Upper Red River of the North Watershed Biotic Stressor Identification Report

A study of local stressors limiting the biotic communities in the Upper Red River of the North Watershed.

Minnesota Pollution Control Agency

June 2016

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Cover photo: Farming the flood plain results in large amounts of crop residue washing off the land and accumulating at culverts within the watershed. This organic matter produces a high oxygen demand on the water as it decomposes reducing the levels of oxygen below that which can support healthy aquatic biological communities. Photo by author.

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Document number: wq-ws5-09020104a

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Acronyms

AUID - Assessment Unit Identification

BMP - Best Management Practices

CADDIS - Causal Analysis/Diagnosis Decision Information System

CD - County Ditch

DEM - Digital Elevation Model

DO - Dissolved Oxygen

EPA - United States Environmental Protection Agency

HUC - Hydrologic Unit Code

IBI - Index of Biological Integrity

IWM - Intensive Watershed Monitoring

LAP - Lake Agassiz Plain

MDA - Minnesota Department of Agriculture

MDNR - Minnesota Department of Natural Resources

MPCA - Minnesota Pollution Control Agency

MSHA - MPCA Stream Habitat Assessment

NCHF - North Central Hardwood Forest

NWI - National Wetland Inventory

SID - Stressor Identification

SOE - Strength-of-Evidence

SWCD - Soil and Water Conservation District

TMDL - Total Maximum Daily Load

TSS - Total Suspended Solids

URRW – Upper Red River of the North Watershed

WRAPS - Watershed Restoration and Protection Strategy

Executive summary

The Minnesota Pollution Control Agency (MPCA) utilizes biological (i.e., fish and macroinvertebrate) monitoring to assess stream health as part of its Intensive Watershed Monitoring (IWM) strategy. The MPCA conducted biological monitoring at 13 sites throughout the Upper Red River of the North Watershed (URRW) in 2008. The resulting data, along with previously collected data, was used to produce an Index of Biological Integrity (IBI) score for the fish (F-IBI) and macroinvertebrate (M-IBI) communities at each site. The biological monitoring results for the watershed were formally assessed as part of the development of the *Upper Red River of the North Watershed Monitoring and Assessment Report* (MPCA, 2013) http://www.pca.state.mn.us/index.php/view-document.html?gid=18986 to determine if individual stream reaches met applicable aquatic life standards. Each stream reach has one or more associated monitoring sites. A stream segment with a low IBI score (i.e., below an established threshold) is considered "impaired" (i.e. unable to support its designated beneficial use) for aquatic life. Whiskey Creek (Reach 520) was the only stream reach in the URRW that was determined to be biologically impaired; the reach has M-IBI impairment. Additionally, two reaches were not assessed due to insufficient information, while seven stream reaches were not assessed, primarily due to extensive channel alteration. No reaches in the watershed were found to be fully supporting a healthy fish and macroinvertebrate community.

The purpose of this report is to identify the causes, or "stressors", that are likely contributing to the biological impairments in the URRW (i.e. Whiskey Creek). A comprehensive review of available data (e.g. plans and reports) for the watershed was initially performed to identify the five candidate causes examined in this report. Further analysis was performed to determine potential connections between each candidate cause and the biological impairments. The results of the stressor identification (SID) process point to several probable stressors in the biologically impaired reach of the watershed. The following summarizes the probable stressors for the impaired reach:

Reach 520 – Whiskey Creek

(T133 R47W S13, east line to Red River/AUID 09020104-520)

M-IBI impairment stressors

- Altered hydrology
- Low dissolved oxygen
- Excess suspended sediment
- Lack of instream habitat

Introduction

Stressor identification (SID) is a formal and rigorous methodology for determining the causes, or "stressors", that are likely contributing to the biological impairment of aquatic ecosystems (EPA, 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred and draws upon a broad variety of disciplines, such as aquatic ecology, biology, geology, hydrology, geomorphology, chemistry, statistics, and toxicology. Figure 1 provides a conceptual model of the SID process.

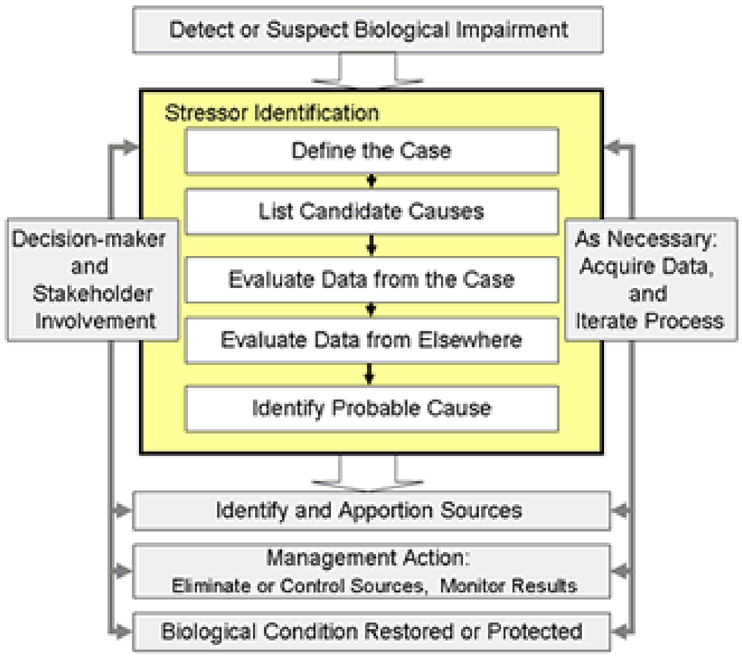

Figure 1. Conceptual model of the SID PR 1 (EPA, 2012).

The initial step in the SID process is to define the subject of the analysis (i.e. the case), by determining the geographic scope of the investigation and the effects that will be analyzed. Thereafter, a list of candidate causes (i.e. potential stressors), which may be responsible for the observed biological effects is developed. Each of the identified candidate causes then undergoes causal analysis, which involves the evaluation of available data. Typically, the majority of the data used in the analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon. Analyses conducted during this step combines measures of the biological response with direct measures of proximate stressors. Upon completion of causal analysis, strength-of-evidence (SOE) analysis is used to determine the most probable stressors for the biological impairment. Confidence in the final SID results often depends on the quality of data available to the process. In some cases, additional data collection may be necessary to accurately identify the stressors.

The five major elements of a healthy stream system are physical connectivity, hydrology, stream channel assessment, water chemistry, and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and a negative biological response often results.

Table 1 lists the common stream stressors to biology, relative to each of the major stream health categories.

Table 1. Common stream stressors to biology (i.e., fish and macroinvertebrates).

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

Section 1: Watershed overview

1.1 Physical setting

The URRW, United States Geological Survey Hydrologic Unit Code (HUC) 09020104, is located along the western border of central Minnesota. The URRW drains a total area of 580 mi² (371,689 acres) of which 75.9% or 441 mi² are located in Minnesota with the remainder located across the Red River in North Dakota.

The Minnesota portion of this well-drained lake plain watershed is comprised of two major subwatersheds: Whiskey Creek (165.6 mi²) and the Wolverton Creek, a.k.a. Comstock Coulee (105.5 mi²). The URRW also includes 134.1 miles of Red River mainstem, with a few small additional contributing subwatershed areas. The stretch of the Red River includes the portion that is bracketed by the Ottertail River on the south in Breckenridge, North Dakota, and the Buffalo River that discharges to the Red River one mile northwest of Georgetown, Minnesota (Figure 2).

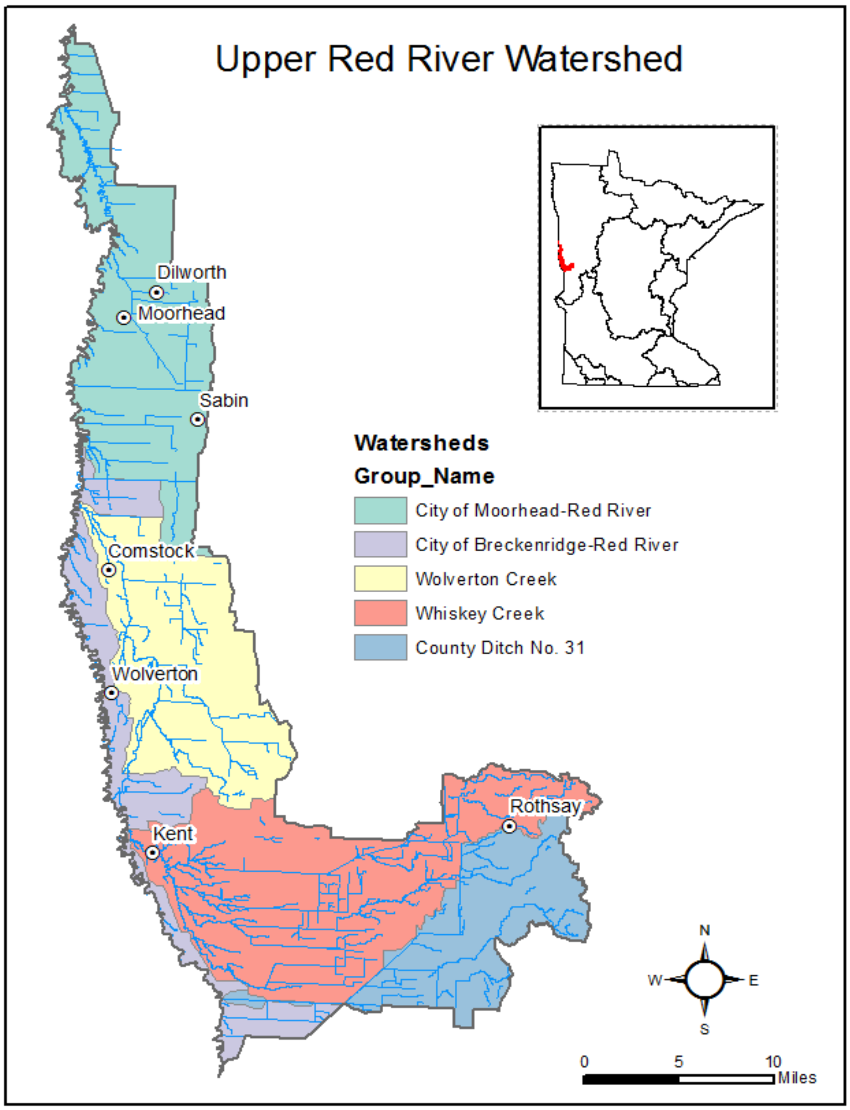

Figure 2. Map of Upper Red River Watershed.

The watershed is characterized by poorly defined floodplains, and low gradients that combine with extensive drainage, widespread conversion of tall grass prairie to farmland, and urban/suburban development. These conditions leave the watershed subject to frequent flooding that affect urban and rural infrastructure and agricultural production. The primary crops grown in the watershed include small grains, corn, sugar beets, and soybeans. Approximately 85% of the land is currently under agricultural production, while approximately 8% of the land use is comprised of residential and commercial development (HEI, Workplan).

The watershed is located in Clay, Wilken, and to a minor extent, Otter Tail counties. The Minnesota communities within the watershed include from north to south: Oakport, Moorhead, Sabin, Rustad, Comstock, Wolverton, Kent, Rothsay, and Breckenridge.

1.2 Surface water resources

The URRW is significantly drained for agricultural purposes, leaving the majority of the stream miles in the watershed, with the exception of the Red River, flowing only intermittently. County Ditch (CD) 6A delivers reliable base flow from the large wetland area west of Rothsay to the lower portion of Whiskey Creek, but the remainder of the system is typically dry outside of runoff events. The well-drained and flashy nature of this watershed results in water being delivered to the Red River relatively quickly following rainfall or snow melt events. This situation is discussed in more detail in the altered hydrology section of this report that includes a figure showing the 2014 Whiskey Creek hydrograph. According to the Statewide Altered Watercourse Project dataset (MPCA, 2013), 69.4% of the watercourses in the URRW have been altered by ditching or channelization. There are no lakes in the watershed.

1.3 Geology and soils

The majority of the URRW lies in the historic Lake Agassiz Plain ecoregion. This ecoregion represents the lake bed of Glacial Lake Agassiz, which receded from the area approximately 8,000 years ago. The lake plain is characterized by flat topography (0-3% slope) and deep, fertile, fine textured soils derived from lacustrine sediments. The Whiskey Creek Subwatershed is the only part of the URRW that has the classic three physiographic regions that are present in most of the subwatersheds within the Red River Basin. The till plain/glacial moraine region encompasses only the far eastern edge of the Whiskey Creek Subwatershed near Rothsay. This area is characterized by a rolling topography, interspersed with wetlands. The soils of this region vary in texture and were formed from glacial till deposited during the last glaciation approximately 12,000 years ago. The beach ridge lies west of the glacial moraine region and east of the lake plain and involves a north-south corridor approximately three to four miles wide. This region represents the ancient shorelines of Glacial Lake Agassiz. The soils of this region are coarse textured and derived from sand and gravel deposits. Soil and stream bank erosion can be a significant concern in this area.

1.4 Land use and ecoregions

The historic land cover in the URRW was tall grass prairie and wet prairie. This land was drained and plowed for agriculture during the late 1800s. The current land use is predominantly agriculture where 84.97% is cropland, 8.0% developed, 3.42% wetland, 2.06% rangeland, 0.84% forest/shrub, 0.75% open water, and 0.01% barren/mining (URRW Monitoring and Assessment Report, 2013).

There are two ecoregions represented in the URRW: the Lake Agassiz Plain (LAP) and the North Central Hardwood Forest (NCHF). However, a majority (>98%) of the watershed is located within the LAP ecoregion as the NCHF ecoregion is found only in the far eastern tip of the Whiskey Creek Subwatershed.

1.5 Ecological health

The Minnesota Department of Natural Resources (MDNR) has developed a web-based tool called the Watershed Health Assessment Framework to assess the overall ecological health of a watershed. The tool evaluates and provides a score to each of the five core components of watershed health: hydrology, geomorphology, biology, connectivity, and water quality. Scores are ranked on a scale from 0 (extremely poor) to 100 (extremely good). Statewide mean health scores ranged from 40 (Marsh River Watershed) to 84 (Rapid River Watershed). Figure 3 presents the watershed health scorecard for the URRW.

The mean health score for the URRW was 41. The overall score was limited by the individual mean component scores for biology (35) and connectivity (21). Specifically, the watershed scored poorly for the following component indexes: terrestrial habitat quality (2), terrestrial habitat connectivity (2), perennial cover (6), non-point source (10), storage (20) and riparian connectivity (23). Attempts to restore the health of this watershed and stream system should focus on improvements to these areas.

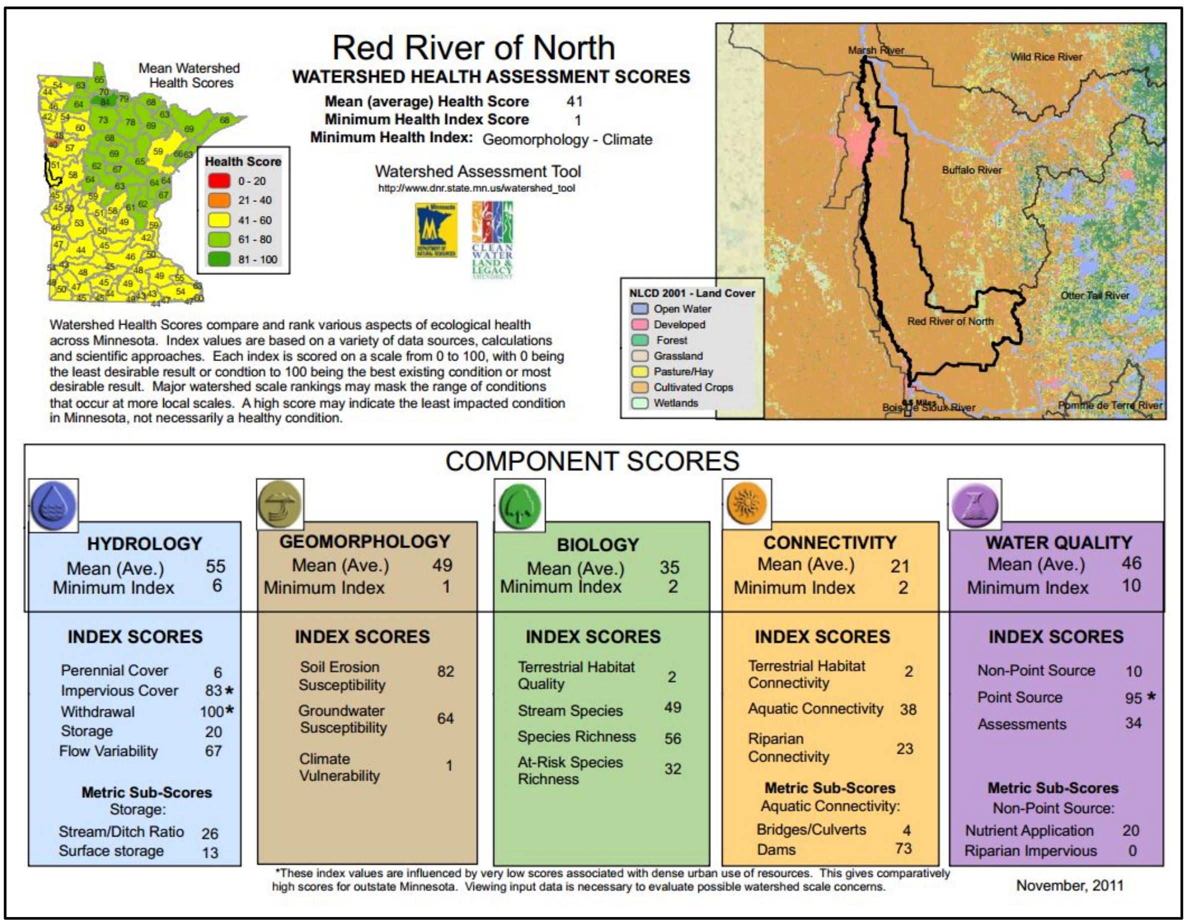

Figure 3. Watershed health assessment scores for the URRW.

