Red Eye River Watershed Stressor Identification Report

This report will describe the stressors to the biological community in the Red Eye River watershed

Minnesota Pollution Control Agency

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Contents

List of tables

List of figures

Abbreviations

ArcAGIS

ARM Agricultural Runoff Model

AUID Assessment Unit Identification Determination

BANCS Bank Assessment for Non-point source Consequences of Sediment

BEHI Bank Erosion Hazard Index

BOD Biological oxygen Demand

C calcium

CADDIS Causal Analysis/Diagnosis Decision Information System.

CD County Ditch

CL Confident Limits

CWLA Clean Water Legacy Act

DarterSculpSucTxPct darter, sclupins and round bodied suckers

DEM Digital Elevation Map

DO Dissolved Oxygen

DomTwoPct dominant two species

EPA U.S. Environmental Protection Agency

EQuIS Environmental Quality Information System

HSPF Hydrological Simulation Program FORTRAN

HUC Hydrologic Unit Code

IBI Index of Biotic Integrity

K Potassium

Mayfly Baetissp sp

MDNR Minnesota Department of Natural Resources

M-IBI

MPCA Minnesota Pollution Control Agency

MSHA Minnesota Stream Habitat Assessment

N Nitrogen

Nitrate-N Nitrate Plus Nitrite Nitrogen

NA Not Assessed/Available

NH3 Ammonia

NPS Nonpoint Source

NTU Nephelometric Turbidity Units

P Phosphorus

PredatorCh taxa richness of predators

RE Red Eye

RCHRESRE

SCUDS Hyallel la

SID Stressor Identification

Snails Physa sp

SOE Stength of evidence

Subwatershed HUC-11 size subwatershed

SWCD Soil and Water Conservation District

TaxaCountAllChir total taxa richness of macroinvertebrates

TKN Total Kjeldahl Nitrogen

TMDL Total Maximum Daily Load

TP Total Phosphorous

TSS Total Suspended Solids

USGS United States Geological Survey

WMA Wildlife Management Area

YSI Yellow Springs Instruments

Vtol Very tolerant

Executive summary

Over the past few years, 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 rivers and streams. The basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat conditions, at sites throughout a major watershed. From the data, an Index of Biological Integrity (IBI) score can be developed, which provides a measure of overall community health. If biological impairments are found, then then next step is to identify stressors to the aquatic community.

Stressor identification is a formal and rigorous process that identifies stressors causing biological impairment(s) of aquatic ecosystems, and provides a structure for organizing the scientific evidence supporting the conclusions (EPA, 2000). In simpler terms, it is the process of identifying the major factors causing harm to fish, macroinvertebrates and other river and stream life. Stressor identification 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 stressor identification work in the Red Eye River Watershed. The biologically impaired Assessment Unit Identification (AUID's) is separated by aggregated Hydrologic Unit Code (HUC)-12 for this report. After examining many candidate causes for the biological impairments, the following stressors were identified for the impaired streams in the Red Eye River Watershed:

		Stressors						
Stream Name	**AUID #**	**Low Dissolved Oxygen**	**Flow Alteration**	**Increased Sediment**	**Increased Bedded Sediment**	**Elevated Nutrients**	**Lack of Physical Habitat**	**Physical Connectivity**
South Bluff Creek	07010107-553	X	•		X		X	
Trib. To East Leaf Lake	07010107-554	X					X	•
Wing River	07010107-559	•	•			•		X
Trib. To Leaf River	07010107-557	•		X	•	•	X	
Union Creek	07010107-	X						

X is primary stressor
• is a secondary stressor

The following stressor identification report details the data analysis conducted to identify the main stressors that are affecting the biological communities in the Red Eye River Watershed.

1. Introduction

1.1. Monitoring and assessment

Water quality and biological monitoring in the Red Eye River Watershed has been active for three years. As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2011-2012, and focused more 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 2011, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1.1.1).

Once a biological impairment(s) is discovered, the next step is to identify the source(s) of stress on the biological community. A Stressor Identification (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 result of the SID process is the identification of the stressor(s) for which the TMDL may be developed. For example, 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 determine the TMDL and implementation goals needed to restore the impaired condition.

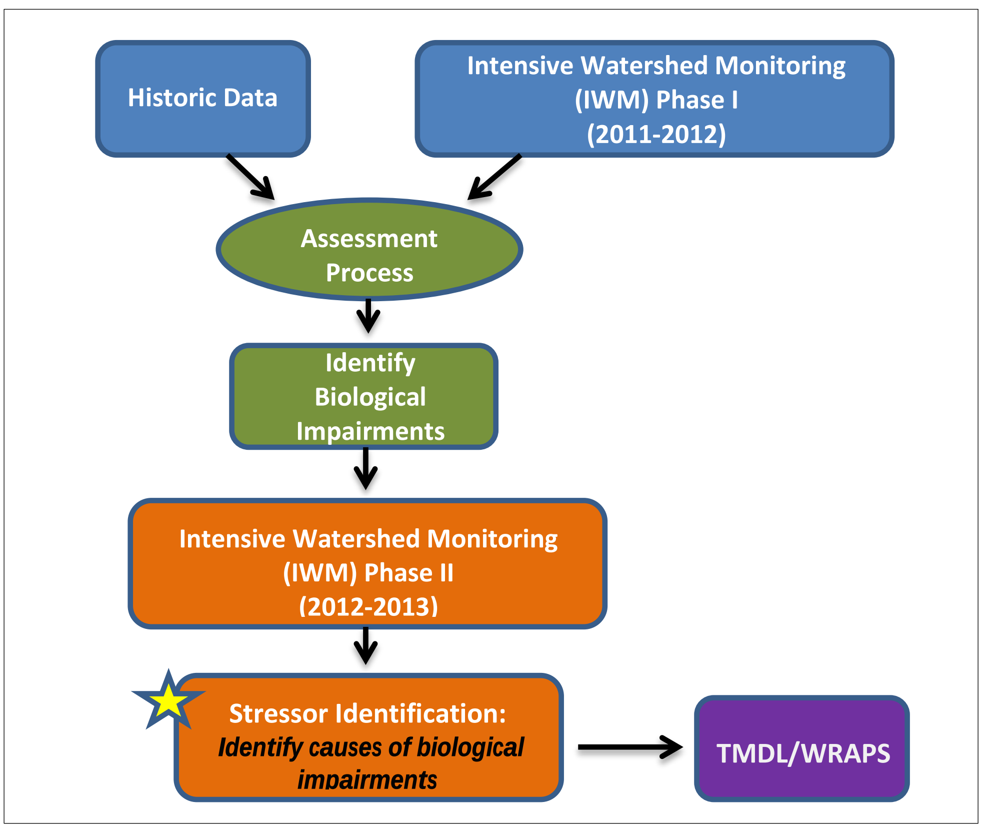


Figure 1.1.1: Process map of Intensive Watershed Monitoring, Assessment, Stressor Identification and TMDL processes.

1.2. Stressor identification process

The MPCA follows the U.S. Environmental Protection Agency's (EPA)'s process of identifying stressors that cause biological impairment, which has been used to develop the MPCA's guidance to stressor identification (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 Stressor Identification. Additional information on the Stressor Identification process using CADDIS can be found here: http://www.epa.gov/caddis/.

Stressor Identification 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 1.2.1. 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.

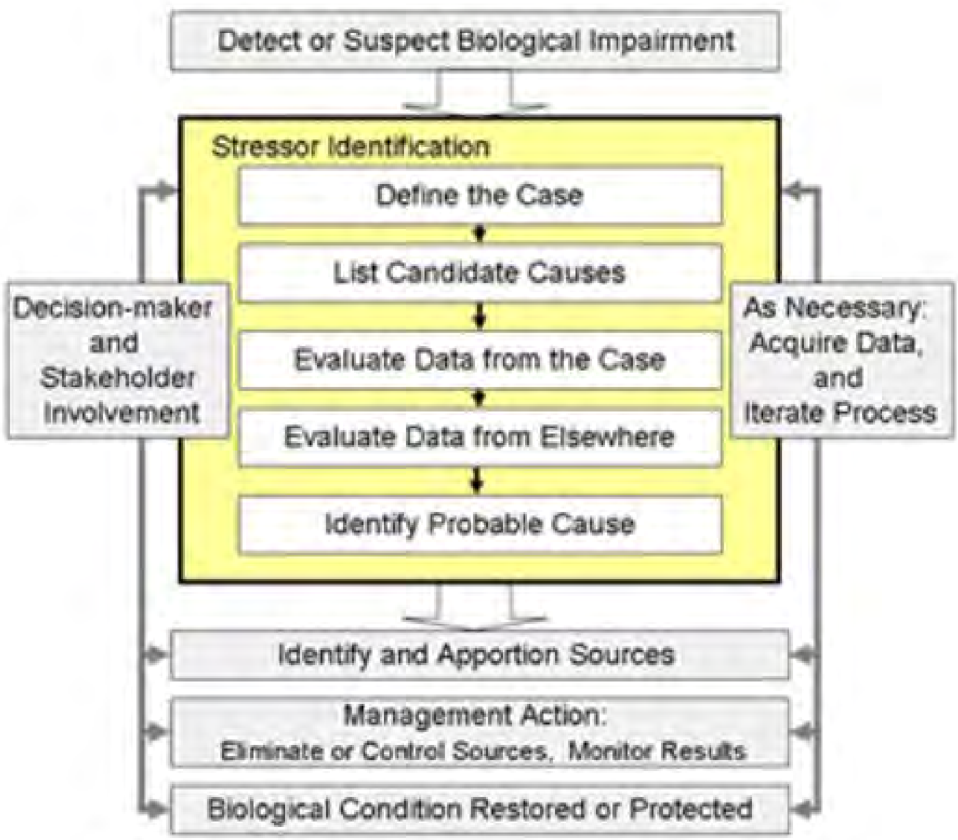


Figure 1.2.1: Conceptual model of Stressor Identification process.

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 (Table A1). 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 has 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. The scoring scale for evaluating each type of evidence in support of or against a stressor is shown in Table A2. 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(s). 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 fails to function properly and is listed as an impaired water body. Table 1.3.1 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 1.3.1: 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 Health	Stressor(s)	Link to Biology
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 TSS** · 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 report will be organized by Assessment Unit Identification (AUID). Each AUID that has a biological impairment will be discussed in detail in Chapter 4 of this report. The candidate stressors that were considered during the stressor identification process will be reviewed and discussed in Chapter 3 of this report.

2. Overview of Red Eye River Watershed

2.1. Background

From its source at Wolf Lake in Becker County (approximately 13 miles northwest of Menahga), the Red Eye River flows southeast to its confluence with the Leaf River ten miles north of Staples. The Leaf River then continues to flow southeast where it flows into the Crow Wing River five miles north of Staples. The Red Eye River Watershed begins in Becker County and also encompasses all or portions of Otter Tail, Todd, and Wadena Counties covering 899 square miles and draining approximately 575,360 acres. The watershed has a large wetland complex that runs through the center from west to east with the northern half of the watershed being predominately hardwood forest and wetland with scattered agricultural lands. The southern half of the watershed is opposite, with predominately agricultural lands and scattered wetlands, hardwood forests, and lakes (Figure 2.1.1).

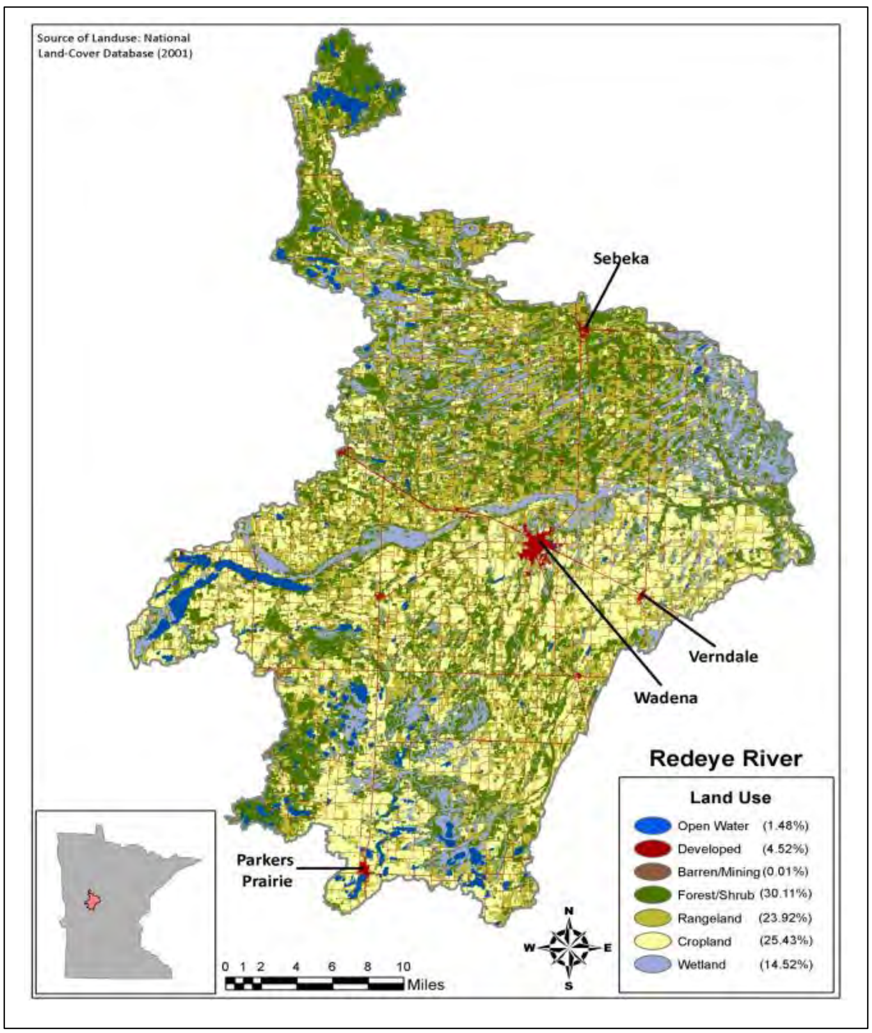


Figure 2.1.1: Land Use in the Red Eye River Watershed

2.1.1 Subwatersheds

Due to the sheer size of the watershed and the presence of channelization and reservoirs, it is difficult to evaluate potential stressors to aquatic life without further stratifying the Red Eye (RE) River drainage into smaller sections. Although there may be some consistent chemical and physical stressors found throughout the RE Watershed, some are likely acting locally, driven by landscape characteristics specific to a certain region of the watershed. For the purpose of addressing biological impairments in the RE, the watershed was stratified in aggregated 12-digit HUC units. The RE Monitoring and Assessment Report uses HUC-11's which are slightly larger in size. Figure 2.1.2 below shows the watershed boundaries used in this report. The Red Eye River Watershed has 10 Aggregated HUC-12 subwatershed units. Six stream AUIDs were impaired for biology in four different Aggregated HUC-12 units. All four of the impaired HUC-12s have a significant amount of agricultural land use occurring in the subwatershed. This report will discuss the stream reach AUID that is impaired as part of the subwatershed that it resides in.

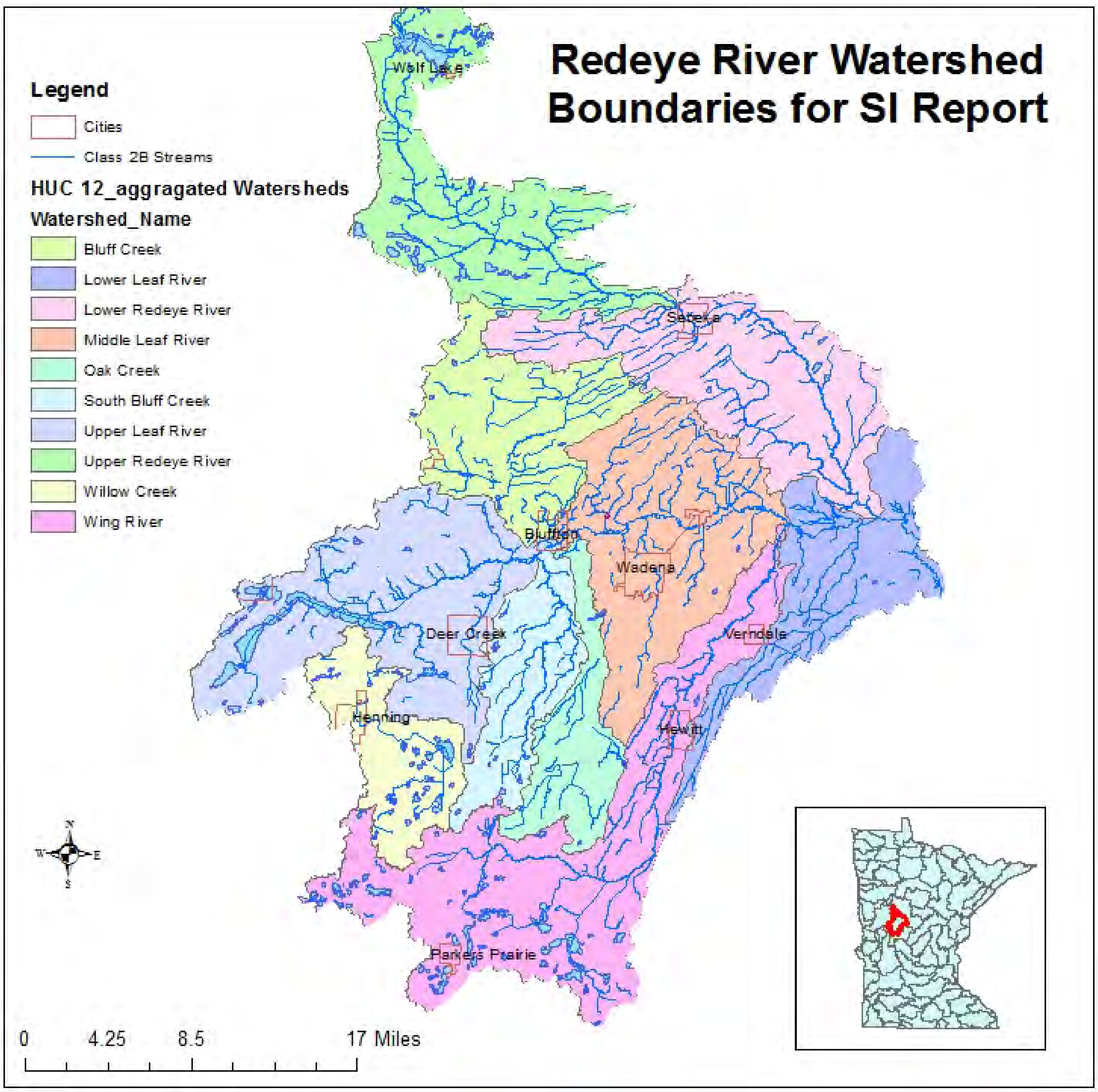


Figure 2.1.2: Aggregated 12-HUC watershed boundaries for use in segregating the watershed into manageable drainage areas for reporting.

2.2. Monitoring and assessment status

The Red Eye River Watershed was assessed in 2013. For the full assessment report access the Red Eye River monitoring and assessment report located here. The Red Eye River Watershed has four AUIDs that are impaired for fish, macroinvertebrates, or both. The watershed was initially sampled in 2011 with follow up biological sampling occurring in 2012 and 2013 at select locations to verify initial results. Figure 2.2.1 shows the water quality stations, dissolved oxygen stations and biologically impaired sampling locations along with all biological sampling locations and cities.

