative abundance of simple lithophilic spawning fish appears to decrease at biological monitoring stations that are channelized (Table 25). Simple lithophils require clean coarse substrate for successful spawning, a habitat feature that is lacking at most of the channelized sites. The channelized biological monitoring stations downstream of Lake Koronis (09UM058, 00UM056, and 07UM074) have a higher percentage of fine substrate (sand/silt) and embeddedness, and deeper depositions of fines throughout the reach than natural channel sites (Figure 27).

Tolerance metrics

Natural channel sites supported a much higher percentage of sensitive fish species than channelized monitoring locations (Table 22). The metric *SensitivePct* was the most responsive metric of the entire set used in this analysis. Sensitive species that were present in healthy populations within natural channels but absent or scare from channelized reaches include lognose dace (*Rhinichthys cataractae*), horneyhead chub (*Nocomis biguttatus*), logperch (*Percina* caprodes) , smallmouth bass (*Micropterus dolomieu*), and tadpole madtom (*Noturus gyrinis*). Channelized monitoring sites had a higher relative abundance of fish that are classified as very tolerant (figure 23), such as central mudminnow (*Umbra limi*), fathead minnow (*Pimephales promelas*), common carp (*Cyprinus carpio*), and bluntnose minnow (*Pimephales notatus*).

Fish community metrics

A higher relative abundance of fish individuals and taxa classified as darter, sculpin, or round-bodies sucker species (e.g. redhorse sp.) were present at natural channel sites compared to channelized sites (Table 8). Fish species in these metrics depend on healthy, productive benthic habitats with minimal embeddedness from fine sediment. Many of the channelized sites on the NF Crow lack these habitat features and thus do not support diverse or abundant populations of these taxa. Fish population density, measured in number of fish per meter (excluding tolerant species), was on average two times greater in natural channels (Table 8).

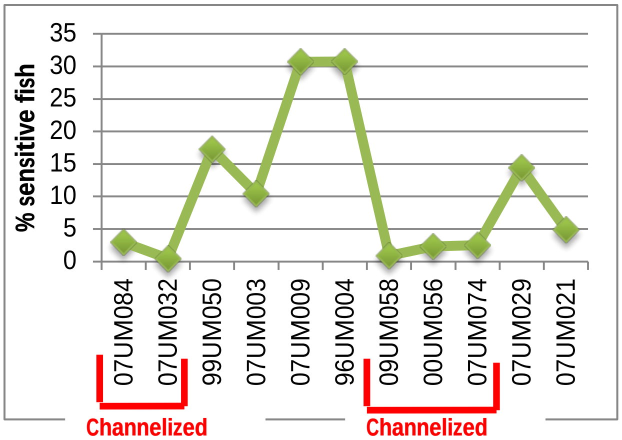


Figure 24: Relative abundance (%) of sensitive fish species

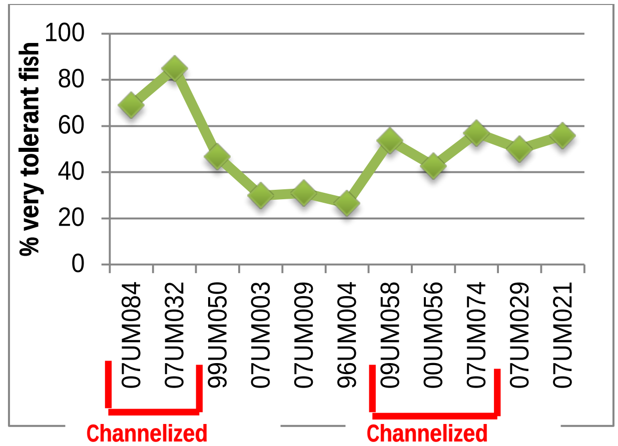


Figure 23: Relative abundance (%) of very tolerant fish species

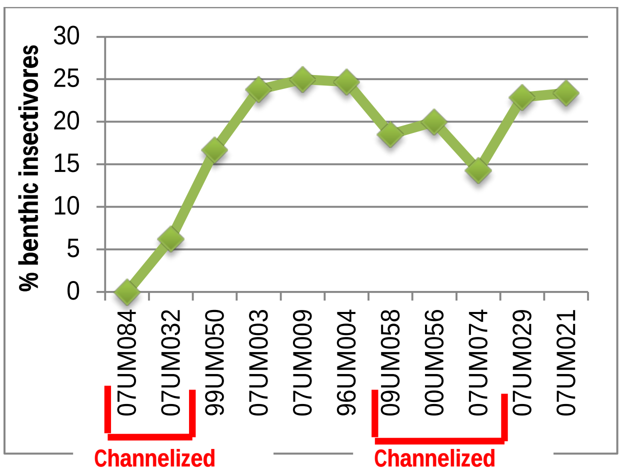


Figure 25: Relative abundance (%) of fish taxa that are benthic insectivores

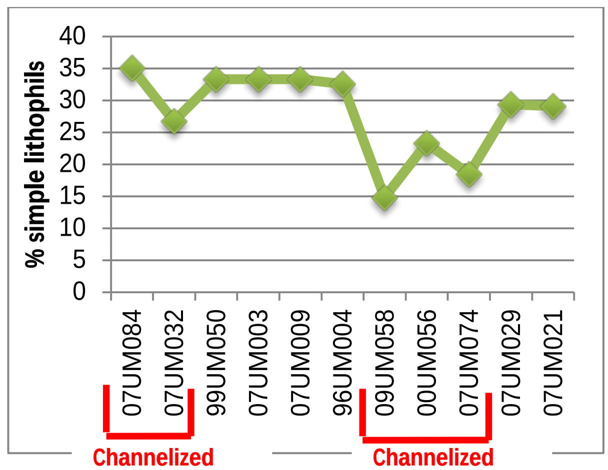


Figure 26: Relative abundance (%) of taxa that are simple lithophilic spawners

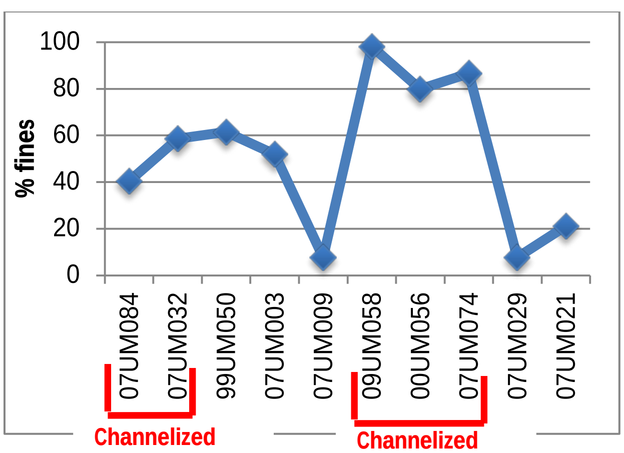


Figure 27: % of stream substrate composed of fine material (silt/sand)

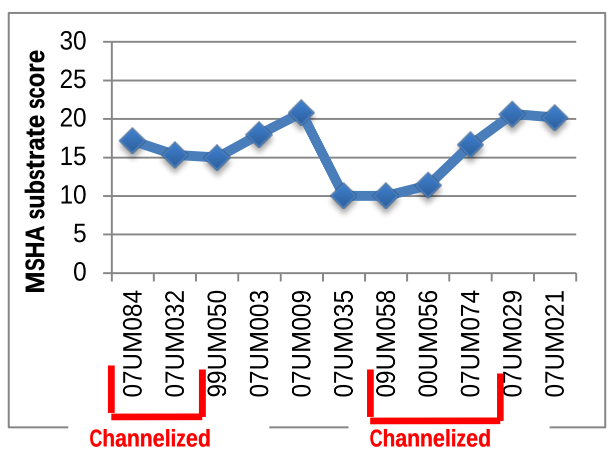


Figure 28: MN Stream Habitat Assessment (MSHA) substrate scores (0=worst; 27=best)

Table 8: A comparison of fish metric values between channelized and natural channel biological monitoring sites on the mainstem NF Crow/Lower Crow River.

Trophic	Metric	Metric Value (Avg.) Channelized	Metric Value (Avg.) Natural Channel	natural channel / ditch ratio**	Predicted Response*
	BenthInsectPct	13.06	20.78	**1.59**	yes
	BenthInsect-TOLPct	7.43	18.56	**2.50**	yes
	BenInsectTxPct	16.39	27.56	**1.68**	yes
	BenInsect-TolTxPct	11.81	22.74	**1.93**	yes
	DetNWQPct	38.90	23.15	0.60	yes
	DetNWQTxPct	19.49	17.78	0.91	yes
	OmnivorePct	16.36	6.15	**0.38**	yes
	OmnivoreTxPct	17.16	11.50	0.67	yes
	GeneralPct	42.49	46.44	1.09	no
	GeneralTxPct	37.18	31.71	0.85	yes
	PiscivorePct	4.44	5.72	1.29	yes
Reproductive	**Metric**	**Channelized**	**Natural Channel**	**natural channel/ditch ratio****	**Predicted Response***
	SLithopPct	21.50	41.81	**1.94**	yes
	SLithopTxPct	23.69	31.84	1.34	yes
Tolerance	**Metric**	**Channelized**	**Natural Channel**	**natural channel/ditch ratio****	**Predicted Response***
	SensitivePct	1.82	18.07	**9.93**	yes
	SensitiveTxPct	11.00	18.89	**1.72**	yes
	TolTxPct	44.47	40.21	0.90	yes
	TolPct	61.47	39.97	0.65	yes
	VtolPct	41.38	13.65	**0.33**	yes
	VTolTxPct	23.62	19.24	0.81	yes
Community	**Metric**	**Channelized**	**Natural Channel**	**natural channel/ditch ratio****	**Predicted Response***
	DarterSculpSucPct	7.22	15.19	**2.11**	yes
	DarterSculpSucTxPct	9.31	15.79	**1.70**	yes
	NumPerMeter-Tolerant	0.86	2.45	**2.84**	yes

* "Predicted response" column indicates whether or not the values represent expected biological effects from channelization
** Represents degree of difference in metrics score between natural channel and channelized sites (metric score natural channel/metric score channelized

The channelization of several reaches of the NF Crow appears to be limiting fish habitat and causing undesirable changes in the fish assemblage. Biological monitoring sites within channelized reaches offer limited riffle and pool habitat, and tend to be dominated by runs with homogenous depth and substrate type (Figure 29). This morphological change favors fish species that are highly adaptable to highly modified habitat conditions (e.g. omnivores, tolerant species).

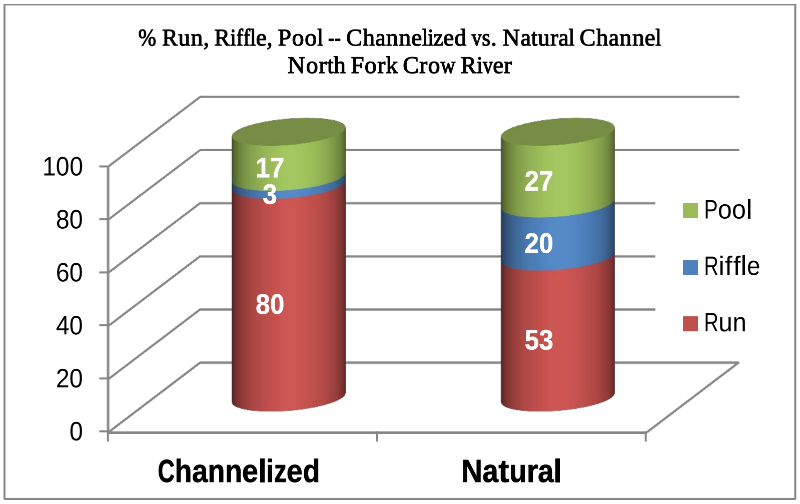


Figure 29: Average ratio of pools, riffles, and runs in channelized vs. natural channel monitoring sites on the NF Crow mainstem

Biological effects -- macroinvertebrates

The channelization of the NF Crow does not appear to be negatively impacting macroinvertebrate populations to the same extent as fish. Although channelized stations in the headwaters area (07UM032 and 07UM084) show clear signs degraded of macroinvertebrate populations, several channelized reaches further downstream achieved some of the highest M-IBI scores in the entire watershed. NF Crow/Lower Crow M-IBI scores from natural channels fall below the impairment threshold at a rate of 60% (6/10) compared to 33% (2/6) from channelized reaches.

Strength of evidence summary – channelization / ditching

Strength of evidence results (Table 9) suggest that channelization/ditching is a probable cause of low fish IBI scores in the channelized headwaters and MRM watershed zones of the NF Crow. There are strong spatial co-occurrence connections between this candidate cause and biological response, particularly within the fish data. In addition, many of the predicted biological responses routinely associated with channelization in the scientific literature (e.g. loss of riffle habitat, change in trophic structure, loss of sensitive species) are evident in the NF Crow ditches as well.

Biological impairments in the other two watershed zones are not as likely to be **directly** affected by this candidate cause, as there are limited areas of channelization in these areas. However, it is important to consider the potential **indirect** impact of channelized tributaries these watershed zones that may be altering hydrology, water quality, and stream morphology in other reaches of the NF Crow.

Table 9: Strength of evidence table for candidate cause #1 – channelization/ditching

Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	Mid-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	+	-	+	-
Temporal sequence	NE	NE	NE	NE
Field evidence of stressor-response	++	-	+	-
Causal pathway	++	-	++	-
Evidence of exposure, biological mechanism	+	-	+	-
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	+	-	+	-
Symptoms	+	-	+	-
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	-	+	-
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	++	-	++	-
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	+++	-	+++	-
Analogous stressors	++	-	++	-
Multiple lines of evidence				
Consistency of evidence	+++	-	+	-
Explanatory power of evidence	++	-	++	-

*** see table 1.1 for scoring interpretations**

4.2 Total suspended solids

Elevated total suspended solids (TSS) concentrations have been identified as a primary water quality concern in the North Fork Crow and Crow River watershed (NFCCR) (Sander et al., 2003). The identification of this water quality concern resulted in a 303(d) listing for turbidity in 2004 that encompasses the lower 1/3 of the river system. Based on current and ongoing suspended-solids related work and several stream reconnaissance trips, there is ample evidence to evaluate elevated TSS concentrations as a candidate cause for biological impairments in the NFCCR.

Biological effects of elevated 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).

Turbidity/TSS standard

Since the late 1960s, MPCA has used a turbidity standard of 25 Nephelometric Turbidity Units (NTU) as a means of addressing aquatic life use impacts resulting from increased suspended particles (sediment, algae, etc.). Although many rivers remain listed as impaired for turbidity (including the NF Crow), the agency is moving towards a water quality standard based on TSS criteria. Unlike turbidity, TSS is a "concentration-based" parameter, which facilitates the development of load allocations during the TMDL process.

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

For the purposes of stressor identification, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. The available turbidity data for the watershed exists in many different units, and at times the equipment used to measure turbidity can produce erroneous results if instrumentation is not calibrated adequately. TSS results are available for the watershed from state-certified laboratories and the existing data covers a much larger spatial and temporal scale in the watershed.

Sources and pathways of sediment in the North Fork Crow River watershed

Riparian grazing

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

Figure 30 shows an example from a site near Regal, MN, where approximately 40 feet of lateral migration of the stream channel occurred over 18 years. Although riparian pasture lands occur throughout the watershed, this type of land-use appears most frequently in this Alluvium Outwash Headwaters zone of the watershed. The outwash soils present within this reach are coarse grained and appear to be susceptible to erosion when vegetative cover is removed or reduced by grazing near the active stream channel.

Figure 30: Lateral migration of NF Crow stream channel near Regal, MN

Inadequate riparian buffer zones

Areas of bank erosion were also observed within urban/developed areas, along the edges of cultivated cropland and turfgrass lawns, steep sloping valley walls, and even heavily wooded riparian corridors. This suggests that there are multiple land-uses and erosional processes contributing to increased sediment inputs and sediment-related stressors to aquatic life. Buffers of inadequate width to protect streambank integrity and aquatic habitat were observed throughout the length of the NF Crow.

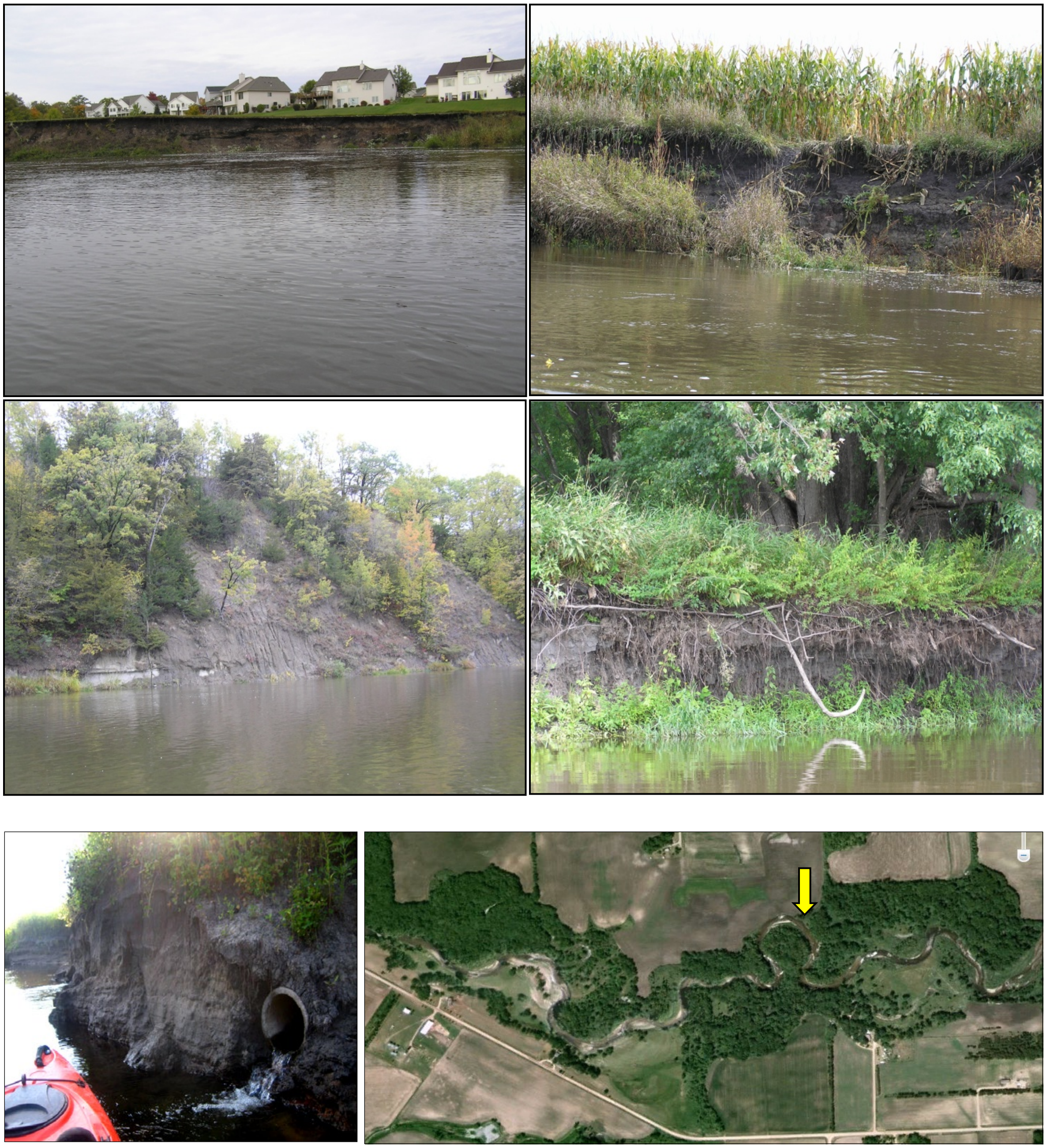


Figure 31: Examples of bank erosion along the NF Crow

Overland runoff

Nearly 60% of the landcover in the NF Crow watershed is cultivated cropland. During the times of the year when crops are not in the ground, cultivated fields are especially vulnerable to erosion via overland runoff processes driven by snowmelt and precipitation events. Figure 32 provides an example of how cultivated land can deliver sediment, nutrients, and other potentially harmful agents to aquatic life (manure, pesticides, etc.) during periods of the year when there is not vegetation to prevent soil loss. These photos were taken during a snowmelt event in March of 2009, and sampling of the runoff indicated high NO2+NO3 concentrations (9.4 mg/L) and extremely high turbidity (508.9 NTU).

Figure 32: Overland runoff from a cultivated agricultural field in the NF Crow watershed

Conceptual model

The conceptual model for elevated TSS concentrations and deposited or bedded sediment (DBS) as candidate causes for impairment is shown in Figure 33. There are numerous potential sources and causal pathways associated with these candidate stressors in the watershed, most of which are associated with landcover changes resulting from urban and/or agricultural land-uses and erosional processes taking place in the stream corridor and ditch networks. The proximate effects, or “stress” on biota follows two potential pathways; (1) effects from elevated turbidity and/or suspended sediment (decreased visibility, gill abrasion, etc.); and/or (2) effects from deposited (bedded) sediment (pool filling, loss of spawning habitat, etc).

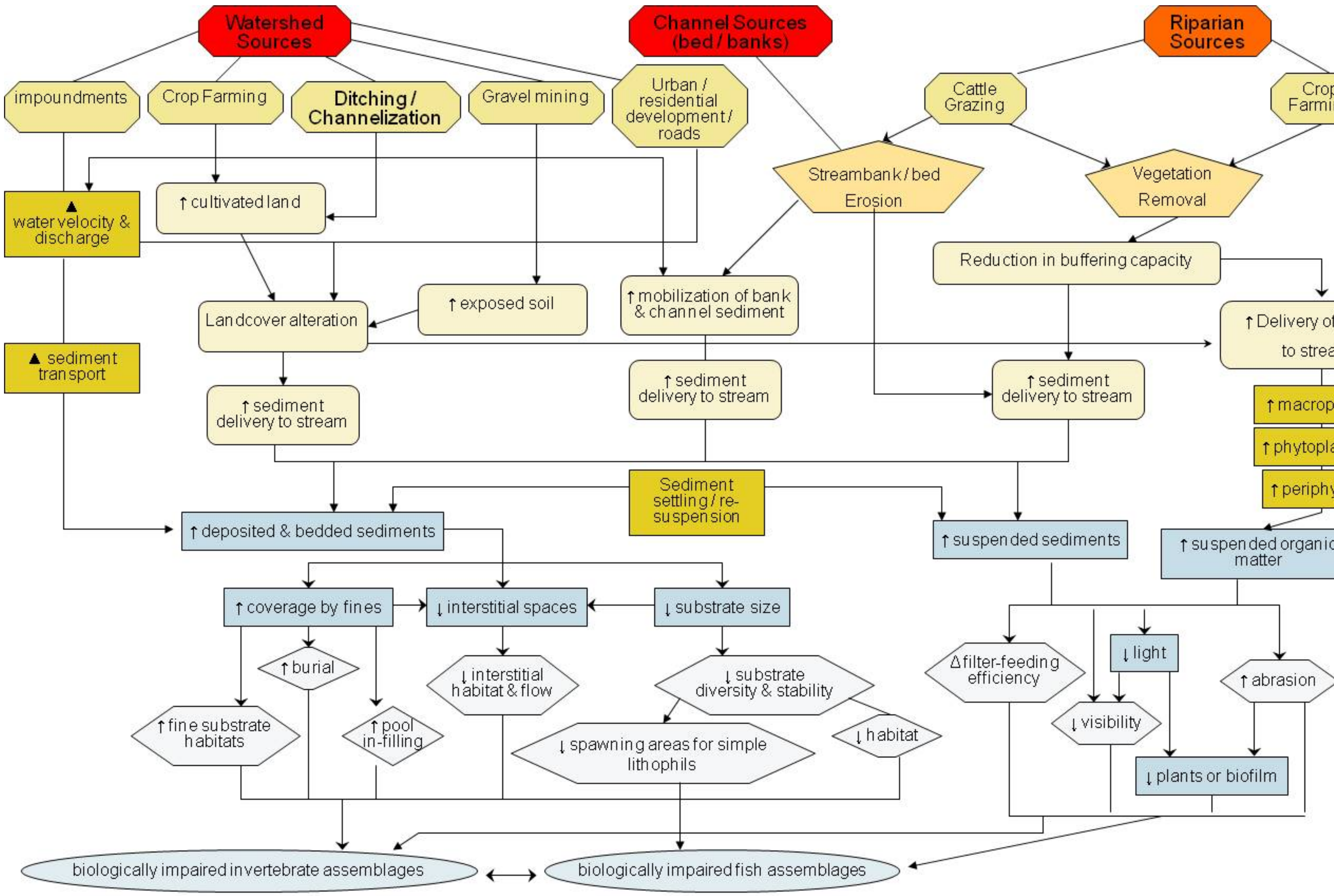


Figure 33: Conceptual model for candidate cause #2: Suspended Sediment (Source: EPA CADDIS website)

Longitudinal and seasonal trends in total suspended solids

Factors such as particle size and stream power dictate whether sediment in rivers is transported as bedload, suspended load, or dissolved load (Allan, 1995). Thus, areas of the NF Crow watershed with different landform slope, soil types, and drainage areas are likely to have different pathways of transporting sediment. In addition, the presence of organic particles such as algae, detritus, and small microorganisms can factor into TSS concentrations and are likely to vary seasonally and geographically due to changes in water temperature and the location of lakes of reservoirs in the watershed.

A selection of paired water chemistry and flow gauging stations were selected to investigate TSS concentrations in different watershed zones of the North Fork Crow River watershed. Figure 34 shows the locations of these sites and corresponding STORET ID codes. Each of these stations has a long term TSS data set and flow data covering several monitoring seasons. The inclusion of seven sites in the analysis provides good longitudinal coverage and representation from all four of the watershed zones that were delineated earlier in this report.

Monitoring data from 1986 – 2010 were used to develop seasonal and longitudinal summaries of TSS data. The summaries of TSS data by season, monitoring site, and NF Crow watershed zone (Figures 35-38; on next few pages) reveal some trends that may influence the probability of TSS as a stressor to aquatic life.

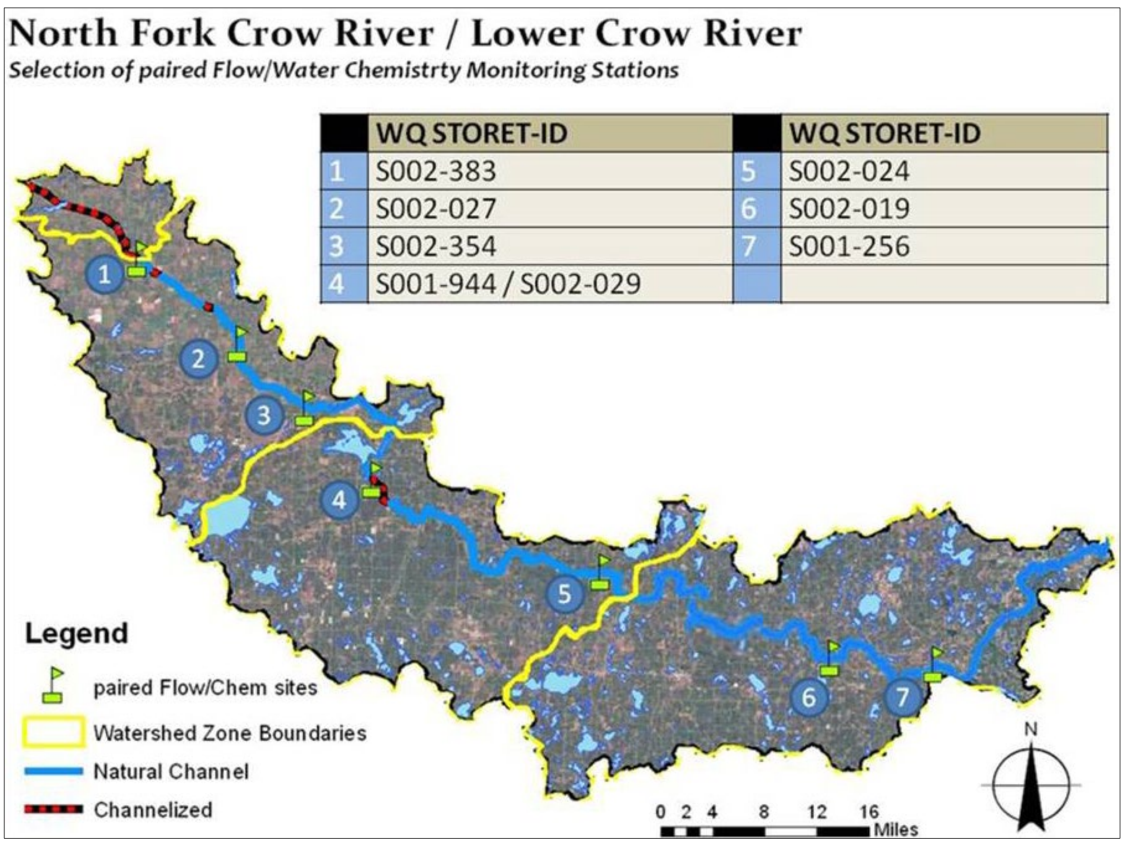


Figure 34: Map of selected flow / WQ paired monitoring stations

TSS concentrations in the NF Crow generally increase near site S004-024 at Kingston, MN and remain at higher concentrations from that point downstream (Figures 35-38, Table 10). This trend is especially true between the months of May – October after snowmelt has subsided and stream temperatures warm. The three downstream-most sites used in this analysis are in violation of the 30 mg/L draft TSS standard frequently enough to be considered "impaired" for TSS (Table 10). However, no official assessment for this parameter has occurred in the watershed to date. Sites in the lower 1/3 of the river violate the draft TSS standard at a much higher rate than sites upstream, which suggests that elevated TSS concentrations may only be a stressor to biota in specific reaches of the river.