Section 2: Biological monitoring and impairments

2.1 Intensive watershed monitoring approach

The MPCA utilizes biological (i.e., fish and macroinvertebrate) monitoring to assess overall stream health as part of its IWM strategy. In 2008, the MPCA conducted biological monitoring at several sites throughout the URRW. The resulting data, along with previously collected monitoring data, were used to produce an IBI score for the F-IBI and M-IBI communities of each site. An assessment of the monitoring results was then performed to identify individual stream reaches within the watershed that were not supporting healthy fish and macroinvertebrate assemblages. A stream segment with a low IBI score(s) (i.e. below an established threshold) is considered "impaired" (i.e. unable to support its designated beneficial use) for aquatic life. The biological impairments of the URRW are the focus of this SID report. Upon completion of the SID process, the results will be used to guide the development of implementation strategies to correct the impaired conditions, which may involve the preparation of a Total Maximum Daily Load (TMDL) study. Figure 4 displays a conceptual model of these processes.

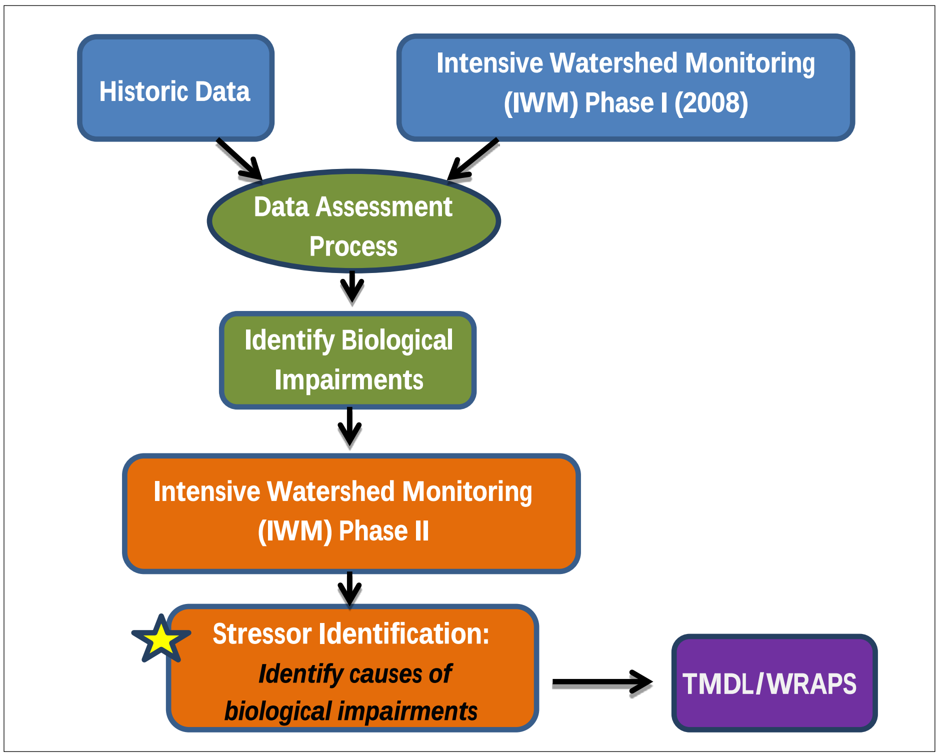

Figure 4. Conceptual model of the IWM, data assessment, SID, and implementation processes.

2.2 Monitoring sites

Table 2 lists the 13 biological monitoring sites in the URRW. The location of the monitoring sites is displayed in Figure 5. In addition to the sites shown in Table 2 there are three sites on the mainstem of the Red River that were sampled in 2006. These sites will be studied in a separate effort specific to the Red River of the North. Therefore the results will not be a part of this report.

Table 2. List of biological monitoring sites in the URRW.

Biological Station Information for the Upper Red River Watershed						
Subwatershed	**Reach Name**	**Biolocial Station ID**	**AUID #**	**Location**	**Drainage Area (Mi^2)**	**Reach Length (Mi)**
Whiskey Creek	Trib to Whiskey Ck	08RD060	09020104-516	1.5 mi. SE of Kent	65.95	3.6
	Whiskey Creek	08RD052	09020104-520	In Kent	144.92	20.0
	Trib to Red River	08RD067	09020104-537	4 mi. N of Breckenridge	71.47	5.0
	County Ditch 23	08RD056	09020104-531	3.5 mi. NE of Brushvale	18.07	5.5
	County Ditch 1	08RD057	09020104-533	2 mi. N of Brushvale	31.31	1.0
	Unnamed Creek	08RD079	09020104-518	2 mi. E of Rothsay	10.51	5.0
	County Ditch 6A	08RD076	09020104-523	7 mi. SW of Rothsay	26.34	0.5
	County Ditch 6A	05RD033	09020104-524	~6 miles SW of Rothsay	26.76	1.8
	Trib to Whiskey Ck	98RD054	09020104-516	2 mi. E of Kent	48.41	3.6
Comstock Coulee	Wolverton Creek	08RD051	09020104-512	7 mi. NW of Comstock	100.46	12.7
	County Ditch 22	08RD065	09020104-538	3 mi. E of Wolverton	19.22	2.4
	Wolverton Creek	08RD063	09020104-512	1.5 mi. NE of Comstock	94.06	12.7
Red River of the North	County Ditch 41	08RD072	09020104-539	in Dilworth	9.57	3.0

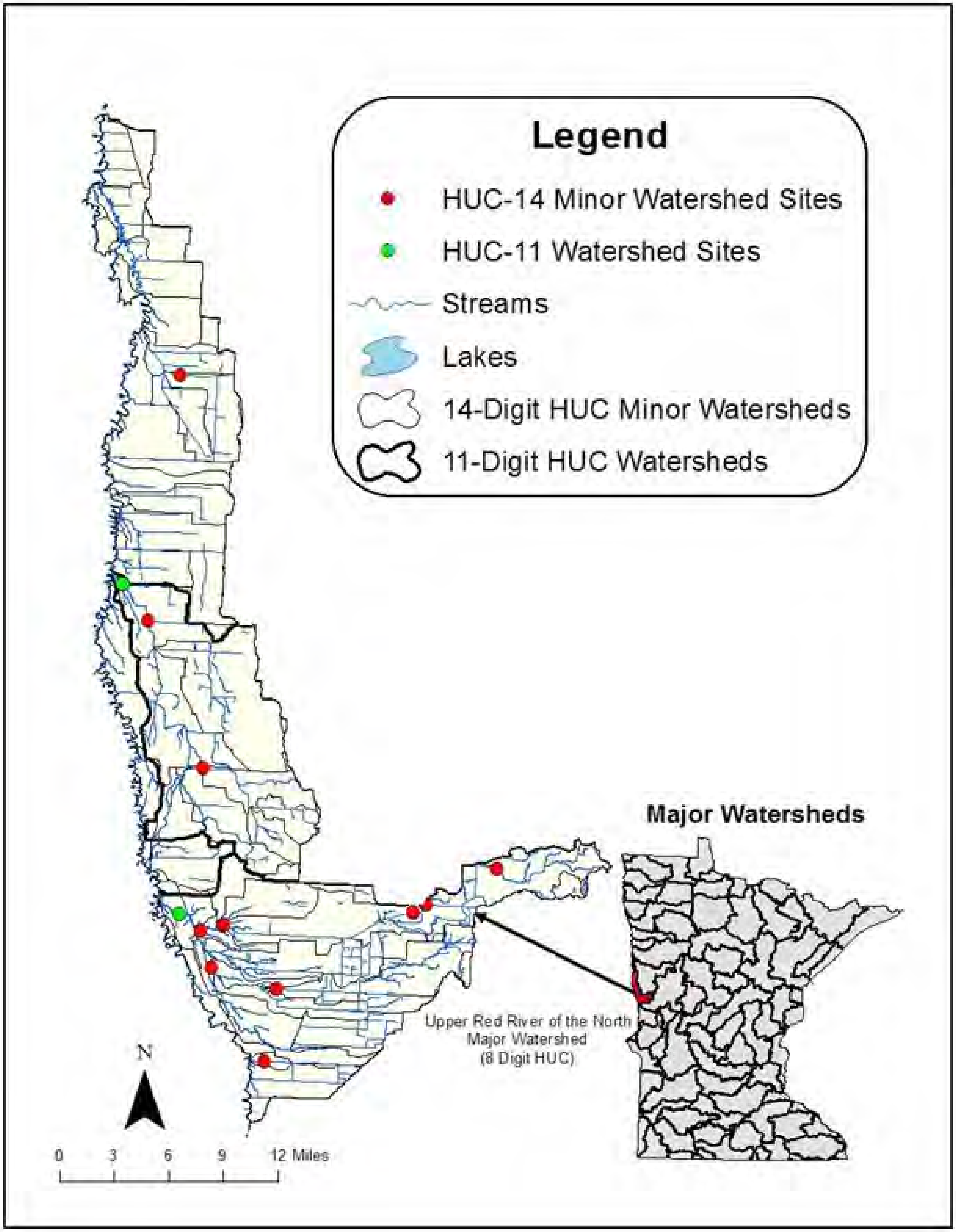

Figure 5. Biological monitoring stations in the Upper Red River Watershed.

2.3 Monitoring results

Fish monitoring results

Table 3 provides the F-IBI scores for each of the monitoring sites in the URRW. The F-IBI scores varied throughout the watershed, with one site exceeding the upper confidence limit for its respective class and five additional sites exceeded the IBI threshold for a healthy fish community. Seven sites fell below the applicable IBI threshold and four of those sites scored below the lower confidence limit for their class, indicating a poor fish community. The seven scores that failed to meet their applicable F-IBI standard are highlighted red.

Table 3. Summary of F-IBI scores for monitoring sites in the URRW.

Fish IBI Summary Information for the Upper Red River Watershed								
Subwatershed	**Waterbody**	**Biolocial Station ID**	**Drainage Area (Mi^2)**	**Fish Class**	**# Visits**	**F- IBI Average**	**F- IBI Threshold**	**Confidence Limits lower/upper**
Whiskey Creek	Trib to Whiskey Ck	08RD060	65.95	2	1	52	45	36/54
	Whiskey Creek	08RD052	144.92	2	1	53	45	36/54
	Trib to Red River	08RD067	71.47	2	2	9	45	36/54
	County Ditch 23	08RD056	18.07	3	1	0	51	44/58
	County Ditch 1	08RD057	31.31	2	1	42	45	36/54
	Unnamed Creek	08RD079	10.51	3	1	57	51	44/58
	County Ditch 6A	08RD076	26.34	3	1	71	51	44/58
	County Ditch 6A	05RD033	26.76	3	1	57	51	44/58
	Trib to Whiskey Ck	98RD054	48.41	2	2	44.5	45	36/54
Comstock Coulee	Wolverton Creek	08RD051	100.46	2	1	43	45	36/54
	County Ditch 22	08RD065	19.22	7	2	9	40	25/39
	Wolverton Creek	08RD063	94.06	2	1	54	45	36/54
Red River of the North	County Ditch 41	08RD072	9.57	7	1	0	40	25/39

Macroinvertebrate monitoring results

Table 4 contains the M-IBI scores for each of the monitoring sites in the URRW. Similar to the fish monitoring results, M-IBI scores varied throughout the watershed. No sites scored above the upper confidence limit for their respective class, while 11 sites scored below the lower confidence limit for their class. All 13 sites failed to meet their applicable M-IBI standard (highlighted red).

Table 4. Summary of M-IBI scores for monitoring sites in the URRW.

Macroinvertebrate IBI Summary Information for the Upper Red River Watershed								
Subwatershed	Waterbody	Biolocial Station ID	Drainage Area (Mi^2)	Invert Class	# Visits	M-IBI Average	M-IBI Threshold	Confidence Limits lower/upper
Whiskey Creek	Trib to Whiskey Ck	08RD060	65.95	7	1	5.71	40	24.7/51.9
	Whiskey Creek	08RD052	144.92	7	1	9.39	40	24.7/51.9
	Trib to Red River	08RD067	71.47	5	1	9.1	35.9	23.3/48.5
	County Ditch 23	08RD056	18.07	7	1	4.08	40	24.7/51.9
	County Ditch 1	08RD057	31.31	7	1	6.13	40	24.7/51.9
	Unnamed Creek	08RD079	10.51	7	1	18.21	40	24.7/51.9
	County Ditch 6A	08RD076	26.34	7	2	37.48	40	24.7/51.9
	County Ditch 6A	05RD033	26.76	7	1	24.16	40	24.7/51.9
	Trib to Whiskey Ck	98RD054	48.41	7	1	12.88	40	24.7/51.9
Comstock Coulee	Wolverton Creek	08RD051	100.46	7	1	30.83	40	24.7/51.9
	County Ditch 22	08RD065	19.22	7	1	21.35	40	24.7/51.9
	Wolverton Creek	08RD063	94.06	7	1	16.56	40	24.7/51.9
Red River of the North	County Ditch 41	08RD072	9.57	7	1	12.9	40	24.7/51.9

2.4 Assessments and impairments

The biological monitoring results for the URRW were formally assessed as part of the development of the Upper Red River Watershed Monitoring and Assessment Report (MPCA, 2013) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 5, there are 13 reaches in the watershed with associated biological monitoring data. For the purpose of this report, individual reaches will be referred to by their respective three digit Assessment Unit Identification (AUID) number suffix. A total of two reaches were assessed (516 and 520): both were supporting healthy fish communities, while Reach 520 was biologically impaired for macroinvertebrates and is highlighted red. The assessments for many of the remaining reaches were deferred due to either insufficient information or extensive channelization. Those that are channelized will be re-assessed during the next IWM cycle using the MPCA's proposed Tiered Aquatic Life Use standards. The "Not Assessed – Channelized" status of 10 of the 13 AUIDs is indicative of the significantly altered condition of this watershed. The only reach that was found to be assessable and non-supportive of aquatic life was Whiskey Creek (Reach 520) which will be the entire focus of the remainder of this report.

Table 5. Assessment results for stream reaches with biological monitoring data in the URRW.

Subwatershed	Reach ID #	AUID #	Waterbody	Biolocial Station ID	Reach Length (Mi)	Biological Impairments
Whiskey Creek	516	09020104-516	Trib to Whiskey Ck	08RD060	3.6	Not Assessed - Insufficient Information
	520	**09020104-520**	**Whiskey Creek**	**08RD052**	**20.0**	**M-IBI**
	537	09020104-537	Trib to Red River	08RD067	5.0	Not Assessed - Channelized
	531	09020104-531	County Ditch 23	08RD056	5.5	Not Assessed - Channelized
	533	09020104-533	County Ditch 1	08RD057	1.0	Not Assessed - Channelized
	518	09020104-518	Unnamed Creek	08RD079	5.0	Not Assessed - Channelized
	523	09020104-523	County Ditch 6A	08RD076	0.5	Not Assessed - Channelized
	524	09020104-524	County Ditch 6A	05RD033	1.8	Not Assessed - Channelized
	516	09020104-516	Trib to Whiskey Ck	98RD054	3.6	Not Assessed - Channelized
Comstock Coulee	512	09020104-512	Wolverton Creek	08RD051	12.7	Not Assessed - Insufficient Information
	538	09020104-538	County Ditch 22	08RD065	2.4	Not Assessed - Channelized
	512	09020104-512	Wolverton Creek	08RD063	12.7	Not Assessed - Channelized
Red River of the North	539	09020104-539	County Ditch 41	08RD072	3.0	Not Assessed - Channelized

In addition to the biological impairment, there are also two reaches in the URRW that are listed for water quality impairments affecting aquatic life (Table 6). Whiskey Creek (AUID 520) is listed for turbidity, dissolved oxygen (DO), E. coliform and fecal coliform. Wolverton Creek (AUID 501) is listed for both low DO and turbidity. These impairments will be addressed in the Watershed Restoration and Protection Strategy (WRAPS) Report that will include a TMDL for bringing each of the impaired parameters back into compliance with state water quality standards.

Table 6. Upper Red River Watershed aquatic life and recreation impairments.

Listed Reach Name and Description	Reach ID #	Listed Pollutant	Impaired Use	303(d) List Scheduled Start Dates
Whiskey Creek	520	Fecal Coliform	Aquatic Recreation	2008
Whiskey Creek	520	Dissolved Oxygen	Aquatic Life	2010
Whiskey Creek	520	E. coli	Aquatic Recreation	2012
Whiskey Creek	520	Turbidity	Aquatic Life	1996
Wolverton Creek	501	Dissolved Oxygen	Aquatic Life	2012
Wolverton Creek	501	Turbidity	Aquatic Life	2012

Section 3: Stressor identification

3.1 Identification of candidate causes

A candidate cause is defined as a "hypothesized cause of an environmental impairment that is sufficiently credible to be analyzed" (EPA, 2012). Identification of a set of candidate causes is an important early step in the SID process and provides the framework for gathering key data for causal analysis. Table 6 lists the nine common biotic stressors that were considered as potential candidate causes in the Whiskey Creek Subwatershed. The list was developed based upon the results of the Red River Valley Biotic Impairment Assessment (EOR, 2009) and other completed SID reports in the State.

The document produced by Emmons and Olivier, Inc. for the MPCA (EOR, 2009) investigated and discussed stressors across the entire Red River Basin (RRB), with an additional closer focus on the Buffalo River Watershed. The stressors defined in this report are likely to occur in most of the RRB watersheds, especially within the Lake Agassiz Plain region, due to the similarities of geographical patterns, land use, and soils. The report listed: "...instream sediment from field and gully erosion, intermittent stream flow, channelization, pesticides, low DO, high temperature, and fish passage blockage" as being the most likely/influential stressors in the RRB (see EOR 2009, Table 22, where relative rankings of each stressor were made based on stream drainage area categories).

The credibility of each stressor as a candidate cause was evaluated through a comprehensive review of available information for the Whiskey Creek Subwatershed, including biology, water quality, hydrology, soils, landuse, as well as existing plans and reports, including the Upper Red River Watershed Monitoring and Assessment Report (MPCA, 2013), the Buffalo Red River Watershed District's Revised Watershed Management Plan Update (Buffalo Red River Watershed District, 2010), the Project No 56, Manston Slough Restoration Report, and the MN Agriculture Water Quality Certification Program Pilot Project Whiskey Creek/Wilken CD No. 31 Watershed Report. Based upon the results of this evaluation (Table 7), five candidate causes were identified to undergo causal analysis (Section 3.2). The remainder of this report will focus on Whiskey Creek as it is the only assessable bio-impaired reach in the URRW.

Table 7. Summary of common biotic stressors evaluated as candidate causes in Whiskey Creek.

