Sand Hill River Watershed Biotic Stressor Identification Report

A study of local stressors limiting the biotic communities in the Sand Hill River Watershed

Minnesota Pollution Control Agency

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Acronyms

AUID - Assessment Unit Identification Number

BMP - Best Management Practice

BOD - Biological Oxygen Demand

CADDIS - Causal Analysis/Diagnosis Decision Information System

CD - County Ditch

Chl-a - Chlorophyll-a

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

NLCD - National Land Cover Dataset

NWI - National Wetland Inventory

SHRW - Sand Hill River Watershed

SI - Stressor identification

SOE - Strength-of-Evidence

TALU - Tiered Aquatic Life Use

TIV - Tolerance Indicator Value

TMDL - Total Maximum Daily Load

TP - Total Phosphorous

TSS - Total Suspended Solids

TSVS - Total Suspended Volatile Solids

USGS - United States Geological Survey

WHAF - Watershed Health Assessment Framework

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 strategy. In 2011, the MPCA conducted biological monitoring at several sites throughout the Sand Hill River Watershed (SHRW). 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 of each site. The biological monitoring results for the watershed were formally assessed as part of the development of the Sand Hill River Watershed Monitoring and Assessment Report (MPCA, 2014) to determine if individual stream reaches met applicable aquatic life standards; each 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. Three stream reaches in the SHRW were determined to be biologically impaired, while two reaches were found to be supporting a healthy fish and macroinvertebrate community. In addition, five stream reaches were not assessed, primarily due to extensive channel alteration.

The purpose of this report is to identify the causes, or "stressors," that are likely contributing to the biological impairments in the SHRW. A comprehensive review of available data (e.g., plans and reports) for the watershed was initially performed to identify the six 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 process point to several probable stressors in each of the biologically impaired reaches of the watershed. The following summarizes the probable stressors per impaired reach:

Reach 541 - Sand Hill River

(Headwaters to County Ditch 17/AUID #09020301-541)

F-IBI Impairment Stressors:

- Loss of Connectivity
- Flow Regime Alteration
- Lack of Instream Habitat
- Low Dissolved Oxygen

M-IBI Impairment Stressors:

- Flow Regime Alteration
- Excess Suspended Sediment
- Low Dissolved Oxygen

Reach 542 - Sand Hill River

(County Ditch 17 to Kittleson Creek/AUID #09020301-542)

F-IBI Impairment Stressors:

- Loss of Connectivity
- Flow Regime Alteration
- Lack of Instream Habitat

Reach 515 - County Ditch 17

(Garden Slough to Sand Hill River/AUID #09020301-515)

M-IBI Impairment Stressors:

- Flow Regime Alteration

Introduction

Stressor identification (SI) 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 SI 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, geomorphology, chemistry, statistics, and toxicology. Figure 1 displays a conceptual model of the SI process.

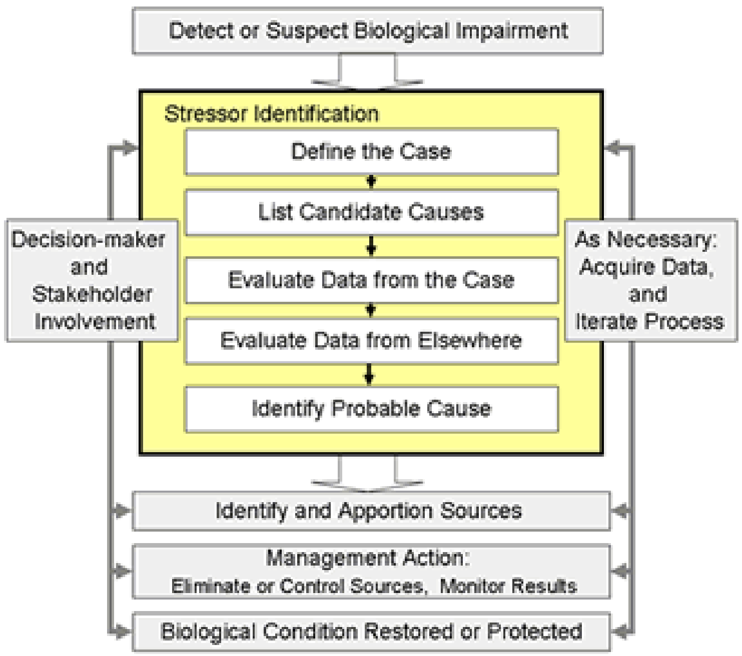

Figure 1. Conceptual model of the SI process (EPA 2012)

The initial step in the SI 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 combine 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 SI 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.

Section 1: Watershed overview

1.1 Physical setting

The Sand Hill River Watershed (SHRW), United States Geological Survey (USGS) Hydrologic Unit Code (HUC) 09020301, is located in northwestern Minnesota and is part of the larger Red River of the North Basin (Figure 4). The SHRW has a drainage area of 618 square miles and is primarily located in Polk County; the watershed also encompasses lesser portions of Mahnomen and Norman counties. Cities in the watershed, listed in order from upstream to downstream, include Fosston, Winger, Fertile, Beltrami, Climax, and Nielsville. The Sand Hill River is the prominent drainage feature in the SHRW and extends from the outlet of Sand Hill Lake, south of Fosston, to its confluence with the Red River of the North, west of Climax. The Sand Hill River Watershed District manages the water resources of a majority of the watershed; the political boundary of the District closely mirrors the HUC boundary.

1.2 Surface water resources

The SHRW contains approximately 94 miles of perennial stream and river (largely the Sand Hill River), 273 miles of intermittent stream, 26 miles of perennial drainage ditch, and 282 miles of intermittent drainage ditch (Groshens, 2006). According to the Statewide Altered Watercourse Project dataset, 55% of the watercourses in the SHRW have been altered by ditching or channelization. There are also several small lakes in the eastern half of the watershed, the largest of which is Union Lake at 887 acres. These lakes tend to be closed basins or have poorly developed outlets.

1.3 Geology and soils

The SHRW is divided into three distinct physiographic regions. These regions, oriented from east to west, include the till plain/moraine, beach ridges, and lake plain. The till plain/moraine region encompasses the eastern half of the SHRW, extending from the eastern boundary of the watershed, to approximately one mile east of Fertile. This area is characterized by a rolling topography, interspersed with small lakes and 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 ridges region follows a north-south corridor approximately ten miles wide through the center of the watershed and is located on the western boundary of the till plain/moraine region. This region represents the ancient shorelines of Glacial Lake Agassiz. The Sand Hill River drops approximately 176 feet in elevation from the highest beach ridge to the base of the lake plain. The soils of this region are coarse textured and derived from sand and gravel deposits. Soil and bank erosion is a significant concern in this area. Lastly, the lake plain region represents the western third of the watershed, from approximately nine miles west of Fertile, to the Red River of the North. This region represents the lake bed of Glacial Lake Agassiz, which receded from the area approximately 8,000 years ago. The lake plain is characterized by an extremely flat topography (0-1% slope) and fine textured soils derived from lacustrine sediments.

1.4 Land use and ecoregions

The predominant land use in the SHRW is agriculture. According to the 2006 National Land Cover Dataset (NLCD), cultivated crops comprised 74% of the watershed. Minor land cover groups in the watershed included wetlands (7%), developed areas (6%), forested areas (5%), and pasture/hay lands (4%). These minor cover groups were primarily found in the beach ridges and till plain/moraine regions of the watershed. There are two ecoregions represented in the SHRW: the Lake Agassiz Plain (LAP) and the North Central Hardwood Forest (NCHF). However, a majority (>95%) of the watershed is located within the LAP ecoregion; the NCHF ecoregion is found in the extreme eastern extent of the watershed.

1.5 Ecological health

The Minnesota Department of Natural Resources (MDNR) has developed a web-based tool called the Watershed Health Assessment Framework (WHAF) 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 2 presents the watershed health scorecard for the SHRW.

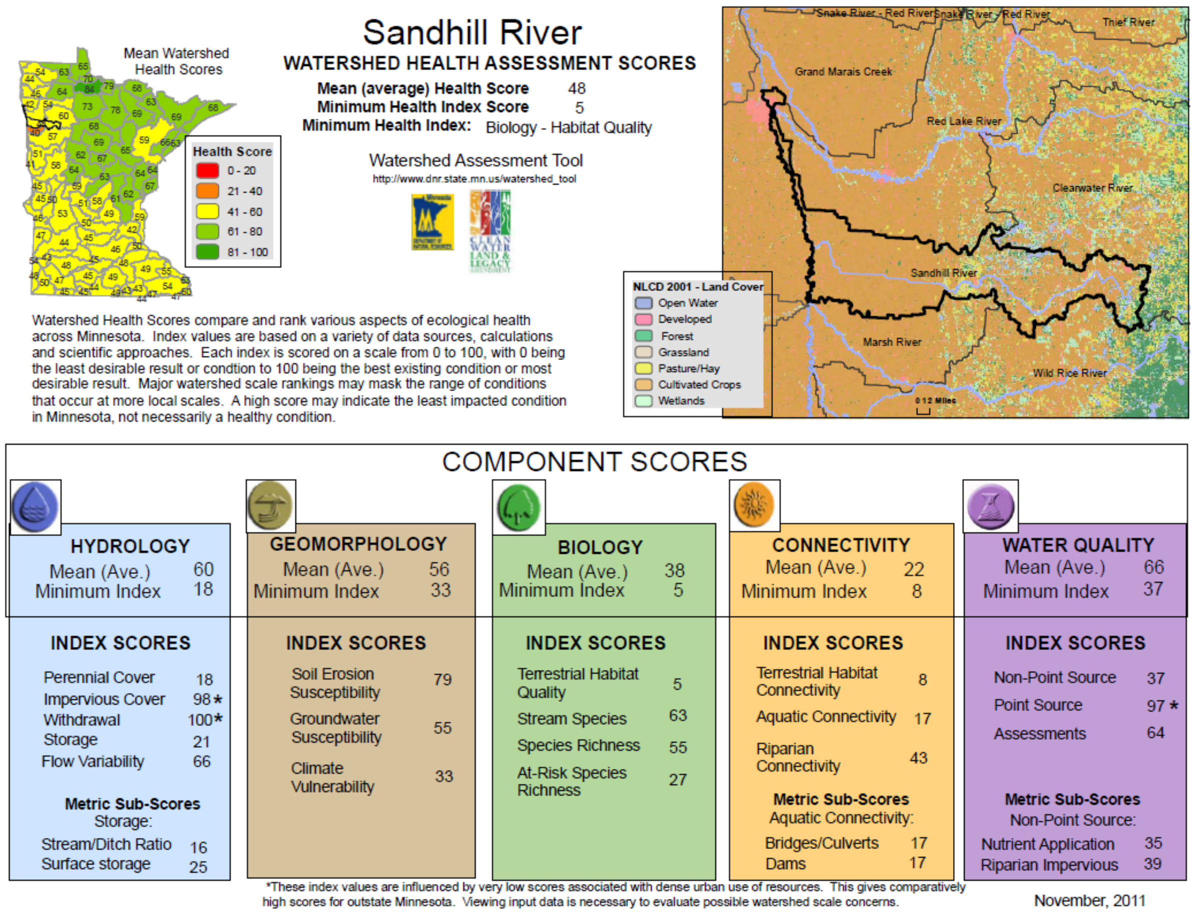

Figure 2. Watershed health assessment scores for the SHRW

The mean health score for the SHRW was 48. The overall score was limited by the individual mean component scores for biology (38) and connectivity (22). Specifically, the watershed scored poorly for the following component indexes: terrestrial habitat quality (5), terrestrial habitat connectivity (8), and aquatic connectivity (17).

Section 2: Biological monitoring and impairments

2.1 Intensive watershed monitoring approach

The Minnesota Pollution Control Agency (MPCA) utilizes biological (i.e., fish and macroinvertebrate) monitoring to assess overall stream health as part of its Intensive Watershed Monitoring (IWM) strategy. In 2011, the MPCA conducted biological monitoring at several sites throughout the SHRW. The resulting data, along with previously collected monitoring data, were used to produce an Index of Biological Integrity (IBI) score for the fish (F-IBI) and macroinvertebrate (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; each 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. The biological impairments of the SHRW are the focus of this SI report. Upon completion of the SI 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 3 displays a conceptual model of these processes.

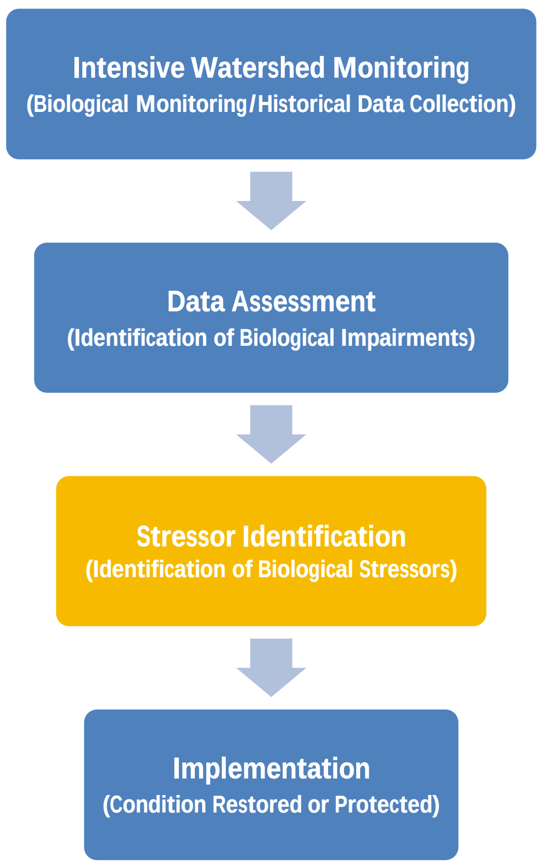

Figure 3. Conceptual model of the IWM, data assessment, SI, and implementation processes

2.2 Monitoring sites

Table 1 lists the 19 biological monitoring sites in the SHRW. The location of the monitoring sites is displayed in Figure 4. For the purpose of this report, each monitoring site was assigned a unique SI site identification number based upon its relative longitudinal position (upstream to downstream) within the reach or watercourse. For instance, Site SHR-01 represents the most upstream monitoring site on the Sand Hill River, while Site SHR-11 represents the most downstream site on the river.