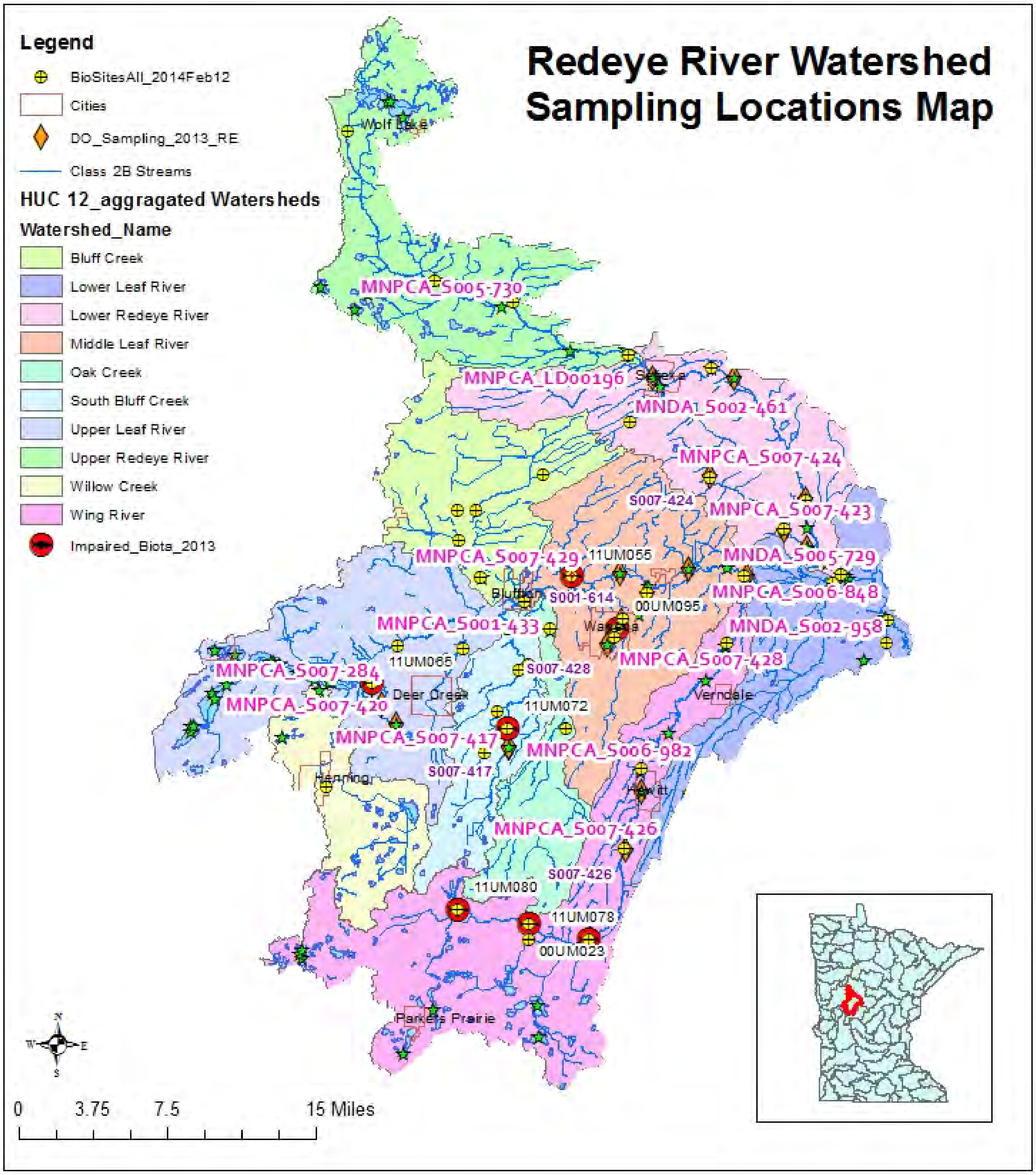


Figure 2.2.1: Map of biological monitoring stations and impaired AUIDs along with Aggregated HUC-12 used for later discussion in this report.

Water chemistry data used in the stressor identification report comes from Environmental Quality Information System (EQuIS) sites. These sites can have data ranging from the 1990's through 2013. The data analyzed for this report is from 2002 through 2013. Nutrient concentrations and sediment concentration data is stored in EQuIS and can accessed through the EQuIS website located here. This website also contains biological monitoring site information as well.

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 develop an index of biological integrity (IBI). The IBI scores can then be compared to a range of thresholds.

The fish and macroinvertebrates within each Assessment Unit Identification (AUID) were compared to a regionally developed threshold and confidence interval and utilized a weight of evidence approach. Within the Red Eye River Watershed, six AUIDs are currently impaired for a lack of biological assemblage (Table 2.3.1). The two AUID's on Union creek were not included in this study. A DO TMDL will be developed for the Union Creek AUID that is impaired for DO.

Table 2.3.1: Biologically impaired AUIDs in the Red Eye River Watershed.

			Impairments	
Stream Name	**AUID #**	**Reach Description**	**Biological**	**Water Quality**
Trib to East Leaf Lake	07010107-554	*County Ditch 49 to East Leaf Lake*	Fish	NA
South Bluff Creek	07010107-553	*Unnamed Ditch to Unnamed Creek*	Fish/Invert	NA
Wing River	07010107-559	*Headwaters (Wing River Lake 56-0043-00) to Hwy 210 bridge*	Fish	NA
Trib. To Leaf River	07010107-557	*Unnamed Creek to Leaf River*	Invert	NA
Union Creek	07010107-508	*Whisky Creek to Leaf River*	Fish/Invert	DO
Union Creek	07010107-509	*Headwaters to Whisky Creek*	Fish/Invert	NA

Abbreviations for Impairment Status: NA= Not Assessed

The assessment process uses a weight of evidence approach when considering the status of the biological community. The water chemistry, biological IBI score for both fish and macroinvertebrates, along with the current land use and potential for pollutant transport are all reviewed when determining the status of the biological community. The IBI score is used as an indicator to the overall biological community health of the stream but it is often not the only factor used to base the decision on calling a site impaired. The fish and macroinvertebrate thresholds and confidence limits are shown by class for sites found in the Red Eye River Watershed in Table 2.3.2 and Table 2.3.3. For a complete description of the fish and macroinvertebrate classes, please see Appendix A.

Each IBI is comprised of a fish or macroinvertebrate metric that is based on community structure and function and produces a metric score scaled 0 to 100 points. The number of metrics that make up an IBI will determine the metric score scale. For example, an IBI with 8 metrics would have a scale from 0-12.5 and an IBI with 10 metrics would have a scale from 0-10.

Table 2.3.2: Fish classes with respective IBI thresholds and upper/lower confidence limits (CL) found in the Red Eye River Watershed.

Class	Class Name	IBI Thresholds	Upper CL	Lower CL
5	Northern Streams	50	59	41
6	Northern Headwaters	40	56	24
7	Low Gradient	40	50	30
11	Northern Coldwater	37	47	37

Table 2.3.3: Macroinvertebrate classes with respective IBI thresholds and upper/ lower CL found in the Red Eye River Watershed.

Class	Class Name	IBI Thresholds	Upper CL	Lower CL
3	Northern Forest Streams RR	50.3	62.9	37.7
4	Northern Forest Stream GP	52.4	66	38.8
5	Southern Streams RR	35.9	48.5	23.3
6	Southern Forest Streams GP	46.8	60.4	33.2
8	Northern Coldwater	26	38.4	13.6

The purpose of stressor identification is to interpret the data collected during the biological monitoring and assessment process. Trends in the IBI scores can help to identify causal factors for biological impairments. The macroinvertebrate and fish IBI scores are shown in Table 2.3.4.

The IBI scores are color coded by relationship to threshold and confidence interval which is available in Table 2.3.5. Figure 2.2.1 shows the location of the impaired AUIDs within the Red Eye River Watershed. The individual impaired AUIDs will be discussed in Section 4 of this report along with a more detailed analysis of the fish and macroinvertebrate metrics.

Overall the biological communities had passing IBI scores for both fish and macroinvertebrates during the 2012 sampling cycle in the Red Eye River Watershed. Many of the passing IBI scores were well above the threshold and were above the upper confidence interval.

Table 2.3.4: Fish and macroinvertebrate IBI scores by biological station within AUID. Key to color coding in Table 2.3.5.

AUID & Reach	Station	Year	Fish IBI Score*	Fish Class	Macroinvertebrate IBI Score*	Macroinvertebrate Class
07010107-554 **Trib. To East Leaf Lake** *County Ditch (CD)49 to East Leaf Lake*	11UM065	2012	34	6	NA	
07010107-553 **South Bluff Creek** *Unnamed Ditch to Unnamed Creek*	11UM072	2011	31 46	6	46.95	6
07010107-559 **Wing River** *(Wing R. Lake 56-0043-00) to Hwy 210 Bridge*	11UM077	2011	37	5	71.99	5
07010107-559 **Wing River** *(Wing R. Lake 56-0043-00) to Hwy 210 Bridge*	11UM078	2011	30	5	51.18	5
07010107-557 **Trib. To Leaf River** *Unnamed Creek to Leaf River*	11UM055	2011	47	6	29.35	3

Table 2.3.5: Key to color coded IBI scores.

≤ lower CL	> lower CL & ≤ Threshold	> threshold & ≤ upper CL	> upper CL	NA = Not available

2.4 Hydrological simulation program - FORTRAN (HSPF) model

The Hydrological Simulation Program - FORTRAN (HSPF) is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates watershed-scale Agricultural Runoff Model (ARM) and NPS models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at the outlet of any subwatershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical.

The HSPF watershed model contains components to address runoff and constituent loading from pervious land surfaces (PERLNDs), runoff and constituent loading from impervious land surfaces (IMPLNDs), and flow of water and transport/transformation of chemical constituents in stream reaches (RCHRESs). Primary external forcing is provided by the specification of meteorological time series. The model operates on a lumped basis within subwatersheds. Upland responses within a subwatershed are simulated on a per-acre basis and converted to net loads on linkage to stream reaches within each subwatershed, the upland areas are separated into multiple land use categories.

An HSPF watershed model was run for the Red Eye watershed to predict water quality condition throughout the watershed on an hourly basis from 1996-2009.

3. Possible Stressors to Biological Communities

A comprehensive list of potential stressors to aquatic biological communities compiled by the EPA can be found here (http://www.epa.gov/caddis/si_step2_stressorlist_popup.html). This comprehensive list serves two purposes. First, it can be 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 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. 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

Initially nine candidate causes were evaluated to address the biological impairments found in the four impaired AUID's in the Red Eye River Watershed. The following sections of the report will describe the reasoning behind either including the candidate causes for further analysis or placing the candidate causes into the inconclusive candidate portion of the report. At this point there are no eliminated candidate causes.

3.2. Inconclusive causes

Elevated stream temperature was deemed to be inconclusive as a stressor to aquatic life in the Red Eye River Watershed. Warm water streams are not to exceed 30°C in any given day as a daily maximum temperature. Temperature data is readily available through much of the Red Eye River Watershed. Most of the temperature data is instantaneous data and was collected sporadically over the course of 2002 through 2012. The temperature data that was reviewed showed no exceedances of the 30°C daily maximum, however; temperature data is limited and a more in depth collection of temperature data would be required to eliminate elevated temperature as a stressor.

Ammonia toxicity can be detrimental to aquatic life when the concentrations of unionized ammonia (NH_3) exceed 0.040 mg/L. There currently is no data on either ionized (NH_4) or unionized ammonia (NH_3). Additional data collection would be required to adequately assess the impact that ammonia is having on the aquatic life in the Red Eye River Watershed.

3.3. Summary of candidate causes in the Red Eye River Watershed

The initial list of candidate/potential causes was narrowed down after the initial data evaluation/data analysis resulting in seven candidate causes for final analysis in this report.

3.3.1. Candidate cause: Low dissolved oxygen

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

3.3.1.1. Water quality standards

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

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

The class 2A (coldwater) water quality standard for DO in Minnesota is 7 mg/L as a daily minimum.

3.3.1.2. Ecoregion information

There currently is no applicable ecoregion information for low DO.

3.3.1.3. Types of dissolved oxygen data

1. **Point measurements**
   Instantaneous DO data is available throughout the watershed and can be used as an initial screening for low DO. These measurements represent discrete point samples. Because DO concentrations can vary significantly with changes in flow conditions and time of sampling, instantaneous measurements need to be used with caution and are not completely representative of the DO regime at a given site.

2. **Longitudinal (synoptic)**
   A series of longitudinal synoptic DO surveys were conducted throughout the RE Watershed in 2013. A synoptic monitoring approach gathers data across a large spatial scale and minimal temporal scale (as close to simultaneously as possible). In terms of DO, the objective was to sample a large number of sites from upstream to downstream under comparable ambient conditions. For the most part, the surveys took place in mid to late summer when low DO is most commonly observed. Dissolved oxygen readings were taken at pre-determined sites in the early morning in an attempt to capture the daily minimum DO reading.

3. **Diurnal (continuous)**
   YSI sondes were deployed for 7-12 day intervals at sites located in the Red Eye River in late summer to capture the diurnal fluctuations. This data revealed the magnitude and pattern of diurnal DO flux at each site. The diurnal DO sampling results for the Red Eye River can be found in Appendix C of this report.

3.3.1.4. Sources and causal pathways model for low dissolved oxygen

Dissolved oxygen concentrations in streams are driven by a combination of natural and anthropogenic factors. Natural background characteristics of a watershed, such as topography, hydrology, climate, and biological productivity can influence the DO regime of a waterbody. Agricultural and urban land uses, impoundments (dams), and point-source discharges are just some of the anthropogenic factors that can cause unnaturally high, low, or volatile DO concentrations. The conceptual model for low DO as a candidate stressor in the RE Watershed is shown in EPA CADDIS website by following this link: Dissolved oxygen simple conceptual diagram | CADDIS: Sources, Stressors & Responses | US EPA.

3.3.1.5. Overview of dissolved oxygen trends in the Red Eye River Watershed

The Red Eye River Watershed has multiple locations where DO data has been collected during the course of 2002-2012. The available DO data has been reviewed during the watershed assessment cycle in 2013. Currently there are two AUID's that are impaired for aquatic life based on DO data. These two AUID's are 07010107-505 which is the Leaf River from Oak Creek to the Wing River, and AUID 07010107-508 which is Union Creek from Whisky Creek to the Leaf River. The remaining AUID's in the watershed either did not have enough DO data to conduct an assessment or are showing full support based on the current DO data. Small individual AUID's that did not have sufficient DO data during assessment but had a low biological IBI have since been investigated with additional DO data being collected which will be presented in Chapter 4 of this report. Based on the available data low DO concentrations do not appear to be a watershed wide problem rather isolated to certain AUID's.

3.3.2. Candidate cause: Flow alteration

Flow alteration is the change of the stream flow regime caused by anthropogenic sources. These sources can include channel alteration, water withdrawals, land cover alteration, agricultural tile drainage, and impoundment. To learn more about flow alteration go to the EPA CADDIS webpage here.

Across the conterminous U.S., Carlisle et al. (Carlisle, Wolcock, & Meador, 2010) found that there is a strong correlation between diminished stream flow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to a decreased wetted width, cross sectional area, and water volume. Aquatic organisms require adequate living space and when flows are reduced beyond normal baseflow, competition for resources increases. Pollutant concentrations can increase when flows are lower than normal, making it more difficult for populations to maintain a healthy diversity. Often tolerant organisms that can outcompete others in such limiting situations will thrive. Low flows of prolonged duration lead to macroinvertebrate and fish communities comprised of generalist species or that have preference for standing water (U.S.EPA, CADDIS Volume 2 Sources, Stressors & Responses, 2012).

3.3.2.1 Water quality standards

There currently is no applicable standard for flow alteration.

3.3.2.2 Ecoregion information

There currently is no applicable ecoregion information for flow alteration.

3.3.2.3 Types of flow alteration data

Each 8-HUC has a minimum of four continuous recording stream gages located at various points within the watershed. The pour point of the 8-HUC has a permanent gage that will be collecting continuous stream stage data and corresponding discharge measurements for rating table calculations. Within the 8-HUC there is variability statewide as to the design and location of the representative 12-HUC scale stream gage locations. At a minimum there should be three smaller scale (12-HUC) stream gages that can be used to review flow conditions during the time of biological monitoring and post biological monitoring conditions. The data from the gages can be used for HSPF Model calibration and can be extrapolated for smaller size streams with the 8-HUC. In some instances special short term gages can be installed to collect a 2-3 year record of stream discharge at smaller scale subwatersheds such as a 14-HUC level. This data would be available upon request and would need to be coordinated with the MPCA regional field staff or local partner for installation and operation. All relevant flow data shall be stored and calculated in the Hydstra database.

3.3.2.4 Sources and causal pathways model for flow alteration

The conceptual model for flow alteration can be found on the EPA webpage. The causes and potential sources for altered flow are modeled at EPA's CADDIS Flow Alteration webpage.

3.3.2.5. Overview of flow alteration trends in the Red Eye Watershed

The Red Eye River Watershed has 49.6% of its stream miles altered. Figure 3.3.1 shows the Red Eye River Watershed with green lines representing natural stream channels and red lines representing altered stream channels. Stream channelization is prevalent throughout the watershed with many of the biologically impaired stream reaches located downstream of channelized stream reaches. The altered stream reaches can impact stream flow and alter the amount of available stream habitat.

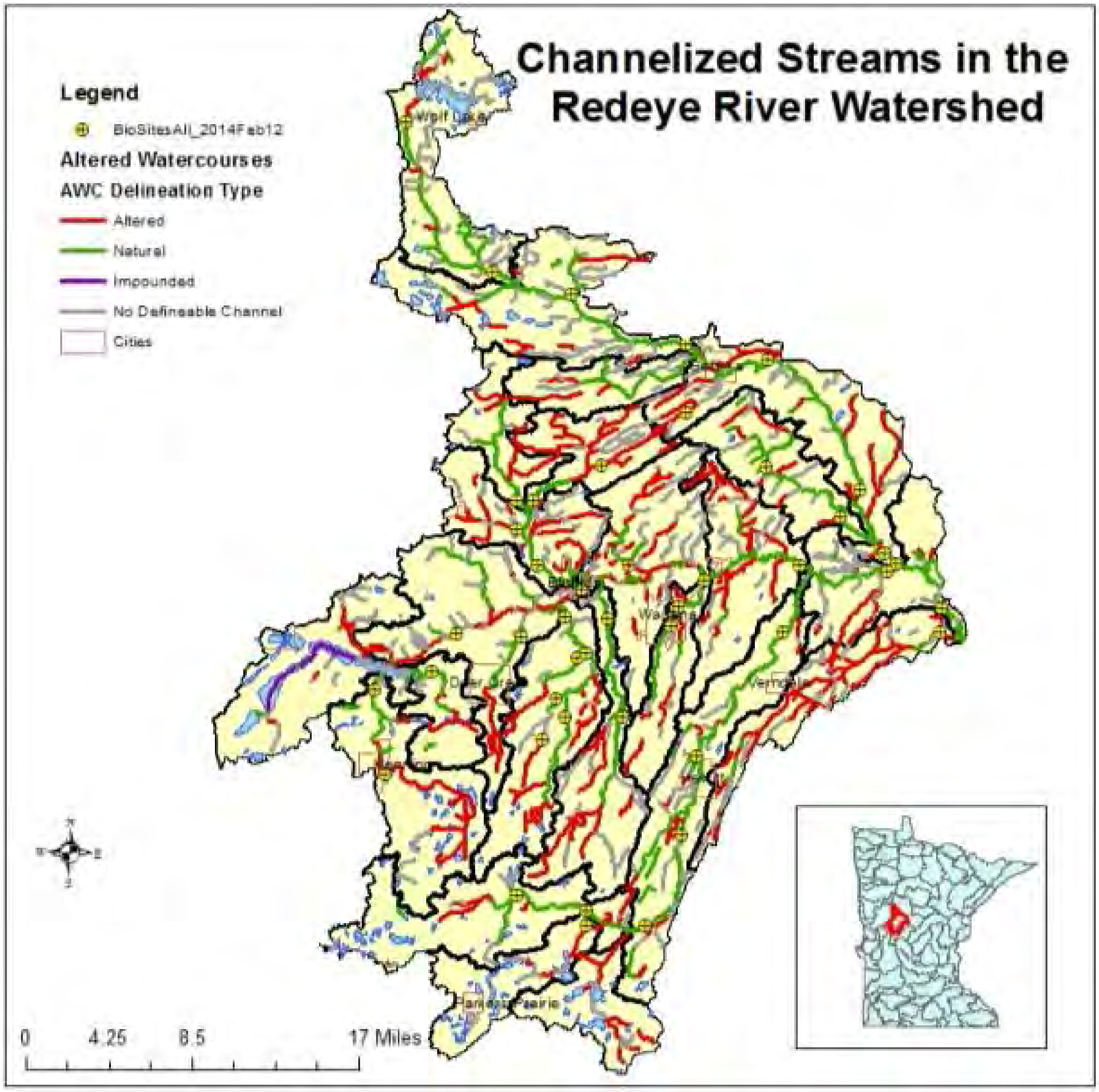


Figure 3.3.2.1: The Red Eye River Watershed and its many altered stream channels.

3.3.3. Candidate cause: Increased sediment

Total suspended solids (TSS) and bedded sediment are related through several common watershed sources and processes, but each can affect aquatic biota in different ways. Due to the inter-related nature of these parameters, they are grouped together in this report for causal analysis purposes, but ultimately each of these candidate causes will be evaluated independently in terms of impact on fish and macroinvertebrate populations.

Whereas suspended solids and turbidity are potential stressors operating in the water column, bedded (= deposited) sediments impact the stream substrate. Excessive deposition of fine sediment can impair macroinvertebrate habitat quality and productivity (Rabeni et al., 2005). To date, bedded sediment has not been extensively studied in the RE Watershed, in part because there is no state or federal water quality standard for this parameter. Quantitative field measurement of bedded sediment (bedload) is very difficult. However, a significant amount of data on substrate composition and embeddedness (the degree in which fine sediments surround coarse substrates on the surface of a stream bed) was collected. These data will be used to determine whether or not natural coarse substrate (a very important habitat type) is being covered or filled in by excess fine sediment.

