Winnebago River Watershed Stressor Identification Report

A study of local stressors limiting the biotic communities in the Winnebago River Watershed.

MINNESOTA POLLUTION CONTROL AGENCY

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Legislative charge

Minn. Stat. § 116.011 Annual Pollution Report

A goal of the MPCA is to reduce the amount of pollution that is emitted in the state. By April 1 of each year, the MPCA shall report the best estimate of the agency of the total volume of water and air pollution that was emitted in the state the previous calendar year for which data are available. The agency shall report its findings for both water and air pollution, etc., etc.

HIST: 1995 c 247 art 1 s 36; 2001 c 187 s 3

Author

Joe Magee (MPCA)

Contributors/acknowledgements

Tiffany Schauls (MPCA)
Jen Ender (MPCA)
Ashley Ignatius (MPCA)
Bill Thompson (MPCA)
Ben Roush (MPCA)
Chandra Henrich (MPCA)
Mel Markert (MPCA)
Joel Chirhart (MPCA)
Joe Hadash (MPCA)
Steven Wolf (MPCA)
Mason Johnson (MPCA)
Kelsey Budahn (MPCA)
Henry Cole (MPCA)
Matt Seha (MPCA)
Jinny Fricke (MPCA)
Jon Lore (DNR)
Jeanine Vorland (DNR)
Craig Soupir (DNR)

Editing and graphic design

PIO staff
Graphic design staff
Administrative Staff

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Key Terms and Abbreviations

AUID	Assessment Unit ID
BOD	Biological Oxygen Demand
CADDIS	Causal Analysis/Diagnosis Decision Information System
Cfs	Cubic feet per second
CL	Confidence limits
cm	Centimeter
DELT	Deformities, Eroded fins, Lesions, and Tumors
DO	Dissolved Oxygen
DOP	Dissolved Orthophosphate Phosphorus
DW	Drinking water
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FIBI	Fish Index of Biological Integrity
GP	Glide/Pool
GSSHA	Gridded Surface Subsurface Hydrologic Analysis
HUC	Hydrologic Unit Code
HSPF	Hydrological Simulation Program – FORTRAN
IBI	Index of Biotic Integrity
IWM	Intensive Watershed Monitoring
µg/L	Microgram per liter
µS/cm	Microsiemens per centimeter
DNR	Minnesota Department of Natural Resources
MIBI	Macroinvertebrate Index of Biological integrity
mg/L	Milligrams per liter
mgy	Million gallons per year
MPCA	Minnesota Pollution Control Agency
MSHA	MPCA Stream Habitat Assessment
N	Nitrate
P	Phosphorus
SID	Stressor Identification
SOE	Strength of Evidence
SSURGO	Soil Survey Geographic Database
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
TSVS	Total Suspended Volatile Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant

Executive Summary

Over the past decade, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of the state's rivers and streams. This basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat conditions at multiple sites throughout a major watershed. From these data, an Index of Biological Integrity (IBI) score can be developed, which provides a measure of overall community health. If biological impairments are found, stressors to the aquatic community must be identified.

Stressor identification (SID) is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems and provides a structure for organizing the scientific evidence supporting the conclusions (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to aquatic life. The SID is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act.

This report summarizes SID work in the Winnebago River Watershed. There are three Assessment Unit ID (AUIDs; 501, 504, and 515) currently impaired for a lack of biological assemblage. Two AUIDs (503 and 505) were not assessed due to their class 7 status.

After examining many candidate causes for the biological impairments, the following stressors were identified as probable causes of stress to aquatic life:

- Nitrate
- Eutrophication
- Dissolved Oxygen (DO)
- Total Suspended Solids (TSS)
- Habitat
- Flow Alteration

1. Introduction

1.1. Monitoring and Assessment

Water quality and biological monitoring in the Winnebago River Watershed has been ongoing. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during 2015, and focused on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data obtained prior to 2015, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1).

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

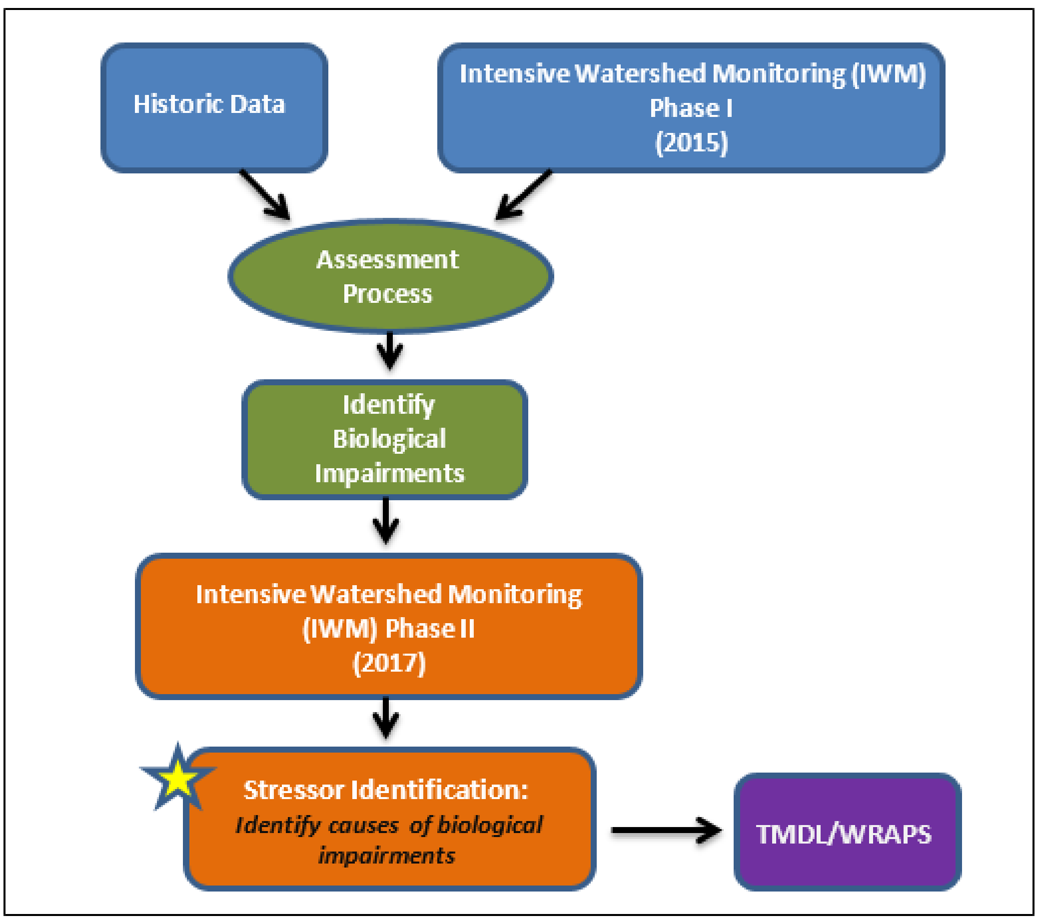


Figure 1. Process map of Intensive Watershed Monitoring, Assessment, Stressor Identification and TMDL processes.

1.2. Stressor Identification Process

The MPCA follows the EPA's process of identifying stressors that cause biological impairment, which has been used to develop the MPCA's guidance to SID (Cormier et al. 2000 MPCA 2008). The EPA has also developed an updated, interactive web-based tool, the Causal Analysis/Diagnosis Decision Information System (CADDIS EPA 2010). This system provides an enormous amount of information designed to guide and assist investigators through the process of SID. Additional information on the SID process using CADDIS can be found here: https://www.epa.gov/caddis-vol1/caddis-volume-1-stressor-identification-summary-tables-types-evidence.

The SID is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act. SID draws upon a broad variety of disciplines and applications, such as aquatic ecology, geology, geomorphology, chemistry, land use analysis, and toxicology. A conceptual model showing the steps in the SID process is shown in Figure 2. Through a review of available data, stressor scenarios are developed that aim to characterize the biological impairment, the cause, and the sources/pathways of the various stressors.

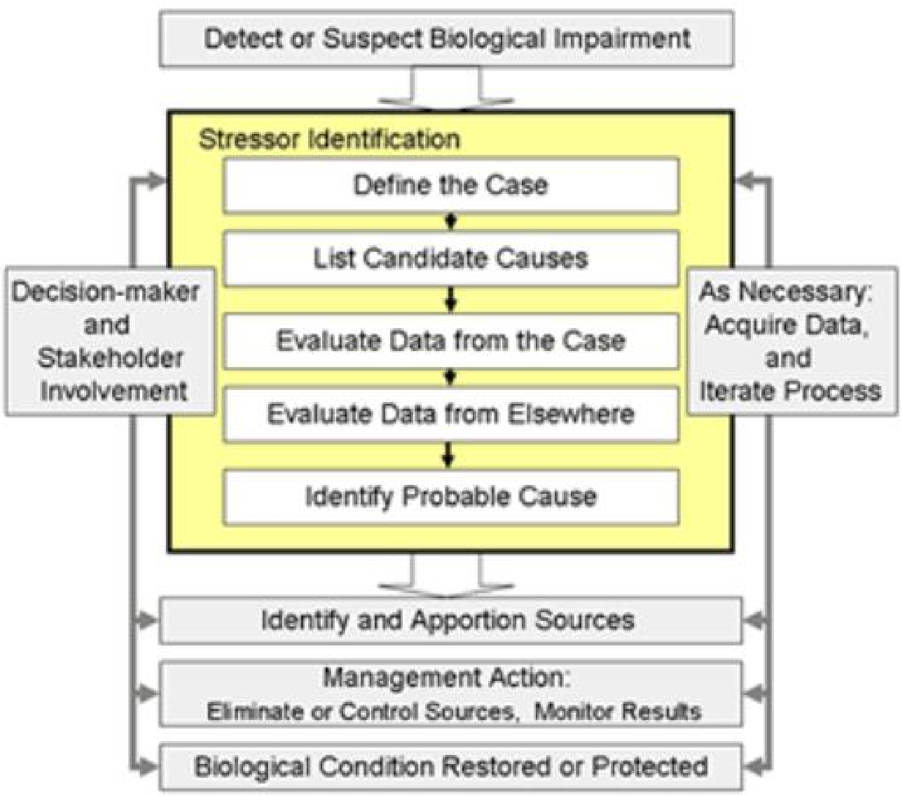


Figure 2. Conceptual model of Stressor Identification process (Cormier et al. 2000).

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

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

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

1.3. Common Stream Stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired water body. Table 1 lists the common stream stressors to biology relative to each of the major stream health categories.

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

Stream Health	Stressor(s)	Link to Biology
Stream Connections	**Loss of Connectivity** · Dams and culverts · Lack of Wooded riparian cover · Lack of naturally connected habitats/ causing fragmented habitats	Fish and macroinvertebrates cannot freely move throughout system. Stream temperatures also become elevated due to lack of shade.
Hydrology	**Altered Hydrology** **Loss of habitat due to channelization** **Elevated Levels of TSS** · Channelization · Peak discharge (flashy) · Transport of chemicals	Unstable flow regime within the stream can cause a lack of habitat, unstable stream banks, filling of pools and riffle habitat, and affect the fate and transport of chemicals.
Stream Channel Assessment	**Loss of Habitat due to excess sediment** **Elevated levels of TSS** · Loss of dimension/pattern/profile · Bank erosion from instability · Loss of riffles due to accumulation of fine sediment · Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.

Water Chemistry	**Low Dissolved Oxygen Concentrations** **Elevated levels of Nutrients** · Increased nutrients from human influence · Widely variable DO levels during the daily cycle · Increased algal and or periphyton growth in stream · Increased nonpoint pollution from urban and agricultural practices · Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream Biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

1.4. Report Format

This SID report follows a format to first summarize candidate causes of stress to the biological communities at the 8-digit Hydrologic Unit Code (HUC) scale. Within the summary (Section 3), there is information about how the stressor relates broadly to the Winnebago River Watershed, water quality standards and general effects on biology. Section 4 is organized by 8-digit HUC, and discusses the available data and relationship to fish and macroinvertebrate metrics in more detail.

2. Overview of the Winnebago River Watershed

2.1. Background

See Winnebago River Watershed Monitoring and Assessment Report and [Winnebago River homepage](#) for background information.

2.2. Monitoring Overview

The Winnebago River Watershed was sampled intensively for fish and macroinvertebrates in 2015 and 2016 (Figure 3). Detailed information regarding the biological monitoring process and impairment decisions can be found in the Winnebago River Watershed Monitoring and Assessment Report.

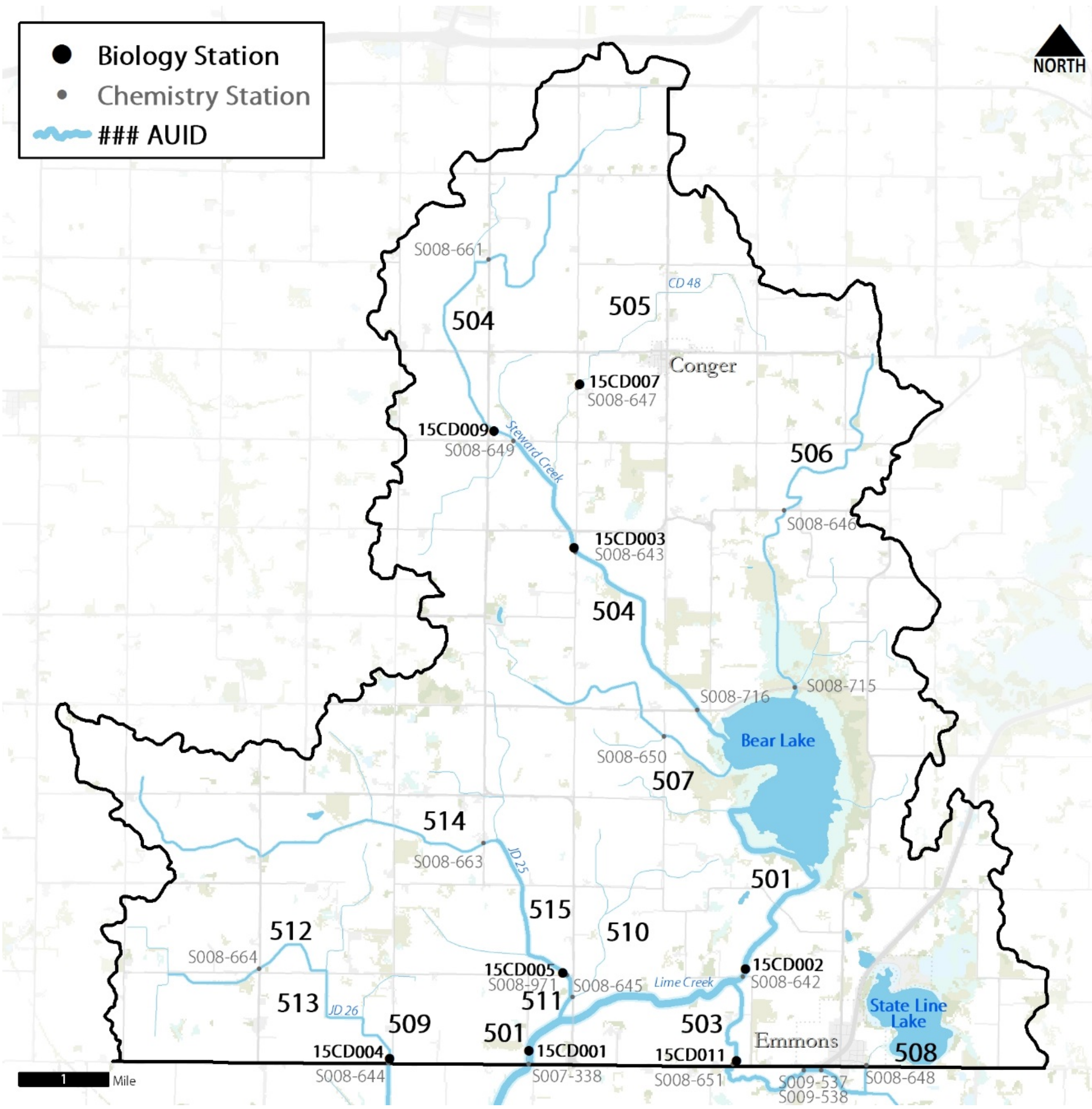


Figure 3: Biology and chemistry monitoring stations for streams in the Winnebago River Watershed.

2.3. Summary of Biological Impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrate communities and related habitat conditions at sites throughout a watershed. The resulting information is used to calculate a specific Index of Biotic Integrity (IBI) for that reach. The IBI scores can then be compared to a range of thresholds (MPCA 2016).

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

In the Winnebago River Watershed, three AUIDs are currently impaired for a lack of biological assemblage (Table 2). Two AUIDs (503 and 505) are Class 7 (Limited Resource Value Water), and therefore not assessed. Class 7 waters do not have biological standards.

Table 2: Biologically impaired AUIDs in the Winnebago River Watershed.

			Impairments	
Stream Name	**AUID #**	**Reach Description**	**Biological**	**Water Quality**
Lime Creek	501	Bear Lk to MN/IA border	Fish and Macroinvertebrates	Bacteria, DO, Eutrophication
Steward Creek (CD 23)	504	Headwaters to Bear Lk	Macroinvertebrates	DO
Judicial Ditch 25	515	Unnamed ditch to Unnamed Cr	Fish	DO

The modified use IBI thresholds for stream classes sampled in the Winnebago River Watershed can be found below in Table 3 and Table 4. Additional information can be found in the Winnebago River Watershed Monitoring and Assessment Report and Development of Biological Criteria for Tiered Aquatic Life Uses (MPCA 2016).

Table 3. Fish classes with respective modified use IBI thresholds and upper/lower CL found in the Winnebago River Watershed.

Class	Class Name	IBI Thresholds	Upper CL	Lower CL
2	Southern Streams	35	44	26
3	Southern Headwaters	33	40	26
7	Low Gradient	15	25	5

Table 4. Macroinvertebrate classes with respective modified use IBI thresholds and upper/ lower CL found in the Winnebago River Watershed.

Class	Class Name	IBI Thresholds	Upper CL	Lower CL
7	Prairie Streams GP	22	35.6	8.4

The purpose of SID is to interpret data collected during the biological monitoring and assessment process. Trends in the IBI scores can help to identify causal factors for biological impairments. A summary of the macroinvertebrate and fish IBI scores can be found in the Winnebago River Watershed Monitoring and Assessment Report.

3. Possible Stressors to Biological Communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found here (https://www.epa.gov/caddis-vol2/caddis-volume-2-sources-stressors-and-responses-learn-about-stressors). This comprehensive list serves two purposes. First, it can serve as a checklist for investigators to consider all possible options for impairment in the watershed of interest. Second, it can be used to identify potential stressors that can be eliminated from further evaluation. In some cases, the data may be inconclusive and limit the ability to confidently determine if a stressor is causing impairment to aquatic life. It is imperative to document if a candidate cause was suspected, but there was not enough information to make a scientific determination of whether or not it is causing harm to aquatic life. In this case, management decisions can include modification of sampling plans and future evaluation of the inconclusive case. Alternatively, there may be enough information to conclude that a candidate cause is not causing biological impairment and therefore can be eliminated. The inconclusive or eliminated causes will be discussed in more detail in the following section.

3.1. Eliminated Causes

There were no causes eliminated from the Winnebago River Watershed.