Table 1. List of biological monitoring sites in the SHRW

SI Site #	Field #	Reach Name	AUID #	Location
SHR-01	11RD002	Sand Hill River	09020301-541	2.5 miles southwest of Fosston
SHR-02	05RD052	Sand Hill River	09020301-541	8 miles southeast of Fosston
SHR-03	11RD009	Sand Hill River	09020301-541	3 miles southwest of Winger
SHR-04	11RD071	Sand Hill River	09020301-542	5 miles east of Fertile
SHR-05	11RD070	Sand Hill River	09020301-542	2 miles northeast of Fertile
SHR-06	11RD014	Sand Hill River	09020301-542	3 miles southwest of Fertile
SHR-07	11RD016	Sand Hill River	09020301-536	6 miles southeast of Beltrami
SHR-08	07RD007	Sand Hill River	09020301-536	9 miles east of Nielsville
SHR-09	11RD021	Sand Hill River	09020301-537	4 miles southeast of Climax
SHR-10	05RD018	Sand Hill River	09020301-537	1.5 miles southeast of Climax
SHR-11	11RD028	Sand Hill River	09020301-537	In Climax
CD16-01	07RD003	County Ditch 16	09020301-512	5 miles west of Fosston
CD16-02	11RD003	County Ditch 16	09020301-512	4 miles south of New Munich
CD17-01	11RD012	County Ditch 17	09020301-515	1.5 miles northwest of Rindall
CD48-01	11RD001	County Ditch 48	09020301-538	2 miles southwest of Fosston
CD55-01	11RD004	County Ditch 55	09020301-540	4.5 miles northwest of Fosston
KC-01	05RD107	Kittleson Creek	09020301-508	2.5 miles north of Fertile
KC-02	11RD015	Kittleson Creek	09020301-508	5.5 miles west of Fertile
UNC-01	11RD008	Unnamed Creek	09020301-539	2 miles southwest of Winger

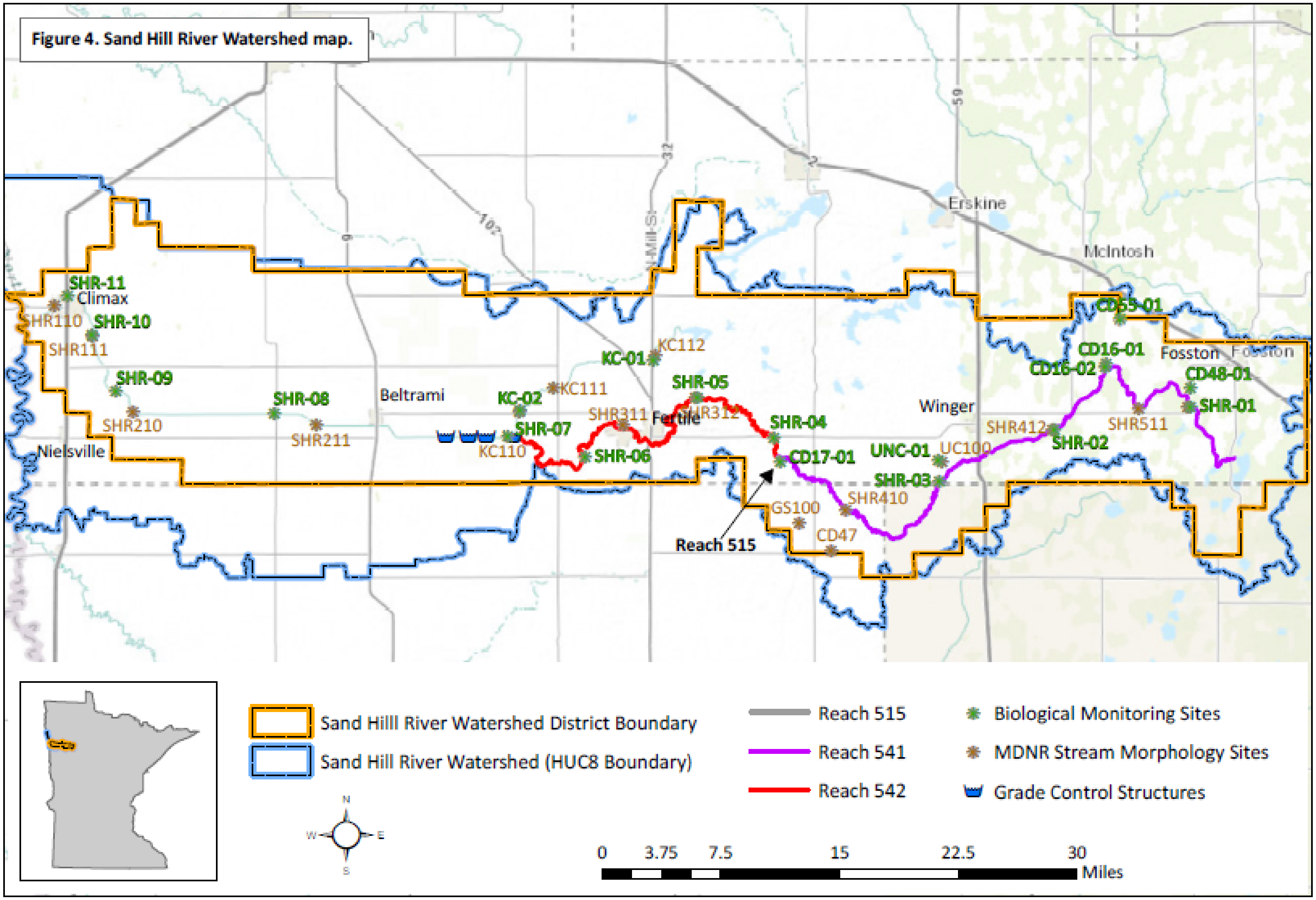

Figure 4. Sand Hill River Watershed Map

2.3 Monitoring results

Fish monitoring results

Table 2 provides the F-IBI scores for each of the monitoring sites in the SHRW. The F-IBI scores varied throughout the watershed, with seven sites exceeding the upper confidence limit for their respective class and five sites scoring below the lower confidence limit for their class. A total of seven sites failed to meet their applicable F-IBI standard; these sites are highlighted red. Appendix A contains a summary of the individual metric values that comprise each site's F-IBI score.

Table 2. Summary of F-IBI scores for monitoring sites in the SHRW

SI Site #	Reach Name	Drainage Area (mi^2)	Class	# Visits	F-IBI Avg.	F-IBI Threshold	Confidence Limits (lower/upper)
SHR-01	Sand Hill River	31.6	6	1	50	40	24/56
SHR-02	Sand Hill River	85.9	5	1	**37**	50	41/59
SHR-03	Sand Hill River	119.4	5	1	**34**	50	41/59
SHR-04	Sand Hill River	182.3	5	1	**31**	50	41/59
SHR-05	Sand Hill River	220.4	5	1	**34**	50	41/59
SHR-06	Sand Hill River	233.5	5	1	**46**	50	41/59
SHR-07	Sand Hill River	300.1	5	1	56	50	41/59
SHR-08	Sand Hill River	314.2	1	1	57	46	35/57
SHR-09	Sand Hill River	340.8	1	1	66	46	35/57
SHR-10	Sand Hill River	359.2	1	2	56	46	35/57
SHR-11	Sand Hill River	462.5	1	2	66	46	35/57
CD16-01	County Ditch 16	15.2	6	1	70	40	24/56
CD16-02	County Ditch 16	15.2	6	1	57	40	24/56
CD17-01	County Ditch 17	18.2	6	1	74	40	24/56
CD48-01	County Ditch 48	10.0	6	1	64	40	24/56
CD55-01	County Ditch 55	9.8	6	1	**37**	40	24/56
KC-01	Kittleson Creek	25.2	6	2	60	40	24/56
KC-02	Kittleson Creek	54.1	5	1	**34**	50	41/59
UNC-01	Unnamed Creek	11.7	6	1	40	40	24/56

Macroinvertebrate monitoring results

Table 3 contains the M-IBI scores for each of the monitoring sites in the SHRW. Similar to the fish monitoring results, M-IBI scores varied throughout the watershed. Four sites scored above the upper confidence limit for their respective class, while three sites scored below the lower confidence limit for their class. A total of seven sites failed to meet their applicable M-IBI standard (highlighted red). Appendix A contains a summary of the individual metric values that comprise each site's M-IBI score.

Table 3. Summary of M-IBI scores for monitoring sites in the SHRW

SI Site #	Reach Name	Drainage Area (mi^2)	Class	# Visits	M-IBI Avg.	M-IBI Threshold	Confidence Limits (lower/upper)
SHR-01	Sand Hill River	31.6	7	1	**8.5**	38.3	24.7-51.9
SHR-02	Sand Hill River	85.9	6	1	**37.8**	46.8	33.2-60.4
SHR-03	Sand Hill River	119.4	6	1	**26.9**	46.8	33.2-60.4
SHR-04	Sand Hill River	182.3	6	1	**43.0**	46.8	33.2-60.4
SHR-05	Sand Hill River	220.4	6	1	75.1	46.8	33.2-60.4
SHR-06	Sand Hill River	233.5	5	1	53.2	35.9	23.3-48.5
SHR-07	Sand Hill River	300.1	5	1	51.3	35.9	23.3-48.5
SHR-08	Sand Hill River	314.2	7	1	42.1	38.3	24.7-51.9
SHR-09	Sand Hill River	340.8	7	2	53.6	38.3	24.7-51.9
SHR-10	Sand Hill River	359.2	7	1	45.8	38.3	24.7-51.9
SHR-11	Sand Hill River	462.5	5	1	37.1	35.9	23.3-48.5
CD16-01	County Ditch 16	15.2	7	1	**33.6**	38.3	24.7-51.9
CD16-02	County Ditch 16	15.2	7	1	46.8	38.3	24.7-51.9
CD17-01	County Ditch 17	18.2	5	1	**29.6**	35.9	23.3-48.5
CD48-01	County Ditch 48	10.0	7	1	**23.1**	38.3	24.7-51.9
KC-01	Kittleson Creek	25.2	6	1	50.8	46.8	33.2-60.4

2.4 Assessments and impairments

The biological monitoring results for the SHRW were formally assessed as part of the development of the *Sand Hill River Watershed Monitoring and Assessment Report* (MPCA, 2014) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 4, there are ten 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 five of these reaches were assessed. Two of the assessed reaches (Reaches 508 and 537) were found to be supporting a healthy fish and macroinvertebrate community, while three reaches (Reaches 515, 541, and 542) were determined to be biologically impaired; the impaired reaches are highlighted red. The assessments for many of the remaining reaches were deferred due to extensive channelization, pending the implementation of the MPCA's proposed Tiered Aquatic Life Use (TALU) standards.

Table 4. Assessment results for stream reaches with biological monitoring data in the SHRW

Reach ID #	AIUD #	Reach Name	Description	Length (mi)	Biological Impairment(s)
508	09020301-508	Kittleson Creek	Headwaters to Sand Hill River	12.4	None
512	09020301-512	County Ditch 16	County Ditch 55 to Sand Hill River	2.0	Not Assessed
515	**09020301-515**	**County Ditch 17**	**Garden Slough to Sand Hill River**	**0.3**	**M-IBI**
536	09020301-536	Sand Hill River	Kittleson Creek to Unnamed Creek	16.7	Not Assessed
537	09020301-537	Sand Hill River	Unnamed Creek to Red River	14.2	None
538	09020301-538	County Ditch 48	Unnamed Creek to Sand Hill River	3.9	Not Assessed
539	09020301-539	Unnamed Creek	Unnamed Creek to Sand Hill River	2.0	Not Assessed
540	09020301-540	County Ditch 55	Unnamed Creek to County Ditch 16	3.1	Not Assessed
541	**09020301-541**	**Sand Hill River**	**Headwaters to County Ditch 17**	**38.1**	**F-IBI and M-IBI**
542	**09020301-542**	**Sand Hill River**	**County Ditch 17 to Kittleson Creek**	**32.1**	**F-IBI**

In addition to the biological impairments, there are also two reaches in the SHRW that were included on the 2012 Impaired Waters List for water quality impairments affecting aquatic life. Reach 537 was listed for turbidity and Reach 509 was listed for both low dissolved oxygen and turbidity. However, Reach 509, which is not listed in Table 4, was later split into Reaches 541 and 542 in order to recognize characteristic differences along this segment of the river. As a result of this action, the impairments associated with Reach 509 are proposed to be isolated to Reach 541 in the draft 2014 Impaired Waters List based upon data indicating that Reach 542 meets the state's dissolved oxygen and turbidity standards.

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 SI process and provides the framework for gathering key data for causal analysis. Table 5 lists the nine common biotic stressors that were considered as potential candidate causes in the SHRW. The list was developed based upon the results of the *Red River Valley Biotic Impairment Assessment* (MPCA, 2009) and other completed SI reports in the state. The credibility of each stressor as a candidate cause was then evaluated through a comprehensive review of available information for the SHRW, including water quality and quantity data, as well as existing plans and reports, including the *Sand Hill River Watershed Monitoring and Assessment Report* (MPCA, 2014), the *Sand Hill River Watershed District's Watershed Management Plan* (Sand Hill River Watershed District, 2012), the *Watershed Conditions Report: Sand Hill River Watershed* (Sand Hill River Watershed District, 2011), and the *Red River Basin Stream Survey Report: Sand Hill River* (Groshens, 2006). Based upon the results of this evaluation (Table 5), six candidate causes were identified to undergo causal analysis (Section 3.2).

Table 5. Summary of common biotic stressors evaluated as candidate causes in the SHRW

Stressor	Candidate Cause Identification - SHRW Biologically Impaired Reaches	
	Summary of Available Information	Candidate Cause (Yes/No)
Loss of Connectivity	There is one existing dam and four grade control structures on the Sand Hill River. The grade control structures are documented barriers to fish passage.	**Yes**
Flow Regime Alteration	The natural hydrology of the SHRW has been highly altered for agricultural drainage-related purposes and there is sufficient evidence of associated biotic impacts.	**Yes**
Lack of Instream Habitat	There is a documented lack of available instream habitat for the fish and macroinvertebrate communities of the SHRW.	**Yes**
Excess Suspended Sediment	The existing turbidity impairment associated with Reach 509 is proposed to be isolated to Reach 541 in the draft 2014 Impaired Waters List.	**Yes**
Low Dissolved Oxygen	The existing low dissolved oxygen impairment associated with Reach 509 is proposed to be isolated to Reach 541 in the draft 2014 Impaired Waters List.	**Yes**
Pesticide Toxicity	Limited sampling results for the Sand Hill River have detected the presence of several pesticides that are potentially toxic to aquatic life.	**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 stress to aquatic life.	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: Loss of connectivity

Background

Connectivity in aquatic ecosystems refers to how waterbodies and waterways are linked to each other on the landscape and how matter, energy, and organisms move throughout the system (Pringle, 2003). Dams and other water control structures on river systems alter hydrologic (longitudinal) connectivity, often obstructing the movement of migratory fish and causing a change in the population and community structure (Brooker, 1981; Tiemann et al., 2004). These structures also alter stream flow, water temperature regime, and sediment transport processes; each of which can cause changes in fish and macroinvertebrate assemblages (Cummins, 1979; Waters, 1995). According to the MDNR (2014), there are more than 1,200 dams in the state that serve a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

In addition to the aforementioned structures, culverts and beaver dams can also interfere with connectivity. A culvert that is raised (or perched) above the stream level can limit the ability of fish to migrate throughout the stream. A similar phenomenon can occur naturally with beaver dams acting as barriers to fish migration.

Applicable standards

There are no applicable standards for connectivity. However, the MDNR's Public Waters Work Permit requires that road crossing structures be designed and installed to allow for fish passage.

Available data

Dams and grade control structures

According to the U.S. Army Corps of Engineers (2013) and Sand Hill River Watershed District (2012), the Sand Hill Lake outlet dam is the only existing dam on the Sand Hill River; Reach 541 begins at the outlet of Sand Hill Lake. The dam was constructed in 1956 and is owned by the MDNR. In addition to the dam, there are four gradient control structures on the Sand Hill River, which are located immediately downstream of Reach 542. These structures were constructed as part of the Sand Hill Ditch Flood Control Project, which was completed in 1958 (Sand Hill River Watershed District, 2012). There are no dams or water control structures along Reach 515.

MPCA connectivity assessment

On September 11, 2013, MPCA SI staff conducted a connectivity assessment of the biologically impaired reaches of the watershed. Staff viewed the aforementioned dam and grade control structures, along with all culverts/bridges located along the reaches, as part of the assessment. The determination of whether or not a structure represented a barrier to connectivity was made using professional judgment by observing its setting and construction, along with water flow characteristics.

The Sand Hill Lake outlet dam (Figure 5) is a barrier to connectivity; water only flows over the dam when the level of the lake exceeds its height. Due to the design of the four grade control structures (Figure 5), fish passage upstream of the structures is obstructed under all flow conditions. Besides manmade connectivity barriers, staff also documented a beaver dam (Figure 5) located in the upstream portion of Reach 542. The beaver dam appeared to be potentially limiting fish passage. No perched culverts were found as part of the assessment.

Figure 5. Photos of connectivity barriers along Reaches 541 and 542, including the Sand Hill Lake outlet dam (upper left), grade control structures (upper right and lower left), and a beaver dam (lower right)

Biotic response

F-IBI impairments - Reaches 541 (Sand Hill River) and 542 (Sand Hill River)

Evidence of a potential connection between a loss of connectivity and the F-IBI impairments associated with Reaches 541 and 542 is provided by a decrease in the relative abundance of individuals with a female mature age equal to or greater than three years, excluding tolerant taxa (MA>3-TolPct). This metric includes late maturing fish species that require well-connected environments in order to access the habitats and resources necessary to complete their life history (e.g., channel catfish, walleye, and yellow perch). Scores for this metric (Figure 6) were low for all Class 5 monitoring sites along Reaches 541 and 542, which are located upstream of the grade control structures. Scores ranged from 0.4 (Site SHR-05) to 2.6 (Site SHR-04). The only late maturing fish species sampled at these sites was yellow perch. Modification of the grade control structures to enable fish passage would restore access to the beach ridges region (e.g., Reach 542), which represents the best spawning and rearing habitat in the watershed for many of these species. The instream habitat and conditions associated with Reach 541 are less conducive to supporting these species.