To learn more about sediment effects on stream organisms go to the EPA CADDIS webpage here.

3.3.3.1 Water quality standards

The water quality standard for turbidity is 25 Nephelometric Turbidity Units (NTUs) for Class 2B waters. Total suspended solids and transparency tube/Secchi tube measurements can be used as surrogate standard. A regression of the TSS to turbidity indicates impairment at 30 mg/L for waters within the North Central Hardwoods Ecoregion.

A strong correlation exists between the measurements of TSS concentration and turbidity. In 2010, MPCA released draft TSS standards for public comment (MPCA, 2009). The new TSS criteria are stratified by geographic region and stream class due to differences in natural background conditions resulting from the varied geology of the state and biological sensitivity. The draft TSS standard for RE Watershed has been set at 30 mg/L. For assessment, this concentration is not to be exceeded in more than 10% of samples within a 10-year data window.

For the purposes of stressor identification, TSS results will be relied upon to evaluate the effects of suspended solids and turbidity on fish and macroinvertebrate populations. TSS results are available for the watershed from state-certified laboratories, and the existing data covers a much larger spatial and temporal scale in the watershed.

3.3.3.2 Ecoregion information

There currently is no applicable ecoregion information for increased sediment.

3.3.3.3 Types of sediment data

TSS data is collected by collecting a stream water sample and having the sample filtered and weighed to determine the concentration of TSS in the sample. Bedded sediment is visually estimated by looking at the fine material surrounding rock or woody substrate within the stream channel. Bedded sediment is also analyzed by conducting pebble counts in stream reaches and analyzing the D_{50} particle size in both the stream reach and the representative riffle site.

3.3.3.4 Sources and causal pathways model for sediment

Rangeland and pasture are common landscape features throughout the RE Watershed. Most of these areas are operated for cattle grazing, but several horse operations were noted during reconnaissance trips throughout the watershed. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase streambank erosion and reduce substrate quality (Kauffman, 1984). In some areas, the riparian corridor along the Red Eye tributaries has been cleared for pasture and heavily grazed, resulting in a riparian zone that lacks deep-rooted vegetation necessary to protect streambanks and provide shading. Exposures of these areas to weathering, trampling, and shear stress (water friction) from high flow events are increasing the quantity and severity of bank erosion.

The causes and potential sources for increases in sediment in the Red Eye watershed are modeled at EPA's CADDIS Sediments webpage.

3.3.3.5. Overview of sediment trends in the Red Eye Watershed

TSS data was collected throughout the Red Eye River Watershed. The TSS results for the various Aggregated 12-HUC s that were sampled in the Red Eye River Watershed were often well below the proposed standard of 30mg/L TSS. The only TSS concentrations sampled that were above the 30 mg/L standard are from the Wing and Leaf Rivers. Each subwatershed had a few sample concentrations above the 30mg/L standard from 2005 and 2006. Figure 3.3.2 and 3.3.3 below show the TSS concentrations for the Leaf and Wing River Subwatersheds.

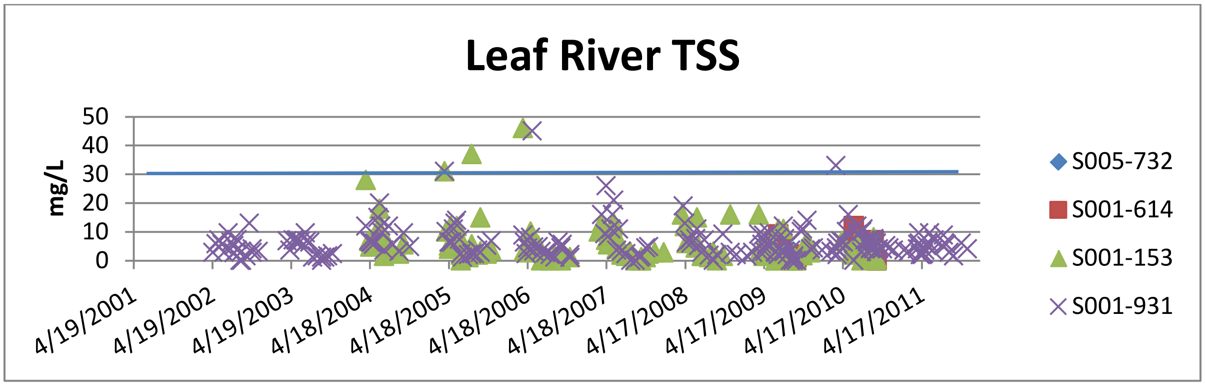


Figure 3.3.1: TSS concentrations from various water quality sampling locations on the Leaf River. Data was collected from 2002-2011.

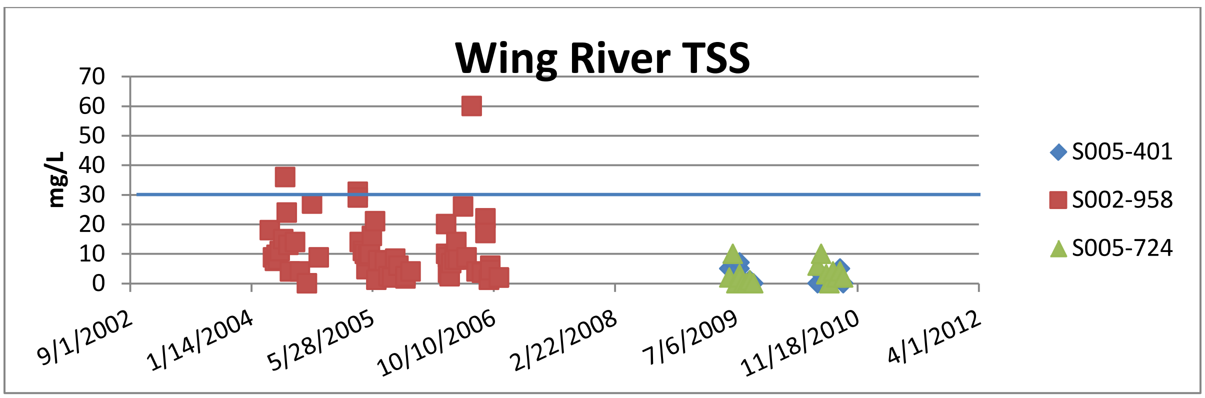


Figure 3.3.2: TSS concentrations from the various water quality sampling locations on the Wing River. Data was collected from 2004-2010.

Overall review of the TSS for the various watershed sites located throughout the Red Eye River Watershed show that TSS is not a problem in the watershed.

3.3.4. Candidate cause: Increased bedded sediment

Excess fine sediment deposition on benthic habitat has been proven to adversely impact fish and macroinvertebrate species that depend on clean, coarse stream substrates for feeding, refugia, and/or reproduction (Newcombe & MacDonald, 1991). Aquatic macroinvertebrates are generally affected in several ways: (1) loss of certain taxa due to changes in substrate composition (Erman & Ligon, 1988); (2) increase in drift (avoidance by movement with current) due to sediment deposition or substrate instability (Rosenberg & Wiens, 1978); and (3) changes in the quality and abundance of food sources such as periphyton and other prey items (Pekarsky, 1984). Fish communities are typically influenced through: (1) a reduction in spawning habitat or egg survival (Chapman, 1988) and (2) a reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985); (Gray & Ward, 1982). Fish species that are simple lithophilic spawners require clean, coarse substrate for reproduction. These fish do not construct nests for depositing eggs, but rather broadcast them over the substrate. Eggs often find their way into interstitial spaces among gravel and other coarse particles in the stream bed. Increased sedimentation can reduce reproductive success for simple lithophilic spawning fish, as eggs become smothered by sediment and become oxygen deprived. The sediments primarily responsible for causing an embedded condition in southern Minnesota streams are sand and silt particles, which can be transported in the water column under higher flows, or as a bedload component. When stream velocities decrease, these sediments can "settle out" into a coarser bottom substrate area, thus causing an embedded condition.

To learn more about sediment effects on stream organisms go to the EPA CADDIS webpage here.

3.3.4.1 Water quality standards

There currently is no applicable standard for lack of habitat due to deposited and bedded sediment for biotic communities.

3.3.4.2 Ecoregion information

There currently is no applicable ecoregion information for increased sediment.

3.3.4.3 Types of sediment data

Bedded sediment is visually estimated by looking at the fine material surrounding rock or woody substrate within the stream channel. Bedded sediment is also analyzed by conducting pebble counts in stream reaches and analyzing the D_{50} particle size in both the stream reach and the representative riffle site.

3.3.4.4 Sources and causal pathways model for sediment

Rangeland and pasture are common landscape features throughout the RE Watershed. Most of these areas are operated for cattle grazing, but several horse operations were noted during reconnaissance trips throughout the watershed. Cattle pasture within the riparian corridor of rivers and streams has been shown to increase streambank erosion and reduce substrate quality (Kauffman, 1984). The causes and potential sources for increases in sediment in the Red Eye watershed are modeled at EPA's CADDIS Sediments webpage.

3.3.4.5. Overview of increased bedded sediment trends in the Red Eye Watershed

The amount of bedded sediment was only quantified at biological sampling locations that did not meet the expected IBI score. Review of watershed wide bedded sediment issues is limited to reviewing the percent of fish that are lithophilic spawners from the entire watershed. This review is difficult due to the fact that the fish communities that passed the IBI may or may not require a high percentage of simple lithophilic spawning fish. This depends on the stream fish class along with the species composition at the site. Watershed wide the average fish community was made up of 33% simple lithophilic spawners. This ranged from 0% to 80%. In Chapter 4 of this report we will discuss the potential of bedded stressors to the individual AUID's that did not meet their biological criteria standard.

3.3.5. Candidate cause: Elevated nutrients

Nutrients are elements that are essential for plant growth, including nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca). N and P are often considered primary nutrients and are the major limiting nutrients in aquatic ecosystems. Nutrient concentrations are often linked to the trophic status of freshwater systems. Increased nutrients can cause excessive plant and algal growth, which can alter physical habitat, alter food chains, and create toxic conditions. Elevated nutrients have indirect effects on aquatic communities and direct impacts to aquatic communities from response variables such as DO flux, chlorophyll-a, and biological oxygen demand (BOD) (Heiskary, Bouchard, & Markus, 2013). Elevated nutrient sources can include urban stormwater runoff, agricultural runoff, animal waste management, fertilizer management, industrial and wastewater facility discharges. To learn more about elevated nutrients as stressor to aquatic life go to the EPA CADDIS webpage here.

3.3.5.1 Water quality standards

Streams classified as Class 1 waters of the state, designated for domestic consumption, in Minnesota have a nitrate-nitrogen water quality standard of 10 mg/L. At this time, none of the AUIDs in the RE Watershed that are impaired for biota are classified as Class 1 streams. Minnesota currently does not have a nitrate standard for other waters of the state besides for Class 1. The MPCA has developed draft standards designed to protect aquatic life.

A stream nutrient criterion for Total Phosphorus (TP) is currently being developed by MPCA. The draft standard can be found in the Minnesota Nutrient Criteria Development for Rivers document published by MPCA in January 2013. This document can be found here. The TP nutrient criteria for rivers are divided into three regions for the state. Table 3.3.1 below lists the proposed river nutrient criteria by region. The current draft standard for Phosphorus is a maximum stream concentration listed in table 3.3.1 with at least one response variable out of desired range (BOD, DO flux, chlorophyll-a, and/or pH).

Table 3.3.1: Draft river eutrophication criteria ranges by River Nutrient Region for Minnesota

	Nutrient	Stressor		
Region	**TP µg/L**	**Chl-a µg/L**	**DO flux mg/L**	**BOD_5 mg/L**
North	≤50	≤7	≤3.0	≤1.5
Central	≤100	≤20	≤3.5	≤2.0
South	≤150	≤35	≤4.5	≤2.0

3.3.5.2 Ecoregion information

McCollor and Heiskary (1993) compiled NO_2 – NO_3 data for minimally impacted streams from Minnesota's ecoregions in an effort to provide a basis for establishing water quality goals. Most of the RE Watershed falls within the North Central Hardwood Forest ecoregion, which has an ecoregion norm of 0.04 to 0.26 mg/L for NO_2+NO_3-N. The one sampling location that routinely was above the ecoregion norm was Spruce Creek at station S007-439. This site ranged from 0.21 to 2 mg/L.

3.3.5.3 Types of nutrient data

Stream and river water samples are collected at various locations throughout the 8-HUC. Samples are sent to a state certified laboratory and analyzed for a number of water quality parameters including nutrients. Laboratory analytical data is then stored in the EQuIS database and can be accessed via the MPCA webpage here.

3.3.5.4 Sources and causal pathways model for elevated nutrients

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

Given the amount of cultivated cropland in the watershed, it is feasible that fertilizer application is a prominent source of nitrate in surface water (Folmar, Samders, & Julin, 1979). Due to the limited nitrate-nitrite data this stressor cannot be fully assessed in the RE watershed. For a complete model of causes and potential causes of nitrates in the Red Eye River Watershed, please see the EPA's CADDIS Nitrogen webpage.

Elevated phosphorus is closely tied to the dissolved oxygen fluxes that occur in streams. Increased phosphorus levels lead to increased algal and macrophyte growth which in turn leads to increased decomposition and respiration rates. Increased plant and algal growth causes increased oxygen production through photosynthesis during the day. The excess plant material eventually dies, and bacterial activity during decomposition strips oxygen from the water. This leads to low early morning DO readings in streams, and high readings in the afternoon. Streams dominated with submerged macrophytes experience the largest swings in DO and pH (Wilcox & Nagels, 2001). Phosphorus is delivered to streams by wastewater treatment facilities, urban stormwater, agricultural runoff, and direct discharges of sewage. Phosphorus bound to sediments in the river channel could be contributing to concentrations; however there is no data available. The causes and potential sources for excess phosphorus are modeled at EPA's CADDIS Phosphorus webpage.

3.3.5.5. Overview of elevated nutrient trends in the Red Eye Watershed

Elevated nutrients alone will not cause a biological response by the fish and macroinvertebrate community. Often the response is seen with eutrophication which will increase the abundance and density of aquatic macrophytes in the stream system. This increase in eutrophication can often lead to increased DO fluctuations during the diurnal DO cycle. The Red Eye Watershed has a proposed in-stream TP concentration of 0.100 mg/L. Watershed wide TP is often above the proposed standard, however; the increase in aquatic macrophytes or peryphyton do not seem to be a problem at most locations at this time.TP data collected from the Red Eye River often show values above the proposed standard but the paired chlorophyll-a (Chl-a) concentrations are often below 5 µg/L. The Leaf River watershed also has elevated TP concentrations however the Chl-a concentrations are below 10µg/L. The Wing River also shows some elevated TP data from the 2005-2006 period but recent data collected from 2009 and 2010 show all TP and Chl-a data well below the proposed standard. Figure 3.3.5 shows the TP and Chl-a concentrations for the various sampling locations that have an extended record of water quality data. This data suggests that currently TP is not a concern to the biological community however elevated TP concentrations should be mitigated to reduce the eutrophication impacts to downstream water bodies.

Elevated NO_2+NO_3 concentrations do not appear to be significant problem in the overall water quality of the Red Eye River Watershed. There are numerous water quality samples that have been collected throughout the watershed. Many of the streams have concentrations below 1 mg/L for the majority of the sampling period. The Wing and Leaf River sites have some concentrations that in the 3-5 mg/L range. Theses concentrations are generally seen during the mid-summer months and do not seem to persist for the entire summer. Hay Creek also has elevated NO_2+NO_3 and during the summer of 2009 and 2010 the concentrations were often between 3 and 5.5 mg/L. Elevated NO_2+NO_3 d concentrations do not appear to be a watershed wide problem but rather isolated to a few tributaries. Figure 3.3.4 below displays the NO_2+NO_3 data from EQuIS stations located around the watershed.

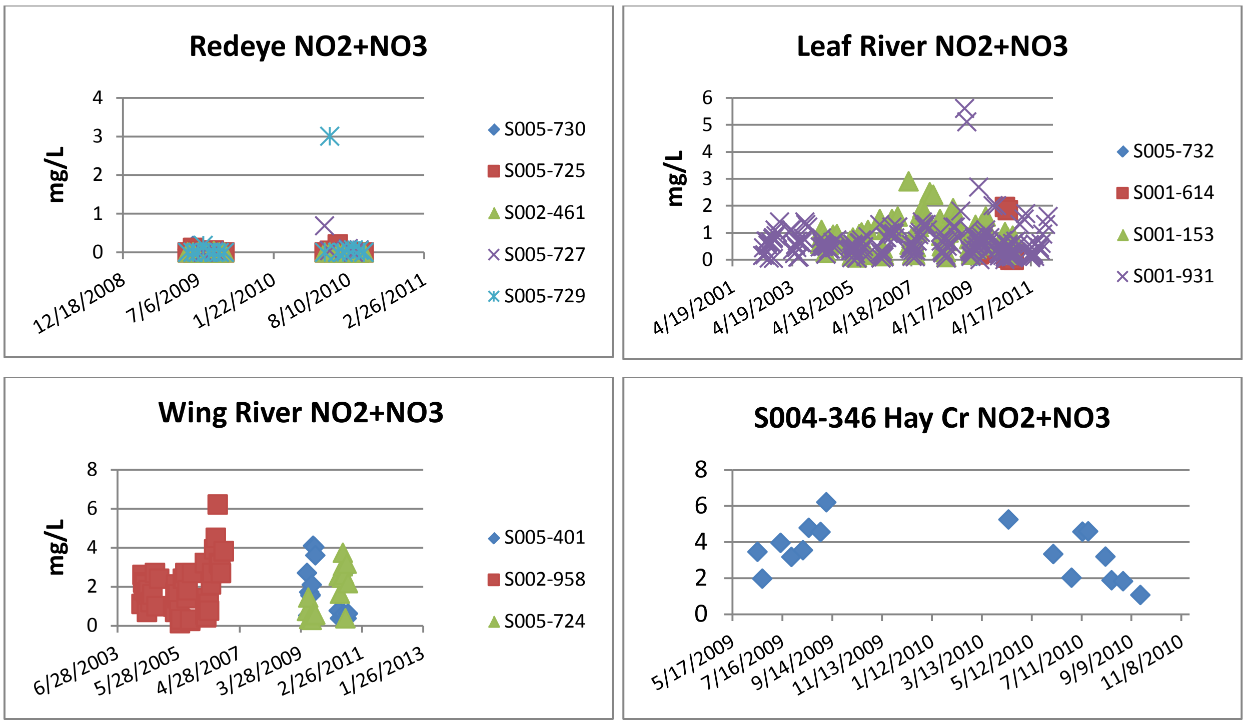


Figure3.3.3: Nitrite-nitrate concentrations at various stream locations throughout the Red Eye Watershed.

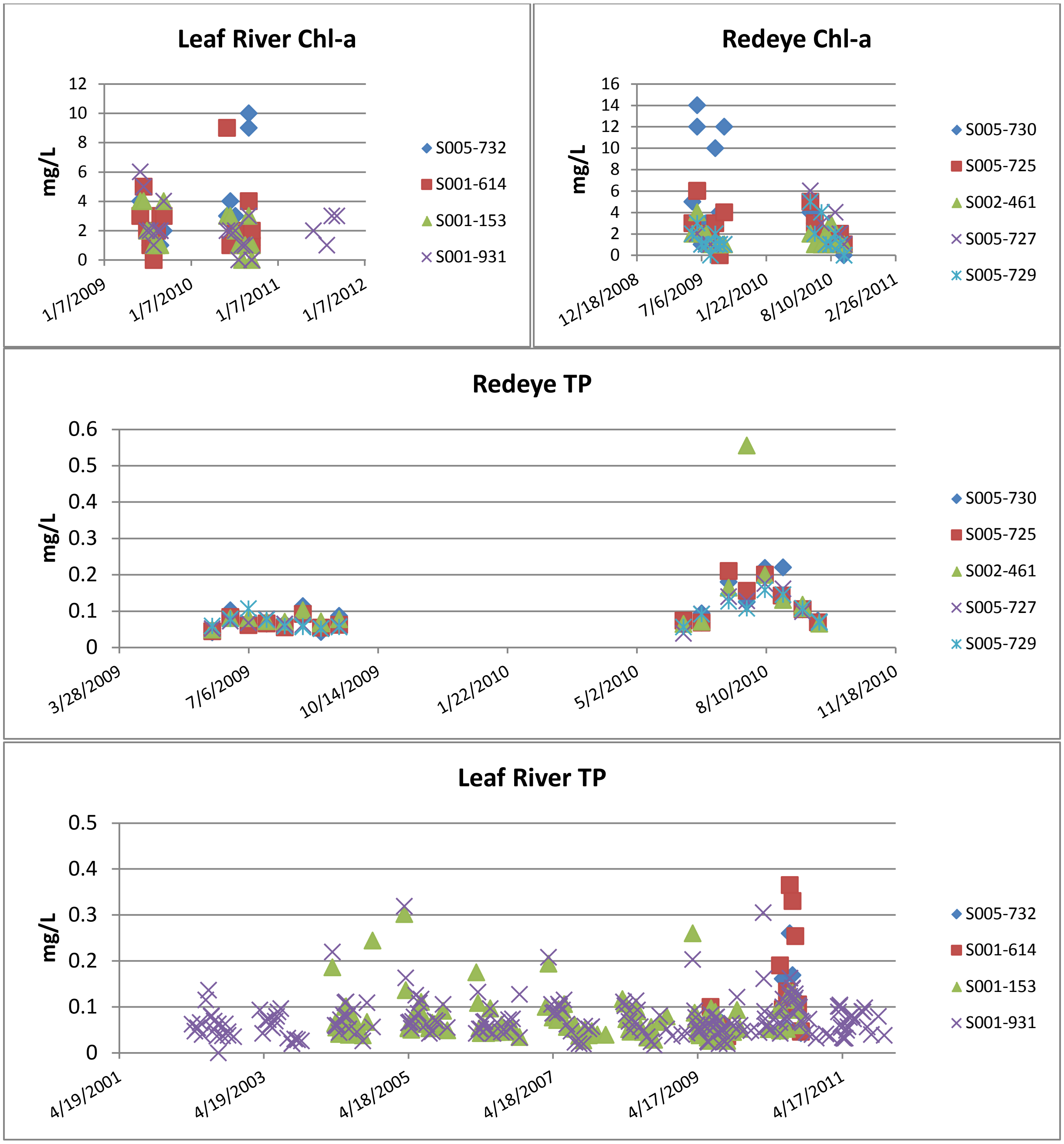


Figure 3.3.4: TP concentrations from the Red Eye and Leaf Rivers along with the corresponding Chlorophyll-a concentrations. The Red Eye and Leaf rivers are the two largest streams in the watershed which will eventually join before discharging to the Crow Wing River.