3.2. Inconclusive Causes (insufficient information)

Some candidate causes were unable to be considered further and therefore were determined inconclusive. These causes were inconclusive due to lack of information, lack of biological connection, and/or mixed results (water quality and/or biological). The potential causes that were inconclusive in the Winnebago River Watershed were pesticides, ammonia, pH, chloride, metals, and conductivity. These causes are discussed in more detail below.

3.2.1. Overview of Pesticides in the Winnebago River Watershed

There is no pesticide data available in the Winnebago River Watershed.

3.2.2. Overview of Ammonia in the Winnebago River Watershed

Very limited ammonia data is available in the Winnebago River Watershed. Only 10 samples have been collected, and they were all collected at station S007-338 (co-located with station 15CD001). Samples were collected May through September in 2015, and ranged from 0.05 to 0.21 mg/L. The unionized fraction, which is most toxic to aquatic life, resulted in one exceedance over the assessment period; unionized ammonia is meeting aquatic life standards.

3.2.3. Overview of pH in the Winnebago River Watershed

Numerous instantaneous pH samples (267) were collected across the watershed in 2015 and 2016, ranging from 5.3 to 9.0. Only one exceedance (less than 1%) was observed, which was below the minimum standard (6.5) and occurred on November 18, 2015, at station S008-644 (co-located with station 15CD004). The exceedance occurred on AUID 509, which is meeting the bio criteria. In addition, all pH values recorded during sonde deployments were at or within the standard.

3.2.4. Overview of Chloride in the Winnebago River Watershed

Thirty-seven chloride samples were collected at nine stations across the watershed in 2015 and 2016. Concentrations ranged from 14.6 to 27.9 mg/L (average of 18.6 mg/L); all samples were well below the chronic standard (230 mg/L).

3.2.5. Overview of Metals in the Winnebago River Watershed

Arsenic, Calcium, Cadmium, Chromium, Copper, Magnesium, Molybdenum, Lead, Selenium, Zinc, and Nickel were sampled at stations S007-338 (co-located with station 15CD001) and S008-643 (co-located with station 15CD003) on August 17, 2016. Flow conditions during sampling were near baseflow, and all concentrations were below the standard (Table 5).

Table 5: Metal concentrations in the Winnebago River Watershed on August 17, 2016.

	S007-338 (15CD001)	S008-643 (15CD003)
Arsenic (µg/L)	2.33	1.65
Calcium (mg/L)	86	120
Cadmium (µg/L)	<0.1	<0.1
Chromium (µg/L)	<1	<1
Copper (µg/L)	<10	<10
Magnesium (mg/L)	24.8	32.3
Molybdenum (µg/L)	2.51	2.9
Lead (µg/L)	<1	<1
Selenium (µg/L)	<1	<1
Zinc (µg/L)	<10	<10
Nickel (µg/L)	<5	<5

3.2.6. Overview of Conductivity in the Winnebago River Watershed

Numerous instantaneous conductivity samples (287) were collected across the watershed in 2015 and 2016. Concentrations ranged from 319 to 945 uS/cm (average of 720 uS/cm). The average concentration is similar to the ecoregion average for the Western Corn Belt Plains (698 uS/cm) (McCollor et al. 1993). Although this average for the Western Corn Belt Plains was derived using an older data set (1970 through 1992), it provides some context to the concentrations documented in the Winnebago River Watershed. In addition, conductivity values recorded during sonde deployments were similar to those observed during point sampling (maximum of 907 uS/cm).

3.3. Summary of Candidate Causes in the Winnebago River Watershed

Fourteen candidate causes were selected as possible drivers of biological impairments in the Winnebago River Watershed. The initial list of candidate/potential causes was narrowed down after the initial data evaluation/data analysis resulting in eight for final analysis in this report. The eight remaining candidate causes are:

- Temperature
- Nitrate

- Eutrophication
- DO
- TSS
- Habitat
- Fish Passage
- Flow Alteration

Background information specific to candidate causes/stressors in Minnesota can be found here. This information provides an overview of the pathway and effects of each candidate stressor considered in the biological SID process with relevant data and water quality standards specific to Minnesota. The U.S. Environmental Protection Agency (EPA) has additional information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on its CADDIS website.

4. Evaluation of Candidate Causes

Candidate causes were evaluated in the Winnebago River Watershed by individual AUID. Each AUID is discussed below within the context of the 8-digit HUC. This report only covers the Minnesota portion of the watershed.

4.1 Winnebago River (8-digit HUC)

This section encompasses biotic impairments in the Winnebago River Watershed (8-digit HUC) (Figure 4). There are three AUIDs with biotic impairments in the watershed; one is a fish and macroinvertebrate impairment (AUID 501), one is a macroinvertebrate impairment (AUID 504), and one is a fish impairment (AUID 515). Two impairments are located in the southern part of the watershed below Bear Lake; one on Lime Creek (AUID 501) and one on Judicial Ditch 25 (AUID 515). The other impairment is located upstream of Bear Lake on Steward Creek (AUID 504). All AUIDs in the watershed are warmwater (2B) and modified use. Modified use reaches have biological communities limited by habitat as a result of legal activities (e.g. ditch maintenance).

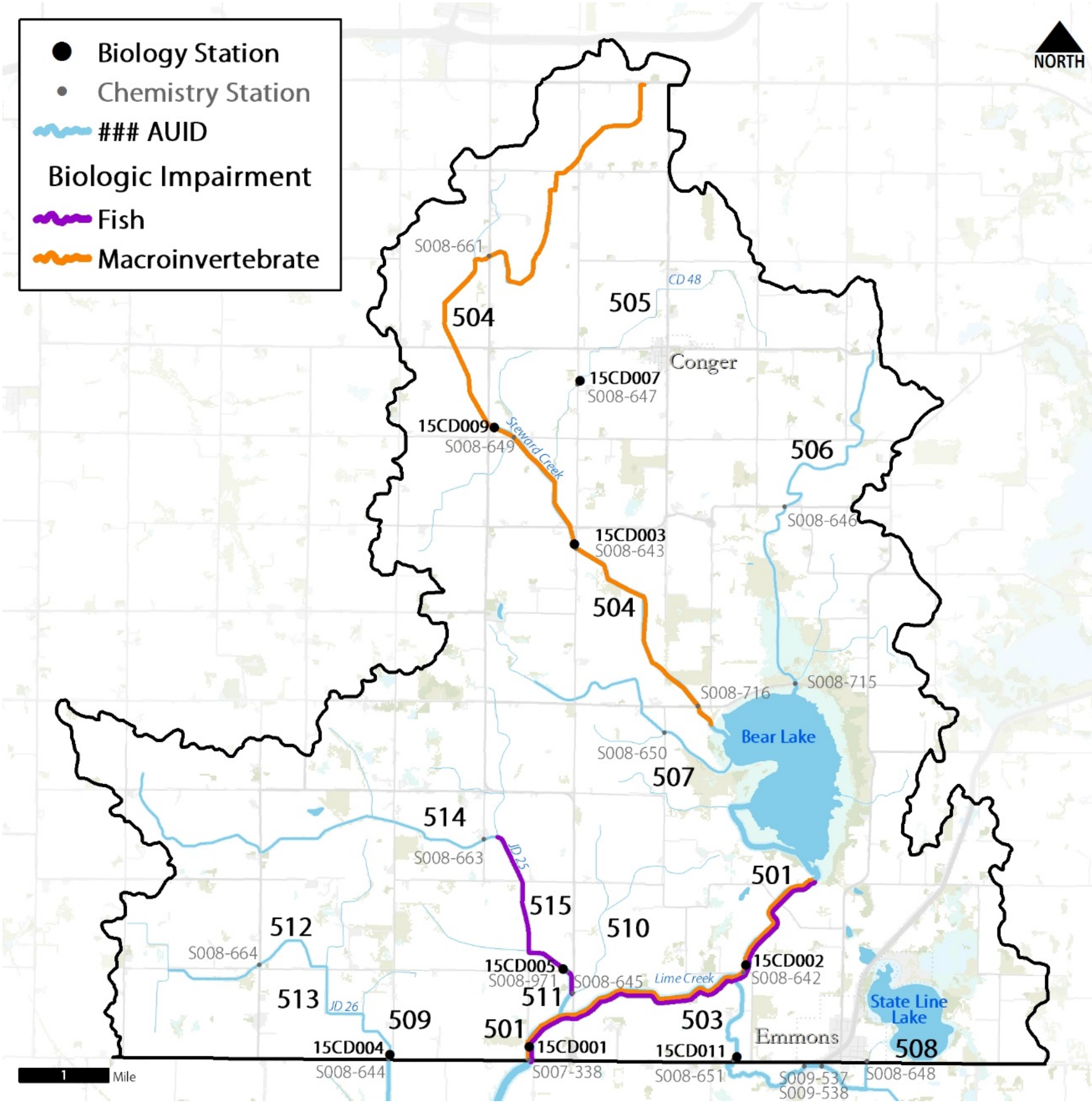


Figure 4: Winnebago River Watershed biota impairments, biology stations, and chemistry stations.

Biological Communities

The Winnebago River Watershed (07080203) is approximately 45,649 acres and is dominated by row crops (84%) (Minnesota Department of Natural Resources (DNR) WHAF). Most of the watershed is in Freeborn County (99%), with the remaining portion in Faribault County (1%). Only two small cities are located within the watershed (Conger and Emmons). All of the streams in the watershed are warmwater (2B) and modified use. The main streams are Steward Creek and Lime Creek; Steward Creek flows into Bear Lake and Lime Creek flows out of Bear Lake. There are also two lakes in the watershed, Bear Lake and State Line Lake. Both lakes have aquatic recreation impairments due to excess nutrients. Biological impairments are located on Lime Creek (fish and macroinvertebrate), Steward Creek (macroinvertebrate), and Judicial Ditch 25 (fish); in addition, all of these reaches have DO impairments and Lime Creek also has bacteria and river eutrophication impairments. Biological stations in the watershed include 15CD001, 15CD002, 15CD003, 15CD004, 15CD005, 15CD007, 15CD009, and 15CD011. The AUIDs containing stations 15CD007 and 15CD011 were not assessed because they are Class 7. The stations on biologically impaired AUIDs are 15CD001, 15CD002, 15CD003, 15CD005, and 15CD009. Stations 15CD001 and 15CD002 are located just below the mouth of Bear Lake on Lime Creek (AUID 501). Station 15CD005 is located on Judicial Ditch 25 (AUID 515), which eventually drains into Lime Creek (just upstream of station 15CD001). Stations 15CD003 and 15CD009 are located just upstream of Bear Lake on Steward Creek (AUID 504). These stations were sampled in 2015 and 2016 for fish and macroinvertebrates.

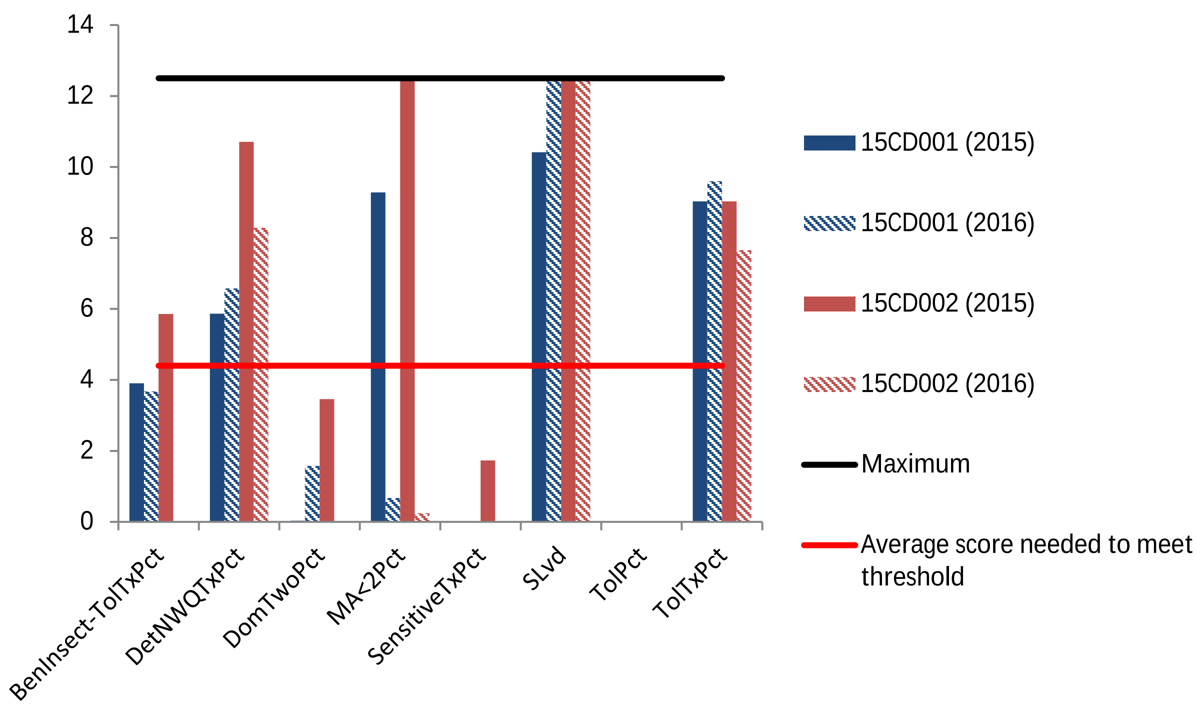
The fish community is impaired and “not supporting” the aquatic life use for AUIDs 501 and 515. Fish Index of Biological Integrity (FIBI) scores for stations 15CD001 and 15CD002 were 29 and 35, and 56 and 29 respectively (Table 6). One score at each station was below the modified use threshold (35), while the other two were at or above the threshold. Both scores below the threshold were within the confidence interval. The FIBI score for station 15CD005 was 0; only 21 fish were collected (all tolerant) and choking vegetation was noted during sampling. Stations 15CD001 and 15CD002 are Southern Streams (class 2), and station 15CD005 is Low Gradient (class 7). In general, for stations 15CD001 and 15CD002, relative abundance of individuals of the dominant two species (DomTwoPct), individuals with Deformities, Eroded fins, Lesions, and Tumors (DELT) anomalies (FishDELTPct), sensitive taxa (SensitiveTxPct), and tolerant individuals (TolPct) scored poorly and contributed to the low FIBI scores (Figure 5). Relative abundance of non-tolerant benthic insectivore taxa (BenInsect-TolTXPct) and individuals with a female mature age less than or equal to two (MA<2Pct) also scored poorly and contributed to the low FIBI score at station 15CD002 in 2016. All FIBI metrics at station 15CD005 were zero.

The macroinvertebrate community is impaired and “not supporting” the aquatic life use for AUIDs 501 and 504. Macroinvertebrate Index of Biological integrity (MIBI) scores for stations 15CD001 and 15CD002 were 33 and 20, and 32 respectively. One score (15CD001 in 2016) was below the modified use threshold (22), while the other two were above the threshold but within the confidence interval. MIBI scores for stations 15CD003 and 15CD009 were 27, 34, and 44, and 17 and 22 respectively. Scores at station 15CD009 were below the modified use threshold, while scores at station 15CD003 were above the threshold (with one above the confidence interval). All stations in the watershed are Prairie Streams Glide/Pool (GP) (class 7). In general, collector-filterers (Collector-filtererPct), pollution scores based on tolerance values (HBI_MN), and intolerant taxa (Intolerant2Ch) scored poorly across these stations and contributed to the low MIBI scores (Figure 6).

Table 6: Fish and macroinvertebrate classes, IBI scores, and modified use thresholds for stations in the Winnebago River Watershed. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station	Class	MIBI	MU Threshold	Class	FIBI	MU Threshold
↑	15CD007 (2015)	7	35	22	3	29	33
	15CD009 (2015)	7	17	22	3	56	33
	15CD009 (2016)	7	22	22	3	43	33
	15CD003 (2015)	7	27	22	7	37	15
	15CD003 (2015)	7	34	22	7	-	15
	15CD003 (2016)	7	44	22	7	27	15
Bear Lake							
↓	15CD001 (2015)	7	33	22	2	29	35
	15CD001 (2016)	7	20	22	2	35	35
	15CD002 (2015)	7	-	22	2	56	35
	15CD002 (2016)	7	32	22	2	29	35
	15CD004 (2015)	7	39	22	3	44	33
	15CD004 (2016)	7	28	22	3	-	33
	15CD005 (2015)	7	47	22	7	0	15
	15CD005 (2016)	7	37	22	7	-	15
	15CD005 (2016)	7	35	22	7	-	15
	15CD011 (2015)	7	17	22	3	48	33

Figure 5: Fish metrics of the Southern Streams (class 2) IBI for the Winnebago River Watershed (07080203). Only stations with fish impairments are included (15CD001 and 15CD002).



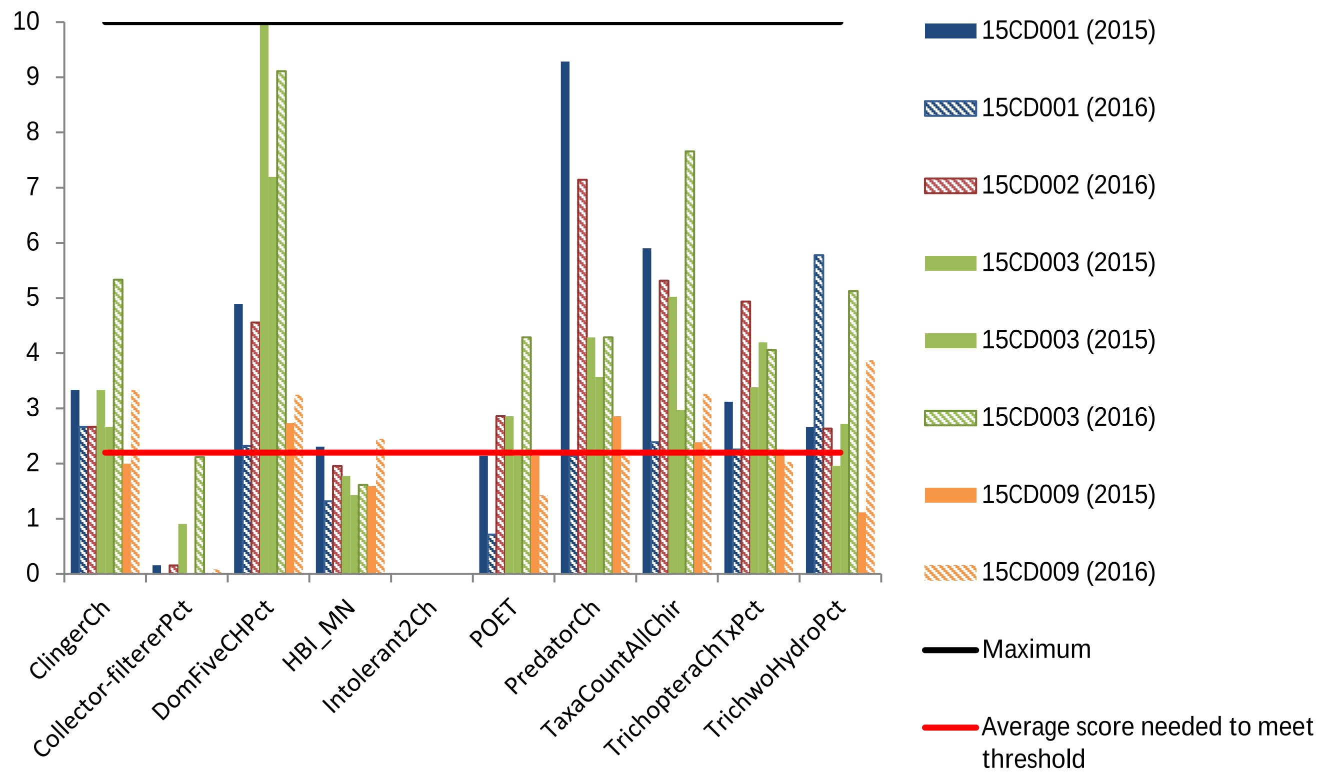


Figure 6: Macroinvertebrate metrics of the Prairie Streams GP (class 7) IBI for the Winnebago River Watershed (07080203). Only stations with macroinvertebrate impairments are included (15CD001, 15CD002, 15CD003, and 15CD009).