Stressor	Candidate Cause Identification for Whiskey Creek	
	Summary of Available Information	Candidate Cause (Yes/No)
Loss of Physical Connectivity	There are no existing dams or perched culverts on the Whiskey Creek.	No
Flow Regime Alteration	The natural hydrology of Whiskey Creek has been highly altered for agricultural drainage-related purposes and there is sufficient evidence of associated	**Yes**
Lack of In-stream Habitat	There is a documented lack of available in-stream habitat for the macroinvertebrate communities of Whiskey Creek.	**Yes**
Excess Suspended Sediment	There is an existing turbidity impairment associated with the Whiskey Creek.	**Yes**
Low Dissolved Oxygen	There is sufficient low DO data for this Creek to consider low DO a candidate cause. Whiskey Creek is listed as impaired for DO.	**Yes**
Pesticide Toxicity	No pesticide data exists for the Whiskey Creek Subwatershed. There is insufficient information to determine the role pesticide toxicity may have on the	**Yes**
Nutrient (Nitrogen and Phosphorus) Regime Alteration	Phosphorus is not directly toxic to aquatic life, but can cause secondary effects (i.e., low DO). Nitrogen concentrations were below levels expected to cause	No
Temperature Regime Alteration	Temperature values were within a range that is not expected to cause stress to aquatic life.	No
pH	Values for pH were within a range that is not expected to cause stress to aquatic life.	No

3.2 Causal analysis

Candidate cause #1: Flow regime alteration

Background

Flow alteration is the change of the stream flow volume and flow pattern caused by anthropogenic activities, which include channel alteration, water withdrawals, wetland drainage, land cover alteration, agricultural tile drainage, and impoundment creation. Changes in landscape vegetation, pavement, and drainage have increased the speed of which rainfall runoff reaches stream channels. This creates a stronger pulse of flow, followed later by decreased baseflow levels. According to Poff et al. (1997), "Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems. Indeed, streamflow, which is strongly correlated with many critical physicochemical characteristics of rivers, such as water temperature, channel geomorphology, and habitat diversity, can be considered a 'master variable'…."

Reduced flow

Fish and macroinvertebrate species have many habits and traits that can be helpful or detrimental in different flow conditions and will either respond positively or negatively with reduced flow. Across the United States, Carlisle et al. (2011) found that there is a strong correlation between diminished streamflow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to decreased wetted width, cross sectional area, water depth and volume. Flows which are reduced beyond normal baseflow decrease living space for aquatic organisms and competition for resources increase. Pollutant concentrations can increase when flows are lower than normal, increasing the dosage of exposure to organisms. Organisms tolerant of degraded conditions will often out-compete others in such limiting situations and thrive. Low flows of prolonged duration lead to macroinvertebrate and fish communities comprised of generalist species or that have preference for standing water (EPA, 2012a).

In their review paper on low-flow effects on macroinvertebrates, Dewson et al. (2007) found that responses were complex, and not easy to generalize. Some cited studies showed increased density, and others decreased. More often, the behavior called drift (using the current to be transported to a new location) increased. Many studies reported changed species composition, and taxonomic richness generally decreased in streams experiencing prolonged low flows. Those macroinvertebrates that filter food particles from the water column have shown negative responses to low flows. Species which actively swim may increase in abundance. The United States Environmental Protection Agency's (EPA) Causal Analysis/Diagnosis Decision Information System (CADDIS) website (EPA, 2012a) lists the responses of reduced flow as lower total stream productivity, elimination of large fish, changes in taxonomic composition of fish communities, fewer migratory species, fewer fish per unit area, and more concentrated aquatic organisms, potentially benefiting predators.

Increased flow

Increasing surface water runoff and seasonal variability in stream flow have the potential for both indirect and direct effects on fish populations (Schlosser, 1990). Indirect effects include alteration in habitat suitability, nutrient cycling, production processes, and food availability. Direct effects include decreased survival of early life stages and potentially lethal temperature and oxygen stress on adult fish (Bell, 2006). Increased flow volume increases channel shear stress, which results in increased scouring and bank destabilization, which negatively impact the fish and macroinvertebrate communities via loss of habitat, including habitat smothering by excess sediment. Fish species that have streamlined body forms experience less drag under high velocities and will have advantage over non-streamlined fish species (Blake, 1983). High flows can also cause the displacement of fish and macroinvertebrates downstream due to high flow velocity and mobilization of habitat features such as woody debris, which form flow refuges for fish and a living surface for clinging invertebrates. Macroinvertebrate types may shift from those species having long life cycles to shorter ones; species that can complete their life history within the bounds of the recurrence interval of the elevated flow conditions (EPA 2012a).

The natural hydrology of Whiskey Creek has been highly altered, primarily to expedite drainage for agricultural purposes. Examples of such alterations include ditching, channelization of natural streams, modification or cultivating through headwater streams, subsurface tiling, and wetland drainage. While hydrologic changes have been occurring since European settlement, there has been a recent increase in drainage with an expansion of tiling use and the increased intensity of agricultural.

According to Mitch and Gosselink (2007), agricultural drainage practices can alter the natural flow regime of streams, resulting in increased and quicker peak discharges following rain events and reduced baseflow during dry periods. Verry (1988) found that bank-full flows increased as much as four times when 30% or more of the watershed was drained. Similarly, Miller (1999) estimated a four-fold increase in bank-full flow rates in an intensively drained watershed in southern Minnesota compared to pre-European conditions.

High flows can directly result in the displacement of fish and macroinvertebrates downstream if they are unable to move into tributaries or refuges along the margins of the river, or if refuges are not available. Additionally, the intensification of channel shear stresses associated with increased flows can cause the mobilization of sediment, woody debris, and plant materials, as well as increased channel scouring and bank destabilization. These effects often negatively impact in-stream habitat and turbidity.

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for flow regime alteration as a candidate cause for impairment.

Applicable standards

There currently is no applicable state of Minnesota standard for flow alteration, however; the Buffalo Red River Watershed District has adopted rules and regulations that require all landowners, governmental units, and other public entities to obtain a permit for most drainage-related activities. Examples of activities that require a permit from the District include:

- Tiling
- Surface drainage (new ditch or improvement)
- Culvert installation/removal/modification
- Bridge installation/removal/modification
- Wetland restoration or other water retention related structures (including water and sediment control basins)
- Road grading
- Dike/levee (including ring dikes)
- Channel stabilization or restoration, erosion control, and other water related facilities

Altered hydrology can contribute to changes in the concentrations of chemical parameters (i.e. turbidity and DO) that do have standards and mitigating altered hydrology can be an implementation strategy for resolving a chemical standard impairment.

Available data

Types of flow alteration data

Stream gauging stations are located in each major watershed of the state. They have differing lengths of monitoring history, and some are very new. In some cases, models can be used to predict the degree of hydrologic alteration in a watershed or subwatershed when measured data is not available. Modelers at the MPCA have suggested that determining flow alteration in Red River Basin streams would be very difficult, due to the high degree of landscape and stream modification here. An indirect determination of flow alteration can be found via geomorphological measurements as channel form and dimension are related to flow volumes.

Public ditch systems

There is an extensive network of approximately 68 miles of legal (County) ditches that contribute water to Whiskey Creek. These systems include CD 1A, CD 1B, CD 1C, CD 1C-1, CD 6A, CD 6A-1, CD 12, CD 23, CD 23-1, CD 28, CD 28-1, and CD 34. The Buffalo Red River Watershed District website has a complete file available for viewing that includes digital Geographic Information System (GIS) aerial and topographic maps of each legal ditch as well as the watershed scale on their GIS viewer. Figure 6 displays a map of the ditch systems (altered watercourses) as well as the natural streams remaining within the Whiskey Creek Subwatershed. The figure shows a highly altered system with only a few remnant natural stream sections remaining. Whiskey Creek, from east of Brushvale to the outlet into the Red River, is the largest remaining natural stream course in the subwatershed.

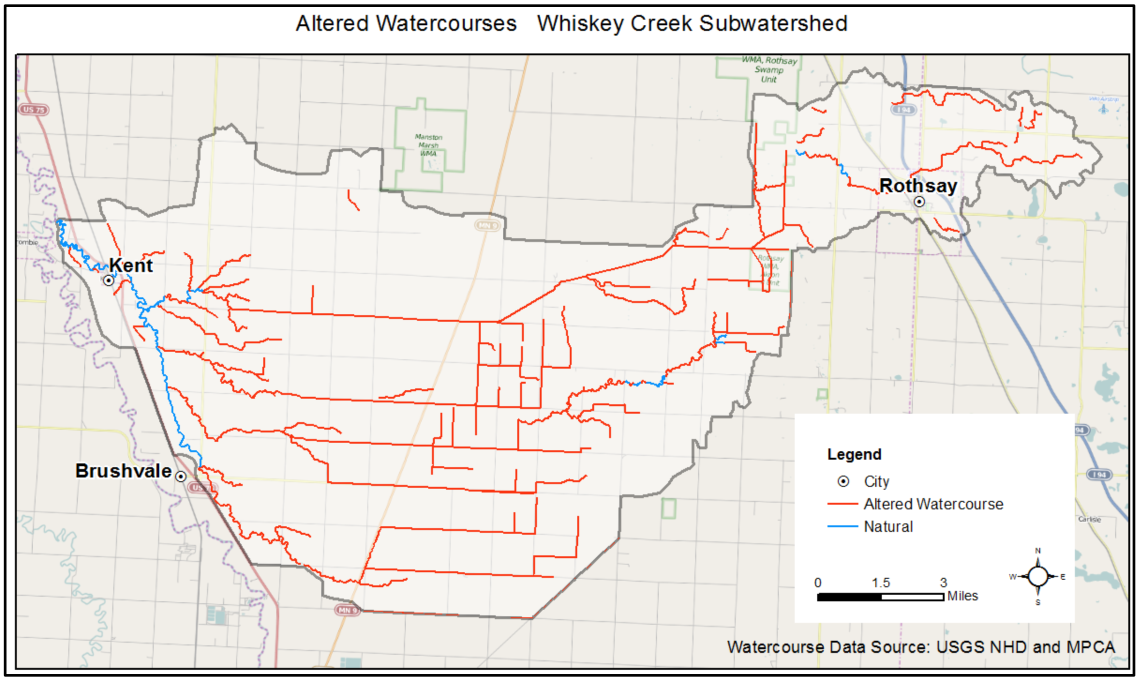

Figure 6. Ditches and remaining natural stream channels in the Whiskey Creek Subwatershed.

Ditching/channelization

According to the Minnesota Statewide Altered Watercourse Project dataset (MPCA, 2013), 69.4% of the URRW has been ditched or channelized. Figure 7 shows the URRW percent of modified streams in relation to the rest of the State.

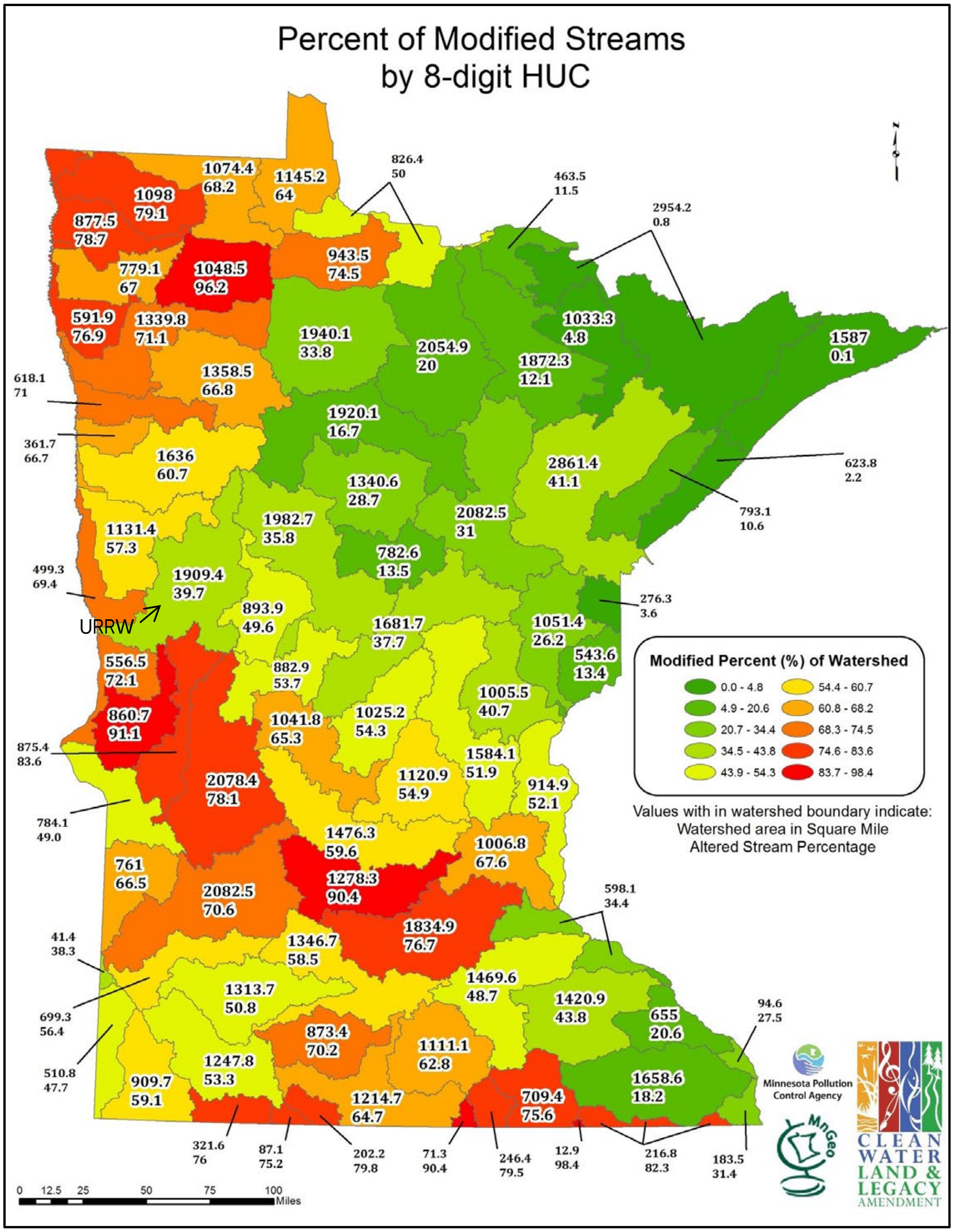

Figure 7. Percent altered watercourse map of Minnesota.

Modification of headwater streams

Headwater streams (i.e., first, second, and third order streams) connect the upland and riparian landscape to the rest of the stream ecosystem (Freeman et al., 2007). These streams typically comprise over two-thirds of the total stream length in a typical river network (Leopold et al., 1964). In a natural state, headwater streams serve several important ecological and hydrological functions (e.g., habitat, flow regime stability, and sediment and nutrient retention).

Agriculture is the predominant land use in the Whiskey Creek Subwatershed where nearly 85% of the land area is cultivated for crop production. Consequently, most of the headwater streams in the subwatershed are farmed-through and/or have been channelized for agricultural drainage-related purposes. These modified streams have lost most of their inherent natural functions and rapidly convey agricultural runoff (including flow, sediment, and nutrients) to receiving waters. Figure 8 shows an aerial image of modified headwater streams in agricultural fields within the Whiskey Creek Subwatershed.

Figure 8. Aerial image of farmed-through headwater streams within the Whiskey Creek Subwatershed courtesy of Google Earth.

Subsurface drainage

While it is believed that the amount of subsurface tile installed by agricultural landowners in the URRW has increased in recent years, there is no available inventory of the spatial extent of this practice.

Wetland drainage

Table 8 provides National Wetland Inventory (NWI) data for the drainage areas of the biologically impaired Whiskey Creek Subwatershed. The NWI indicates that there are 3,050 acres of wetlands remaining in the subwatershed. The most prevalent wetland types are 2 (1,991 acres) and 3 (591 acres). These wetlands are located primarily in the upstream portion of the Whiskey Creek Subwatershed as shown in blue on Figure 9. This large area of wetland is an important hydrologic feature in this subwatershed as it supplies the only reliable source of base flow to this system. County Ditch (CD) 6A brings this flow west into Whiskey Creek immediately upstream of the MPCA flow monitoring station (S001-061) and approximately four river miles from the confluence of Whiskey Creek with the Red River.

According to the Restorable Depressional Wetland Inventory, there are 2,350 acres of restorable wetlands in the Whiskey Creek Subwatershed. The drainage/loss of these wetlands, many of which were closed basins, has reduced the water storage capacity of the landscape and this has impacts to both peak and low flows within the system.

Table 8. NWI data for the Whiskey Creek Subwatershed.

Wetland Type (Circular 39)	Count	Acres	Wetland Type (Circular 39)	Count	Acres
1 - Seasonal Flooded Basin	292	191	5 - Shallow Open Water	28	34
2 - Wet Meadow	26	1991	6 - Shrub Swamp	21	156
3 - Shallow Marsh	164	591	7 - Wooded Swamp	20	40
4 - Deep Marsh	11	37	8 - Bog	1	10

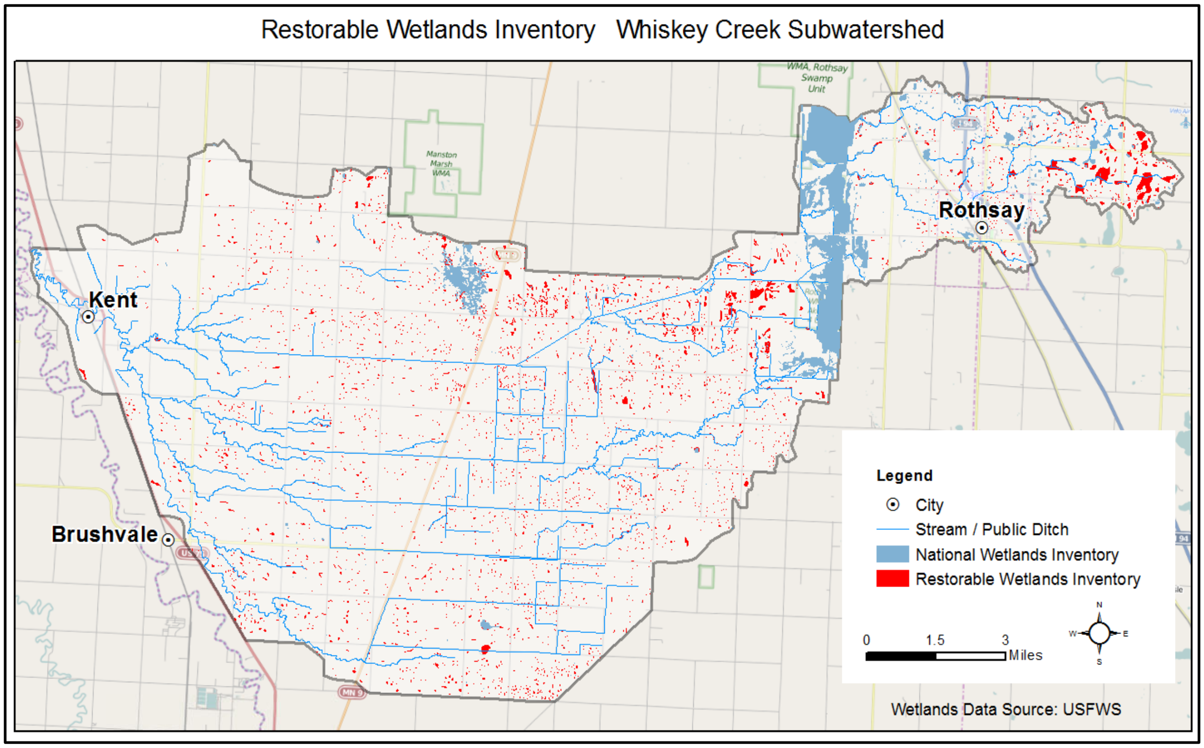

Figure 9. NWI and restorable wetlands in the Whiskey Creek Subwatershed.