In general, monitoring sites located in the upper portion of the MRM and AOH watershed zones had TSS concentrations that were well below the draft TSS standard of 30 mg/L (Table 10). Monitoring data from the 10-year data window (2000-2010) used in Table 11 indicates that 1.6% and 5.0% of samples exceeded the draft TSS standard in these watershed zones. The lower TSS concentrations in the AOH may be attributed to the coarser-grained glacial outwash soils in this region of the watershed. Most of the streambank and bed material observed in this reach of the river consisted of coarse sand, gravel, and small cobble-sized particles. These particle sizes require more streampower to suspend, and are often transported as bedload.

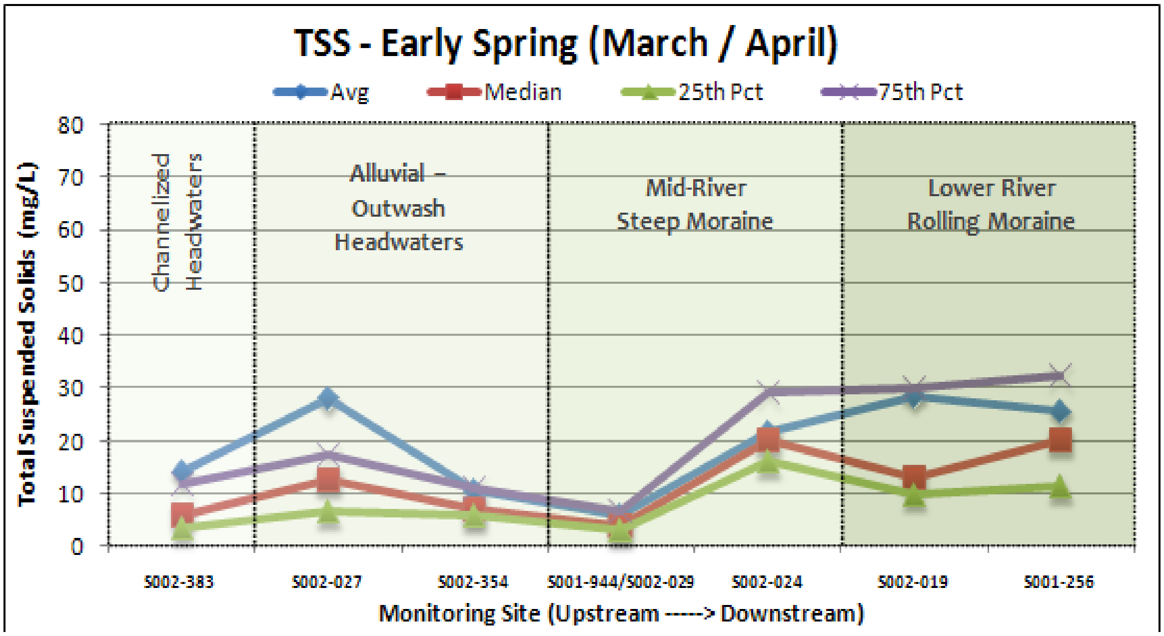
The CHH of the NF Crow showed elevated TSS concentrations compared to sites immediately downstream. TSS concentrations at site S002-383 during mid-summer and fall months were nearly enough to put this reach in violation of the draft TSS standard. TSS concentrations were above the standard for 9.5% of samples collected during the 10 year (2000 – 2010) data period used in Table 10. A site is in violation of the standard if 10% of qualifying samples exceed the standard.

Table 10: TSS data from 2000 – 2010 (April – September) and frequency of standard TSS standard exceedence (30 mg/L). Values in red indicate a violation of the draft TSS standard.

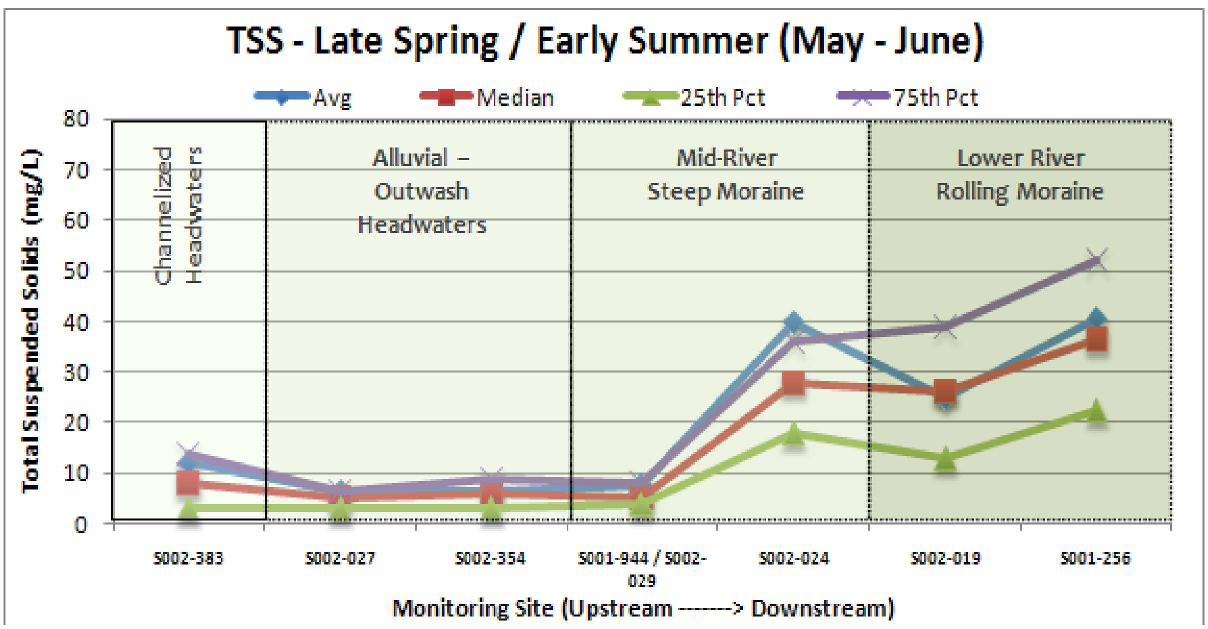
Site	Watershed Zone	# samples	Avg. (mg/L)	25th Pct (mg/L)	Median (mg/L)	75th Pct (mg/L)	# Exc *	Exc % **
S002-383	CHH	42	12.2	4	7.5	15.5	4	9.5%
S002-027	AOH	62	7.5	3	5	9	1	1.6%
S002-354	AOH	60	8.3	3	5	8.5	3	5.0%
S001-944 / S002-029 ***	MSM	101	8.3	4	6	11.3	1	1.0%
S002-024	MSM	48	29.9	17	22	33	13	**27.1%**
S002-019	LRRM	40	29.8	13	26	42	17	**42.5%**
S001-256	LRRM	154	41.7	20.2	40	60	96	**62.3%**

*** number of TSS standard exceedences** **** Pct of samples in violation of TSS standard** ***** sites are co-located**

CHH = Channelized Headwaters Watershed Zone
MSM = Mid-River Steep Moraine Watershed Zone
AOW = Alluvium-Outwash Headwaters Watershed Zone
LRRM = Lower River Rolling Moraine Watershed Zone

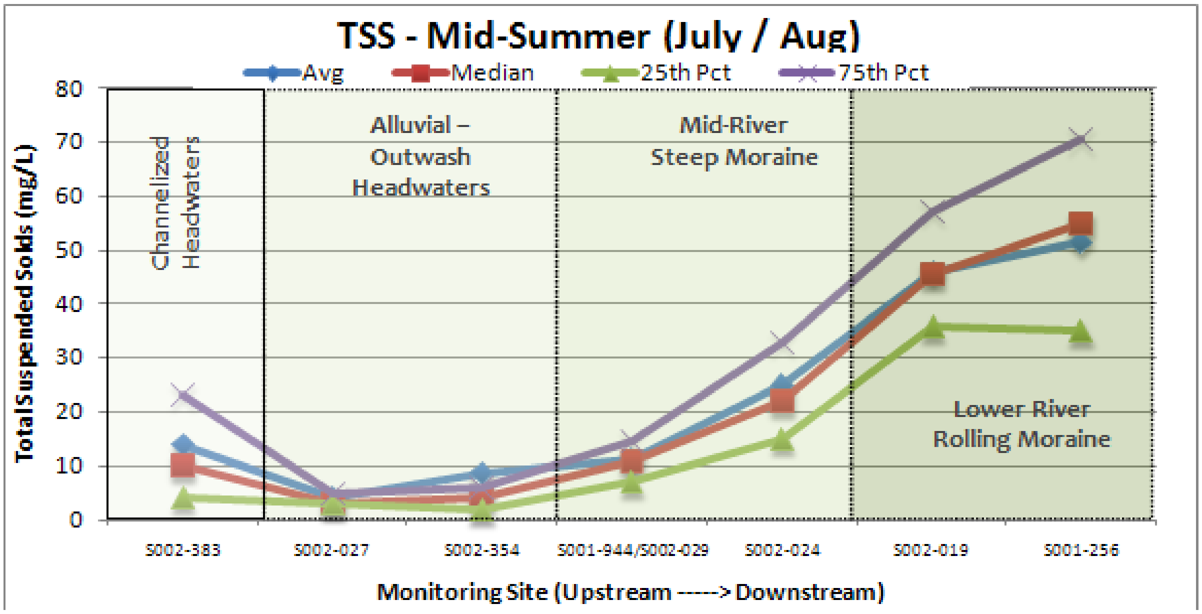


site	S002-383	S002-027	S002-354	S001-944 / S002-029	S002-024	S002-019	S001-256
# samples	15	16	17	26	7	11	36

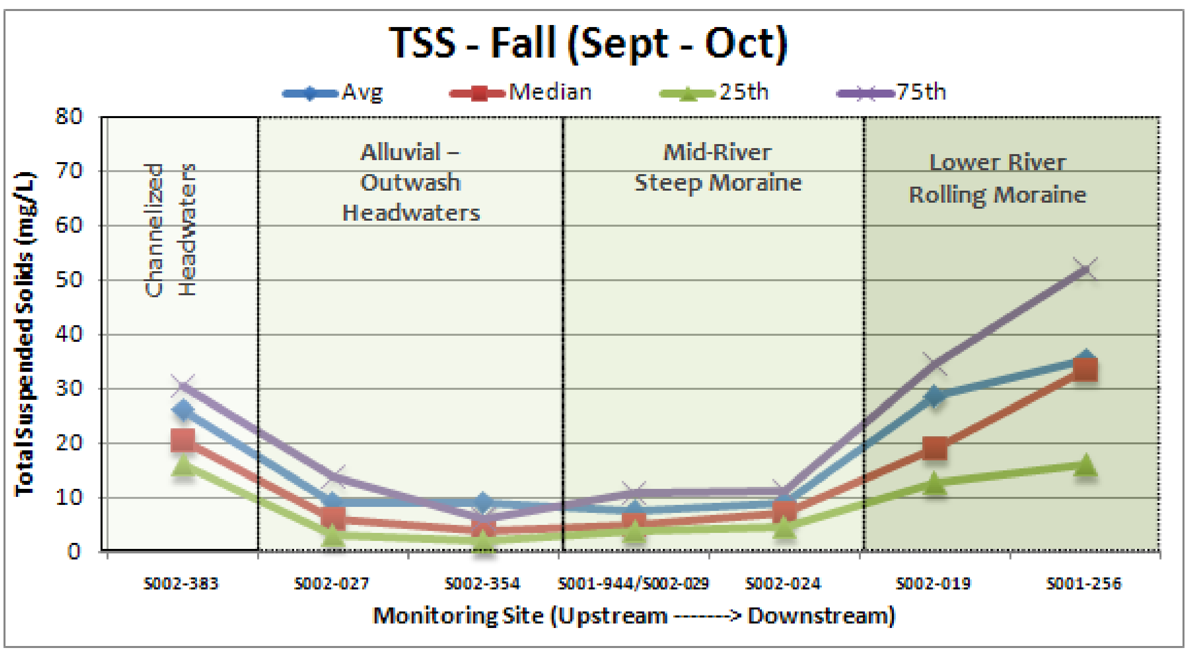


site	S002-383	S002-027	S002-354	S001-944 / S002-029	S002-024	S002-019	S001-256
# samples	21	36	28	49	21	17	54

Figures 35 - 36: Summary of TSS concentrations observed at NF Crow monitoring stations by season.



Site	S002-383	S002-027	S002-354	S001-944 / S002-029	S002-024	S002-019	S001-256
# samples	8	17	21	35	15	10	55



Site	S002-383	S002-027	S002-354	S001-944 / S002-029	S002-024	S002-019	S001-256
# samples	4	10	9	17	8	4	28

Figures 37 - 38: Summary of TSS concentrations observed at NF Crow monitoring stations by season.

Streamflow and TSS relationships

Streamflow and TSS data were compiled for a selection of NF Crow monitoring sites to evaluate discharge vs. TSS relationships. Based on the seasonal analysis of TSS concentrations in at select NF Crow sites shown in Figures 35-38 on the previous page, it appeared that TSS concentrations were higher in the lower portion of the river during summer months, which usually correspond with lower streamflows. Paired streamflow and TSS data from 2009 (shown in Figure 39) show a similar trend. TSS concentrations at stations above Lake Koronis increase during high flow events driven by snowmelt and precipitation, but are generally quite low (under 10 mg/L) during typical summer flow conditions. In contrast, monitoring sites in the Lower NF Crow (e.g. LRRM watershed zone) exhibit TSS concentrations well over 30 mg/L during summer low flow periods. TSS concentrations do not appear to be influenced greatly by mid-summer increases in discharge, but instead remain consistently around 30 – 80 mg/L from late May to early September.

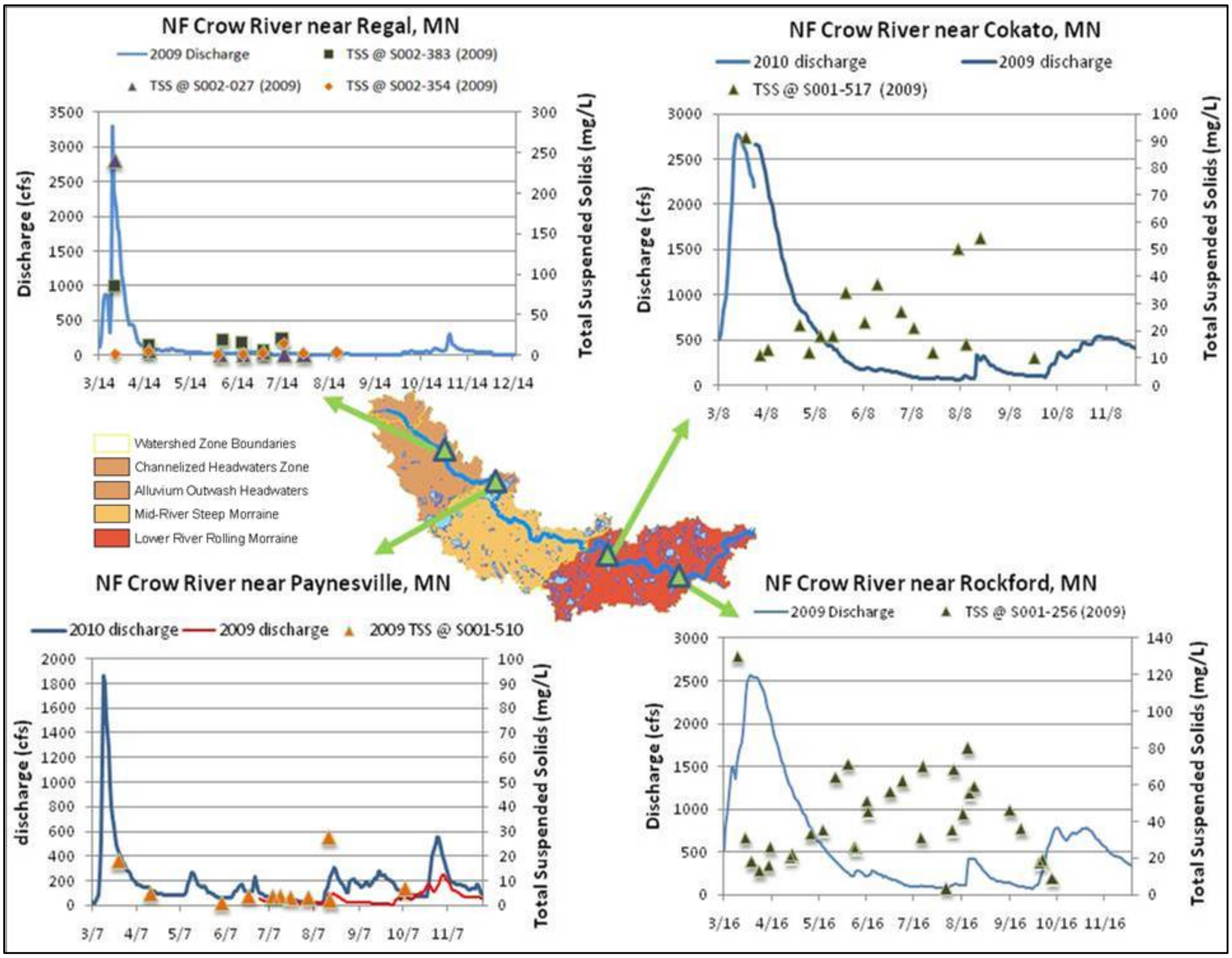


Figure 39: Discharge and TSS data from a selection of NF Crow monitoring sites. In some cases, 2010 streamflow data was used to fill data gaps.

The streamflow vs. TSS relationships in Figure 39 suggest:

1. In watershed zones upstream of Lake Koronis, elevated TSS concentrations occur during episodic high flow events and are likely driven by sediment inputs from overland runoff and streambank erosion. The duration of exposure to high TSS concentrations is short, but the magnitude of exposure can be high (e.g. S002-027 – 225 mg/L). However, these high magnitude TSS events appear to be infrequent and seasonal.
2. Elevated TSS concentrations (greater than 30 mg/L) occur throughout the open water season in the LRRM watershed zone. The duration of exposure is long (nearly continuous) during summer low flows. The high TSS concentrations during baseflow are an indicator that algae and/or other suspended organic matter play a role in the TSS regime in the lower river.
3. Lake Koronis does not appear to have a large impact on the TSS regime of the NF Crow. Figure 40 shows streamflow and TSS concentrations measured at S002-029, near the outlet of the lake. The lake appears to serve as a sink for sediment during spring runoff periods, as TSS concentrations are lower at this site than observed in other sections of the river during peak spring snowmelt periods. Mid-summer baseflow TSS concentrations are between 15-20 mg/L, slightly elevated compared to monitoring sites upstream of the Koronis. It is likely that algae production in the lake has some role in these slightly elevated TSS concentrations.

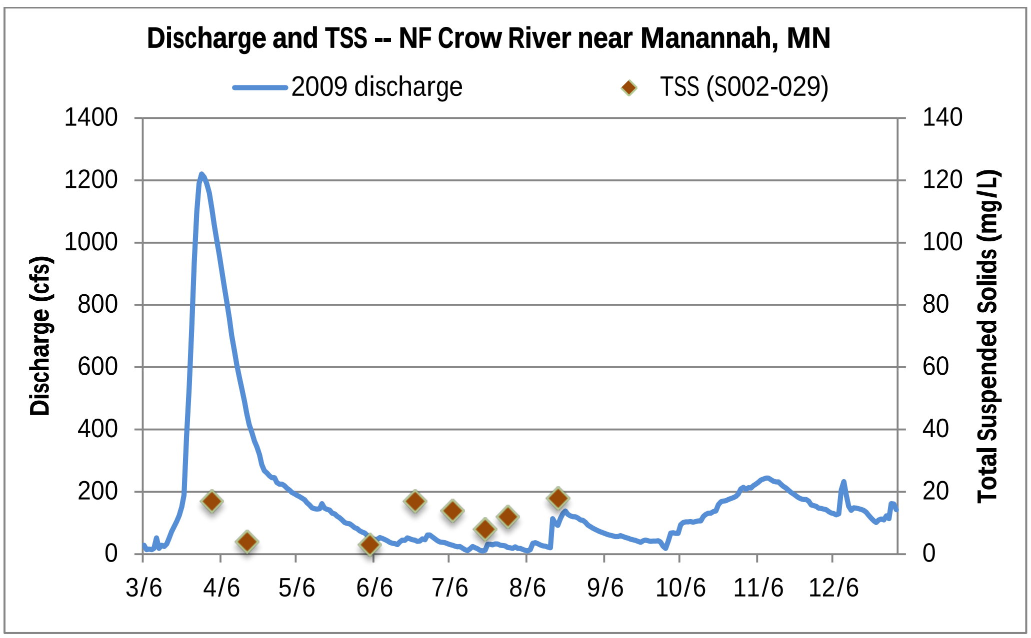


Figure 40: 2009 discharge and TSS concentrations @ S002-029, NF Crow.

Influence of total volatile solids

As previously mentioned, the presence of suspended organic solids in the water column can contribute to elevated TSS concentrations and high turbidity. Total volatile solids (TVS) concentration is a parameter than can be used to evaluate the amount of organic matter present in suspension in the water column. Examples of TVS constituents in streams include algae and other aquatic microorganisms and detritus. Elevated TVS concentrations can impact aquatic life in a similar manner as TSS – with the suspended particles reducing light penetration – but unusually high concentrations of TVS can also be indicative of nutrient imbalance and an unstable DO regime.

TVS concentrations increase significantly in the NF Crow/Lower Crow River near Kington, MN and remain high until the confluence with the Mississippi River (Figure 41). Upstream of Kingston, TVS concentrations are very low and do not appear to be a significant component of the TSS regime in those stream reaches.

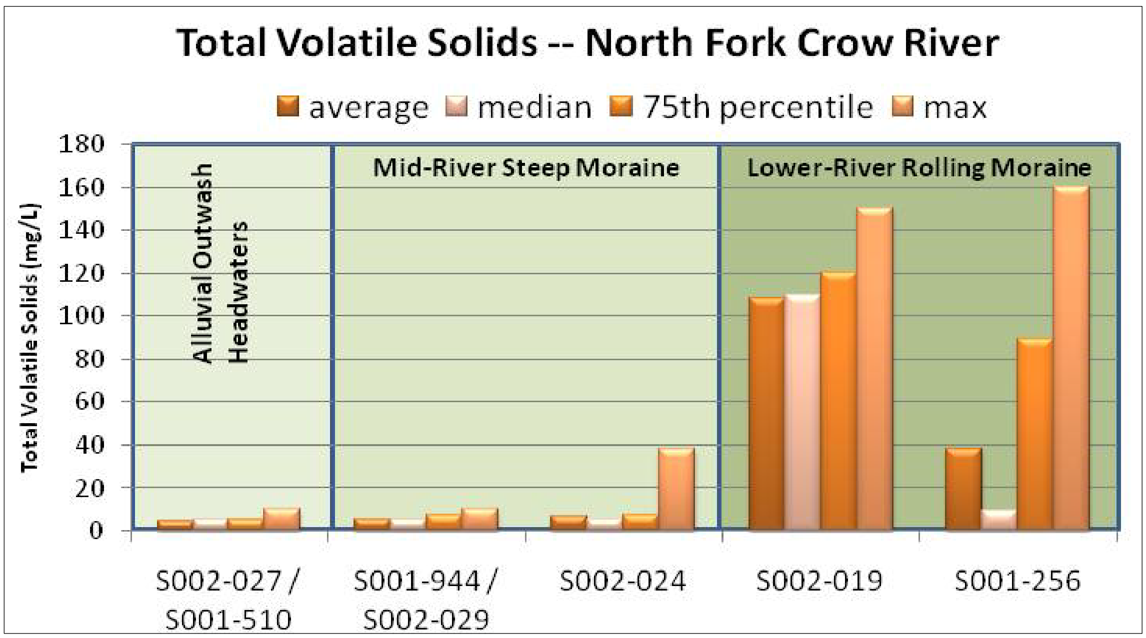


Figure 41: Summary of TVS concentrations observed in the North Fork Crow/Lower Crow River

The available data for the NF Crow does not allow for the calculation of % suspended solids that are volatile (organic, e.g. algae) and non-volatile (inorganic, e.g. sediment). All available volatile solids results are reported as "total volatile solids" (TVS) which cannot be directly related to total suspended solids (TSS) due to differences in lab methodologies. In order to better understand the sources and pathways of the elevated TSS concentrations in the Lower NF Crow/Crow River, additional data collection of paired TSS/VSS should be considered so a direct measure of the volatile portion of the suspended solids can be calculated. The TVS concentrations from sites located within the LRRM watershed zone suggest that volatile particles are a significant contributor to the high TSS values in the Lower NF Crow/Crow River system.

Causal analysis – effects of elevated TSS concentrations on biota

Fish and macroinvertebrate IBI scores are compared against average TSS concentrations by watershed zone in Figures 42 and 43. The IBI scores are represented by the average number of points that each site was above or below the impairment threshold for the applicable IBI class. Looking at IBI scores in this manner reflects the severity of impairment, or degree to which the standard was met (or not met) for each site on the NF Crow/Crow River mainstem. The TSS values used were the same figures calculated in Table 11, which represent the general range of TSS concentrations observed in each watershed zone.

Fish IBI scores below the impairment threshold were observed throughout the length of the NF Crow, and the frequency or severity of impairment does not appear to be highly correlated with increases in TSS. The most severely impaired fish sites occur downstream of Lake Koronis, a section of the river in which average TSS concentrations around are around 8.3 mg/L. This concentration is well below the draft standard of 30 mg/L and is not likely to negatively impact aquatic life.

Higher TSS concentrations are observed in the lower 1/3 of the river system (beginning at site 07UM021) and fish IBI scores fail to meet established impairment thresholds in this section of the stream. However, based on the longitudinal display in Figure 42, fish IBI scores generally improve from site 07UM029 downstream as TSS concentrations increase. This observation does not refute TSS as a candidate cause for fish impairment. However, it does present a strong case for the presence of other highly influential stressors in the system, especially below Lake Koronis where fish IBI impairments are most severe and TSS concentrations are relatively low.

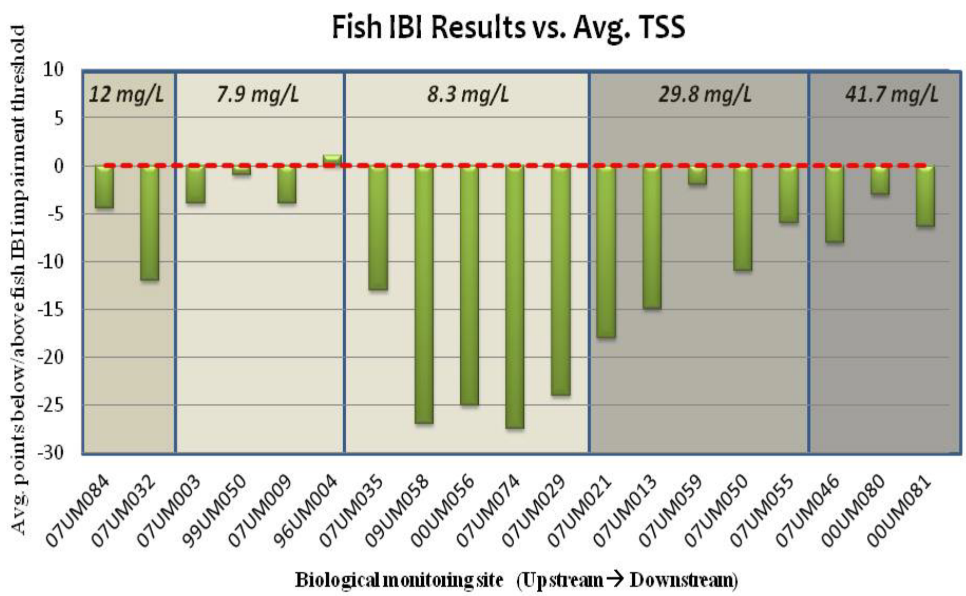


Figure 42: Longitudinal display of average TSS (mg/L) and fish IBI +/- from the impairment threshold value

Macroinvertebrate IBI (M-IBI) scores indicate impairment of moderate severity in the CHH and LRRM watershed zones. M-IBI results for sites in the middle reaches of the river generally scored above the impairment threshold, in some cases by wide margins (e.g. 00UM056 and 07UM021). The change in average TSS concentrations from around 8.0 mg/L to nearly 30 mg/L did not appear to significantly affect M-IBI scores, although a downward trend in M-IBI scores begins at the tail end of this section at site 07UM055 (Figure 43).