Data Evaluation for each Candidate Cause

Temperature

Temperatures ranged from 12.5°C to 31.0°C across the watershed during sonde deployments in July and August of 2015 and 2016 (Table 7). Station 15CD002 was the only station to have values greater than 30°C (daily average warmwater standard); 5% were above the standard and exceedances ranged from approximately 6 to 9 hours in duration on two separate days. Station 15CD002 is just below the outlet of Bear Lake on Lime Creek. In addition to sonde deployments, continuous temperature sensors were deployed at stations 15CD003 (2016 and 2017), 15CD002 (2017), 15CD001 (2015), and 15CD005 (2017). The only station with values above 30 °C was 15CD002; values exceeded the standard 1% of the time (maximum of 31.7 °C). There were also several instantaneous (point) measurements collected throughout the watershed in 2015 and 2016, all of which were below 30 °C.

Table 7: Temperature range during sonde deployments in the Winnebago River Watershed in 2015 and 2016. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow).

	Station (Year Sampled)	AUID	Sonde Deployment Dates	Temperature Min (°C)	Temperature Max (°C)	%Exceedance of Standard (30 °C)
↑	15CD009 (2015)	504	7/24/15 - 8/5/15	14.5	23.6	0.0
	15CD003 (2016)		7/13/16 - 7/25/16	16.0	22.3	0.0
Bear Lake						
↓	15CD001 (2015)	501	7/21/15 - 8/5/15	16.3	27.4	0.0
	15CD002 (2016)		7/13/16 - 7/25/16	18.6	31.0	5.4
	15CD004 (2015)	509	7/24/15 - 8/5/15	12.5	24.1	0.0
	*15CD005 (2015)	511	7/24/15 - 8/5/15	15.5	24.1	0.0
	15CD005 (2016)	515	7/13/16 - 7/25/16	17.3	23.7	0.0

***Sonde deployment was downstream of station 15CD005.**

Temperature effects on biological communities in warmwater systems is not as well understood as in coldwater systems. Elevated temperature can decrease macroinvertebrate taxa richness (EPA CADDIS 2010). Total taxa richness (TaxaCountAllChir) ranged from 24 to 45 across the watershed. All stations except 15CD001 (2015) and 15CD003 (2016) were worse than the statewide median (39) of stations meeting the MIBI threshold. The poor taxa richness across the watershed is likely due to other stressors; there is no distinct response at station 15CD002 (where the elevated temperature occurred).

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 8). A study in the Minnesota River Basin examining relationships between stream temperature and fish community attributes found significant relationships between increased temperatures (and temperature fluctuations) and top carnivores (decrease), sucker species (decrease) and minnow species (increase) (Feist and Niemela 2005). Relative abundance of carnivores (CarnPct), Cyprinidae species (MinnowPct), and Catostomidae individuals (SuckerPct) were worse than average at station 15CD002 in 2016; this is also the year and station where elevated temperature has been documented. However, it is hard to attribute this metric response to elevated temperature as other stations (with zero temperatue exceedances) exhibit a similar response.

Table 8: Fish metrics that respond to temperature stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	CarnPct	MinnowPct	SuckerPct
↑	15CD007 (2015) (3)	505	46.8	**91.5**	**0.7**
	15CD009 (2015) (3)	504	**13.9**	22.6	66.1
	15CD009 (2016) (3)		34.9	48.2	21.0
	15CD003 (2015) (7)		**10.4**	**56.4**	12.3
	15CD003 (2016) (7)		**13.4**	**60.4**	12.4
Bear Lake					
	15CD001 (2015) (2)	501	41.6	**42.6**	**13.6**
	15CD001 (2016) (2)		**17.0**	**54.4**	**2.5**
	15CD002 (2015) (2)		75.2	11.0	**7.3**
	15CD002 (2016) (2)		**16.0**	**76.3**	**0.5**
	15CD004 (2015) (3)	509	**1.0**	8.5	45.2
↓	15CD005 (2015) (7)	515	23.8	33.3	**0.0**
	15CD011 (2015) (3)	503	**8.5**	**66.8**	**7.5**
	Southern Streams Average (Ditched Channel) (2)		*31.7*	*35.2*	*15.9*
	Southern Headwaters Average (Ditched Channel) (3)		*24.8*	*55.2*	*12.4*
	Low Gradient Average (Ditched Channel) (7)		*13.9*	*46.7*	*5.8*
	Expected response to stress		↓	↑	↓

In general, temperatures in the Winnebago River Watershed are suitable for warmwater fish and macroinvertebrate communities. Station 15CD002, which is just downstream from the mouth of Bear Lake, is the only station with temperature exceedances of 30 °C. The fish and macroinvertebrate metrics don't provide clear indication if temperature is a stressor in this AUID (501); additional monitoring is recommended to gain better understanding of the temperature dynamics in this AUID. Temperature is not a stressor in AUIDs 504 (stations 15CD003 and 15CD009) and 515 (station 15CD005), and inconclusive as a stressor in AUID 501 (stations 15CD001 and 15CD002).

Nitrate

Nitrate concentrations during fish sampling in 2015 and 2016 ranged from 0.06 to 14 mg/L (average of 6.3 mg/L). Additional samples were collected in 2015 and 2016 as part of SID, and noticeable differences in concentration were observed above and below Bear Lake (Table 9 and Figure 7). Nitrate concentrations at three stations (15CD007, 15CD009, and 15CD003) upstream of Bear Lake on Steward Creek and County Ditch 48 ranged from 5.5 to 29 mg/L. Averages at these stations ranged from 16 to 19.7 mg/L. Nitrate concentrations at six stations (S008-663, 15CD005, 15CD004, 15CD001, 15CD011, and 15CD002) below Bear Lake (not necessarily connected to the lake) ranged from 0.5 to 19 mg/L. Averages at these stations ranged from 3.1 to 7.3 mg/L. Samples were collected year round at most sites, with a majority during low flow conditions. Station 15CD001 had 10 additional samples collected in 2015 as part of the MPCA IWM process; these samples are not included in the statistics above or table and figure below, but ranged from 0.65 to 4.9 mg/L (average of 2.4 mg/L). Elevated nitrate concentrations have been documented across the entire watershed including all stations on biologically impaired AUIDs (15CD001, 15CD002, 15CD003, 15CD005, and 15CD009), with much higher concentrations upstream of Bear Lake. Denitrification and plant uptake in Bear Lake are likely explanations for the reduced concentrations in Lime Creek.

Table 9: Nitrate concentrations (mg/L) across the Winnebago River Watershed. Stations on left side of table are located above Bear Lake, and stations on right side of table are located below Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow).

N (mg/L)	15CD007	15CD009	15CD003	←U.S. of Bear Lake D.S. of Bear Lake→	S008-663	15CD005	15CD004	15CD001	15CD011	15CD002
Min	8.4	5.6	5.5		1.3	2	0.7	0.9	2.1	0.5
Max	29	25	26		14	14	15	11	19	11
Average	19.7	16.0	16.9		6.4	7.3	6.0	4.4	6.5	3.1
Count	22	23	23		23	12	23	22	22	22

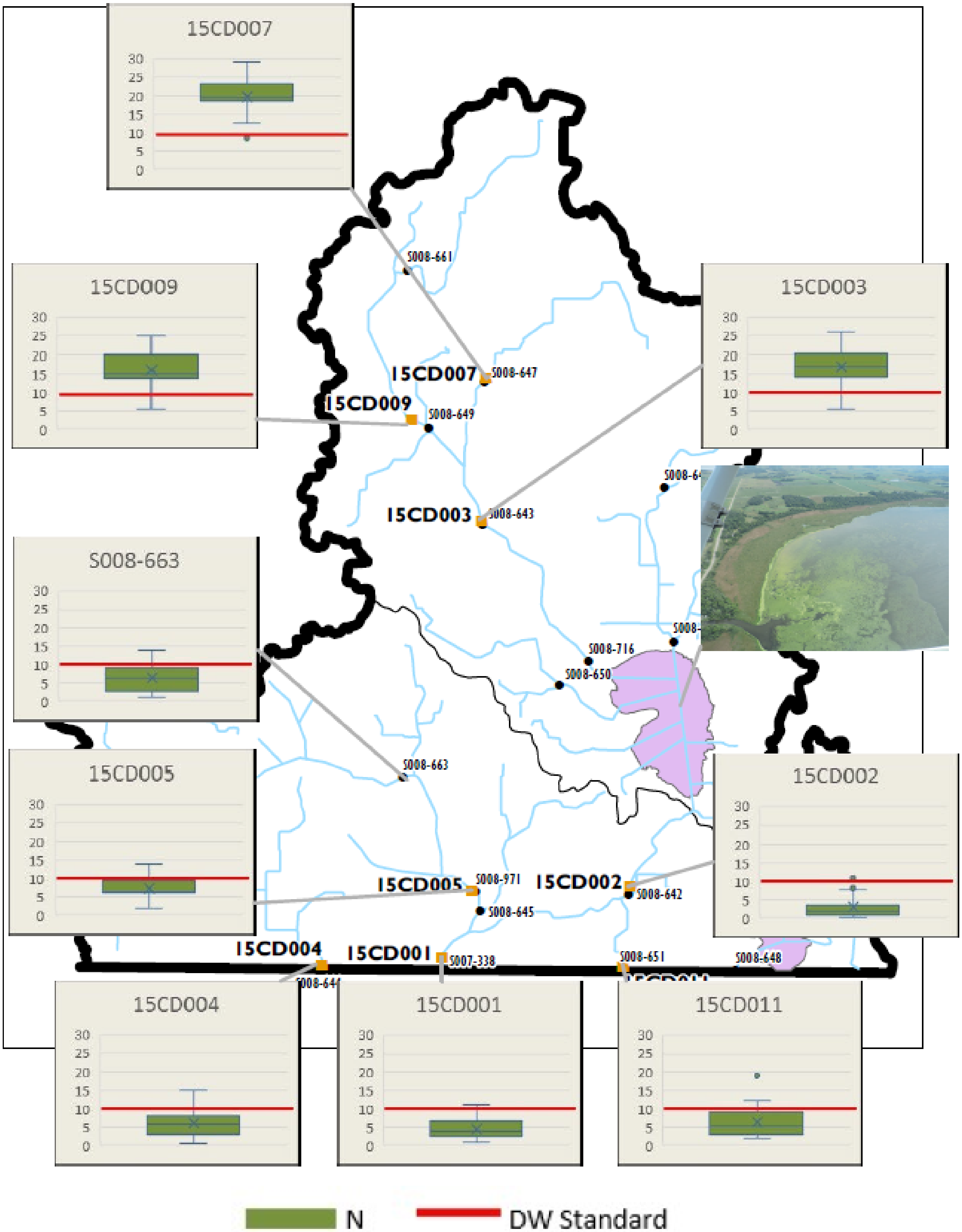


Figure 7: Nitrate concentrations (mg/L) across the Winnebago River Watershed in 2016. The drinking water (DW) standard was included to provide context to the sample values. The photo of Bear Lake is from 2014, courtesy of DNR.

Taxa richness of Trichoptera (TrichopteraCh) was at or below the statewide median of stations meeting the MIBI threshold at all stations (Table 10). Relative abundance of non-hydropsychid Trichoptera individuals (TrichwoHydroPct) was below the median at all stations above Bear Lake, while stations below the lake were a little more mixed. There were 0 to 1 nitrate intolerant taxa throughout the watershed, and 14 to 33 nitrate tolerant taxa comprising 17% to 94% of the community. In general, there were more nitrate tolerant individuals above Bear Lake. The macroinvertebrate nitrate index scores were worse than the median above the lake, but a little more mixed below the lake. Nitrate index scores ranged from 3.7 to 4.2 above the lake, and 2.4 to 4.5 below the lake. Overall, a majority of the macroinvertebrate metrics are indicative of nitrate stress. Stronger signals of nitrate stress exist on the biologically impaired AUID upstream of Bear Lake (AUID 504), compared to the two biologically impaired AUIDs below the lake (AUID 501 and 515) which have much more mixed results.

Table 10: Macroinvertebrate metrics that respond to nitrate stress in the Winnebago River Watershed compared to the statewide median of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

↑	Station (Year Sampled)	AUID	Nitrate Index Score	Nitrate Intolerant Taxa	Nitrate Intolerant Pct	Nitrate Tolerant Taxa	Nitrate Tolerant Pct	TrichopteraCh	TrichwoHydroPct
	15CD007 (2015)	505	**3.7**	**0**	**0.0**	**25**	**85.8**	**3**	**1.3**
	15CD009 (2015)	504	**4.2**	0	**0.0**	**22**	**94.3**	**1**	**0.3**
	15CD009 (2016)		**4.1**	0	**0.0**	**22**	**87.2**	**1**	**1.6**
	15CD003 (2015)		**4.2**	0	**0.0**	**21**	**63.5**	**2**	**0.6**
	15CD003 (2015)		**4.1**	1	**0.3**	**25**	**77.3**	**2**	**1.0**
	15CD003 (2016)		**4.2**	**0**	**0.0**	**33**	**78.8**	**3**	**2.5**
Bear Lake									
↓	15CD001 (2015)	501	2.9	1	**0.3**	19	42.6	**2**	**0.9**
	15CD001 (2016)		2.6	**0**	**0.0**	14	19.9	**1**	3.2
	15CD002 (2016)		2.4	**0**	**0.0**	16	16.7	**3**	**0.9**
	15CD004 (2015)	509	**4.5**	**0**	**0.0**	**24**	**81.7**	**3**	4.3
	15CD004 (2016)		3.0	1	**0.9**	19	54.6	**3**	**1.8**
	15CD005 (2015)	515	**3.8**	1	1.3	**24**	51.9	4	5.4
	15CD005 (2016)		**4.4**	**0**	**0.0**	19	**63.5**	**3**	9.9
	15CD005 (2016)		**3.3**	**0**	**0.0**	19	43.8	**2**	5.0
	15CD011 (2015)	503	2.7	**0**	**0.0**	19	27.4	**0**	**0.0**
	Prairie Streams Median		*3.2*	*1*	*1.0*	*19*	*56.7*	*4*	*2.9*
	Expected response to stress		↑	↓	↓	↑	↑	↓	↓

Nitrate concentrations are elevated in the Winnebago River Watershed, particularly upstream of Bear Lake on Steward Creek. AUID 504 (stations 15CD003 and 15CD009), which is upstream of Bear Lake, has elevated nitrate index scores, very few nitrate intolerant taxa, and several nitrate tolerant taxa that comprise a high percentage of the overall macroinvertebrate community. Nitrate is a stressor in AUID 504. AUID 501 (stations 15CD001 and 15CD002), which is directly downstream of Bear Lake, has very few nitrate intolerant taxa, but the nitrate index scores and percentage of nitrate tolerant individuals are much lower than the median. Nitrate is not a stressor in AUID 501. AUID 515 (station 15CD005), which is a tributary to AUID 501, has mixed biological response. This AUID has elevated nitrate index scores and very few nitrate intolerant taxa, but nitrate tolerant individuals were moderate and trichoptera were present in good numbers. Nitrate is inconclusive as a stressor in AUID 515.

Eutrophication

Total phosphorus (TP) concentrations during fish sampling in 2015 and 2016 ranged from 0.034 to 0.372 mg/L (average of 0.118 mg/L); 3 of these 13 samples exceeded the river eutrophication standard for the South Region (0.150 mg/L). Additional samples were collected as part of SID in 2016, from February through October with a goal to sample various flow conditions and establish a range of TP concentrations (Table 11 and Figure 9). Exceedances of the TP standard occurred above and below Bear Lake. TP concentrations at three stations (15CD007, 15CD009, and 15CD003) upstream of Bear Lake on Steward Creek and County Ditch 48 ranged from 0.038 to 0.211 mg/L. Averages at these stations ranged from 0.082 to 0.126 mg/L. TP concentrations at six stations (S008-663, 15CD005, 15CD004, 15CD001, 15CD011, and 15CD002) below Bear Lake (not necessarily connected to the lake) ranged from 0.023 to 0.404 mg/L. Averages at these stations ranged from 0.043 to 0.223 mg/L. There were 6 (18%) exceedances above the lake, and 23 (35%) below. Exceedances occurred across various months and flow conditions. Station 15CD001 had 10 additional samples collected in 2015 as part of the MPCA IWM process; these samples are not included in the statistics above or tables and figure below, but ranged from 0.05 to 0.128 mg/L (average of 0.097 mg/L). All stations on biologically impaired AUIDs had TP exceedances documented except station 15CD005 (AUID 515), and most have good photographic evidence of productivity (Figure 8).

In general, DOP (Dissolved Orthophosphate Phosphorus) was the dominant form of phosphorus at most stations, except the two stations (15CD002 and 15CD001) directly downstream of Bear Lake on Lime Creek. Phosphorus in the particulate form dominated these stations, which can likely be attributed to primary productivity in the lake; export of algae and other organic matter would increase particulate phosphorus. Water from State Line Lake and the Emmons Wastewater Treatment Plant (WWTP) effluent eventually flow past stations 15CD011 and 15CD001, and are also sources of phosphorus. Monthly average phosphorus concentrations of the Emmons effluent from 2008 through 2016 ranged from 0.23 to 7.83 mg/L (average of 2.93 mg/L). Samples were collected downstream of State Line Lake, and upstream and downstream of the Emmons WWTP effluent in an attempt to quantify nutrient contributions. Minimal samples were collected in the summer of 2017 (one in July and one in August), but elevated TP, chl-*a*, and Biological Oxygen Demand (BOD) were observed below State Line Lake (above Emmons WWTP). In general, TP was elevated and increased downstream of the Emmons effluent, and minimal changes occurred in chl-a concentrations. BOD increased and one exceedance was observed. Both State Line Lake and Emmons WWTP are nutrient sources, but additional sampling is recommended to better understand their contributions.

Both lakes are impaired due to excess nutrients (eutrophication), and appear to be a source of phosphorus at certain times of year. TP samples collected from 1994 through 2016 at various locations in Bear Lake ranged from 0.069 to 0.644 mg/L (average of 0.243 mg/L). TP samples collected from 1979 through 2016 at various locations in State Line Lake ranged from 0.113 to 1.01 mg/L (average of 0.434 mg/L). Drawdowns and rotenone treatments have been conducted on both lakes in an attempt to remove carp (and other rough fish), and improve habitat and water quality. The carp in both lakes are believed to be playing a role in the degraded conditions (personal communication with DNR 2017). A recent study on a shallow lake in Minnesota (Kohlman Lake) found that the "increase in sediment mixing depth caused by carp increased the amount of mobile P potentially available for release by 55% to 92%" (Huser et al. 2015). Both lakes also experience occasional winterkills. In addition to the lakes, there is a wetland just south of State Line Lake in Iowa that has potential to be a source of nutrients.