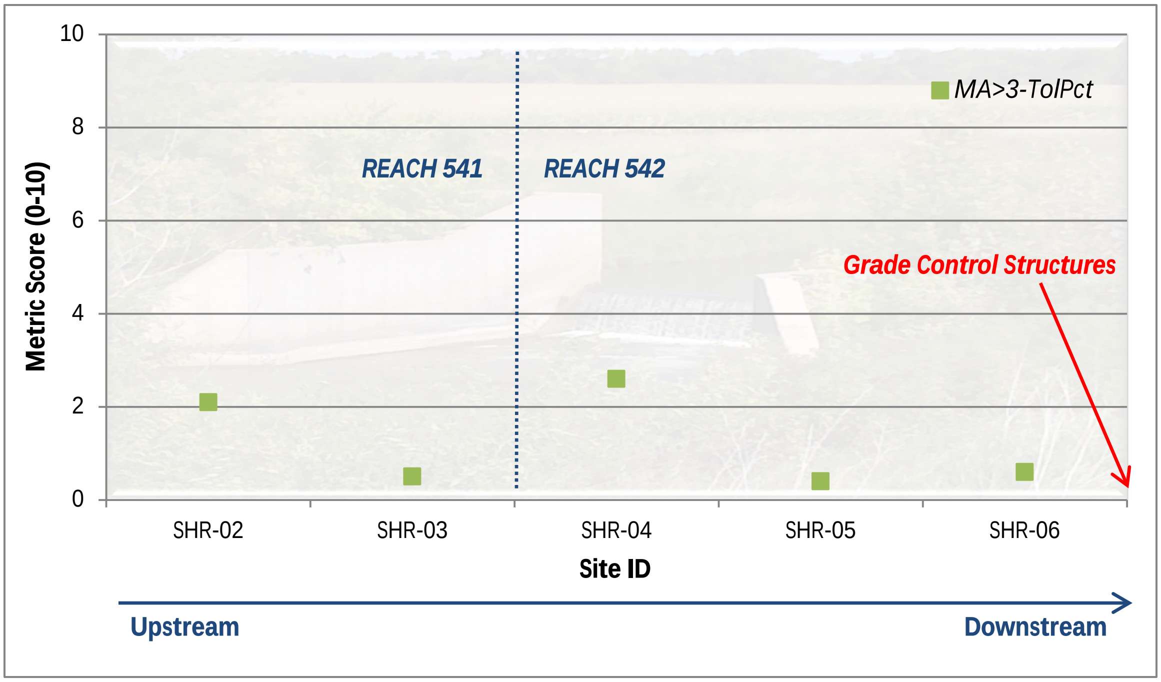

Figure 6. Loss of connectivity-related F-IBI metric scores for Class 5 monitoring sites along Reaches 541 and 542

Additional evidence of the impact of the grade control structures on the fish community of the Sand Hill River includes a discernible difference in the species sampled upstream and downstream of the structures. According to Table 6, the fish assemblage below the structures (Site SHR-08 to Site SHR-11) contained several large bodied, longer-lived species characteristic of well-connected riverine habitats (e.g., channel catfish, shorthead redhorse, and walleye). These species were entirely absent from the fish assemblage above the structures (Site SHR-01 to Site SHR-07).

Table 6. Summary of fish species sampled upstream and downstream of the grade control structures on the Sand Hill River

Fish Species	# Individuals Sampled Upstream of Structures (Site SHR-01 to Site SHR-07)	# Individuals Sampled Downstream of Structures (Site SHR-08 to Site SHR-11)
Channel catfish	0	85
Shorthead redhorse	0	16
Silver redhorse	0	15
Smallmouth bass	0	4
Walleye	0	6

Huberty (2004) also documented the detrimental influence of the grade control structures on the fish community of the Sand Hill River. Between 2002 and 2003, a total of 23 species were sampled from various locations along the river. Eleven of the species (i.e., common carp, channel catfish, freshwater drum, golden redhorse, goldeye, quillback, rock bass, sauger, shorthead redhorse, stonecat, and trout perch) were only found downstream of the structures.

The connectivity-related impacts of the Sand Hill Lake outlet dam and the beaver dam were unable to be determined due to data limitations; fish sampling was not performed on Sand Hill Lake and the date that the beaver dam was established is unknown. Based upon the results of the MPCA connectivity assessment, it is apparent that the Sand Hill Lake outlet dam presents a significant barrier to fish passage. However, restoration of connectivity would require sustained outflow from the lake, which is unlikely to occur given its location at the top of the watershed.

M-IBI impairments - Reaches 541 (Sand Hill River) and 515 (County Ditch 17)

There are no evident connections between a loss of connectivity and the M-IBI impairments associated with Reaches 541 and 515. The monitoring sites situated between these reaches and the grade control structures, located approximately 30 miles downstream, all had IBI scores above the threshold for their respective class; the lone exception was SHR-04, which scored slightly below the threshold. The impact of the Sand Hill Lake outlet dam on the macroinvertebrate community of the Sand Hill River is unknown due to the fact that sampling was not performed on the lake. However, given the negligible influence of the grade control structures on the macroinvertebrate community of the river, the impact of the dam is believed to be minimal.

Strength-of-evidence analysis

Table 7 presents the SOE analysis scores for loss of connectivity as a candidate cause. The multiple lines of evidence used in the analysis suggest that loss of connectivity is a probable stressor for the F-IBI impairments associated with Reaches 541 and 542. Several of the evidence types convincingly support this conclusion. Conversely, the multiple lines of evidence indicate that loss of connectivity is not a likely stressor for the M-IBI impairments associated with Reaches 541 and 515. Many of the evidence types strongly weaken the case for this cause as a stressor for the M-IBI impairments.

Table 7. SOE analysis scores for Candidate Cause #1: loss of connectivity

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	+++	--	+++	--
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	+++	--	+++	--
Causal Pathway	+++	--	+++	--
Evidence of Exposure/Biological Mechanism	+++	--	+++	--
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	+++	--	+++	--
Symptoms	+++	--	+++	--
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	+++	--	+++	--
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	+++	NE	+++	NE
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	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: Flow regime alteration

Background

The natural hydrology of the SHRW has been highly altered, primarily to expedite drainage for agricultural purposes (Sand Hill River Watershed District, 2012). Examples of such alterations include ditching, channelization of natural streams, modification of headwater streams, subsurface tiling, and wetland drainage. While many of these changes occurred fifty or more years ago (e.g., ditching and channelization), subsurface tiling is a relatively new practice in the region that is increasing in extent.

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 baseflows 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. 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 instream habitat and turbidity.

Diminished baseflows result in decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space, and when flows are reduced beyond normal baseflow, habitat can be scarce and the competition for resources increases.

The United States Environmental Protection Agency's (EPA) Causal Analysis/Diagnosis Decision Information System (CADDIS) webpage contains a conceptual diagram of the sources and pathways for flow regime alteration as a candidate cause for impairment.

Applicable standards

There are no applicable standards for flow regime alteration. However, the Sand Hill 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:

- Drainage of any wetland
- Construction of a bridge or placement of a culvert on any natural or legal drainage system
- Change in the bed, banks, or shores of natural drainage ways, lakes, or wetlands
- Excavation, grading, or filling of, or near, any natural or legal drainage system
- Diversion of water into a legal drainage system from lands not assessed for the drainage system

Available data

Public ditch systems

There is an extensive network of approximately 36 miles of public ditch systems that contribute water to the upper portion of Reach 541. These systems include County Ditch (CD) 16, CD 48, CD 49, CD 55, CD 83, and CD 176; the latter two systems make up the upper-most seven miles of this reach. Figure 7 displays images of these ditch systems. Additionally, CD 17 is a tributary of Reach 515 and extends approximately five miles in length. There are no public ditch systems along Reach 542; however, the reach is downstream of Reaches 541 and 515.

Figure 7. Photos of public ditch systems associated with Reach 541, including CD 16 (upper left), CD 48 (upper right), CD 49 (lower left), and CD 176 (lower right)

Ditching/channelization

According to the Statewide Altered Watercourse Project dataset, 17% of Reach 541 has been ditched or channelized; SHR-01 is located on a ditched portion of this reach. Figure 8 shows examples of channelization along Reach 541. The level of ditching/channelization decreases downstream in Reaches 542 (<5%) and 515 (0%). However, Reach 515 has approximately 49 miles of tributaries that are mostly (79%) ditched or channelized.

Figure 8. Photos of stream channelization associated with Reach 541

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 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 Upper Sand Hill River Subwatershed, which includes the drainage areas for the biologically impaired reaches of the SHRW; cultivated crops and pasture/hay comprise 65% of the land cover. Consequently, many 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 many of their inherent functions and rapidly convey agricultural runoff (including sediment and nutrients) to receiving waters. Figure 9 shows an image of modified headwater streams in agricultural fields along Reach 541.

Figure 9. Image of modified headwater streams along Reach 541

Subsurface drainage

While the amount of subsurface tile installed by agricultural landowners in the SHRW has increased substantially 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 Upper Sand Hill River Subwatershed, which includes the drainage areas for the biologically impaired reaches of the SHRW. Overall, there is a substantial amount of wetlands (>16,000 ac) in the subwatershed. The most prevalent wetland types are 3 (7,873 ac), 5 (3,533 ac), and 6 (2,232 ac). These wetland types have semi-permanent to permanent water regimes, making them difficult to drain for agricultural purposes. Conversely, there are relatively few Type 1 (1,100 ac) and Type 2 (356 ac) wetlands in the subwatershed. These wetland types have a temporary water regime, making them easy to drain and to farm through.

Table 8. NWI data for the Upper Sand Hill River Subwatershed

Wetland Type (Circular 39)	Count	Acres	Wetland Type (Circular 39)	Count	Acres
1 - Seasonal Flooded Basin	1237	1100	5 - Shallow Open Water	343	3533
2 - Wet Meadow	49	356	6 - Shrub Swamp	954	2232
3 - Shallow Marsh	2819	7874	7 - Wooded Swamp	444	787
4 - Deep Marsh	107	103	8 - Bog	6	60

According to the Restorable Depressional Wetland Inventory, there are 5,427 acres of restorable wetlands in the Upper Sand Hill River Subwatershed. The drainage of these wetlands, many of which were closed basins, has reduced the water storage capacity of the landscape.

Flow analysis

The USGS has operated a continuous flow monitoring station on the Sand Hill River at Climax, Minnesota (USGS 05069000) since 1943. This station records flows from a drainage area of 420 square miles, which represent a majority of the SHRW and includes the biologically impaired reaches. Select annual flow statistics for the station from 2002 to 2011 are plotted in Figure 10. The average annual flow for the time period was 145 cubic feet per second (cfs), while the highest peak flow was 4,800 cfs (2011) and the lowest flow was 7 cfs (2008). The flow duration curve for the station from 2001 to 2010 is shown in Figure 11. The figures demonstrate the variability in the flow regime of the Sand Hill River. Groshens (2006) indicated that changes in land cover (i.e., native vegetation to cropland) and drainage patterns (e.g., ditching and channelization) have caused streams in the watershed to be “flashy,” with increased and quicker peak flows, along with prolonged periods of very low discharge.

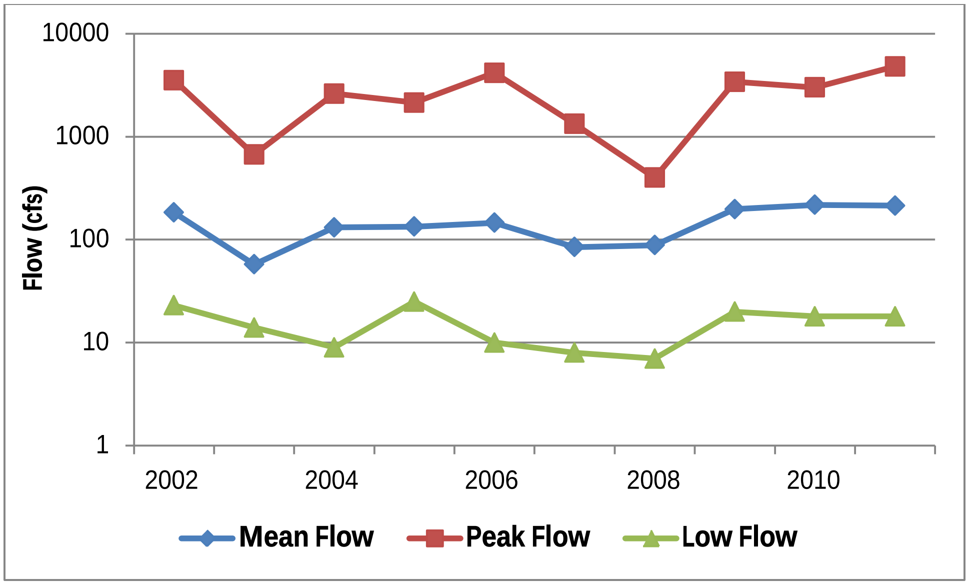

Figure 10. Annual flow statistics (2002-2011) for the Sand Hill River USGS streamgage at Climax, Minnesota (Sand Hill River Watershed District, 2011)

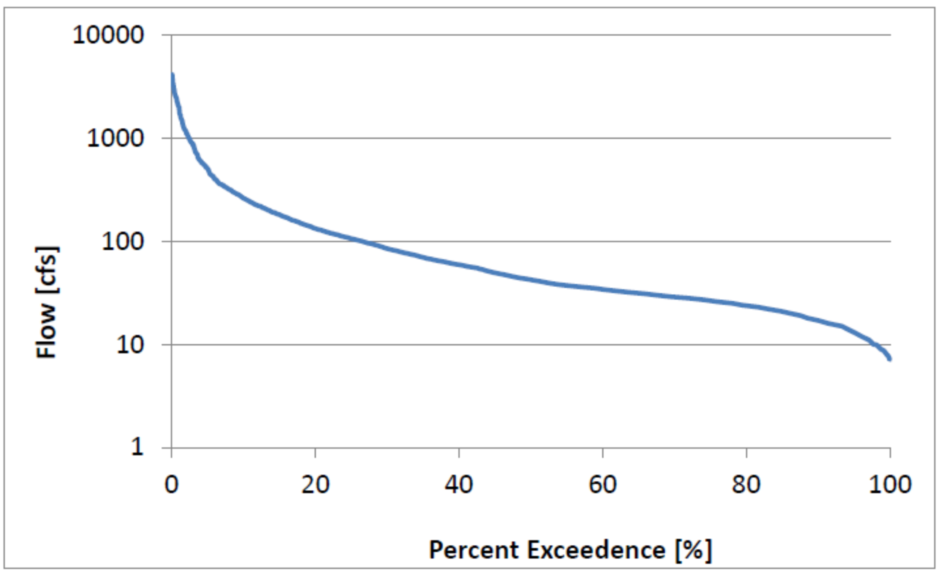

Figure 11. Flow duration curve (2001-2010) for the Sand Hill River USGS streamgage at Climax, MN (Sand Hill River Watershed District, 2011)

Figure 12 presents a comparison of mean annual flow values for the Sand Hill River USGS streamgage at Climax, Minnesota (1972-2011) and mean annual precipitation for Polk County (1972-2011); over 88% of the SHRW is located in Polk County. Annual precipitation for the area has trended upward during the 40-year period. Not surprisingly, the mean annual flow values for the USGS station have also trended upward. However, the slope of the flow trendline (2.7271) is substantially higher than the precipitation trendline (0.1121). Shottler et al. (2014) encountered a similar trend in 21 watersheds in southern Minnesota and attributed the disproportional increase in flow to climate, precipitation, crop conversation, and artificial drainage. Of these factors, drainage was determined to be responsible for more than 50% of the increase in flow in those watersheds.

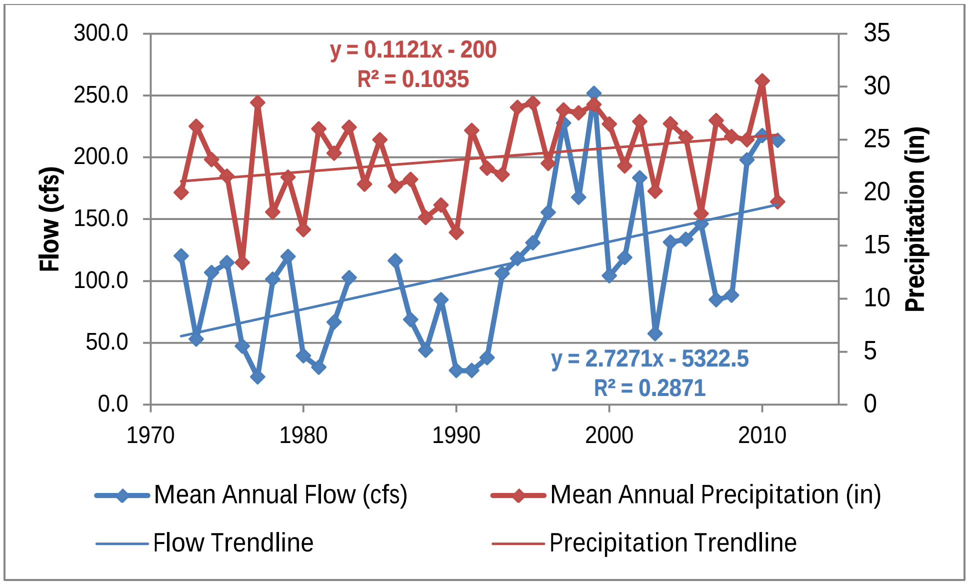

Figure 12. Comparison of mean annual flow for the Sand Hill River USGS streamgage at Climax, Minnesota (1972-2011) and mean annual precipitation for Polk County (1972-2011)

Biotic response

F-IBI impairments - Reaches 541 (Sand Hill River) and 542 (Sand Hill River)

Evidence of a potential connection between flow regime alteration and the F-IBI impairments associated with Reaches 541 and 542 is provided by an increase in the relative abundance of taxa that are serial spawners (*SSpnTXPct*). Serial spawners are those species that have the ability to spawn multiple times throughout the year (e.g., fathead minnow and brown bullhead). This ability is advantageous in extreme flow regime environments, as these species have several opportunities to spawn under optimum conditions. Scores for the metric (Figure 13) were relatively moderate for all Class 5 monitoring sites in the impaired reaches.