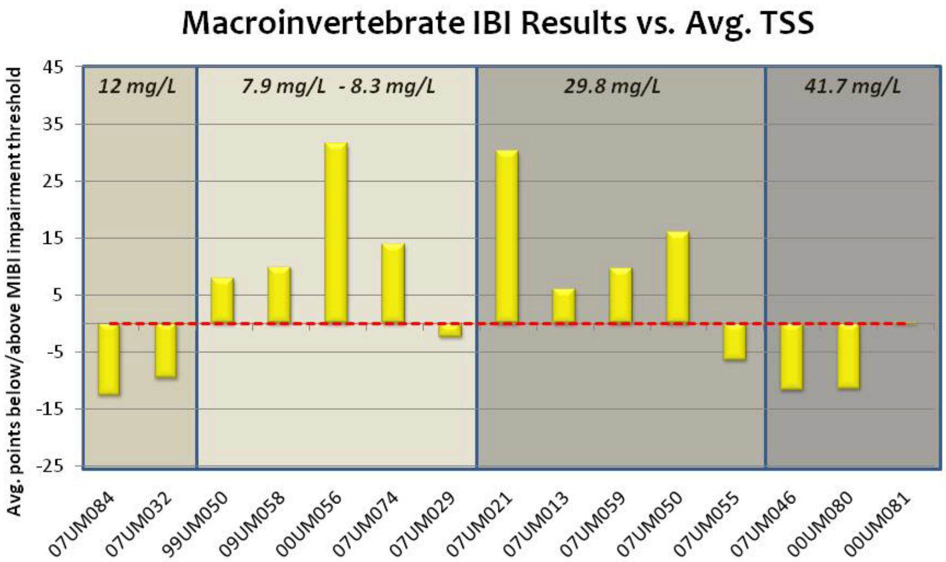


Figure 43: Longitudinal display of average TSS (mg/L) and macroinvertebrate IBI +/- from the impairment threshold value

Specific effects of TSS on fish and macroinvertbrates

Based on overall IBI scores alone, it is difficult to isolate the potential effects of elevated TSS on biota from other confounding stressors. In-depth analysis of specific symptoms or biological metrics that may be sensitive to elevated TSS concentrations can offer some insight into potential influence of this stressor. Table 11 is a compilation of observed biological responses to elevated TSS and suspended sediment gathered from other case studies and scientific literature.

Table 11: Impacts of elevated concentrations of suspended sediment on fish and macroinvertebrate assemblages

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

Most of the common macroinvertebrate responses to elevated TSS listed in table 12 are not observed in the NF Crow. The metric results shown in Figure 44 do not show strong response to the increases or decreases in TSS. The relative abundance of tolerant macroinvertebrate taxa decreases in the lower reaches where TSS concentrations are noticeably higher. In addition, other indices of macroinvertebrate health –EPT taxa percent, Shannon Diversity Index, and relative abundance of chironomid taxa – all respond to TSS concentrations in a manner that suggest no direct or significant impact.

The one metric that does appear to be influenced by increases in TSS is *TaxaCountAllCH*, which provides a measure of overall macroinvertebrate taxa richness. A general trend of decreasing scores in this metric is observed downstream of site 07UM021, which corresponds with the location on the NF Crow where TSS concentration increases noticeably. Scores for this metric drop substantially in the lower reaches of the NF Crow/Crow River where TSS concentrations exceed the draft 30 mg/L standard regularly and for long durations.

The response of the collector-filterer metric to TSS is somewhat contradictory to observations recorded by Arruda et al. (1983), Lemley (1982), and Strand and Merritt (1997). These studies found that increases in suspended sediment concentrations can result in respiratory stress and clogging or ripping of the nets used by these organisms to collect food. An important distinction, however, is that those studies focused on suspended ***sediment*** as the stressor, while the data available for the NF Crow watershed is recorded in suspended solids. Collector-filter feeders are likely to be more heavily impacted by suspended sediment than suspended particles that are organic. Suspended organic particles provide a food resource for these organisms, whereas inorganic sediments (silt/sand) generally cause harm or mortality. The majority of collector-filterer organisms in the lower reaches are of the family *Hydropsychidae* (net-spinning caddisflies), and these organisms may actually benefit from higher TSS concentrations if the suspended particles are organic.

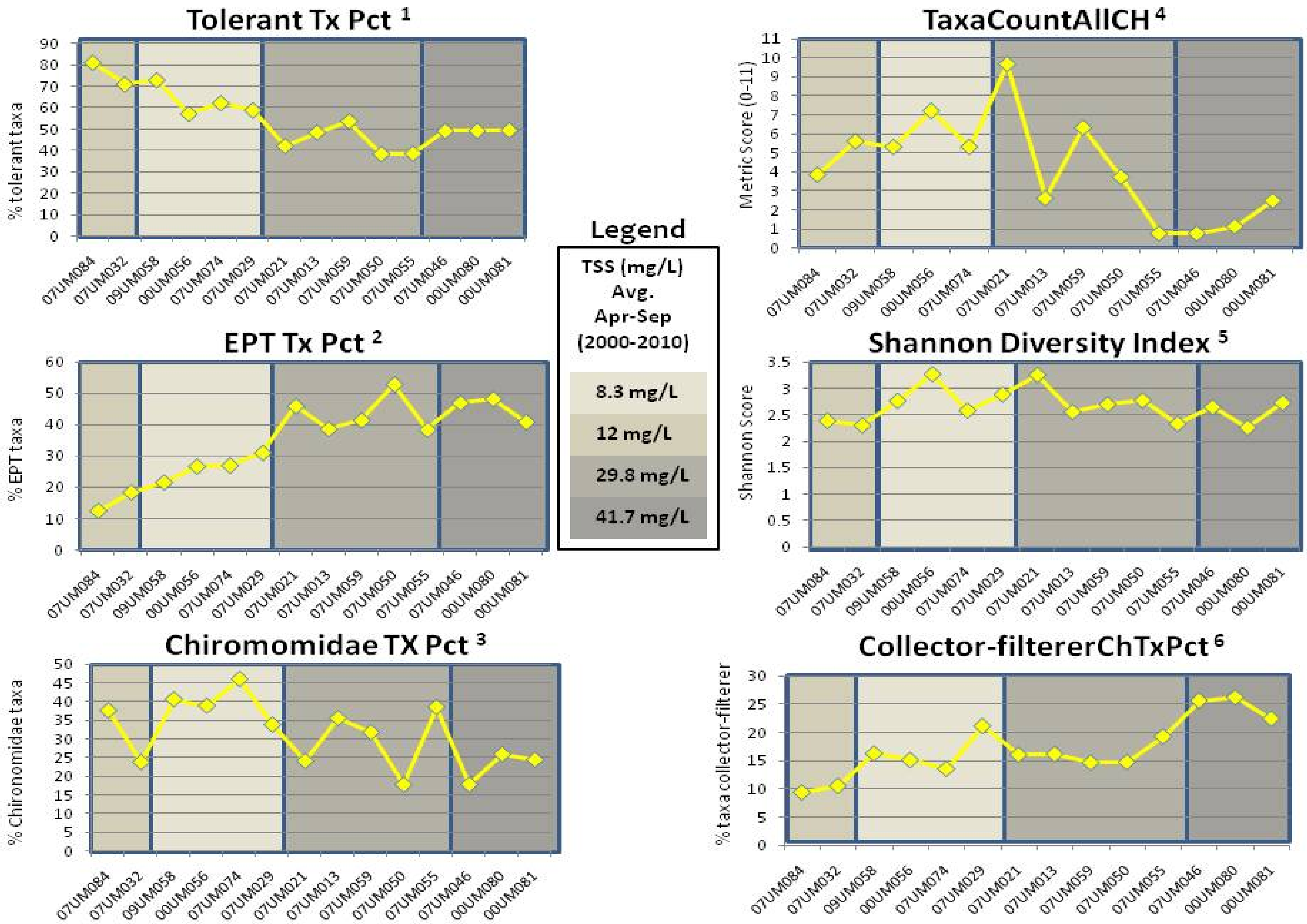


Figure 44: Selection of macroinvertebrate metrics and response to different TSS regimes of the NF Crow/Lower Crow River

1 - Relative abundance (%) of taxa that are tolerant species; **2 -** Relative percentage of taxa belonging to Ephemeroptera, Plecoptera & Trichoptera ; **3 -** Relative percentage of taxa belonging to Chironomidae; **4 -** Total taxa richness of macroinvertebrates; **5 -** Shannon Diversity Index: -1*sum(p*natural log(p)); **6 -** Relative percentage of collector-filterer taxa

Meador and Carlisle (2007) developed suspended sediment tolerance indicator values (TIVs) for 105 common fish species in the United States (Figure 49). These TIVs were used to determine the suspended sediment tolerance levels of NF Crow fish species and provide an additional means of evaluating suspended solids as a potential stressor. The suspended sediment TIVs for a selection of NF Crow watershed fish species, displayed in terms of ordinal rank, are shown in Figure 45. The TIVs calculated in Meador and Carlisle (2007) is based on suspended sediment (SS), not TSS. Therefore, more emphasis will be placed on the general tolerance of specific fish species than actual concentrations of SS or TSS used to develop the TIVs.

Common Name	OR	Common Name	OR	Common Name	OR	Common Name	OR
bowfin	3	blacknose dace	5	black crappie	7	bigmouth shiner	9
brown bullhead	3	bluegill	5	green sunfish	7	black bullhead	9
logperch	**3**	golden redhorse	5	johnny darter	7	channel catfish	9
silver redhorse	3	tadpole madtom	5	shorthead redhorse	7	common carp	9
yellow perch	3	bluntnose minnow	6	white sucker	7	fathead minnow	10
central stoneroller	4	common shiner	6	blackside darter	8	orangespotted sunfish	10
golden shiner	4	creek chub	6	hornyhead chub	8	sand shiner	10
largemouth bass	4	longnose dace	6	spotfin shiner	8		
northern hogsucker	4	northern pike	6	spottail shiner	8		
pumpkinseed	4	walleye	6	yellow bullhead	8		
rock bass	4						
smallmouth bass	**4**						

Less tolerant to SS → **More tolerant to SS**

Figure 45: Tolerance of specific fish species to suspended sediment, shown in ordinal ranks. Based on Meador and Carlisle (2007). {OR of 0 to 4 = intolerant; OR 5 to 6 = moderately tolerant; OR of 7 to 10 = tolerant

Among the fish species that are "intolerant" to high SS concentrations shown in Figure 45, smallmouth bass (SMB) is one that may be of particular interest in the NF Crow watershed. Viable SMB populations are synonymous with healthy, functioning river systems of medium to large rivers in the midwestern United States, particularly in the state of Minnesota. SMB are a top predator in several streams in the Mississippi River drainage, including the Rum River, Sauk River, and NF Crow. Optimal habitat for SMB includes cool, clear water, the presence of some coarse substrate (gravel, cobble, boulder), abundant shade and cover, moderate current, and deep pools (Larimore et al., 1952; Coble 1975; Pflieger, 1975).

Some research suggests that increases in turbidity and/or suspended sediment can limit abundance, reproductive success, and growth rates in SMB populations. Paramagian (1991) concluded that sediment was a major habitat factor limiting the viability of smallmouth bass populations in Iowa rivers and streams. Centrachid fish (e.g. smallmouth bass, largemouth bass, rock bass) may be severely impacted in their ability to feed after minor increases in turbidity or suspsended solids concentrations (Berry et al., 2003). Exposure of early SMB in early life-stages to relatively low concentrations (11.4 mg/L) of bentonite over short durations (24 hours) were enough to inhibit growth rates (Sweeten and McCreedy, 2002). The authors concluded that low concentrations of suspended sediment at early life-stages may strongly affect recruitment success.

Feeding efficiency and effectiveness of SMB may also be impaired by increases in SS and/or turbidity. Sweka (1999) found that reactive distance (distance at which prey are recognized) decreased significantly as turbidity increased and a greater amount of potential prey eluded SMB under higher turbidity levels. This resulted in an overall reduction in prey consumption compared to experiments in less turbid conditions. Other studies related to the issue of turbidity and prey recognition/consumption have found that slower growth rates in fish occur in turbid water compared to clear water (Easton et al., 1996; Sigler et al., 1984).

Based on MPCA fish data, the overall abundance and maximum size of SMB in the NF Crow /Crow River appear to be below measures seen in the nearby Rum River (also a tributary to the upper Mississippi River). In a comparison of Class 5 (northern rivers) fish stations on these two streams, SMB catch-per-unit-effort (CPUE) is consistently higher at Rum River stations by quite a large margin (Table 12). In addition, the maximum size of SMB sampled appears to be slightly larger for Rum River stations, but an overall size-structure analysis is not possible due to data limitations (only max/min size is recorded).

Larger populations of SMB in the Rum River may be related to a wide variety of habitat variables, but the contrast in TSS concentration between the two rivers is likely a factor. Mean TSS concentrations at Rum River station S000-066 (drainage area = 1,325 mi^2) for the time period April-Sept (2000-2010) is 10 mg/L (n = 46; max =20mg/L). In comparison, a NF Crow site of the similar drainage area, S001-256, has a mean TSS concentration of 41.7 mg/L (n = 154; max = 193mg/L). Clearly, there is a significant difference in the exposures of SMB to TSS between these two river systems.

The Logperch (*Percina caprodes*) is another fish species common to the NF Crow region that is considered intolerant to elevated SS concentrations (see Figure 45). Logperch commonly occupy the transition habitats between riffles and pools (i.e. runs) and are often found suspended above the substrate in the water column (Welsh and Perry, 1998). In a study conducted in the Red River drainage basin (encompassing areas of Minnesota and North Dakota), Koel and Pterka (2003) found Logperch to be highly correlated with stream locations that had low concentrations of suspended residue. A similar trend is seen when comparing Logperch abundance between NF Crow and Rum River biological monitoring sites. As shown in Table 12, Logperch were much more abundant in the less-turbid Rum River than the NF Crow/Crow River, which frequently exceeds the current turbidity standard.

Table 12: Comparison of CPUE for smallmouth bass and Logperch in the NF Crow/Crow River and Rum River, Minnesota.

Station		Drainage (mi2)	Total # SM Bass	CPUE (SM Bass/min)	Max Length (inches)	Total # logperch	CPUE (logperch/min)
Rum River	**00UM032**	**570**	83	1.33	14.1	30	0.48
	10EM036	**1,051**	9	1.51	19.0	0	0
	00UM044	**1,274**	88	2.40	19.1	3	0.04
	00UM066	**1,325**	140	0.17	17.0	50	0.85
	10EM164	**1,333**	41	0.83	18.9	162	2.78
	10EM100	**1,396**	38	0.65	18.7	33	0.67
North Fork Crow / Lower Crow	**07UM029**	**326**	4	0.04	17.2	1	0.01
	07UM021	**683**	0	0	-	0	0.00
	07UM013	**791**	4	0.05	11.0	1	0.01
	07UM059	**1,002**	10	0.13	10.3	6	0.08
	07UM050	**1,096**	4	0.01	10.8	1	0.02
	07UM055	**1,199**	2	0.06	8.6	0	0
	07UM046	**1,340**	14	0.14	16.3	2	0.02
	00UM080	**2,637**	12	0.16	14.1	3	0.03
	00UM081	**2,750**	14	0.16	13.0	1	0.02

Strength of evidence summary for TSS

Based on existing water quality data and several biological indicators, there is substantial evidence available in support of elevated TSS concentrations as a stressor to aquatic life. The negative impacts of elevated TSS are likely limited to reaches of the NF Crow/Crow River from a few miles upstream of Kingston, MN to the confluence of the Crow River with the Mississippi. This reach of the stream encompasses the lower portion of the MRM watershed zone and the entire LRRM watershed zone. TSS concentrations upstream of this point are much lower and consistently below draft water quality standards for this parameter. Biological impairments within the headwaters reach of the NF Crow (Channelized Headwaters watershed zone) may also be driven by slightly elevated TSS concentrations, although there are likely more prominent stressors operating in this region of the watershed (e.g. channelization).

Table 13: Strength of Evidence table for elevated TSS as a cause of biological impairment by watershed zone

Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	id-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	+	-	+	+
Temporal sequence	0	0	0	0
Field evidence of stressor-response	+	-	+	++
Causal pathway	+	-	++	++
Evidence of exposure, biological mechanism	0	-	++	++
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	0	-	+	+
Symptoms	0	0	+	+
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	-	+	+
Stressor-response in other lab studies	+	-	+	++
Stressor-response in other field studies	+	-	+	++
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	+	-	+	++
Multiple lines of evidence				
Consistency of evidence	+	-	+	+++
Explanatory power of evidence	0	-	++	++

*** see Table 1.1 for scoring interpretations**

4.3 Deposited and bedded sediment

Deposited and bedded sediments (DBS) are mineral and organic particles that settle out of the water column and collect on the streambed. DBS is one of the leading causes of biological impairments in rivers and streams of the United States (US EPA, 2003). Numerous stressor identification studies involving biologically impaired Minnesota streams have identified DBS as a primary cause of impairment (Jasperson, 2010; Felix et al., 2009; Lane and Cormier, 2004; EOR, Inc., 2009.)

To date, the presence and effects of DBS have not been extensively documented in the NF Crow watershed, most likely because there is no state or federal water quality standard for this parameter. However, a significant amount of data on substrate composition and embeddedness is available through MPCA's habitat data from biological monitoring stations. These data will be used to determine whether or not bedded sediment is a significant stressor to aquatic life in certain areas of the watershed.

Biological effects of deposited and bedded sediment

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

Longitudinal assessment of deposited and bedded sediment

The amount of DBS in rivers is related to several stream and watershed features that vary longitudinally throughout the length of a river system. Sediment transport and deposition rates are factors of sediment grain size, delivery rates, stream gradient, channel geometry, and stream discharge. All of these variables are driven local topography, geology, and land-use factors. Along the 160 miles of the North Fork of the Crow River, the nature of these variables changes considerably. As a result, the presence of DBS and the magnitude of its impact on aquatic life are likely to vary throughout the river.

A regression of stream gradient and several parameters related to DBS (% emdeddedness and % fine sediment) shows a negative relationship at North Fork Crow biological monitoring sites (Figure 46). This relationship is typical of many streams, as finer sediments typically accumulate at much higher rates as gradient flattens and stream power decreases. Even taking this into consideration, NF Crow biological monitoring sites still appear to have a higher rate of embeddedness and greater abundance of fine substrate compared to sites of similar gradient in the nearby Rum River watershed (Figure 46). In comparison to the NF Crow, Rum River watershed is more forested, contains more functioning wetlands, and has significantly less agricultural and urban land-use. These land-use differences likely contribute to lower sediment inputs to the Rum River and its tributaries in comparison to the NF Crow.

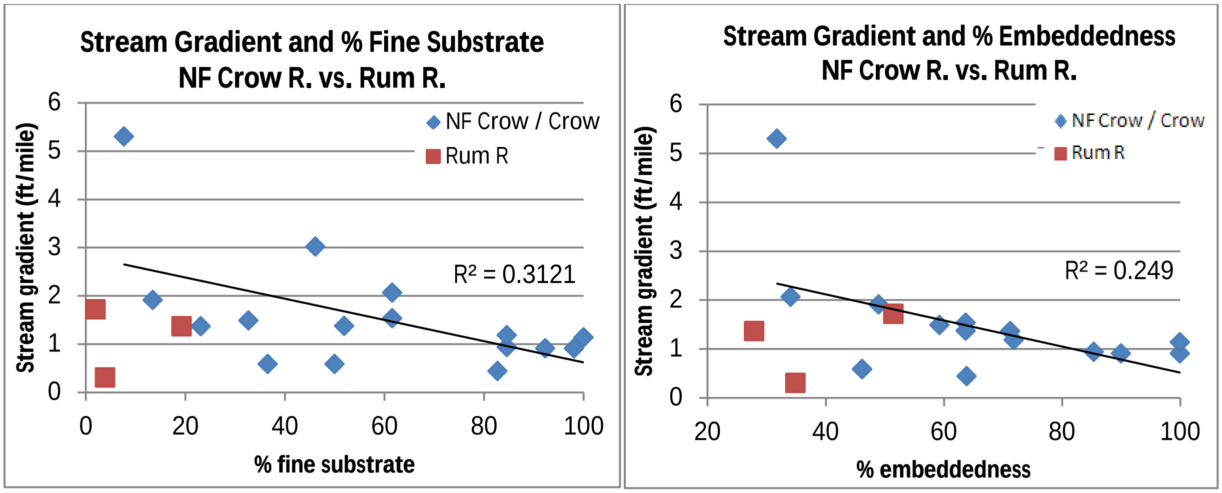
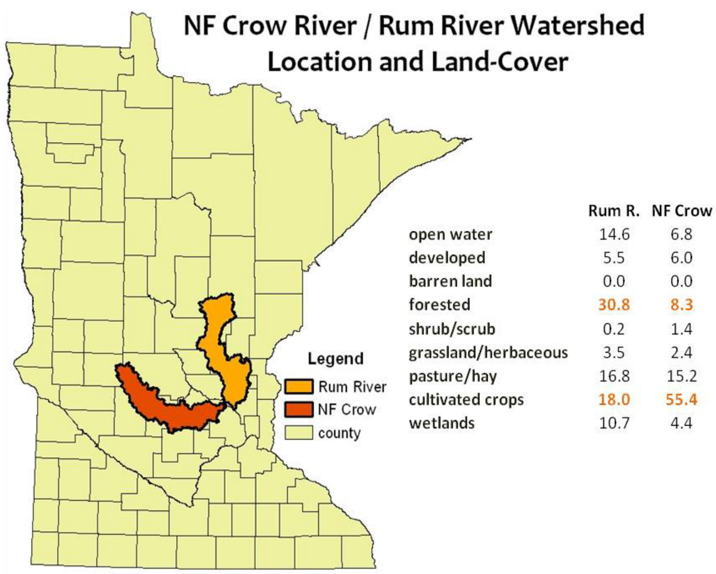
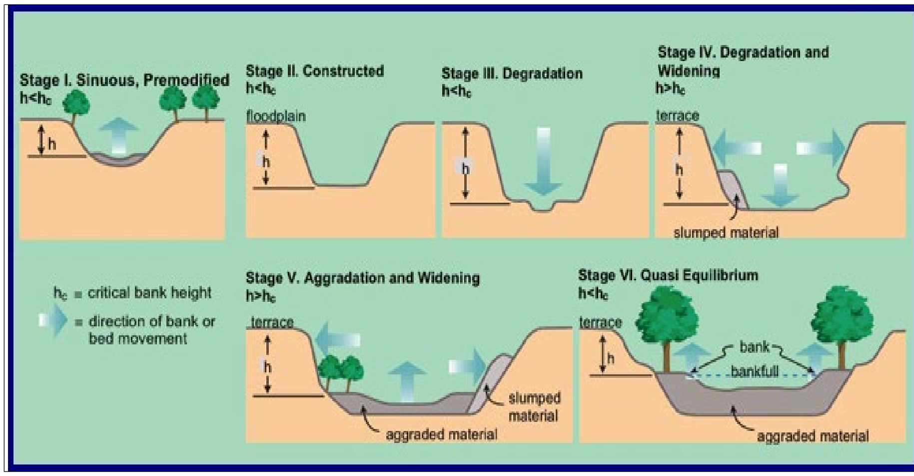


Figure 46: Relationship between stream reach gradient and measures of DBS at biological monitoring stations on the NF Crow and Rum River. Linear trend lines are associated with NF Crow / Crow points only.



Longitudinally, the amount of DBS appears to highest in the channelized reaches (CHH and MRM watershed zones), especially downstream of Lake Koronis in the MRM zone (Figure 48). Steep eroding banks, channel incision, and homogeneous fine substrate were observed in the channelized reach that extends for 2-3 miles downstream of Lake Koronis. The stream channel in this reach has a very high width to depth ratio and is frequently choked with large woody debris deposited from collapsing streambanks. Much of this reach appears to be in stage IV or V of the channel evolution model developed by Simon and Hupp (1986). Some areas appeared to be actively down-cutting (Stage IV) as many mature trees had slumped into the river. Other reaches, such as the one pictured in Figure 47, looked to be widening and aggrading (Stage V).



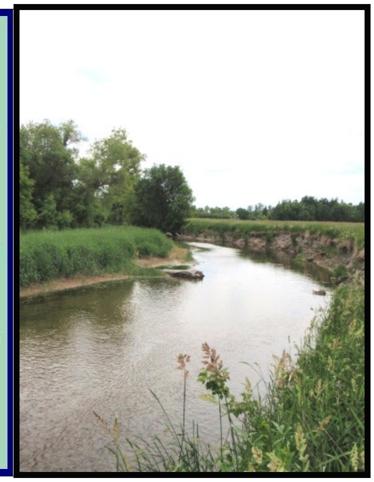
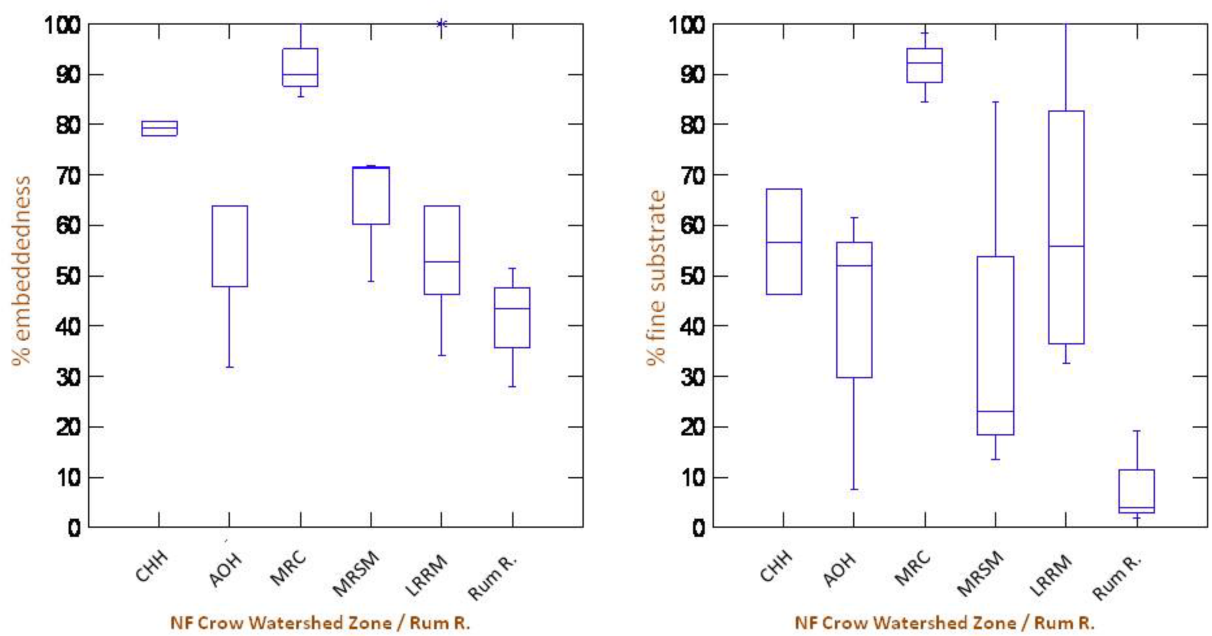


Figure 47: Stream reach below Lake Koronis with slumping banks and widening stream channel

On average, sites in the MRM watershed zone between the cities of Mannanah and Kingston had the highest rate of embeddedness among natural channel sites. Stream substrate becomes more dominated by fines in the LRRM watershed zone, an area that encompasses the lower ¼ of the NF Crow and Crow River to its confluence with the Mississippi River (Figure 48). Despite the increase in fine substrate within this reach, embeddedness levels remained similar to other non-channelized monitoring sites on the NF Crow. Rum River biological monitoring sites had significantly less fine substrate when sampled; however, embeddedness levels appear to be only slightly better than the least embedded of the NF Crow sites (Figure 48).



CHH = Channelized Headwaters **AOH =** Alluvium Outwash Headwaters **MRC =** Mid-River Channelized
MRSM = Mid-River Steep Moraine **LRRM =** Lower-River Rolling Moraine **Rum R. =** Rum River (inserted for comparison to NF Crow sites)

Figure 48: Percent embeddedness and percent fine substrate based on biological monitoring in NF Crow watershed zones and nearby Rum River.