Chlorophyll–*a* (Chl-*a*), BOD, DO flux, and pH flux are also considered when evaluating eutrophication stress. Chl-*a* and BOD samples were collected throughout the watershed in July and August 2016 (Table 12). A total of 27 samples (three per site) were collected for each parameter. Chl-a samples ranged from 1.3 to 197.0 µg/L, and there were eight (30%) exceedances of the standard for the South Region (35 µg/L). All but one exceedance was located below Bear Lake at stations 15CD001, 15CD002, and 15CD011; stations 15CD001 and 15CD002 are downstream of the mouth and all samples exceeded the standard. Station 15CD011 had one exceedance; this station receives water from State Line Lake and the Emmons WWTP. The one exceedance upstream of Bear Lake was at station 15CD003. Forty-six chl-*a* samples collected from 1994 through 2016 at various locations in Bear Lake ranged from 1 to 278 µg/L (average of 102.7 µg/L). BOD samples ranged from 0.5 to 13.0 mg/L, and there were nine (33%) exceedances of the standard for the South Region (3 mg/L). All exceedances were below Bear Lake at stations 15CD001, 15CD002, and 15CD011; all samples at each site were above the standard. Daily DO flux exceeded the standard (4.5 mg/L) at all stations, ranging from 1.9 through 13.7 mg/L (see Table 15 in DO section). Also, low DO was frequently observed throughout the watershed, which can be a product of eutrophication. The pH values collected during sonde deployments ranged from 6.5 to 8.9, all of which are at or within the standard. However, pH flux was elevated, supporting the case for eutrophication. Typical daily pH fluctuations are 0.2 to 0.3 (Heiskary et al. 2013); most stations had values exceeding this range.

Table 11: TP concentrations (mg/L) across the Winnebago River Watershed. Stations on left side of table are located above Bear Lake, and stations on right side of table are located below Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow).

TP (mg/L)	15CD007	15CD009	15CD003	←U.S. of Bear Lake D.S. of Bear Lake→	S008-663	15CD005	15CD004	15CD001	15CD011	15CD002
Min	0.038	0.038	0.049		0.037	0.023	0.036	0.069	0.140	0.045
Max	0.211	0.198	0.198		0.134	0.057	0.153	0.257	0.404	0.391
Average	0.126	0.082	0.094		0.068	0.043	0.067	0.167	0.223	0.190
Count	11	11	11		11	10	11	11	11	11

Table 12: TP, chl-a, and BOD samples in the Winnebago River Watershed. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Exceedances are highlighted in red font.

TP (mg/L)/**chl-a** (µg/L)/**BOD** (mg/L)	15CD007		15CD009		15CD003	
7/6/2016	0.118/23.9/1.6		0.054/26.0/1.3		0.056/61.8/2.0	
7/25/2016	0.126/1.5/0.5		0.097/1.3/0.5		0.11/1.3/0.5	
8/17/2016	0.183/2.9/1.6		0.059/2.5/1.3		0.088/2.5/1.3	
Bear Lake						
	S008-663	15CD005	15CD004	15CD001	15CD011	15CD002
7/6/2016	0.039/18.0/1.2	0.044/2.8/1.2	0.044/2.6/0.8	0.247/124.0/12.0	0.201/3.1/4.0	0.323/197.0/13.0
7/25/2016	0.076/2.2/0.7	0.057/2.1/0.8	0.115/1.9/0.7	0.21/89.2/5.3	0.232/79.8/6.1	0.238/70.0/7.6
8/17/2016	0.058/2.9/1.2	0.045/6.6/1.4	0.05/6.5/1.2	0.155/40.1/4.3	0.282/33.1/7.2	0.237/99.3/7.0

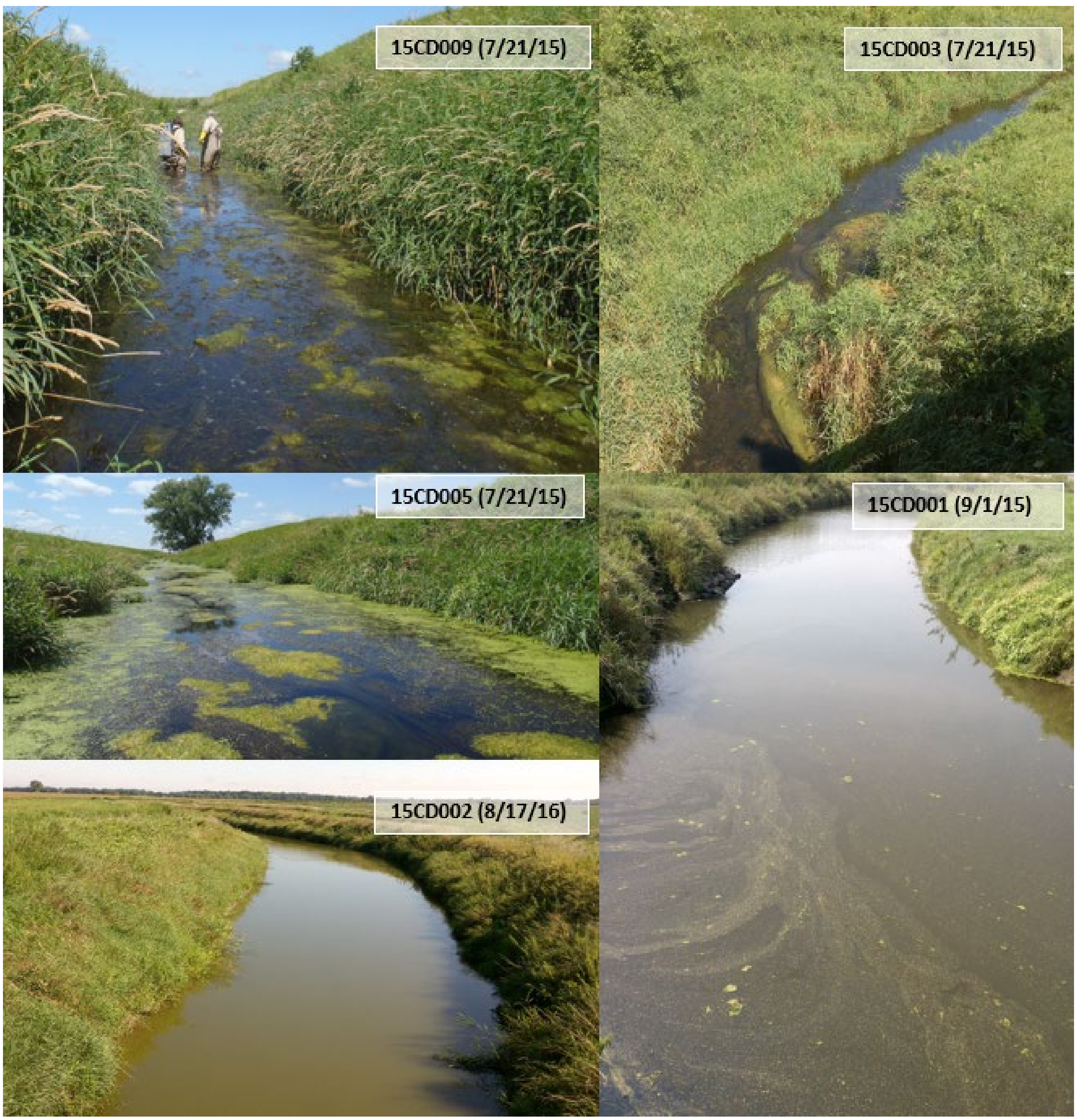


Figure 8: Examples of primary productivity in biologically impaired stations in the Winnebago River Watershed.

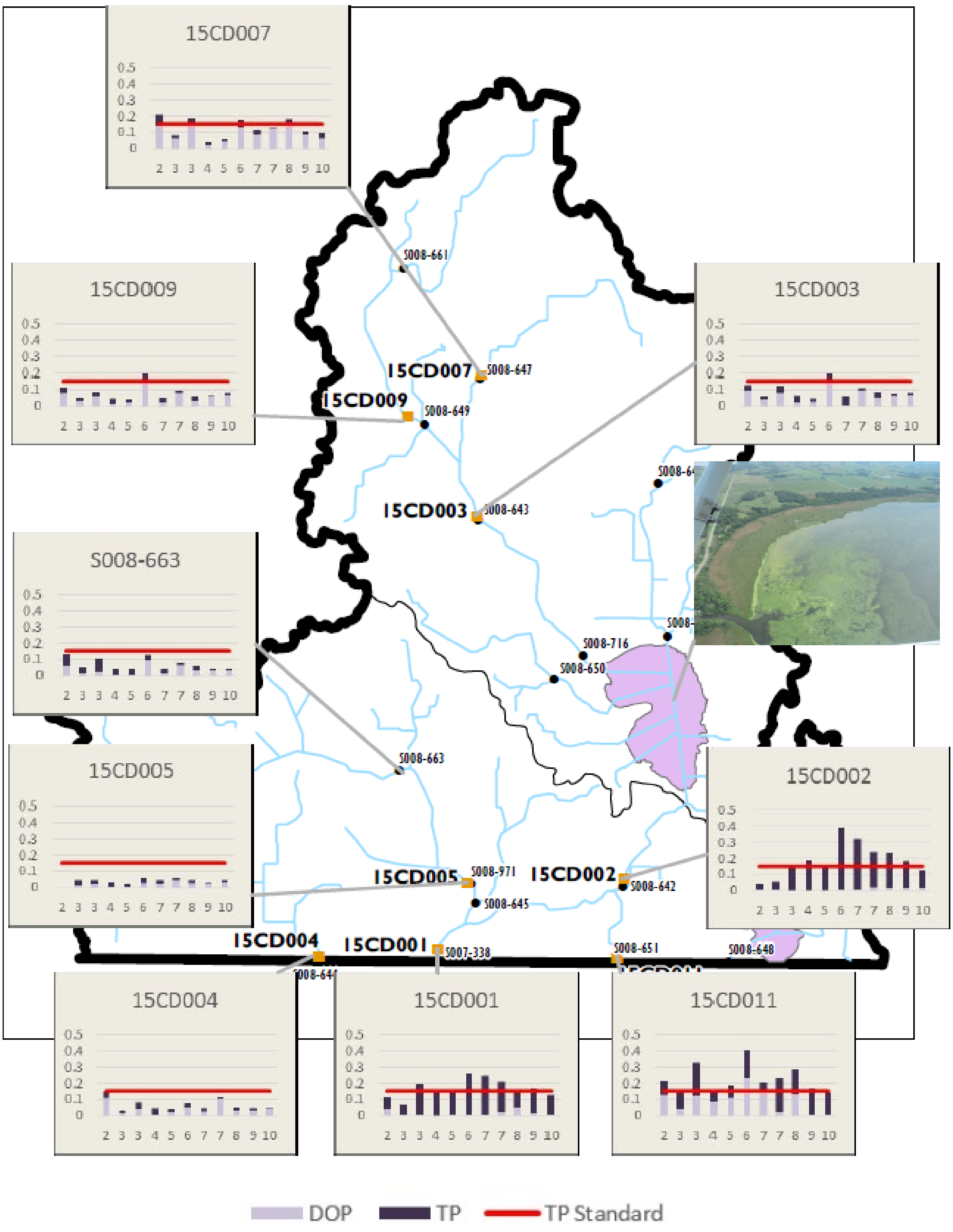


Figure 9: TP and DOP concentrations (mg/L) across the Winnebago Watershed in 2016. Numbers along the x-axis represent the month in which the sample was collected. The photo of Bear Lake is from 2014, courtesy of DNR.

A majority of the macroinvertebrate metrics were worse than the statewide median of stations meeting the MIBI threshold (Table 13). Taxa richness of collector-filterers (Collector-filtererCh) and Ephemeroptera, Plecoptera, and Trichoptera (EPT) were below the median at all stations. Taxa richness of collector-gatherers (Collector-gathererCh) was more mixed, with some below the median and some above. There were 0 to 1 phosphorus intolerant taxa throughout the watershed comprising 0% to 1% of the community, and 8 to 24 phosphorus tolerant taxa comprising 13% to 87% of the community. In general, most of the stations were dominated by phosphorus tolerant individuals, and there were higher percentages below Bear Lake. The macroinvertebrate phosphorus index scores were worse than the median at all stations. Phosphorus index scores ranged from 0.138 to 0.163 above the lake, and 0.143 to 0.187 below the lake.

Table 13: Macroinvertebrate metrics that respond to eutrophication stress in the Winnebago River Watershed compared to the statewide median of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled)	AUID	Phosphorus Index Score	Phosphorus Intolerant Taxa	Phosphorus Intolerant Pct	Phosphorus Tolerant Taxa	Phosphorus Tolerant Pct	Collector-filtererCh	Collector-gathererCh	EPT
↑	15CD007 (2015)	505	**0.151**	**0**	**0.0**	**14**	**59.5**	**4**	**11**	**5**
	15CD009 (2015)	504	**0.147**	0	**0.0**	8	15.8	**0**	13	**3**
	15CD009 (2016)		**0.138**	0	**0.0**	**14**	12.5	**2**	15	**3**
	15CD003 (2015)		**0.151**	0	**0.0**	**13**	**41.7**	**2**	15	**4**
	15CD003 (2015)		**0.163**	0	**0.0**	**15**	**49.2**	**0**	**10**	**4**
	15CD003 (2016)		**0.149**	**1**	**0.3**	**18**	**36.7**	**4**	20	**6**
Bear Lake										
↓	15CD001 (2015)	501	**0.168**	**0**	**0.0**	**22**	**72.4**	**1**	**11**	**3**
	15CD001 (2016)		**0.183**	**0**	**0.0**	**15**	**87.3**	**0**	**8**	**2**
	15CD002 (2016)		**0.187**	**0**	**0.0**	**24**	**86.6**	**1**	13	**5**
	15CD004 (2015)	509	**0.143**	**1**	**0.3**	10	23.2	**4**	15	**5**
	15CD004 (2016)		**0.160**	**0**	**0.0**	**13**	**70.7**	**3**	**12**	**4**
	15CD005 (2015)	515	**0.167**	**1**	1.3	**16**	**62.2**	**2**	**12**	**6**
	15CD005 (2016)		**0.161**	**0**	**0.0**	11	**54.5**	**1**	**12**	**5**
	15CD005 (2016)		**0.165**	**0**	**0.0**	**16**	**70.6**	**1**	14	**5**
	15CD011 (2015)	503	**0.153**	**0**	**0.0**	8	**63.1**	**1**	**10**	**2**
	Prairie Streams Median		*0.137*	*1.5*	*1.1*	*11*	*29.8*	*5*	*13*	*8*
	Expected response to stress		↑	↓	↓	↑	↑	↓	↓	↓

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 14). Relative abundance of individuals that are darter species (DarterPct), simple lithophilic spawners (SLithopPct), omnivore species (OmnivorePct), and tolerant species (TolPct) were all worse than average at stations 15CD009 (2016), 15CD001, 15CD002, and 15CD005. All stations except 15CD011 had elevated numbers of tolerant individuals, and omnivores were worse than average at all stations except 15CD007. In general, all metrics and stations scored poorly across the watershed.

Table 14: Fish metrics that respond to eutrophication stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	DarterPct	SLithopPct	OmnivorePct	TolPct
↑	15CD007 (2015) (3)	505	**0.0**	35.5	12.8	**100.0**
	15CD009 (2015) (3)	504	**1.7**	73.0	**73.0**	**96.5**
	15CD009 (2016) (3)		**2.6**	**29.4**	**54.4**	**80.9**
	15CD003 (2015) (7)		23.7	**13.8**	**63.2**	**71.2**
	15CD003 (2016) (7)		23.0	24.4	**35.9**	**76.0**
Bear Lake						
	15CD001 (2015) (2)	501	**1.5**	**2.4**	**93.3**	**90.7**
	15CD001 (2016) (2)		**1.0**	**6.0**	**51.1**	**85.5**
	15CD002 (2015) (2)		**0.6**	**7.7**	**77.4**	**80.2**
	15CD002 (2016) (2)		**0.0**	**0.0**	**78.8**	**98.0**
	15CD004 (2015) (3)	509	**0.5**	49.7	**49.2**	**99.5**
↓	15CD005 (2015) (7)	515	**0.0**	**0.0**	**47.6**	**100.0**
	15CD011 (2015) (3)	503	23.5	**26.1**	**47.2**	68.0
	Southern Streams Average (Ditched Channel) (2)		13.3	25.7	25.1	45.5
	Southern Headwaters Average (Ditched Channel) (3)		10.4	30.4	19.6	76.5
	Low Gradient Average (Ditched Channel) (7)		*6.7*	*21.0*	*16.8*	*55.9*
	Expected response to stress		↓	↓	↑	↑

In general, the Winnebago River Watershed is rich with nutrients and primary productivity. Elevated phosphorus, chl-*a*, and BOD concentrations have been documented throughout the watershed, with a majority of exceedances occurring on reaches downstream of lakes (Bear and State Line) and the Emmons WWTP; both lakes and AUID 501 are impaired due to excess nutrients (eutrophication). The excess nutrients and productivity are impacting the DO conditions, as low DO and elevated daily DO flux is common throughout the watershed. The fish and macroinvertebrates appear negatively impacted, as most metrics are worse than the median/average. Although elevated water column phosphorus has not been documented at all stations (station 15CD005 in particular), good photo documentation of eutrophication exists as well as an altered DO regime. It's possible in those scenarios that ditch sediments are supplying phosphorus and/or a good portion of the phosphorus is tied up in the plants/algae. These situations may require further research and understanding in order to develop appropriate restoration strategies. It should also be noted that Bear Lake and State Line Lake are having significant impacts on AUID 501. Eutrophication is a stressor in all biologically impaired AUIDs (501, 504, and 515).

Dissolved Oxygen

Multiple YSI sondes were deployed throughout the watershed in 2015 and 2016. Low DO was observed frequently, and was below the 5 mg/L standard at all stations where deployment occurred (Table 15 and Figure 10). DO ranged from 0.5 to 18.2 mg/L, and standard exceedance ranged from 5% to 71%. In addition to exceedances observed during deployment, there were many exceedances documented across the watershed via instantaneous (point) measurements. Daily DO flux also exceeded the standard (4.5 mg/L) at all stations, ranging from 1.9 to 13.7 mg/L. All biologically impaired AUIDs also have DO impairments.

Table 15: DO concentrations and daily DO flux for sonde deployments in the Winnebago River Watershed in 2015 and 2016. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow).