M-IBI impairments - Reaches 541 (Sand Hill River) and 515 (County Ditch 17)

Most 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 regimes of Reach 515 and the upper portion of Reach 541 have been substantially altered by ditching and channelization. Average M-IBI scores for monitoring sites along these reaches were substantially below their applicable class standard. Although biological monitoring staff encountered normal to above normal water levels in these reaches at the time of macroinvertebrate sampling in August 2011, these reaches commonly have limited flow during the late summer months. For instance, on September 11, 2013, MPCA SI staff observed no flow and only pooled, stagnant water at Site SHR-01 and very minimal flow at Site CD17-01. Figure 14 provides a comparison of the flow conditions observed by MPCA biological monitoring staff on October 11, 2011, and those observed by MPCA SI staff on September 11, 2013.

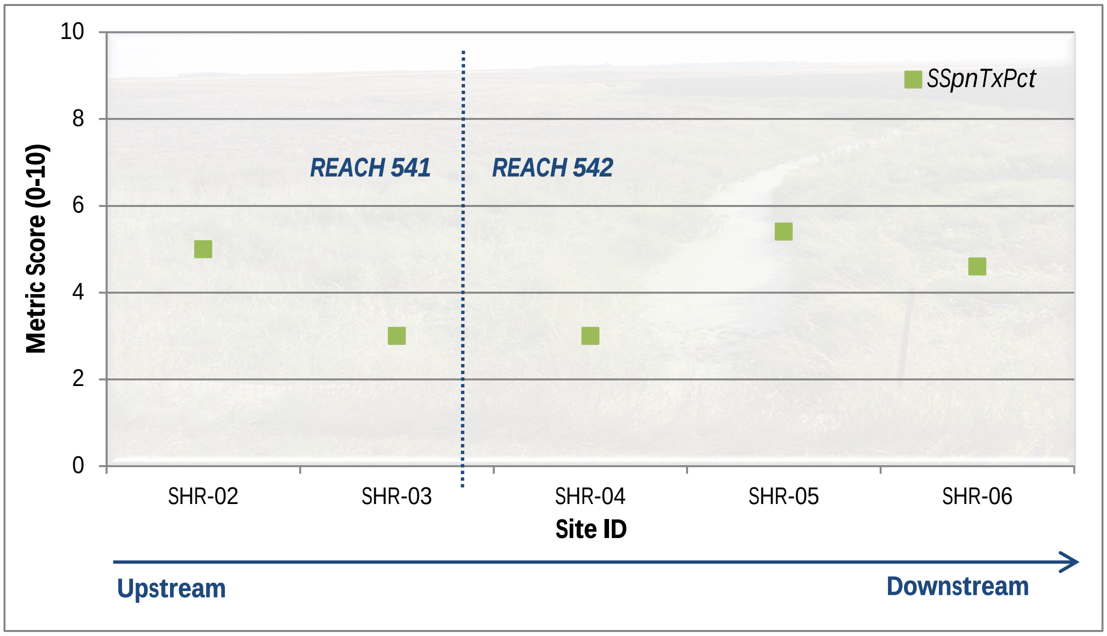

Figure 13. Flow regime alteration-related F-IBI metric scores for Class 5 monitoring sites along Reaches 541/542

Figure 14. Photos of Site SHR-01 in October 2011 (upper left) and September 2013 (upper right), as well as Site CD17-01 in October 2011 (lower left) and September 2013 (lower right)

Strength-of-evidence analysis

Table 9 presents the SOE analysis scores for flow regime alteration as a candidate cause. The multiple lines of evidence used in the analysis suggest that flow regime alteration is a probable stressor for the F-IBI impairments associated with Reaches 541 and 542 and the M-IBI impairments associated with Reaches 541 and 515. Several of the evidence types strongly support the case for flow regime alteration as a stressor.

Table 9. SOE analysis scores for Candidate Cause #2: flow regime alteration

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	++	++	+	++
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	++	++	++	++
Causal Pathway	++	++	++	++
Evidence of Exposure/Biological Mechanism	++	++	+	++
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	++	++	++	++
Symptoms	++	++	++	++
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	++	++	++	++
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	NE	NE	NE	NE
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	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: Lack of instream 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 instream 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 et al., 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 MPCA's Stream Habitat Assessment (MSHA) was used to evaluate the quality of habitat present at each of the biological monitoring sites in the SHRW. The MSHA is comprised of four scoring categories, including land use, riparian zone, instream zone (substrate and 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 SHRW and ranged from 27.0 (Site SHR-09) to 83.8 (Site UNC-01). The overall mean site score for the watershed was 53.2, which is nearly in the middle of the scale for the "Fair" MSHA rating. A majority of sites in the watershed (12) received a "Fair" rating, while three sites were rated "Good" and three sites were rated "Poor." Scores for the sites associated with the biologically impaired reaches (highlighted red) ranged from 33.8 (Site SHR-02) to 78.0 (Site SHR-06). The mean score for these sites was 48.0, which is slightly lower than the overall mean site score for the watershed. With the exception of Site SHR-06, these sites had low scores in the Land Use and Instream Zone Substrate assessment categories.

Table 10. MSHA data for biological monitoring sites in the SHRW

Reach	SI Site #	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)			
541	SHR-01	0.0	5.0	14.0	14.0	16.0	49.0	Fair
	SHR-02	0.0	6.0	10.8	6.0	11.0	33.8	Poor
	SHR-03	1.3	10.0	10.8	12.0	18.0	52.0	Fair
542	SHR-04	0.0	6.0	10.2	16.0	23.0	55.2	Fair
	SHR-05	0.0	8.5	10.0	16.0	20.0	54.5	Fair
	SHR-06	5.0	14.0	19.0	12.0	28.0	78.0	Good
536	SHR-07	0.0	10.0	20.0	7.0	11.0	48.0	Fair
	SHR-08	0.0	7.0	17.6	8.0	15.0	47.6	Fair
537	SHR-09	0.0	6.0	12.0	5.0	4.0	27.0	Poor
	SHR-10	1.0	8.8	14.9	5.5	20.5	50.7	Fair
	SHR-11	2.5	11.0	13.7	14.0	26.0	67.2	Good
512	CD16-01	0.0	11.0	20.0	15.0	19.0	65.0	Fair
	CD16-02	0.0	10.0	16.0	11.0	8.0	45.0	Fair
515	CD17-01	1.3	12.0	11.5	16.0	16.0	56.8	Fair
538	CD48-01	0.0	5.0	14.4	11.0	16.0	46.4	Fair
540	CD55-01	1.8	6.0	9.0	7.0	5.0	28.8	Poor
508	KC-01	4.4	11.5	14.3	9.0	29.0	68.2	Good
	KC-02	4.0	12.0	15.3	13.0	10.0	54.3	Fair
539	UNC-01	0.0	13.0	26.8	17.0	27.0	83.8	Good

[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 instream zone substrate data for each of the biological monitoring sites in the SHRW. Substrate scores in the watershed ranged from 9.0 (Site CD55-01) to 26.8 (Site UNC-01), with an overall mean of 14.8. With the exception of Site SHR-06, the sites located along the biologically impaired reaches scored below the watershed average. The low scores for these sites can be attributed to a lack of coarse substrate or the embeddedness of coarse substrate. Site SHR-06 was one of only a few sites in the watershed to offer both coarse substrate and a minimal level of embeddedness.

Table 11. MSHA instream zone substrate data for biological monitoring sites in the SHRW

Reach	SI Site #	Pool (%)	Riffle (%)	Run (%)	Glide (%)	Predominate Substrate(s)	Embeddedness	MSHA Substrate Score (0-27)
541	SHR-01	10	5	85	0	Gravel, Clay	Moderate	14.0
	SHR-02	25	0	75	0	Sand, Clay	No Coarse Substrate	10.8
	SHR-03	20	5	75	0	Clay	No Coarse Substrate	10.8
542	SHR-04	40	0	60	0	Silt	No Coarse Substrate	10.2
	SHR-05	30	0	70	0	Silt	Moderate	10.0
	SHR-06	15	10	75	0	Cobble, Clay	Light	19.0
536	SHR-07	0	10	90	0	Cobble, Gravel	Light	20.0
	SHR-08	0	20	80	0	Sand, Clay	Light	17.6
537	SHR-09	0	0	0	100	Sand, Clay	No Coarse Substrate	12.0
	SHR-10	40	5	55	0	Gravel, Sand	Moderate-Severe	14.9
	SHR-11	30	10	60	0	Clay	Moderate	13.7
512	CD16-01	10	0	90	0	Gravel, Sand	Light	20.0
	CD16-02	10	20	70	0	Gravel	Moderate	16.0
515	CD17-01	5	20	75	0	Silt	Moderate	11.5
538	CD48-01	10	10	80	0	Gravel, Clay	Moderate	14.4
540	CD55-01	15	0	85	0	Silt	No Coarse Substrate	9.0
508	KC-01	25	25	50	0	Gravel, Clay	Light-Severe	14.3
	KC-02	10	25	65	0	Gravel, Sand	Moderate	15.3
539	UNC-01	10	30	60	0	Gravel	Light	26.8

Table 12 provides detailed MSHA instream zone fish cover data for each of the biological monitoring sites in the SHRW. Cover scores in the watershed ranged from 5 (Site SHR-09) to 17 (Site UNC-01), with an overall mean of 11. With the exception of Site SHR-02, all of the sites located along the biologically impaired reaches scored above the watershed average. The cover was diverse for most sites in the watershed, with multiple cover types noted. The most prominent cover types were overhanging vegetation, undercut banks, and macrophytes.

Table 12. MSHA instream zone fish cover data for biological monitoring sites in the SHRW

Reach	SI Site #	Cover Types	Cover Amount	MSHA Fish Cover Score (0-17)
541	SHR-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Emergent and Submergent Macrophytes	Extensive	14
	SHR-02	Undercut Banks, Overhanging Vegetation, Emergent, Floating Leaf, Submergent Macrophytes	Sparse	6
	SHR-03	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Emergent, Floating Leaf, and Submergent Macrophytes	Moderate	12
542	SHR-04	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Rootwads, Floating Leaf and Submergent Macrophytes	Extensive	16
	SHR-05	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Rootwads, Emergent and Submergent Macrophytes	Extensive	16
	SHR-06	Overhanging Vegetation, Deep Pools, Logs, Boulders, Submergent Macrophytes	Moderate	12
536	SHR-07	Undercut Banks, Overhanging Vegetation, Logs, Submergent Macrophytes	Sparse	7
	SHR-08	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Boulders	Sparse	8
537	SHR-09	Undercut Banks, Overhanging Vegetation	Sparse	5
	SHR-10	Overhanging Vegetation, Deep Pools, Logs, Boulders	Sparse	6
	SHR-11	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Boulders, Rootwads, Emergent and Submergent Macrophytes	Moderate	14
512	CD16-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Boulders, Emergent Macrophytes	Extensive	15
	CD16-02	Undercut Banks, Overhanging Vegetation, Logs, Submergent Macrophytes	Moderate	11
515	CD17-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Rootwads, Emergent and Submergent Macrophytes	Extensive	16
538	CD48-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Emergent and Submergent Macrophytes	Moderate	11
540	CD55-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Emergent and Submergent Macrophytes	Sparse	7
508	KC-01	Undercut Banks, Overhanging Vegetation, Logs, Emergent and Submergent Macrophytes	Moderate-Sparse	9
	KC-02	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Rootwads, Submergent Macrophytes	Moderate	13
539	UNC-01	Undercut Banks, Overhanging Vegetation, Deep Pools, Logs, Boulders, Rootwads, Submergent Macrophytes	Extensive	17

MDNR stream morphology and stability evaluations

In 2005, MDNR staff conducted stream morphology evaluations at 16 sites in the SHRW. The location of these sites is shown in Figure 4. Channel cross-section, longitudinal profile, and substrate particle compostion were surveyed at each evaulation site. Survey data were then used to estimate bankfull cross sectional areas and dimensionless ratios (i.e., width to depth ratio, slope, sinuosity, riffle, and pool ratio) needed to describe stream morphology and classify the stream segements according to Rosgen (1996). Table 13 presents a summary of selected results from the stream morpology evaluations. The sites located along the biologically impaired reaches of the SHRW are highlighted red.

Table 13. Results of MDNR stream morphology evaluations conducted in the SHRW

Stream	MDNR Site ID	Width/ Depth Ratio	Flood Prone Width (ft)	Entrenchment Ratio	D50 Substrate Type	Sinuosity Ratio	Stream Type (Rosgen)
Sand Hill River	SHR110	22.4	58.3	1.2	Silt/clay	1.9	F6
Sand Hill River	SHR111	9.7	70.7	2.1	Silt/clay	2.0	E6
Sand Hill River	SHR210	16.4	50.4	1.2	Sand	1.1	F5
Sand Hill River	SHR211	9.3	68.7	2.6	Silt/clay	1.0	E6
Sand Hill River	SHR311	33.8	63.5	1.1	Sand	1.4	F5
Sand Hill River	SHR312	13.0	111.1	2.7	Sand	1.4	C5
Sand Hill River	SHR410	21.7	>600	~11.2	Silt/clay	1.3	C6c
Sand Hill River	SHR412	32.7	560.0	16.1	Silt/clay	1.3	C6c
Sand Hill River	SHR511	11.5	~600	~31.0	Silt/clay	1.4	E5
Sand Hill River	SHR512	8.5	38.0	2.5	Silt/clay	1.3	E6
Garden Slough	GS100	47.6	356.0	7.7	Silt/clay	1.1	C6c
County Ditch 47	CD47	13.2	25.1	1.3	Silt/clay	1.0	F6
Kittleson Creek	KC110	5.4	16.9	1.6	Sand	1.2	G5
Kittleson Creek	KC111	8.6	19.8	1.3	Sand	1.4	G5
Kittleson Creek	KC112	3.8	63.5	10.9	Sand	1.2	E5
Unnamed Creek	UC100	27.3	14.8	1.0	Sand	1.5	F5

The evaluation sites along Reaches 541 (Site SHR410 to Site SHR512) and 515 (Site GS100) generally had the following characteristics: 1) a high flood prone width, 2) a high entrenchment ratio, 3) a silt/clay D50 substrate type, and 4) a moderate sinuosity ratio. The sites located on the upstream portion of Reach 541 (Sites SHR511 and SHR512) had a "E" stream type. The remaining sites along this reach, along with Reach 515, had a "C" stream type. The sites associated with Reach 542 (Sites SHR311 and SHR312) shared the following characteristics: 1) a moderate flood prone width, 2) a sand D50 substrate type, and 3) a moderate sinuosity ratio. However, Site SHR311 was considerably more entrenched than Site SHR312 and had a "F" stream type.

Table 14 provides stream stability interpretations (Rosgen, 1996) for the morphology evaluation sites in the SHRW. All of of the sites in the watershed were determined to be very sensitive to disturbance (i.e., changes in hydrology and sediment supply). A majority of the sites, especially those associated with the biologically impaired reaches, received a "High" or greater rating for sediment supply potential and stream bank erosion potential. According to Groshens (2006), much of the stream channel instability in the watershed is likely the result of altered hydrologic regimes. If properly managed, many of the sites in the watershed have a "Good" recovery potential rating.