Although negative impacts to biota from sedimentation are most likely occurring in channelized areas of the NF Crow, a few non-channelized reaches are also impacted by this stressor. Several biological monitoring stations near Kingston and Cokato had substrates dominated by fines (sand, silt, clay) and all coarser substrate was severely or completely embedded. Significant bank erosion and indicators of channel instability were observed during stream reconnaissance efforts in this stretch of the river which are increasing sediment inputs. As shown in Figure 49, reaches immediately upstream and downstream of these areas show lower rates of embeddedness and percent fines. These observations suggest that elevated levels of DBS may be a localized stressor in specific reaches of the NF Crow.

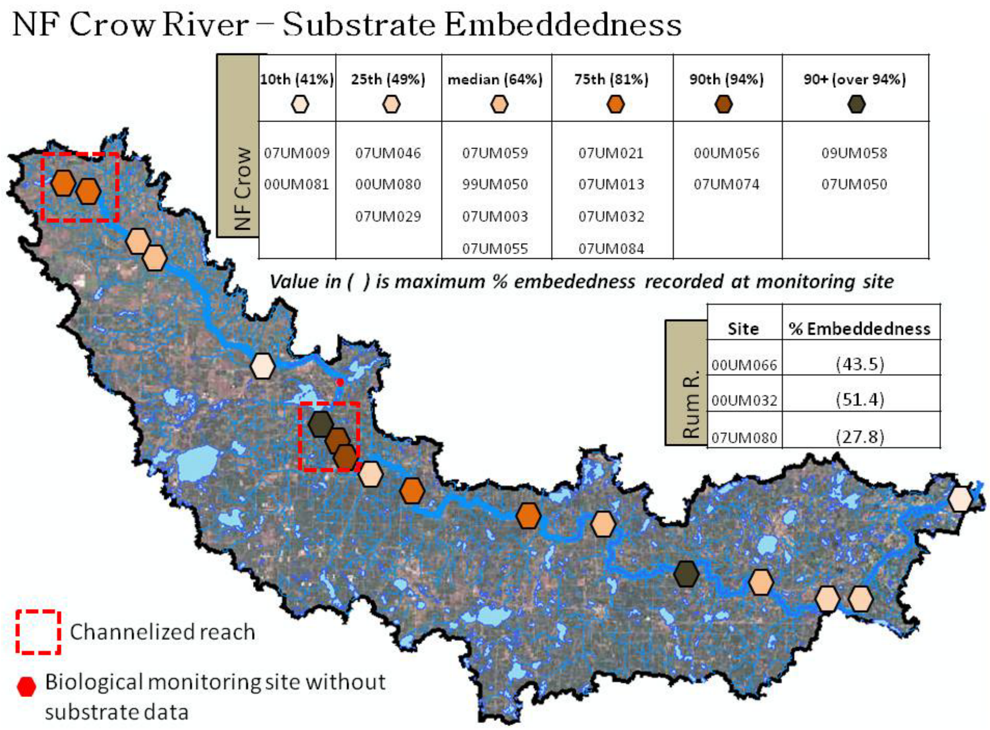


Figure 49: Longitudinal profile of substrate embeddedness values along the NF Crow

Causal analysis – deposited and bedded sediment

As mentioned in the introduction to this stressor, elevated levels of DBS can be particularly harmful to certain fish and macroinvertebrate species that depend on coarse stream substrates. Table 14 highlights several key biological metrics that are likely to respond in a predictable way to increases in DBS. The fish and macroinvertebrate species included in these metrics have certain reproductive, trophic, and habitat suitability traits that are directly affected as benthic habitats become influenced by sedimentation. Sedimentation can also have more general impacts on a biotic community, such as limiting overall species diversity or reducing the number of sensitive organisms in the assemblage.

Table 14: A selection of biological metrics that may be sensitive to increases in DBS

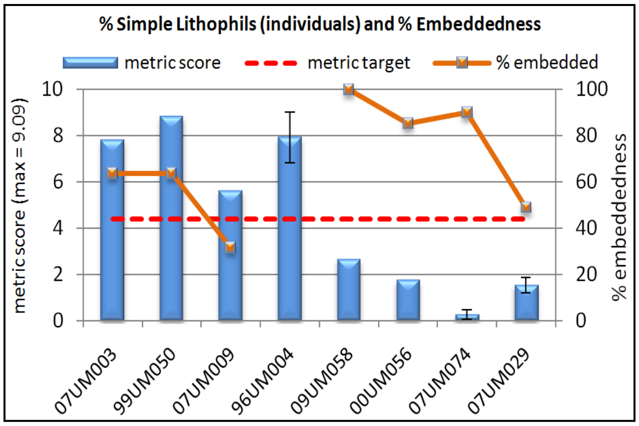
Metric	Metric Description	Expected Response to increase in DBS
Trophic		
BenthInsectPct	Relative abundance (%) of individuals that are benthic insectivore species	*Decrease*
BenInsectTxPct	Relative abundance (%) of taxa that are benthic insectivores	*Decrease*
SLithopPct	Relative abundance (%) of individuals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

Results for the biological metrics listed in Table 14 are shown in Figures 50-52 with % substrate embeddedness recorded at each monitoring station. The "target score" indicated on each graph is calculated by taking the total IBI score needed to meet the standard divided by the total number of metrics used to generate the IBI score. An example is shown in Table 15. These target scores are not meant to be indicators of overall impairment at a given site. Instead, they provide a benchmark to use for identifying sites that may be responding to a specific stressor.

Table 15: Calculating a target score for a metric in the Northern Rivers (Class 4) fish IBI

Fish Class	IBI Impairment threshold	Total # metrics	Metric Target Score
Class 4 – Northern Rivers	32	9	32 ÷ 9 = 3.55

Fish that are simple lithophilic spawners are found in low numbers or entirely non-existent at sites with over 80% substrate embeddedness (Figure 50-51). An exception to this observation occurs at sites 07UM084 and 07UM032 in the extreme headwaters of the river. These two channelized sites achieved adequate scores in the fish metric *SLithop* (taxa richness of simple lithophilic spawners). Downstream of Lake Koronis, metric scores for simple lithophilic spawning fish show a severe and sudden drop. Most of these sites are located within a channelized portion of the stream with significant substrate embeddedness. However, scores for this metric remained low at site 07UM029, a natural channel site with relatively low embeddedness (Figure 50). This may be an indication that there are other stressors limiting the abundance of these fish species in this reach of the river.



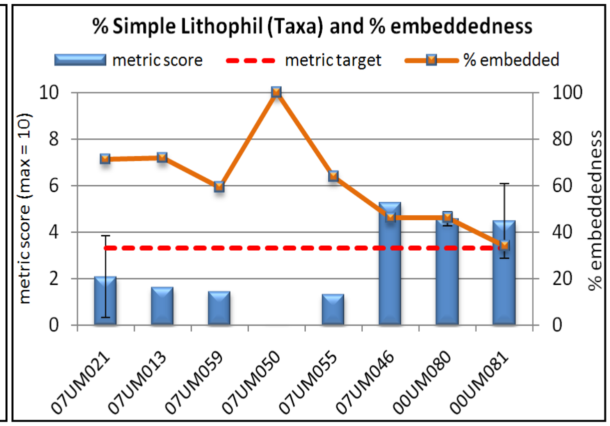
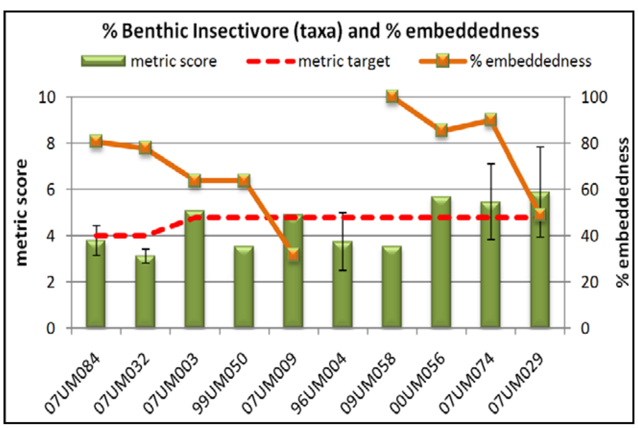


Figure 50: (left) and Figure 51 (right): This set of graphs compares longitudinal trends in % simple lithophilic spawning fish and substrate embeddedness. The graph on the left represents “Class 5” biological monitoring sites, while the right-hand graph covers “Class 4” stations. The metric used changes slightly between the two classes.

Benthic insectivorous fish were present in generally low numbers at most sites in the NF Crow, but did not show consistent relationships with substrate embeddedness. Most monitoring sites scored below the “target score” for benthic insectivore metrics, although there were several exceptions scoring above the target and numerous others that were just below. Sites that were most severely embedded (09UM058, 07UM050) had relatively low metric scores for benthic insectivores, but site 07UM074, which was also severely impacted by embeddedness, had an average score for this metric that was above the target score (Figure 52).



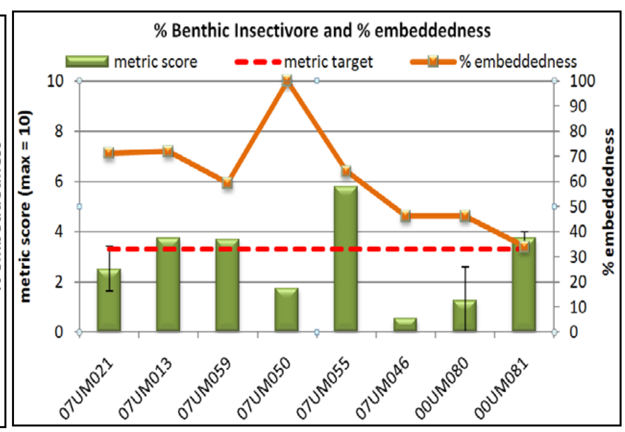


Figure 52: (left) and Figure 53 (right): This set of graphs compares longitudinal trends in % benthic insectivorous fish and substrate embeddedness. The graph on the left represents “Class 5” and “Class 6” biological monitoring sites, while the right-hand graph covers “Class 4” stations. The metric used changes slightly between the two classes.

Scores for the metric *InsectCyp* (a measure of insectivourous minnow species) were low at the two channelized headwaters monitoring sites As embeddedness values decreased to around 40-50% near the lower reaches of the Crow (e.g. sites 00UM046 through 00UM081), metric scores for insectivorous fish remained low until rising sharply at 00UM081 (Figure 53). DBS may be a stressor in this reach of the river, but there also appears to be other conditions that are limiting fish that are benthic insectivores.

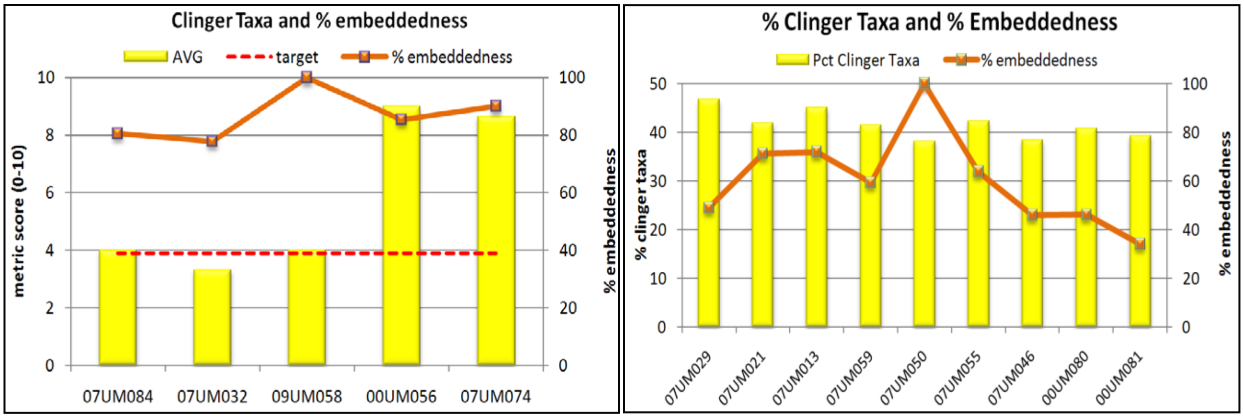


Figure 54: (left) and Figure 55 (right): This set of graphs compares longitudinal trends in "clinger" macroinvertebrate measures and substrate embeddedness. The graph on the left represents "Class 7" biological monitoring sites, while the right-hand graph covers "Class 5" and "Class 2" stations.

Macroinvertebrate "clinger" taxa are only used to calculate M-IBI scores for Class 7 and Class 5 stations. As shown in Figure 54, scores for this metric were low in the channelized headwaters reaches of the NF Crow, but several channelized sites downstream of Lake Koronis scored quite high in these metrics despite over 80% substrate embeddedness. Site 07UM029 had an average score of 9.0 (out of 10) for a metric measuring relative abundance of clinger taxa and had relatively low levels of substrate embeddedness (49%).

Percent clinger taxa did not vary much throughout the lower half of the river system despite changes in substrate embeddedness (Figure 55). Similar to some of the selected fish metrics, relationships between clinger metric scores and substrate conditions are variable and somewhat inconsistent. A possible explanation for this is if significant amounts of wood were present and sampled. Since it is often suspended above the bottom, it is less affected by sedimentation, and some of the clingers will definitely utilize wood as a habitat.

DBS is likely a factor in the limited abundance and diversity of darter fish species in the headwaters of the NF Crow. A single Iowa darter (*Etheostoma exile*) was documented in a total of four sampling visits between sites 07UM032 and 07UM084 in this area of the watershed. Both of these stations have around 80% substrate embeddedness – a habitat characteristic that is typically not favorable to darter species.

Further downstream, the metric *DarterSculpSucTxPct* is used at Class 5 biological monitoring stations to assess the relative abundance (%) of fish taxa that are darters, sculpins, and round-bodied suckers (e.g. redhorse spp.). This group of taxa can be sensitive to disturbances that affect the condition of benthic habitat. Overall, scores for this metric were right around the target score at most sites (Figure 56), an indication that these taxa make up a moderate percentage of the overall fish community at these locations. There does not appear to be a consistent correlation with *DarterSculpSucTxPct* metric scores and substrate embeddedness, but there may be a lack of quality habitat for these species throughout the river system, such that there is little variation between sites with moderate embeddedness and heavy embeddedness.

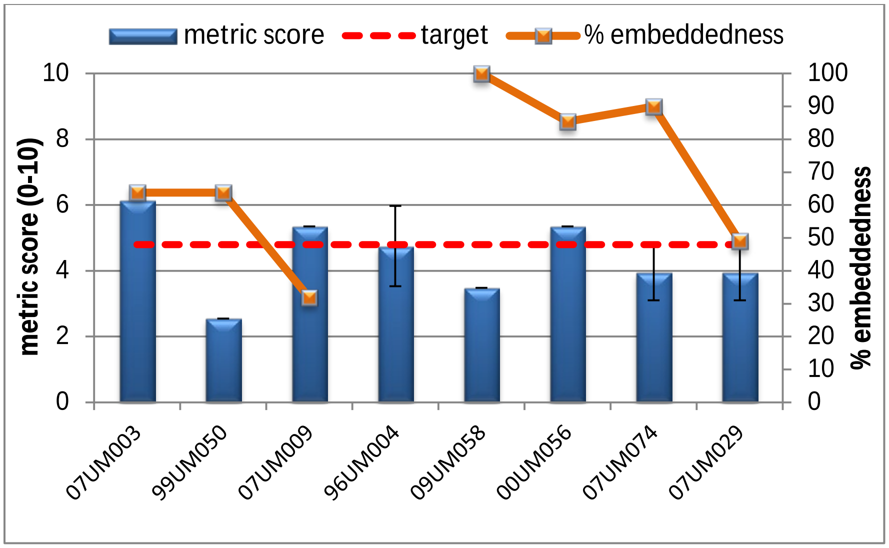


Figure 56: Metric scores for darter, sculpin, round-bodied sucker fish taxa % vs. % embeddedness

Strength of evidence summary for deposited and bedded sediment

DBS are likely a stressor to fish and macroinvertebrate assemblages in the CHH and MRM watershed zones. This is especially the case in channelized reaches in the extreme headwaters and downstream of Lake Koronis. Substrate embeddedness levels were very high (80%) in these areas, and the response from biota indicated a cause and effect relationship (low darter taxa richness, decrease in simple lithophils).

The presence of excess DBS and negative effects on biota are more difficult to determine in the AOH and Lower River Rolling Moraine (LRRM) watershed zones. Measures of embeddedness and overall substrate quality generally improved in these stream reaches, although several sites remained severely embedded (esp. 99UM050) and showed some negative response to fish metrics. Metric scores for benthic insectivorous fish were relatively low at the majority of the biological monitoring stations in these two areas, and data also indicated a high percentage of fish species that are considered detritivores. This suggests that benthic productivity is low and that fish species specialized for benthic feeding are thus not abundant or diverse in these watershed zones.

Table 16: Strength of evidence scores for DBS

Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	Mid-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	+	+	+	0
Temporal sequence	NE	NE	NE	NE
Field evidence of stressor-response	++	+	++	0
Causal pathway	++	++	++	++
Evidence of exposure, biological mechanism	+	+	+	0
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE
Symptoms	+	0	+	0
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	+	+	+
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	++	++	++	++
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	++	++	++	++
Multiple lines of evidence				
Consistency of evidence	+	+	+	0
Explanatory power of evidence	++	0	++	0

4.4 Nitrate toxicity

NO_3 - NO_2 water quality standards / ecoregion expectations

Minnesota has a draft standard for nitrate-nitrogen (Nitrate-N) designed to protect aquatic life in Class 2 waters of the state. Streams and rivers designated as Class 2 waters are protected to support cool and warm water sport fish, indigenous aquatic life, and functional wetland habitats. The draft acute value (maximum standard) for class 2 waters is 41 mg/L nitrate-N for a 1-day duration, while the draft chronic value is 4.9 mg/L nitrate-N for a 4-day duration (Monson, 2010). There is currently no standard for nitrite-N.

McCollor & Heiskary (1993) compiled $NO_2 - NO_3$ data for minimally impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. Nearly all of the NF Crow watershed falls within the North Central Hardwood Forest (NCHF) ecoregion (Figure 57) (Omernik, 1987). The annual 75^{th} percentile nitrate-N values for minimally impacted streams in each ecoregion of Minnesota are shown in Figure 57. Nitrate-N concentrations increase from north to south, with significantly higher concentrations in the Western Corn Belt Plains ecoregion.

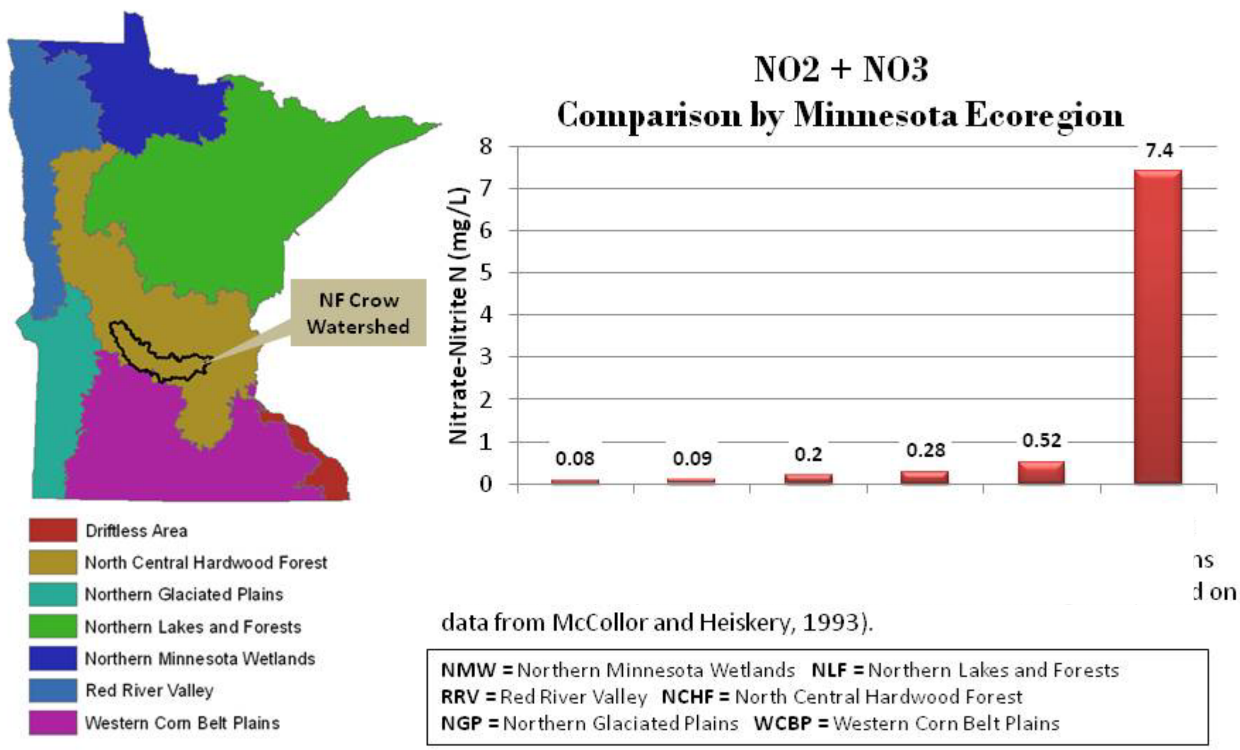


Figure 57: Comparison of 75th percentile NO2+NO3 concentrations from minimally impacted streams in Minnesota's six ecoregions (based on McCollor and Heiskary, 1993).

Effects of nitrate-N toxicity on aquatic organisms

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

Nitrate toxicity to freshwater aquatic life is dependent on concentration and exposure time, as well as the overall sensitivity of the organism(s) in question. Comargo et al (2005) cited a maximum level of 2 mg/L nitrate-N as appropriate for protecting the most sensitive freshwater species, although the in the same review paper, the authors also offered a recommendation of NO3 concentrations under 10 mg/L as protective of several sensitive fish and aquatic invertebrate taxa.

The difficulty in applying current knowledge of nitrate toxicity to Minnesota waters is that most of the research has been focused on species that are either not native to North America, or coldwater (salmonid) fish species (no cold water impairments in the NF Crow watershed). 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. The MPCA draft standard falls within the range of published literature on nitrate toxicity and will be the criteria used to evaluate this stressor.

Sources and causal pathways of NO_3 - NO_2 toxicity

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

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

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

The sources and potential causal pathways for nitrate toxicity in the NF Crow watershed are shown in the conceptual model in Figure 58. Given the abundance of cultivated cropland in the watershed, it is feasible that fertilizer application is prominent source of nitrate in surface water. Lefebvre et al. (2007) determined that fertilizer application and land-cover were the two major determinants of higher nitrate concentrations in surface water and that concentrations increased with fertilization intensity.

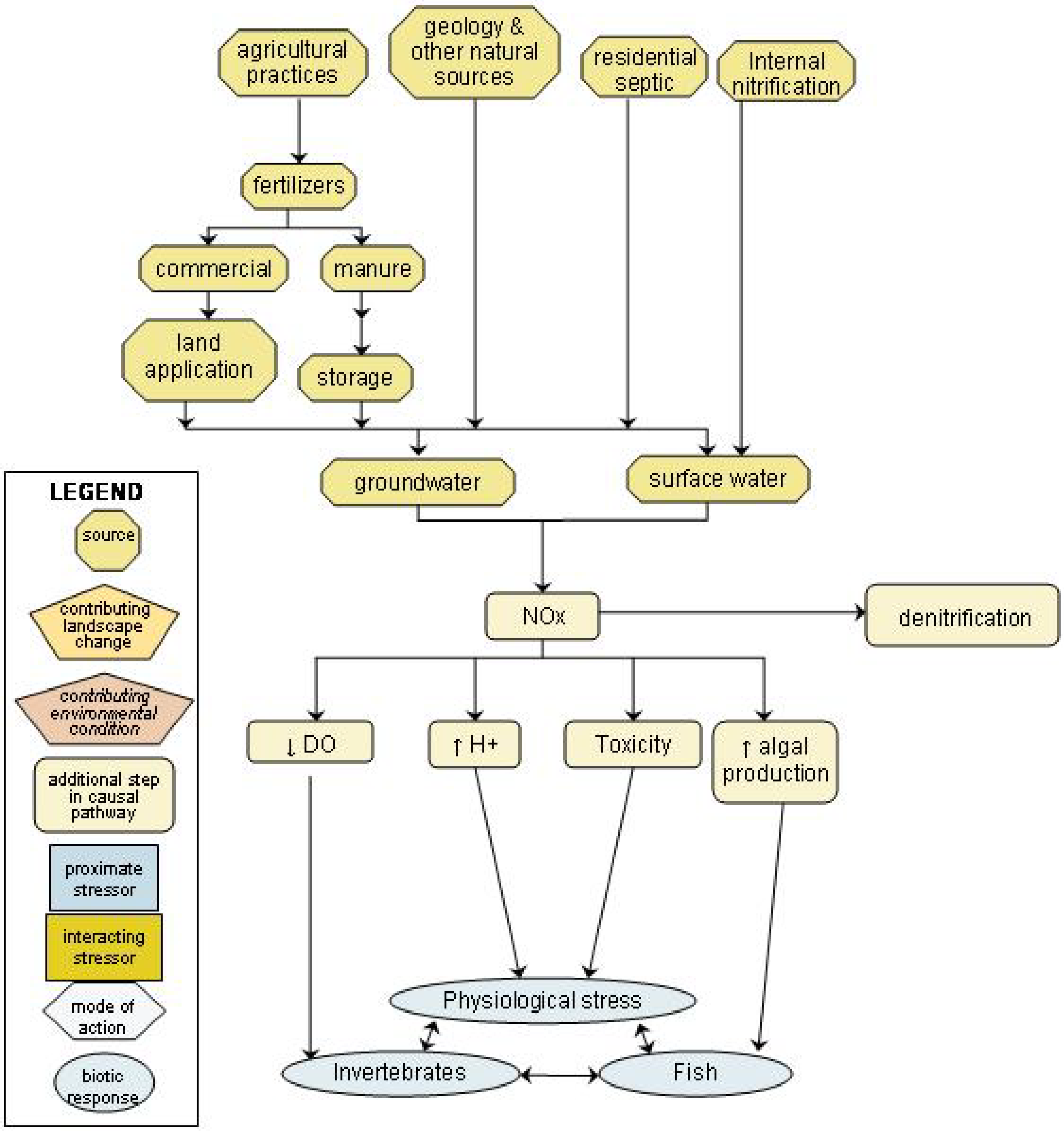


Figure 58: Conceptual model for nitrate-N / nitrite-N toxicity (from Laing, 2011)

Nitrate-N concentrations in the NF Crow/Lower Crow River

Summary statistics for NO_2 + NO_3 concentrations in the NF Crow and Crow River are displayed by watershed zone in Figure 59. All data used in the summary were collected at mainstem monitoring stations and do not represent tributary nitrate concentrations in the watershed zones. No data were available from mainstem sites in the CHH watershed zone. Nitrate-N concentrations appear to be higher during March and April sampling events for all watershed zones, which likely represents some inputs from snowmelt runoff. In general, the average and maximum nitrate concentrations on the mainstem of the NF Crow/Lower Crow River were highest in the AOH watershed zone.

Nitrate-N concentrations in the NF Crow are several times higher than the "minimally impacted" reference streams of the NCHF ecoregion selected by McCollor and Heiskary (1993). However, there were very few samples in exceedence of the Minnesota draft chronic nitrate standard value of 4.9 mg/L. About 5% of NO_2 + NO_3 samples in the AOH watershed zone exceeded the chronic value (3 / 59 samples), and less than 1% of samples in the MRM (1 / 119 samples) and the LRRM (1 / 202 samples) watershed zones. Additional sampling would be required to determine if those concentrations exceeding 4.9 mg/L remained at or above that level for duration of four days and violated the draft nitrate-N chronic standard.