3.3.6. Candidate Cause: Lack of physical habitat

Habitat is a broad term encompassing all aspects of the physical, chemical, and biological conditions needed to support a biological community. This section will focus on the physical habitat structure including geomorphic characteristics and vegetative features (Griffith, Rashleigh, & Schofield, 2010). Physical habitat is often interrelated to other stressors (e.g., sediment, flow, dissolved oxygen) and will be addressed separately.

Specific habitats that are required by a healthy biotic community can be minimized or altered by practices on our landscape by way of resource extraction, agriculture, forestry, silviculture, urbanization, and industry. These landscape alterations can lead to reduced habitat availability, such as decreased riffle habitat; or reduced habitat quality, such as embedded gravel substrates. Biotic population changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (Griffith, Rashleigh, & Schofield, 2010).

Degraded physical habitat is a leading cause of impairment in streams on 303(d) lists. According to the USEPA CADDIS website six attributes are the main features of physical habitat structure provided by a stream: *stream size and channel dimensions*, *channel gradient*, *channel substrate size and type*, *habitat complexity and cover*, *vegetation cover and structure in the riparian zone*, *and channel-riparian interactions*. To learn more about physical habitat go to the EPA CADDIS webpage here.

3.3.6.1 Water quality standards

There are no State water quality standards for physical habitat.

3.3.6.2 Ecoregion information

There currently is no applicable ecoregion information for lack of physical habitat.

3.3.6.3 Types of physical habitat data

MPCA biological survey crews conduct a qualitative habitat assessment using the MPCA Stream Habitat Assessment (MSHA) protocol for stream monitoring sites. The MSHA protocol can be found here. MSHA scores can be used to review habitat conditions at biological sampling locations and compare those conditions against similar size streams and a variety of IBI scores. MPCA and Minnesota Department of Natural Resources (MDNR) partners are collecting stream channel dimension, pattern and profile data at select stream locations of various sizes and biological condition. This data can be used to compare channel departure from a reference condition. Habitat features can be analyzed to determine if a stream is lacking pool depth, pool spacing, adequate cross sectional area to convey discharge, and various other physical habitat features that are too numerous to list here. The applied river morphology method created by (Rosgen, 1996) is the accepted method for this data collection by the MPCA and MDNR.

3.3.6.4 Sources and causal pathways model for lack of physical habitat

Alterations of physical habitat, defined here as changes in the structural geomorphic or vegetative features of stream channels, can adversely affect aquatic organisms. Many human activities and land uses can lead to myriad changes in in-stream physical habitat. Mining and resource extraction, agriculture, forestry and silviculture, urbanization, and industry can contribute to increased sedimentation (e.g., via increased erosion) and changes in discharge patterns (e.g., via increased stormwater runoff and point effluent discharges), as well as lead to decreases in stream bank habitat and instream cover, including large woody debris (see the Sediment and Flow modules for more information on sediment- and flow-related stressors).

Direct alteration of stream channels also can influence physical habitat, by changing discharge patterns, changing hydraulic conditions (water velocities and depths), creating barriers to movement, and decreasing riparian habitat. These changes can alter the structure of stream geomorphological units (e.g., by increasing the prevalence of run habitats, decreasing riffle habitats, and increasing or decreasing pool habitats).

Typically, physical habitat degradation results from reduced habitat availability (e.g., decreased snag habitat, decreased riffle habitat) or reduced habitat quality (e.g., increased fine sediment cover). Decreases in habitat availability or habitat quality may contribute to decreased condition, altered behavior, increased mortality, or decreased reproductive success of aquatic organisms; ultimately, these effects may result in changes in population and community structure and ecosystem function. Narrative and conceptual model can be found on the EPA CADDIS webpage here.

3.3.6.5. Overview of lack of physical habitat trends in the Red Eye Watershed

Habitat quality differs throughout the Red Eye River Watershed and is an essential tool when understanding and describing the biological communities. Habitat was measured using the Minnesota Stream Habitat Assessment (MSHA) during the fish sampling event. The MSHA is useful in describing the aspects of habitat needed to obtain an optimal community. It includes five subcategories: land use, riparian zone, substrate, cover, and channel morphology.

In the Red Eye River Watershed, habitat scores were predominately fair or poor throughout the watershed (Figure 3.3.6). Many of these areas are channelized or have intensive agricultural land use. Habitat scores generally improved in the larger streams with slightly higher gradient or more forested landscapes.

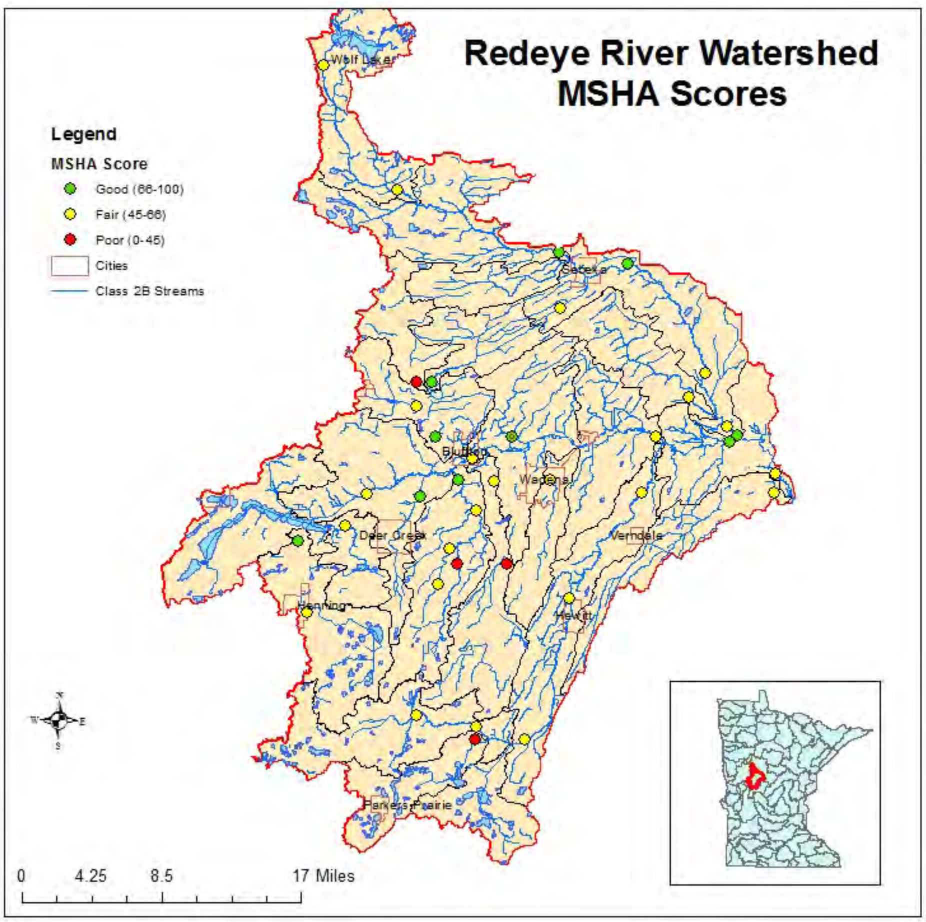


Figure 3.3.5: Average MSHA scores at biological sampling stations in the Red Eye River Watershed.

3.3.7 Candidate cause: Physical connectivity

Connectivity in river ecosystems refers to how waterbodies and waterways are linked to each other on the landscape and how matter, energy, and organisms move throughout the system (Pringle, 2003). Impoundment structures (dams) on river systems alter steamflow, water temperature regime, and sediment transport processes – each of which can cause changes in fish and macroinvertebrate assemblages (Cummins, 1979; Waters, 1995). Dams also have a history of blocking fish migrations and can greatly reduce or even extirpate local populations (Brooker, 1981; Tiemann et al., 2004). In Minnesota, there are more than 800 dams on streams and rivers for a variety of purposes, including flood control, wildlife habitat, and hydroelectric power generation.

Dams, both human-made and natural, can cause changes in flow, sediment, habitat and chemical characteristics of a waterbody. They can alter the hydrologic (longitudinal) connectivity, which may obstruct the movement of migratory fish causing a change in the population and community structure. The stream environment is also altered by a dam to a predominately lentic surrounding (Mitchell and Cunjak, 2007). Longitudinal connectivity of flowing surface waters is of the utmost importance to fish species. Many fish species' life histories employ seasonal migrations for reproduction or overwintering. Physical barriers such as dams, waterfalls, perched culverts and other instream structures disrupt longitudinal connectivity and often impede seasonal fish migrations. Disrupted migration not only holds the capacity to alter reproduction of fish, it also impacts mussel species that utilize fish movement to disperse their offspring. Structures, such as dams, have been shown to reduce species richness of systems, while also increasing abundance of tolerant or undesirable species (Winston et al*.* 1991, Santucci et al*.* 2005, Slawski et al. 2008, Lore 2011).

Longitudinal connectivity of a system's immediate riparian corridor is an integral component within a healthy watershed. Continuous corridors of high quality riparian vegetation work to sustain stream stability and play an important role in energy input and light penetration to surface waters. Riparian connectivity provides habitat for terrestrial species as well as spawning and refuge habitat for fish during periods of flooding. Improperly sized bridges and culverts hinder the role of riparian connectivity as they reduce localized floodplain access, disrupt streambank vegetation, and bottle neck flows that can wash out down stream banks and vegetation.

Lateral connectivity represents the connection between a river and its floodplain. The dynamic relationship amongst terrestrial and aquatic components of a river's floodplain ecosystem comprises a spatially complex and interconnected environment (Ickes et al. 2005). The degree to which lateral connectivity exists is both a time-dependent phenomenon (Tockner et al. 1999) and dependent upon the physical structure of the channel. Rivers are hydrologically dynamic systems where their floodplain inundation relates to prevailing hydrologic conditions throughout the seasons. Riverine species have evolved life history characteristics that exploit flood pulses for migration and reproduction based on those seasonally predictable hydrologic conditions that allow systems to access their floodplains (Weclomme 1979, McKeown 1984, Scheimer 2000). When a system degrades to a point where it can no longer access its floodplain, the system's capacity to dissipate energy is lost. Without dissipation of energy through floodplain access, sheer stress on streambanks builds within the channel causing channel widening. Channel widening reduces channel stability and causes loss of integral habitat that in turn reduces biotic integrity of the system until the stream can reach a state of equilibrium once again.

3.3.7.1. Water quality standards

There is no applicable water quality standard for connectivity impacts.

3.3.7.3. Types of physical connectivity data

GIS layers with locations of dams and road culverts are a good source of potential connectivity issues within the watershed. Additionally, visual inspections of dams and road crossings showing the elevation difference between the upstream and downstream river stages.

3.3.7.4 Sources and causal pathways model for physical connectivity

The conceptual model for physical connectivity as a candidate stressor is found in Figure 3.3.7.

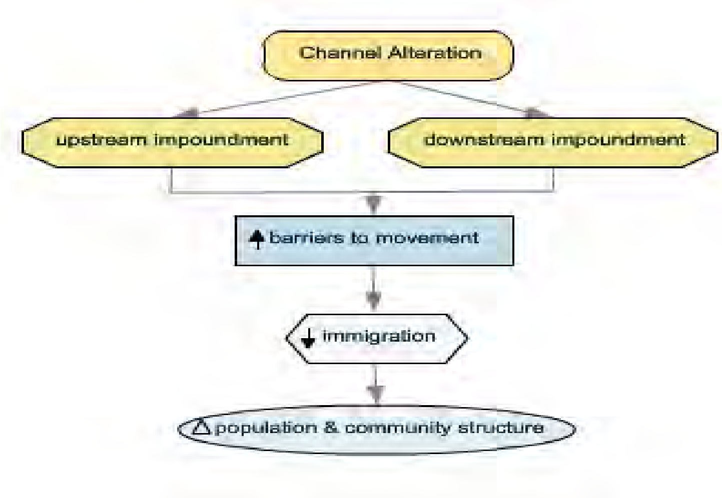
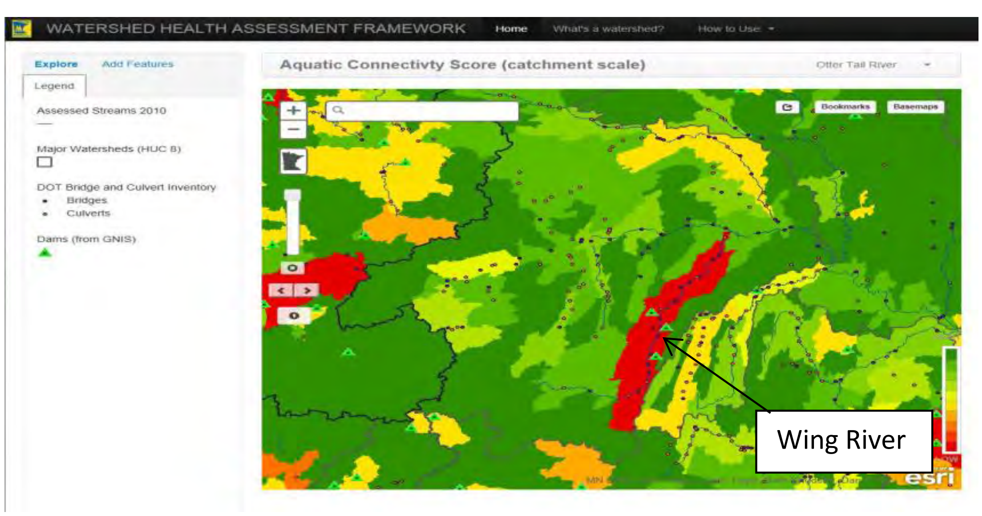


Figure 3.3.6: Conceptual Model for Connectivity.

3.3.7.5. Overview of physical connectivity in the Red Eye River Watershed

Aquatic connectivity was reviewed by using the MDNR Watershed Health Assessment Framework tool. This tool ranks catchment areas within the HUC-8 based on the location and abundance of dams and road culvert crossings. Dams place an immediate threat to fish migration due to the physical barrier present. Road culverts may or may not pose a fish migration issue depending on the position and elevation of the culvert. Overall the Red Eye River Watershed does not have an abundance of fish passage barriers. The locations of the dams on the Wing River however; pose a threat to fish migration and will be discussed further in Chapter 4.3 of this report.



4. Evaluation of Candidate Causes

4.1. South Bluff Creek (AUID-07010107-553)

4.1.1. Biological communities

The fish and aquatic macroinvertebrate communities in South Bluff Creek are impaired. South Bluff Creek is located in the South Bluff Creek aggregated HUC-12 which is part of the Ridge Creek Subwatershed (11HUC 07010107040). The fish and macroinvertebrate community at site 11UM072 was sampled in 2011. The downstream section (AUID 07010107-530), site 11UM070; has a passing fish and macroinvertebrate IBI score. The fish metrics that show the greatest difference between AUID 553 and AUID 530 is insectivorous Cyprinidae percent, minnows-tolerant percent, number of fish per meter-tolerant and simple lithophilic spawners. All four of these class 6 IBI fish metrics score significantly lower at 11UM072 than in 11UM070. Table 4.1.1 below displays the fish metric scores for both AUIDs. The fish community at 11UM072 is dominated by central mudminnow and white sucker. These species are considered tolerant and commonly found in degraded conditions. The fish community at 11UM070 was dominated by blacknose dace, hornyhead chub, and mottled sculpin. The fish sample had far fewer central mudminnow at site 11UM070 than site 11UM072. Ten fish species were sampled at 11UM070 compared to five fish species at 11UM072.

The macroinvertebrate IBI at site 11UM072 is being lowered based on two metric scores: PredatorCh (taxa richness of predators) and TaxaCountAllChir (total taxa richness of macroinvertebrates). The median MIBI score of 4.68 would need to be scored for each metric in order for the MIBI to meet the threshold score and pass. The PredatorCh metric scores 1.42 and the TaxaCountAllChir metric scores 2.39 at site 11UM072. The PredatorCh metric is the taxa richness of predators. As the predator taxa richness decreases the MIBI score would also decrease. The TaxaCountAllChir is the total taxa richness of macroinvertebrates in the sample. As the total taxa richness decreases the MIBI score would also decrease. The low MIBI scores for each of these metrics indicates a low taxa richness and low predator richness in the respective macroinvertebrate sample. Low taxa richness could be an indicator of low DO and lack of suitable habitat which will be discussed later in this report.

The macroinvertebrate community is also lacking the ClingerCh (taxa richness of clingers).

Table 4.1.1: Class 6 Fish metric scores for the two sampling locations in South Bluff Creek. Biological site 11UM070 passes the Fish IBI while biological site 11UM072 fails the Fish IBI and is impaired.

Site ID	Date	FishIBI	InsectCypPct	Minnows-TolPct	FishDELTPct	Insect-TolTxPct	PioneerTxPct	TolTxPct	DarterSculp	Hdw-Tol	Sensitive	SLithop	NumPerMeter-Tolerant
11UM070	17-Aug-11	65	6.25	5.700	0	6.998	6.6244	7.4999	10	3.33	7.5	9.35	1.4672
11UM070	21-July-11	60	4.28	3.316	0	7.775	4.9367	7.4999	10	6.67	7.5	7.02	1.1371
11UM072	17-Aug-11	31	0	0	0	4.665	6.6245	5.9999	5	3.33	2.5	2.34	0.0734
11UM072	20-June-11	46	0.37	0.152	0	7.776	3.7311	8.5714	10	3.33	5	4.68	0.2568

Macroinvertebrate metrics in South Bluff Creek indicate potential issues with low DO concentrations and lack of riffle habitat.

4.1.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen (DO) was collected at two locations in the impaired South Bluff Creek AUID in 2013. DO data was well below the Class 2B standard of 5 mg/L at both sampling sites during late July through early September. Stream flow was very low to almost stagnant during some of the site visits during this time. Figure 4.1.1 shows the DO data collected at S007-416 and S007-417 on South Bluff Creek. The two sampling events at 11UM072 showed that central mudminnow were the dominant species found which are known to be tolerant to low DO readings. Figure 4.1.2 graphically displays the DO tolerance values for both 11UM072 sampling events. The majority of the fish sample is tolerant to low DO. Low DO is a stressor to the fish and macroinvertebrate community at South Bluff Creek (AUID 07010107-553).