Table 14. Stream stability interpretations (Rosgen, 1996) for the MDNR morphology evaluation sites in the SHRW

Stream	MDNR Site ID	Sensitivity to Disturbance	Sediment Supply Potential	Stream Bank Erosion Potential	Recovery Potential
Sand Hill River	SHR110	Very High	High	Very High	Fair
Sand Hill River	SHR111	Very High	Low	Moderate	Good
Sand Hill River	SHR210	Very High	Very High	Very High	Poor
Sand Hill River	SHR211	Very High	Low	Moderate	Good
Sand Hill River	**SHR311**	**Very High**	**Very High**	**Very High**	**Poor**
Sand Hill River	**SHR312**	**Very High**	**High**	**Very High**	**Good**
Sand Hill River	**SHR410**	**Very High**	**High**	**High**	**Good**
Sand Hill River	**SHR412**	**Very High**	**High**	**High**	**Good**
Sand Hill River	**SHR511**	**Very High**	**Moderate**	**High**	**Good**
Sand Hill River	**SHR512**	**Very High**	**Low**	**Moderate**	**Good**
Garden Slough	**GS100**	**Very High**	**High**	**High**	**Good**
County Ditch 47	CD47	Very High	High	Very High	Fair
Kittleson Creek	KC110	Very High	Very high	Very High	Good
Kittleson Creek	KC111	Extreme	Very high	Very High	Very Poor
Kittleson Creek	KC112	Extreme	Moderate	High	Very Poor
Unnamed Creek	UC100	Very High	Very High	Very High	Poor

Figure 15 displays examples of stream bank erosion documented by MPCA SI staff along Reaches 541 and 542. Staff noted several instances of channel widening and extensive stream bank erosion caused by the unrestricted access of cattle to the river.

Figure 15. Photos of stream bank erosion along Reaches 541 and 542

Elevation profile

Gradient is an important factor in stream stability and sediment transport. Figure 16 displays a digital elevation model (DEM)-derived elevation profile of the Sand Hill River. The location of the biological monitoring sites, as well as Sand Hill Lake outlet and the Red River of the North, are highlighted red. According to the plot, the river maintains gradient of 5.6 ft/mi between the Sand Hill Lake outlet and approximately three miles downstream of Site SHR-01. Thereafter, the gradient increases substantially to 11.6 ft/mi for the next three miles. The increase 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 degradation. Over the next 34 miles, the river essentially plateaus and the mean gradient decreases to 2.3 ft/mi. However, near Site SHR-03 the gradient drops even further to 1.2 ft/mi. Due to the low gradient, much of this segment of the river exhibits wetland-like characteristics. Aggradation of sediment is a concern along this portion of the river. From Site SHR-05 to Site SHR-07, the river meanders through the beach ridges region of the watershed and drops 176 feet in elevation. The mean gradient (9.0 ft/mi) and presence of loose, unconsolidated materials, makes this region prone to degradation. Finally, the river flows through the glacial lake plain for the next 32 miles, eventually reaching its confluence with the Red River of the North. The mean gradient of the river on the lake plain is 4.1 ft/mi.

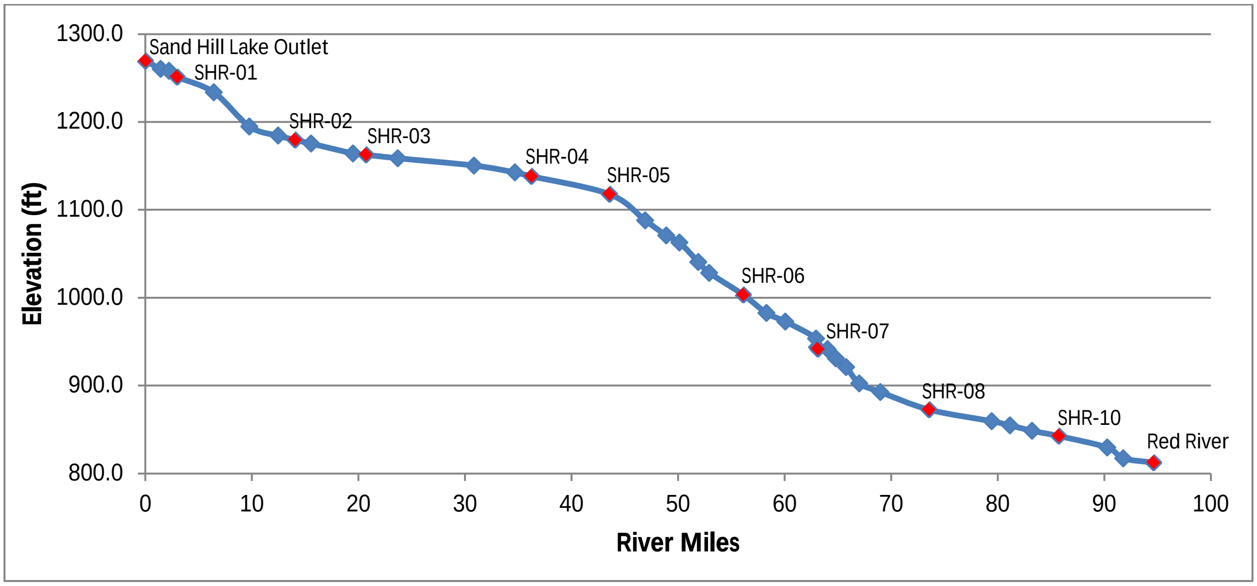

Figure 16. Elevation profile of the Sand Hill River

Biotic response

F-IBI impairments - Reaches 541 (Sand Hill River) and 542 (Sand Hill River)

Potential connections between a lack of instream habitat and the F-IBI impairments associated with Reaches 541 and 542 include: 1) a decrease in the relative abundance of individuals that are intolerant (*IntolerantPct*); and 2) a decrease in the relative abundance of taxa that are simple lithophilic spawners (*SLithopPct*). Figure 17 provides a summary of the scores for these F-IBI metrics for Class 5 monitoring sites along Reaches 541 and 542.

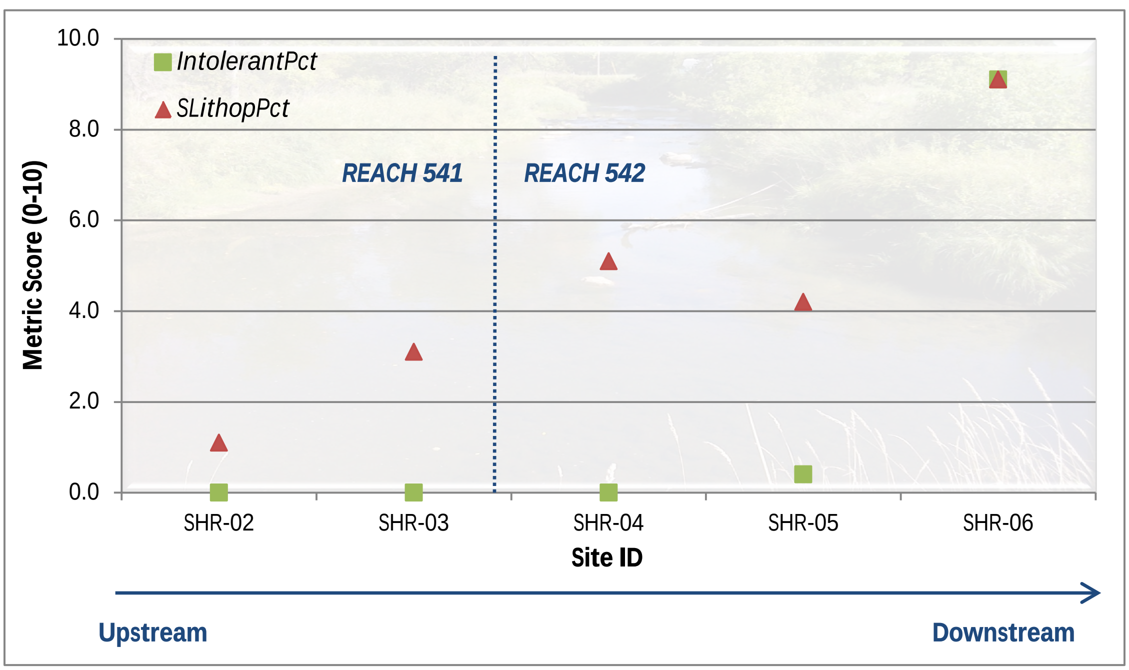

Figure 17. Lack of instream habitat-related F-IBI metric scores for Class 5 monitoring sites along Reaches 541 and 542

The *IntolerantPct* metric includes species that are the most sensitive to environmental disturbances, such as habitat degradation (e.g., longnose dace, logperch, and least darter). There appears to be a strong correlation between this metric and the MSHA scores. Site SHR-06 had good *IntolerantPct* metric and MSHA scores. Conversely, the sites located further upstream (Site SHR-02 to Site SHR-05) had extremely low *IntolerantPct* metric scores, as well as substantially lower MSHA scores.

The *SLithopPct* metric includes species that require clean gravel substrate habitat to spawn (e.g., blacknose dace, common shiner, and white sucker). There appears to be a direct relationship between this metric and the MSHA instream zone substrate scores. Site SHR-06, which has coarse substrate and a "Light" level of embeddedness, had good substrate and *SLithopPct* metric scores. Conversely, the upstream sites (Site SHR-02 to Site SHR-05), which either naturally lack coarse substrate or are affected by a "Moderate" level of embeddedness, had markedly lower substrate and *SLithopPct* metric scores.

M-IBI impairments - Reaches 541 (Sand Hill River) and 515 (County Ditch 17)

There are no evident connections between a lack of instream habitat and the M-IBI impairments associated with Reaches 541 and 515; none of the individual M-IBI metrics exhibited a correlation to the MSHA data.

Strength-of-evidence analysis

Table 15 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 F-IBI impairments associated with Reaches 541 and 542. Several of the evidence types strongly support this conclusion. Conversely, the multiple lines of evidence also indicate that lack of instream habitat is not a likely stressor for the M-IBI impairments associated with Reaches 541 and 515. Many of the evidence types weaken the case for this cause as a stressor for these impairments.

Table 15. SOE analysis scores for Candidate Cause #3: lack of instream habitat

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	++	--	++	--
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	++	--	++	--
Causal Pathway	++	--	++	--
Evidence of Exposure/Biological Mechanism	++	--	++	--
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	++	--	++	--
Symptoms	++	--	++	--
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	++	++	++	++
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	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: Excess suspended sediment

Background

Turbidity and total suspended solids (TSS) are measurements of the amount of sediment suspended in the water column, whether mineral (e.g., soil particles) or organic (e.g., algae). 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).

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 state water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2B waters, which includes the biologically impaired reaches of the SHRW. Total suspended solids can be used as a surrogate to the turbidity standard. However, the alternate TSS standards are based upon ecoregions and there currently is no standard for the LAP ecoregion; all of the water quality monitoring stations associated with the biologically impaired reaches of the SHRW are located in the LAP ecoregion. For additional information regarding the state turbidity standard, refer to the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2013).

Available data

Biological monitoring water quality data

The MPCA biological monitoring staff collected water quality data at the time of fish and macroinvertebrate sampling in the SHRW. Several of the parameters tested relate to excess suspended sediment, including TSS, total suspended volatile solids (TSVS), and transparency (tube). Table 16 presents the sampling results for these water quality parameters.

Table 16. Suspended sediment-related water quality data collected at the time of biological sampling in the SHRW

Reach	SI Site #	Fish Sampling Data			Macroinvertebrate Sampling Data
		TSS (mg/L)	TSVS (mg/L)	Transparency Tube (cm)	Transparency Tube (cm)
541	SHR-01	2.8	2.4	100.0	100.0
	SHR-02	58.0	Not Sampled	15.0	Not Sampled
	SHR-03	67.0	12.4	13.0	11.5
542	SHR-04	5.2	4.0	100.0	100.0
	SHR-05	4.0	4.0	100.0	100.0
	SHR-06	5.2	4.0	100.0	100.0
536	SHR-07	7.8	4.0	87.0	100.0
	SHR-08	43.0	Not Sampled	20.0	Not Sampled
537	SHR-09	44.0	5.8	22.0	23.0
	SHR-10	70.5	Not Sampled	9.3	Not Sampled
	SHR-11	29.0	4.0	23.5	13.0
512	CD16-01	15.0	Not Sampled	Not Sampled	Not Sampled
	CD16-02	8.0	4.4	100.0	58.6
515	CD17-01	2.4	1.6	100.0	100.0
538	CD48-01	6.0	4.0	94.5	67.5
540	CD55-01	18.0	4.0	66.0	Not Sampled
508	KC-01	20.7	Not Sampled	76.0	Not Sampled
	KC-02	4.0	2.0	100.0	Not Sampled
539	UNC-01	4.4	2.0	100.0	Not Sampled

The sampling results reveal high TSS and low transparency tube values in two distinct areas of the watershed: from Site SHR-02 to Site SHR-03 and from Site SHR-08 to Site SHR-11. These areas are located within Reaches 541 and 537, which are impaired for turbidity. The relatively low TSVS values for these sites indicate that the majority of the suspended solids were inorganic (i.e., soil particles).

Turbidity Monitoring Data

Figure 18 provides a summary of available turbidity data and IBI scores for Reaches 541 and 542 of the Sand Hill River; the water quality monitoring stations and biological monitoring sites are arranged from upstream (left) to downstream (right) in the plot. The highest mean turbidity levels were recorded in the downstream extent of Reach 541, specifically from Station S004-198 to Station S004-199, where values were near or exceeded the 25 NTUs state standard. Turbidity levels were substantially less in the upstream portion of Reach 541 (Station S003-139 to Station S003-143) and in Reach 542, where mean values were less than 12 NTUs. Overall, the data affirms the turbidity impairment associated with Reach 541. There is no available turbidity data for Reach 515; routine monitoring is not feasible given its intermittent flow regime.

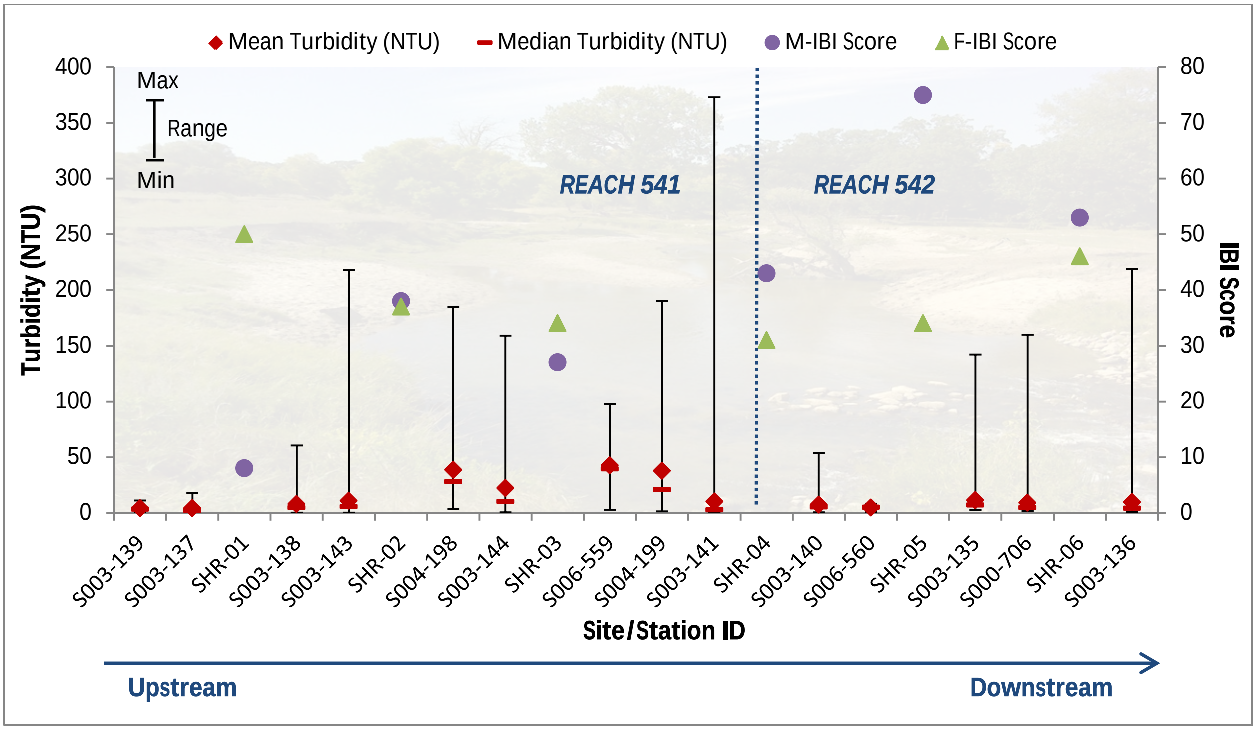

Figure 18. Turbidity data and IBI scores for Reaches 541 and 542

TSS monitoring data

Figure 19 provides a summary of available TSS data and IBI scores for Reaches 541 and 542 of the Sand Hill River; the water quality monitoring stations and biological monitoring sites are arranged from upstream (left) to downstream (right) in the plot. Station S006-559, located in the downstream extent of Reach 541, and Station S003-135, located in the downstream portion of Reach 542, had mean TSS concentrations of 30 mg/L or greater. The remaining stations along these reaches had mean TSS concentrations of 16 mg/L or less. While there is no TSS standard for the LAP ecoregion, all of the stations had mean values well below the 100 mg/L standard for the adjacent NCHF ecoregion. There is no TSS data for Reach 515.