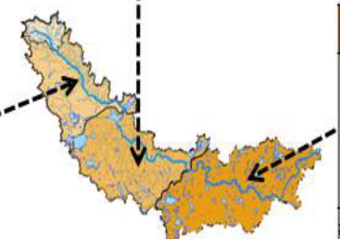
Nitrate – Nitrite ($NO_2 + NO_3$) Concentrations by Watershed Zone
North Fork Crow River / Lower Crow River

* All concentrations in mg/L $NO_2 + NO_3$

MRM[2]	Mar- Apr	May-Jun	Jul-Aug	Sep-Dec
Avg.	2.2	1.1	0.9	0.8
Median	2.2	1.0	0.8	0.6
75th	2.9	1.2	1.3	1.0
Max	5.3	2.4	2.7	2.2
# samples	21	45	31	22

[1] Alluvial Outwash Headwaters
[2] Mid-River Steep Moraine
[3] Lower River Rolling Moraine

AOH[1]	Mar- Apr	May-Jun	Jul-Aug	Sep-Dec
Avg.	3.1	1.7	0.9	2.2
Median	2.9	1.5	0.7	1.9
75th	4.1	2.4	1.2	2.6
Max	7.0	4.0	1.9	5.1
# samples	15	22	10	12



LRM[3]	Mar- Apr	May-Jun	Jul-Aug	Sep-Dec
Avg.	2.1	0.9	0.4	0.7
Median	1.9	0.8	0.4	0.6
75th	3.4	1.3	0.5	1.1
Max	6.3	2.4	2.0	2.5
# samples	37	71	60	34

Figure 59: Summary of NO2+NO3 data for three watershed zones of the NF Crow/Lower Crow River. All sampling data is from mainstem monitoring sites (tributary concentrations not included).

Paired streamflow and $NO_2 + NO_3$ concentrations appear to support the claim that nitrate values in the NF Crow are elevated during spring snowmelt, and again during higher flow events in early to late fall (Figures 60-62). Based on available data, low-flow or baseflow nitrate values on mainstem NF Crow/ Crow River are typically around 0.5 mg/L and occasionally range up to 2.5 - 3.0 mg/L during summer rain events. The higher nitrate concentrations in spring and fall may be the result of surface runoff from fields when crops are not established and fertilization and erosion rates are high.

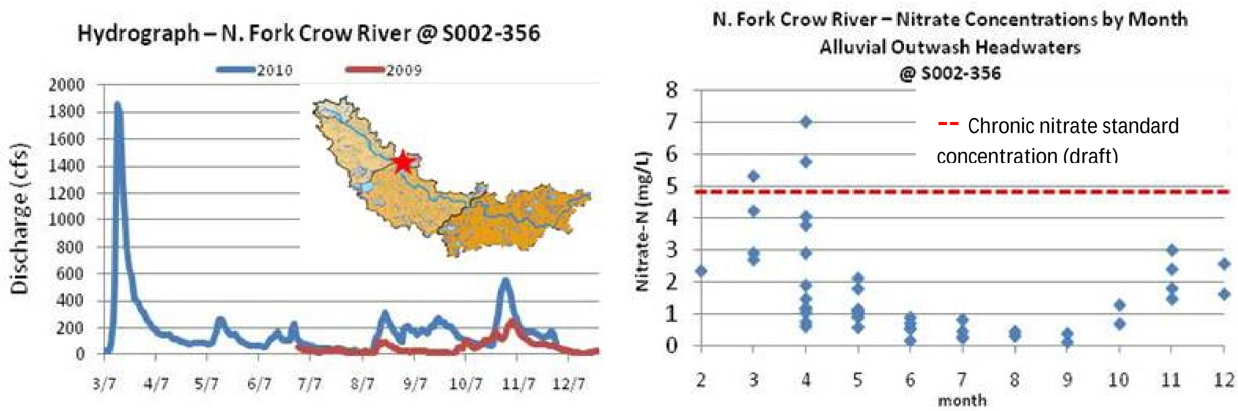


Figure 60: Hydrograph and available nitrate-N data for station S002-356 near Paynesville, MN in the Alluvium Outwash Headwaters watershed zone. Hydrograph data is only available for 2010 and portions of 2009, but represents timing of snowmelt runoff and baseflow.

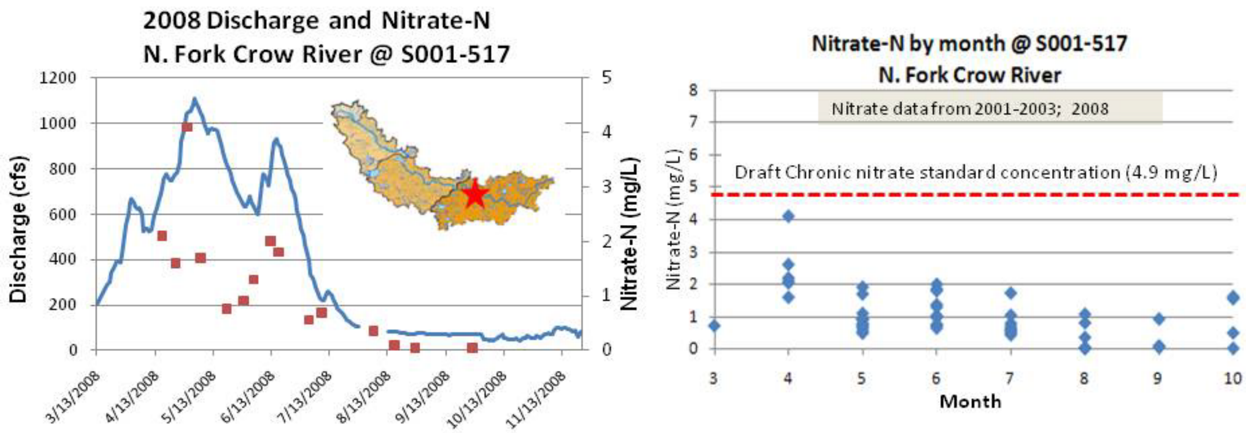


Figure 61: Hydrograph and available nitrate-N data for station S002-356 near Paynesville, MN in the Alluvium Outwash Headwaters watershed zone. Hydrograph data is only available fo4 2010 and portions of 2009, but represents timing of snowmelt runoff and baseflow.

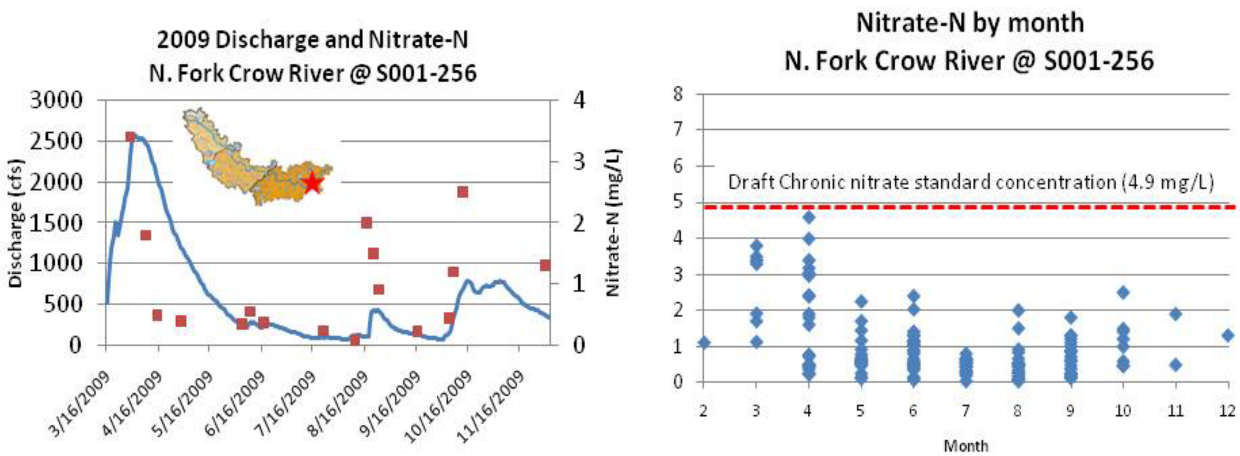


Figure 62: Hydrograph and available nitrate-N data for NF Crow station S001-256 near Rockford, MN in the Lower River Moraine watershed zone. Hydrograph data represents 2009 sampling year. Results by month (on right) include all available Nitrate-N data available for this site.

Although Nitrate-N data are lacking from the channelized portion of the headwaters NF Crow, Nitrate-N concentrations over 50 mg/L have been observed in Stearns County Ditch #31, which enters the NF Crow from the north near the town of Brooten, MN. Multiple samples from this ditch exceed the draft acute nitrate-N toxicity standard of 41 mg/L. These concentrations are almost certain to cause harm, or even mortality to sensitive aquatic life at short duration exposures of less than 1 hour. Seasonal nitrate-N trends in this ditch are similar to those seen throughout the NF Crow, with higher concentrations observed during spring snowmelt.

Biological monitoring site 07UM033 is located on CD #31. Fish IBI results at this site are below the impairment threshold but above the lower confidence limit indicating a marginally degraded fish assemblage. Nitrate-N concentrations at the time of fish sampling (June/July 2007) were below 0.1 mg/L and not likely causing any harm to aquatic life. This ditch, and likely other ditches in the area, are carrying high nitrate-N concentrations during spring and early summer, and then become more suitable for supporting fish and macroinvertebrates in late summer months. It is unclear whether fish migrate during nitrate-N spikes, or whether harmful concentrations occur infrequently enough for the community to repopulate.

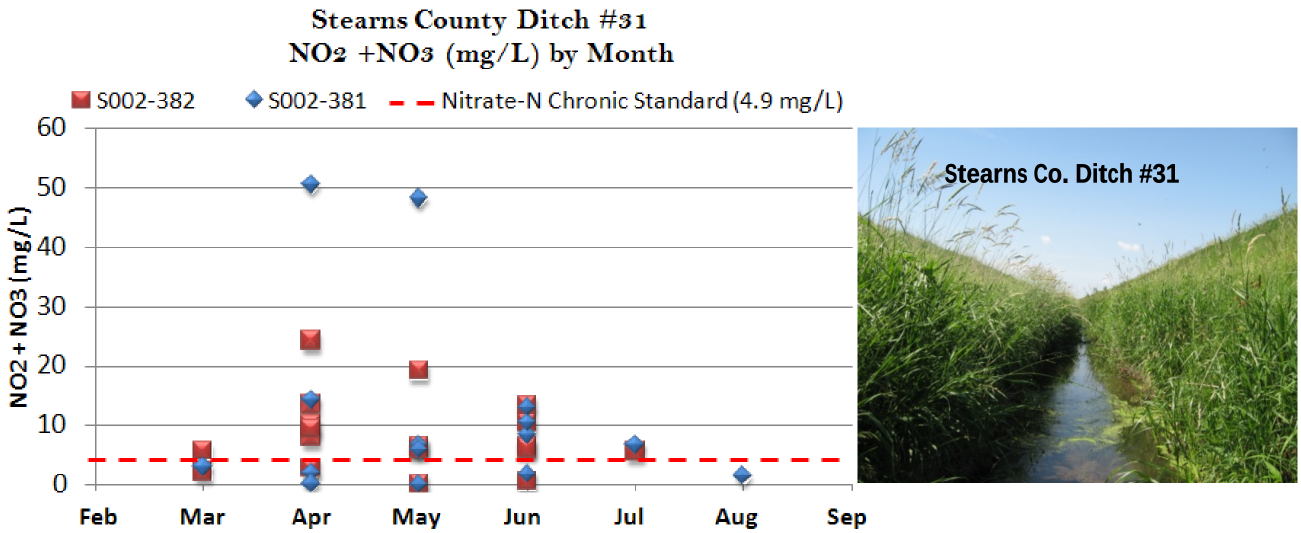


Figure 63: Summary of available NO2 + NO3 results for stations S002-382 and S002-381 on Stearns County Ditch #31, a tributary to the NF Crow. Data spans the years 2003 – 2007.

Biological response to Nitrate-N

Specific biological responses to nitrate-N are difficult to decipher in the NF Crow, particularly because concentrations are relatively similar throughout the length of the mainstem. Examples of potential biological effects from nitrate-N toxicity include:

- Abrupt increases in fish or invertebrate mortality
- Other significant community changes, such as large reductions in species richness or abundance
- Abnormal behaviors, such as fish leaping from the water, gasping at the surface, or crowding into tributaries
- Appearance of new parasites, disease

Based on available biological data, there does not appear to be any abrupt increases in fish or invertebrate mortality in the NF Crow/Lower Crow River. MDNR fisheries offices in this region of the state were not aware of any significant fish kills on these river systems (written communication, 6/21/2011). Abnormally high rates of parasite infestation or disease were not evident in the fish or macroinvertebrate surveys conducted on the river, and no other abnormal behaviors were observed.

Fish and macroinvertebrate taxa richness at NF Crow/Lower Crow sites are shown (from upstream to downstream L à R) in Figures 63 and 64. Macroinvertebrate taxa richness varies significantly within relatively short distances along the river, but no severely depauperate sites were observed. Most of the monitoring stations supported invertebrate taxa counts that were near the median for sites in the NCHF ecoregion (Figure 63). The exceptions, on the lower scoring end, are sites 07UM035 and the lower ¼ of the river system encompassing sites 07UM055 through 00UM081. There is an obvious downward trend in macroinvertebrate taxa richness starting at site 07UM055, but it is unlikely that this is related to high nitrate-N levels, as there is no co-located spike in nitrate-N concentrations within this reach. Rather, the decrease in taxa richness in this reach of the NF Crow/Lower Crow is spatially correlated with an increase in DO flux and nutrient/chlorophyll-a (Chl-a) concentrations, which will be discussed in Section 4.7 of this report.

Overall fish taxa richness shows a similar pattern to the invertebrate results in that taxa counts vary quite a bit from site to site (Figure 64). Taxa richness is relatively low in the channelized headwaters watershed zone of the river that encompasses sites 07UM084 and 07UM032, but the results are similar to other class 6 biological monitoring sites in the NCHF ecoregion (Figure 63). Similar to the macroinvertebrate taxa counts, fish taxa richness decreases at site 07UM055 and remains low for most of the Lower Crow River sites with the exception of site 00UM080.

Evidence for linking the oscillating nature of fish (and macroinvertebrate) taxa richness in this river system to nitrate-N toxicity is ambiguous. As previously mentioned, the nitrate-N concentrations were relatively similar throughout the length of the river. Therefore, it would be unlikely that stress from nitrate-N would affect taxa richness on such short reaches of river without localized spikes in nitrate-N concentrations.

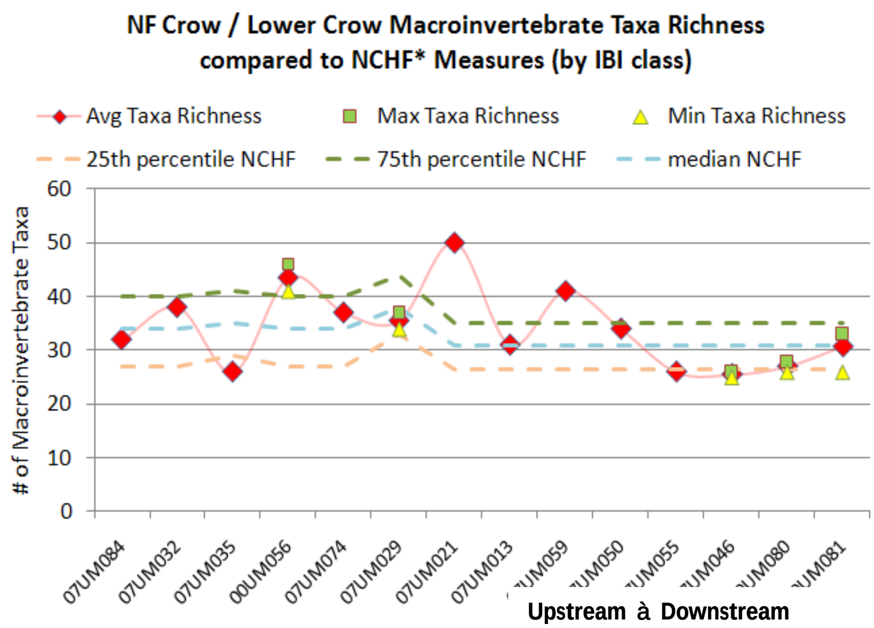


Figure 64: NF Crow/Lower Crow River macroinvertebrate taxa richness compared to median, 25th, and 75th percentile taxa richness values for NCHF ecoregion monitoring sites.

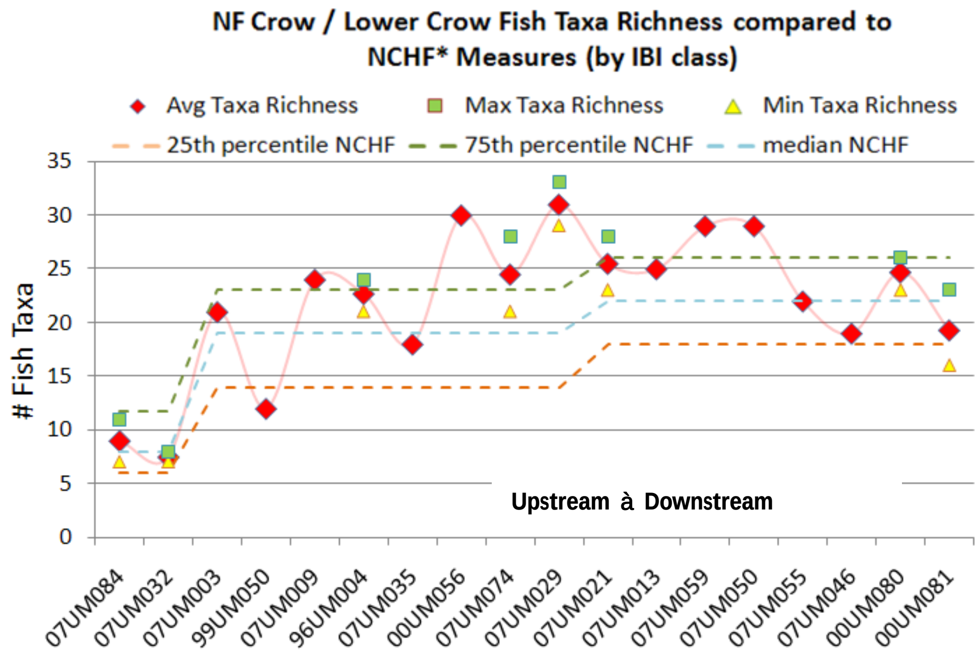


Figure 65: Fish taxa richness at NF Crow/Crow River monitoring sites. Percentile lines correspond to ecoregion values partitioned by fish IBI class.

NO2 + NO3 tolerance indicator values (TIVs)

Meador and Carlisle (2007) analyzed common fish species and derived tolerance indicator values (TIVs) for NO2 + NO3 concentrations. These TIVs do not represent acute or chronic toxicity values for nitrate. Rather, the TIVs were developed by identifying rivers and lakes where these fish species were commonly found and examining the NO2+NO3 regime from that particular body of water. The fish species observed in the NF Crow were quartiled for comparison in Table 17, with the first quartile indicating more sensitivity to nitrate and the fourth quartile species are less sensitive to nitrate. Several fish species found in the Crow River system do not have tolerance data available through the Meador and Carlisle (2007) study.

Table 17: North Fork Crow River/Crow River fish quartiled based on tolerance indicator value (TIV) for nitrate nitrogen (Meador and Carlisle, 2007)

1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
CommonName	***TIV***	***CommonName***	***TIV***	***CommonName***	***TIV***	***CommonName***	***TIV***
bowfin	0.3	central stoneroller	0.88	pumpkinseed	1.31	yellow bullhead	1.77
golden shiner	0.44	black crappie	0.98	rock bass	1.32	spotfin shiner	1.81
logperch	0.47	brown bullhead	0.99	spottail shiner	1.32	bluntnose minnow	1.96
tadpole madtom	0.68	northern pike	1.03	shorthead redhorse	1.35	blacknose dace	2.44
silver redhorse	0.79	channel catfish	1.04	longnose dace	1.36	common carp	2.45
bluegill	0.8	johnny darter	1.04	green sunfish	1.42	sand shiner	2.46
walleye	0.81	largemouth bass	1.15	northern hog sucker	1.46	fathead minnow	2.57
smallmouth bass	0.82	creek chub	1.21	golden redhorse	1.55	white sucker	2.6
hornyhead chub	0.87	common shiner	1.28	blackside darter	1.74	black bullhead	2.61
						orangespotted sunfish	2.66

Sensitive to Nitrate → Less Sensitive to Nitrate

Tolerance Data Not Available		
Common Name		
bigmouth buffalo	brook stickleback	trout-perch
blackchin shiner	central mudminnow	yellow perch
blacknose shiner	hybrid sunfish	
brassy minnow	Iowa darter	
brook silverside	pugnose shiner	

Fish with TIVs in Tier 1 (T1) were absent from biological monitoring sites in the CHH watershed zone. However, 38% of the fish population at these sites were not included in the Meador and Carlisle (2007) study and therefore did not receive TIVs for nitrate. Downstream of the channelized headwaters reach, more fish were observed in the T1 category, but a sharp drop in T1 percentage was evident moving from the MRM watershed zone into the LRRM (Figure 66). Many of the fish and macroinvertebrate taxa observed in the lower reaches of the NF Crow/Crow are tolerant to many forms of disturbances. Although the decrease in the percentage of T1 fish species could be related to stress from elevated nitrate concentrations, the presence of separate or confounding stressors (e.g. low DO and/or elevated TSS concentrations) may also be responsible for the lack of "sensitive" species.

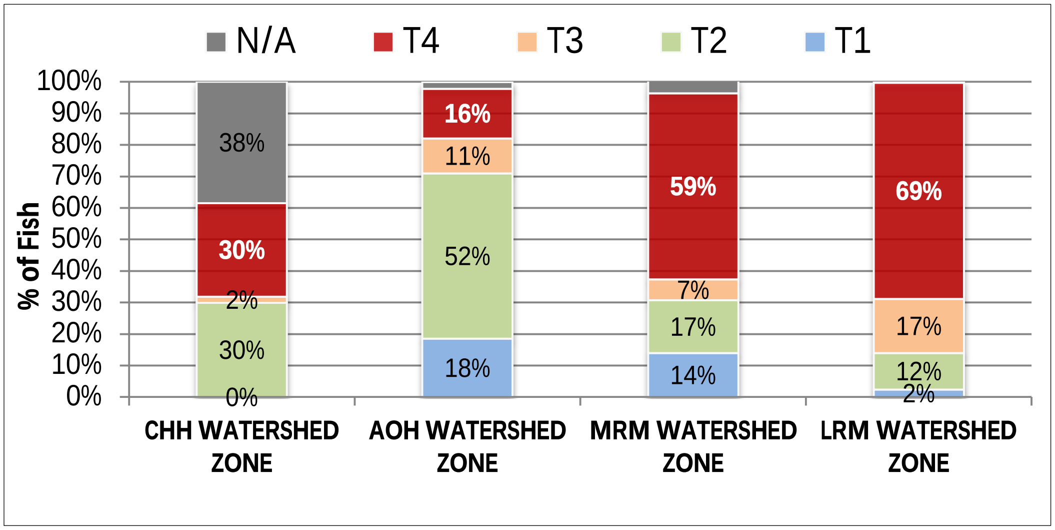


Figure 66: Percentage of fish individuals that fall within established quartiles for nitrate-N tolerance based on tolerance indicator values (TIVs) from Meador and Carlisle, 2007. Results are separated by the four watershed zones established for this stressor ID report.

Conclusions and strength of evidence results

Channelized Headwaters (CHH) watershed zone

Nitrate-N toxicity is a probable stressor to aquatic life in the headwaters tributaries (esp. ditches) and extreme headwaters of the NF Crow, although data limitations reduce confidence in this diagnosis. The high nitrate-N concentrations seen in the tributaries suggest that fish and invertebrate populations in the headwaters of the NF Crow are also exposed to nitrate-N levels that could be chronically or acutely toxic. Nitrate-N concentrations as high as 51 mg/L were observed in several ditches entering the NF Crow in this area of the watershed.

Alluvium Outwash Headwaters (AOH) watershed zone

Nitrate-N concentrations in the AOH watershed zone occasionally exceed the chronic standard **concentration** of 4.9 mg/L, but it is unclear whether or not the duration component of standard (4-days) is violated. Nitrate-N concentrations above 4.9 mg/L were observed in seasons that are associated with higher streamflow and runoff events (early spring and fall). It does not appear that fish and macroinvertebrate communities are exposed to harmful concentrations of nitrate-N for long periods of time (e.g. during summer baseflow). However, it is impossible to determine if the 4-day condition of the chronic standard is met given the available monitoring data.

Impaired fish assemblages in this watershed zone can be characterized by a low number of intolerant species and a lack of species that cannot reproduce until three years of age. Although these symptoms of impairment are not obvious indicators of nitrate-N toxicity, they may be indicative of pulse-type stressors, such as seasonally high nitrate-N concentrations that force sensitive or long-lived species into stream reaches with more favorable conditions.

The evidence compiled for nitrate-N as a stressor in this watershed zone is somewhat inconclusive. It is feasible to consider nitrate-N a potential stressor in this watershed zone, but additional monitoring may be required to improve confidence in the decision.

Mid-River Moraine and Lower River Moraine watershed zones

A very low percentage (less than 1%) of NO2 + NO3 samples from these watershed zones exceeded the 4.9 mg/L chronic standard. Nitrate-N toxicity is not a likely stressor to aquatic life in these watershed zones. Low fish and macroinvertebrate IBI scores in these watershed zones have a much stronger correlation to low DO and elevated TSS as stressors.

Table 18: Strength of Evidence results for nitrate-N toxicity

Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	Mid-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River/Lower Crow River Data				
Spatial/temporal co-occurrence	+	+ / 0	-	-
Temporal sequence	0	0	-	-
Field evidence of stressor-response	+	+	-	-
Causal pathway	+	+	-	-
Evidence of exposure, biological mechanism	0	0	-	-
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE
Symptoms	0	0	-	-
Mechanistically plausible cause	+	+	-	-
Stressor-response in other lab studies	+	+	+	+
Stressor-response in other field studies	NE	NE	NE	NE
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	+	+	+	+
Consistency of evidence	+/0	+/0	-	-
Explanatory power of evidence	0	0	-	-

* see table 1.1 for scoring interpretations

4.5 Toxicity from insecticides and herbicides

Background and conceptual model (text courtesy of EPA CADDIS)

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

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

Impairments are also more likely when herbicides are applied together or with other pesticides resulting in additive or synergistic effects (Streibig et. al. 1998). Atrazine has been shown to increase the effects of other pesticides in mosquito larvae, fruit flies, houseflies, and midge flies (Belden and Lydy 2000, Lydy and Linck 2003). The surfactants used in herbicide solutions also can be toxic to biota and are not considered when testing active ingredients (Folmar et al. 1979).

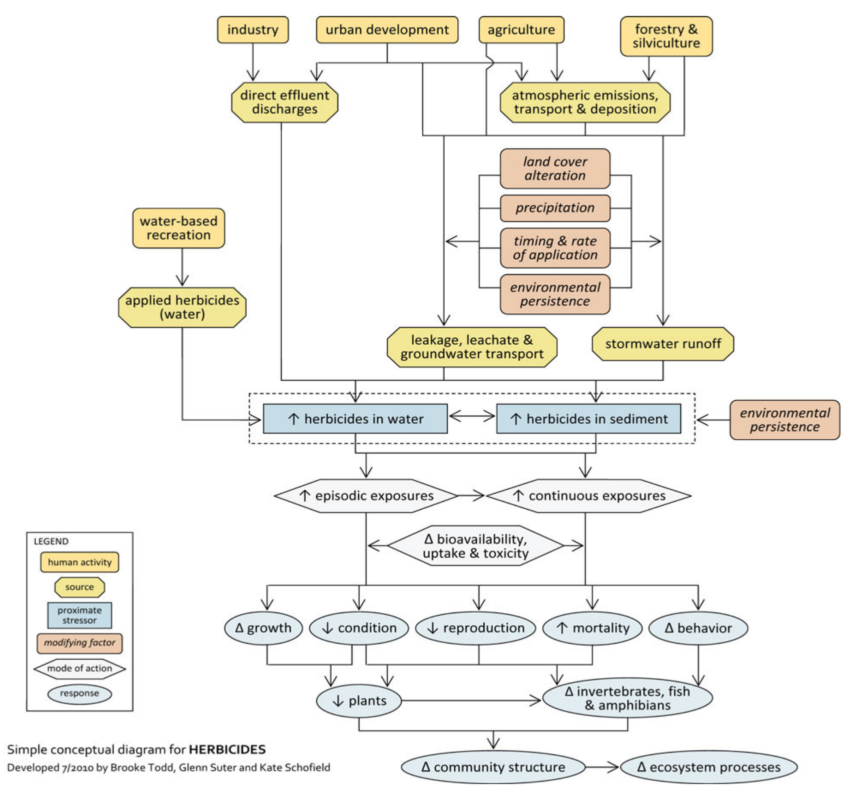


Figure 67: Conceptual model for herbicide application as a candidate cause for biological impairment (Source: EPA CADDIS website)

Insecticides are chemicals used to control insects by killing them or preventing them from engaging in behaviors deemed undesirable or destructive. Many insecticides act upon the nervous system of the insect while others act as growth regulators. Insecticides are commonly used in agricultural, public health, and industrial applications, as well as household and commercial uses (e.g., control of roaches and termites). The USDA (2001) reported that insecticides accounted for 12% of total pesticides applied to the surveyed crops. Corn and cotton account for the largest shares of insecticide use in the United States.