Precipitation

The hydrologic conditions present during the 2008 water year when macroinvertebrate samples were collected on Whiskey Creek are important to the discussion regarding altered hydrology. The Minnesota precipitation totals map for 2008 is presented in Figure 10. In addition, the precipitation departure from normal map is also provided in Figure 11 to put the data into perspective.

These maps indicate that Wilken County and the Whiskey Creek Subwatershed were significantly wetter than normal during 2008 when the biological data used to determine the impairment was collected. The data indicate that 10 inches or more of additional precipitation fell during 2008 than in normal years. Precipitation data for 2014 from a Breckenridge station indicates that 27.63 inches fell during the year with over half of the annual total (13.9 inches) coming during April (3.74 inches), May (3.72 inches), and June (6.46 inches) of 2014.

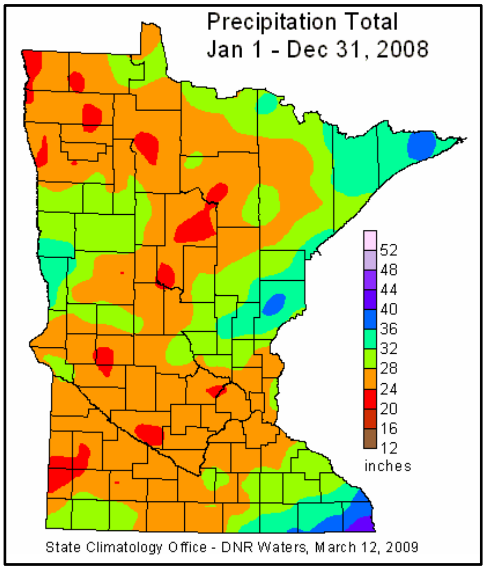

Figure 10. 2008 Minnesota precipitation totals map from (Source MDNR waters).

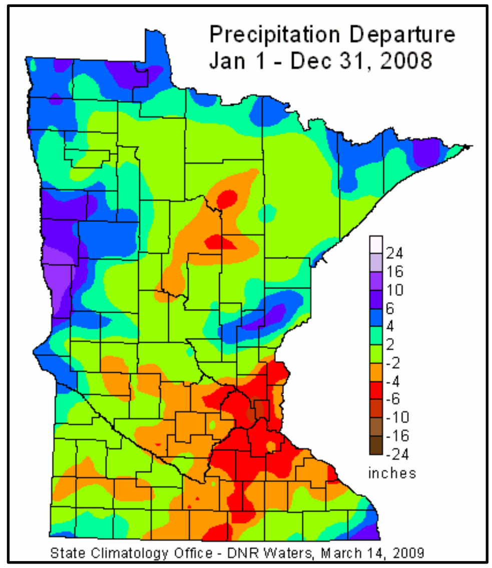

Figure 11. 2008 Minnesota precipitation departure normal map (Source MDNR waters)

Stage and flow

Whiskey Creek was considered for flow monitoring in 2003 when the author developed the Red River Basin Pollutant Load Monitoring Program. During the spring, flow proportional sample collection began at 18 major Minnesota tributaries along with six mainstem Red River sites. Whiskey Creek was one of several minor tributaries (including Wolverton Creek) that were considered for monitoring for this program; however, it was eliminated from consideration because it was too small of a tributary, with a relatively minor contribution of flow to the Red River system. In addition, Whiskey Creek is considered very flashy and when it does flow in the spring and/or during summer storm events, it often has backwater issues with the Red River at what was considered the preferred flow monitoring location.

In 2014, the MPCA installed a flow station in Whiskey Creek about one mile southeast of Kent on the 240th Street Bridge in an effort to document flow conditions for the purpose of this watershed study. The station is equipped with ultrasonic stage detection, a solar panel, battery and stage recorder. Three flow measurements were taken at the site during the summer and fall; however, this data is insufficient to construct a rating curve. Figure 12 provides the stage and precipitation data for the 2014 growing season. This figure shows the rapid stage pulse following storm events that are typical of flashy systems. The lack of storage and base flow in the system is also expressed by how rapidly the system dewaters following the 13.9 inches of precipitation that fell from April through June.

The late August and early September stage data appears to be influenced by a downstream obstruction as the stage remains uncharacteristically high during this period. It is believed that a beaver dam that was created downstream of the station is responsible for the shift in stage. It appears that it may have been removed causing the sharp drop in stage and then reconstructed in mid-September.

Figure 12. Whiskey Creek stage and precipitation data for 2014.

Biotic response

M-IBI impairment - Whiskey Creek

Most stream macroinvertebrate taxa inherently lack the ability to rapidly respond to and recover from the effects of extreme flow changes (Gore et al., 2001). The flow regime of Whiskey Creek has been substantially altered by ditching, channelization and wetland loss and is considered excessively flashy with extreme peaks and a lack of base flow for the majority of the stream length. These conditions are not favorable for most macroinvertebrate taxa and are likely contributing to the lack of macroinvertebrate diversity within this portion of Whiskey Creek. The M-IBI score for the Whiskey Creek monitoring site in Kent (08RD052) was 9.39, substantially below the invertebrate Class 7 threshold of 40.

A field reconnaissance survey was conducted on Whiskey Creek by the author and MPCA SID scientist Mike Sharp on July 31, 2014. The survey involved longitudinal sonde sampling, watershed and stream observations, and macroinvertebrate sampling. During this sampling, there was no flow present within the upper 75% of Whiskey Creek. Streamflow was present at the 240th Street Bridge which is downstream of the CD 6A discharge point into Whiskey Creek. An estimated two cubic feet per second of base flow was being delivered by CD 6A to the system about one mile upstream of Kent. The upper portion of Whiskey Creek on this day and for much of the remainder of the summer and fall was made up of a series of isolated pools. Figure 13 shows a photo taken during this July 31, 2014, field work on the upstream side of the 250th Street road crossing. The stream was a series of isolated pools from this road all the way to the upstream headwaters of Whiskey Creek.

Figure 13. Whiskey Creek at 250th Street Road crossing on July 31, 2014.

Macroinvertebrate sampling during the July 31, 2014, field work found a relatively consistent invertebrate community at the three sites on Whiskey Creek that were sampled. These sites were located (in order from upstream to downstream) at 250th Street, 240th Street, and near Main Street in Kent at the impaired bio-site 08RD052; all near the lower end of the Creek. The samples primarily consisted of crayfish, damselflies, dragonflies, snails, water boatman, water beetles, and freshwater shrimp. This community of macroinvertebrates is similar to the community collected during the 2008 sampling event when 91.3% of the taxa sampled were pollutant tolerant. It should be noted that the site at 250th Street (Figure 13) was the only site that had no flow present and consisted of isolated pools; however, all three sites had the same pollutant tolerant macroinvertebrate community. These taxa don't require moving water among their habitat needs and can survive in remnant pools when the flow stops during the intermittent periods, such as was the case for most of Whiskey Creek.

The 2014 precipitation and stage data (Figure 12) show that even following an extremely wet spring and early summer (13.9 inches of rain during April through June), the highly altered watershed quickly delivered the runoff to the Red River and was at base flow roughly a week following the end of this wet period. The evidence provided suggests that the biological impairment in Whiskey Creek is due, in part, to the frequent intermittency this system experiences. The macroinvertebrate sensitive taxa (e.g., Ephemeroptera, Plecoptera, and Trichoptera (EPT)) are simply unable to survive the rapid reduction in flow and sustained zero flow conditions that characterize this flashy system. Nearly all EPT taxa have delicate, external gills that cannot dry out and must have moving water continually deliver oxygen to them. The fact that these periods of intermittent conditions persist immediately following unusually wet periods is a direct indictor of the degree of hydrologic alteration within this subwatershed.

The lack of sensitive taxa is indicative of the repeated occurrence of this phenomenon and a lack of opportunity for the macroinvertebrates to re-colonize the stream from nearby refuge habitat. Those macroinvertebrates that remain in pooled-up water within the creek are wetland-oriented taxa that can withstand warm, stagnant, low DO water due to their ability to breath from the atmosphere. The extensive hydrologic alteration has resulted in a significant increase of the frequency, areal extent, severity and duration of these dry down events and has a significant impact on the biological communities in this degraded habitat.

Strength-of-evidence analysis

Table 9 presents the SOE analysis scores for flow regime alteration as a candidate cause for the M-IBI impairment in Whiskey Creek. The multiple lines of evidence used in the analysis suggest that flow regime alteration is a probable stressor for the associated M-IBI impairment. Several of the evidence types strongly support the case for flow regime alteration as a stressor.

Table 9. SOE analysis scores for candidate cause #1: Flow regime alteration.

Types of Evidence	SOE Scores for Whiskey Creek Biologically Impaired Reach[1]
Types of Evidence that Use Data from the Case	
Spatial/Temporal Co-occurrence	+++
Temporal Sequence	NE
Stressor-Response Relationship from Field	+++
Causal Pathway	+++
Evidence of Exposure/Biological Mechanism	+++
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	+++
Symptoms	+++
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	++
Stressor-Response in Other Lab Studies	NE
Stressor-Response in Other Field Studies	++
Stressor-Response in Ecological Models	NE
Manipulation Experiments at Other Sites	NE
Analogous Stressors	NE
Multiple Lines of Evidence	
Consistency of Evidence	+++

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Candidate cause #2: Lack of in-stream habitat

Background

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community (EPA, 2012). Healthy biotic communities have diverse in-stream habitat, enabling fish and macroinvertebrate habitat specialists to prosper. Instream habitat is primarily a function of channel geomorphology (Rosgen, 1996) and flow (Bovee, 1986). Geomorphology is determined naturally by geology and climate (Leopold, 1994), but may be altered directly by channelization and indirectly by land use changes affecting runoff and the removal of riparian vegetation (Aadland et al., 2005). Increases in bank-full flows can result in subsequent increases in channel cross-sectional area (Verry, 2000) and decreases in sinuosity (Verry and Dolloff, 2000). These geomorphic changes can result in reduced habitat quality and diversity, loss of interstitial space due to embeddedness, loss of pool depth due to sedimentation, and loss of cover (Aadland et al., 2005). Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (EPA, 2012).

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for lack of instream habitat as a candidate cause for impairment.

Applicable standards

There are no applicable standards for instream habitat.

Available data

MPCA Stream Habitat Assessment Data

The Minnesota Stream Habitat Assessment (MSHA) was used to evaluate the quality of habitat present at each of the biological monitoring sites in the Whiskey Creek Subwatershed. The MSHA is comprised of five scoring categories, including land use, riparian zone, substrate, fish cover, and channel morphology, which are summed for a total possible score of 100 points. Table 10 provides the individual category scores, the total MSHA score, and a narrative habitat condition rating for each for the monitoring sites.

Total MSHA scores varied throughout the Whiskey Creek Subwatershed and ranged from 33.5 (08RD056) to 59 (05RD033). The overall mean score for the subwatershed was 43.2, which receives a "poor" MSHA rating. A majority of sites in the subwatershed (seven) received a "poor" rating, while two sites were rated "fair." The score for site 08RD052 associated with the biologically impaired Whiskey Creek reach 520 (highlighted red in Table 10) was 44.95 (at the top end of "poor"). Land use was the lowest scoring MSHA component due to the intensive agricultural land use, with only one site scoring above a zero. The site also scored poorly in the substrate category, with only 8.5 points out of a total of 27 possible, and scored half the possible points in the riparian zone and channel morphology categories.

Table 10. Minnesota Stream Habitat Assessment (MSHA) results for biological monitoring sites in the Whiskey Creek 11-Digit HUC.

Reach	Biological Station ID	Land Use Score (0-5)	Riparian Zone Score (0-15)	Instream Zone Scores		Channel Morph. Score (0-36)	Total MSHA Score (0-100)	MSHA Rating[1]
				Substrate (0-27)	Fish Cover (0-17)			
531	08RD056	0.0	6.5	7.0	10.0	10.0	33.5	Poor
518	08RD079	0.0	10.5	6.5	13.0	13.0	43.0	Poor
523	08RD076	0.0	6.0	10.8	8.0	14.0	38.8	Poor
524	05RD033	0.0	8.0	16.0	14.0	21.0	59.0	Fair
533	08RD057	0.0	7.5	13.6	10.0	12.0	43.1	Poor
537	08RD067	0.0	7.0	15.2	7.5	17.5	47.2	Fair
520	08RD052	0.0	7.5	8.4	12.0	17.0	44.9	Poor
516	08RD054	0.6	6.8	15.0	9.5	10.5	42.3	Poor
	08RD060	0.0	7.0	8.0	9.0	13.0	37.0	Poor
Mean Habitat Results		0.1	7.4	11.2	10.3	14.2	43.2	Poor

[1] **Qualitative Habitat Ratings:**

Good: MSHA score above the median of the least-disturbed sites (MSHA>66)

Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)

Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 11 contains detailed MSHA substrate data for each of the biological monitoring stations in the Whiskey Creek Subwatershed. Substrate scores in the watershed ranged from 6.5 (08RD079) to 16.0 (05RD033), with an overall mean of 11.2 out of the 27 possible points for this category. The bio-impaired site 08RD052 (highlighted in red) scored only 8.45. Only three of the nine sites had coarse substrate consisting of gravel or cobble.

The low scores for these sites can be attributed to a lack of coarse substrate or the embeddedness of the coarse substrate by fine sediment. The lack of clean coarse substrate presents a biologically important habitat deficiency within this subwatershed.

Table 11. MSHA in-stream zone substrate data for biological sites in the Whiskey Creek Subwatershed.

Reach	Biological Station ID	Pool%	Riffle %	Run %	Glide %	Predominant Substrate(s)	Embeddedness	MSHA Substrate Score (0-27)
531	08RD056	0	0	0	100	Clay, Silt	No	7.0
518	08RD079	25	10	65	0	Sand, Silt	Severe	6.5
523	08RD076	20	0	80	0	Gravel, Silt	Moderate	10.8
524	05RD033	5	5	90	0	Sand, Gravel	Moderate	16
533	08RD057	40	0	60	0	Clay	No	13.6
537	08RD067	5	5	10	80	Clay, Cobble	Severe	15.2
520	08RD052	30	5	65	0	Clay, Silt	No	8.45
516	08RD054	10	0	90	0	Clay	No	15.0
	08RD060	25	0	75	0	Clay, Silt	No	8.0

Stream geomorphic data

There has been no geomorphic study or morphometric data available for Whiskey Creek.

Elevation profile

Stream gradient is an important factor in stream stability and sediment transport. Figure 14 displays a Digital Elevation Model (DEM) derived elevation profile of Whiskey Creek. The location of the water quality and biological monitoring sites are highlighted red. According to the DEM, the river maintains a mean decreasing gradient of 3.21 feet/mile (range from 2.55 to 4.54 feet/mile) from the headwater road crossing at 210th Avenue 12 miles downstream to 250th Street (water quality site S001-061). Thereafter, the gradient decreases substantially to 0.63 feet/mile for the next 1.69 miles. The decrease in gradient, coupled with the extensive amount of channelization and ditching upstream and the presence of fine sediment, makes this segment of the river especially vulnerable to siltation.

Over the next 5.11 miles, the river gradient increases to a mean of 2.68 feet/mile. Biological Monitoring Site 08RD052 is located midway through this portion of the stream. The final 1.63 miles to the mouth of Whiskey Creek is characterized by little to no gradient as back water from the Red River has this lower section of the creek inundated during most flow situations, with the exception occurring during times of very low flow in the Red River.

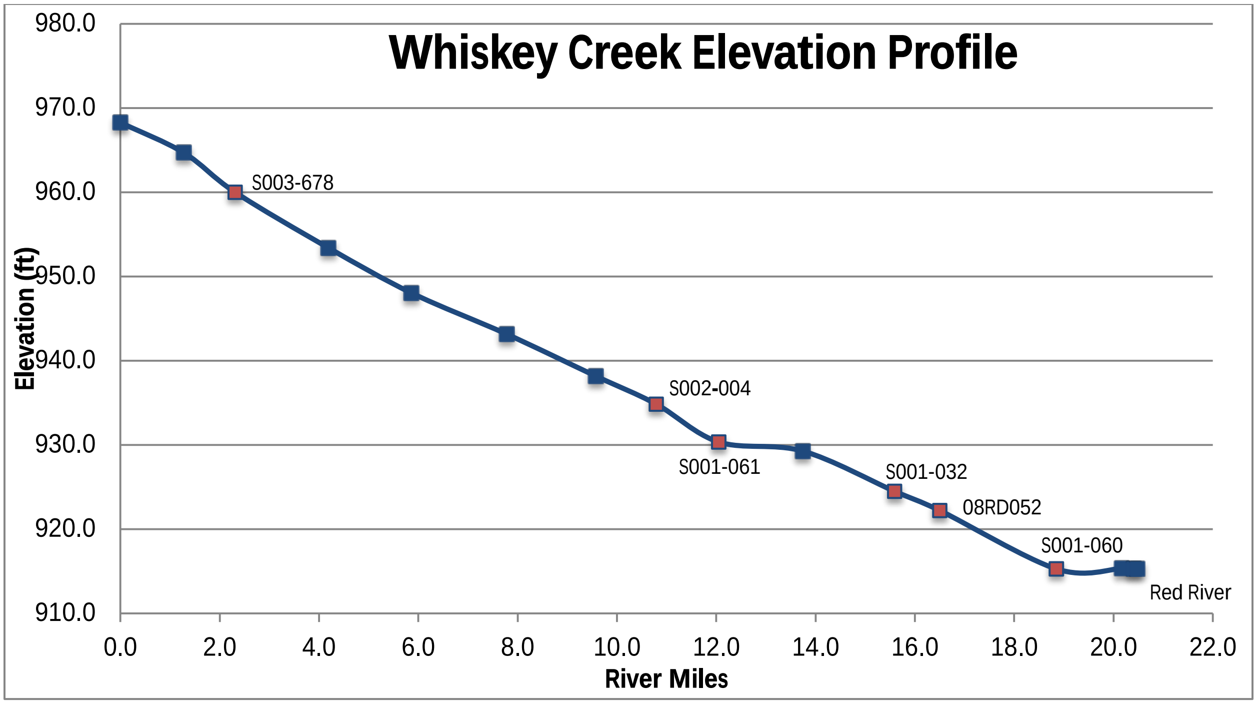

Figure 14. Elevation profile of Whiskey Creek.