	Station (Year Sampled)	AUID	DO Min (mg/L)	DO Max (mg/L)	%Exceedance of Standard (5 mg/L)	Daily DO Flux Min (mg/L)	Daily DO Flux Max (mg/L)
↑	15CD009 (2015)	504	2.1	10.0	41.4	4.7	6.6
	15CD003 (2016)		4.3	15.3	5.0	1.9	10.9
Bear Lake							
↓	15CD001 (2015)	501	1.8	18.2	33.2	3.7	13.7
	15CD002 (2016)		4.3	15.0	10.3	2.7	9.8
	15CD004 (2015)	509	2.5	10.9	44.6	4.2	6.9
	*15CD005 (2015)	511	0.5	11.9	70.6	3.6	10.6
	15CD005 (2016)	515	2.7	10.1	52.7	2.2	7.4

***Sonde deployment was downstream of station 15CD005.**

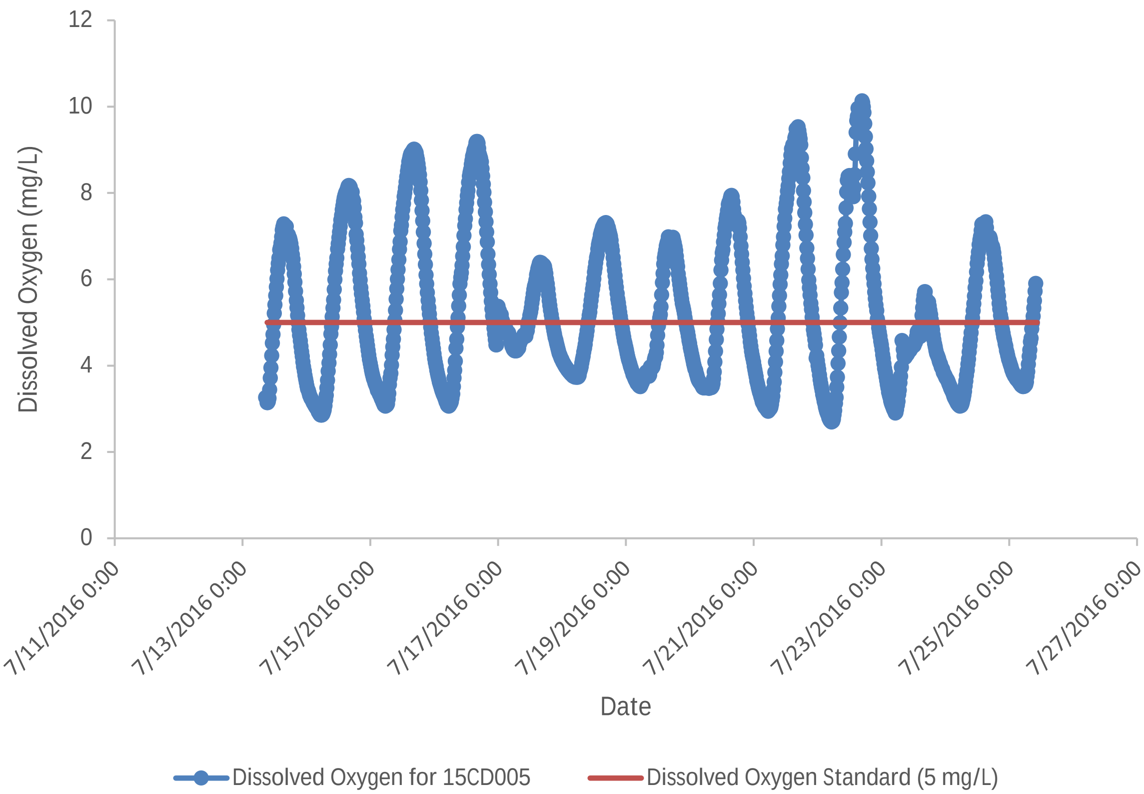


Figure 10: Example of DO conditions (low DO and elevated DO flux) in the Winnebago River Watershed. This data is from a sonde deployment at station 15CD005 in 2016.

Nearly all of the macroinvertebrate metrics were worse than the statewide median of stations meeting the MIBI threshold (Table 16). Taxa richness of EPT was below the median at all stations. There were 0 to 3 low DO intolerant taxa throughout the watershed comprising 0% to 2% of the community, and 3 to 18 low DO tolerant taxa comprising 25% to 90% of the community. There were numerous low DO tolerant individuals across the watershed, with higher percentages below Bear Lake. The macroinvertebrate low DO index scores were worse than the median at all stations. Low DO index scores ranged from 6.1 to 6.7 above the lake, and 5.7 to 6.5 below the lake. All macroinvertebrate metrics on biologically impaired AUIDs were worse than the median.

Table 16: Macroinvertebrate metrics that respond to DO stress in the Winnebago River Watershed compared to the statewide median of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled)	AUID	Low DO Index Score	Low DO Intolerant Taxa	Low DO Intolerant Pct	Low DO Tolerant Taxa	Low DO Tolerant Pct	EPT
↑	15CD007 (2015)	505	**6.2**	**3**	**2.3**	**11**	**53.4**	**5**
	15CD009 (2015)	504	**6.7**	1	**0.3**	**7**	**42.1**	**3**
	15CD009 (2016)		**6.4**	0	**0.0**	**10**	**33.9**	**3**
	15CD003 (2015)		**6.4**	1	**0.3**	**11**	**37.7**	**4**
	15CD003 (2015)		**6.1**	1	**0.3**	**9**	**47.0**	**4**
	15CD003 (2016)		**6.4**	**2**	**1.6**	**9**	**31.6**	**6**
Bear Lake								
↓	15CD001 (2015)	501	**6.1**	**0**	**0.0**	**17**	**76.7**	**3**
	15CD001 (2016)		**6.0**	**0**	**0.0**	**15**	**89.6**	**2**
	15CD002 (2016)		**5.7**	**1**	**0.6**	**18**	**84.2**	**5**
	15CD004 (2015)	509	**6.5**	**2**	**0.6**	**7**	**25.1**	**5**
	15CD004 (2016)		**6.1**	**0**	**0.0**	**7**	**70.7**	**4**
	15CD005 (2015)	515	**6.1**	**0**	**0.0**	**12**	**59.6**	**6**
	15CD005 (2016)		**6.3**	**0**	**0.0**	**9**	**54.5**	**5**
	15CD005 (2016)		**6.0**	**0**	**0.0**	**12**	**67.8**	**5**
	15CD011 (2015)	503	**6.4**	**3**	**1.5**	3	**60.9**	**2**
	Prairie Streams Median		*6.9*	*4*	*5.2*	*6*	*10.4*	*8*
	Expected response to stress		↓	↓	↓	↑	↑	↓

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 17). Relative abundance of individuals with a female mature age greater than or equal to three (MA>3Pct), serial spawning species (SSpnPct), and tolerant species (TolPct) were all worse than average at stations 15CD007, 15CD001, 15CD002 (2016), and 15CD005. In general, late maturing individuals scored better above Bear Lake than below, and tolerant fish species dominated the watershed. Low DO index scores and probability of meeting the DO standard was below average at all stations except 15CD007 and 15CD009. The fish community shows signs of low DO stress, with a stronger signal below Bear Lake; all stations with fish impairments (15CD001, 15CD002, and 15CD005) appear stressed by low DO.

Table 17: Fish metrics that respond to DO stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	Low DO Index Score (RA)	Probability of meeting DO std.	MA>3Pct	SSpnPct	TolPct
↑	15CD007 (2015) (3)	505	7.3	0.59	**0.7**	**12.8**	**100.0**
	15CD009 (2015) (3)	504	**7.1**	0.51	66.1	6.1	**96.5**
	15CD009 (2016) (3)		**6.8**	**0.37**	37.5	**32.0**	**80.9**
	15CD003 (2015) (7)		**6.5**	**0.26**	16.9	**50.8**	**71.2**
	15CD003 (2016) (7)		**6.9**	**0.41**	13.4	24.4	**76.0**
	Bear Lake						
↓	15CD001 (2015) (2)	501	**6.1**	**0.15**	**14.9**	**42.2**	**90.7**
	15CD001 (2016) (2)		**6.5**	**0.26**	**3.2**	**73.8**	**85.5**
	15CD002 (2015) (2)		**5.9**	**0.11**	**15.1**	12.6	**80.2**
	15CD002 (2016) (2)		**6.3**	**0.20**	**1.0**	**81.4**	**98.0**
	15CD004 (2015) (3)	509	**6.5**	**0.27**	45.2	3.5	**99.5**
	15CD005 (2015) (7)	515	**5.8**	**0.10**	**0.0**	**28.6**	**100.0**
	15CD011 (2015) (3)	503	**6.7**	**0.35**	**7.5**	**41.3**	68.0
	Southern Streams Average (Ditched Channel) (2)		*7.2*	*0.45*	*27.6*	*26.5*	*45.5*
	Southern Headwaters Average (Ditched Channel) (3)		*7.2*	*0.45*	*13.9*	*11.2*	*76.5*
	Low Gradient Average (Ditched Channel) (7)		*7.1*	*0.44*	*10.1*	*28.3*	*55.9*
	Expected response to stress		↓	↓	↓	↑	↑

Low DO and elevated DO flux occur frequently in the Winnebago River Watershed. These conditions are reflected in the fish and macroinvertebrate communities, as low DO tolerant individuals dominate most stations. Low DO is a stressor in all biologically impaired AUIDs (501, 504, and 515).

TSS

TSS concentrations during fish sampling in 2015 and 2016 ranged from 1.2 to 97 mg/L (average of 17.3 mg/L); 1 of these 13 samples exceeded the TSS standard for the South Region (65 mg/L). Additional samples were collected as part of SID in 2016, from February through October with a goal to sample various flow conditions and establish a range of TSS concentrations (Table 18 and Figure 11). In general, concentrations were low across the watershed with only a few exceedances of the TSS standard. TSS concentrations at three stations (15CD007, 15CD009, and 15CD003) upstream of Bear Lake on Steward Creek and County Ditch 48 ranged from 2.4 to 55 mg/L. Averages at these stations ranged from 9.4 to 16 mg/L. TSS concentrations at six stations (S008-663, 15CD005, 15CD004, 15CD001, 15CD011, and 15CD002) below Bear Lake (not necessarily connected to the lake) ranged from 1 to 95 mg/L. Averages at these stations ranged from 3.6 to 49.5 mg/L. The four exceedances occurred at stations 15CD002 and 15CD011; each station had two exceedances. Exceedances took place in March, April, and June (2), with most during elevated flows. Bear Lake appears to be a source of TSS, as concentrations are noticeably higher at stations 15CD002 and 15CD001, which are just downstream of the outlet (although not as distinct, State Line Lake is likely contributing TSS to station 15CD001). Algae and other organic matter as a result of elevated primary productivity in the lake are likely sources of the higher TSS; Total Suspended Volatile Solids (TSVS) is a large fraction of the TSS at these two sites, supporting this notion (Table 19). The elevated chl-*a* concentrations (see eutrophication section) below Bear Lake are also supporting evidence. Station 15CD001 had 10 additional samples collected in 2015 as part of the MPCA IWM process; these samples are not included in the statistics above or tables and figure below, but ranged from 7.2 to 57 mg/L (average of 31 mg/L). The only TSS exceedances on biologically impaired AUIDs occurred at station 15CD002 (AUID 501).

Table 18: TSS concentrations (mg/L) across the Winnebago River Watershed. Stations on left side of table are located above Bear Lake, and stations on right side of table are located below Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow).

TSS (mg/L)	15CD007	15CD009	15CD003	←U.S. of Bear Lake D.S. of Bear Lake→	S008-663	15CD005	15CD004	15CD001	15CD011	15CD002
Min	2.4	3.6	5.6		1.6	1	1	10	5.2	3.2
Max	55	18	29		27	8.4	10	65	73	95
Average	16.0	9.4	11.1		8.5	4.7	3.6	36.4	23.4	49.5
Count	11	11	11		11	10	11	11	11	11

Table 19: TSS (mg/L) and TSVS (mg/L and %) comparison between stations 15CD003 and 15CD002; station 15CD003 is just upstream of Bear Lake and station 15CD002 is just downstream of Bear Lake. TSVS percentages were higher on all sampling dates at station 15CD002, highlighting the organic contribution from Bear Lake.

TSS (mg/L)/TSVS (mg/L)/TSVS (%)	**15CD003**			←U.S. of Bear Lake D.S. of Bear Lake→	**15CD002**		
Date	TSS (mg/L)	TSVS (mg/L)	TSVS (%)		TSS (mg/L)	TSVS (mg/L)	TSVS (%)
2/22/2016	16.0	3.2	20.0		3.2	3.2	100.0
3/9/2016	5.6	2.8	50.0		7.6	5.6	73.7
3/31/2016	14.0	1.6	11.4		59.0	16.0	27.1
4/26/2016	16.0	4.4	27.5		95.0	29.0	30.5
5/23/2016	6.8	2.4	35.3		53.0	26.0	49.1
6/15/2016	29.0	5.6	19.3		73.0	39.0	53.4
7/6/2016	6.8	4.0	58.8		61.0	38.0	62.3
7/25/2016	6.8	2.0	29.4		64.0	24.0	37.5
8/17/2016	6.8	2.4	35.3		43.0	22.0	51.2
9/15/2016	6.0	2.0	33.3		44.0	21.0	47.7
10/11/2016	8.8	2.4	27.3		42.0	17.0	40.5

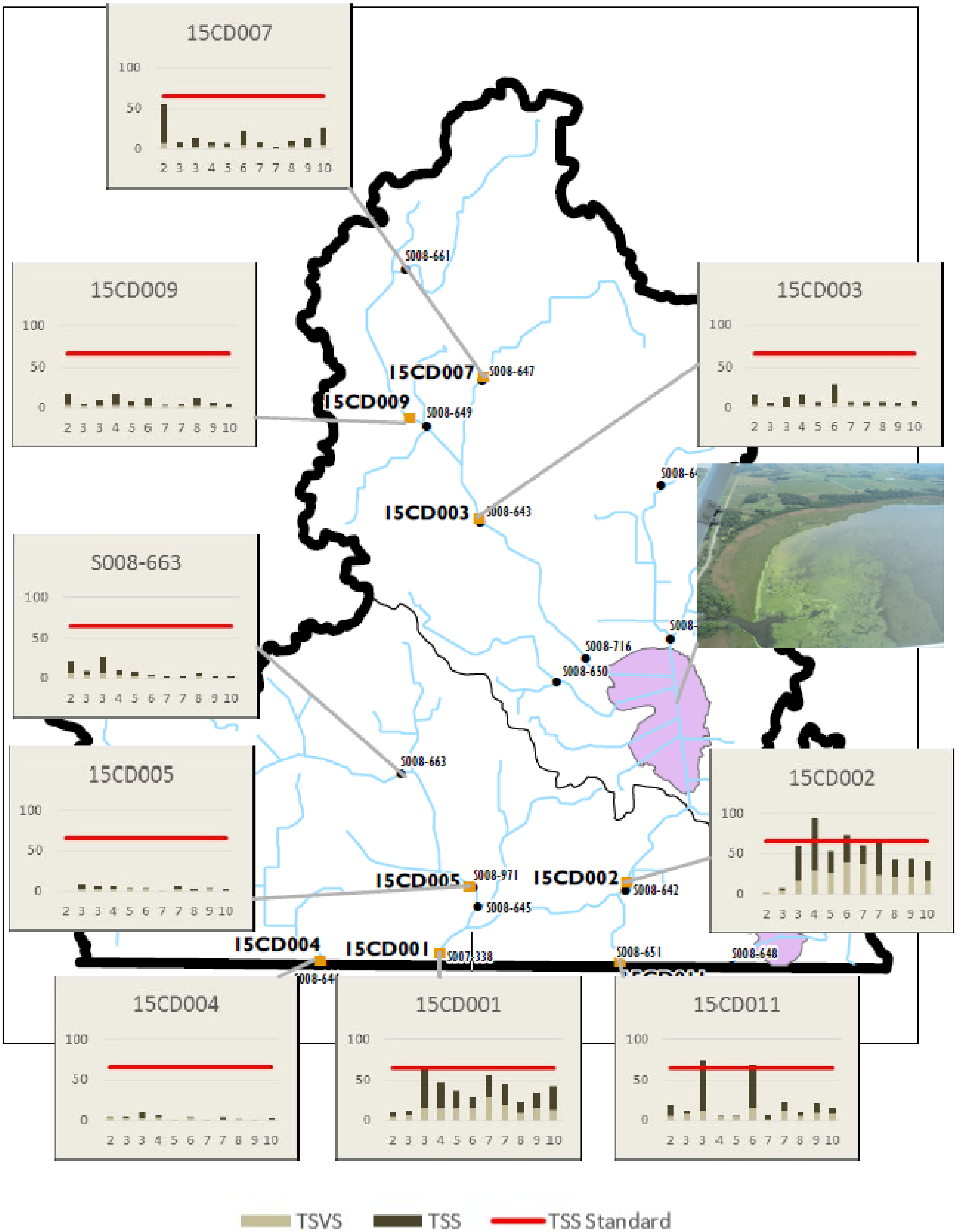


Figure 11: TSS and TSVS concentrations (mg/L) across the Winnebago River Watershed in 2016. Numbers along the x-axis represent the month in which the sample was collected. The photo of Bear Lake is from 2014, courtesy of DNR.

The macroinvertebrate metrics were mixed; some were above the statewide median of stations meeting the MIBI threshold and some were below (Table 20). Relative abundance of collector-filterer individuals (Collector-filtererPct) was below the median at all stations. Relative abundance of Plecoptera individuals (PlecopteraPct) was zero at all stations. There were 0 to 1 TSS intolerant taxa throughout the watershed comprising 0% to 1% of the community, and 5 to 17 TSS tolerant taxa comprising 11% to 65% of the community. In general, there were limited TSS tolerant individuals. The macroinvertebrate TSS index scores were better than the median at all stations above Bear Lake, and more mixed at stations below. TSS index scores ranged from 14.8 to 17.0 above the lake, and 15.3 to 21.1 below the lake. The macroinvertebrates don't appear impacted by TSS stress on AUID 504 (stations 15CD003 and 15CD009) and 515 (station 15CD005), but do appear affected on AUID 501 (stations 15CD001 and 15CD002).

Table 20: Macroinvertebrate metrics that respond to TSS stress in the Winnebago River Watershed compared to the statewide median of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled)	AUID	TSS Index Score	TSS Intolerant Taxa	TSS Intolerant Pct	TSS Tolerant Taxa	TSS Tolerant Pct	Collector-filtererPct	PlecopteraPct
↑	15CD007 (2015)	505	15.4	**0**	**0.0**	10	14.6	**4.2**	0.0
	15CD009 (2015)	504	15.2	**0**	**0.0**	7	13.3	**0.0**	0.0
	15CD009 (2016)		14.8	**0**	**0.0**	9	13.7	**0.6**	0.0
	15CD003 (2015)		16.0	**0**	**0.0**	11	33.7	**3.7**	0.0
	15CD003 (2015)		17.0	**0**	**0.0**	5	21.5	**0.0**	0.0
	15CD003 (2016)		15.6	**0**	**0.0**	**14**	19.0	**8.3**	0.0
Bear Lake									
↓	15CD001 (2015)	501	**17.7**	**0**	**0.0**	12	27.3	**0.9**	0.0
	15CD001 (2016)		**21.1**	**0**	**0.0**	10	**64.6**	**0.0**	0.0
	15CD002 (2016)		**20.5**	**0**	**0.0**	**17**	**52.3**	**0.9**	0.0
	15CD004 (2015)	509	16.5	**0**	**0.0**	8	28.8	**7.4**	0.0
	15CD004 (2016)		15.6	**0**	**0.0**	8	11.3	**2.1**	0.0
	15CD005 (2015)	515	16.6	1	1.3	10	26.0	**2.2**	0.0
	15CD005 (2016)		**17.9**	**0**	**0.0**	9	36.9	**0.6**	0.0
	15CD005 (2016)		16.2	**0**	**0.0**	10	25.3	**2.8**	0.0
	15CD011 (2015)	503	15.3	**0**	**0.0**	7	11.7	**6.8**	0.0
	Prairie Streams Median		*17.0*	*1*	*0.3*	*13*	*41.7*	*13.7*	*0.0*
	Expected response to stress		↑	↓	↓	↑	↑	↓	↓

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 21). Relative abundance of individuals that are exclusively benthic feeders (BenFdFrimPct), non-tolerant Centrarchidae (Centr-TolPct), herbivore species (HrbNWQPct), intolerant species (IntolerantPct), long-lived (LLvdPct), individuals of the Order Perciformes excluding tolerant individuals (Percfm-TolPct), riffle dwelling species (RifflePct), sensitive species (SensitivePct), and simple lithophilic spawners (SLithFrimPct) were all worse than average at stations 15CD007, 15CD001, 15CD002, and 15CD005. Non-tolerant Centrarchidae and intolerant species were worse than average at all stations; there were zero intolerant species across the watershed. TSS index scores and probability of meeting the TSS standard were worse than average at all stations except 15CD004, 15CD007, and 15CD009 (2015). The fish community shows signs of TSS stress, with a stronger signal below Bear Lake. All stations with fish impairments (15CD001, 15CD002, and 15CD005) had metric values indicative of TSS stress, but it's possible some of this response is due to other stressors. This is likely the case at station 15CD005 (which has very low TSS concentrations documented); only twenty-one fish were collected, which likely skewed the metric values.