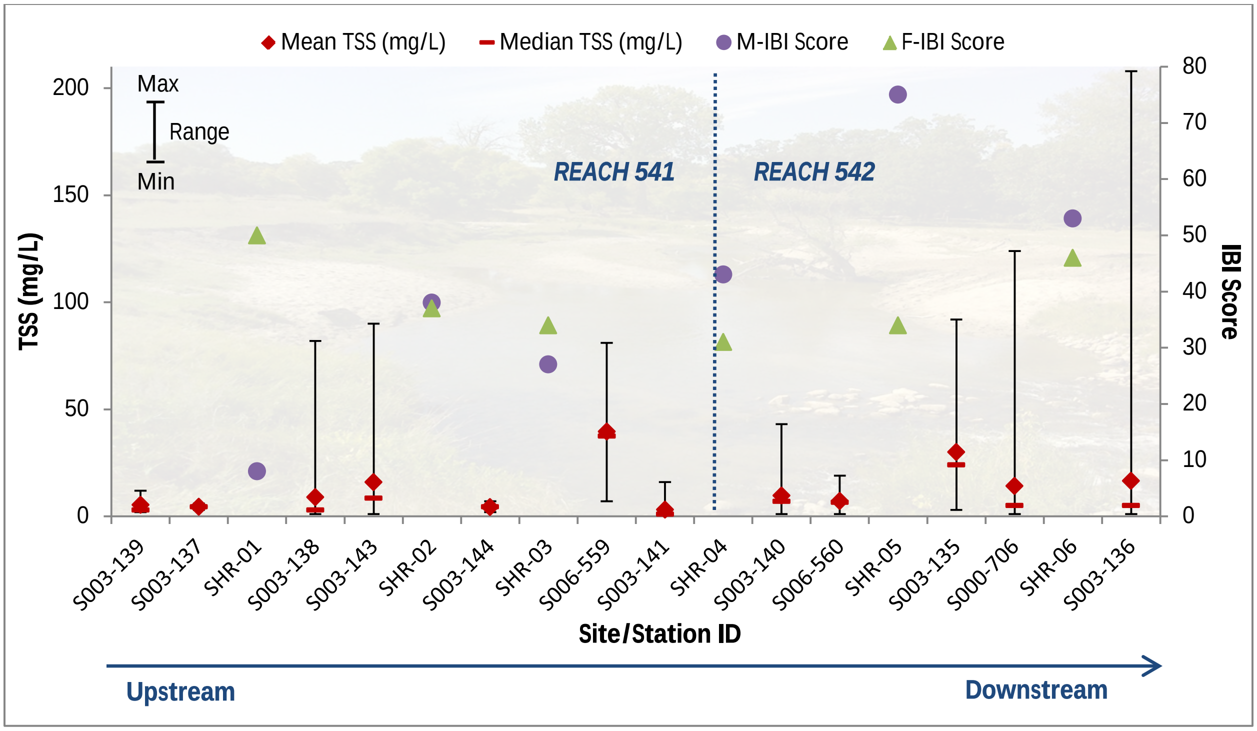

Figure 19. TSS data and IBI scores for Reaches 541 and 542

Biotic response

F-IBI impairments - Reaches 541 (Sand Hill River) and 542 (Sand Hill River)

While Reaches 541 and 542 are subject to stream bank erosion and channel instability, and Reach 541 is prone to elevated turbidity, there are no evident connections between excess suspended sediment and the F-IBI impairments associated with these reaches. Sites SHR-02 and SHR-03 are situated along a portion of Reach 541 that is prone to high turbidity; however, these sites had F-IBI scores (37.2/33.7) comparable to Site SHR-04 (31.3) and Site SHR-05 (34.0), which are located along segments of the Sand Hill River that do not have a turbidity issue. Additionally, none of the individual F-IBI metrics exhibited a correlation to the turbidity/TSS-related data. In fact, Sites SHR-02 and SHR-03 had the highest *SensitiveTxPct* metric scores (4.1 and 5.5) of any Class 5 sites in the SHRW. The *SensitiveTxPct* metric represents the relative abundance of taxa that are sensitive to environmental stressors, including excess suspended sediment.

M-IBI Impairment - Reach 541 (Sand Hill River)

Potential connections between excess suspended sediment and the M-IBI impairment associated with Reach 541 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*). Macroinvertebrates belonging to the collector-filterer group gather and filter their food, which can be impeded by excess sediment. Species belonging to the order Trichoptera (i.e., caddisflies) tend to be intolerant of excess sediment in their habitat (Barbour et al. 1999). Figure 20 provides a summary of the scores for these M-IBI metrics for monitoring sites located along Reach 541.

There is a high level of spatial co-occurrence between this candidate stressor and the aforementioned M-IBI metrics. Sites SHR-02 and SHR-03 are located along portions of Reach 541 that are prone to high turbidity. These sites also scored very poorly for the *Collector-filtererPct*, *TrichopteraChTxPct*, and *TrichwoHydroPct* metrics. Metric score tended to improve downstream in Reach 542 where turbidity levels decrease. The poor metric scores for SHR-01 are likely a result of the pronounced impact of flow regime alteration in this segment of the Sand Hill River.

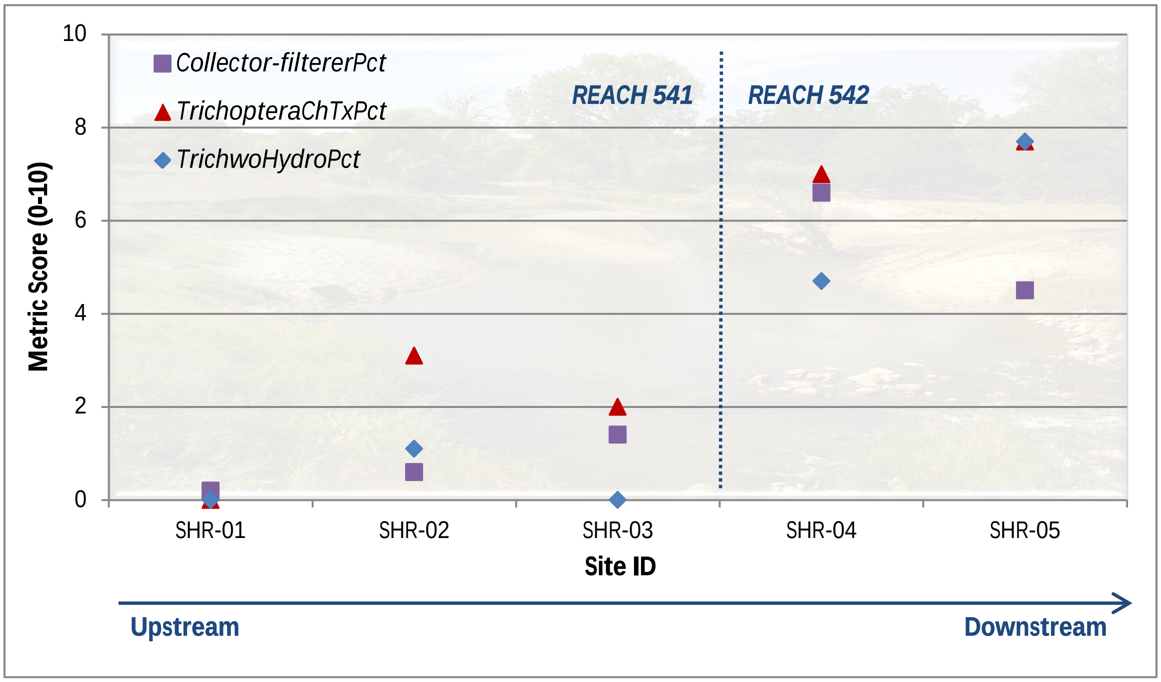

Figure 20. Excess suspended sediment-related M-IBI metric scores for Class 6 and 7 monitoring sites along Reaches 541 and 542

M-IBI Impairment - Reach 515 (County Ditch 17)

The only turbidity/TSS data available for Reach 515 were collected in conjunction with fish and macroinvertebrate sampling at Site CD17-01 during the summer of 2011. The results of this sampling are shown in Table 16. Due to the overall lack of data, potential connections between excess suspended sediment and the M-IBI impairment associated with Reach 515 cannot be identified.

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 Reach 541. Several of the evidence types strongly support this conclusion. Conversely, the multiple lines of evidence indicate that excess suspended sediment is not a likely stressor for the F-IBI impairments associated with Reaches 541 and 542. Many of the evidence types strongly weaken the case for excess suspended sediment as a stressor for these impairments. Due to the lack of turbidity and TSS data for Reach 515, the limited evidence available does not support or weaken the case for this cause as a stressor for the M-IBI impairment.

Table 17. SOE analysis scores for Candidate Cause #4: excess suspended sediment

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	--	++	--	NE
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	--	++	--	NE
Causal Pathway	--	++	--	NE
Evidence of Exposure/Biological Mechanism	--	++	--	NE
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	--	++	--	NE
Symptoms	--	++	--	NE
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	++	++	++	++
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	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.

Candidate Cause #5: 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 dissolved oxygen 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 reaches of the SHRW. 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 instantaneous DO measurements at the time of fish and macroinvertebrate sampling in the SHRW. The results, which are provided in Table 18, show that nearly all of the biological monitoring sites had a DO concentration above the 5.0 mg/L standard. The lone exception was Site SHR-01, which had a DO level of 4.6 mg/L at the time of fish sampling and 1.0 mg/L at the time of macroinvertebrate sampling.

Table 18. DO data collected at the time of biological sampling in the SHRW

Reach	SI Site #	Fish Sampling Data	Macroinvertebrate Sampling Data
		DO (mg/L)	DO (mg/L)
541	SHR-01	4.6	1.0
	SHR-02	5.8	Not Sampled
	SHR-03	6.37	6.8
542	SHR-04	5.8	5.8
	SHR-05	8.75	8.1
	SHR-06	9.51	10.7
536	SHR-07	8.14	8.8
	SHR-08	8.41	Not Sampled
537	SHR-09	7.62	7.8
	SHR-10	7.06	Not Sampled
	SHR-11	8.78	8.0
512	CD16-01	11.1	Not Sampled
	CD16-02	13.9	7.9
515	CD17-01	6.08	5.3
538	CD48-01	19.6	8.6
540	CD55-01	7.18	Not Sampled
508	KC-01	7.65	Not Sampled
	KC-02	9.11	Not Sampled
539	UNC-01	8.73	Not Sampled

Instantaneous DO monitoring data

Instantaneous DO measurements represent discrete point samples that are usually collected in conjunction with surface water sampling. Figure 21 provides a summary of available instantaneous DO data and IBI scores for Reaches 541 and 542 of the Sand Hill River; the water quality monitoring stations and biological monitoring sites are arranged from upstream (left) to downstream (right) in the plot. The lowest mean DO values were recorded along Reach 541. Stations S003-137 and S003-141 had mean DO values only slightly above the 5.0 mg/L state standard. More importantly, the minimum DO concentration for stations along Reach 541 was generally below 2.0 mg/L. In contrast, only two stations along Reach 542 (Stations S003-140 and S000-706) had a minimum DO measurement below the standard. Overall, the data affirms the low DO impairment associated with Reach 541. There is no available instantaneous DO data for Reach 515; routine monitoring is not feasible given its intermittent flow regime.

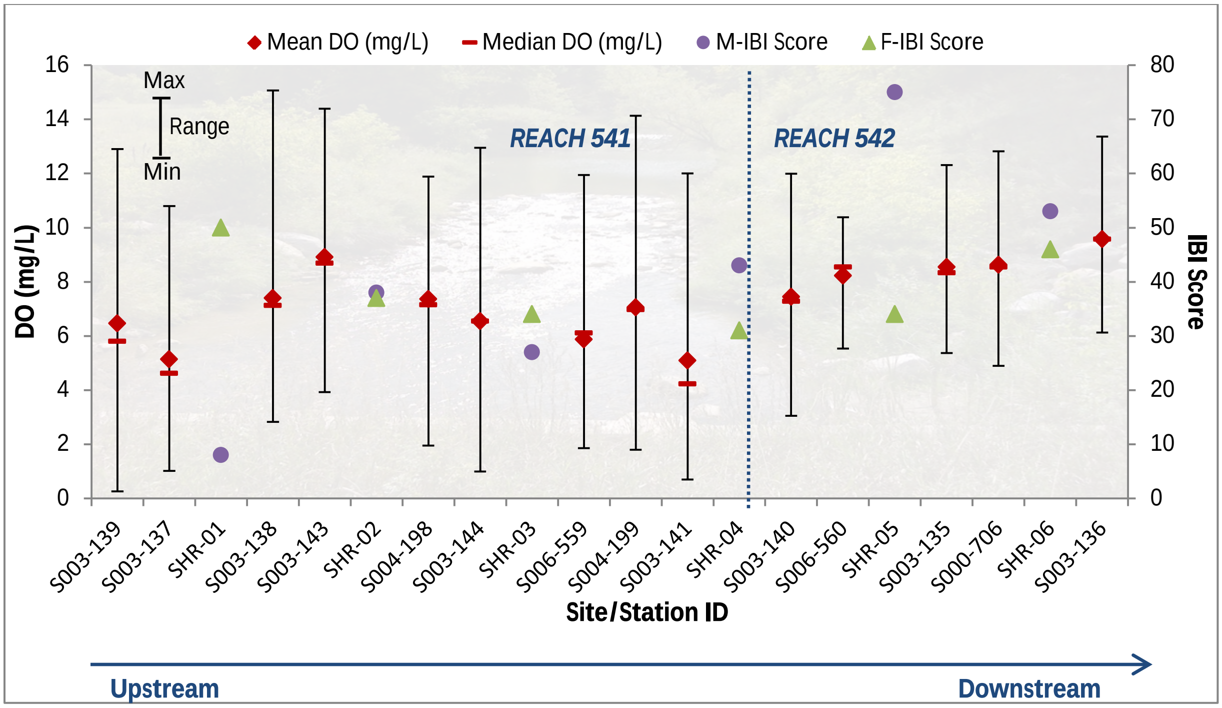

Figure 21. Instantaneous DO data and IBI scores for Reaches 541 and 542

Continuous DO monitoring data

From August 22, 2013, through September 12, 2013, the MPCA conducted continuous DO monitoring at four sites located along Reaches 541 and 542. Monitoring of Reach 515 was not possible due to the absence of flow. The conditions at the time of monitoring were ideal for low DO levels, with warm water temperatures and low flow. Dissolved oxygen measurements were collected at 15 minute intervals by deploying YSI 6920 multi-parameter sondes in selected locations within the reaches. Table 19 provides a summary of the continuous DO data collected at each station.

Table 19. Continuous DO data for selected stations along Reaches 541 and 542

Reach	Site ID	# Readings	Min. DO (mg/L)	Max. DO (mg/L)	% Readings Below Standard	Max. Duration Below Standard (hours)	Avg. 24 hr. Flux (mg/L)
541	S003-143	2019	4.05	10.01	11.44	12.25	3.12
	S003-499	2019	4.38	13.97	<0.01	0.50	3.94
542	S003-140	2019	3.56	10.69	16.25	17.25	2.83
	S003-136	2023	6.17	12.83	NA	NA	3.99

The majority of DO measurements were above the 5 mg/L standard. Station S003-140, which is located along the upstream portion of Reach 542, had the highest proportion of readings below the standard (16.25%) and the longest duration below the standard (17.25 hours). Dissolved oxygen levels improved markedly downstream in this reach, as Station S003-136 had no readings below the standard. The average daily DO flux was moderate for all stations and ranged from 2.83 mg/L (Station S003-140) to 3.99 mg/L (Station S003-136).