Biotic response

M-IBI impairment

The Whiskey Creek macroinvertebrate community is dominated (67% of individuals) by snails (Hydrobiidae, Lymnaeidae, Ferrissia, Physa) and tolerant midges (Polypedilum). Roughly 91% of the community is comprised of tolerant taxa, while 60% are considered very tolerant. The stream appears to have limited habitat, as snags/woody debris was the only habitat type sampled. Often streams of this size, where the habitat includes snags/woody debris, have several sensitive taxa, as the EPT taxa require hard substrate to live on. The Whiskey Creek sample was devoid of sensitive taxa. The two mayfly taxa collected, Baetis and Caenis (total of six individuals) have moderate to high pollutant tolerance levels. The taxa dominating the sample do not require moving water as a habitat condition and can survive in remnant pools during the prolonged intermittent periods that Whiskey Creek experiences. In some streams, benthic macroinvertebrates are known to take refuge deeper into the substrate (the hyporheic zone) when flows cease. This phenomenon requires a substrate having interstitial spaces (small gaps between substrate particles, meaning gravel and/or coarse sand composition) because most benthic invertebrates are not adapted to burrowing in fine sediments, especially if the material is relatively compacted, such as clay. In clay dominated substrate, Wood et al. (2010) found that the hyporheic zone is not a refuge for benthic macroinvertebrates. Whiskey Creek has a fine particle, silt/clay substrate and little if any acceptable substrate refuge habitat exists to support a more diverse macroinvertebrate assemblage.

The macroinvertebrate taxa present are also predominantly habitat and or feeding generalists. This coincides well with the habitat data found during the biological sampling visit, as macroinvertebrate habitat diversity was poor (only one of the four target habitats were found at 08RD052), and MSHA habitat scores were in the “poor” category, also suggesting that habitat diversity is lacking. Lack of habitat diversity translates to poor biological diversity.

The macroinvertebrate impairment in Whiskey Creek appears to be driven by frequent intermittency in late summer/fall and over the winter. This intermittency greatly reduces the physical habitat availability and habitat quality. The absence of three of the four habitat types along with the lack of refuge habitat is a significant cause of the lack of a more diverse macroinvertebrate community and a lack of sensitive taxa. Whiskey Creek macroinvertebrates annually trapped in isolated pool habitat encounter a setback in abundance and result in the elimination of any sensitive taxa (e.g., EPT). The lack of sensitive taxa in Whiskey Creek is likely a result of the repeated occurrence of this no-flow phenomenon and a lack of opportunity for the macroinvertebrates to re-colonize the stream from nearby refuge habitat. Coarse substrate is present in the CD 6A tributary upstream of Whiskey Creek station 08RD052; however, any sensitive organisms that might migrate downstream don't appear in the 08RD052 sample. The macroinvertebrates found within Whiskey Creek tend to be wetland-oriented taxa that are adapted to slow moving or stagnant water due to their ability to breathe from the atmosphere.

Strength-of-evidence analysis

Table 12 presents the SOE analysis scores for lack of instream habitat as a candidate cause. The multiple lines of evidence used in the analysis suggest that lack of instream habitat is a probable stressor for the M-IBI impairments associated with Whiskey Creek. Several of the evidence types strongly support this conclusion.

Table 12. SOE analysis scores for candidate cause #2: Lack of in-stream habitat.

Types of Evidence	**SOE Scores for Whiskey Creek Biologically Impaired Reach[1]**
Types of Evidence that Use Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from Field	++
Causal Pathway	++
Evidence of Exposure/Biological Mechanism	++
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	0
Symptoms	++
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	++
Stressor-Response in Other Lab Studies	NE
Stressor-Response in Other Field Studies	++
Stressor-Response in Ecological Models	NE
Manipulation Experiments at Other Sites	NE
Analogous Stressors	NE
Multiple Lines of Evidence	
Consistency of Evidence	++

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Candidate cause #3: Excess suspended sediment

Background

Turbidity and total suspended solids (TSS) are measurements of the amount of sediment suspended in the water column including both mineral (e.g., soil particles) or organic (e.g., algae or decaying plant material). Specifically, turbidity is a measurement of the amount of light scattered from a sample (more suspended particles cause greater scattering), while TSS is a measurement of the actual weight of material per volume of water.

Klimetz and Simon (2008) indicated that streams in the Red River of the North Basin had the highest median suspended sediment concentration of any region in Minnesota, with the exception of the Western Corn Belt Plains ecoregion (e.g., the Minnesota River Basin). The vast majority of the annual suspended sediment load associated with the streams in the Red River of the North Basin is discharged between the months of March and May, when soils are particularly vulnerable to erosion (MPCA, 2009).

According to Waters (1995), excess suspended sediment can cause harm to fish and macroinvertebrates through two major pathways: 1) direct, physical effects (e.g., abrasion of gills and avoidance behavior) and 2) indirect effects (e.g., loss of visibility and increase in sediment oxygen demand). Excess suspended sediment can also reduce the penetration of sunlight and thus impede photosynthetic activity and limit primary production (Munavar et al., 1991; Murphy et al., 1981).

Figure 15. A Whiskey Creek tributary stream receives sediment from several agricultural sources. (July 11, 2014 photo by author)

Evidence of sediment loss in the Whiskey Creek Subwatershed was apparent during the early summer of 2014. The precipitation totals during May (3.72 inches) and June (6.46 inches) resulted in excessive soil erosion within the subwatershed. Figure 15 shows an example of several types of erosion occurring into a tributary located a half mile from Whiskey Creek. Gully and sheet erosion are present in the field to the right of the tributary and farming too close to the tributary and stream bank erosion are occurring on the left side of the photo.

The increase in the intensity and frequency of heavy storm events due to climate change appears to be driving higher soil loss rates and water quality degradation.

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for excess suspended sediment as a candidate cause for impairment.

Applicable standards

The Minnesota state water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2B (warm water) waters, which includes the biologically-impaired Whiskey Creek. A strong turbidity to TSS relationship (R^2 = .86, n = 765) in the Red River Basin was documented by Paakh et al. (2006). The recently approved Minnesota state TSS standards are based upon ecoregions. The TSS standard applicable to the streams in the URRW is 65 mg/L. For additional information regarding the state standards, refer to the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2013).

The other water quality parameter that is strongly influenced by sediment in the water column and well correlated with turbidity and TSS is transparency. The transparency to turbidity relationship in the Red River Basin had an R^2 value of .95, whereas the transparency to TSS relationship was an R^2 of .86 (Paakh et al. 2006). Analysis of transparency tube and Secchi tube data in relation to the TSS standard finds that a value of about 10 cm transparency is approximately equivalent to the 65 mg/L TSS standard.

Available data

Water quality data

Turbidity and TSS monitoring

Water quality data has been collected within the Whiskey Creek Subwatershed since 1985. As discussed, several of the parameters collected directly relate to suspended sediment, including TSS, turbidity, and transparency.

Table 13 presents a summary of the sampling results for turbidity and TSS for sites located on Whiskey Creek. The sites are listed in order from upstream to downstream.

A review of the turbidity data in Table 13 finds that all Whiskey Creek sites exceed the turbidity standard greater than 10% (highlighted in red) of the time; hence the turbidity impairment on Whiskey Creek previously presented in Table 6. A closer look at the data finds that the downstream sites (S004-881 and S001-060), that are situated upstream and downstream (respectively) of the macroinvertebrate impaired biological site (08RD052), have the highest rate of exceedance on the stream at 50% compared with the sites located further upstream.

Table 13. Turbidity and TSS data for Whiskey Creek.

Site	Parameter	n	Years with Data	Min	Max	Mean	Median	% Exceeds
S003-678	Turbidity (NTU)	15	05-06	0.0	79.7	11.5	3.0	13.3
	TSS (mg/L)	14	05-06	1.0	86.0	15.6	6.5	14.3
S002-004	Turbidity (NTU)	9	02, 13-14	0.0	62.0	17.9	2.5	33.3
	TSS (mg/L)	10	02,13-14	1.0	22.0	6.2	4.0	0.0
S001-061	Turbidity (NTU)	38	86, 01-03, 05-06	0.0	75.0	14.6	6.5	18.4
	TSS (mg/L)	36	86, 01-03, 05-06	1.0	86.0	22.1	13.5	5.6
S001-032	Turbidity (NTU)	59	85-87, 01-03	0.7	285.0	27.3	14.0	23.7
	TSS (mg/L)	42	85-87, 01-03	8.4	190.0	37.7	31.0	11.9
S004-881	Turbidity (NTU)	16	08-09, 13	8.8	90.7	32.4	24.9	50.0
	TSS (mg/L)	16	08-09, 13	7.0	92.0	37.9	32.0	18.8
08RD052	Turbidity (NTU)	0						
	TSS (mg/L)	1	2008	43.0	43.0	43.0	43.0	0.0
S001-060	Turbidity (NTU)	19	86, 05-06	5.4	225.0	42.0	25.0	52.6
	TSS (mg/L)	20	86, 05-06	7.0	184.0	54.6	46.0	30.0

Table notes: n = number of samples. % Exceeds = % of samples exceeding the MN WQ Standard

The TSS data shows a similar pattern, with the two sites on either side of the bio-impaired site having the highest rate of exceedance of the 65 mg/L TSS standard (those with greater than a 10% rate of exceedance are highlighted in red). This is likely due to a combination of factors including the increase in stream gradient (Figure 16), and the resultant higher flow velocities that would tend to transport larger sediment particles than the farther-upstream sites with lower gradient. In addition, the presence of finer clay particles associated with the change in soil type to swelling clay lake sediments (Figure 16) near the town of Kent likely contributes to the increase in TSS values.

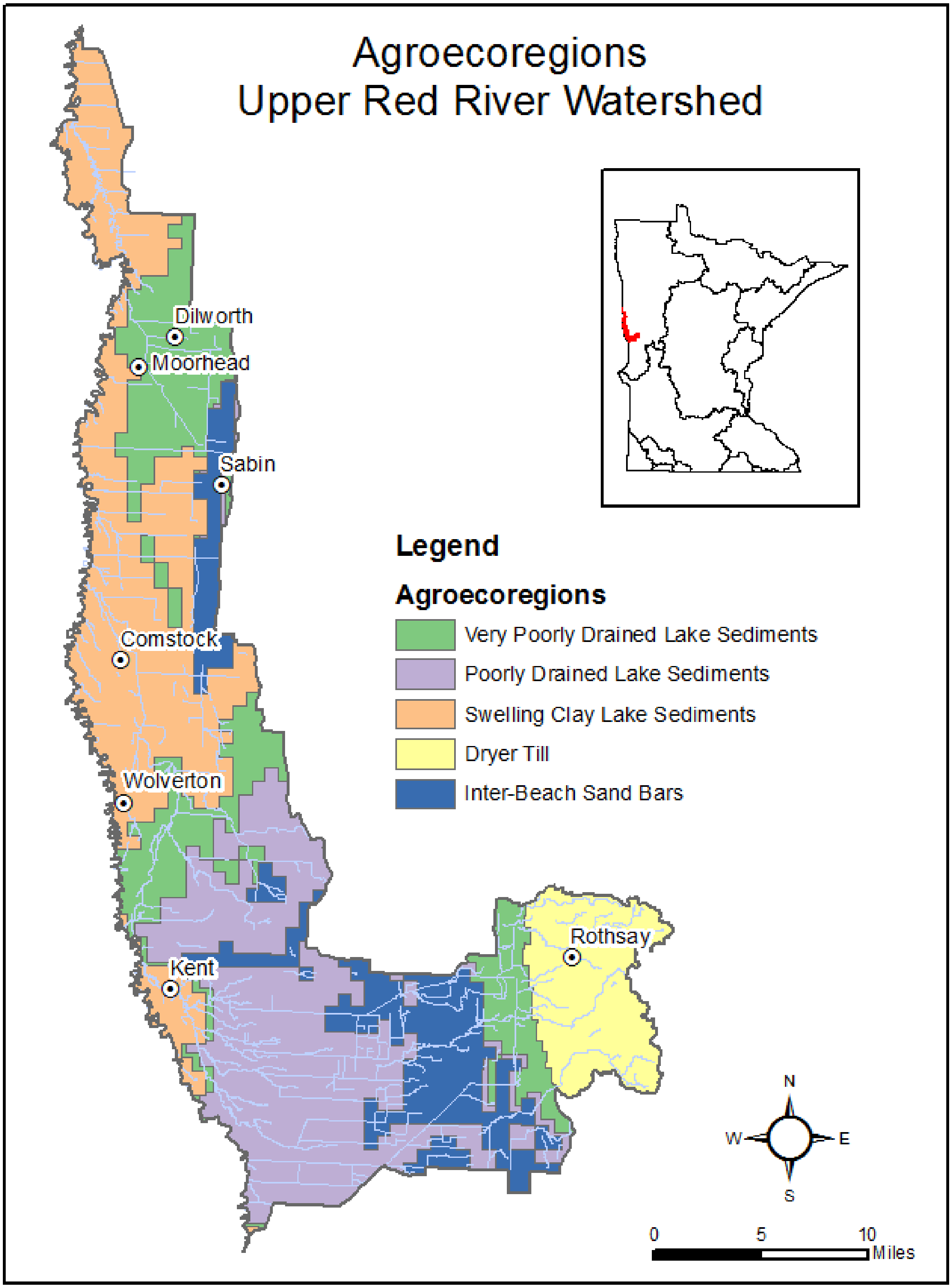

Figure 16. Agroecoregions with generalized soil types.

Transparency monitoring data

The available Whiskey Creek transparency data is presented in Table 14. This less robust dataset provides additional support to the data previously presented in Table 13.

Table 14. Transparency data for Whiskey Creek.

Site	n	Date Range (yrs.)	Min	Max	Mean	Median	% Exceeds
S003-678	15	05-06	8	60	51.3	60	6.7
S002-004	8	13-14	11	100	67.9	83	0
S001-061	25	05-06	8	60	35.4	36	8
S001-032	0						
S004-881	27	08-09, 13	7	47	20.5	20	11.1
08RD052	0						
S001-060	26	05-06	4	56	19.5	16	26.9

As expected, this data follows the pattern discussed regarding the turbidity and TSS data where the upstream sites have less suspended sediment and clearer water than the downstream locations adjacent to the impaired biological station (08RD052). Each of the downstream sites have greater than 10% exceedance of the 10 cm transparency reading that roughly equates to the 65 mg/L TSS standard.

Biotic response

M-IBI impairment –Whiskey Creek

Potential connections between excess suspended sediment and the M-IBI impairment associated with Whiskey Creek include: 1) a decrease in the relative abundance of collector-filterer individuals (Collector-filtererPct), 2) a decrease in the relative percentage of taxa belonging to Trichoptera (TrichopteraChTxPct), and 3) a decrease in the relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct). These three attributes of the macroinvertebrate sample are presented in Table 15. Macroinvertebrates belonging to the collector-filterer group gather and filter their food, which can be impeded by high suspended sediment (Arruda et al., 1983; Lemley, 1982; Strand and Merritt, 1997). Species belonging to the order Trichoptera (i.e., caddisflies) tend to be intolerant of excess sediment in their habitat (Barbour et al. 1999). Table 15 provides a summary of the M-IBI metric scores for site 08RD052 on Whiskey Creek.

Table 15. M-IBI metric scores for impaired biological site 08RD052.

Metric Name	Predicted Response	Transformation	Value	Score
ClingerCh	Decrease	none	3.00	0.67
Collector-filtererPct	Decrease	none	4.66	1.15
DomFiveCHPct	Increase	none	85.71	1.07
HBI_MN	Increase	none	8.13	2.43
Intolerant2Ch	Decrease	Log10+1	0.00	0.00
POET	Decrease	none	3.00	0.71
PredatorCh	Decrease	none	7.00	2.14
TaxaCountAllChir	Decrease	none	23.00	1.22
TrichopteraChTxPct	Decrease	none	0.00	0.00
TrichwoHydroPct	Decrease	Log10+1	0.00	0.00
M-IBI				9.39

Analyzing the other sites in the Whiskey Creek Subwatershed for the relationship between key metric scores and sediment levels can help determine if sediment is a significant habitat factor causing poor macroinvertebrate community composition in the subwatershed. M-IBI metric scores with corresponding mean sediment data are provided in Table 16 for comparison purposes for four biological sites within the Whiskey Creek Subwatershed, including impaired site 08RD052 (highlighted red). It should be noted that all of the biological sites in Table 16 fall below the M-IBI threshold. Data is provided for the three indicators of sediment concentration including TSS, turbidity and transparency for water quality sites that are closest to the biology sites listed. The table indicates a relationship between the biology sites with the lowest M-IBI scores and the higher sediment levels.

Table 16. Comparison of M-IBI score and metric results with mean sediment data.