Table 21: Fish metrics that respond to TSS stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	TSS Index Score (RA)	Probability of meeting TSS std.	BenFdFrimPct	Centr-TolPct	HrbNWQPct	IntolerantPct	LLvdPct	Percfm-TolPct	RifflePct	SensitivePct	SLithFrimPct
↑	15CD007 (2015) (3)	505	15.5	0.71	**0.7**	**0.0**	**0.7**	**0.0**	**0.0**	**0.0**	**0.7**	**0.0**	**0.7**
	15CD009 (2015) (3)	504	15.6	0.70	67.8	**0.0**	67.8	**0.0**	**0.0**	**1.7**	66.1	**0.0**	66.1
	15CD009 (2016) (3)		**18.3**	**0.53**	**21.7**	**0.0**	**21.0**	**0.0**	16.9	19.1	**21.0**	**1.8**	21.0
	15CD003 (2015) (7)		**19.4**	**0.46**	12.8	**0.0**	12.6	**0.0**	**4.8**	28.3	12.3	23.2	12.3
	15CD003 (2016) (7)		**18.2**	**0.53**	26.3	**0.0**	12.4	**0.0**	**0.9**	24.0	12.4	**9.2**	12.4
	Bear Lake												
	15CD001 (2015) (2)	501	**25.8**	**0.13**	**5.2**	**0.4**	**2.8**	**0.0**	**18.0**	**3.2**	**2.4**	**0.0**	**2.4**
	15CD001 (2016) (2)		**27.5**	**0.09**	**2.7**	**2.5**	**1.0**	**0.0**	**6.5**	**4.2**	**0.7**	**0.0**	**0.7**
	15CD002 (2015) (2)		**23.5**	**0.22**	**9.6**	**4.1**	**7.3**	**0.0**	**20.2**	**12.4**	**7.5**	**0.2**	**7.3**
	15CD002 (2016) (2)		**25.6**	**0.14**	**0.0**	**0.4**	**0.1**	**0.0**	**3.9**	**0.9**	**0.0**	**0.0**	**0.0**
	15CD004 (2015) (3)	509	14.9	0.74	45.7	**0.0**	45.2	**0.0**	**0.0**	**0.5**	45.2	**0.0**	45.2
	15CD005 (2015) (7)	515	**19.4**	**0.46**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
↓	15CD011 (2015) (3)	503	**17.9**	**0.56**	**9.1**	**0.2**	**8.7**	**0.0**	**0.2**	23.7	**8.5**	23.1	**7.5**
	Southern Streams Average (Ditched Channel) (2)		*17.2*	*0.59*	*29.5*	*7.8*	*17.7*	*0.8*	*22.6*	*30.0*	*19.2*	*8.2*	*15.9*
	Southern Headwaters Average (Ditched Channel) (3)		*16.9*	*0.60*	*31.8*	*1.0*	*21.5*	*0.6*	*5.2*	*12.3*	*22.7*	*5.5*	*15.0*
	Low Gradient Average (Ditched Channel) (7)		*15.8*	*0.62*	*12.5*	*4.5*	*12.1*	*3.7*	*7.3*	*13.7*	*7.5*	*16.7*	*9.3*
	Expected response to stress		↑	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

While there are some elevated TSS readings, recent geomorphology work completed by the DNR at station 15CD001 noted that “bank erosion does not appear to be an issue at this site, and upstream sediment supply is minimal due to Bear and State Line Lakes acting as sediment sinks” (DNR 2017). Similar conditions were observed at station 15CD004; this site had “low sediment contribution from stream banks” and was “starting to develop floodplain within the ditch.”

TSS concentrations are low across the Winnebago River Watershed, with some exceptions during elevated flows and downstream of Bear Lake (AUID 501). Stream bank erosion is minimal, but eutrophic conditions in Bear Lake (and State Line Lake) appear to be contributing to the TSS concentrations as a large fraction is in the organic form. The fish and macroinvertebrate communities are suggestive of TSS stress on AUID 501 (stations 15CD001 and 15CD002). TSS is a stressor in AUID 501, and not a stressor in AUIDs 504 (stations 15CD003 and 15CD009) and 515 (station 15CD005).

Lack of Habitat

The MPCA Stream Habitat Assessment (MSHA) scores throughout the watershed ranged from 14 (“Poor”) to 55.35 (“Fair”) (Table 22). All stations except 15CD011 (2015) had “poor” MSHA scores. In general, all sub-categories (Land Use, Riparian, Substrate, Cover, and Channel Morphology) scored low to moderate. Land Use scores were zero for all stations due to the surrounding row crops. Substrate and Channel Morphology were very poor due to severe embeddedness and the predominance of sand, silt, and channelization. Runs were the dominant channel type, with very minimal pools and riffles. There was minimal bank erosion throughout the watershed (ranging from none to little). The amount of cover at stations above Bear Lake (15CD007, 15CD009, and 15CD003) ranged from sparse to extensive, with most falling in the moderate to extensive range. The amount of cover at the remaining stations (15CD001, 15CD002, 15CD004, 15CD005, and 15CD011) ranged from choking vegetation only to extensive; AUID 501 (stations 15CD001 and 15CD002) had very little cover available (nearly absent to sparse).

Table 22: MSHA scores in the Winnebago River Watershed. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled)	AUID	Land Use (5)	Riparian (14)	Substrate (28)	Cover (18)	Channel Morphology (35)	**MSHA Total (100)**
↑	15CD007 (2015)	505	0	9	5	12	7	**33 (Poor)**
	15CD007 (2015)		0	9	7	9	6	**31 (Poor)**
	15CD009 (2015)	504	0	10	5	12	3	**33 (Poor)**
	15CD009 (2015)		0	8	7	9	5	**29 (Poor)**
	15CD009 (2016)		0	10	7	11	3	**31 (Poor)**
	15CD009 (2016)		0	10.5	5	11	8	**34.5 (Poor)**
	15CD003 (2015)		0	7.5	19	6	8	**40.5 (Poor)**
	15CD003 (2015)		0	7	7	8	8	**30 (Poor)**
	15CD003 (2016)		0	8.5	15	10	10	**43.5 (Poor)**
	15CD003 (2016)		0	9.5	9	9	10	**37.5 (Poor)**
Bear Lake								
↓	15CD001 (2015)	501	0	7	8	5	5	**25 (Poor)**
	15CD001 (2015)		0	6.5	7	1	5	**19.5 (Poor)**
	15CD001 (2016)		0	8	5	5	5	**23 (Poor)**
	15CD001 (2016)		0	5	2	2	5	**14 (Poor)**
	15CD002 (2015)		0	8	5	5	3	**21 (Poor)**
	15CD002 (2015)		0	8	6	1	6	**21 (Poor)**
	15CD002 (2016)		0	8	7	5	3	**23 (Poor)**
	15CD002 (2016)		0	8	6	4	4	**22 (Poor)**
	15CD004 (2015)	509	0	10.5	6	11	3	**30.5 (Poor)**
	15CD004 (2015)		0	8	6	11	8	**33 (Poor)**
	15CD004 (2016)		0	11	8	12	12	**43 (Poor)**
	15CD005 (2015)	515	0	7	7	1	5	**20 (Poor)**
	15CD005 (2015)		0	6	6	11	7	**30 (Poor)**
	15CD005 (2016)		0	9	7	12	12	**40 (Poor)**
	15CD011 (2015)	503	0	9	14.35	13	19	**55.35 (Fair)**
	15CD011 (2015)		0	7	13	10	12	**42 (Poor)**

The macroinvertebrate metrics suggest that lack of habitat and fine substrate are stressing the community (Figure 12). Although not observed at all stations, the elevated burrowers, reduced clingers, elevated legless, and elevated sprawlers are symptoms of habitat stress. Elevated burrowers and sprawlers are likely a result of all the fine sediments in the watershed; burrowers "burrow" in fine sediment and sprawlers can inhabit surfaces of fine sediment or floating aquatic plants (Kolbe and

Luedke 2005). Clingers attach to rock or woody debris, and are likely reduced due to the lack of riffles and coarse substrate. Legless species are tolerant individuals that can withstand degraded habitat conditions.

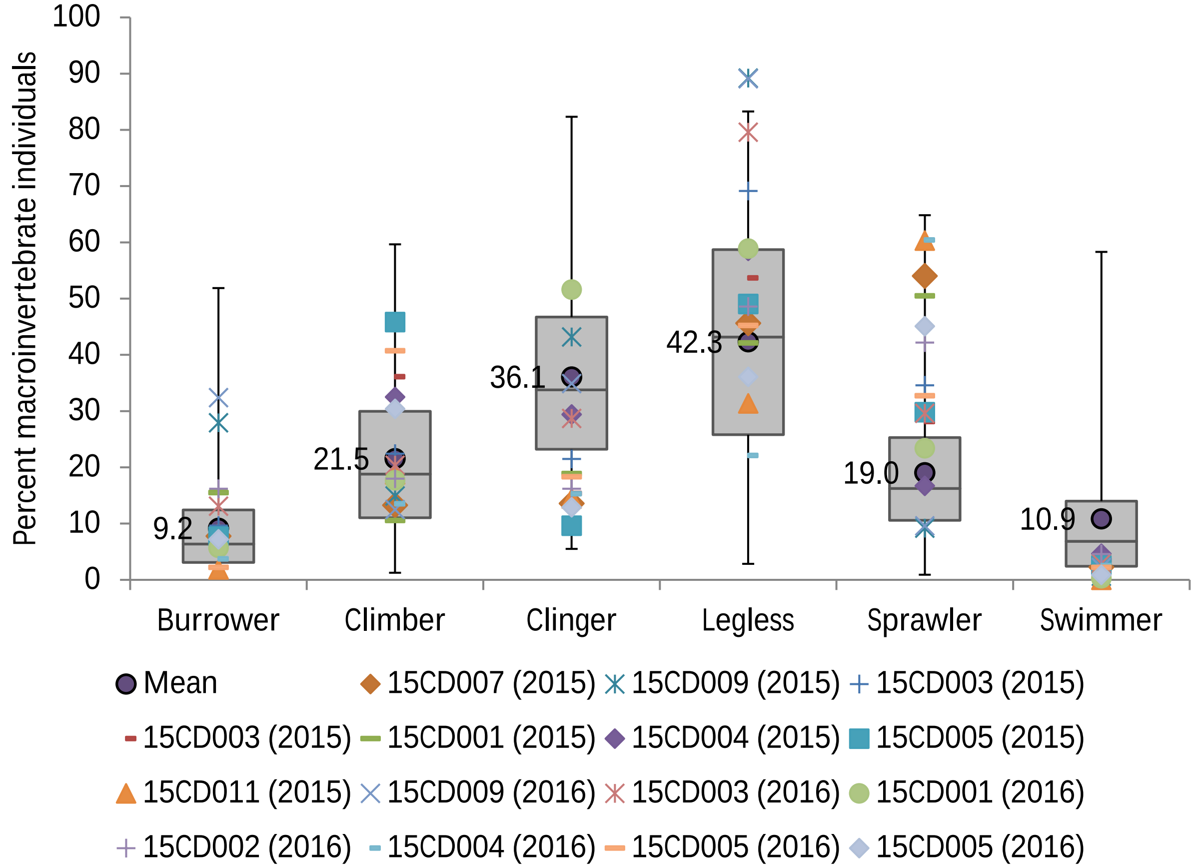


Figure 12: Macroinvertebrate habitat metrics with box plot showing range of values from Prairie Streams (class 7) stations meeting the bio criteria, mean of those stations, and metric values from Winnebago Watershed stations.

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 23). Relative abundance of individuals that are tolerant species (TolPct), benthic insectivore species (BenInsectPct), lithophilic spawners (LithFrimPct), darter, sculpin, and round bodied sucker species (DarterSculpSucPct), dominant two species (DomTwoPct), and riffle-dwelling species (RifflePct) were all worse than average at stations 15CD001, 15CD002, and 15CD005. These stations are below Bear Lake and are biologically impaired. In general, most metrics and stations scored poorly, and tolerant fish dominate the watershed. Of the metrics that scored well, most were above Bear Lake.

Table 23: Fish metrics that respond to habitat stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	TolPct	BenInsectPct	LithFrimPct	DarterSculpSucPct	DomTwoPct	RifflePct
↑	15CD007 (2015) (3)	505	**100.0**	**0.0**	79.4	**0.0**	**78.7**	**0.7**
	15CD009 (2015) (3)	504	**96.5**	**1.7**	82.6	**1.7**	**75.7**	66.1
	15CD009 (2016) (3)		**80.9**	**2.6**	**36.4**	**2.6**	52.9	**21.0**
	15CD003 (2015) (7)		**71.2**	23.7	**17.4**	23.7	**73.6**	12.3
	15CD003 (2016) (7)		**76.0**	23.0	34.1	23.0	36.9	12.4
Bear Lake								
↓	15CD001 (2015) (2)	501	**90.7**	**1.7**	**2.6**	**1.5**	**74.9**	**2.4**
	15CD001 (2016) (2)		**85.5**	**1.2**	**29.4**	**1.2**	**69.8**	**0.7**
	15CD002 (2015) (2)		**80.2**	**2.4**	**8.1**	**0.6**	**63.7**	**7.5**
	15CD002 (2016) (2)		**98.0**	**0.0**	**6.8**	**0.0**	**86.1**	**0.0**
	15CD004 (2015) (3)	509	**99.5**	**0.5**	**50.3**	**0.5**	**88.4**	45.2
	15CD005 (2015) (7)	515	**100.0**	**0.0**	**4.8**	**0.0**	**76.2**	**0.0**
	15CD011 (2015) (3)	503	68.0	23.9	**34.2**	23.5	60.7	**8.5**
	Southern Streams Average (Ditched Channel) (2)		45.5	19.5	34.9	16.1	54.0	19.2
	Southern Headwaters Average (Ditched Channel) (3)		76.5	11.9	58.7	10.4	62.9	22.7
	Low Gradient Average (Ditched Channel) (7)		55.9	*8.7*	*26.4*	*7.0*	66.0	7.5
	Expected response to stress		↑	↓	↓	↓	↑	↓

Recent geomorphology work completed by DNR on stations 15CD001 and 15CD004 noted that "channelized drainage ditches like those exhibited in the Winnebago River Watershed typically lack natural habitat features (i.e. riffles and pools), have minimal bank erosion, and have fine stream bed particles. The sites surveyed by DNR crews were no exception to these generalizations" (DNR 2017). This summary report also identifies station 15CD001 as deeply incised with no access to its floodplain (Figure 13).

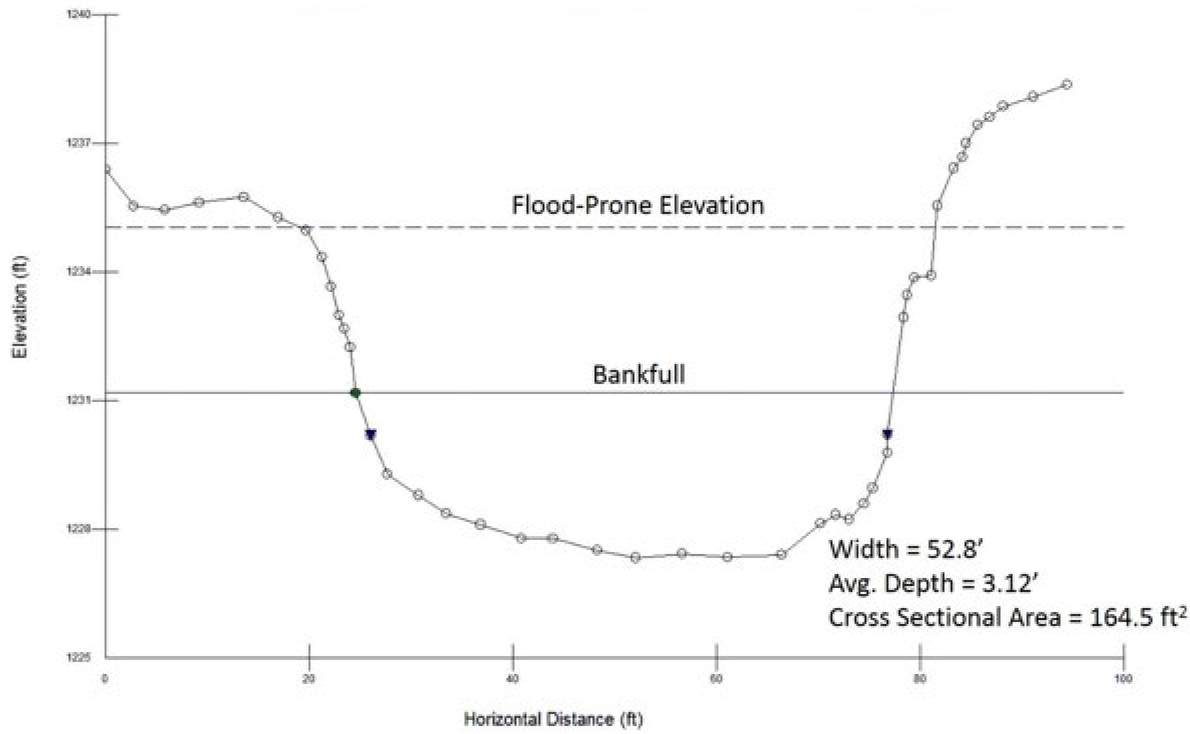


Figure 13: Riffle cross section at station 15CD001 illustrating channel incision. Image provided by DNR.

Habitat conditions in the Winnebago River Watershed are poor due to lack of habitat and fine substrate. Severe embeddedness, sand, silt, and channelization dominate this watershed and limit the fish and macroinvertebrate communities. In Modified Use channels, habitat is determined to be limiting the biological communities; lack of habitat is a stressor in all biologically impaired AUIDs (501, 504, and 515).

Fish Passage

The Winnebago River Watershed contains several fish barriers that have potential to limit the fish community (Figure 14). Bear Lake and State Line Lake both have dams in place that limit fish migration (Figure 15). According to the DNR, both dams are partial barriers to fish passage when stop logs are in place, but can become ineffective during high flows. Also worth noting is that the road culvert below the State Line Lake dam is designed to act as a fish barrier and exclude common carp (email correspondence with DNR 2017).

The AUIDs (501 and 515) with fish impairments appear free of barriers, but there are a few on neighboring AUIDs and tributaries. Just upstream of AUID 501 is the Bear Lake dam (mentioned above), which limits fish migration to the lake during most flows. AUID 503 is a tributary to AUID 501, and had a fish barrier on the upper end (Figure 16). This barrier, however, was recently removed during a high flow event. There are also two other culverts on AUID 503 that may be barriers; these culverts are located on private property and their status is unknown. AUID 510, a tributary to the lower end of AUID 515, seems to have a potential barrier during certain flows (Figure 17). There are also a couple private culverts in close proximity to AUID 515; their status is unknown.