Eutrophication data

Eutrophication is the nutrient enrichment of a waterbody, often resulting in increased primary production (i.e., plant growth) and the depletion of DO (EPA, 2012). Phosphorus is usually the limiting nutrient to primary productivity in Minnesota waterbodies. The MPCA (2013) is in the process of developing eutrophication standards for rivers, with specific criteria for total phosphorous (TP) and several related effects, specifically high chlorophyll-a (Chl-a) concentrations, elevated biological oxygen demand (BOD) levels, and high diurnal DO flux. A profile of each of these eutrophication factors for the SHRW is provided below:

1) *Total Phosphorous*. Phosphorus is not toxic to aquatic life, and in small amounts, is essential to the functioning of healthy aquatic ecosystems. Elevated TP concentrations can result in excessive algae and periphyton growth, which can lead to an increase in turbidity, a decrease in DO concentrations, and an increase in diurnal DO flux. Figure 22 provides a summary of available TP data and IBI scores for Reaches 541 and 542 of the Sand Hill River; the water quality monitoring stations and biological monitoring sites are arranged from upstream (left) to downstream (right) in the plot. All of the stations along these reaches had maximum TP concentration above the proposed 0.15 mg/L standard for the LAP ecoregion. However, all of the stations had a mean TP concentration below the proposed standard. There is no data available for Reach 515.
2) *Chlorophyll-a*. The concentration of Chl-a is used as a measurement of algal productivity in surface water. The proposed Chl-a standard for the LAP ecoregion is 35 μg/L. There is limited Chl-a data for streams in the SHRW. Reach 541 has 14 sample results and Reach 542 has 29 sample results. The highest Chl-a concentration for these reaches was 12 μg/L. There is no data available for Reach 515.
3) *Biological Oxygen Demand*. This parameter represents the amount of oxygen required by aerobic microorganisms to decompose the organic matter within a water sample. The proposed BOD standard for the LAP ecoregion is 3.0 mg/L. There is limited BOD data for the SHRW. Reach 542 has four sample results, ranging from 1.7 to 2.7 mg/L. There is no data available for Reaches 541 and 515.
4) Dissolved Oxygen Flux. The proposed diurnal (24 hour) DO flux standard for the LAP ecoregion is 4.5 mg/L. As previously mentioned, MPCA SI staff conducted continuous DO monitoring at four sites located along Reaches 541 and 542 during the summer of 2013. The mean diurnal DO flux at these sites ranged from 2.83 to 3.99 mg/L. There is no data available for Reach 515.

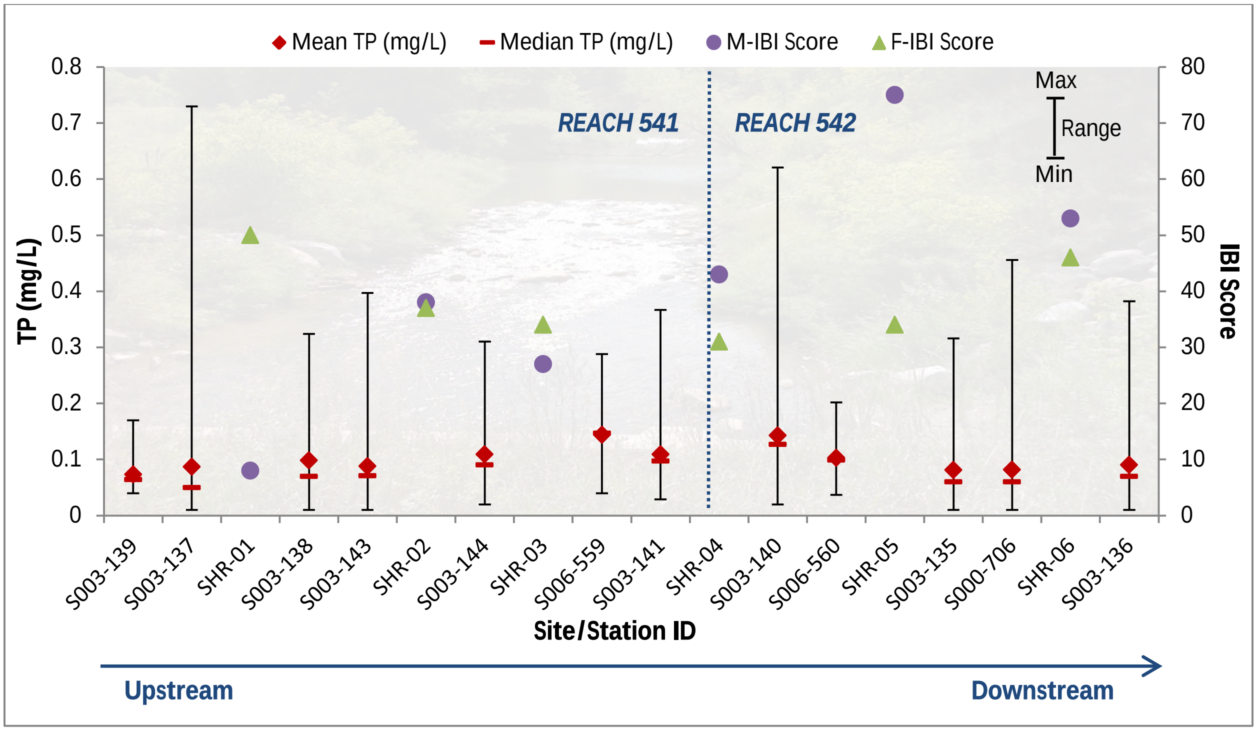

Figure 22. TP data and IBI scores for Reaches 541 and 542

Biotic response

F-IBI impairments - Reaches 541 (Sand Hill River) and 542 (Sand Hill River)

There are no evident connections between the DO data and the individual F-IBI metric scores associated with Reaches 541 and 542. However, the MPCA's DO Tolerance Indicator Values (TIVs), which provide a means of comparing the relative tolerance of species, offer evidence of the impact of low DO on the fish community of the Sand Hill River. Figure 23 displays DO TIVs data for fish species sampled at monitoring sites along these reaches. The TIVs were quartiled based upon an inventory of fish species known to be present in the Red River of the North Basin. Species assigned to Quartile 1 (e.g., central mudminnow and fathead minnow) represent those that are most tolerant of low DO conditions, while species within Quartile 4 (e.g., blacknose dace and longnose dace) are those that are most sensitive to low DO conditions. The monitoring sites within Reach 541, which is prone to low DO levels, were dominated by Quartile 1 (tolerant) species. The percentages of Quartile 1 species were substantially less for monitoring sites within Reach 542; DO levels tend to improve in this reach. In fact, Site SHR-06 had a large percentage of Quartile 4 (sensitive) species.

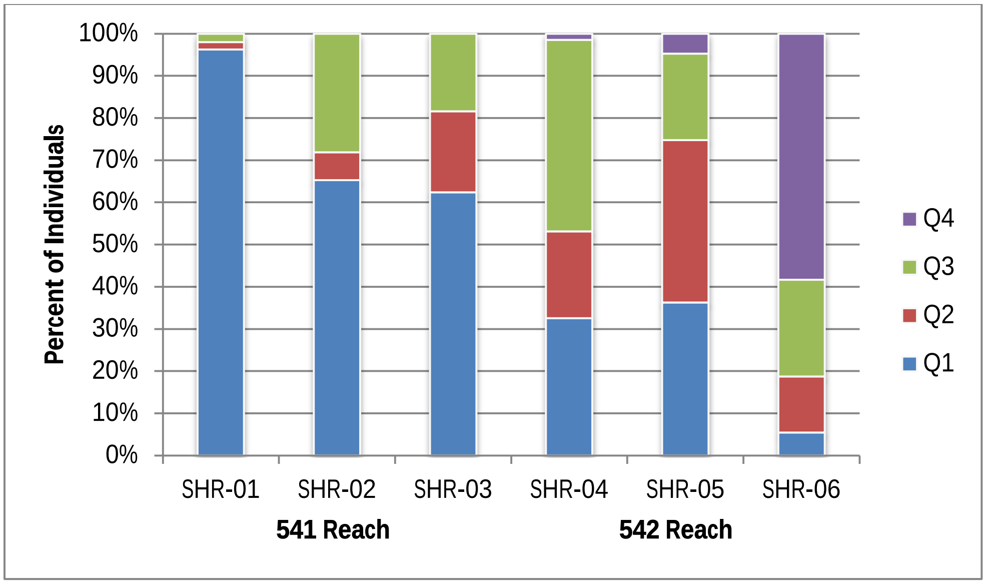

Figure 23. DO TIVs data for fish species sampled at monitoring sites along Reaches 541 and 542

M-IBI impairment - Reach 541 (Sand Hill River)

Potential connections between low DO and the M-IBI impairment associated with Reach 541 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 relative percentage of non-hydropsychid Trichoptera individuals (TrichwoHydroPct); and 4) a decrease in the total taxa richness of macroinvertebrates (TaxaCountAllChir). The taxa included in each of these M-IBI metrics are known to negatively respond to low DO (EPA, 2012; Weber, 1973). Figure 24 provides a summary of the scores for these M-IBI metrics for Class 6 and 7 monitoring sites located along Reaches 541 and 542.

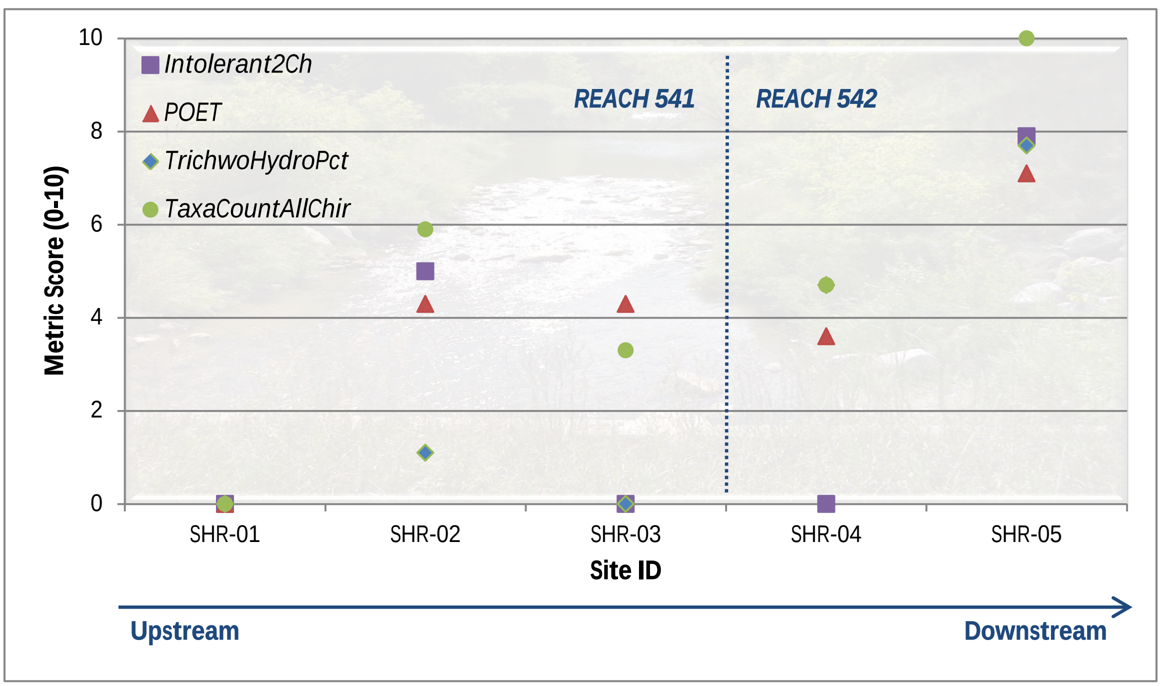

Figure 24. Low DO-related M-IBI metric scores for Class 6 and 7 monitoring sites along Reaches 541 and 542

There is a high level of spatial co-occurrence between this candidate stressor and the aforementioned M-IBI metrics. Sites SHR-01 and SHR-03 (Reach 541) are located along segments of the Sand Hill River that are prone to low DO. These sites scored relatively poorly for each of the metrics; Site SHR-01 scored 0.0 for all of the metrics. Metric scores improved dramatically downstream at Site SHR-05, which coincides with the improvement of DO conditions.

M-IBI impairment - Reach 515 (County Ditch 17)

The only DO data available for Reach 515 were collected in conjunction with fish and macroinvertebrate sampling at Site CD17-01 during the summer of 2011; these readings were 6.1 mg/L and 5.3 mg/L respectively. Due to the overall lack of data, potential connections between low DO and the M-IBI impairment associated with Reach 515 cannot be identified.

Strength-of-evidence analysis

Table 20 presents the SOE analysis scores for low DO as a candidate cause. The multiple lines of evidence used in the analysis suggest that low DO is a probable stressor for the F-IBI and M-IBI impairments associated with Reach 541. Several of the evidence types support this conclusion. Conversely, the multiple lines of evidence indicate that low DO is not a likely stressor for the F-IBI impairment associated with Reach 542. Many of the evidence types somewhat weaken the case for low DO as a stressor for this impairment. Also, the limited DO data available for Reach 515 does not support or weaken the case for low DO as a stressor for the M-IBI impairment.

Table 20. SOE analysis scores for Candidate Cause #5: low DO

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	+	++	-	NE
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	+	++	-	NE
Causal Pathway	+	++	-	NE
Evidence of Exposure/Biological Mechanism	+	++	-	NE
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	0	++	-	NE
Symptoms	0	++	-	NE
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	++	++	++	++
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	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.

Candidate Cause #6: 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 pathway for pesticides to enter surface water is through runoff or leachate. 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 21 presents a summary of the state's chronic and maximum standard values for common pesticides used in Minnesota.

Table 21. 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 Minn. R. ch. 7050 as toxicity-based for aquatic organisms and is protective for an exposure duration of four days.

[2] Maximum standard value for aquatic life and 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 warmwater 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. In 2011, the MDA collected samples from the Sand Hill River at Climax on four separate dates. The results of this sampling are reported in Table 22.

Table 22. Summary of MDA pesticide monitoring results for the Sand Hill River at Climax (2011)

Pesticide	Sampling Date			
	05/17/2011	06/01/2011	06/07/2011	06/21/2011
Acetochlor (µg/l)	ND	ND	0.11	ND
Atrazine (µg/l)	P	ND	ND	ND
Deispropylatrazine (µg/l)	ND	ND	ND	ND
Desethylatrazine (µg/l)	P	ND	P	ND
Dimethenamid (µg/l)	ND	ND	ND	ND
Malathion (µg/l)	ND	ND	ND	ND
Metolachlor (µg/l)	ND	ND	ND	ND
Metribuzin (µg/l)	ND	ND	ND	ND
Metribuzin DADK (µg/l)	ND	ND	ND	ND
Prometon (µg/l)	ND	ND	ND	ND
Propazine (µg/l)	ND	ND	ND	ND
Simazine (µg/l)	P	ND	ND	ND

"P" (present) indicates that the analytical result meets qualitative reporting criteria for identification of the pesticide, but cannot be quantified below the Method or Estimated Reporting Limit.

"ND" (not-detected) indicates that the analytical result does not meet qualitative reporting criteria.

Each of the samples collected from the Sand Hill River were analyzed for 12 different pesticide compounds. While four compounds were detected in these samples, only Acetochlor (06/07/2011 sample) was found at a level high enough to report a concentration. It is important to note that the concentration of this pesticide was still well below the state water quality standards.

Biotic response

F-IBI and M-IBI impairments - Reaches 541 (Sand Hill River), 542 (Sand Hill River), and 515 (County Ditch 17)

While the MDA's pesticide data did not reveal any standard violations, the data is limited to four sampling events within one year and the sampling site is located approximately 30 miles downstream of the nearest biologically impaired reach. Given the overall lack of data and the fact that agriculture is the predominant land use in the Upper Sand Hill River Subwatershed, which includes the drainage areas for the biologically impaired reaches of the SHRW, it is impossible to definitively rule out pesticide toxicity as a possible stressor to aquatic life. Additional monitoring is recommended to further understand the presence of pesticides in the watershed and the potential impact to the fish and macroinvertebrate community. Targeted storm flow monitoring during the peak pesticide runoff period (spring and early summer) would improve confidence in the ability to diagnose or refute pesticide toxicity as a stressor in this watershed.

Strength-of-evidence analysis

Table 23 presents the SOE analysis scores for pesticide toxicity as a candidate cause. Due to the fact that there is no data on the presence of pesticides in the biologically impaired reaches of the SHRW, the limited data available from other sources does not support or weaken the case for pesticide toxicity as a stressor for the biological impairments.