Bio Site #	M-IBI Score	% Tolerant	% Collector Filterer	% Tric-hoptera	# Taxa Intolerant	Mean TSS (mg/L)	Mean Turbidity (FNU)	Mean Transpar. (cm)	WQ Site #
08RD052	9.39	13	4.66	0	0	37.7	29.4	na	S001-032
08RD054	12.9	90.5	7.1	0	0	38.7	28.5	16.4	S004-150
05RD033	24	0.9	21.3	0	0	24.4	18.8	43	S004-149
08RD076	24	1.3	16.1	24.15	1	24.4	18.8	43	S004-149

The two biological sites with the lowest M-IBI scores have mean turbidity levels in excess of the state standard of 25 NTU, whereas the higher scoring biological sites have mean turbidity values below the state standard. Table 16 shows sites 08RD052 and 08RD054 with low scores for the percent filterer and percent Trichoptera metrics and higher percent tolerant taxa indicating a possible link to sediment impacts.

This relationship between M-IBI scores and metric data with the TSS data (from corresponding water quality sites) is also provided in Figure 17. There appears to be a fairly good level of spatial co-occurrence between excess sediment levels and the aforementioned M-IBI metrics. Biological sites 08RD052 and 08RD054 are located on Whiskey Creek and a tributary of Whiskey Creek, respectively. These sites are prone to high turbidity, as demonstrated by the TSS data from the nearby water quality sites (site numbers that begin with an S). These sites also scored very poorly for the Percent Tolerant (a high score is poor), Percent Filterer, and Percent Trichoptera Taxa metrics. Metric score tend to improve upstream in CD 6A (biological sites 08RD076 and 05RD033) where TSS levels decrease. All of the sites used in this assessment are in the area of the subwatershed that has base flow in an effort to minimize the bias that altered flow regime would have on this analysis.

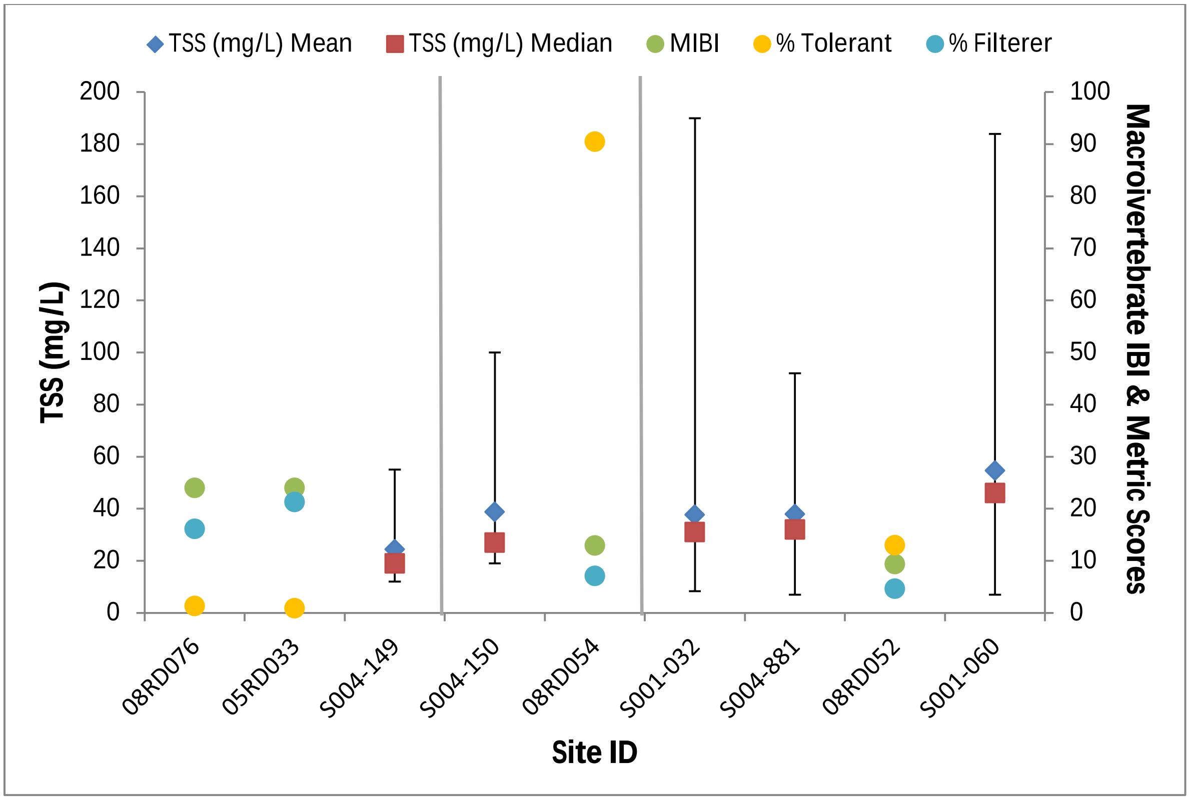

Figure 17. M-IBI and sediment-related metric scores compared to TSS data at nearby water quality sites.

Strength-of-evidence analysis

Table 17 presents the SOE analysis scores for excess suspended sediment as a candidate cause. The multiple lines of evidence used in the analysis suggest that excess suspended sediment is a probable stressor for the M-IBI impairment associated with Whiskey Creek. Several of the evidence types strongly support the conclusion for excess suspended sediment as a macroinvertebrate stressor in Whiskey Creek.

Table 17. SOE analysis scores for candidate cause #3: excess suspended sediment.

Types of Evidence	SOE Scores for Whiskey Creek Biologically Impaired Reach[1]
Types of Evidence that Use Data from the Case	
Spatial/Temporal Co-occurrence	+
Temporal Sequence	NE
Stressor-Response Relationship from Field	+
Causal Pathway	+
Evidence of Exposure/Biological Mechanism	++
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	+
Symptoms	+
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	++
Stressor-Response in Other Lab Studies	NE
Stressor-Response in Other Field Studies	++
Stressor-Response in Ecological Models	NE
Manipulation Experiments at Other Sites	NE
Analogous Stressors	NE
Multiple Lines of Evidence	
Consistency of Evidence	+

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Candidate cause #4: Low dissolved oxygen

Background

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. The concentration of DO changes 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.

Low or highly fluctuating DO concentrations can cause adverse effects (e.g., avoidance behavior, reduced growth rate, and fatality) for many fish and macroinvertebrate species (Allan, 1995; Davis, 1975; Nebeker et al., 1992; Raleigh et al., 1986). In most streams and rivers, the critical conditions for DO usually occur during the late summer season, when water temperatures are high and stream flows are reduced to baseflow. As the temperature of water increases, the saturation level of DO decreases. High water temperatures also raise the DO needs for many species of fish (Raleigh et al., 1986). Low DO can be an issue in streams with slow currents, excessive temperatures, high biological oxygen demand, and/or high groundwater seepage (Hansen, 1975).

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for low DO as a candidate cause for impairment.

Applicable standards

The state water quality standard for DO is 5.0 mg/L as a daily minimum for Class 2B waters, which includes the biologically impaired reach of Whiskey Creek. For additional information regarding this standard, refer to the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2013).

Available data

Biological monitoring DO data

The MPCA biological monitoring staff collected a DO measurement at Whiskey Creek site 08RD052 during fish sample collection on July 23, 2008. The sample, taken at 12:04 p.m., found a DO concentration of 6.63 mg/L. No DO measurements were taken during the macroinvertebrate sample.

Instantaneous DO monitoring data

Instantaneous DO measurements represent discrete point samples that are usually collected using a water quality sonde in conjunction with surface water sampling. Table 18 provides a summary of available instantaneous DO data for Whiskey Creek. The water quality monitoring sites in the table are arranged from upstream (top) to downstream (bottom) in the table. The lowest mean DO values were found in the two most upstream sites (S003-678 and S002-004) with means of 6.85 and 6.68 mg/L, respectively. These sites exceeded the state of Minnesota DO standard of 5.0 mg/L by 27.3 and 40.0%, respectively. The minimum DO concentration for all of the sites was below the state standard with the three more upstream sites showing the lowest minimum concentrations.

Table 18. Instantaneous DO data for Whiskey Creek.

Whiskey Creek Site ID	Number of DO Readings	Minimum DO (mg/L)	Mean DO (mg/L)	Median DO (mg/L)	Maximum DO (mg/L)	Number Exceeding 5.0 mg/L Standard	Percent Exceeding 5.0 mg/L Standard
S003-678	11	3.51	6.85	6.45	13.05	3/11	27.3
S002-004	10	1.39	6.68	6.43	13.70	4/10	40.0
S001-061	42	2.40	10.55	10.45	20.00	2/42	4.8
S004-881	27	4.77	7.34	7.17	10.93	2/27	7.4
S001-060	23	4.78	8.21	8.21	15.28	1/23	4.3

Continuous DO monitoring data

The MPCA conducted continuous DO monitoring at two sites (08RD052 and S001-061) on Whiskey Creek from July 22, 2014, to August 8, 2014. A second deployment occurred at the bio-impaired site (08RD052) from August 14, 2014, to August 27, 2014. The warm water temperatures (19 to 25° C) and low flow conditions at the time of monitoring were ideal for capturing seasonally-low DO levels. Dissolved oxygen, temperature, conductivity, pH and turbidity measurements were collected at 15 minute intervals utilizing deployed YSI 6920 multi-parameter sondes. Table 19 provides a summary of the continuous DO data collected at each station.

Table 19. Continuous DO summary data for selected stations on Whiskey Creek.

Whiskey Creek Site ID #	Sonde Deployment Dates	Number of DO Readings	Min. DO (mg/L)	Max. DO (mg/L)	% Readings Below 5.0 mg/L DO Standard	Max. Duration Below Standard (hours)	Avg. 24 hr. Flux (mg/L)	Max 24 hr. Flux (mg/L)
S001-061	7/22/14 to 8/8/2014	1632	1.4	8.88	89.95	105	2.78	4.26
08RD052	7/22/14 to 8/8/2014	1630	1.7	7.23	38.77	105.5	1.37	3.76
08RD052	8/14/14 to 8/27/14	1248	3.43	7.49	32.77	45.25	1.22	1.83

The continuous DO data shows a failure of the stream to provide DO concentrations above the five mg/L standard for a significant percentage of the time during each of the three deployments. The deployment at site S001-061 had concentrations failing to meet the aquatic life threshold 90% of the time during the 16 day deployment. 08RD052 also showed a high rate of low DO readings with 38.8 and 32.8% falling below the 5.0 mg/L DO threshold during the first and second deployment respectively. In addition, the duration of the low DO conditions during the first deployment period was 105 hours (4.37 days) for both of the Whiskey Creek sites.

The diurnal (24 hour) mean DO flux standard for the LAP ecoregion is 4.5 mg/L. The mean diurnal DO flux at these sites ranged from 1.22 to 2.78 mg/L. Figure 18 to Figure 20 shows the continuous DO data for each of the three deployments in graphic form.

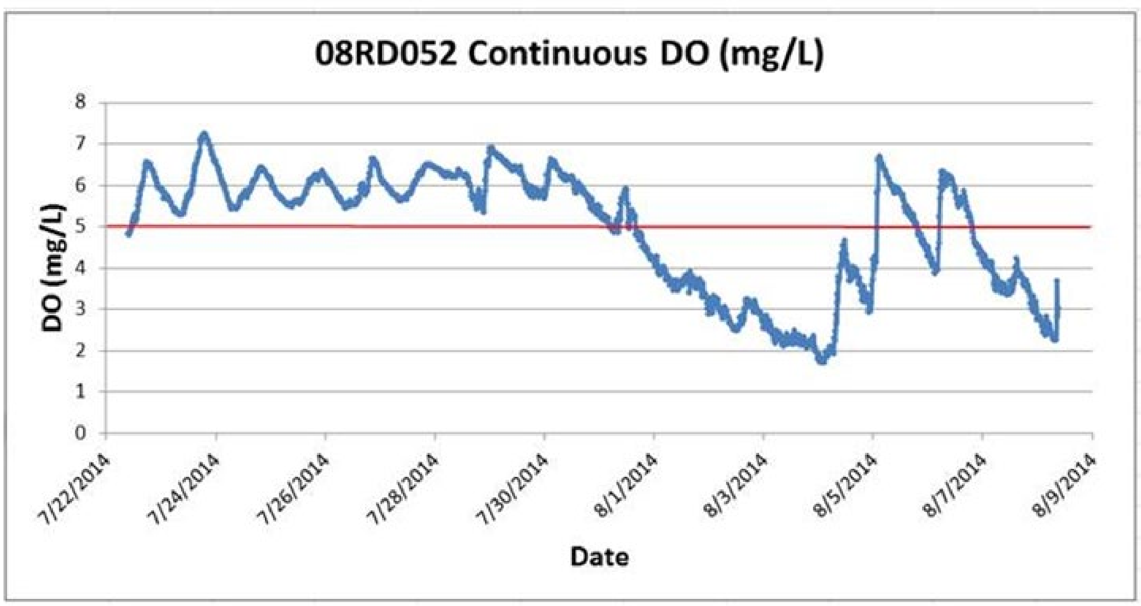

Figure 18. Continuous DO data for Whiskey Creek site 08RD052 from July 22 to August 8, 2014.

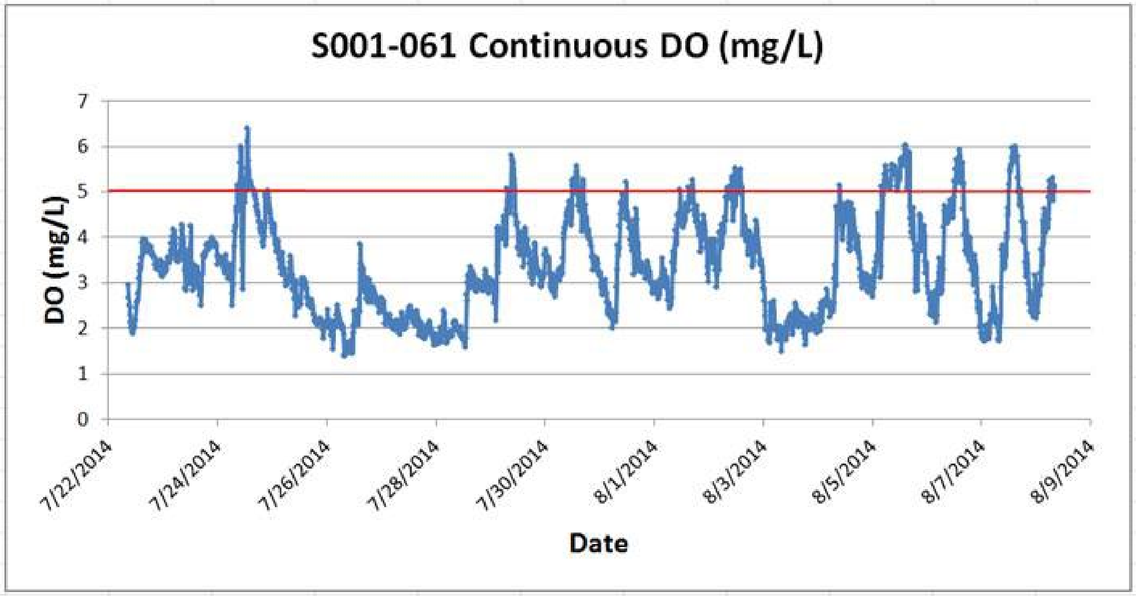

Figure 19. Continuous DO data for Whiskey Creek site S001-061 from July 22 to August 8, 2014.

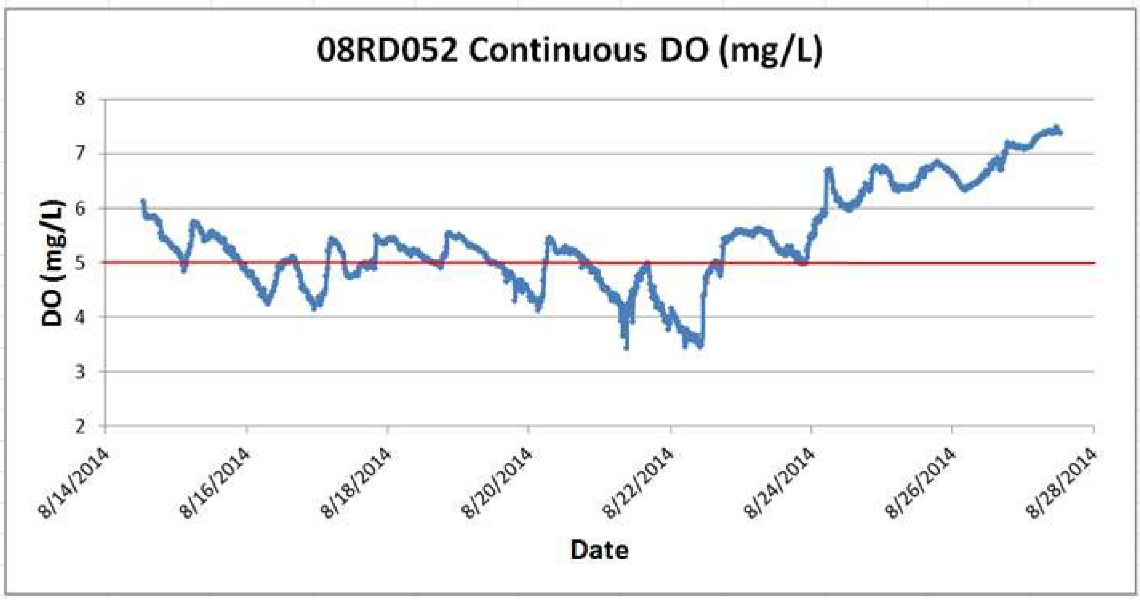

Figure 20. Continuous DO data for Whiskey Creek site 08RD052 from August 14 to August 28, 2014.

Biotic response

M-IBI Impairment – Whiskey Creek

The evidence of low DO (the instantaneous DO data and the results of the continuous sonde deployment) appears to be correlated with the M-IBI impairment on Whiskey Creek. Potential connections between low DO and the M-IBI impairment include: 1) a decrease in the taxa richness of macroinvertebrates with tolerance values less than or equal to two (Intolerant2Ch), 2) a decrease in the taxa richness of Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET), 3) a decrease in the total taxa richness of macroinvertebrates (TaxaCountAllChir), and 4) a decrease in the relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct). The taxa included in each of these M-IBI metrics are known to negatively respond to low DO (EPA, 2012; Weber, 1973). Table 20 provides a summary of the scores for these M-IBI metrics (highlighted in red) for the Class 7 monitoring site 08RD052 located on Whiskey Creek.

Table 20. DO related metric scores for impaired biological site 08RD052.