Insecticides are applied in various formulations and delivery systems that influence their transport and chemical transformation. Mobilization of insecticides can occur via runoff (either dissolved or sorbed to soil particles), atmospheric deposition (primarily spray drift), or sub-surface flow (Goring and Hamaker 1972, Moore and Ramamoorthy 1984). Soil erosion from high intensity agriculture, facilitates the transport of insecticides into waterbodies (Kreuger et al. 1999). Some insecticides may be accumulated by aquatic organisms and transferred to their predators. 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.

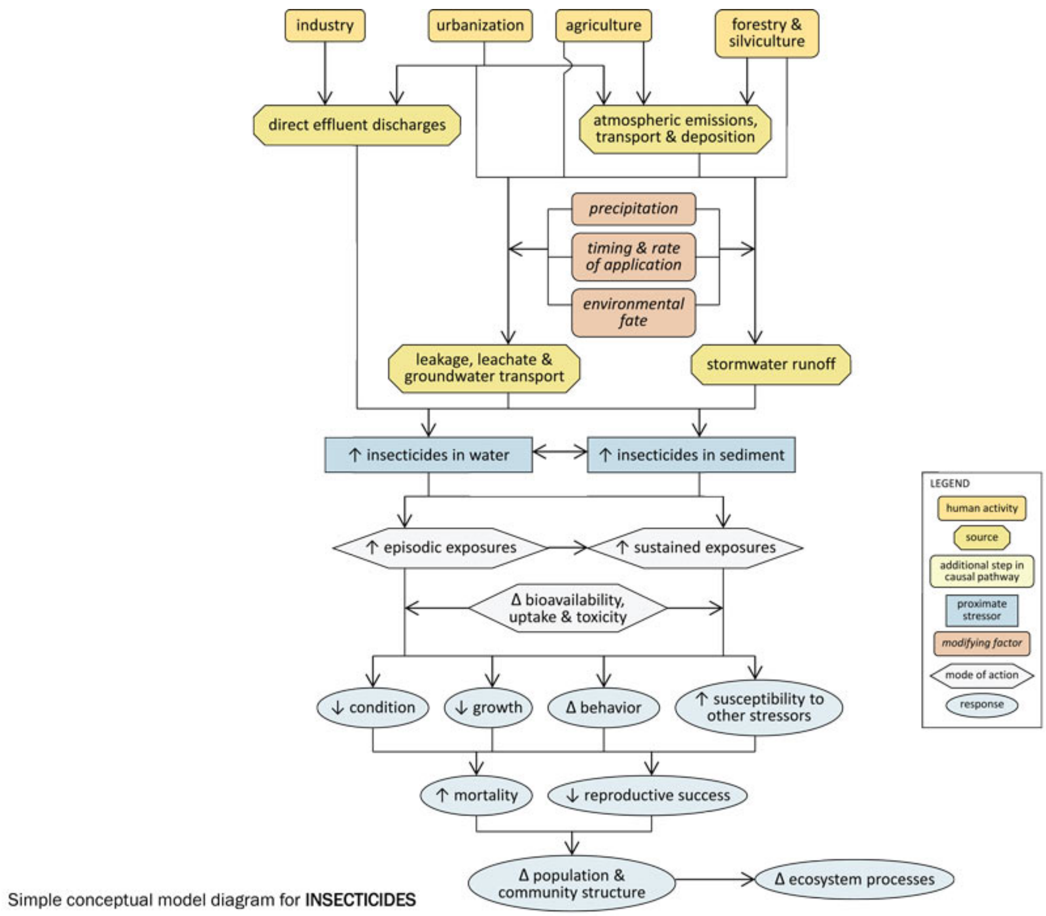


Figure 68: Conceptual model diagram for insecticide toxicity as a stressor to aquatic life. (Source: EPA CADDIS website)

In streams, insecticides may be dissolved in the water column or associated with sediments, and the effects they have will depend upon the medium in which they occur. Exposures may be episodic (e.g., pulsed deliveries of insecticides with stormwater runoff) or sustained (e.g., long-term exposure to insecticide-contaminated sediments), and the bioavailability, uptake, and toxicity of insecticides during these exposures will vary with environmental conditions (e.g., temperature). Risk of additive toxicity is also a concern with insecticides, as are the breakdown products of these pesticides that are not well characterized for toxic effects. Increased insecticide concentrations within streams can result in decreased condition, decreased growth, altered behavior, increased susceptibility to other stressors, increased mortality, and decreased reproductive success in affected biota (macroinvertebrates may be especially susceptible), and ultimately may alter population and community structure and ecosystem function.

Pesticide monitoring in Minnesota and water quality standards

The Minnesota Department of Agriculture (MDA) monitors pesticides in both surface waters and groundwater within ten pesticide monitoring regions (PMRs) having relevant internal similarity (MDA, 2010). The NF Crow watershed falls within three different PMRs; Region 4 (Central Sands), Region 8 (south central), and Region 10 (metro). MDA reports test results for pesticides used in MN and which could eventually migrate to water resources.

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.

"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. 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 19.

Table 19: 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. R. ch. 7050 as toxicity-based for aquatic organisms and is protective for an exposure duration of 4 days

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

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

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

Causal analysis – pesticide toxicity

Pesticide data from the NF Crow watershed is somewhat limited, as only one sampling event for pesticides targeted NF Crow sites. However, multiple years of pesticide data have been collected in surrounding watersheds that have similar agricultural land-uses, and likely comparable rates and types of pesticide application. Historically, MDA has collected data from four locations in the greater Crow River watershed as part of their statewide survey of surface water (Figure 69). Two of these stations are located on the South Fork Crow River, one is located on the Middle Fork Crow River, and the fourth site is located on the Crow River in Rockford, MN. Data from these surrounding watersheds, as well as the limited data from the NF Crow and Crow River are used in this report to characterize the concentrations of pesticides in surface water and the threats posed to aquatic life.

Each of the monitoring sites listed in Table 20 were sampled for the pesticides included in MDA's statewide monitoring program. Eleven pesticides and two degradates were detected at surface water monitoring stations in the greater Crow River watershed. The frequency at which these pesticides were observed and maximum concentrations are shown in Table 21. The majority of the sampling events were conducted in the Middle and South Forks of the Crow River, and as a result most of the detections of pesticides occur in those streams. Sampling on the NF Crow was limited to one sampling event in August of 2010. Herbicides are often detected in surface waters with greater regularity and higher concentrations in spring and early summer after significant rain events. Therefore, the sampling results for the NF Crow are not entirely representative of herbicide concentrations in the watershed.

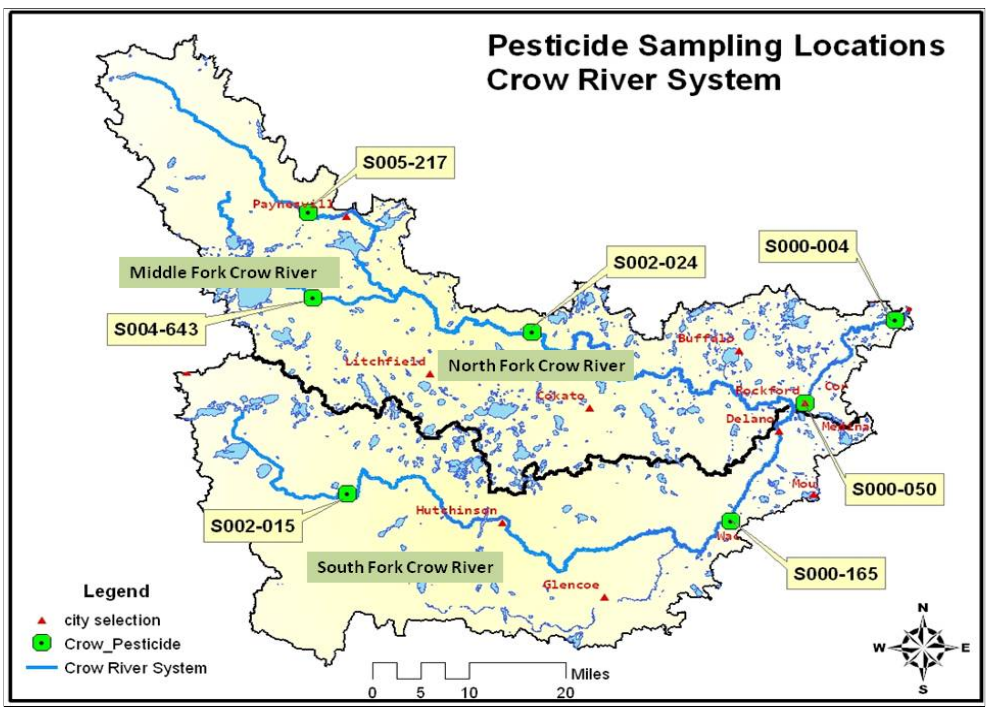


Figure 69: Pesticide sampling locations in the Crow River watershed

Table 20: Site descriptions and sampling years for pesticide monitoring in the Crow River watershed

Site ID	Description	Years Sampled	Active?
S005-217	North Fork Crow River @ 182nd Ave NE; 3.3 miles W of Paynesville	2010	N
S002-024	North Fork Crow River @ CSAH-19 in KINGSTON	2010	N
S000-050	Crow River @ state HWY 55 in Rockford	1991-1993	N
S000-004	Crow River @ CSAH 36 in Dayton	2010	N
S004-643	Middle Fork Crow River @ 195th St NE; 7.3 miles N of Atwater	2009	Y
S002-015	South Fork Crow River @ state HWY 7 in Cosmos	2005-2009	Y
S000-165	South Fork Crow River @ CSAH 23 in Mayer	2005-2009	Y

Acetochlor, atrazine, and metachlor were the most commonly detected herbicides in the greater Crow River watershed (Table 21). Atrazine was detected in approximately 97% (31 of 32) of samples collected on the three forks of the Crow River, while acetochlor was detected at a rate of 78 % (25 of 32) and metachlor at 81% (26 of 32) (Table 21). A degradate of atrazine called desethylatrazine was also commonly detected. The only insecticide detected was the compound chlorpyrifos, which was only detected at a concentration below the MRL during a single sampling event at station S000-165 on the South Fork Crow River.

Based on current data, there are no exceedences of Minnesota state pesticide standards in the greater Crow watershed. It should be noted that several of the pesticides that were detected do not currently have state water quality standards associated with them. The fungicides tetraconazole and propicanazole were present in samples collected on the South Fork Crow River (station S000-165) in concentrations below the minimum reporting limit (MRL). MDA lab analysis procedures indicate that the MRL for tetraconazole at 0.15 µg/L. The USEPA/OPP (Office of Pesticide Protection) benchmarks for tetraconazole are 0.1 µg/L (acute) and 0.03 µg/L (chronic). This benchmark is based on protection of aquatic macroinvertebrates. These benchmark values indicate that harmful effects may occur from exposure to concentrations of this compound that are much lower than the MRL as analyzed through MDA lab procedures. Pesticides were detected more frequently and in higher concentrations in the South Fork Crow River in comparison to the North Fork and Middle Fork Crow.

Table 21: Herbicides, insecticides, and fungicides detected in the greater Crow River watershed (includes South, Middle, and North Forks as well as the Crow River mainstem)

	S006-295[A] NF Crow River	S002-024[A] NF Crow River	S000-050 Crow River	S000-004[A] Crow River	S004-643 Middle Fork Crow	S002-015 South Fork Crow R	S000-165 South Fork Crow R
Herbicide							
Acetochlor	ND	ND	D - 1 of 1 (0.45)	ND	D - 3 of 4 (P*)	D - 11 of 12 (0.89)	D - 10 of 12 (0.58)
Alachlor	ND	ND	ND	ND	ND	ND	D - 1 of 12 (P*)
Atrazine	ND	D – 1 of 1 (P*)	D - 1 of 1 (0.82)	D – 1 of 1 (P*)	D - 4 of 4 (P*)	D - 12 of 12 (1.38)	D - 12 of 12 (1.45)
Deisopropylatrazine	ND	ND	ND	ND	ND	D - 1 of 12 (P*)	D - 12 of 12 (0.07)
Deethylatrazine	D – 1 of 1 (P*)	ND	ND	ND	D - 4 of 4 (P*)	D - 12 of 12 (0.18)	D - 8 of 12 (0.07)
Dimethenamid	ND	ND	D - 1 of 1 (0.24)	ND	NA	D - 9 of 12 (0.28)	ND
Ethofumesate	ND	ND	ND	ND	ND	D - 1 of 12 (1.51)	ND
Metolachlor	ND	ND	D - 1 of 1 (0.18)	D – 1 of 1 (P*)	ND	D - 12 of 12 (3.36)	D - 12 of 12 (0.63)
Prometon	ND	ND	ND	ND	ND	D - 1 of 4 (P*)	D - 2 of 12 (0.11)
Propazine	ND	ND	ND	ND	ND	D - 1 of 4 (P*)	D - 1 of 12 (P*)
Insecticide							
Chlorpyrifos	ND	ND	ND	ND	ND	D - 1 of 12 (P*)	ND
Fungicide							
Propiconazole	ND	ND	ND	ND	ND	D - 1 of 12 (P*)	ND
Tetraconazole	ND	ND	ND	ND	ND	D - 1 of 12 (P*)	ND

[A] These stations were only sampled once during low-flow conditions in August 2010
P – Present, but below detection limits
D – Detection – maximum concentration detected in parenthesis ( )
ND – non-detect
NA – parameter not available

Strength of evidence / conclusions

There is little evidence to support pesticide toxicity as a major cause of fish and macroinvertebrate impairments in the NF Crow. Additional monitoring is recommended to further understand the presence of pesticides in the NF Crow and their potential impact to fish, macroinvertebrates, and other aquatic and terrestrial biota. Monitoring data from spring or early summer rain events would improve confidence in the ability to diagnose or refute pesticide toxicity as a stressor in this watershed. Given these current gaps in the pesticide data, it is difficult to completely rule out pesticide toxicity as a possible stressor.

Table 22: Strength of evidence results for pesticide toxicity

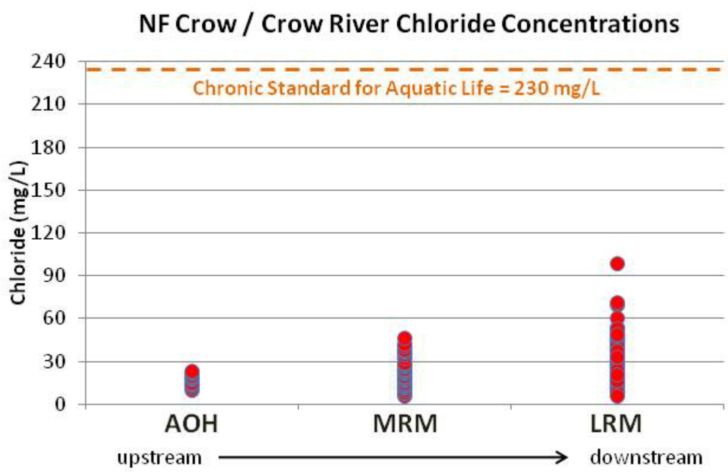
Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	Mid-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	NE	0	0	0
Temporal sequence	NE	NE	NE	NE
Field evidence of stressor-response	NE	0	0	0
Causal pathway	NE	0	0	0
Evidence of exposure, biological mechanism	NE	0	0	0
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE
Symptoms	NE	0	0	0
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	+	+	+
Stressor-response in other lab studies	+	+	+	+
Stressor-response in other field studies	+	+	+	+
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	+	+	+	+
Multiple lines of evidence				
Consistency of evidence	0	0	0	0
Explanatory power of evidence	- / 0	- / 0	- / 0	- / 0

* see table 1.1 for scoring interpretations

4.6 Chloride toxicity

The negative effects of elevated chloride concentrations on aquatic life have been well documented, especially in urban areas. The use of road salt and de-icing products has increased considerably in the United States since 1950, putting more urban streams at risk for this stressor (Kostick, 1993). The EPA-recommended chronic criterion for aquatic life is a 4-day average chloride concentration of 230 mg/L with an occurrence interval of once every three years, and the recommended acute criterion concentration for chloride is 860 mg/L (USEPA, 1988). Concentrations above chronic criterion were found in more than 40% of urban streams tested in a recent study conducted by the U.S. Geological Survey.

Chloride toxicity was considered a candidate cause for impairment due to the expanding urban, commercial, and residential development in the Lower NF Crow/Crow watershed. Existing chloride data were evaluated for the four NF Crow watershed zones that were established earlier in this report (see section 1.0). A total of 447 chloride samples were evaluated spanning three of the four watershed zones (no data was available for the CHH watershed zone). Chloride concentrations increased longitudinally from upstream to downstream, but were well below the chronic standard for Class 2B waters of Minnesota (Figure 70). It does not appear that chloride toxicity is a stressor to aquatic life in the NF Crow/Lower Crow River.



AOH = Alluvium Outwash Headwaters MRM = Mid-River Steep Moraine LRRM = Lower River Rolling Moraine

Figure 70: Surface water chloride concentrations by NF Crow/Lower Crow River watershed zones

4.7 Low dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Low or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975; Nebeker et al., 1991). Dissolved oxygen 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 water temperature increases, the saturation level of DO decreases. Increased water temperature also raises the DO needs for many species of fish (Raleigh et al., 1986). Low DO concentrations are often an issue in streams with slow currents, elevated water 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.*

Potential sources and pathways for low dissolved oxygen

The DO regime of streams is driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the DO regime of a waterbody. Agricultural and urban land-uses, impoundments (dams), and point-source discharges are just some of the anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. A conceptual model showing some of the typical human-caused sources and pathways of low DO is shown in Figure 71.

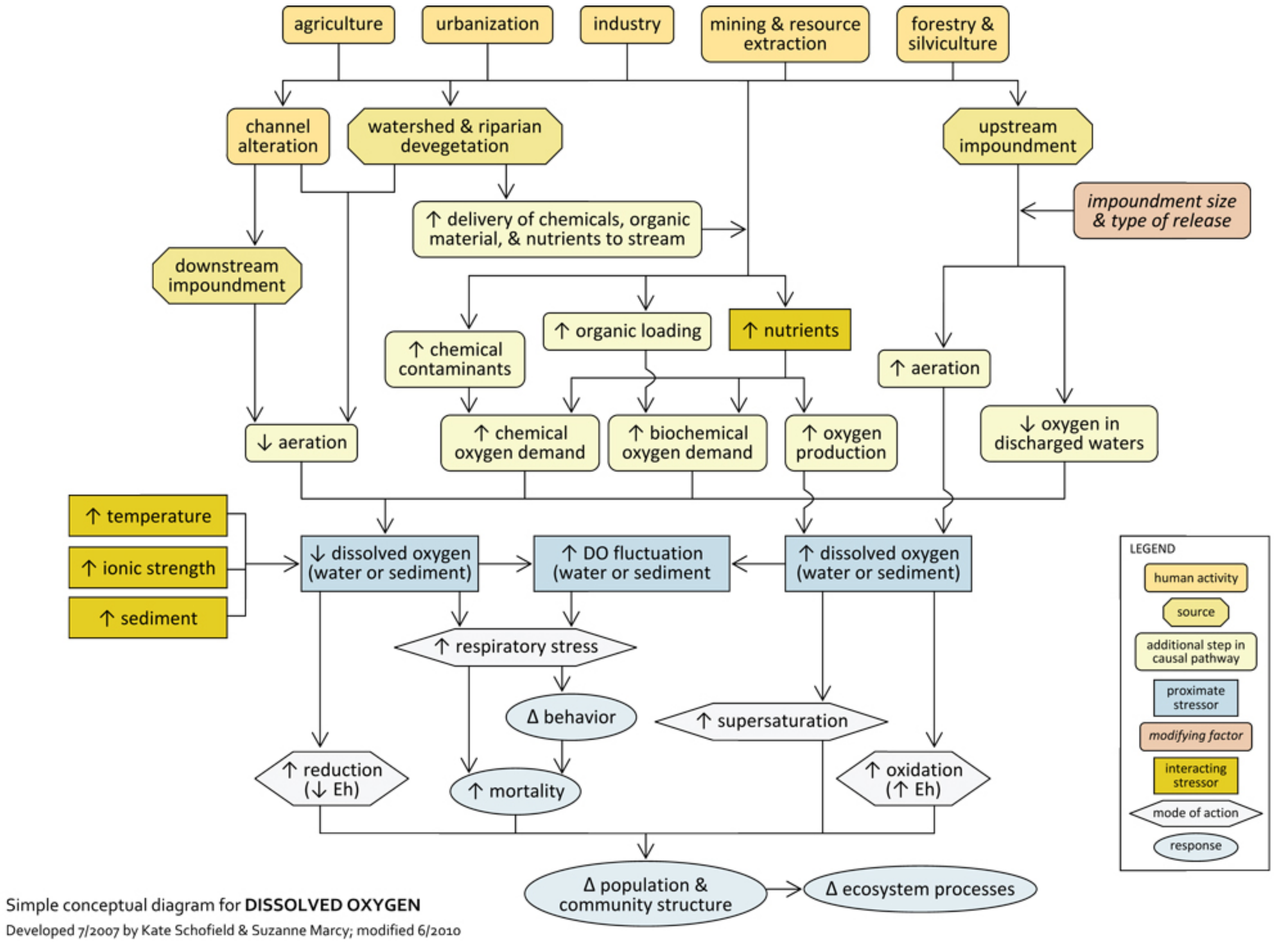


Figure 71: Conceptual model for low DO as a stressor in the NF Crow/Lower Crow River.

Dissolved oxygen data

Point measurements

Instantaneous DO data is available throughout the watershed and can be used as an initial screening for low DO. 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.

Longitudinal (synoptic)

A series of longitudinal synoptic DO surveys were conducted throughout the length of the NF Crow/Lower Crow River 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. For the most part, the surveys took place in mid to late summer when low DO is most commonly observed. Dissolved oxygen readings were taken at pre-determined sites in late afternoon/evening and early morning in an attempt to capture the peak and trough of the diurnal fluctuation.

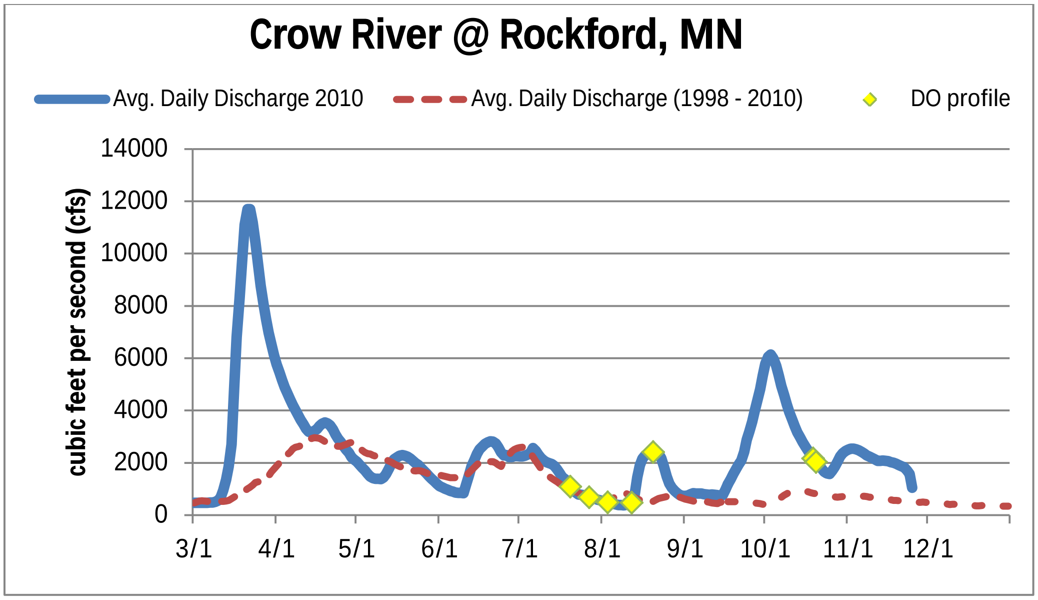


Figure 72: Comparison of 2010 average daily discharge at NF Crow gauging station at Rockford, MN with average from 1998 – 2010. Dates of synoptic monitoring surveys for DO are shown as yellow diamonds.

North Fork Crow River/Lower Crow River dissolved oxygen data summary

Channelized Headwaters – Alluvium Outwash Headwaters

Instantaneous DO measurements are available from four sites in the Channelized Headwaters watershed zone (CHH), two of which are MPCA biological monitoring stations. Dissolved oxygen concentrations in this reach of the river are quite high in early spring during snowmelt runoff, but drop steadily during mid-summer months. Monitoring data from several sites, including biological monitoring station 07UM084, show values falling well below the DO standard of 5 mg/L (Figure 73). The majority of July/August DO readings from sites in this watershed zone were below 5 mg/L, with a minimum concentration of 2 mg/L.

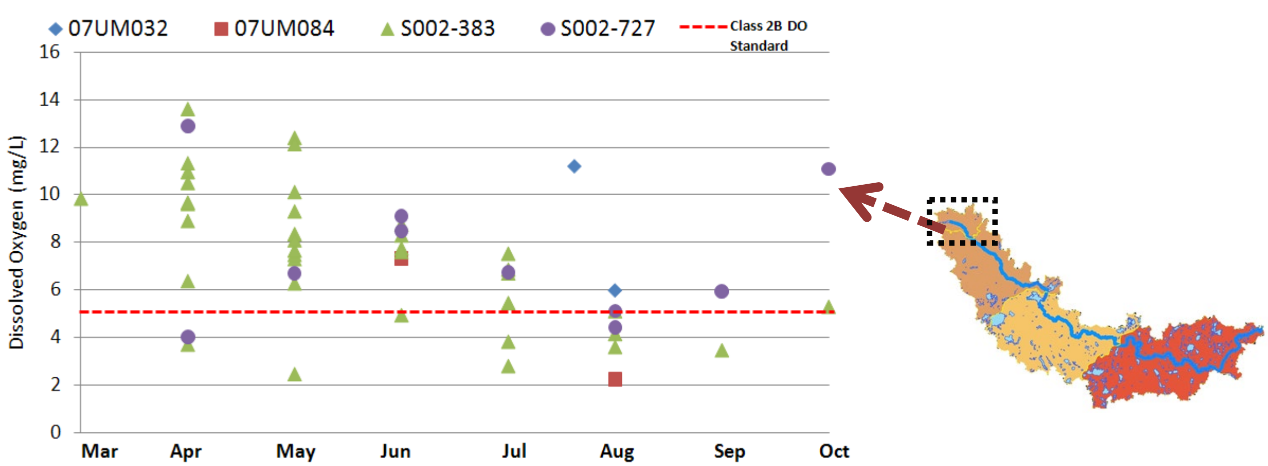


Figure 73: Instantaneous DO readings from NF Crow monitoring sites in the CHH watershed zone

Just downstream in theAOH watershed zone, instantaneous DO measurements also show several DO concentrations below 5 mg/L in summer months of June – September (Figure 74). Low DO readings appear to be less common in this reach of the NF Crow, as the majority of mid-summer DO concentrations were above 5 mg/L at most monitoring locations.

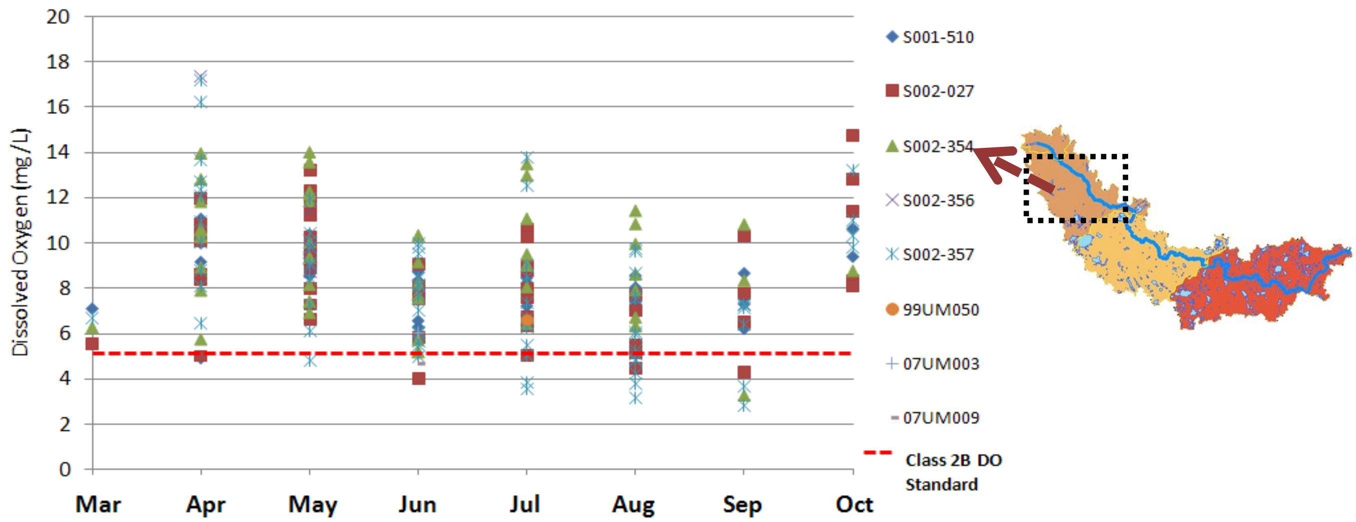


Figure 74: Instantaneous DO readings from NF Crow monitoring sites in the AOH watershed zone

Synoptic longitudinal DO surveys (collected in summer 2010) from these two watershed zones indicated a general increase in DO concentrations from the headwaters to Lake Koronis. Dissolved oxygen concentrations fell below the Class 2B DO standard frequently at headwaters sites NFHW-11 downstream to NFHW-9 (Figure 75). The river is channelized at these monitoring locations and numerous tributaries with wetland characteristics (e.g. Sedan Brook) enter the stream within this reach. The very low DO reading (1.36 mg/L) at site NFHW-7 in the early morning of 7/20/10 appears to be somewhat of an anomaly, as an early AM reading from 5 days later was 5.06 mg/L.