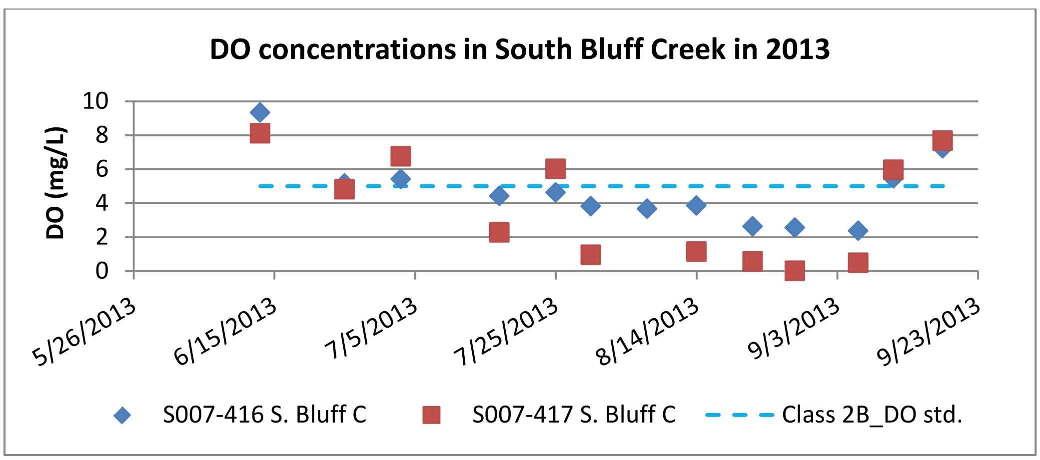


Figure 4.1. 1: Early morning DO data collected at two EQuIS sites in South Bluff Creek in 2013.

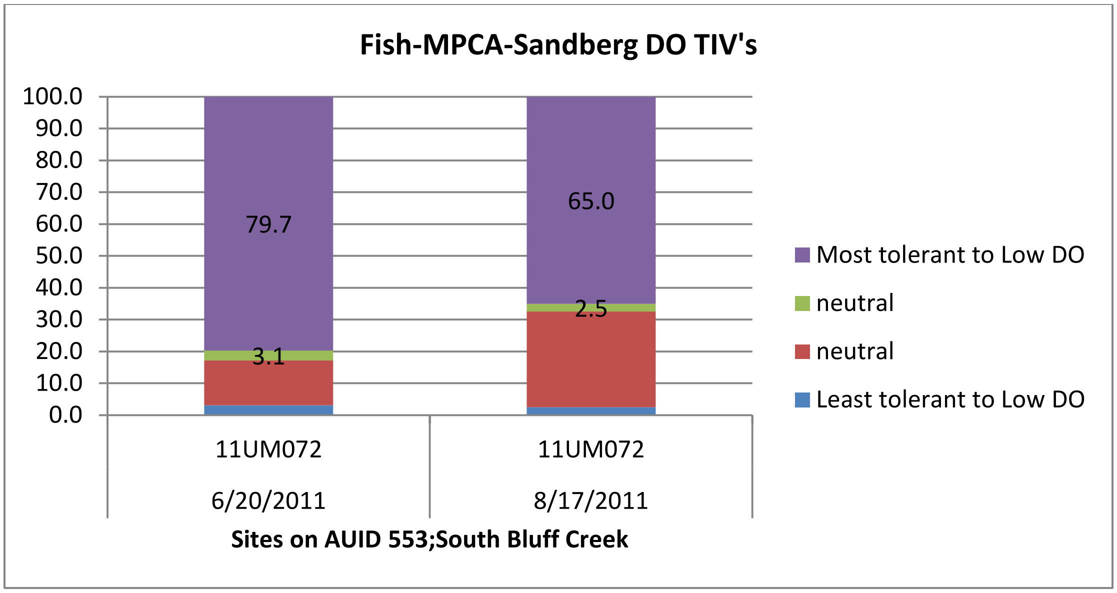


Figure 4.1.2: DO tolerance values for fish at sampling site 11UM072 in South Bluff Creek from 2011.

The low DO in this AUID is partially caused by the influence of low oxygenated groundwater being introduced to the creek. During periods of little precipitation the groundwater base flow is the dominate source of water which is also being reflected in the observed DO concentrations. Stream temperatures in August of 2013 ranged from 11.2 °C to 15.07°C. Theses temperatures were collected during very low flow. Temperatures in this range can only be attributed to groundwater influence as surficial water temperatures would tend to be much higher during the hottest summer months. Total phosphorus (TP) concentrations were also very low during this low flow time period. TP ranged from 0.017 to 0.018 mg/L in August 2013. During the summer of 2012 a YSI sonde was deployed at site 11UM072 for an eight day period. Figure 4.1.3 displays the daily DO flux (fluctuated between 2.0 and 4.5 mg/L per day) during the sampling period along with daily minimum and maximum DO concentrations. The degree of DO flux suggests that the stream is elevated in nutrient concentrations. Stream flow was greater during the summer of 2012 than in 2013. This led to slightly warmer stream temperatures in 2012 as well.

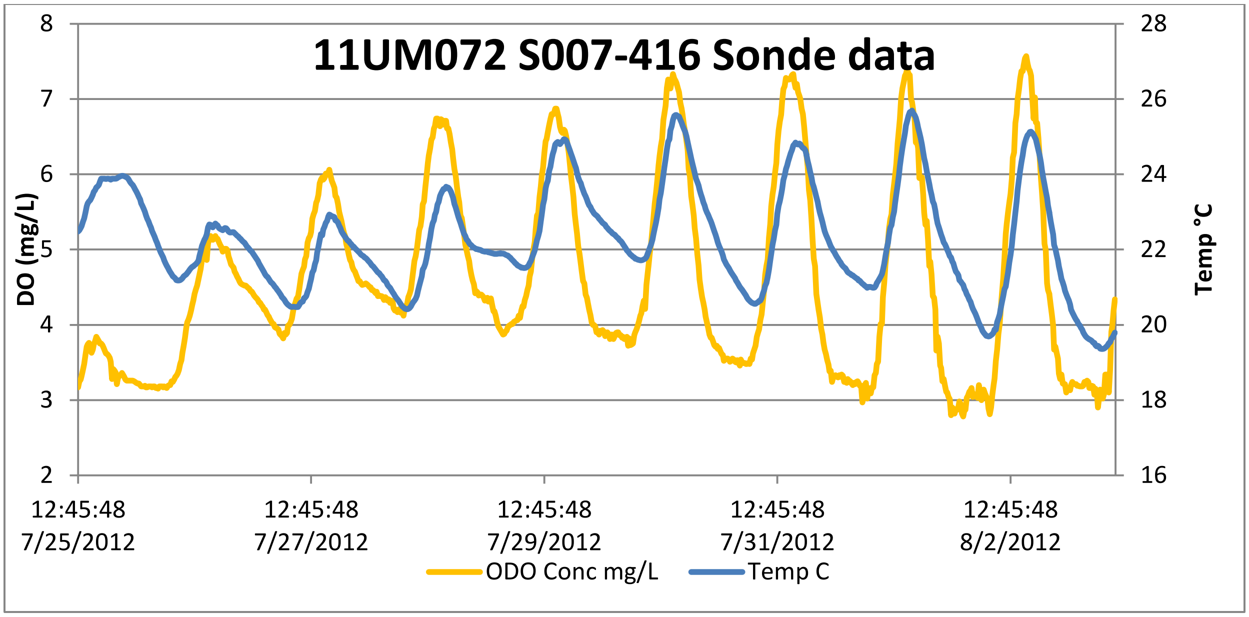


Figure 4.1.3: YSI continuous sonde data collected at Biological Site 11UM072 in July, 2012. Dissolved oxygen levels are daily below the Class 2B five mg/L water quality standard.

Lack of physical habitat

Habitat quality varies from poor to fair/good on the two biologically monitored sites reviewed in South Bluff Creek. The MSHA was the main tool used for evaluating this potential stressor and the results of these habitat scores can be seen in Figure 4.1.4 below. Biological site 11UM072 is impaired for fish and macroinvertebrates, while biological site 11UM070 passes both the fish and macroinvertebrate IBI. Multiple site visits occurred at both biological stations. The scores from the two site visits have been averaged and the average value is presented in Figure 4.1.4. Land use at both sites scored a zero out of a possible five because both sites are located in pasture or row crop agriculture settings. The main habitat value difference between the two sites is the unstable channel morphology and the lack of gravel/cobble substrate at site 11UM072.

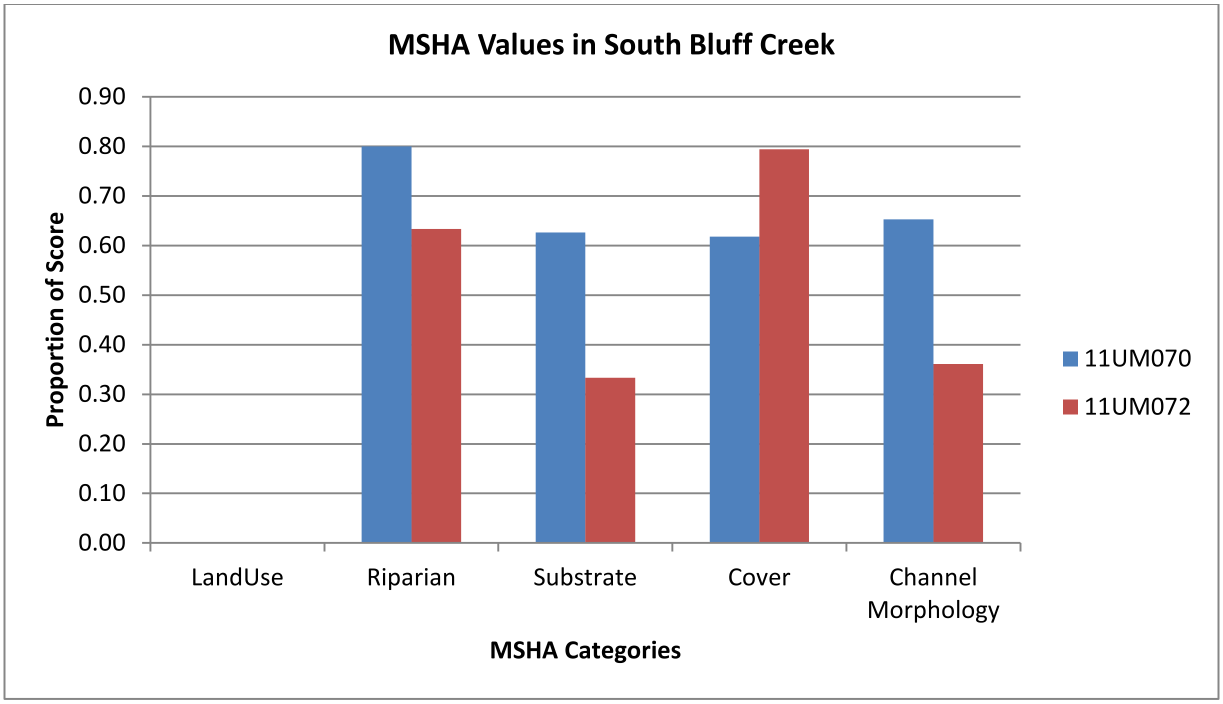


Figure 4.1.4: MSHA Values at Biologically Sites in South Bluff Creek. Site 11UM072 is biologically impaired and Site 11UM070 in not biologically impaired.

Multiple visits at the lone biological station (11UM072) in the upstream AUID of South Bluff Creek (07010107-553) produced an average MSHA score of 45 (poor). Factors bringing down the score are the surrounding land use, severe bank erosion (causing increased fine sediment), moderate embeddedness, and poor channel stability.

Biologically,11UM072 had a higher percentage of simple lithophilic spawning fish than the downstream site, 11UM070. However, the number of fish sampled was lower at 11UM072 and the number of intolerant fish was very low at 11UM072. The number of fish that are simple lithophilic spawners at 11UM072 is 18 and at site 11UM070 is 58. Also the highly tolerant fish species stickleback/mudminnow is 101 individuals on June 20, 2011 out of a sample size of 128 individuals at 11UM072 and 23 individuals out of 123 individuals on June 21, 2011 at site 11UM070. Due to the highly tolerant fish species and lack of simple lithophilic taxa at site 11UM072, along with 82% of the macroinvertebrate sample is tolerant , and the poor habitat score, lack of physical habitat is a stressor to biotic community in South Bluff Creek.

Increased bedded sediment

On October 7th, 2013 a stream channel survey was conducted to assess the stability of the reach using methods developed by Dave Rosgen (Rosgen, 1996). Stream channel dimension, pattern and profile were inventoried to determine stream type, slope, substrate composition, and available habitat features. Table 4.1.2 shows the stream classification along with mean particle size of the substrate for sampling site 11UM072.

Table 4.1.2: Pool and riffle cross section measurements used for stream classification.

XS-Feature	Bankfull width (ft)	Floodprone width (ft)	Entrenchment Ratio	W/D Ratio	Bankfull Area(ft^2)	Classification	Particle D_{50}(mm)
XS2-riffle	13.59	200	14.717(slightly)	7.04 (Low)	26.26	E	0.40
XS6-pool	27.9	200	7.16 (slightly)	13.22(mod-High)	58.99	C	0.65

Stream habitat features can be analyzed by viewing the channel profile survey. Features such as pool depths and spacing along with riffle depths and spacing can be analyzed to determine if habitat features are missing in the study reach. Stream substrate particle size can also be used to determine if habitat features are being buried with fine substrate particles. The D_{50} particle size in the riffle that was surveyed was 0.40 mm. This particle size is very small and shows that the riffles are being covered with fine sand and silt. 18.1% of the particles in the riffle were silt, 52.4% of the particles were sand and 29.5% of the particles were gravel. The gravel was as large as 45 mm indicating that the stream has potential for gravel substrate riffles; however, the gravel is being smothered by the introduction of fine particles from bank erosion that is occurring throughout this reach. The pool is also being filled by fine particles. 14.8% of the pool pebble count was silt, 61.4% was sand and 23.8% was gravel or cobble. The pool pebble count had 2 cobble size particles ranging from 90-180 mm in size. Figure 4.1.5 shows the stream channel profile. This figure depicts the stream bankfull elevation in green and the channel bottom in black.

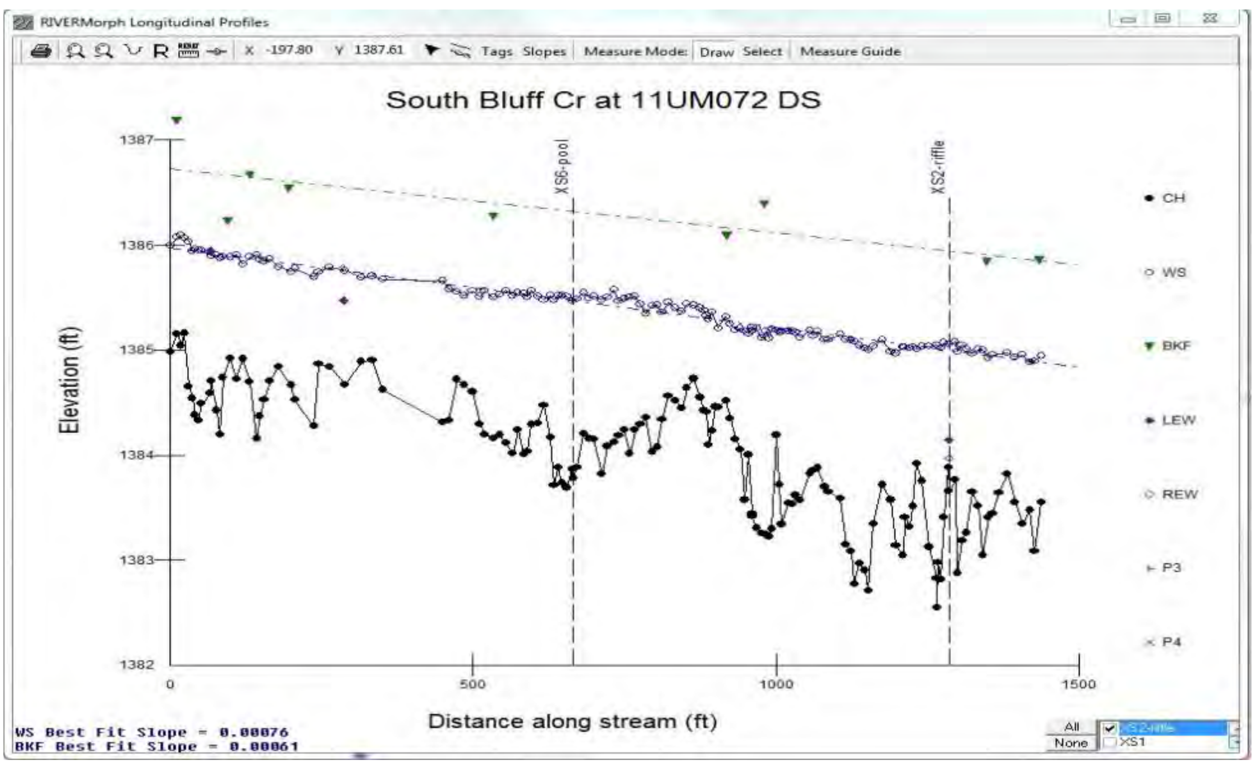


Figure 4.1.5: Long profile of South Bluff Creek at site 11UM072.

The stream pools are spaced close together and the pool depths are generally not greater than 2 times the depths of the riffles and runs. Pool depths are generally thought to be optimal at 2.5 to 3.0 times the depth of the riffles and runs. This shallow pool depth indicates filling of pools corresponding with the small particle size from the pool pebble counts. The surveyed reach is located in an area that is pastured. The free access of cattle to the stream is causing bank failure which is causing the channel to over widen in areas and depositing sediment into the stream channel. . The eroding banks are causing the channel to over widen, fill with fine sediment (becoming shallower) and losing the depth to support fish and macroinvertebrates during periods of low water. Grazed stream banks and lack of riparian vegetation can be seen in Figure 4.1.6. The stream is the sole watering source for the pastured animals. Stream banks are hummicked from cattle walking along the top of stream banks and multiple cattle crossings were evident in the channel survey area.

Figure 4.1.6: Photo of the downstream and upstream pastured areas along 280th Street in South Bluff Creek. Both sides of the road have a fair amount of cattle and horse pasturing activity that is causing bank instability.

Figure 4.1.7: South Bluff Creek, photo on the left shows the fine sediment deposited on the stream bed. Photo on the right shows the stream bank eroding with a lack of deep rooted vegetation on the bank. Bank root density is low and stream banks are susceptible to erosion.

Figure 4.1.7 shows a typical eroded stream bank along with the fine sediment that is deposited on the stream bed when bank material enters the stream. Increased bedded sediment is a stressor to the aquatic biological community. Small particle size along with pool filling is limiting the amount of habitat available to fish and macroinvertebrates.

4.1.3. AUID Summary

South Bluff Creek lies in the southwestern portion of the Red Eye River Watershed. Figure 4.1.8 below shows the South Bluff Creek Subwatershed along with sampling locations and permitted feedlots. The streams in the subwatershed are a mixture of natural channel and channelized or altered stream channel. Land use is a mixture of row crop agriculture and animal pasturing operations with 31 registered feedlots. These feedlots can pose stream channel bank stability problems when animals are given access to the stream corridor. Stream banks can experience accelerated erosion ranks due to loss of riparian vegetation due to grazing along with bank failure due to hoof shear and animal crossings. Excess sediment and elevated nutrients from manure and agricultural field runoff can impede the biology. The elevated nutrients can cause fluctuation in DO concentrations. Samples collected in 2013 did not show elevated nutrient concentrations but did show DO concentrations that are well below the state Class 2B DO standard of 5 mg/L.

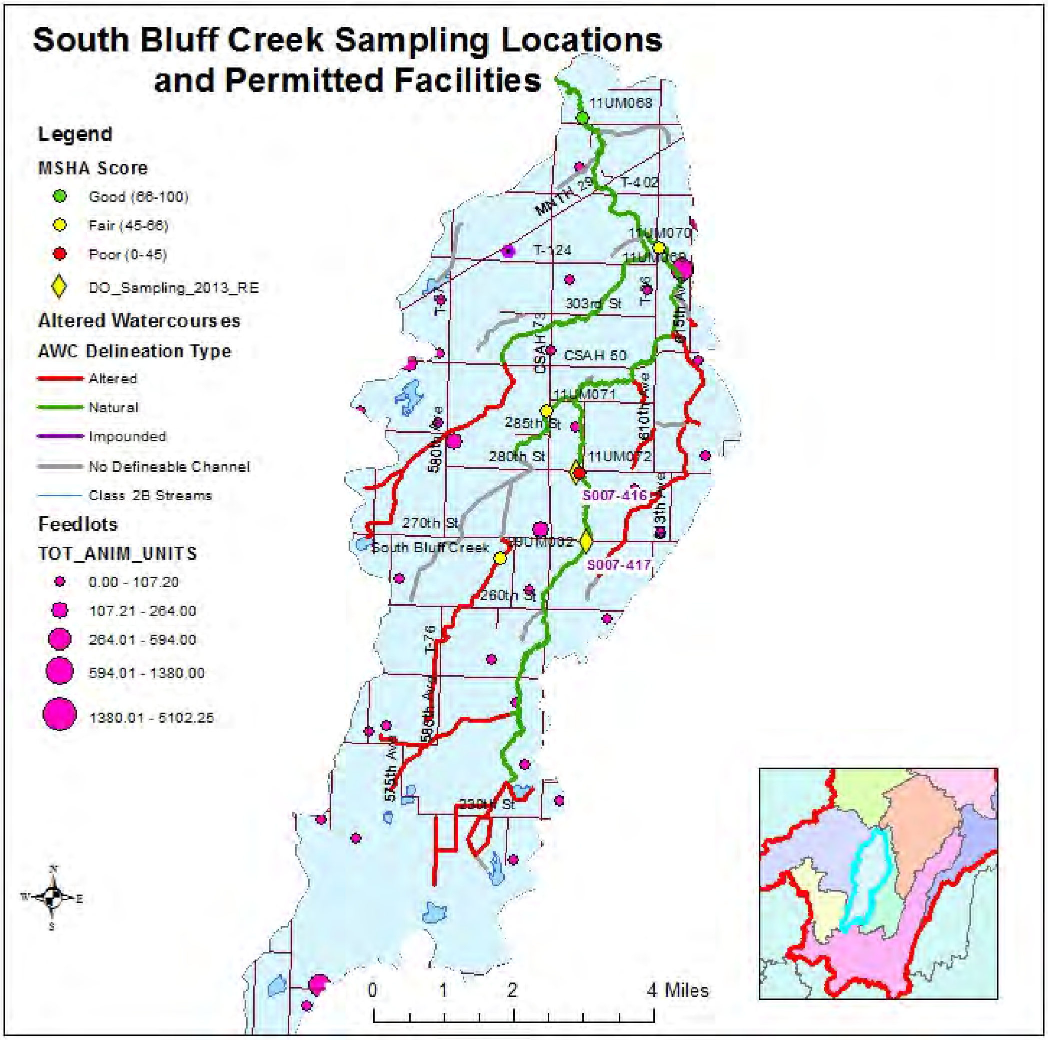


Figure 4.1.8: Map of South Bluff Creek showing sampling locations, road crossings and permitted facilities. MSHA habitat scores are also displayed at the biological monitoring locations.