Metric Name	Predicted Response	Transformation	Value	Score
ClingerCh	Decrease	none	3.00	0.67
Collector-filtererPct	Decrease	none	4.66	1.15
DomFiveCHPct	Increase	none	85.71	1.07
HBI_MN	Increase	none	8.13	2.43
Intolerant2Ch	Decrease	Log10+1	0.00	0.00
POET	Decrease	none	3.00	0.71
PredatorCh	Decrease	none	7.00	2.14
TaxaCountAllChir	Decrease	none	23.00	1.22
TrichopteraChTxPct	Decrease	none	0.00	0.00
TrichwoHydroPct	Decrease	Log10+1	0.00	0.00
M-IBI				9.39

The macroinvertebrate sample from 2008 at site 08RD052 on Whiskey Creek was dominated (67% of individuals) by snails (Hydrobiidae, Lymnaeidae, Ferrissia, Physa) and tolerant midges (Polypedilum) that are tolerant of low DO conditions. Follow-up qualitative macroinvertebrate sampling at three locations along the length of Whiskey Creek (including 08RD052 and two additional upstream sites at 250th and 240th Streets) on July 31, 2014, verified that the system is dominated by pollutant tolerant and specifically low DO tolerant genera. The samples contained crayfish, dragonflies, damselflies, snails, water boatman, water beetles, freshwater shrimp and water bugs. The stream was void of invertebrate taxa that are considered intolerant of low DO conditions.

The Whiskey Creek invertebrate taxa collected both in 2008 and during the 2014 SID sampling has a wetland signature, as a high percentage of the individuals are commonly found in wetland habitat. Wetland habitats typically have lower DO concentrations than healthy streams due to the accumulation and decomposition of organic material in wetlands. Organisms that can live in wetlands typically are tolerant of low DO. The predominance of wetland-oriented macroinvertebrate taxa in Whiskey Creek agrees with the findings of frequent low DO in both the instantaneous measurements and the continuous sonde recordings and fits well with the determination of the DO impairment in Whiskey Creek.

Strength-of-evidence analysis

Table 21 presents the SOE analysis scores for low DO as a candidate cause. Many of the types of evidence used in the analysis strongly support the case for low DO as a probable stressor for the M-IBI impairment associated with Whiskey Creek.

Table 21. SOE analysis scores for candidate cause #4: low dissolved oxygen.

Types of Evidence	SOE Scores for Whiskey Creek Biologically Impaired Reach[1]
Types of Evidence that Use Data from the Case	
Spatial/Temporal Co-occurrence	+++
Temporal Sequence	NE
Stressor-Response Relationship from Field	+++
Causal Pathway	++
Evidence of Exposure/Biological Mechanism	++
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	++
Symptoms	++
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	++
Stressor-Response in Other Lab Studies	NE
Stressor-Response in Other Field Studies	++
Stressor-Response in Ecological Models	+
Manipulation Experiments at Other Sites	NE
Analogous Stressors	NE
Multiple Lines of Evidence	
Consistency of Evidence	+++

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Candidate cause #5: Pesticide toxicity

Background

A pesticide is defined by the EPA (2012) as "any substance intended for preventing, destroying, repelling or mitigating any pest." Pesticides may cause biological impairment if they are present in water or sediment at sufficient concentrations. The most common pathways for pesticides to enter surface water are through runoff, leachate, overspray or drift. For the purpose of this report, pesticides refer to herbicides, insecticides, and fungicides.

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

Insecticides are chemicals used to control insects by killing them or preventing them from engaging in behaviors deemed undesirable or destructive. Many insecticides act upon the nervous system of the insect, while others act as growth regulators. Insecticides are commonly used in agricultural, public health, and household applications.

Fungicides include biocidal chemical compounds or biological organisms used to kill or inhibit fungi or fungal spores. They are commonly used in agricultural applications. Fungicides can either be contact, translaminar, or systemic. Contact fungicides are not taken up into the plant tissue and only protect the plant where the spray is deposited. Translaminar fungicides redistribute the fungicide from the upper, sprayed leaf surface to the lower, unsprayed surface. Lastly, systemic fungicides are taken up and redistributed through the plant's xylem vessels.

The EPA's CADDIS webpage contains a conceptual diagram of the sources and pathways for pesticides as a candidate cause for impairment.

Applicable standards

Table 22 presents a summary of the state's chronic and maximum standard values for common pesticides used in Minnesota.

Table 22. Summary of state surface water standards for common pesticides.

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

[1] Chronic standards are defined in Minnesota Rule Chapter 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 surface waters.
[3] State water classification for cool and warm water streams and all recreation.

Available data

MDA pesticide monitoring data

The Minnesota Department of Agriculture (MDA) is the lead state agency for the oversight of pesticides. As such, the MDA routinely collects and analyzes water samples from selected locations throughout the state to determine the identity, concentration, and frequency of detections of pesticides in ground and surface water resources. The MDA has not collected samples from Whiskey Creek so no pesticide data is available for review/assessment at this time.

Discussion

The lack of available pesticide data prevents one from a robust assessment of pesticide presence and concentration. These assessments aren't conclusive regarding the role of pesticides in the biological impairment unless the data shows concentrations in excess of levels determined to be toxic to aquatic life. The cumulative impact of low level exposure to multiple pesticides on sensitive aquatic organisms has not been adequately studied, so even levels of pesticides below their known toxicity may present a problem. Given that agriculture is the predominant land use in the Whiskey Creek Subwatershed and that we lack the data necessary to make an assessment, it is not possible to rule out pesticide toxicity as a possible stressor to aquatic life.

The MPCA has not designed a monitoring program to specifically answer the questions regarding whether pesticides are having impacts to the aquatic biology. The Tier 3 MDA monitoring program incorporates season-long automated base flow and time-weighted storm runoff sampling, representing the highest level of pesticide monitoring available in Minnesota today. In order to document the potential contribution of pesticides to stream biology impairment one would have to design a site-specific study that, among other factors, simultaneously looked at pesticide application timetables while measuring pesticide concentrations in adjacent water bodies, complete water chemistry (including the presence of other toxins), water temperature, and fluctuations in hydrology and biological diversity. The study would need to ascertain how the chemical is entering the water, the exposure time, and look for impacts to sensitive organisms.

Monitoring that is specifically designed to determine the potential impact of pesticides on fish and macroinvertebrate communities is needed. Targeted storm runoff monitoring following instances of pesticide application along with monitoring for drift and overspray into surface water would improve our ability to diagnose or refute pesticide toxicity as a biological stressor. At this time there exists insufficient information to determine the role pesticides play on the health of aquatic biota across Minnesota's agricultural landscapes.

Strength-of-evidence analysis

Table 23 presents the SOE analysis scores for pesticide toxicity as a candidate cause. There is insufficient information available to support the case for pesticide toxicity as a probable stressor for the M-IBI impairment associated with Whiskey Creek.

Table 23. SOE analysis scores for candidate cause #5: pesticide toxicity.

Types of Evidence	SOE Scores for Whiskey Creek Biologically Impaired Reach[1]
Types of Evidence that Use Data from the Case	
Spatial/Temporal Co-occurrence	NE
Temporal Sequence	NE
Stressor-Response Relationship from Field	NE
Causal Pathway	NE
Evidence of Exposure/Biological Mechanism	NE
Manipulation of Exposure	NE
Laboratory Tests of Site Media	NE
Verified Predictions	NE
Symptoms	NE
Types of Evidence that Use Data from Elsewhere	
Mechanistically Plausible Cause	++
Stressor-Response in Other Lab Studies	NE
Stressor-Response in Other Field Studies	++
Stressor-Response in Ecological Models	NE
Manipulation Experiments at Other Sites	NE
Analogous Stressors	NE
Multiple Lines of Evidence	
Consistency of Evidence	0

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Section 4: Conclusions and recommendations

4.1 Stressor discussion and summary of findings

The poor biological condition of Whiskey Creek is the product of the intensive agricultural activity within its subwatershed that is common to the fertile soils of the Lake Agassiz Plain Ecoregion. The efficient surface water drainage, channelization, shallow groundwater tiling, wetland loss and cultivation through first and second order streams has led to a significant alteration of hydrology within this subwatershed. The flashy hydrograph, with the increase in peak flows and rapid post-event reduction of flow to dry down conditions, results in unstable habitat conditions that do not support diverse biological communities. The loss of base flow in this system is particularly hard on stream organisms that are unsuited for life in stagnant, isolated pools that occur in this system during typical late summer and fall/winter periods. It is not surprising that pollutant intolerant taxa were absent from lower Whiskey Creek given the relatively poor habitat condition in this stream. Efforts to restore a more natural hydrology to this stream system are needed if improvements to the biological communities are to be realized.

The DO impairment on Whiskey Creek appears to be caused by the lack of baseflow (altered hydrology), as well as additional oxygen consuming wastes entering the system. Figure 21 (left photo) shows a large pile of crop residue (primarily corn stalks) that accumulated against the 250th Street box culvert that carries CD 23 water to Whiskey Creek. The use of oxygen, by bacteria in the process of decomposing this crop residue, rapidly depletes the DO levels in the tributary stream. The photo on the right side of Figure 21 shows the downstream side of the culvert with milky white water indicating a high organic load and high bacteria levels. The DO concentration taken at the time of the photos (July 31, 2014) from the downstream side of the culvert was 0.71 mg/L.

Figure 21. Upstream and downstream photos of the 250th Street crossing of CD 23.

The crop residue typically floats off agricultural fields when they are flooded during spring melt or heavy rain events. Some of the debris is then carried downstream until it hits a road embankment above a flooded culvert where it piles up as seen in Figure 21. Where floodplain areas are tilled and planted (Figure 22), this situation can occur annually. One of the recommendations in this report (in the following section) is to put farmed floodplains back into natural perennial vegetation so they can provide a buffer to soil erosion, help reduce flow rates, reduce nutrient and sediment loads, minimize the effects of crop residue on DO concentrations and improve the riparian zone habitat scores that were determined to be low (Table 10). Figure 23 shows an aerial view of a section of Whiskey Creek and portions of two tributaries. The extent of farming within the floodplain is evidenced by the drowned out crops. Crops appear to have been replanted and emerging in the upper half of this photo. An assessment of aerial photos can assist in determining the location and extent of the farmed floodplain for restoration planning.

Figure 22. Examples of Whiskey Creek floodplain areas being farmed.

Figure 23. Aerial photo of farmed floodplain along Whiskey Creek.
Photo source: Google Earth/USDA, 6/22/09 photo.

The **lack of in-stream habitat** within Whiskey Creek appears to be a contributing factor to the low M-IBI score and impairment. This stressor, much like the low DO stressor, is being driven by the effects of altered hydrology on the stream system. The “boom and bust” hydrology in this flashy system significantly impacts both the availability and quality of habitat. The taxa present were moderately to highly pollutant tolerant and able to exist for prolonged periods in stagnant, pooled conditions. In addition, the lack of habitat diversity, with only one of the four target macroinvertebrate habitats present (i.e., large woody debris), appears to be a factor. A good M-IBI score requires a diversity of taxa, and the absence of coarse substrate within Whiskey Creek, appears to play a role in the low score. The presence of poor habitat and specifically the embeddedness of hard substrate in the tributaries

(Table 11) can have a significant negative impact on the macroinvertebrate taxa present in a stream system. However, even if better habitat existed, it would likely still be mostly void of sensitive taxa due to the large hydrologic fluctuations and significant summer DO problems.

Excess sediment is another stressor that may be impacting the biology of Whiskey Creek, but much like in-stream habitat, the effects of this stressor appear to be secondary to the significant impacts that altered hydrology and low DO have on the system. Sediment sources appear to be from upland sources where there is a lack of adequate buffers. Farming through headwater (first and second order) streams is a significant problem where gullies recut these historic small stream channels each time sufficient runoff occurs to begin the channel forming process. Farming of the floodplain is another source of sediment to the system as the unprotected soil can be easily lost to the stream flow during flood events. In-stream erosion resulting from the increased flow rates due to extensive drainage throughout the watershed is another concern. Many of the efforts and/or best management practices (BMPs) used to mitigate or reduce the impacts of altered hydrology and low DO will have the added benefit of reducing the sediment load both from upland and in-stream sources and this should help to correct the sediment and embeddedness habitat concerns.

4.2 Strength-of-evidence analysis summary

Table 24 presents a summary of the strength-of-evidence for the various candidate causes associated with the biologically impaired reach of Whiskey Creek. The evidence indicates that the M-IBI impairment associated with Whiskey Creek is likely the result of flow regime alteration, low DO, lack of in-stream habitat, and excess suspended sediment. The primary stressor impacting the macroinvertebrate community is altered hydrology. This stressor is driving the low DO and appears to be having the most direct impact on the poor macroinvertebrate community inhabiting Whiskey Creek. Both excess suspended sediment and lack of in-stream habitat appear to be impacting the stream organisms, however these are, in part, follow-on effects of the root stressor, altered hydrology. If the flow regime alteration and DO issues were resolved, the biological stress from excess suspended sediment and lack of in-stream habitat would have a greater chance of impacting the biology than they currently appear to.

Table 24. Summary of SOE analysis scores for candidate causes associated with Whiskey Creek.

Stressors	Multiple Lines of Evidence (Consistency of Evidence) SOE Scores for M-IBI Impaired Whiskey Creek[1]
Flow Regime Alteration	+++
Lack of In-stream Habitat	++
Excess Suspended Sediment	+
Low DO	+++
Pesticide Toxicity	0

[1] **Score Key: +++** *convincingly supports* the case for the candidate cause, **++** *strongly supports* the case for the candidate cause, **+** *somewhat supports* the case for the candidate cause**, 0** *neither supports nor weakens* the case for the candidate cause**, -** *somewhat weakens* the case for the candidate cause**, --** *strongly weakens* the case for the candidate cause**, ---** *convincingly weakens* the candidate cause, **R** *refutes* the case for the candidate cause, and **NE** *no evidence* available.

Section 5: Implementation recommendations

The impaired reach of Whiskey Creek has the potential to support healthy biological communities. The following section is provided to assist local units of government during the planning stages of implementation. The general management actions below are provided as suggestions that should help address the identified stressors which are limiting the quality of the macroinvertebrate community. Whenever possible, actions should be implemented progressing from upstream to downstream as the benefits from reductions in nutrients and sediment and improved habitat and hydrology are often transferred downstream and can have a greater overall effect on the system.

- Restore floodplains along Whiskey Creek and its tributaries using diverse native vegetation where possible. The goal should be to restore the 10-year floodplain. The meander belt-width concept can be utilized however the vegetated setbacks should extend beyond the floodplain width and this may require a wider buffer. Permanent easements should be sought for these areas rather than short term set-aside that will continually need to be re-enrolled into conservation programs.

  A meeting at the Wilkin County Soil and Water Conservation District (SWCD) office was held on February 11, 2015, to discuss the status of Whiskey Creek and any actions taken or being considered to address hydrology or water quality issues. Those in attendance included Don Bajumpaa (District Manager), Wilkin County SWCD board members, Bruce Poppel (Wilkin County Environmental Officer), Bruce Albright (Buffalo Red River Watershed District Administrator), and Bruce Paakh (MPCA). Bruce Poppel provided information regarding an application for funds that has been submitted to conduct surveying of Whiskey Creek. The results of the survey will be used to develop a hydrology model that will help establish the location of the 2, 5, and 10 year floodplains for the purposes of buffer setback plan development. This well-thought out project, if implemented, should go a long ways toward protecting and restoring this watercourse in terms of water chemistry, flow and biology.
- Prevent or mitigate activities that will further alter the hydrology of the subwatershed. All new tile systems should include control structures so that they don't contribute to peak flow during local or regional flood events. Retrofitting tile systems with controls, where they don't exist, would help to mitigate the impact of these systems on peak flow rates.
- Consider opportunities and options to attenuate peak flows and augment base flows in streams throughout the subwatershed. A project of this type to address hydrology issues was discussed by Bruce Albright at the February 11, 2015, meeting. Bruce indicated that there was a need for a water retention impoundment east of Minnesota State Highway 9. The general location and project type discussed could serve to provide the reduction of peak flows and augmentation of base flows that Whiskey Creek needs. Projects that provide base flow in the upper to middle portion of Whiskey Creek would be most beneficial.
- Re-establish natural functioning stream channels wherever possible using natural channel design principles.
- Increase the quantity and quality of instream habitat throughout the subwatershed. Restoring riparian zones will help to achieve this goal.
- Establish and/or protect riparian corridors along all waterways, including ditches.
- Implement agricultural BMPs to reduce soil erosion, sedimentation and nutrient loss.
- Provide protection of stable, self-maintaining ditches/channels. As petitions for ditch maintenance come to the watershed district, an assessment of the ditch system should take place by a professional trained in fluvial geomorphology. The assessment should identify those

systems that are stable and self-maintaining, to ensure solutions to hydrologic problems are done in a manner that protects the services these ditches provide. Figure 24 shows a photo of the 2014 clean out of Wilken CD 28. The photo shows what appears to be a stable low flow channel in the bottom of the ditch above the point of cleanout. Maintaining the low flow channel in this scenario would have benefits of efficient sediment transport, providing a low flow channel for fish and macroinvertebrates, and reducing the likelihood of cattails becoming established in the ditch bottom where they impede flow and trap sediment, requiring additional mechanical maintenance.

- The design and construction of stable ditch systems is important when any excavation within ditches is planned and implemented. Ditch bank slopes should be constructed so that they are stable and minimize the occurrence of bank slumping and erosion. The two-stage ditch concept should be considered where practical.

Figure 24. County Ditch 28 cleanout south of the Whiskey Creek Subwatershed.

A large blow-out on Ditch 6A was discussed during the February 11, 2015 meeting. Since this ditch is the most important ditch in terms of delivering base flow to Whiskey Creek it is important that it be repaired and maintained in a stable form. In addition, Ditch 6A has some of the best coarse substrate within the Whiskey Creek Subwatershed (Table 11, reaches 523 and 524) and this substrate was found to be embedded with sediment during the 2008 biological sampling runs. Repair of this blow-out and the maintenance of the ditch as a stable system will allow this coarse substrate to wash clean and potentially become an important habitat area for fish and macroinvertebrates within the Whiskey Creek Subwatershed.

The MDNR Watershed Health Score for the URRW was 41 which is only one point above the lowest Watershed Health Score in the state. The overall score was limited by the individual mean component scores for biology (35) and connectivity (21). Specifically, the subwatershed scored poorly for the following component indexes: terrestrial habitat quality (2), terrestrial habitat connectivity (2), perennial cover (6), non-point source (10), storage (20) and riparian connectivity (23). Attempts to restore the health of this subwatershed and stream system should focus on improvements to these specific areas.