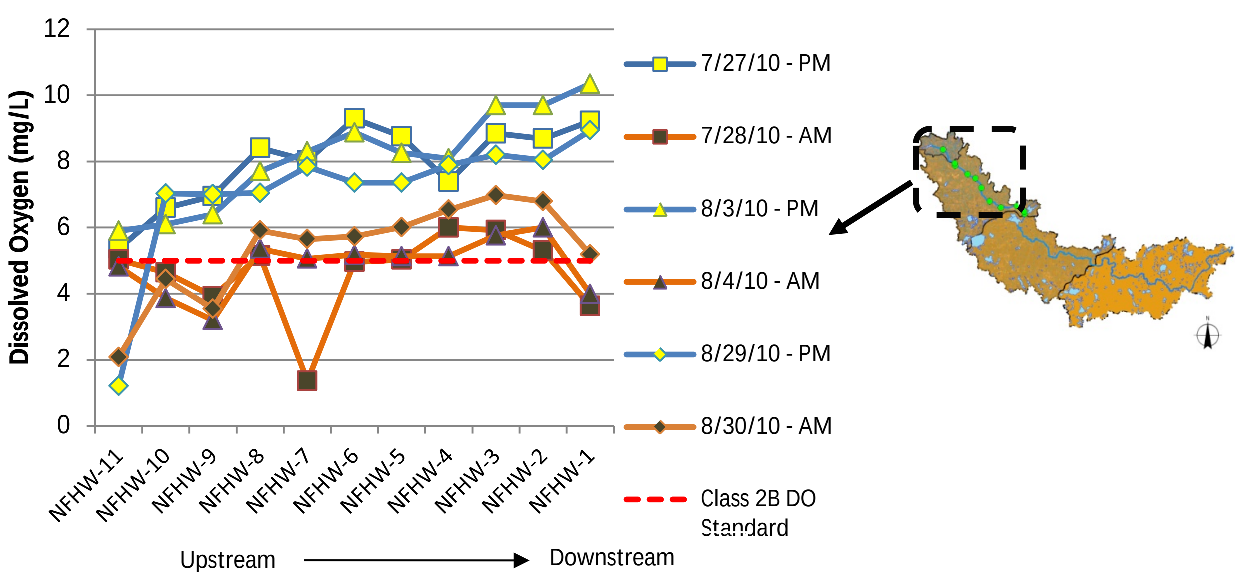


Figure 75: Results of synoptic longitudinal DO surveys from NF Crow sites in the CHH and AOH watershed zones

Early morning DO levels remain near the Class 2B standard downstream of NFHW-7 to Lake Koronis, with a gradual increase near Paynesville, MN. An increase in stream gradient and fewer wetland characteristics within this reach are probable factors for this increase in DO. Several DO readings below 5.0 mg/L were recorded at site NFHW-1 (biological site 07UM035), which is located at the outlet of Rice Lake (Figure 75). The DO regime at this site is highly influenced by lake conditions, which are nutrient rich and produce severe blue-green algae blooms and large diurnal swings in DO (MDNR). Also, the stream channel at this site is low-gradient and supports an abundance of emergent and submergent wetland vegetation which likely affect the DO regime. Based on the longitudinal data from this section of the river, low DO conditions may be acting as a stressor to aquatic life, particularly in the extreme headwaters reaches and in the short channel connecting Rice Lake to Lake Koronis.

Mid-River Moraine watershed zone

The majority of instantaneous DO measurements from the MRM are adequate for supporting aquatic life, as over 96% (380 of 396) measurements were above the 5 mg/L standard in this reach of the NF Crow. Several DO concentrations fell below the standard at sites near Forest City and Kingston in late June/early July 2002, but recovered to concentrations above 5 mg/L shortly after.

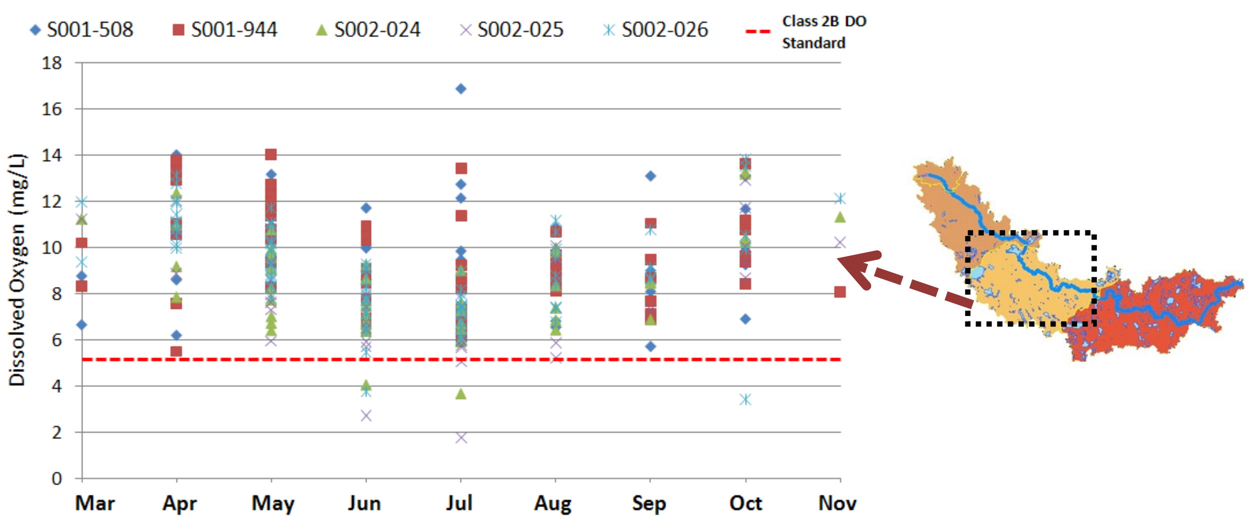


Figure 76: Instantaneous DO readings from NF Crow monitoring sites in the MRM watershed zone

Synoptic longitudinal DO surveys in this watershed zone were conducted from the outlet of Lake Koronis to Kingston in the summer of 2010. The lowest DO concentrations, including the only reading below the Class 2B DO standard, occurred at the outlet of Lake Koronis in late August.

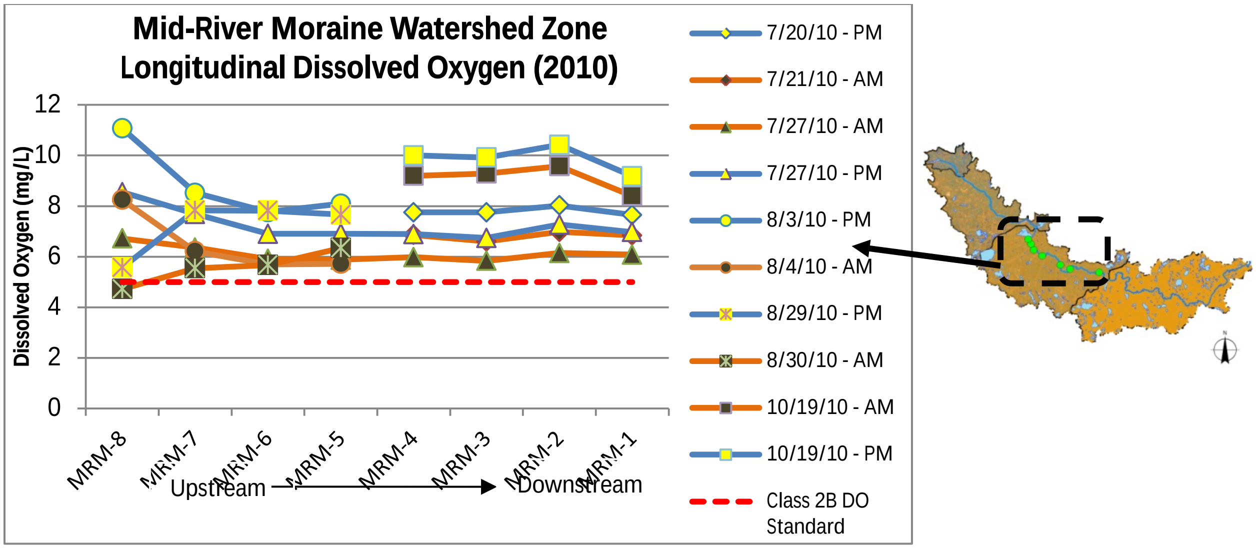


Figure 77: Results of synoptic longitudinal DO surveys from NF Crow sites in the MRM watershed zone

Lower River Rolling Moraine

Instantaneous DO measurements from the upper portion of the LRRM watershed zone generally met the DO standard for warm water rivers. The two monitoring stations in the upper LRRM with the most DO data, S001-517 and S001-029, met the standard at rates of 96% (n=75) and 97% (n=69) respectively. However, the DO regime appears to change in the lower reaches of this watershed zone as the NF Crow nears the confluence with the South Fork Crow (Figure 78). DO measurements taken at site S001-256, the last NF Crow station before the confluence with the South Fork Crow, show low DO levels in the months of May through September and regular DO concentrations below 4 mg/L in July and August. From this site downstream, there appears to be an increased rate of violations of the 5 mg/L DO standard and a higher likelihood that low DO conditions are stressing fish and macroinvertebrate populations (Figure 78).

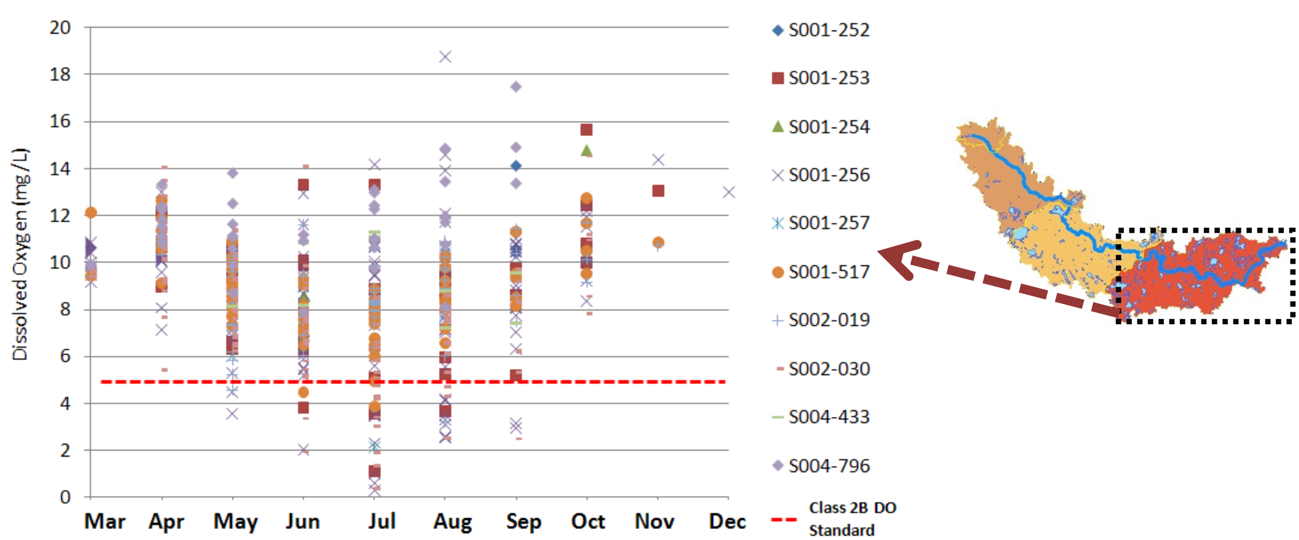


Figure 78: Instantaneous DO readings from NF Crow monitoring sites in the MRM watershed zone

Longitudinal DO monitoring data collected from NF Crow sites in this watershed zone in 2010 is somewhat contradictory to the many years of point measurements in this watershed zone. No DO readings below 5 mg/L were observed during these surveys (Figures 79 and 80). Streamflow in 2010 was comparable to flow seen over the past 12 years of record (Figure 72).

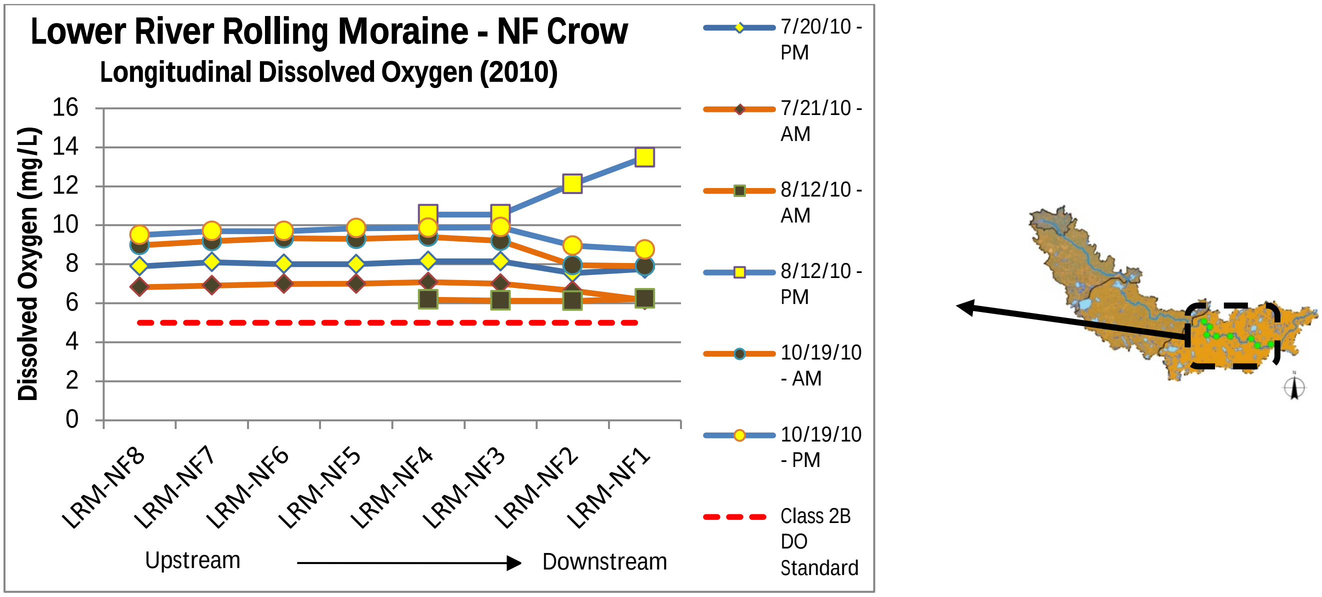


Figure 79: Results of synoptic longitudinal DO surveys from NF Crow sites in the LRRM watershed zone

Results from 2010 longitudinal DO monitoring on the Lower Crow River are shown in Figure 80. In mid-July, the diurnal flux in DO was less than 2 mg/L and concentrations were in a good range for support of aquatic life. Just less than one month later, in mid-August, diurnal flux had increased significantly, with evening concentrations around 14 mg/L and early morning readings of near 5 mg/L. Although there were no recorded violations of the 5 mg/L DO standard, the level of diurnal fluctuation in DO may be indicative of high primary productivity driven by nutrient enrichment.

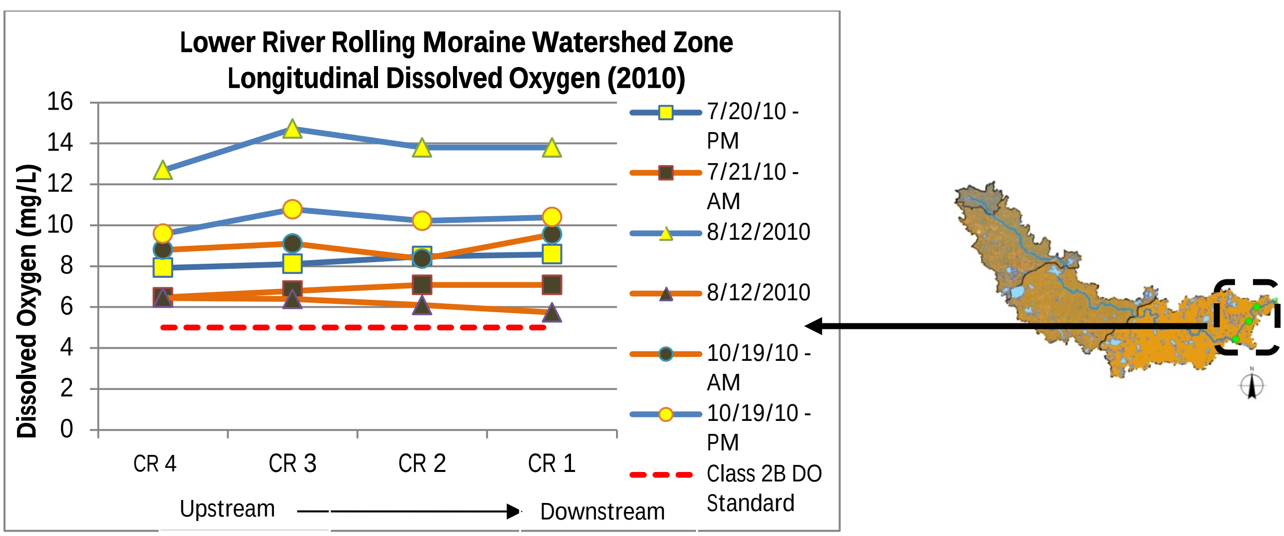


Figure 80: Results of synoptic longitudinal DO surveys from Crow River sites in the LRRM watershed zone

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

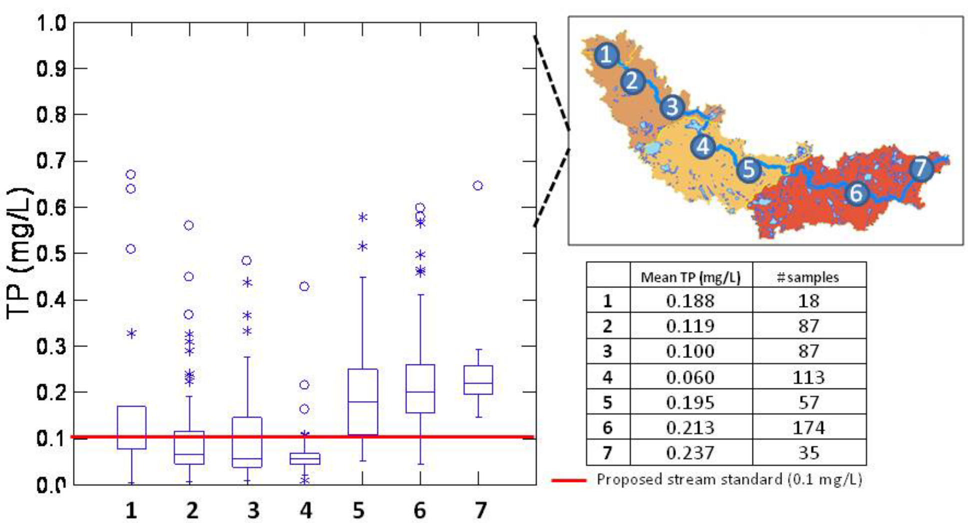
Nutrient enrichment, Chl-a concentrations, and measures of biological oxygen demand (BOD) are all factors in the DO regime of streams and rivers. MPCA has developed nutrient criteria for Minnesota rivers (not yet official state rules) with thresholds for total phosphorous (TP) and several related stressor effects linked to excess nutrients -- high diurnal DO flux, high Chl-a concentrations, and elevated BOD levels. NF Crow data for these parameters and the river nutrient criteria in development can be used to investigate potential pathways and sources causing low DO.

Table 23: Draft river eutrophication criteria ranges by River Nutrient Region for Minnesota.

	Nutrient	Stressor		
Region	TP µg/L	Chl-a µg/L	DO flux mg/L	BOD_5 mg/L
North	55	<10	≤4.0	≤1.5
Central	100	<20	≤4.5	≤2.0
South	150	<40	≤5.0	<3.5

1. Total phosphorous

A summary of TP concentrations in the NF Crow / Crow River watershed are shown in Figure 81. The North Fork Crow River watershed lies in the Central River Nutrient Region. Mean TP levels are slightly above the draft standard of 0.1 mg/L in the CHH and AOH watershed zones due to some high concentration-samples in the 0.3 to 0.7 mg/L range. Between the Lake Koronis Outlet and Kingston, the NF Crow appears to carry a higher nutrient load (between Site 4 and 5 in Figure 81). From this point downstream, the TP concentrations in the NF Crow and Lower Crow River are around two times higher than the proposed river TP standard of 0.1 mg/L (Figure 81). Based on these observations, excess nutrients and a resulting in primary production as well, is a logical causal pathway for low DO in the lower reaches of the NF Crow/Crow River.

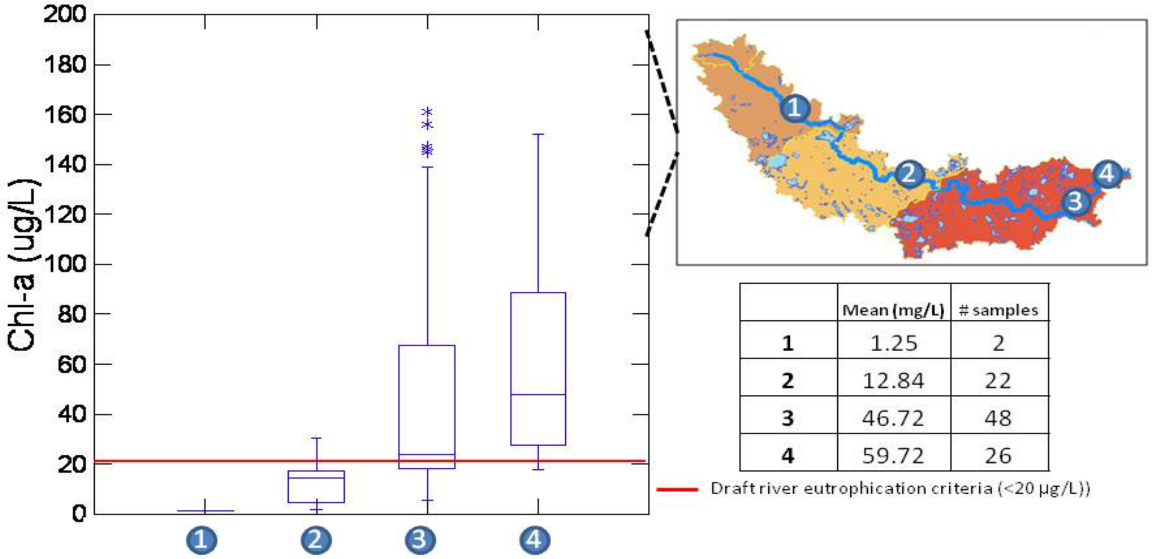


	Mean TP (mg/L)	#samples
1	0.188	18
2	0.119	87
3	0.100	87
4	0.060	113
5	0.195	57
6	0.213	174
7	0.237	35

Figure 81: Summary of TP data for select NF Crow and Crow River monitoring stations

2. Chlorophyll-a

Chlorophyll-a concentrations are commonly used to measure algal productivity in surface water and have shown correlations to maximum DO concentrations and DO flux (Heiskary et al., 2010). In the NF Crow mainstem, Chl-a concentrations increase considerably moving from the headwaters downstream to the confluence with the South Fork Crow (Figure 82). In the Lower NF Crow and Crow River, concentrations of Chl-a are consistently above the draft river criteria of 20 µg/L and reach levels as high as 160 µg/L. Average Chl-a concentrations in the Lower NF Crow and Crow are 2-3 times greater than the proposed criteria.

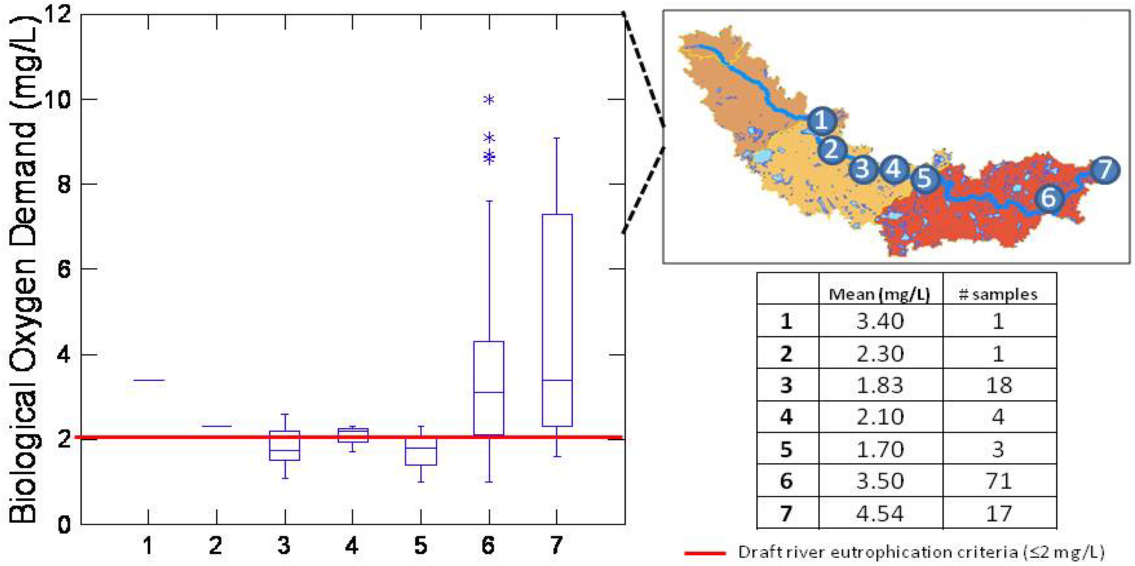


	Mean (mg/L)	# samples
1	1.25	2
2	12.84	22
3	46.72	48
4	59.72	26

Figure 82: Summary of Chl-a concentrations for a selection of monitoring sites on the NF Crow/Crow River.

3. Biological oxygen demand

Biological oxygen demand is an important measure of potential stress on a biological community. Increases in BOD can lead to lower DO levels and may also result in a shift in fish and invertebrate trophic structure. Heiskary et al. (2010) observed that many biological metrics indicated a negative shift in biological condition (stress response) at about 2-3 mg/L BOD. The majority of the NF Crow/Crow sites shown in Figure 83 fall within this range, and the lower river exhibited BOD concentrations as high as 10 mg/L. Based on these observations it is likely that elevated BOD concentrations are a prominent causal pathway for low DO conditions.



	Mean (mg/L)	# samples
1	3.40	1
2	2.30	1
3	1.83	18
4	2.10	4
5	1.70	3
6	3.50	71
7	4.54	17

Figure 83: Summary of BOD concentrations at selected NF Crow monitoring sites

4. Dissolved oxygen flux

Hieskary et al. (2010) found that a diurnal (24 hour) DO flux over 4.5 mg/L reduced macroinvertebrate taxa richness and the relative abundance of sensitive fish species in a population (Heiskary et al., 2010).

Diurnal DO flux can be generated from the longitudinal DO monitoring completed on the NF Crow/Crow in 2010. Not surprisingly, DO flux is highly variable across a seasonal gradient and geographical location in this river system. In the headwaters of the NF Crow, DO flux is generally within 1.0 – 3.5 mg/L, although several sites exhibited DO flux of greater than 5 mg/L (Figure 89 - A). One of these sites was NFHW-1, located in the flowage between Rice Lake and Lake Koronis. NFHW-7 is the other site where a DO flux of over 5 mg/L was observed, however, other measurements of DO flux at this station were much lower (Figure 89 - A). Aside from the flowage between the two lakes, DO flux observed in this reach of the river was suitable for supporting healthy fish and macroinvertebrate populations.