Relative abundance of migratory taxa (MgrTxPct) and individuals (MgrPct) ranged from 0% to 18% and 0% to 67% respectively (Table 24). In general, there were more migratory taxa and individuals upstream of Bear Lake. Very few migratory individuals were present at stations with fish impairments, ranging from 0% to 7%.

Table 24: Fish migration metrics in the Winnebago River Watershed. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red; stations with fish impairments include 15CD001, 15CD002, and 15CD005.

	Station (Year Sampled)	AUID	MgrTxPct	MgrPct
↑	15CD007 (2015)	505	14.3	0.7
	15CD009 (2015)	504	18.2	67.0
	15CD009 (2016)		16.7	22.8
	15CD003 (2015)		14.3	35.6
	15CD003 (2016)		16.7	21.7
Bear Lake				
↓	15CD001 (2015)	501	12.5	3.5
	15CD001 (2016)		17.6	1.7
	15CD002 (2015)		6.3	7.3
	15CD002 (2016)		0.0	0.0
	15CD004 (2015)	509	12.5	45.2
	15CD005 (2015)	515	0.0	0.0
	15CD011 (2015)	503	14.3	29.6

The Winnebago River Watershed has several fish barriers that limit migration, but the extent of stress on fish communities in the impaired reaches is uncertain. Migratory taxa and individuals are limited at stations with fish impairments, but this metric response could also be due to other stressors. Regardless, future culvert and bridge replacements should allow proper water conveyance and fish passage; worth noting is that road construction began at the time of this report, which appeared to involve culvert replacement. In addition to limiting fish migration, improperly sized and placed culverts create channel instability, which can have negative impacts on other stressors (e.g. TSS and habitat). Fish passage (or lack thereof) is likely having a negative impact on fish communities in the watershed, but it’s inconclusive as a stressor in both of the AUIDs (501 and 515) with fish impairments.

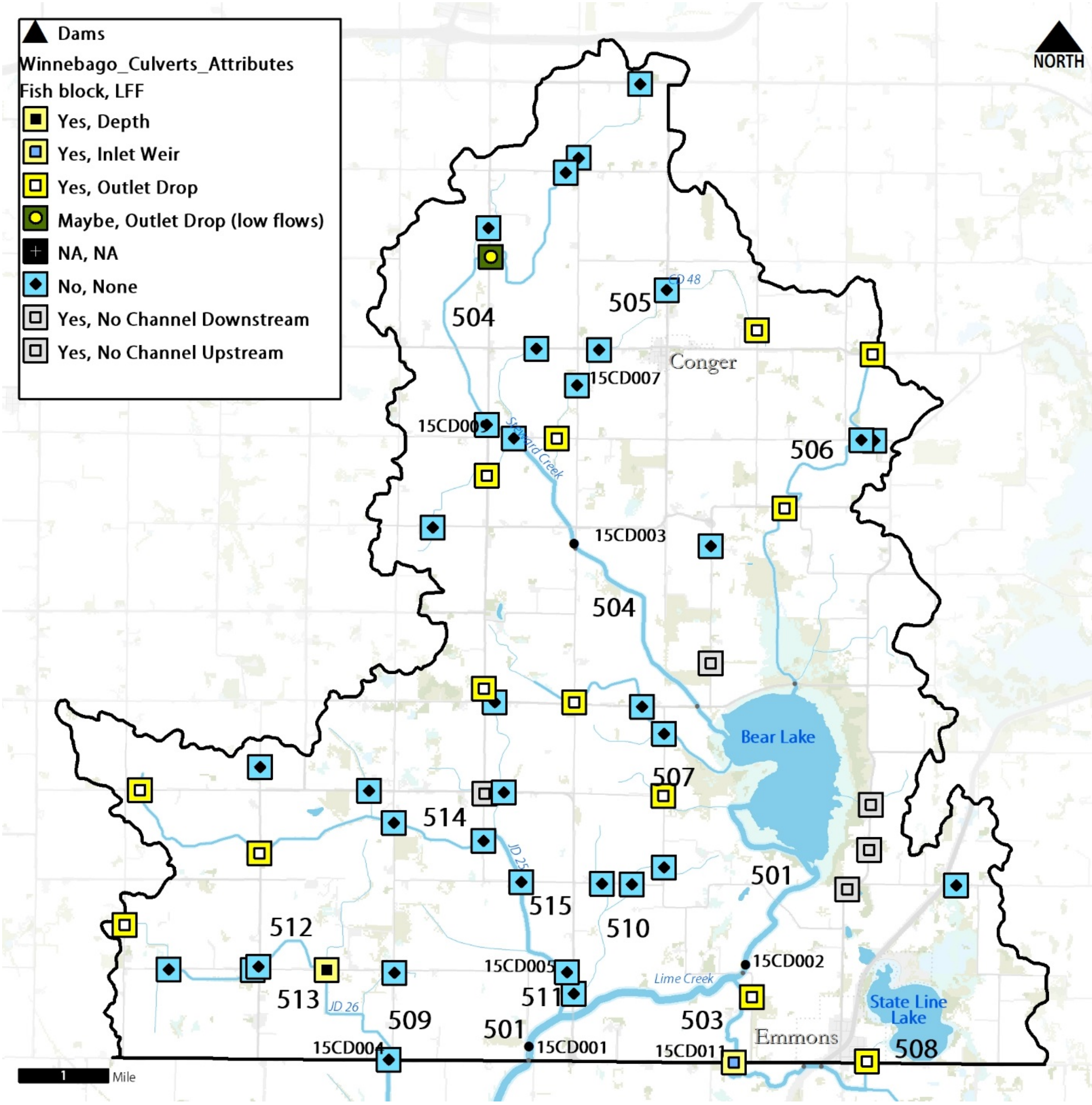


Figure 14: Fish barrier information for culverts in the Winnebago River Watershed. This map depicts whether or not a culvert is a fish barrier (yes, no, maybe, or NA), and what the limiting factor for passage is (depth, inlet weir, outlet drop, no channel downstream, or no channel upstream). Information for this map was collected by the DNR, and is limited to public road crossings.

Figure 15: Outlet structure on Bear Lake (left) and State Line Lake (right). Aerial photos courtesy of Google Earth and others courtesy of DNR.

Figure 16: Fish barrier on AUID 503 (left). This barrier was documented in 2015, and was blown out (right) during a high flow event sometime late summer/early fall of 2016.


Figure 17: Potential fish barrier during certain flows on AUID 510.

Flow Alteration

Flow alteration (altered hydrology) is a significant driver of many stressors in the Winnebago River Watershed. Hydrology is affected by several components in the watershed, some of which include wetland drainage, tile drainage, channelization, ground water and surface water appropriation, precipitation, land use, dams, and impervious surface. All of these components alter stream flow, which in turn can negatively impact the biology and have direct or indirect effects on stressors such as temperature, nitrate, phosphorus, DO, TSS, habitat, and fish passage. Ultimately, flow alteration impacts several stressors and is a major contributor to the impaired biological communities in the Winnebago River Watershed.

There are currently no stream gaging stations in the watershed, but modeled flows via the Hydrological Simulation Program – FORTRAN (HSPF) model are available for the watershed from 1996 through 2012 (RESPEC 2014) (MPCA 2015). Modeled flows at the mouth of Steward Creek range from 0.7 to 1,166 cubic feet per second (cfs) (average of 19.9 cfs), and flows on Lime Creek (just south of Minnesota/Iowa border) range from 1.8 to 1,218 cfs (average of 63.0 cfs). Steward Creek flows were less than one cfs approximately 2% of the time. Local staff noted that Steward Creek went dry during the 2012 drought.

Altered (channelized) watercourses dominate the Winnebago River Watershed (Figure 18). These channelized reaches have direct impacts on hydrology and habitat, as well as other variables. With exception of the lakes (Bear and State Line) and a few small no defineable channels, the Winnebago River Watershed is entirely altered. Agricultural tile drainage is a common practice used in the Winnebago River Watershed (Figure 18). Although tile drainage can increase agricultural productivity, it has negative impacts on hydrology (e.g. increasing peak flows and reducing base flows) and water quality (e.g. increasing nitrogen loading). A recent study comparing changes in hydrology for 21

Minnesota watersheds, which included several watersheds (e.g. Blue Earth, Cedar, and Le Sueur) near the Winnebago, found that "artificial drainage is a major driver of increased river flow, exceeding the effects of precipitation and crop conversion" (Schottler et al. 2013) (Figure 19). It also noted, "twentieth century crop conversions and the attendant decreases in ET from depressional areas due to artificial drainage have combined to significantly alter watershed hydrology on a very large scale, resulting in more erosive rivers." Winnebago River Watershed tile calculations, which were derived using the 2009 United States Department of Agriculture (USDA) crop data layer, United States Geological Survey (USGS) National Elevation Dataset, and Soil Survey Geographic Database (SSURGO) soil drainage class, estimate that roughly 41% (~18,716 acres) of the watershed is tiled.

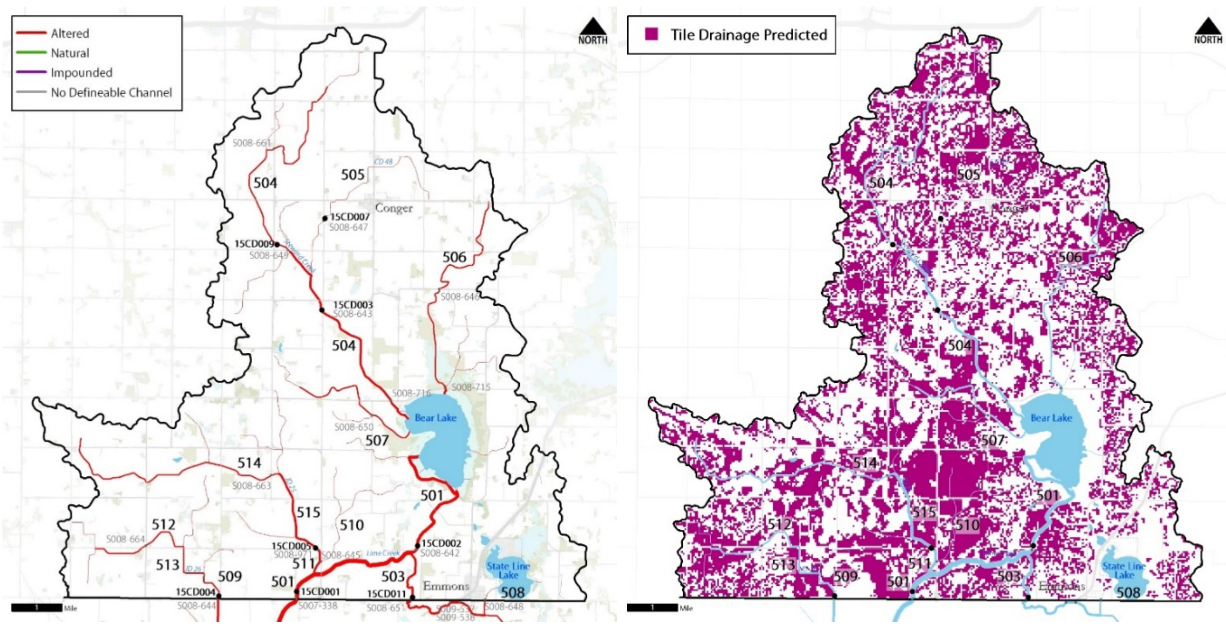


Figure 18: Altered, natural, impounded, and no definable channel watercourses in the Winnebago River Watershed (left), and tile drainage estimates in the Winnebago River Watershed (right).

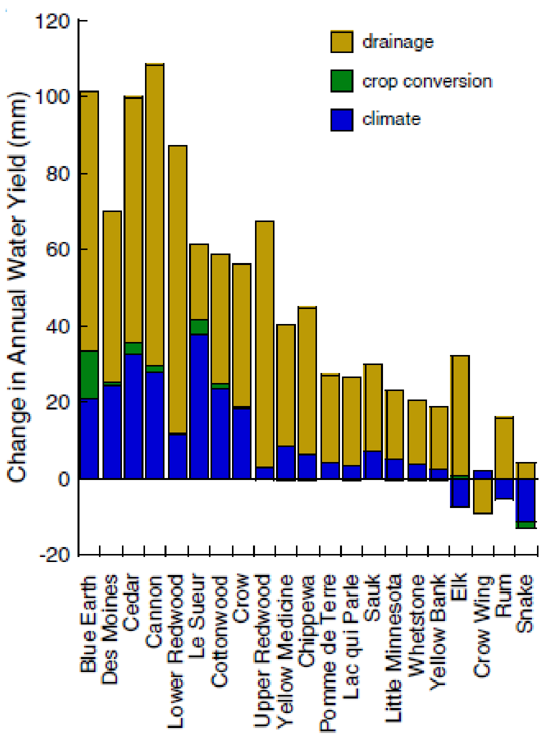


Figure 19: Apportionment of changes in mean annual water yield for each watershed. In rivers with significant changes in flow, climate and crop conversions account for less than half of the total change in water yield. Excess water yield is the portion that cannot be attributed to changes in crop ET and climate and is hypothesized to result from artificial drainage. The above figure was taken from the journal article titled "Twentieth century agricultural drainage creates more erosive rivers" (Schottler et al. 2013).

Wetland impacts on hydrology include providing water storage and reducing peak flows; anthropogenic activities such as draining wetlands alter the flows, timing, and quality of water. Today, very few wetlands remain in the Winnebago River Watershed (Figure 20). This decrease in storage has no doubt had an impact on hydrology. A recent publication from the DNR stated that "Bear Lake Watershed is extensively drained, severely reducing its ability to clean polluted water, mitigate flooding, recharge groundwater supplies, provide habitat and recreation opportunities. Strategically placed wetland restorations can reverse this situation" (DNR 2010). As part of a special project (2010 through 2013) for the Bear Lake Watershed, DNR staff developed a watershed hydrology model. The U.S. Corp of Engineer's Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model (Ogden et al. 2004) was selected, as it is a physically-based distributed model that can explicitly simulate tile drainage systems. The modeling period for the Bear Lake Watershed was 2008 through 2012. A focus for the modeling efforts was two wetlands as well as Bear Lake. For a larger storm event, the GSSHA model predicted a lake level bounce of +1.5', which can be compared to a +1.0' bounce when pre-settlement vegetation conditions were assessed. A scenario was developed that increased wetland coverage to 20% of the land use in the Bear Lake Watershed, which resulted in a decline in flow by about 9% (compared to current conditions). To achieve greater reductions in ditch and stream flow from this watershed, water storage in the soil profile itself was suggested as being important, as a 1% increase in soil organic matter can hold 0.75 to 1.0 inches of water. County Ditch 48 (5 sq. mile drainage area) was also modeled; this smaller-scaled modeling effort showed that surface runoff is occurring quickly (within hours) of the onset of a rainstorm event (Solstad 2013).

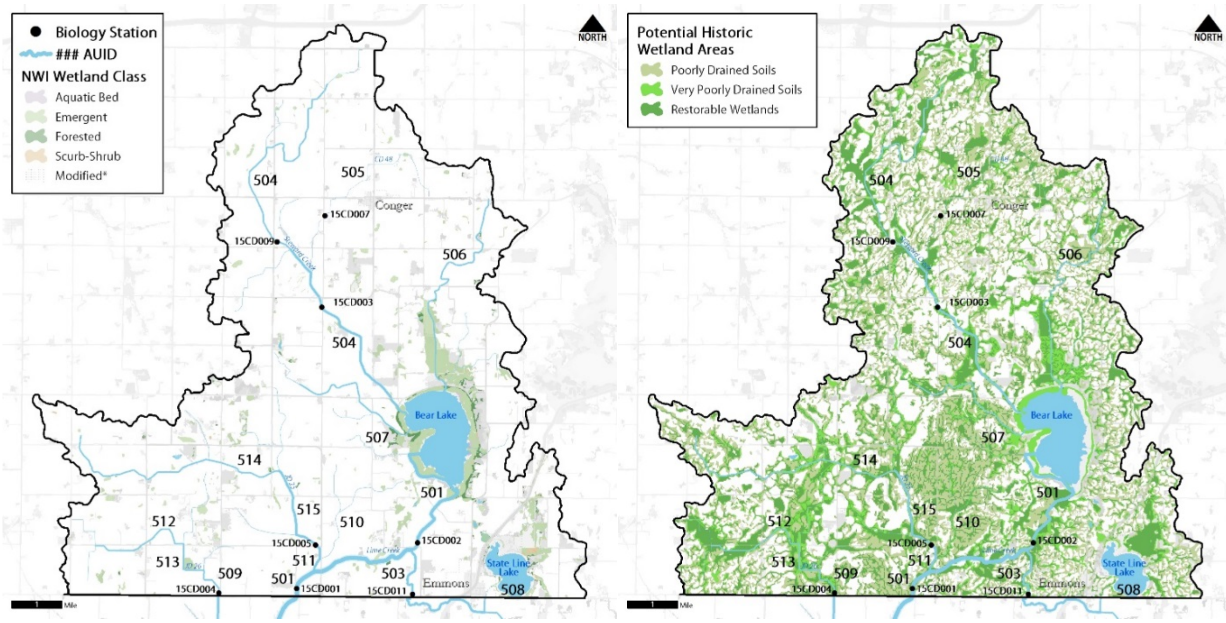


Figure 20: Current wetlands (left) and potential wetland areas (right) in the Winnebago River Watershed. Current wetlands are from the U.S. Fish and Wildlife Service's National Wetland Inventory; potential wetland areas were derived using poorly drained and very poorly drained soils from the SSURGO data and the restorable wetland inventory from the Center for Water and the Environment Natural Resources Research Institute.

Land use in a watershed has significant impacts on the hydrology. Perennial cover, cropland, forest, wetlands, and developed (impervious) land affect hydrology in different ways, with some ultimately reducing runoff and river flows while others increase these flows. Agriculture is the dominant land use in the Winnebago River Watershed; additional information regarding land use can be found in the Winnebago River Watershed Monitoring and Assessment Report.

Groundwater and surface water appropriation also influence hydrology in a watershed. Types of appropriation in the Winnebago River Watershed include major crop irrigation, sod farm irrigation, golf course irrigation, municipal waterworks, livestock watering, and agricultural/food processing. Permitted volumes according to DNR for these categories range from 10 to 429 mgy; average use rates from 1988 through 2015 range from 0.4 to 70 mgy. Major crop irrigation is the dominant form.

A majority of the macroinvertebrate metrics were worse than the statewide median of stations meeting the MIBI threshold (Table 25). Relative abundance of EPTPct, long-lived individuals (LongLivedPct), non-hydropsychid Trichoptera individuals (TrichwoHydroPct), tolerant taxa (Tolerant2ChTxPct), and total taxa richness (TaxaCountAllChir) were all worse than the median at stations 15CD002, 15CD003 (2015), 15CD004 (2016), 15CD009, and 15CD011. Flow regime instability tends to limit macroinvertebrate diversity, particularly taxa that belong to the orders of EPT, and favor taxa that are shorter-lived and tolerant of environmental disturbances (Klemm et al. 2002; Poff and Zimmerman 2010; EPA 2012).