Land use in the South Bluff Creek Subwatershed is primarily agricultural (either cropland or rangeland) with 29% of the land use in forest (Figure 4.1.9). During dry summers CRP acres are opened up to emergency grazing and haying. When these acres are opened for grazing often the cattle's only source of water is the streams that are flowing through these CRP acres. The upper headwaters area of impaired AUID 07010107-553 is a drained wetland. There is some center pivot irrigation that is occurring in a few sections of land just downstream of the sampling location 11UM072. The withdrawal of groundwater from the surficial aquifer may be reducing the amount of stream flow in South Bluff Creek during the dry summer months.

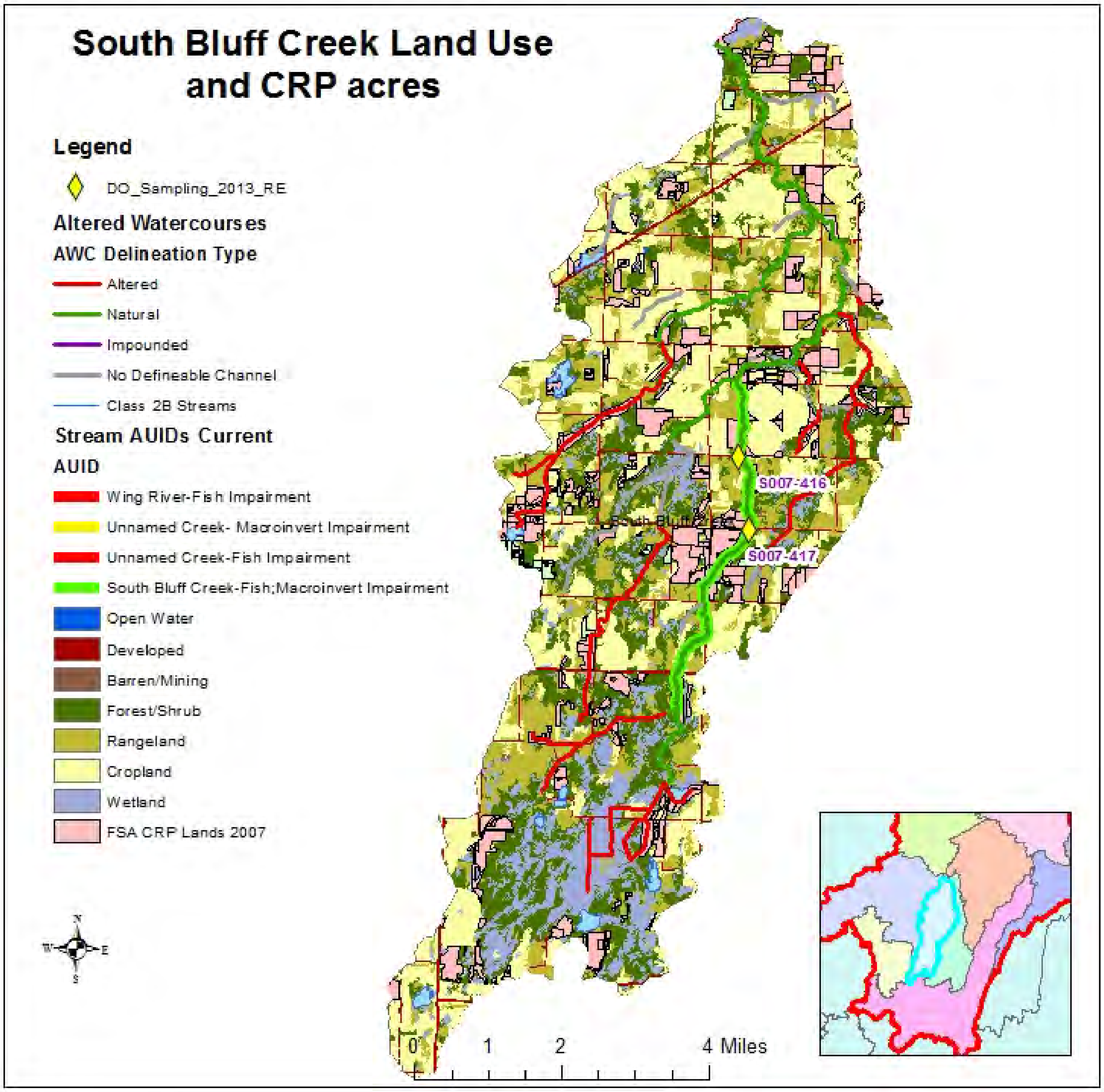


Figure 4.1.9: Land use in the South Bluff Creek watershed. Green highlighted stream section is AUID 07010107-553 which is impaired for fish and macroinvertebrates.

The drained wetlands along with the amount of riparian pasture land are causing some in stream habitat issues in this AUID. The upstream drainage is causing increased peaks in flow during snowmelt periods which are causing bank erosion. The cattle being pastured in the riparian corridor are also causing bank erosion by trampling on banks and grazing down the much needed riparian vegetation that is required to hold the banks together. The increased sediment entering the stream is causing a filling of pools and a general loss of gravel and cobble substrate because of increased fine sediment being deposited in the channel.

Stream DO concentrations are often below the state Class 2B DO standard of 5 mg/L. This is being driven by an increase in the upstream drainage and delivery of water via ditching of upstream wetlands. During the dry summer of 2013 the base flow was dominated by shallow groundwater which is also low in DO. The driving factors behind the lack of fish and macroinvertebrates in South Bluff Creek are low DO, lack of physical habitat and increased fine bed sediment in the channel.

4.1.3.1. Stressor pathway discussion

Flow gaging was conducted in neighboring Oak Creek near Bluffton (Figure 4.1.10) from spring on 2011 through fall of 2013. This stream gage is representative of the stream flows that occurred during the 3 year study period. Figure 4.1.11 below shows the hydrograph at Oak Creek during the 3 year study period. Stream flow typically was high in spring during the study period and was reduced by mid to late summer in all three years. Stream flow is directly influenced by rainfall and surficial runoff. During periods of crop and tree growth, rainfall is taken up by plants and utilized before traveling into the surficial aquifer and or running of the surface of the landscape. When rainfall is in short supply as was the case in August of 2013 the stream is left with shallow groundwater, which brings base flow down to a very low rate.

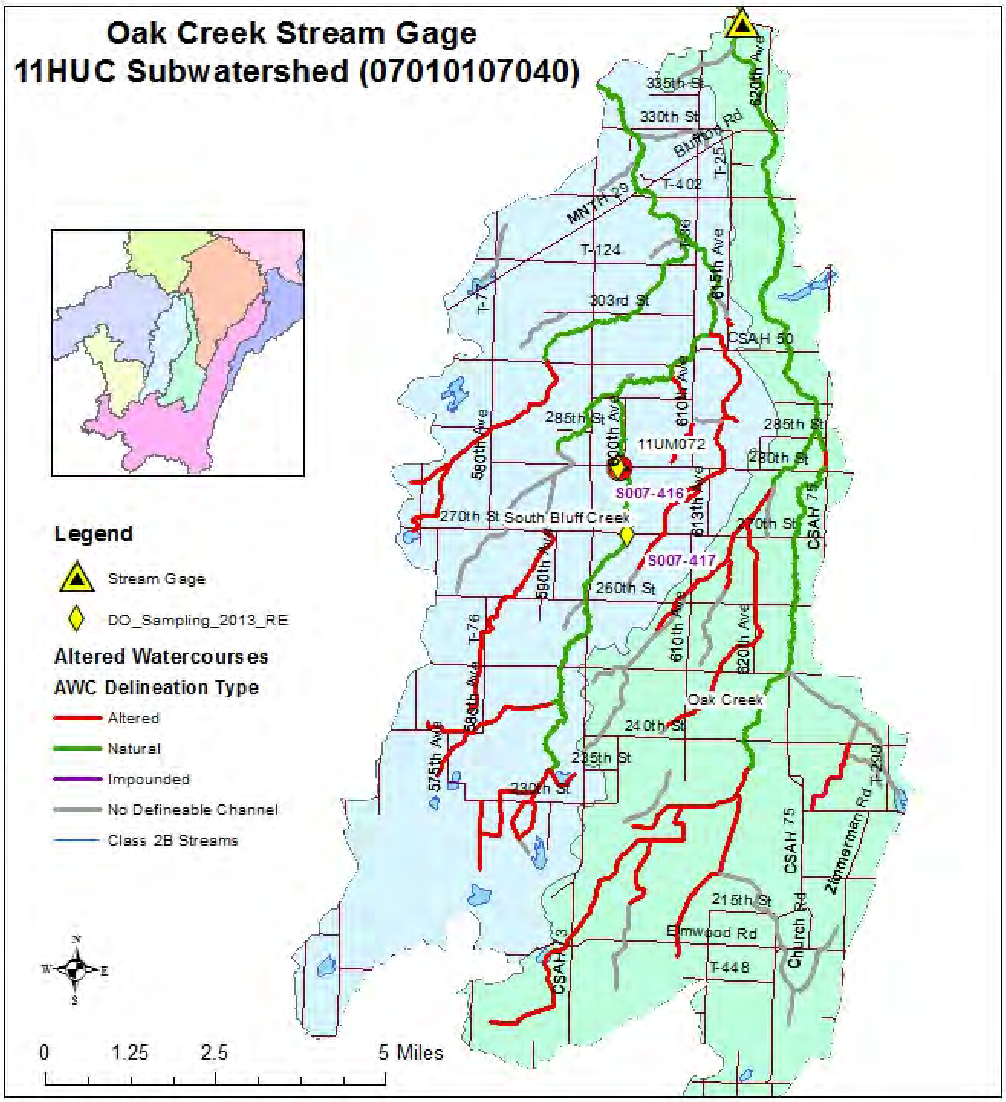


Figure 4.1.10: Oak Creek stream gage location. Gage was located at downstream end of Oak Creek watershed and operated form spring of 2011 through fall of 2013. Oak and South Bluff Creek are adjoining watersheds with similar land use characteristics.

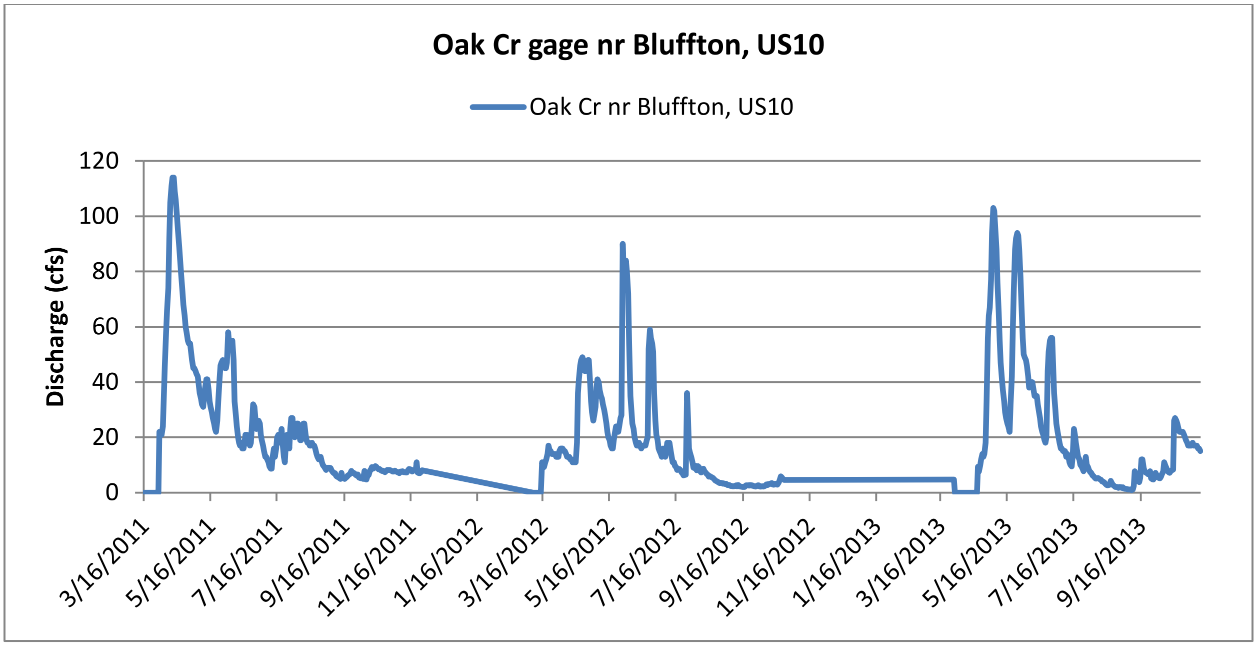


Figure 4.1.11: Hydrograph for neighboring Oak Creek. Continuous stream stage was collected in 30 minute intervals from spring of 2011 through fall of 2013. Stream stage was then converted to discharge using a rating table developed for Oak Creek.

Most of the observed stressors in South Bluff Creek are indirectly tied to stream flow.

4.1.3.2. Weight of evidence (See Appendix B)

4.1.3.3. Stressor conclusions

The main stressors that are affecting the biological community in South Bluff Creek are low dissolved oxygen, lack of physical habitat and increased bedded sediment. During the summer of 2012 and 2013 instantaneous and continuous YSI sonde data was collected to determine if DO was a cause of stress to the biotic community. During both summer sampling periods DO was often below the state Class 2B water quality standard of 5 mg/L. DO concentrations appear to be driven by low DO concentration groundwater and a lack of aeration potential within the stream. The headwaters of South Bluff Creek start in a series of partially drained wetlands. This is also stripping the DO from the surficial sources as it is probably high in SOD and BOD. Bedded sediment is a problem in South Bluff Creek. The stream banks are eroding because of high spring flow conditions along with animal access along the banks. The animal pasture areas are causing bank erosion due to animal grazing activity and hoof stress along the top of the banks. Excessive fine sediment is entering the stream and filling the pools causing a general lack of physical habitat. The pool quality is diminished in South Bluff Creek. Riffle quality in the study area is also diminished. The mean sediment particle size in the riffles is very fine sand and this sand is smothering any gravel and cobble that was present. There is very little quality habitat for macroinvertebrates and simple lithophilic spawning fish.

4.2. Unnamed Creek (AUID-07010107-554)

4.2.1. Biological communities

One site (11UM065) was located on Unnamed Creek which was not sampled for macroinvertebrates but was sampled for fish and is impaired. The Upper Leaf River 11HUC (07010107020) had five biological monitoring sites in five different streams. Tributary to East Leaf Lake (11UM065) flows into East Leaf Lake from the southeast and is located in the Upper Leaf River aggregated HUC-12 subwatershed. This stream has a low FIBI score at 34, which is below the FIBI threshold of 40 for Class 6 streams. The neighboring stream Deer Creek (11UM061) had a FIBI score of 68. This was the highest FIBI score in the 11HUC. Table 4.2.1 lists the FIBI scores for individual metrics and compares the differences between the two sites. Median passing score for each FIBI metric would need to be at 4.0 or above to pass the FIBI. Scores below 4.0 are labeled red in Table 4.2.1 and indicate a potential problem with the fish community.

Table 4.2.1: Comparison of two FIBI scores and the metric scores for the highest and lowest scoring Fish sites in the Tributary to East Leaf Lake 11HUC.

Site ID	Date	FishIBI	DarterSculp	Hdw-Tol	InsectCypPct	Insect-TolTxPct	Minnows-TolPct	NumPerMeter-Tolerant	PioneerTxPct	Sensitive	SLithop	TolTxPct	FishDELTPct
11UM061	21-Jun-11	68	5	10	10	6.998	10	4.73	3.25	7.5	4.68	6.0	0
11UM065	11-Jul-12	34	5	0	0	7.776	0.23	0.62	7.75	0	2.34	10.0	0

Comparison of the two sites shows that there is a lack of simple lithophilic spawners at 11UM065, along with a general lack of sensitive fish species sampled. The overall fish community at 11UM065 was made up of 6 fish species and 84 individual fish. The majority of the sampled fish were central mudminnow and Johnny darter. Both of these species are tolerant to low DO conditions and poor habitat quality in general. The main difference with 11UM061 is the fish sample had 10 species, 200 individuals, and 4 sensitive species. The fish community was dominated by pearl dace (which is a fish species sensitive to human disturbance) and creek chub instead of central mudminnow and Johnny darter.

Downstream of 11UM065 the stream flows through an extensive wetland before draining to East Leaf Lake. The upstream portion of this AUID also flows through wetland that is impounded by beaver dams. Both areas are either known to have or are suspected to have very low DO concentrations. This will affect the species of fish available to repopulate the stream. The boundary conditions are such that site 11UM065 may not have the potential for a much better fish community.

4.2.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen data was collected at three locations on AUID 07010107-554 to better understand and characterize the DO concentrations throughout the summer of 2013. The DO sampling sites separated the stream into three segments as shown by Figure 4.2.1. DO data was collected between June 13, 2013 and September 18, 2013. All DO data was collected before 9 am except for the initial June 13 readings which were collected around 12pm. Sample locations S007-420 and S007-419 were routinely below the Class 2B 5 mg/L standard for DO. Site S007-420 is located in a drainage ditch portion of the stream that is directly below a drained wetland as can be seen in Figure 4.2.1. Sampling location S007-419 is located on 290th St. about mid-way down the AUID and is directly below an active beaver dam. This location also experienced very low flows (almost 0cfs) during mid-July through September, 2013. On September 11, 2013 it was documented that the stream had no flow. DO concentrations improve longitudinally downstream and at site S007-418 (11UM065) the DO is almost always above the standard. Figure 4.2.2 displays the DO data from the three 2013 sampling locations.