Table 23. SOE analysis scores for Candidate Cause #6: pesticide toxicity

Types of Evidence	SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *(Sand Hill River)* **F-IBI**	**541** *(Sand Hill River)* **M-IBI**	**542** *(Sand Hill River)* **F-IBI**	**515** *(CD 17)* **M-IBI**
Types of Evidence that Use Data from the Case				
Spatial/Temporal Co-occurrence	NE	NE	NE	NE
Temporal Sequence	NE	NE	NE	NE
Stressor-Response Relationship from Field	NE	NE	NE	NE
Causal Pathway	NE	NE	NE	NE
Evidence of Exposure/Biological Mechanism	NE	NE	NE	NE
Manipulation of Exposure	NE	NE	NE	NE
Laboratory Tests of Site Media	NE	NE	NE	NE
Verified Predictions	NE	NE	NE	NE
Symptoms	NE	NE	NE	NE
Types of Evidence that Use Data from Elsewhere				
Mechanistically Plausible Cause	++	++	++	++
Stressor-Response in Other Lab Studies	NE	NE	NE	NE
Stressor-Response in Other Field Studies	++	++	++	++
Stressor-Response in Ecological Models	NE	NE	NE	NE
Manipulation Experiments at Other Sites	NE	NE	NE	NE
Analogous Stressors	NE	NE	NE	NE
Multiple Lines of Evidence				
Consistency of Evidence	**0**	**0**	**0**	**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 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 reaches of the SHRW. The evidence suggests that the F-IBI impairments linked to Reaches 541 and 542 are likely attributed to the following stressors: loss of connectivity, flow regime alteration, lack of instream habitat, and low DO. Of these stressors, the loss of connectivity has the most supporting evidence. The evidence indicates that the M-IBI impairment associated with Reach 541 is likely the result of flow regime alteration, excess suspended sediment, and low DO. Lastly, the available evidence suggests that flow regime alteration is responsible for the M-IBI impairment associated with Reach 515.

Table 24. Summary of the SOE analysis scores for the candidate causes associated with the biologically impaired reaches in the SHRW

Stressors	Multiple Lines of Evidence (Consistency of Evidence) SOE Scores for SHRW Biologically Impaired Reaches[1]			
	541 *Sand Hill River* F-IBI	541 *Sand Hill River* M-IBI	542 *Sand Hill River* F-IBI	515 *CD 17* M-IBI
Loss of Connectivity	+++	--	+++	--
Flow Regime Alteration	++	++	++	++
Lack of Instream Habitat	++	-	++	-
Excess Suspended Sediment	--	++	--	0
Low DO	+	++	-	0
Pesticide Toxicity	0	0	0	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.

4.2 Recommendations

The biologically impaired reaches of the SHRW have the potential to support healthier fish and macroinvertebrate communities. The recommended management actions listed below will help address the aforementioned stressors, which are limiting these communities. Whenever possible, actions should be implemented progressing from upstream to downstream.

- Modify the grade control structures to restore fish passage along the Sand Hill River.
- Prevent or mitigate activities that will further alter the hydrology of the watershed.
- Consider opportunities and options to attenuate peak flows and augment base flows in streams throughout the watershed.
- Re-establish natural functioning stream channels wherever possible using natural channel design principles.

- Increase the quantity and quality of instream habitat throughout the watershed.
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible.
- Implement agricultural BMPs to reduce soil erosion and sedimentation.
- Limit or exclude the access of livestock to waterways.

References

Aadland, L.P. 2005. Changes in fish assemblage structure of the Red River of the North. American Fisheries Society Symposium 45:293-321.

Allan, J.D. 1995. Stream ecology: Structure and function of running waters. Kluwer Academic Publishers, Dordrecht, Netherlands.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper No. 21, U.S. Fish and Wildlife Service, Fort Collins, CO.

Brooker, M.P. 1981. The impact of impoundments on the downstream fisheries and general ecology of rivers. Advances in Applied Biology 6:91-152.

Bruton, M.N. 1985. The effects of suspensoids on fish. Hydrobiologica 125:221-241.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.

Cummins, K.W. 1979. The natural stream ecosystem. Plenum Press, New York.

Davis, J.C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. Journal of the Fisheries Research Board of Canada 32(12):2295-2331.

Erman, D.C., and F.K. Ligon. 1988. Effects of discharge fluctuation and the addition of fine sediment on stream fish and macroinvertebrates below a water-filtration facility. Environmental Management 12:85-97.

Freeman, M.C., C.M. Pringle, and C.R. Jackson. 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales. Journal of the American Water Resources Association 43(1):5-14.

Folmar, L.C., H.O. Sanders, and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. Archives of Environmental Contamination and Toxicology 8(3):269-278.

Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: A role in stream management and restoration. Regulated Rivers: Research & Management 17:527-542.

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

Groshens, T.P. 2006. Red River Basin stream survey report: Sand Hill River Watershed 2006. Minnesota Department of Natural Resources, Division of Fisheries, NW Region, Bemidji, MN.

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

Huberty, G. 2004. Stream special assessment: Sand Hill River reaches 1-3, June 4-7, 2002 and August 25-27, 2003. Minnesota Department of Natural Resources, Division of Fisheries, NW Region, Bemidji, MN.

Klimetz, L., and A. Simon. 2008. Characterization of “reference” suspended-sediment transport rates for Level III Ecoregions of Minnesota. ARS National Laboratory Technical Report No. 63. U.S. Department of Agriculture, Vicksburg, MS.

Leopold, L.B. 1994. A view of the river. Harvard University Press, Cambridge, MA.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Company, San Francisco.

McKenna, J.E. 2013. Multi-class community structure within a temperate freshwater wetland complex: Evidence for the metacommunity. The Open Ecology Journal 6:24-46.

Miller, R.C. 1999. Hydrologic effects of wetland drainage and land use change in a tributary watershed of the Minnesota River Basin: a modeling approach. M.S. thesis. Univ. of Minnesota, St. Paul.

Minnesota Department of Natural Resources. 2014. Dams and dam safety in Minnesota [Online]. Available at http://www.dnr.state.mn.us/waters/surfacewater_section/damsafety/brochure.html (verified 12 Mar. 2014).

Minnesota Pollution Control Agency. 2009. Red River Valley biotic impairment assessment [Online]. Available at http://www.eorinc.com/documents/RedRiverBioticImpairmentAssessment.pdf (verified 5 Dec. 2013).

Minnesota Pollution Control Agency. 2013. Guidance manual for assessing the quality of Minnesota surface waters [Online]. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=16988 (verified 24 Jan. 2014).

Minnesota Pollution Control Agency. 2013. Minnesota nutrient criteria development for rivers-revised draft, January 2013 [Online]. Available at http://www.pca.state.mn.us/index.php/view-document.html?gid=14947 (verified 08 Apr. 2014).

Minnesota Pollution Control Agency. 2014. Sand Hill River Watershed monitoring and assessment report [Online]. Available at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/red-river-of-the-north-sandhill-river.html (verified 25 Apr. 2014).

Mitsch, W.J., and J.G. Gosselink. 2007. Wetlands. 7th ed. John Wiley and Sons, Inc., New York.

Munavar, M., W.P. Norwood, and L.H. McCarthy. 1991. A method for evaluating the impacts of navigationally induced suspended sediments from the Upper Great Lakes connecting channels on the primary productivity. Hydrobiologia 219:325-332.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Transactions American Fisheries Society 110:469-478.

Nebeker, A.V., S.T. Onjukka, D.G. Stevens, G.A. Chapman, and S.E. Dominguez. 1992. Effects of low dissolved oxygen on survival, growth and reproduction of Daphnia, Hyalella and Gammarus. Environmental Toxicology and Chemistry 11(3):373-379.

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

Pekarsky, B.L. 1984. Predator-prey interactions among aquatic insects. p. 196-254. *In* V.H. Resch and D.M. Rosenberg (eds.) The ecology of aquatic insects. Praeger Scientific, New York.

Pringle, C.M. 2003. What is hydrologic connectivity and why is it ecologically important? Hydrological Processes 17:2685-2689.

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

Rosenberg, D.M., and A.P. Wiens. 1978. Effect of sediment addition on macrobenthic invertebrates in a northern Canadian river. Water Resource Management 12:753-763.

Rosgen, D.L. 1996. Applied river morphology. Printed Media Companies. Minneapolis, MN.

Sand Hill River Watershed District. 2011. Watershed conditions report: Sand Hill River Watershed [Online]. Available at http://sandhillwatershed.org/SHRW%20Condition%20Report%201812_006%20Final%20(updated%2012_12_11).pdf (verified 17 Dec. 2013).

Sand Hill River Watershed District. 2012. Overall plan [Online]. Available at http://sandhillwatershed.org/OverallPlan.html (verified 12 Nov. 2013).

Schottler, S.P., J. Ulrich, P. Belmont, R. Moore, J.W. Lauer, D.R. Engstrom, and J.E. Almendinger. 2014. Twentieth century agricultural drainage creates more erosive rivers. Hydrological Processes 28(4):1951-1961.

Tiemann, J.S., D.P. Gillette, M.L. Wildhaber, and D.R. Edds. 2004. Effects of lowhead dams on riffle-dwelling fishes and macroinvertebrates in a midwestern river. Transactions of the American Fisheries Society 133:705-717.

U.S. Army Corps of Engineers. 2013. National inventory of dams [Online]. Available at http://geo.usace.army.mil/pgis/f?p=397:1:0::NO (verified 12 Nov. 2013).

U.S. Environmental Protection Agency. 2000. Stressor identification guidance document. EPA 822-B-00-025. U.S. Gov. Print Office, Washington, DC.

U.S. Environmental Protection Agency. 2012. CADDIS: The Causal Analysis/Diagnosis Decision Information System [Online]. Available at http://www.epa.gov/caddis/ (verified 12 Nov. 2013).

U.S. Environmental Protection Agency. 2012. Pesticides [Online]. Available at http://www.epa.gov/pesticides/ (verified 12 Nov. 2013).

Verry, E.S. 1988. The hydrology of wetlands and man's influence on it. p. 41-61. *In* Symposium on the hydrology of wetlands in temperate and cold regions. Vol. 2. Publications of the Academy of Finland, Helsinki.

Verry, E.S. 2000. Water flow in soils and streams sustaining hydrologic function. p. 99-124. *In* E.S. Verry, J.W. Hornbeck, and C.A. Dollhoff (eds.) Riparian management in forests of the continental eastern United States. Lewis Publishers, Boca Raton, FL.

Verry, E.S., and C.A. Dolloff. 2000. The challenge of managing for healthy riparian areas. p. 1-22 *In* E.S. Verry, J.W. Hornbeck, and C.A. Dolloff (eds.) Riparian management in forests of the continental eastern United States. Lewis Publishers, Boca Raton, FL.

Waters, T.F. 1995. Sediment in streams: Sources, biological effects, and control. American Fisheries Society, Bethesda, MD.

Weber, C.I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73-001. U.S. Environmental Protection Agency, Cincinnati, OH.

Appendix A: IBI Metric Scores for Biological Monitoring Sites in the SHRW.

F-IBI metric scores.

F-IBI Metric	Metric Scores (0-10) per SI Site #																		
	SHR 01	SHR 02	SHR 03	SHR 04	SHR 05	SHR 06	SHR 07	SHR 08	SHR 09	SHR 10	SHR 11	CD16 01	CD16 02	CD17 01	CD48 01	CD55 01	KC 01	KC 02	UNC 01
DarterSculp	5.0											5.0	5.0	10.0	5.0	5.0	5.0		5.0
DarterSculpSucTxPct		3.1	2.0	4.2	4.0	2.2	5.4											4.6	
DetNWQPct		4.1	4.6	0.0	4.0	6.8	8.1											7.4	
DetNWQTxPct								6.4	8.1	6.6	5.8								
DomTwoPct		5.1	8.6	7.2	9.1	4.1	3.6	5.0	8.3	6.9	4.9							8.5	
FishDELTPct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General		4.6	1.4	1.4	1.4	3.0	3.0											1.4	
GeneralPct								6.6	2.3	7.2	8.1								
Hdw-Tol	6.7											6.7	6.7	6.7	6.7	3.3	6.7		6.7
InsectCypPct	5.4											10.0	8.1	6.9	1.2	0.0	8.2		1.8
Insect-TolPct								5.2	3.9	4.4	7.0								
Insect-TolTxPct	7.0	2.5	1.4	1.4	0.8	0.0	3.5					4.4	5.8	5.5	6.4	6.7	6.2	0.0	5.8
IntolerantPct		0.0	0.0	0.0	0.4	9.1	6.5											0.0	
MA>3-TolPct		2.1	0.5	2.6	0.4	0.6	1.2											1.4	
Minnows-TolPct	3.6											6.6	3.4	9.1	8.2	1.1	8.8		1.0
NumPerMeter-Tolerant	1.8											10.0	5.1	10.0	10.0	0.7	6.0		2.0
PioneerTxPct	6.6											7.0	7.7	5.4	7.2	8.6	4.3		4.9
Piscivore								5.3	5.3	3.3	4.0								

F-IBI metric scores *(continued)*.

F-IBI Metric	Metric Scores (0-10) per SI Site #																		
	SHR 01	SHR 02	SHR 03	SHR 04	SHR 05	SHR 06	SHR 07	SHR 08	SHR 09	SHR 10	SHR 11	CD16 01	CD16 02	CD17 01	CD48 01	CD55 01	KC 01	KC 02	UNC 01
Sensitive	7.5											7.5	7.5	7.5	7.5	5.0	7.5		7.5
SensitiveTxPct		4.1	5.5	2.8	2.6	3.0	1.7											1.5	
SensitiveTxPctGR1								0.7	3.3	1.3	0.2								
SLithop	0.0											7.0	2.3	7.0	4.7	0.0	0.0		0.0
SLithopGR1								4.8	5.8	5.7	3.5								
SLithopPct		1.1	3.1	5.1	4.2	9.1	9.1											3.4	
SLvdPct								5.7	5.9	2.5	8.5								
SSpnTxPct		5.0	3.0	3.0	5.4	4.6	8.5	7.2	9.1	7.9	9.1							2.4	
TolPct								5.6	5.9	5.8	8.1								
TolTxPct	6.0											5.6	5.0	6.2	6.8	6.4	7.0		5.6
Vtol		5.5	3.6	3.6	1.8	3.6	5.5											3.6	
VtolTxPct								4.5	7.8	6.7	6.7								
Total F-IBI Score	**49.6**	**37.2**	**33.7**	**31.3**	**34.0**	**46.0**	**56.0**	**57.1**	**65.6**	**55.8**	**65.8**	**69.8**	**56.7**	**74.2**	**63.7**	**36.8**	**59.8**	**34.3**	**40.4**

M-IBI metric scores.

M-IBI Metric	Metric Scores (0-10) per SI Site #															
	SHR 01	SHR 02	SHR 03	SHR 04	SHR 05	SHR 06	SHR 07	SHR 08	SHR 09	SHR 10	SHR 11	CD16 01	CD16 02	CD17 01	CD48 01	KC 01
ClimberCh						3.5	3.5				0.3			7.8		
ClingerCh	0.7	5.3	4.7	4.0	10.0			6.0	3.3	8.0		5.3	6.0		4.0	6.0
ClingerChTxPct						4.9	6.9				7.7			0.6		
Collector-filtererPct	0.2	0.6	1.4	6.6	4.5			1.4	6.3	0.5		4.0	3.9		1.6	10.0
DomFiveCHPct	0.0	6.4	4.2	4.4	10.0	10.0	9.2	1.4	2.9	2.7	5.7	7.8	6.0	5.5	5.7	3.5
HBI_MN	6.9	2.6	4.2	4.4	5.7	4.4	3.0	4.3	3.7	1.3	2.5	2.5	2.8	1.5	2.3	6.1
InsectTxPct						7.3	8.4				5.2			2.3		
Intolerant2Ch	0.0	5.0	0.0	0.0	7.9			0.0	2.5	0.0		0.0	5.0		0.0	0.0
Intolerant2lessCh																
Odonata						3.9	0.0				0.0			6.1		
Plecoptera						7.9	7.9				5.0			0.0		
POET	0.0	4.3	4.3	3.6	7.1			7.1	7.1	6.4		1.4	3.6		2.1	5.0
Predator						2.3	1.5				1.5			3.1		
PredatorCh	0.7	3.6	2.9	3.6	4.3			0.7	5.4	3.6		5.0	5.7		3.6	5.0
TaxaCountAllChir	0.0	5.9	3.3	4.7	10.0			1.2	3.9	3.3		4.4	5.0		3.9	5.3
Tolerant2ChTxPct						7.0	5.8				6.1			2.7		
Trichoptera						2.0	5.0				3.0			0.0		
TrichopteraChTxPct	0.0	3.1	2.0	7.0	7.7			10.0	8.5	10.0		1.8	6.8		0.0	6.6
TrichwoHydroPct	0.0	1.1	0.0	4.7	7.7			10.0	10.0	10.0		1.2	2.0		0.0	3.3
VeryTolerant2Pct																
Total M-IBI Score	**8.5**	**37.8**	**26.9**	**43.0**	**75.1**	**53.2**	**51.3**	**42.1**	**53.6**	**45.8**	**37.1**	**33.6**	**46.8**	**29.6**	**23.1**	**50.8**