Table 25: Macroinvertebrate metrics that respond to flow alteration stress in the Winnebago River Watershed compared to the statewide median of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled)	AUID	EPTPct	LongLivedPct	TaxaCountAllChir	Tolerant2ChTxPct	TrichwoHydroPct
↑	15CD007 (2015)	505	46.3	**0.3**	**35**	**88.6**	**1.3**
	15CD009 (2015)	504	**3.2**	**2.2**	**27**	**96.3**	**0.3**
	15CD009 (2016)		**4.8**	**0.6**	**30**	**96.7**	**1.6**
	15CD003 (2015)		**15.3**	**3.7**	**36**	**94.4**	**0.6**
	15CD003 (2015)		**15.0**	**3.5**	**29**	**96.6**	**1.0**
	15CD003 (2016)		**9.6**	**2.2**	45	**93.3**	**2.5**
Bear Lake							
↓	15CD001 (2015)	501	**14.2**	6.2	39	**84.6**	**0.9**
	15CD001 (2016)		**7.6**	**1.9**	**27**	**100.0**	3.2
	15CD002 (2016)		**1.8**	**0.6**	**37**	**94.6**	**0.9**
	15CD004 (2015)	509	**22.9**	**2.2**	**34**	**88.2**	4.3
	15CD004 (2016)		**30.4**	**4.0**	**29**	**93.1**	**1.8**
	15CD005 (2015)	515	**16.0**	**4.2**	**36**	**91.7**	5.4
	15CD005 (2016)		**20.5**	**3.2**	**31**	**93.5**	9.9
	15CD005 (2016)		**16.0**	**1.6**	**33**	**93.9**	5.0
	15CD011 (2015)	503	**0.9**	**2.8**	**24**	**83.3**	**0.0**
	Prairie Streams Median		*35.2*	*5.2*	*39*	*82.1*	*2.9*
	Expected response to stress		↓	↓	↓	↑	↓

A majority of the fish metrics were worse than the statewide average of stations meeting the FIBI threshold (Table 26). Relative abundance of individuals of the dominant two species (DomTwoPct), generalist species (GeneralPct), individuals with a female mature age less than or equal to two (MA<2Pct), pioneer species (PioneerPct), short-lived individuals (SLvdPct), and the number of individuals per meter of stream sampled excluding tolerant species (NumPerMeter-Tol) were all worse than average at stations 15CD001 (2016), 15CD002 (2016), and 15CD007. Flow regime instability tends to limit species diversity and favor taxa that are trophic generalists, early maturing, pioneering, short-lived, and tolerant of environmental disturbances (Aadland et al. 2005; Poff and Zimmerman 2010).

Table 26: Fish metrics that respond to flow alteration stress in the Winnebago River Watershed compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. Stations in the upper portion of the table are upstream of Bear Lake, and stations in the lower portion are downstream of Bear Lake (but not necessarily connected to the lake; stations 15CD001 and 15CD002 are the only stations receiving outflow). Biologically impaired stations are highlighted red.

	Station (Year Sampled) (Class)	AUID	DomTwoPct	GeneralPct	MA<2Pct	NumPerMeter-Tol	PioneerPct	SLvdPct
↑	15CD007 (2015) (3)	505	**78.7**	**95.0**	**99.3**	**0.00**	**59.6**	**52.5**
	15CD009 (2015) (3)	504	**75.7**	**93.0**	31.3	**0.03**	16.5	13.9
	15CD009 (2016) (3)		52.9	**80.1**	61.4	**0.35**	**50.0**	**43.0**
	15CD003 (2015) (7)		**73.6**	**70.5**	82.8	**0.79**	**56.4**	**76.0**
	15CD003 (2016) (7)		36.9	**61.3**	85.7	**0.35**	**49.8**	**60.4**
Bear Lake								
↓	15CD001 (2015) (2)	501	**74.9**	**93.7**	47.2	**0.09**	**40.7**	**39.4**
	15CD001 (2016) (2)		**69.8**	**68.8**	**94.0**	**0.12**	**59.4**	**46.4**
	15CD002 (2015) (2)		**63.7**	**83.3**	24.4	**0.36**	9.4	3.3
	15CD002 (2016) (2)		**86.1**	**91.5**	**96.4**	**0.05**	**86.1**	**73.5**
	15CD004 (2015) (3)	509	**88.4**	54.3	54.3	**0.01**	4.5	**51.3**
	15CD005 (2015) (7)	515	**76.2**	**52.4**	81.0	**0.00**	**33.3**	**76.2**
	15CD011 (2015) (3)	503	60.7	**73.3**	**91.3**	1.01	**47.6**	**73.9**
	Southern Streams Average (Ditched Channel) (2)		*54.0*	*43.1*	*59.7*	*0.60*	*23.1*	*14.1*
	Southern Headwaters Average (Ditched Channel) (3)		*62.9*	*55.8*	*75.3*	*0.48*	*31.9*	*28.8*
	Low Gradient Average (Ditched Channel) (7)		*66.0*	*35.9*	*87.2*	*1.29*	*19.7*	*33.2*
	Expected response to stress		↑	↑	↑	↓	↑	↑

Flow alteration (directly and/or indirectly) is negatively influencing the biology in the Winnebago River Watershed. It's reasonable to assume that flow alteration is contributing to all (or most) of the stressors in the watershed, some examples include nitrogen loading via tile lines and loss of habitat via channelization. Flow alteration is a stressor in all biologically impaired AUIDs (501, 504, and 515).

Conclusion

Tolerant fish and macroinvertebrates dominate the Winnebago River Watershed, and several stressors are contributing to these degraded biological communities (Table 27 and Figure 21). Excess nutrients (nitrogen and phosphorus) are present in the watershed, and are fueling eutrophic conditions in the lakes (Bear and State Line) and stream reaches. Bear Lake and State Line Lake are impaired for eutrophication and are significantly impacting Lime Creek (AUID 501); the elevated productivity (and associated organic matter and nutrients) is driving eutrophication, DO, and TSS stressors in this AUID. Biological restoration of Lime Creek is probably unlikely until conditions in the lakes improve. Carp are present in both lakes, and are likely contributing to these conditions. The DNR manages these lakes and has attempted to remove the carp via dams, drawdowns, and rotenone treatment in an effort to improve water quality, native aquatic plant growth, and habitat. To date, there are still carp present in both lakes and management efforts are ongoing. The excessive plant and algae growth in the watershed is also altering DO dynamics, resulting in low DO and elevated DO flux. Flow alteration is a major source of stress and it's reasonable to assume it's contributing directly or indirectly to all stressors in the Winnebago River Watershed. Nitrate and habitat stressors in particular are impacted by flow alteration through tile drainage and channelization. The entire watershed is channelized, greatly reducing habitat availability and quality for fish and macroinvertebrates; most reaches are severely embedded with fine substrate and lack habitat complexity necessary for healthy biologic communities. Biological restoration may prove difficult as long as drainage ditches continue to be maintained using standard, less comprehensive procedures. Although fish passage is inconclusive as a stressor, barriers to fish migration are common across the watershed; future bridge and culvert replacements should allow adequate passage. Nitrate, eutrophication, DO, TSS, habitat, and flow alteration are stressors in the Winnebago River Watershed.

Nutrient reduction and habitat improvement are key in improving the biological communities. Nutrient reduction should account for any internal loading in Bear Lake and State Line Lake, in addition to conventional loading sources (point and nonpoint). Further research and monitoring may be necessary to determine internal loading rates in the lakes, and what affect carp may be having on these rates. Habitat improvement in this highly altered watershed could involve establishing two-stage (self-maintaining) ditches in targeted locations to enhance sediment transport and habitat.

Table 27: Summary of stressors in the Winnebago River Watershed (• = stressor, ○ = inconclusive stressor, blank = not a stressor). Strength of evidence analysis was completed for each AUID and parameter, and is available upon request.

					Stressors							
Waterbody	AUID	Stations	Biological Impairment	Class	Temperature	Nitrate	Eutrophication	DO	TSS	Habitat	Fish Passage	Flow Alteration
Lime Creek	501	15CD001, 15CD002	Fish and Inverts	2B	○		●	●	●	●	○	●
Steward Creek	504	15CD003, 15CD009	Inverts	2B		●	●	●		●		●
Judicial Ditch 25	515	15CD005	Fish	2B		○	●	●		●	○	●

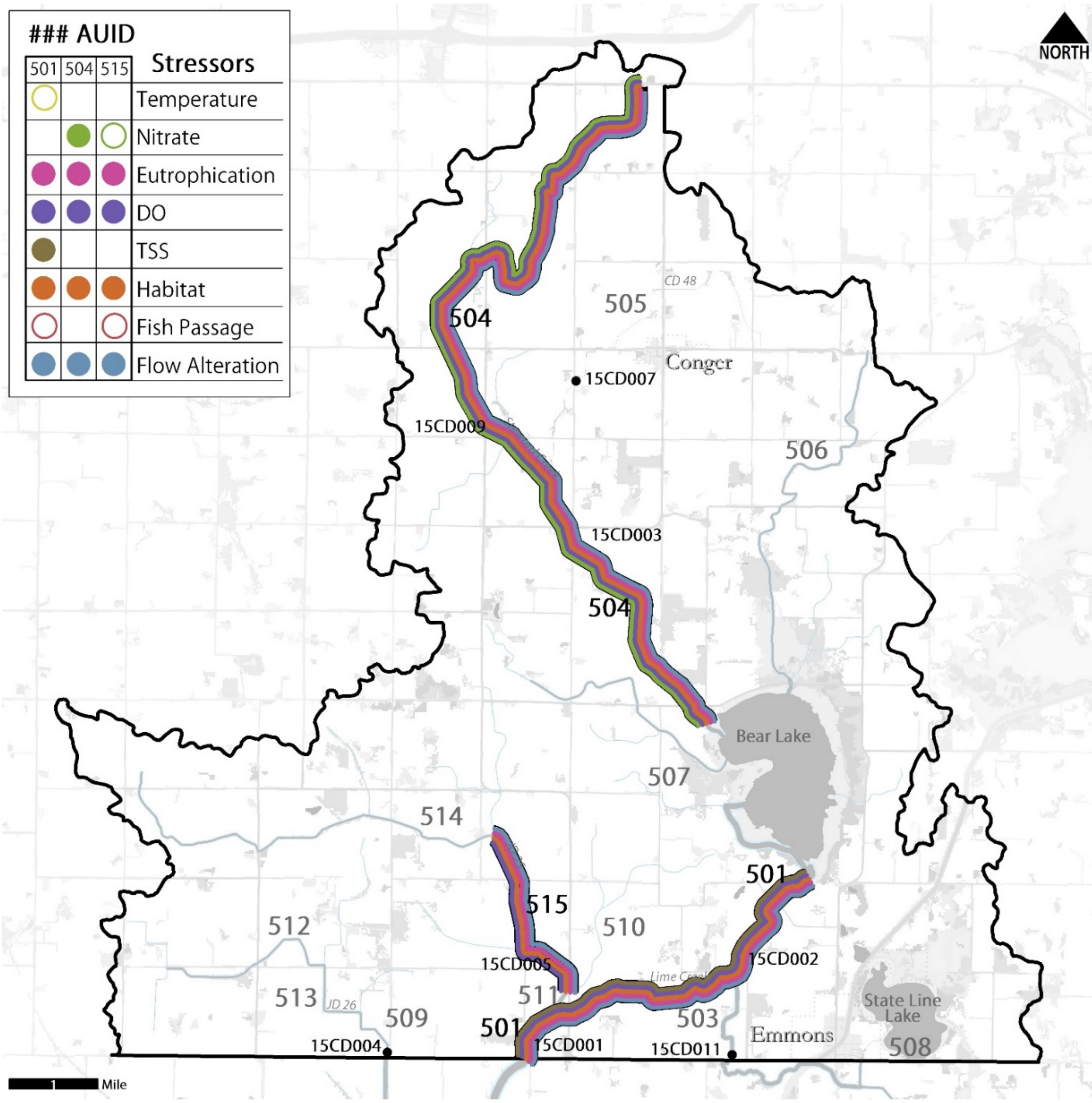


Figure 21: Map of stressors in the Winnebago River Watershed. Stressors are color coded using the same symbology as the table above (• = stressor, ○ = inconclusive stressor, blank = not a stressor). Only stressors (•) are mapped.

5. References

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6. Appendix

Table 28: Fish and macroinvertebrate metrics used in stressor analysis in the Winnebago River Watershed.

Metric Name	Type	Metric Description
BenFdFrimPct	Fish	Relative abundance (%) of individuals that are exclusively benthic feeders (Frimpong)
BenInsectPct	Fish	Relative abundance (%) of individuals that are benthic insectivore species
BenInsect-TolTXPct	Fish	Relative abundance (%) of taxa that are non-tolerant benthic insectivores
Burrower	Macroinvertebrates	Taxa richness of burrowers (excluding chironomid burrower taxa)
CarnPct	Fish	relative abundance (%) of individuals that are carnivorous
Centr-TolPct	Fish	relative abundance (%) of individuals that are non-tolerant Centrarchidae
Climber	Macroinvertebrates	Taxa richness of climbers (excluding chironomid climber taxa)
Clinger	Macroinvertebrates	Taxa richness of clingers (excluding chironomid clinger taxa)
ClingerCh	Macroinvertebrates	Taxa richness of clingers
Collector-filtererCh	Macroinvertebrates	Taxa richness of collector-filterers
Collector-filtererPct	Macroinvertebrates	Relative abundance (%) of collector-filterer individuals in subsample
Collector-gathererCh	Macroinvertebrates	Taxa richness of collector-gatherers
DarterPct	Fish	Relative abundance (%) of individuals that are darter species
DarterSculpSucPct	Fish	Relative abundance (%) of individuals that are darter, sculpin, and round bodied sucker species
DetNWQTXPct	Fish	relative abundance (%) of taxa that are detritivorous (NAWQA database)
DomFiveCHPct	Macroinvertebrates	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)
DomTwoPct	Fish	Relative abundance (%) of individuals of the dominant two species
EPT	Macroinvertebrates	Taxa richness of Ephemeroptera, Plecoptera & Trichoptera (baetid taxa treated as one taxon)
EPTPct	Macroinvertebrates	Relative abundance (%) of Ephemeroptera, Plecoptera & Trichoptera individuals in subsample

Metric Name	Type	Metric Description
FishDELTPct	Fish	Relative abundance (%) of individuals with DELT anomalies (deformities, eroded fins, lesions, or tumors)
GeneralPct	Fish	Relative abundance (%) of individuals that are generalist species
HBI_MN	Macroinvertebrates	A measure of pollution based on tolerance values assigned to each individual taxon developed by Chirhart
Hdw-TolPct	Fish	Relative abundance (%) of individuals that are headwater species (excludes tolerant species)
HrbNWQPct	Fish	Relative abundance (%) of individuals that are herbivore species (NAWQA database)
Intolerant2Ch	Macroinvertebrates	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs
IntolerantPct	Fish	Relative abundance (%) of individuals that are tolerant species
Legless	Macroinvertebrates	Taxa richness of legless macroinvertebrates (chironomid taxa treated as one taxon)
LithFrimPct	Fish	Relative abundance (%) of individuals that are lithophilic spawners
LLvdPct	Fish	Relative abundance (%) of individuals that are long-lived (Frimpong)
LongLivedPct	Macroinvertebrates	Relative abundance (%) of longlived individuals in subsample
Low DO Index Score	Macroinvertebrates	Low DO index score
Low DO Index Score (RA)	Fish	Low DO Index Score (RA)
Low DO Intolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Low DO Intolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Low DO Tolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
Low DO Tolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
MA<2Pct	Fish	relative abundance (%) of individuals with a female mature age <=2 (Frimpong)
MA>3Pct	Fish	relative abundance of individuals with a female mature age >=3 (Frimpong)

Metric Name	Type	Metric Description
MgrPct	Fish	Relative abundance (%) of individuals that are migratory species
MgrTxPct	Fish	Relative abundance (%) of taxa that are migratory
MinnowPct	Fish	Relative abundance (%) of individuals that are Cyprinidae species
Minnows-TolPct	Fish	Relative abundance (%) of individuals that are Cyprinidae species (excludes tolerant species)
Nitrate Index Score	Macroinvertebrates	Nitrate index score
Nitrate Intolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Nitrate Intolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Nitrate Tolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
Nitrate Tolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
NumPerMeter-Tolerant	Fish	Number of individuals per meter of stream sampled (excludes individuals of tolerant species)
OmnivorePct	Fish	Relative abundance (%) of individuals that are omnivore species
OmnivoreTxPct	Fish	Relative abundance (%) of taxa that are omnivorous
Percfm-TolPct	Fish	Relative abundance (%) of individuals of the Order Perciformes (excluding tolerant)
Phosphorus Index Score	Macroinvertebrates	Phosphorus Index Score
Phosphorus Intolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Phosphorus Intolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
Phosphorus Tolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
Phosphorus Tolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
PioneerPct	Fish	Relative abundance (%) of individuals that are pioneer species

Metric Name	Type	Metric Description
PioneerTxPct	Fish	Relative abundance (%) of taxa that are pioneers
PlecopteraPct	Macroinvertebrates	Relative abundance (%) of Plecoptera individuals in subsample
POET	Macroinvertebrates	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)
PredatorCh	Macroinvertebrates	Taxa richness of predators
Probability of meeting DO std.	Fish	Probability of meeting DO std.
Probability of meeting TSS std.	Fish	Probability of meeting TSS std.
RifflePct	Fish	Relative abundance (%) of individuals that are riffle-dwelling species
Sensitive	Fish	Taxa richness of sensitive species
SensitivePct	Fish	Relative abundance (%) of individuals that are sensitive species
SensitiveTXPct	Fish	Relative abundance (%) of taxa that are sensitive
SLithFrimPct	Fish	Relative abundance (%) of individuals that are simple lithophilic spawners, as per Frimpong database
SLithop	Fish	Taxa richness of simple lithophilic spawning species
SLithopPct	Fish	Relative abundance (%) of individuals that are simple lithophilic spawners
SLvd	Fish	Taxa richness of short-lived species
SLvdPct	Fish	Relative abundance (%) of individuals that are short-lived
Sprawler	Macroinvertebrates	Taxa richness of sprawlers (excluding chironomid and baetid sprawler taxa)
SSpnPct	Fish	Relative abunance (%) of individuals that are serial spawning species
SuckerPct	Fish	Relative abundance (%) of individuals that are Catostomidae
Swimmer	Macroinvertebrates	Taxa richness of swimmers (excluding chironomid, baetid taxa treated as one taxon)
TaxaCountAllChir	Macroinvertebrates	Total taxa richness of macroinvertebrates
Tolerant2ChTxPct	Macroinvertebrates	Relative percentage of taxa with tolerance values equal to or greater than 6, using MN TVs
TolPct	Fish	Relative abundance (%) of individuals that are tolerant species
TolTXPct	Fish	Relative abundance (%) of taxa that are tolerant species
TrichopteraCh	Macroinvertebrates	Taxa richness of Trichoptera

Metric Name	Type	Metric Description
TrichopteraChTxPct	Macroinvertebrates	Relative percentage of taxa belonging to Trichoptera
TrichwoHydroPct	Macroinvertebrates	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample
TSS Index Score	Macroinvertebrates	TSS index score
TSS Index Score (RA)	Fish	TSS index score (RA)
TSS Intolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
TSS Intolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the lower 25th percentile of stressor tolerance scores
TSS Tolerant Pct	Macroinvertebrates	Relative abundance of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
TSS Tolerant Taxa	Macroinvertebrates	Number of taxa with tolerance values in the upper 25th percentile of stressor tolerance scores
Wetland-Tol	Fish	Taxa richness of wetland species (excludes tolerant species)(wetland species thrive in low gradient systems dominated by a wetland riparian zones)