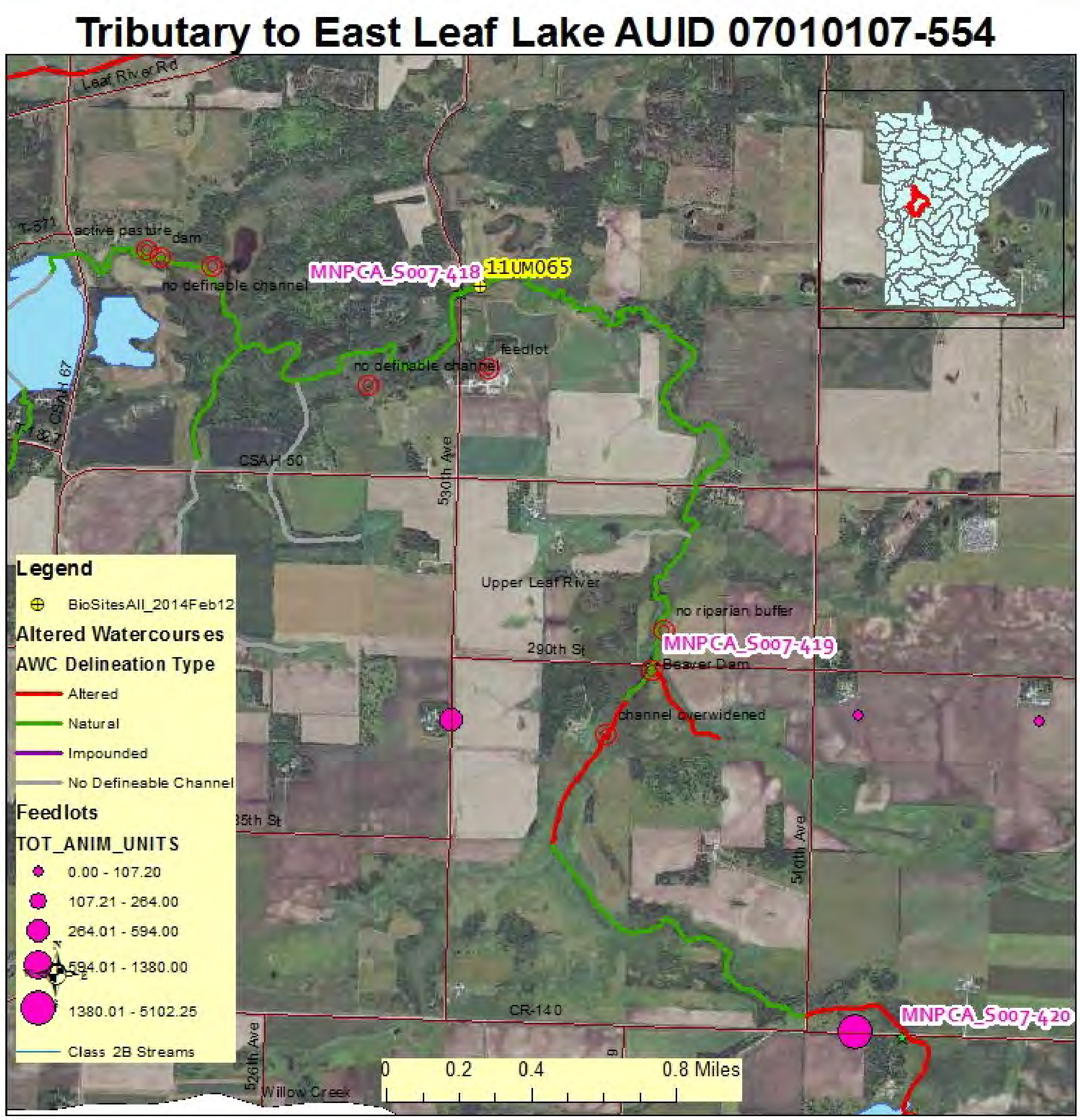


Figure 4.2.1: Sampling locations on Tributary to East Leaf Lake, along with points of interest and current channel condition.

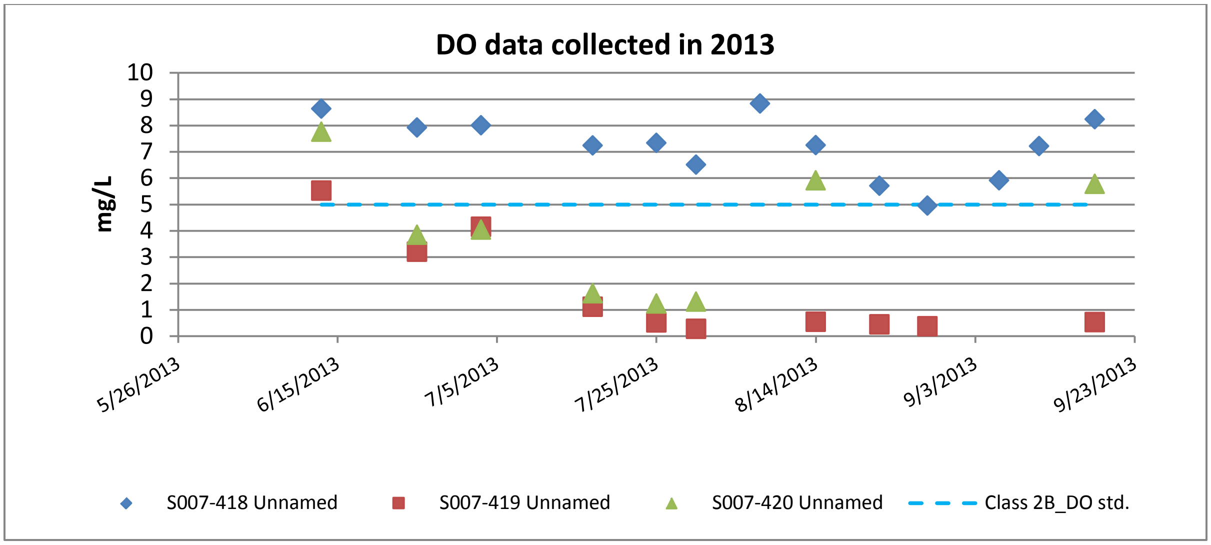


Figure 4.2.2: 2013 Dissolved Oxygen sampling results from AUID 07010107-554

The fish community at 11UM065 is dominated by species that are DO tolerant (82%). MPCA (Sandberg, 2013)created a tolerance value (TV) for each fish species commonly sampled in Minnesota. The TV value is assigned to the fish species and is divided into quartiles of even distribution. The lowest quartile is assigned a tolerant value and if the fish community has greater than 50% of its sample in this quartile the community is dominated by fish species that thrive in low DO conditions. The top quartile is assigned an intolerant value and indicates fish species that require high DO concentrations. The fish community at the sampling location is dominated by central mudminnow and northern pike both of which can tolerate low DO concentrations. Site 11UM065 fish community falls in quartile 1 which is most tolerant to low DO. Review of the DO data and the fish community data suggest that low DO is a stressor in this AUID.

Elevated nutrients

Nutrient data was collected seven times between June 11, 2013 and September 24, 2013. Grab samples were collected and analyzed for Total Phosphorus (TP), Nitrate-Nitrite (NO_2+NO_3), Ammonia (NH_4), and Total Kjeldahl Nitrogen (TKN). The TP concentrations were all below 0.075 mg/L and averaged 0.051 mg/L. This is below the proposed TP standard of 0.100 mg/L. NO_2+NO_3 data averaged 1.063 mg/L and is elevated from ecoregion norms. Elevated nutrients do not seem to be a stressor to the aquatic biological community and eutrophication does not appear to be driving the low DO concentrations.

Lack of physical habitat

The maximum MSHA score that a site can achieve is 100. Habitat quality based on the MSHA score was fair (58) at site 11UM065. Neighboring Deer Creek (11UM061) scored a 71 which is good. The MSHA was the main tool used for evaluating this potential stressor and the comparative results for the two sites habitat scores can be seen in Figure 4.2.3 . Habitat scores were divided by the maximum score to obtain the proportion on each score to the total. Deer Creek had a high F- IBI as well indicating that the poorer conditions in physical habitat at 11UM065 may be limiting the fish community. The substrate MSHA score at 11UM065 was nine. This indicates fine sediments and a lack of coarse substrate at the sampling location. The Channel morphology score was also low at 19.

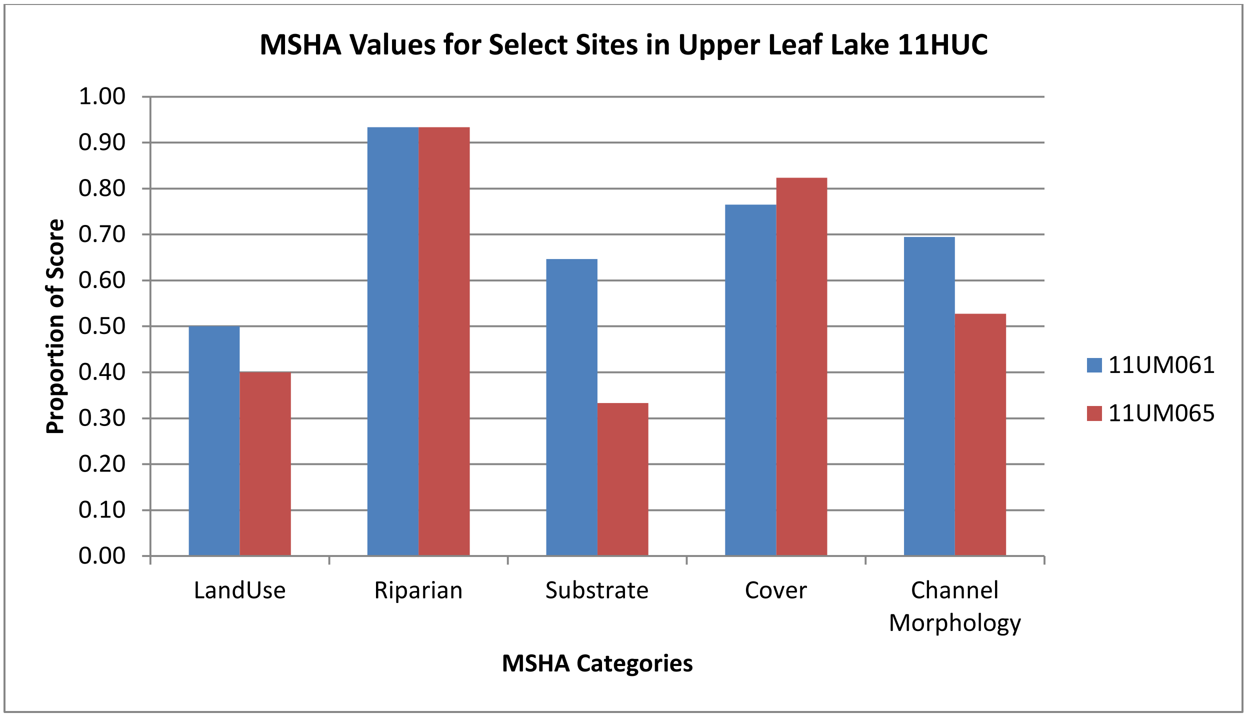


Figure 4.2.3: MSHA Values at Biologically Impaired Site 11UM065 and Biologically Unimpaired Site 11UM061.

Biologically, Site 11UM065 had no lithophilic spawning fish, benthic insectivores, or darter/sculpin/round bodied suckers. These fish metrics tend to decrease when habitat becomes degraded. Due to the fair MSHA score as well as the fish metrics scoring poorly, the lack of habitat is a stressor to the impaired biological community in Tributary to East Leaf Lake. Figure 4.2.4 below shows the condition of the site at the downstream section of the biological monitoring site.

Figure 4.2.4: Photos of the road crossing below Biological site 11UM065. Photo on the left shows sediment delta downstream of road crossing. Photo on the right is upstream of the road crossing and shows the narrow channel in an abandoned pasture.

Increased bedded sediment

The MDNR conducted a stream classification survey at this reach. The survey results classified the stream channel as an E5 stream type in a VIIIc valley type. Figure 4.2.2.5 shows the longitudinal profile from site 11UM065. The stream bed slope from head-of-riffle to head-of-riffle was at 0.00227. The bankfull indicators at cross sections that provided the highest confidence resulted in a slope line of 0.00192. It seemed reasonable to use 0.002 as the energy slope for velocity and discharge calculations. The water surface slope was 0.00057 but may been influenced by the road crossing downstream, which appears to have an undersized culvert based on the scour pool downstream of the road. The pool cross-section at stationing 1+85 was located in a hammer head pool. The tight radius of curvature at this location was causing the water to scour out a deep, wide pool, relative to the rest of the study reach.

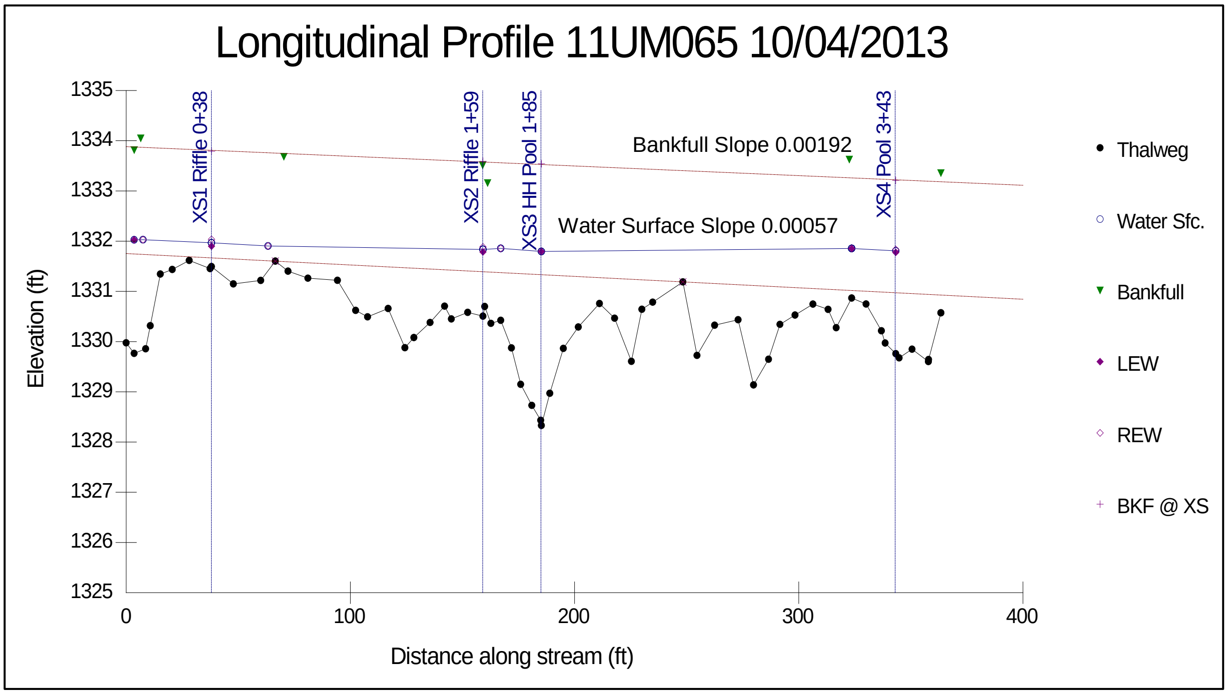


Figure 4.2.5: Longitudinal profile at site 11UM065

Study reach 11UM065 was a classified as a stable E5 stream. The modified (by stream type) Pfankuch stability rating was 69. A good, or stable, rating range for an E5 stream type is 50-75. Very little deposition was seen at this site. Appendix C has details of the full reach survey at site 11UM065. There is no evidence of increased bedded sediment as a stressor to the biotic community.

4.2.3. AUID summary

Tributary to East Leaf Lake (AUID 07010107-554) lies in the southern portion of the Upper Leaf River aggregated HUC-12. Figure 4.2.5 below shows the relative position of this AUID in relation to the larger aggregated HUC-12. The land use surrounding this impaired AUID is a mixture of row crop agriculture, rangeland, partially drained wetland, and forest/shrub. The majority of the riparian corridor along this AUID is low laying shrub dominated landscape. Some of the area is pastured and other areas have row crop agriculture starting to encroach on the stream corridor. Partially drained wetlands in the headwaters area of the AUID along with impoundments caused by active beaver dams are potential sources of the observed low DO conditions in the stream.

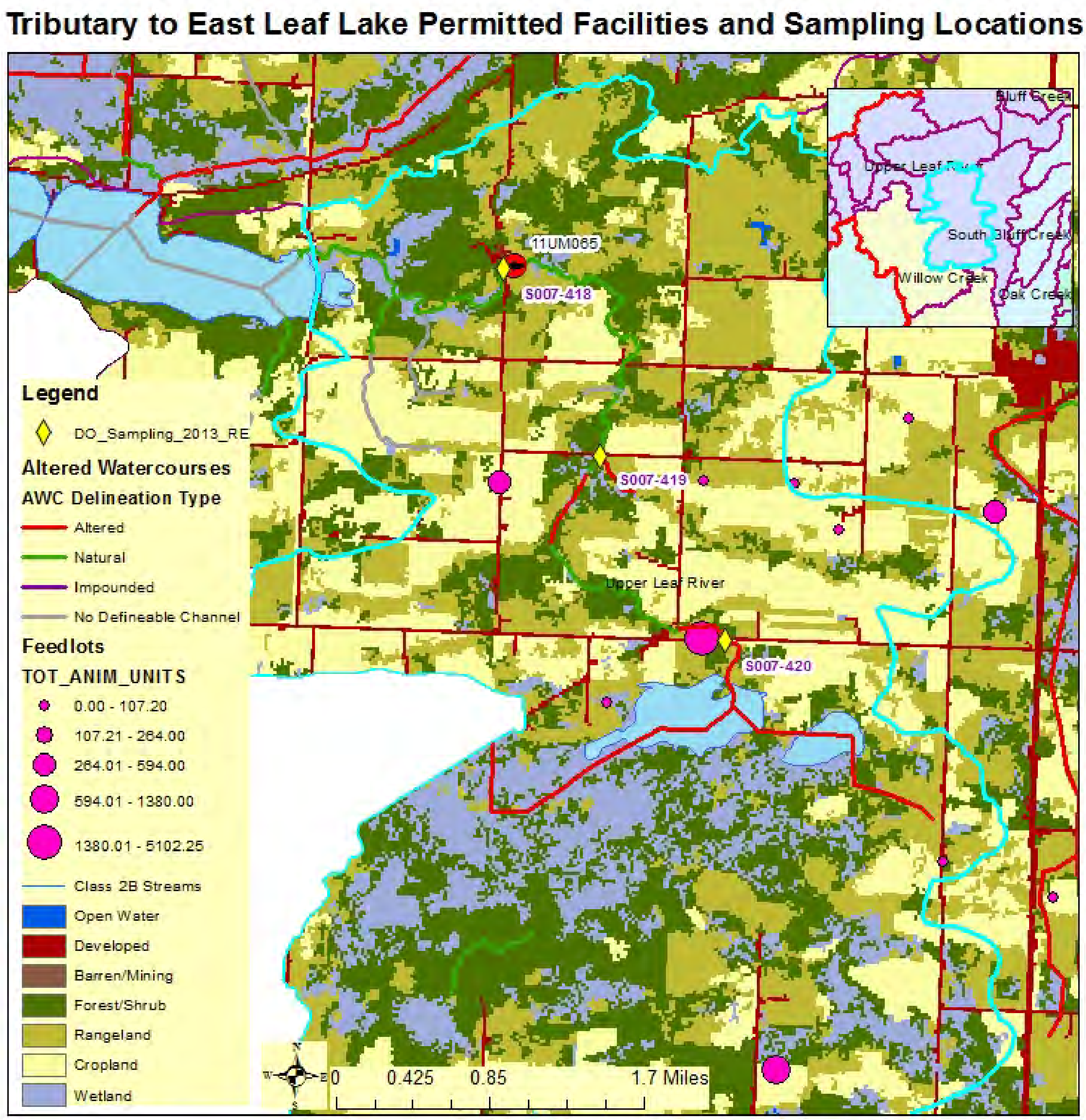


Figure 4.2.6: Permitted facilities located in the watershed for AUID 07010107-554. 2006 Land use is depicted as the background for this map.

There are five permitted feedlots located in this subwatershed, including two large turkey producing operations and one major cattle operation. The potential for animal waste entering the stream system appears to be moderate to high. Field slopes along with the location of row crop production in relationship to the stream corridor show a risk of animal manure entering the surface water if not properly applied to the fields. Viewing the 1m DEM (digital elevation model) created by MPCA show the stream channel quite a bit lower in elevation that the field used for row crop production which would potentially have animal manure used as fertilizer. Figure 4.2.6 shows the 1m DEM for AUID 07010107-554 along with the MDNR flowline information. This map shows the potential for field runoff to enter the main stream from all areas of the watershed.