A guidance tool (Table 25) has been developed to assist in the selection of BMPs based on the specific stressors that have been identified. The Biological Stressor and BMP Relationship Guide provide a list of the BMPs that act to reduce the impact of the stressor on the biology. This table is developed to assist resource managers and landowners working on watershed projects to identify the specific BMPs that are known to positively affect the identified stressor(s). The table is intended for use following the completion of the stressor identification process so that implementation aimed at addressing a stressor can be focused on the BMP or combination of BMPs that are best suited to reduce the impacts from the known stressor.

This chart is for general guidance purposes and should always be used in conjunction with a good understanding of the onsite conditions (e.g., soils, slopes, landuse, hydrology, etc.). The selection of BMPs for implementation on a specific parcel must work in conjunction with how the land is operated and meet landowner approval. A comprehensive list of BMP alternatives can expand the options from which to choose and allow the resource manager and landowner to select the best alternatives for the given situation. BMPs must be properly located, designed, implemented/constructed and maintained in order to be effective. Please note that this table is under final revision. Contact the author to get the most current version prior to use.

Table 25. Biological stressor and BMP relationships guide.

Land Use Type	Treatment Group	BMP's	Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
			STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
Agricultural	Education, Training & Regulation	Ag Drainage System Design Training	● green		● green	● green	● green	● green	● green	● green	● green			● green			
		Controlled Tile Ordinance	● green														
		Ditch Set-back Ordinance. MN 103E.021			● green			● green						● green			
		Individual Sewage Treatment Regs & Training						● green	● green	● green	● green	● green		● green		● green	● green
		MN Shoreland Ordinance - 50' Shoreland Setback			● green			● green	● green	● green	● green			● green	● green		
		Restricted Use Pesticide Training													● green		
		Wetland Conservation Act, 401 Certification	● green		● green			● green									
	Pollution Prevention - Source Controls	Biochar Soil Amendment	● green		● green		● green	● green	● green	● green	● green				● green		
		Conservation Cover (327)	● yellow 13	● yellow 1	● yellow 1,13			● yellow 1,13	● yellow 13	● blue 1,13				● yellow 13	● yellow 13		
		Conservation Crop Rotation (328)			● yellow 13				● yellow 13	● blue 1,13					● yellow 13		
		Cons. Tillage - No Till (329), Reduced Till (345)			● blue 1,13			● blue 1,13	● blue 1,13	● blue 1,13					● blue 13		
		Contour Farming (330)			● yellow 1,13			● yellow 1,13	● yellow 13	● yellow 13					● yellow 13		
		Cover Crop (340)			● blue 1,13			● yellow 1,13	● yellow 13	● blue 1,13					● yellow 13		
		Grade Stabilization Structure (410)	● yellow 1		● yellow 1,13												
		Grade Stabilization @ Side Inlets (410)			● yellow 1			● yellow 1									
		Nutrient Management (590)			● blue 1			● blue 1,13	● blue 1,13	● blue 1,13	● blue 1,13			● yellow 1			
		Integrated Pest Management (595)													● blue 1,13		
		Terrace (600)			● blue 1,13			● yellow 13	● yellow 13	● yellow 13					● yellow 1,13		
	Filtration	Contour Buffer Strips (332)			● blue 1,13			● yellow 13	● yellow 13	● yellow 13					● blue 1,13	● yellow 13	● yellow 13
		Field Border (386)		● green	● blue 1,13		● green	● blue 1,13	● blue 1,13	● blue 1,13	● blue 1,13				● blue 1,13		
		Filter Strip (393)		● green	● blue 1,13		● green	● blue 1,13	● blue 1,13	● blue 1,13	● blue 1,13				● blue 1,13	● blue 13	● blue 13
		Grassed Waterway (412)	● yellow 1,13		● blue 1,13	● yellow 13		● yellow 13	● yellow 13	● yellow 13	● green				● yellow 1,13		
		Vegetative Barrier (601)			● yellow 13			● yellow 13	● yellow 13	● yellow 13					● yellow 13		
	Infiltration	Alternative Tile Intakes	● yellow 1		● yellow 1			● yellow 1	● yellow 1				● green				
		Controlled Drainage (587)	● yellow 1,13			● green	● yellow 13	● yellow 1	● yellow 1	● yellow 1			● green				
		Drainage Water Management (554)						● yellow 13	● yellow 13	● red 13					● yellow 13		
		Irrigation Water Management (449)			● yellow 1			● yellow 1,13	● yellow 13	● yellow 1,13					● yellow 1,13	● yellow 13	● yellow 13
		Tile System Design	● yellow 1							● yellow 1			● green				

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Agricultural	Settling	Alternative Side Inlet	🟡[13]		🟢			🟢		🟢	🟢				🟢		
		Culvert Sizing/Road Retention/Downsizing	🟡[1]		🟡[1]			🟢									
		Sediment Basin (350)	🟡[13]		🔵[1,13]			🔵[1,13]	🟡[13]	🟡[1,13]	🟡[1,13]				🟡[13]		
		Water and Sediment Control Basin (638)	🟡[1,13]		🔵[1,13]			🟡[1]	🟡[1]								
	Nutrient Removal	Saturated Buffers - Veg. Subsurface Drain (739)	🟡[12,13]					🟡[12]	🟡[12]	🟡[12,13]							
		Two Stage Ditch Design	🟡[1]	🟡[1]	🟡[1]		🟢	🟢		🟡[1]				🟢			
		Wetland Creation (658) - Constructed Treatment	🟡[13]	🟡[1]	🟡[1,13]			🟡[1,13]	🟡[13]	🟡[1,13]	🔵[7]			🟡[1]	🟡[13]	🔵[7]	🟡[13]
		Wetland Enhancement (659)			🟡[13]			🟡[13]	🟡[13]	🟡[13]					🟡[13]		🟡[13]
		Wetland Restoration (657)	🟡[1]	🟡[1]	🟡[1,13]			🟡[1,13]	🟡[13]	🟡[1,13]	🔵[7]				🟡[1,13]	🔵[7]	🟡[13]
		Woodchip Bioreactor (Denitrification Beds)						🟡[1]	🟡[1]	🟡[1]					🟡[1]		
	Livestock Management	Constructed Wetland (656)						🔵[13]	🔵[13]	🔵[13]	🔵[13]						
		Feedlot Clean Water Diversion			🟡[1,13]			🟡[1]	🟡[1]	🟡[1]	🟢		🟢				
		Fence (382) - Livestock Exclusion		🟡[1]	🟡[1]		🟡[1]	🟢	🟢	🟢	🟢			🟢			
		Prescribed Grazing (528) - Rotational			🟡[1,13]		🟡[1,13]	🟡[1,13]	🟡[13]	🟡[1,13]	🟡[13]				🟡[13]		
		Stream Crossing (578)			🟡[13]			🔴[13]	🔴[13]	🔴[13]	🔴[13]						
		Vegetated Treatment Area (635) - Feedlot Runoff	🟡[13]		🔵[1,13]			🔵[1,3]	🔵[1,13]	🔵[1,13]	🔵[13]		🟢				
		Waste Storage Facility (313) - Manure						🔵[1,13]	🔵[13]	🔵[1,13]	🔵[13]						
Riverine	Vegetative Cover	Streambank and Shoreline Protection (580)	🟡[1]	🟡[1,13]	🟡[1,3]		🟡[13]	🟡[13]	🟡[13]	🟡[13]							
		Streambank Stabilization with Vegetation	🔵[7]	🔵[7]	🔵[6,7]		🔵[7]	🟡[6]	🟡[6]	🟡[6]	🔵[7]			🔵[7]			
		Re-establish Riparian Trees & Brush	🔵[7]	🔵[7]	🔵[7]		🔵[7]				🔵[7]			🔵[7]		🔵[7]	
		Riparian Forest Buffer (391)			🔵[13]		🔵[13]	🔵[13]	🔵[13]	🔵[13]					🟡[13]		
		Riparian Herbaceous Cover (390)		🟡[1,13]	🔵[1,13]		🟡[1,13]	🔵[1,13]	🔵[13]	🔵[1,13]					🟡[13]		
	In-Stream Restoration	Alter Dam Operation to Mimic Natural Conditions	🔵[7]	🔵[7]													
		Dam Removal	🔵[5]	🔵[5]	🔵[7]	🔵[5]	🟢							🔵[5]			
		Grade Control / Drop Structures	🔵[7]	🔵[7]	🔵[7]						🔵[7]			🔵[7]			
		Nature-Like Fish Passage		🔵[11]	🔵[11]	🔵[11]											
		Proper Culvert Sizing or Replace with Bridge	🟢	🟢	🟢	🟢											
		Reset Culverts @ Proper Elevation	🟢			🔵[1]											
		Restore Natural Stream Meander and Complexity	🔵[7]			🔵[11**]								🔵[7]			
		Restore Riffle Substrate		🔵[7]	🔵[7]						🔵[7]			🔵[7]			
		Retrofit Dams with Multilevel Intakes					🔵[7]										
		Stream Habitat Improvement & Management (395)		🟡[13]	🟡[13]	🟡[13]	🟡[13]										
		Terraces				🔵[11**]											
		Two Stage Ditch	🟢	🟢	🟡[1]	🔵[11**]	🟢	🟢		🟡[1]							

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Urban	Education, Training & Regulation	Erosion & Sediment Control Training		●	●2			●2	●2	●2	●2			●2			
		Establishing a Buffer Ordinance	●2	●	●2		●2	●2	●2	●2	●2						
		Establishing an Infiltration Standard(s)	●2		●2		●2	●2	●2	●2	●2						
		Illicit-Discharge Identification & Risk Reduction						●2	●2	●2	●2			●2			●2
		Pet Waste Ordinance						●2	●2	●2	●2			●2			
		Storm Drain Stenciling						●2	●2	●2	●2			●2		●2	●2
	Pollution Prevention - Source Controls	Park & Open Space Fert/Chem Appl. Programs						●2	●2	●2	●2			●2	●		
		Composting Programs			●6			●6	●6	●6	●6			●			
		Fertilizer Management						●	●	●	●						
		Hazardous Material Storage & Handling													●	●2	●2
		Open Space Design	●2	●	●2		●2	●2	●2	●2	●2						
		Reducing Impervious Surfaces	●2		●2		●2	●2	●2	●2	●2	●2				●2	●2
		Residential Waste Collection & Clean-up Program		●				●2	●2	●2	●2			●2		●2	
		Septic System Maintenance Programs			●2			●2	●2	●2	●2			●2			
		Street & Parking Lot Sweeping			●2			●2	●2	●2	●2			●2			
		Urban Forestry	●2		●		●2	●2	●2	●2	●2					●2	
		Vehicle Washing			●6			●2	●2	●2	●2			●2		●2	●2
		Volume Control Using Compost /Soil Amendments	●2		●2			●2	●2	●2	●2						
		Winter Road Materials Management			●2			●2	●2	●2	●2	●2	●2			●2	
	Infiltration	Green Roofs	●2		●6		●2	●6	●6	●6	●6					●6	
		Improved Turf			●6			●6	●6	●6	●6						
		Infiltration Basin/Trench	●2		●2		●2	●2,6	●2,6	●2	●2					●2	
		Pervious Pavements	●2		●2		●2	●2	●2	●2	●2	●2				●6	●6
		Vegetated Swales	●		●6			●6	●6	●6	●6					●6	●6
	Filtration	Bioretention						●6	●6	●6	●6			●		●6	●6
		Dry Swales	●2		●2		●2	●6	●6	●6	●6					●6	●6
		Filter Strips/Buffers	●2		●2		●2	●2	●2	●2	●2						
		Permeable Pavement with Underdrains	●		●			●									
		Sand Filters						●6									
		Tree Trenches/Boxes	●				●	●	●	●	●	●					●
		Wet Swales	●6		●6			●6	●6	●6	●6					●6	●6

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Urban	Reuse	Rainwater Harvest/Reuse & Rain Barrel Programs	🔵[2]		🔵[2]			🔵[6]	🔵[6]	🔵[6]	🔵[6]	🔵[6]			🔵[6]	🔵[2]	🔵[6]
Urban	Reuse	Underground Storage Systems	🟢														
Urban	Settling	Constructed Wetland	🟢		🔵[6]			🔵[6]	🔵[6]	🔵[6]	🔵[6,7]					🔵[6]	🔵[6]
Urban	Settling	Hydrodynamic Separators			🟢												🟢
Urban	Settling	Stormwater Ponds	🟢		🟢		🔴[6]	🔵[6]	🔵[6]	🟢	🟢					🔵[6]	🔵[6]
Urban	Chemical Treatment	Iron & Aluminum Enhanced BMPs			🔵[6]			🔵[6]	🔵[6]	🔵[6]	🔵[6]					🔵[6]	
Forestry	Pollution Prevention - Source Controls	Avoidance of Logging Residue into Waterbodies		🟡[3,4]	🟡[3,4]		🟢	🟢	🟢					🟢			
Forestry	Pollution Prevention - Source Controls	Careful Pesticide Selection													🟡[3,4]		
Forestry	Pollution Prevention - Source Controls	Erosion Control (water bars, silt fence, etc.)			🟢			🟢	🟢								
Forestry	Pollution Prevention - Source Controls	Integrated Pest Management													🟡[3,4]		
Forestry	Pollution Prevention - Source Controls	Minimization of Soil Disturbance			🟡[3,4]			🟢	🟢								
Forestry	Pollution Prevention - Source Controls	Precautions During Pesticide Use Cycle													🟡[3,4]		
Forestry	Pollution Prevention - Source Controls	Properly Clearing Debris in Rights-of-Way			🟡[3,4]	🟡[3,4]											
Forestry	Pollution Prevention - Source Controls	Proper Use of Mechanical Site Prep Techniques			🟡[3,4]												
Forestry	Pollution Prevention - Source Controls	Soil Protection/Seeding			🟡[3,4]			🟢	🟢								
Forestry	Pollution Prevention - Source Controls	Site Reconnaissance/Protect Sensitive Areas	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]	🟡[3,4]			🟡[3,4]	🟡[3,4]		
Forestry	Pollution Prevention - Source Controls	Water Diversion Structures	🟡[3,4]		🟡[3,4]							🟢	🟢				
Forestry	Pollution Prevention - Source Controls	Wetland Protection	🟢	🟡[3]		🟡[3]											
Forestry	Infrastructure Management	Appropriate Wetland Road Construction	🟡[3]	🟢	🟡[3,4]			🟢	🟢								
Forestry	Infrastructure Management	Appropriate Winter Road Construction			🟡[3,4]			🟢									
Forestry	Infrastructure Management	Closure of Inactive Roads & Post-Harvest	🟡[3,4]	🟢	🟡[3,4]			🟢									
Forestry	Infrastructure Management	Forest Road Cross-Drainage			🟡[3,4]			🟢									
Forestry	Infrastructure Management	Location & Sizing of Landings			🟡[3,4]			🟢	🟢								🟢
Forestry	Infrastructure Management	Maintaining Active Forest Roads			🟡[3,4]	🟡[3,4]		🟢									
Forestry	Infrastructure Management	Proper Alignment of Forest Roads	🟢		🟡[3,4]	🟢		🟢									
Forestry	Infrastructure Management	Proper Water Crossings	🟡[3,4]		🟡[3,4]	🟡[3,4]		🟢									
Forestry	Infrastructure Management	Road Construction, Excavation, & Surfacing			🟡[3,4]			🟢	🟢								

Land Use Type	Treatment Group	BMP's	STRESSORS TO AQUATIC BIOTA														
			Physical					Chemical							Toxic		
								Nutrients									
			Flow Alteration *	Habitat	Sediment	Connectivity	Thermal Loading	Total P	Soluble P	Nitrate N	Ammonia N	Chloride	Salts	D. O.	Pesticides	Metals	Oil & Grease
Forestry	Vegetative Cover / Structure	Improve Tree Longevity & Diversity of Composition		blue ●[8]		blue ●[8]											
Forestry	Vegetative Cover / Structure	Minimization of Young Forest/Open Area Cover	blue ●[9]	blue ●[9]	blue ●[9]												
Forestry	Vegetative Cover / Structure	Prescribed Burning		yellow ●[3,4,8]	yellow ●[3,4,8]	blue ●[8]											
Forestry	Vegetative Cover / Structure	Riparian Management Zone Widths		blue ●[8]	blue ●[8]	blue ●[8]	blue ●[8]	blue ●[8]	blue ●[8]	blue ●[8]	blue ●[8]			blue ●[8]			
Forestry	Vegetative Cover / Structure	Shade Strips Next to Lakes, Streams & Wetlands		yellow ●[3,8]			yellow ●[3,8]							green ●	blue ●[8]		blue ●[8]
Forestry	Infiltration	Proper Timing of Harvest (minimize compaction) or of Vegetative Treatments	blue ●[8,10]	blue ●[8,10]	blue ●[8,10]			blue ●[8,10]	blue ●[8,10]	blue ●[8,10]	blue ●[8,10]						
Forestry	Filtration	Filter Strips Adjacent to Lakes, Streams & Wetlands		yellow ●[3,4,8]	yellow ●[3,4,8]			yellow ●[3,4,8]	yellow ●[3,4,8]	yellow ●[3,4,8]	yellow ●[3,4,8]				yellow ●[3,4,8]		

Key: A dot in a cell (with the exception of red) indicates the BMP should have a positive affect on the stressor.

blue ●	Well documented. Stressor is primary target of BMP.
yellow ●	Some study. Stressor is secondary target of BMP.
green ●	Reasonable to assume stressor affected by BMP.
red ●	BMP has potential to aggravate the stressor.
1,2..	Literature cited supporting the BMP-stressor relationship

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CLEAN WATER LAND & LEGACY AMENDMENT

Notes:

A. * BMPs for Flow Alteration may be included for their impact to reduce the effects of either low and/or high flow.
B. ** Indicates that this BMP addresses lateral connectivity (access to floodplain) rather than longitudinal connectivity.
C. The numbers in parenthesis behind some of the BMPs are the NRCS, Conservation Practice (CP) numbers.
D. Habitat for the purposes of this guide refers to the physical, structural attributes of stream habitat.
E. Salts or Ionic Strength is typically measured by conductivity, salinity or total dissolved solids.
F. This is a working document. Contact Bruce Paakh, MPCA (bruce.paakh@state.mn.us) for current version.
G. April 20, 2015 version.

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