In 2010, DO flux in the MRM watershed zone was the lowest among all reaches of the NF Crow and Crow River. DO flux ranged from 1-3 mg/L in all summer and early fall sampling events (Figure 84-B). Diurnal DO flux in this reach of the NF Crow does not appear to be a stressor itself or an indicator of river eutrophication.

Available data shows an increase in diurnal DO flux within the Lower River Moraine watershed zone. A relatively low DO flux was observed at all sites in this watershed zone in mid to late July and early October, but August readings revealed a high DO flux of around 4.5 – 7 mg/L at several locations, beginning at site LRRM-NF2 (Figure 84-C). This station is directly downstream of where Mill Creek enters the NF Crow. Mill Creek is currently listed on the 303(d) list of impaired waters for low DO and turbidity. In the Lower Crow River, DO flux was over 8 mg/L at site CR 3 in August (Figure 84-D). The other Crow River sampling locations also showed high DO flux in August, ranging from 6-8 mg/L (Figure 84-D). Aside from the mid-August sampling run, DO flux was below 2 mg/L in the Lower North Fork and Crow Rivers in July and October sampling events (Figure 84 C-D).

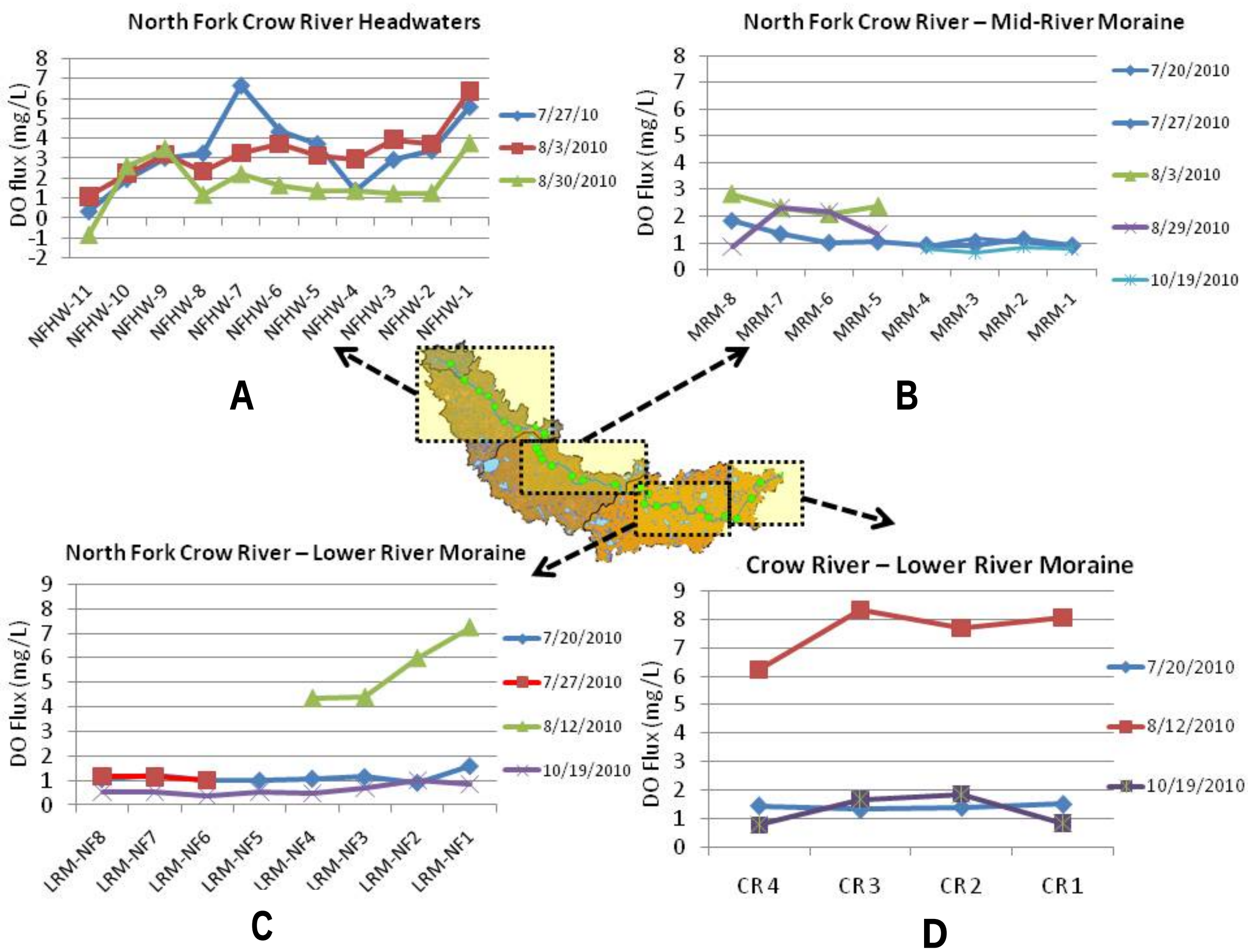


Figure 84 A-D: Dissolved oxygen diurnal fluctuation at select NF Crow/Crow River sites based on longitudinal (synoptic) monitoring completed in 2010.

These data related to DO concentrations and river eutrophication suggest that excess nutrients, elevated BOD concentrations, and primary productivity (represented by Chl-a levels) are likely causal pathways for low DO concentrations in specific reaches of the NF Crow/Crow River system. These lines of evidence are particularly strong for the Lower NF Crow (from Kingston to the confluence with the South Fork Crow) and Lower Crow River (Rockford to confluence with Mississippi River).

Causal analysis – biological response

Channelized Headwaters watershed zone

Dissolved oxygen concentrations in this reach of the NF Crow are routinely below the Class 2B standard, including a low measurement of 2 mg/L at biological station 07UM084. Several biological indicators of low DO are also present in this reach:

1. **Lack of sensitive fish taxa**

   Both biological monitoring sites in this watershed zone exhibited a general lack of sensitive fish taxa and low taxa richness of headwaters minnow species. Two sampling events at 07UM032 revealed a fish community dominated by central mudminnow (*Umbra limi*), a species that is known to be tolerant of low DO conditions (Becker, 1983). This species accounted for 76% and 67% of the total fish population at these sites during the two surveys.

2. **Low fish abundance**

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

3. **Lack of sensitive macroinvertebrate taxa**

   Both biological sites in this reach lacked intolerant macroinvertebrate taxa. Both sites 07UM084 and 07UM032 scored a 0 (out of 10) in the metric Intolerant2Ch, which counts the number of macroinvertebrate taxa with low tolerance to a variety of stressors.

4. **Low Plecoptera richness**

   Macroinvertebrates from the orders Ephemeroptera (mayflies), Plectopera (stoneflies), and Trichoptera (caddisflies) (EPT) are widely used bio-indicators that are typically abundant in healthy streams. Plecoptera are especially sensitive to low DO concentrations and are not often found in streams with unstable or low concentrations of DO. There were no Plecoptera taxa present at the two biological monitoring sites in this reach of the NF Crow. Suitable habitat (cobble/wood) may also be a limiting factor for Plecoptera abundance at these stations.

Alluvium Outwash Headwaters

The majority of instantaneous DO readings from this watershed zone are above the 5 mg/L water quality standard; however several readings taken in late summer fell below this target. Although daytime minimum DO concentrations do not appear to be a common problem in this reach, DO flux during several 2010 samples was greater than 4.5 mg/L, and DO concentrations have been historically as high as 14 mg/L. Large mats of filamentous algae have been observed within this reach during mid-summer months (Figure 85). The daytime oxygen-producing photosynthetic activity from these algae growths is the probable cause of the higher than normal DO concentrations, while the nighttime, oxygen-using respiration of the algae (along with dead algae decay) is likely contributing to suppressed DO concentrations in the early morning hours. At site 07UM009 shown in Figure 85, DO concentrations have been recorded below 5 mg/L in the early morning hours.

Figure 85: Large mats of filamentous algae near site 07UM009 (June 2007)

The biological metrics driving the fish and macroinvertebrate impairments in this reach have some possible linkages to low and/or highly fluctuating DO concentrations:

1. **Lack of intolerant / sensitive fish taxa**

   Heiskary (2010) observed a strong negative correlation between DO flux and % of sensitive fish species. The majority of the biological monitoring stations in this reach received relatively low scores in the metric *SensitiveTxPct* which measures the % of the fish community composed of sensitive taxa. Metric scores for *IntolerantPct* were also quite low within this reach of the river, especially at site 07UM009 (pictured in Figure 87). These metrics can respond to many forms of disturbance, but several of the stressors noted in other reaches of the NF Crow (elevated TSS, deposited and bedded sediment, channelization) are not as evident in this reach, leaving low DO as a more probable stressor.

2. **Serial spawning fish taxa**

   Fish species that are serial spawners are able to spawn multiple times during the year. Examples of fish species with this trait that are common to the NF Crow include white sucker, spotfin shiner, and horneyhead chub. A fish community dominated by fish taxa that are serial spawners may be indicative of an unstable environment or one that experiences “pulse-type” stressors, such as hydrologic variability or low/unstable DO concentrations. On average, metric scores for the SSpnTxPct (percent of fish taxa that are serial spawners) were poor through the AOH watershed zone of the NF Crow.

3. **MA>3-TolPct (lack of “late maturing” fish species)**

   This metric is a measure of the relative abundance of taxa with a female mature age greater than or equal to three years (or “late maturing”) (based on Frimpong and Angermeir, 2008) excluding tolerant taxa. These species need to have their life history requirements met for several consecutive years before they can begin to reproduce and contribute to a stable population. Even though this is a “reproductive” metric, it may actually be more indicative of whether or not sufficient habitat conditions are being maintained for relatively long periods of time. Though late-maturing species might be sensitive to chronic disturbances, they are also sensitive to infrequent but acute disturbances because a single severe event might severely reduce the older, breeding adults and there would be a resulting lag time where the population lacks mature fish to produce younger age classes.

All monitoring stations in the AOH zone scored very low in the MA>3-TolPct metric. Late maturing fish species, on average, comprised 3.8% of the fish community across all monitoring stations in this reach of the NF Crow. Site 99UM050 did not support any late maturing fish species, while only 0.9% of the fish sampled at site 07UM003 were late maturing species.

Mid-River Moraine watershed zone

The DO regime in this reach of the NF Crow River appears relatively stable and adequate for supporting aquatic life. Very few measurements below 5 mg/L were recorded during instantaneous measurements, and longitudinal monitoring completed in 2010 showed adequate DO concentrations and DO flux within a healthy range (less than 3 mg/L).

Lower-River Moraine watershed zone

The Lower NF Crow and Crow River are frequently in violation of the 5 mg/L DO standard and exhibit a high range of DO flux. Several biological metrics respond in a manner that supports low DO/DO flux as a stressor in this reach of the NF Crow and Lower Crow River.

1. **Macroinvertebrate taxa richness**

   Heiskary (2010) found a strong negative correlation between invertebrate taxa richness and DO flux, total phosphorous, and chlorophyl concentration. Using a Minnesota statewide data set, Heiskary (2010) observed that invertebrate taxa richness remained between the 25th and 75th percentiles at DO flux below 4.5 mg/L, but fell below the 25th percentile at DO flux above that range. Data from the NF Crow River/Crow River agree with this observation, as metric scores for invertebrate taxa richness decreased markedly in the lower reaches of the river where DO flux was well above 4.5 mg/L (Figure 86).

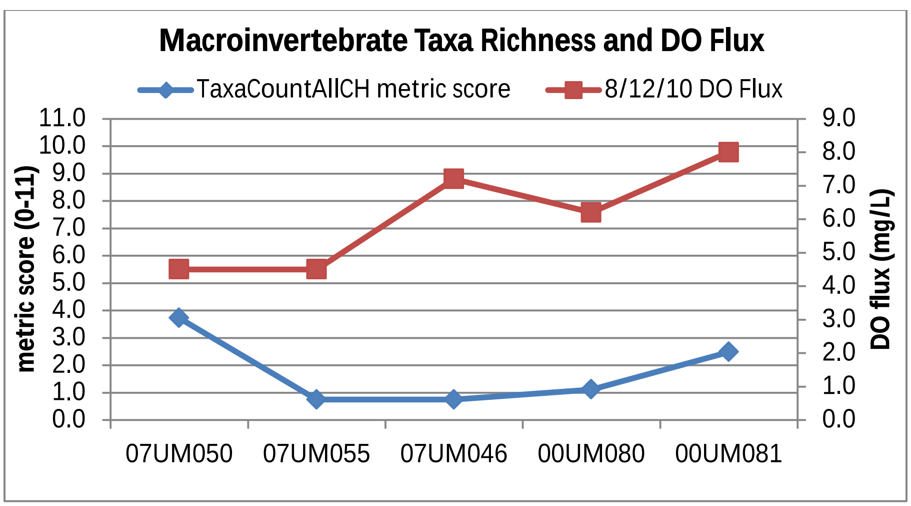


Figure 86: Measure of macroinvertebrate taxa richness vs. DO flux in Lower NF Crow and Lower Crow River

2. **Lack of sensitive fish species**

   All biological monitoring sites in this watershed zone scored low in metrics measuring abundance and richness of sensitive fish species. Heiskary (2010) observed strong negative relationships between % sensitive fish and total phosphorous, Chlorophyl-T, and DO flux. This reach of the NF Crow/Crow exhibits a similar biological response to these stressor indicators.

3. **Serial spawning fish taxa**

   All biological monitoring sites in this watershed zone score poorly in the SSpnTxPct metric. Similar to monitoring results from the AOH sites, this could be an indication that conditions present in this reach favor species that can reproduce multiple times and avoid catastrophic losses due to pulse stressors, such as flow variability or unstable DO concentrations.

Figure 87: Site 00UM080 in July of 2007. Note the green color of the water from high algae content.

Summary/strength of evidence

Based on the available data, low DO and/or DO flux is likely a stressor to aquatic life in the lower reaches of the NF Crow, as well as the Crow River from Rockford downstream to the Mississippi River. The diagnosis of DO as a stressor in the Lower NF Crow River/Crow River is supported by previous water quality assessment decisions for this parameter (see Figure 9). Currently, the NF Crow River is listed as impaired for DO from the point where Mill Creek enters downstream to the confluence with the SF Crow River. The Crow River is listed as impaired for DO from the confluence of the north and south forks of the Crow downstream to the Mississippi River. These listings provide further support of DO as a stressor to biota in these areas of the watershed.

Low DO is also a probable stressor in the extreme headwaters reaches of the NF Crow. Existing water chemistry data from this reach indicates frequent and severe violations of the 5 mg/L DO standard. Longitudinal synoptic monitoring completed in 2010 also produced several low DO readings. The biological community in this reach exhibits symptoms of DO stress, including an abundance of fish taxa that are tolerant of low DO conditions and a general lack of sensitive fish and invertebrate taxa.

The NF Crow within the AOH zone may be affected by low DO conditions, but to a lesser extent than the Lower NF Crow and headwaters areas. Confidence in diagnosing DO as a stressor in this reach is much lower than for the headwaters and lower river. Longitudinal monitoring completed in 2010 indicate minimum DO concentrations right around the established standard of 5 mg/L at most stations in this watershed zone. Biological site 07UM035, which is located on a flowage between Rice Lake and Lake Koronis, is very likely impaired due to low DO concentrations and high DO flux. Several instantaneous measurements in this section of the river were below 5 mg/L, including the measurement taken during the time of biological sampling at site 07UM003 when the stream channel appeared to be choked with filamentous algae (Figure 90). Dissolved oxygen stress in the AOH may be related more to the high rate of DO flux as opposed to minimum concentrations.

Low DO concentrations / DO flux do not appear to be significant stressors in the MRM watershed zone of the NF Crow. Aside from a few instantaneous measurements that fell below the DO water quality standard, the DO regime in this section of the river appears to be adequate to support warmwater fish and macroinvertebrate species.

Table 24: Strength of evidence scoring for DO as a stressor to aquatic life.

*** see table 1.1 for scoring interpretations**

Types of Evidence	Channelized Headwaters	Alluvium – Outwash Upper River	Mid-River Steep Moraine	Lower-River Rolling Moraine
Evidence from North Fork Crow River / Lower Crow River Data				
Spatial/temporal co-occurrence	+	+	-	+
Temporal sequence	+	+	-	+
Field evidence of stressor-response	++	+	-	++
Causal pathway	++	++	0	++
Evidence of exposure, biological mechanism	++	+	--	++
Field experiments /manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	NE	NE	NE	NE
Symptoms	+	+	+	D
Evidence using data from other watersheds / Scientific Literature				
Mechanistically plausible cause	+	+	+	+
Stressor-response in other lab studies	++	++	++	++
Stressor-response in other field studies	++	0	-	++
Stressor-response in ecological models	NE	NE	NE	NE
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	++	+	+	++
Multiple lines of evidence				
Consistency of evidence	+++	0	-	+++
Explanatory power of evidence	++	0	-	+++

4.8 Loss of connectivity

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

There are no major hydroelectric or flood control dams located on the NF Crow/Crow River. However, there are several water and/or carp control structures located at the outlet of several lakes that are hydologically connected to the river. The U.S. Army Corp of Engineers maintains a permanent dam structure at the outlet of Lake Koronis control lake water elevation. This structure also serves as a carp control barrier and seems to be effectively preventing carp from moving upstream from the NF Crow into the lake. Although effective for carp control, this barrier also limits movements of desirable fish species (e.g. northern pike and walleye) that are known to move between river and lake habitats for spawning, feeding, and/or refuge.

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

5.0 Conclusions and summary of probable stressors

The final weight of evidence table for candidate stressors impacting the NF Crow is shown in Table 25. Several stressors seem to be more systemic in nature, and therefore have widespread influence on the fish and macroinvertebrate community (DO, deposited and total suspended solids). Other stressors are more localized, and are the result of land-uses in a specific zone of the watershed, or direct stream channel alterations (ditching).

The evidence available for evaluating several stressors was found to be insufficient for diagnosing or refuting them as a cause of impairment. These include nitrate toxicity, loss of connectivity resulting from in-stream impoundments, and pesticide toxicity, and flow alteration. These remain candidate stressors for impairment and will need to be further investigated during future monitoring efforts.

Table 25: Summary of stressors by stream Assessment Unit ID (AUID)

Primary Stressors by stream AUID	07010204-508 (channelized)	07010204-508 natural Channel	07010204-504	07010204-507	07010204-506	07010204-555	07010204-556	07010204-503	07010204-502
Loss of Habitat due to Channelization / Ditching	X		X						
Total Suspended Solids	0				X	X	X	X	X
Deposited and Bedded Sediments	X		X	X					
Pesticide Toxicity	0	0	0	0	0	0	0	0	0
Nitrate Toxicity	0	0	0	0	0	0	0	0	0
Dissolved Oxygen	X						X	X	X
Connectivity – Loss of fish passage		0	0	0					

X = Probable Stressor **0 = Potential Stressor (unable to diagnose or refute)**

	Channelized Headwaters Zone
	Alluvium Outwash Headwaters Zone
	Mid-River Steep Moraine
	Lower River Rolling Moraine

6.0 Priority management zones

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

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

6.1 Improving habitat in channelized streams

Once a ditch is constructed or a stream channelized, it will attempt to return to a natural, stable state by meandering (Hansen et al., 2006). Due to differences in management approach, some ditches are not actively cleaned out and have begun to function like natural streams again. Examples of unmaintained

and "naturalizing" drainage ditches occur in the NF Crow watershed, and several of them achieve fish and macroinvertebrate IBI scores that are higher than ditches that are routinely cleaned and straightened.

An example of this can be seen on a Kandiyohi County Ditch B6, a tributary to the Middle Fork Crow River. The biological monitoring station 07UM007 located on this ditch achieved the highest fish and macroinvertebrate IBI scores of its class in the NF Crow River watershed. Historical imagery shows that this reach was channelized prior to 1938 (Figure 88 -left photo), but the present day condition supports a more vegetated riparian corridor (mature deciduous trees) and a meandering stream pattern (Figure 88 – right photo). It is likely that this section of County Ditch B6 has not been dredged out and re-straightened for several decades, and in that time span the riparian corridor has recovered and is once again providing ecological benefits to the stream.

Figure 88: County Ditch B6 in 1938 (left) and 2009 (right) at biological monitoring site 07UM007

The "naturalization" of this section of ditch over several decades may have created habitat suitable for diverse fish and macroinvertebrate assemblages. In comparison to the other ditches in the area, this site offers more riffle habitat, less fine sediment deposition, and a greater abundance of woody debris, which serves as cover for fish and food/refugia for macroinvertebrates (Table 26). The superior habitat present at this station appears to be supporting a much healthier fish and macroinvertebrate community than other ditch systems in the upper NF Crow River watershed. A healthy population of Iowa darter (*Etheostoma exile*) were present at 07UM007, along with other sensitive fish species such as northern redbelly dace (*Phoxinos eos*) and blacknose shiner (*Notropis heterolopis*). EPT and clinger macroinvertebrate richness was two times higher at this station than the channelized sites monitored in the CHH watershed zone.

Table 26: Comparison of "Channelized Headwaters Zone" ditches and naturalized ditch at biological monitoring site 07UM007

	Site	% Woody	% Fines	% Embed	% Riffle	Avg Fish IBI	M-IBI
Channelized Headwaters Ditches	07UM084	1.43	46.15	80.59	11.16	35.5	25.7
	07UM032	0.00	67.31	77.88	0.00	28	28.7
	07UM033	0.00	40.38	91.67	11.43	11	n/a
	07UM034	0.00	84.62	34.38	1.69	32.5	n/a
	Avg.	***0.36***	***59.62***	***71.13***	***6.07***	***26.7***	***27.2***
"Naturalized" ditch	**07UM007**	**8.21**	**38.46**	**47.66**	**34.80**	**68**	**68.83**

Figure 89: Photos from biological monitoring station 07UM007

Current ditch management practices often return these "naturalized" ditches back to the original trapezoidal design via regular cleanouts. The sequence of photos in Figure 90 from the South Branch Buffalo River watershed in western Minnesota provides an example of this process. The upper photos show a section of drainage ditch that was left unmaintained for over 50 years, and in that time the stream re-meandered and developed a small floodplain bench to dissipate stream energy during high flow events. The result of this transformation was improved habitat (undercut banks, riffles, pools), lower width/depth ratio, greater channel stability, floodplain storage, and an improved riparian corridor that supported native vegetation (personal communication, MDNR, 2009). After cleanout (lower photos in Figure 90) the stream returned to an unstable form, with high width/depth ratio, silt substrate, and no active floodplain for high flow events.

Figure 90: Photos from the South Branch Buffalo River showing a "naturalized" ditch before (top photos), during (bottom left photo), and after (bottom right photo) ditch clean-out maintenance.

Two-stage ditch design

Two-stage ditch design is gaining popularity in the field of stream restoration as a means of improving drainage and restoring ecological function. In contrast to conventional trapezoidal ditches, the two-stage variety is constructed with a low-flow channel and a floodplain bench within the ditch configuration (Figure 91). This ditch design has the potential to improve biological integrity scores, reduce maintenance costs, and improve stream channel stability (Powell et al., 2010). A properly functioning two-stage ditch more closely mimics a stable, natural stream in that energy from high flows are dispersed across a floodplain and normal to low flows still fill the channel to provide pools, riffles, and other habitat features. This innovative ditch-design is currently being supported by conservation organizations such as the Nature Conservancy and governmental agencies like the Natural Resources Conservation Service.

Figure 91: Cross-section of design for two-stage ditch (left) and natural forming two-stage ditch (tributary to Grove Creek in NF Crow watershed)

An improvement in biological integrity scores in the channelized headwaters watershed zone and in river reaches immediately downstream of Lake Koronis is not likely without a change in ditch management and/or stream restoration. On a statewide and local scale, there are numerous examples of ditches that have evolved undisturbed over time to more closely mimic the natural stream that existed before it was channelized. Management practices in this watershed zone should focus on establishing and/or protecting riparian buffers to promote the natural recovery of these systems where it is feasible and supported by local agencies and citizens. Stream restoration using the two-stage design should also be considered at a few sites to improve ecological function. If successful, these ditch management techniques could be employed on a larger scale in the watershed.

6.2 Loss of riparian buffer zones

The NF Crow/Lower Crow River watershed becomes increasingly populated and developed from the city of Kingston, MN east to the confluence with the Mississippi River. Near the cities of Rockford and St. Michael, individual residences and multi-home sub-developments are more common features of the riparian corridor. The presence of turfgrass lawns in the immediate riparian corridor of the river can increase runoff rates and nutrient delivery to surface waters, increase bank erosion rates, and decrease shading and woody debris/detritus inputs that provide habitat and support aquatic food webs.

Figure 92: Examples of residential properties that do not support functional riparian corridors

Animal agriculture is a prominent land-use in the NF Crow/Crow River watershed. Large tracts of pasture land are common features of the landscape in this region of Minnesota, supporting herds of cattle, horses, sheep, and swine. In the NF Crow watershed, pasture areas in the riparian corridor are quite common in the headwaters area and Alluvium Outwash watershed zone upstream of and around Paynesville, MN.

Uncontrolled grazing of riparian corridors can negatively impact habitat for fish, macroinvertebrates, and other organisms found in riparian zones. Some common impacts are (1) wider, shallower, less stable stream channel (Rosgen, 1996); (2) increased bank erosion and sediment deposition; and (3) reduced shading, woody debris, and fish cover. Figure 93 shows a wide, shallow reach of the NF Crow that has been impacted by grazing in the riparian corridor.

Figure 93: Reach of NF Crow with uncontrolled cattle grazing in the riparian corridor.

The predominant land use in the watershed zones of the NF Crow is cultivated cropland. In most locations along the river, vegetated buffers of varying width and quality are in place to separate cultivated land from the active stream channel and floodplain. However, several areas along the NF Crow River lack buffers and have shown high susceptibility to erosion and lateral channel migration (Figure 94). The development of PMZs in this watershed should include these areas where adequate buffers are not in place.

Figure 94: Aerial photos of an outside bend of the NF Crow River near Forest City, MN. A cultivated field is adjacent to the river without any vegetated riparian buffer. Comparing aerial photos from 1991 to 2009 reveals about 70 feet of lateral migration in the stream channel, for an average of about 3.9 ft of eroded bank per year

6.3 Protection areas

Index of Biological Integrity (IBI) scores are quite low throughout the length of the NF Crow/Lower Crow River mainstem. As a result, it is difficult to identify areas of outstanding ecological health that are deserving of protection status based solely on IBI data. Without question, the majority of implementation efforts in this watershed must be in the form of restoration, effective use of best management practices, and education and outreach.

Stream reconnaissance efforts revealed a few reaches of the NF Crow that may represent "best available "conditions for supporting healthy fish/macroinvertebrate populations. Most of these locations do not have biological data associated with them. Future monitoring in the watershed should target these locations to assess their condition and status as potential protection targets.

Figure 95: Section of Upper NF Crow River with healthy riparian corridor and good fish habitat Protection Area #1: This reach is located approximately 2 miles west of Paynesville, MN.

Compared to most reaches of the NF Crow in this watershed zone, this particular reach has a good riparian corridor of mature trees and streambanks are relatively stable (Figure 95). Coarse substrate for gravel spawning fish and darter species is abundant and substrate embeddedness appeared to be lower compared to other sites in the area. Fish IBI scores at site 96UM004, which is located in the upper portion of this potential protection PMZ, are some of the highest on the NF Crow.

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Appendix A – Descriptions of IBI classifications used in North Fork Crow River bioassessment

Fish IBI Class 4 – northern rivers

Classification criteria

Large warm/coolwater rivers in northern MN
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 CL: 44
Impairment threshold: 35
Lower CL: 26

MetricName	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 MN
Sites in northern Minnesota, excluding the Glacial Lake Agassiz Basin (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 CL: 59
Impairment threshold: 50
Lower CL: 41

MetricName	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 MN
Sites in northern Minnesota, excluding the Glacial Lake Agassiz Basin (GLAB) ecoregion, where watershed area is less than 50 square miles and gradient is greater than 0.5 m/km.

Examples

Twelve Mile Creek, Grove Creek, Flint Creek, Mayhew Creek, Tibbetts Brook, Shingle Creek, Little Ann River, Hardwood Creek, Barber Creek

Biocriteria

Upper CL: 56
Impairment threshold: 40
Lower CL: 24

MetricName	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 criteria

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, Zumbro River

Biocriteria

Upper CL: 41.5
Threshold: 30.7
Lower CL: 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, Zumbro River

Biocriteria

Upper CL: 48.5
Threshold: 35.9
Lower CL: 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, Wells Creek

Biocriteria

Upper CL: 60.4
Threshold: 46.8
Lower CL: 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), Yellow Medicine River

Biocriteria

Upper CL: 51.9
Threshold: 38.3
Lower CL: 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