Tributary to East Leaf Lake 1m DEM along with DNR flowlines

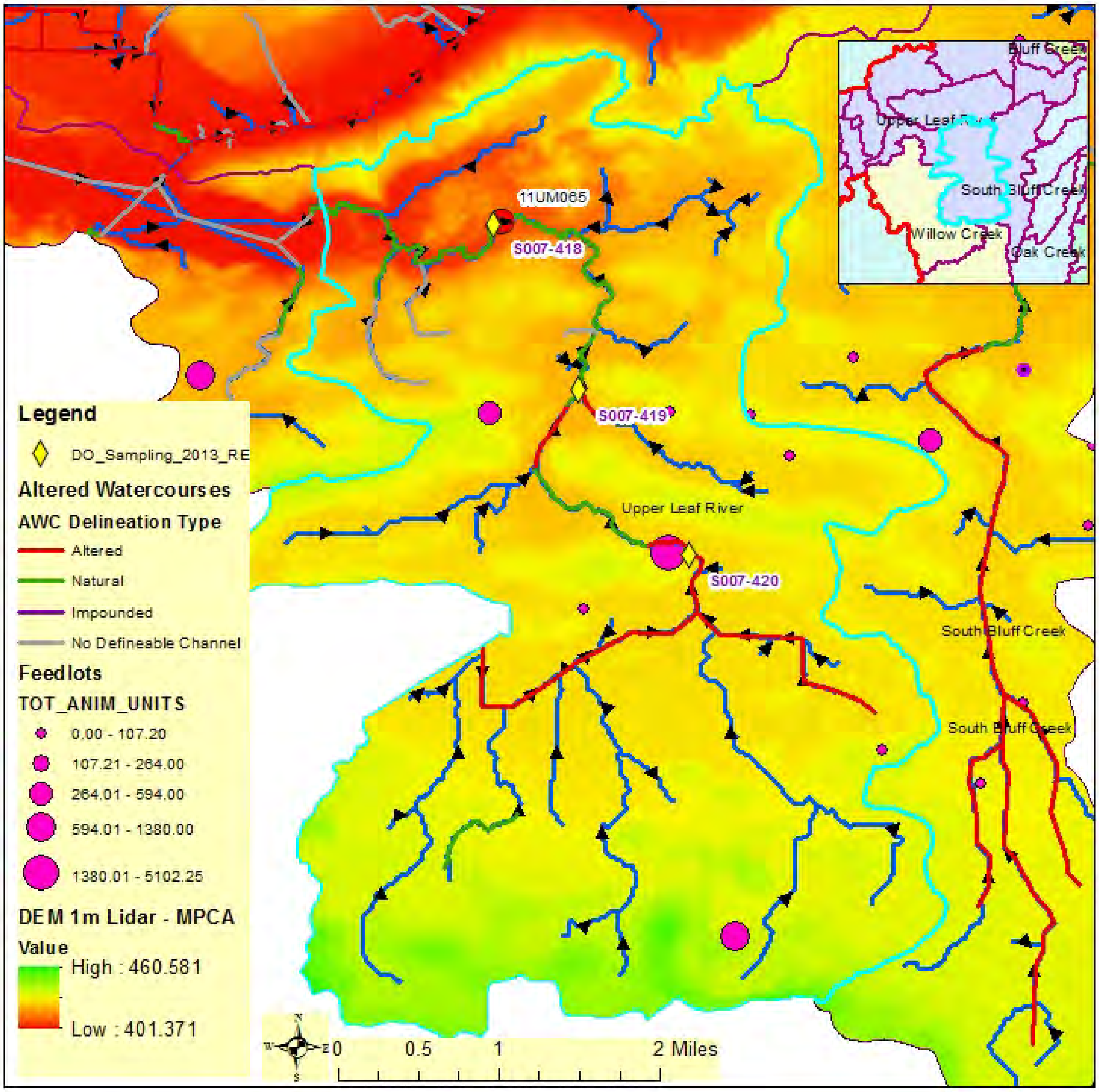


Figure 4.2.7: AUID 07010107-554 showing the 1m DEM generated by using LiDar data. The MDNR flowlines are present on this map to show the direction of surficial flow.

The MDNR flowlines line work indicates the general direction of how water will move through the landscape and eventually into AUID 07010107-554. This can give us additional information on how water and chemicals can move through the uplands and into the receiving stream.

4.2.3.1. Stressor pathway discussion

Low DO appears to be a main stressor to the biological community in AUID 07010107-554. It is believed that the partially drained wetlands upstream of sampling location S007-420 are partially contributing to the low DO concentrations in the stream. There is also a major beaver dam located just upstream of sampling location S007-419. The impoundment caused by the beaver dam is causing elevated stream temperatures and very low DO concentrations. The pictures below show the extent of the beaver dam at this location. The picture on the left was taken in July, 2013 the picture on the right is from late August, 2013.

Downstream of the beaver dam at sampling location S007-418 the DO rebounds and is often above the 5 mg/L standard. The fish community however, does not rebound and is dominated by fish species (83%) that are tolerant to low DO conditions.

4.2.3.2. Weight of evidence (See Appendix B)

4.2.3.3. Stressor conclusions

Tributary to East Leaf Lake is biologically impaired for fish. There was no macroinvertebrate sample collected at this location during 2011. The stream flows through areas of drained or partially drained wetland in the headwaters and flows through an area of impoundment caused by active beaver dams. Downstream of the sampling site the channel again flows through a riparian wetland before discharging into East Leaf Lake. The DO data that was collected during 2013 shows significant time periods during the middle of the summer when DO concentrations are well below the class 2B water quality standard for DO. This drop in DO appears to be caused by the riparian wetland corridor upstream along with the beaver impoundment during periods of low flow. Nutrient concentrations are relatively low based on the water chemistry samples collected in 2013 and increased algal or peryphyton growth does not appear to be a driving factor in the low DO concentrations. The DO appears to be affected by wetland soil SOD and microbial activity occurring in the impounded sections of the stream. Downstream of the sampling location there is also a significant amount of wetland riparian area that the stream flows through before entering East Leaf Lake. This area was not monitored in 2013; however, it is believed that this wetland riparian is reducing the DO concentration through similar mechanisms as seen in the upstream corridor that was sampled.

Lack of physical habitat is also a concern in this section of stream. The use of the MSHA score to compare to a neighboring stream with high biological scores can help reveal which habitat features may be lacking in Tributary to East Leaf Lake. The substrate and channel morphology scores are lower in the 11UM065 sample location than in the adjoining 11UM061 sample location. This suggests along with the fish that were sampled that the lack of coarse substrate along with the instability of channel banks at 11UM065 is contributing to the lack of a healthy fish community at this site.

4.3. Wing River (AUID-07010107-559)

4.3.1. Biological communities

The fish community in the section of the Wing River upstream of the Highway 210 bridge in Hewitt, Minnesota is impaired. Five biological sampling sites (11UM077, 13UM183, 11UM078, 00UM023, and 11UM080) are located in this AUID. Biological sampling sites 11UM077, 13UM183, and 11UM078 are in the Northern Streams fish class (Fish Class 5), while 00UM023 and 11UM080 are in the low gradient fish class (Fish Class 7). Table 4.3.1 below lists the F-IBI metrics for the Northern Streams class (Fish Class 5) sampling locations. The macroinvertebrate communities were above their respective threshold during the 2011 sampling at all five monitored locations.

The median IBI score required to pass the F-IBI is 4.54 per metric, meaning if the score is above that median value the individual metric passes. Scores that are below that median threshold bring the overall score down and are causing the low IBI score. Table 4.3.1 has the metric values highlighted in red that are below the median value. The relative abundance (%) of taxa that are serial spawners (SpnTXPct) metric is the relative abundance (%) of taxa that are serial spawners (multiple times per year). The IBI score will decrease when the SpnTXPct score increases. Site 11UM077 had 27% of the serial spawner taxa, and 11UM078 had 31.6% of serial spawner taxa in the 2011 fish sample. These high relative percentages are bringing down the overall F-IBI score, as serial spawners are indicative of stress in the community causing multiple spawning to try and increase survival. The very tolerant (Vtol) metric is the number of taxa that are very tolerant to disturbance. As this number increases the F-IBI metric score would decrease. For the 2011 sample events both 11UM077 and 11UM078 had 6 species of very tolerant fish samples, which will produce a low F-IBI score for that metric. The percentage of individual intolerant fish (IntolerantPct) is the relative abundance (%) of individuals that are intolerant. As this relative percentage increases in the individual sample the F-IBI score would also increase. The relative abundance of intolerant fish individuals in 11UM077 and 11UM078 were 2.65 and 0.95% of the sample. This is a low enough percentage to bring the F-IBI score well below the median threshold.

Table 4.3.1: Fish IBI metrics used to compute IBI scores for Northern Streams Class (Fish Class 5). Sites are listed in order going upstream.

Site ID	Date	Darter SculpSucTxPct	DetNWQPct	DomTwoPct	General	Insect-TolTxPct	IntolerantPct	MA>3-TolPct	SensitiveTxPct	SLithopPct	SSpnTxPct	tol	F_IBI
11UM077	17-Aug-11	5.86	7.93	0	0	4.52	0.57	0.60	5.63	9.09	2.82	0	37
11UM077	23-July-13	5.06	7.95	3.65	3.03	4.67	0.26	1.67	5.44	5.20	3.11	3.64	44
13UM183	23-July-13	4.79	7.78	1.98	3.03	5.69	0.08	0.09	5.16	7.06	2.01	3.64	41
11UM078	17-Aug-11	1.52	7.63	3.97	0	1.27	0.21	0.63	5.44	7.85	1.54	0	30
11UM078	22-July-13	1.73	8.74	3.83	1.44	4.17	0.05	0.11	3.65	6.67	0.43	1.82	32

4.3.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

Dissolved oxygen data was collected at four locations throughout this AUID. The data was collected from EQuIS stations S007-425, S007-426, S007-427 and biological station 11UM080. Figure 4.3.1 below displays the results from the 2013 DO data collection. The farthest two upstream sampling locations (S007-427 and 11UM080) experience periods of low DO; however, the DO appears to recover at the lowest reaches of the AUID and is often well above the 5 mg/L standard. Figure 4.3.8 displays the DO sampling locations. With the current data DO does not appear to be a significant stressor to the biological community in the lower half of the AUID. As we move toward the headwaters of the Wing River the fish community is showing signs of low DO as a stressor**.** Biological station 11UM080 has 80%of the fish community is very tolerant to low DO concentrations as can be seen in Figure 4.3.2. Low DO does appear to be limiting the fish and macroinvertebrate community in the upper reaches of the AUID above sampling location 00UM023. Biological site 11UM080 has 73% of the fish species sampled are tolerant to low DO concentrations. The macroinvertebrate DO Index value is 4.45 at biological site 11UM080. This value indicates that there is a 99% probability that the macroinvertebrate community is affected by low DO concentrations. At biological site 11UM077 the macroinvertebrate DO Index value is 7.12. This value indicates that there is a 25% probability that low DO concentrations are affecting the macroinvertebrate community.

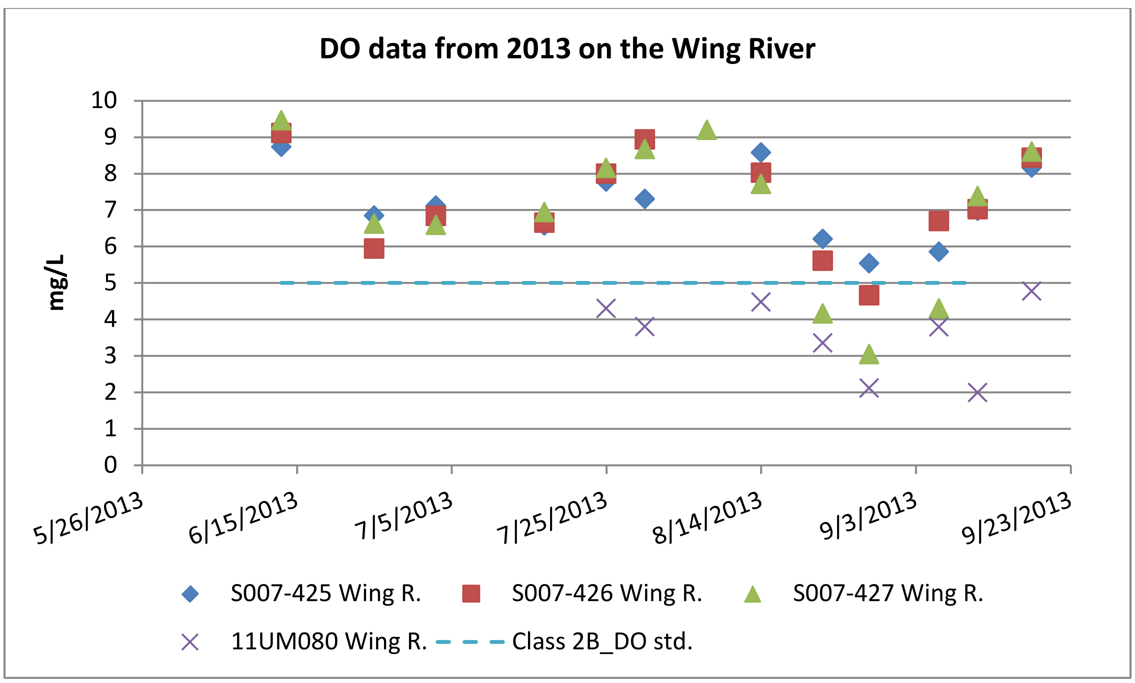


Figure 4.3.1: Synoptic DO data from AUID 07010107-559 above the Highway 210 dam in Hewitt, Minnesota.

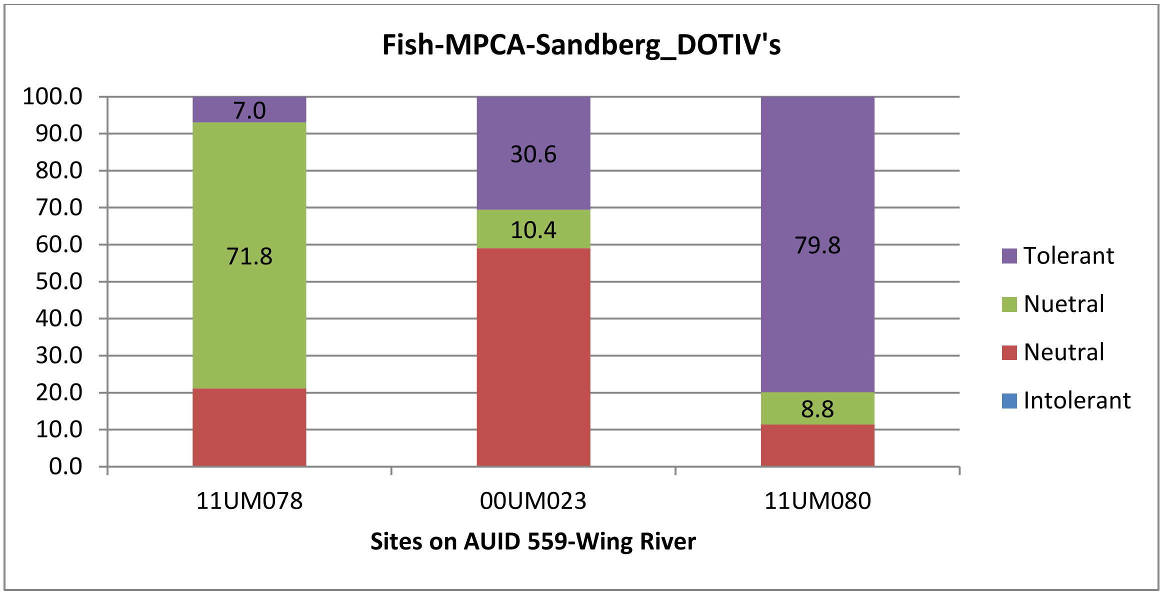


Figure 4.3.2: Fish DO TIV's based on MPCA data (Sandberg 2013). Sites are displayed going upstream. Site 11UM080 is the farthest upstream sampling location for biology.

Elevated nutrients

The Wing River has three EQuIS stations that have a history of water quality sampling. The three stations are S005-401, S002-958 and S005-724. Water quality data was collected and analyzed for TP, TKN, NO_2NO_3, BOD, and Chlorophyll-a. Samples were collected from 2004 through 2010. The nutrient concentrations were mostly below the Ecoregion TP standard of 0.100 mg/L. All of the recent samples collected after 2007 are well below the 0.100 mg/L standard (Figure 4.3.3).Eutrophication caused by elevated TP concentrations do not appear to be an issue in the Wing River. Stream chlorophyll-a samples were also collected at S005-724 in 2009 and 2010. The values are all below 5 µg/L which indicates there is very little planktonic algal growth in the Wing River. Review of the relative abundance (%) of taxa that are planktivorous (USGS-NAWQA) (PinkNWQTXPct) also shows that the abundance of this feeding style of fish is very low at site 11UM077 (7.5%) and 11UM078(5.5%). At sampling location 11UM080 there were no fish taxa sampled that are planktivorous.

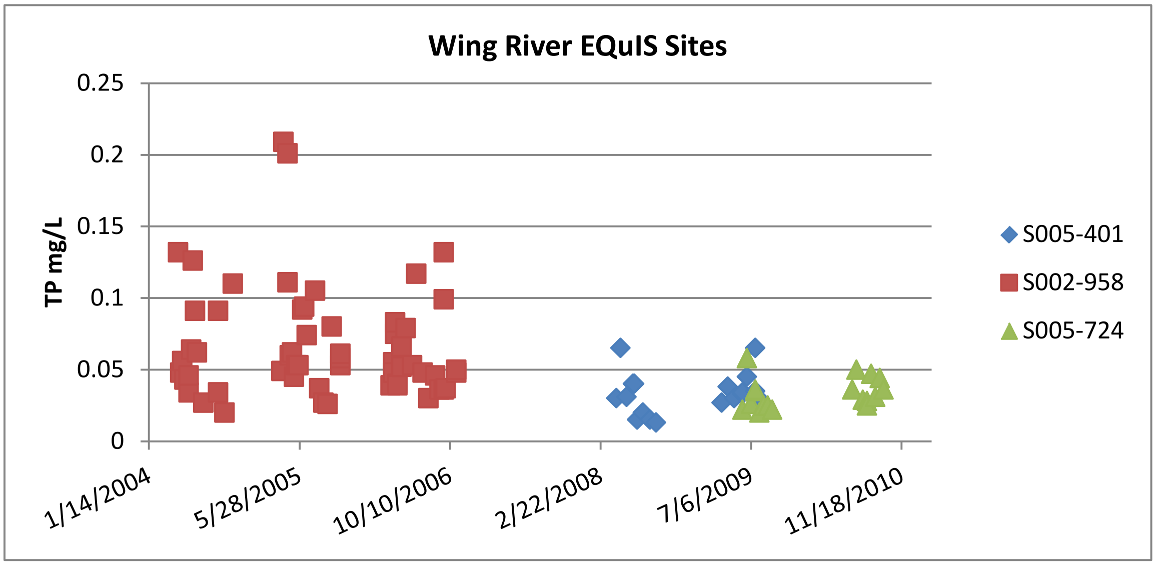


Figure 4.3.3: Total phosphorus concentrations at three water quality sampling locations along the Wing River. Data was collected from 2004 - 2010.

Nitrite-nitrate (NO_2NO_3) concentrations are elevated in the Wing River. Both sampling sites show multiple concentrations above two mg/L, and many of the sample concentrations are above three mg/L (Figure 4.3.4). Although this may not be a high enough concentration to cause toxicity to the fish community; it does indicate that excess amounts of fertilizer or animal waste are entering the Wing River. Using the relative abundance (%) of individuals that are sensitive (SensitivePct) may help reveal if NO_2NO_3 is affecting the fish community. Site 11UM080 had 20% sensitive fish found in the sample, while 11UM078 had 25% and 11UM077 had 31% sensitive fish in there samples. In comparison site 11UM076 which has a passing fish IBI score has 33% of the fish sample was sensitive. This site is near EQuIS station S002-958. It is unclear if the elevated nitrite-nitrate levels are affecting the fish community at this time. There is significant groundwater withdrawal occurring in the downstream section of the AUID. There are numerous center pivot irrigation systems in operation downstream of biological site 11UM077. Sampling location S002-958 is located downstream of the Highway 210 bridge near biological site 11UM076.

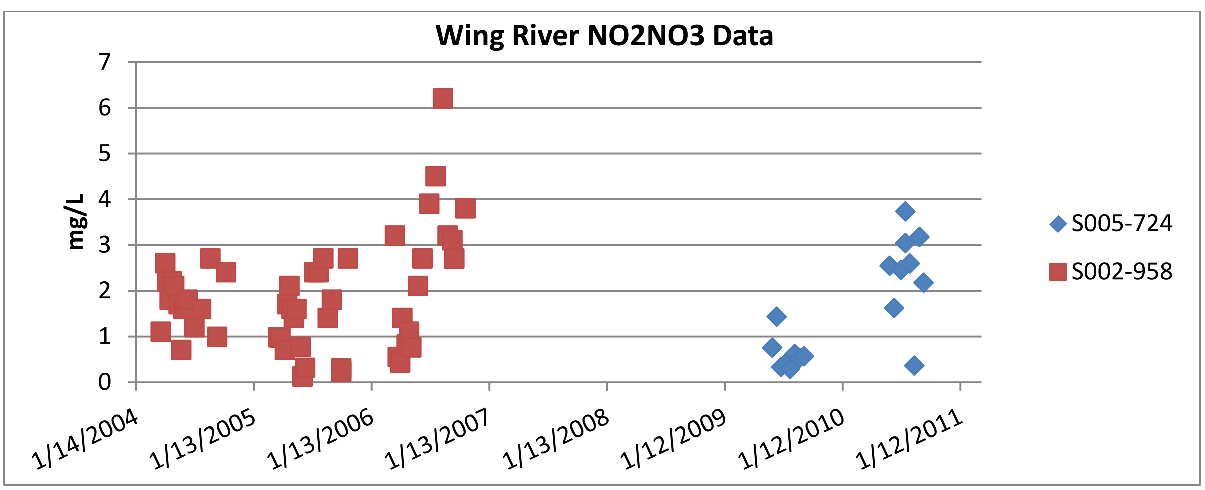


Figure 4.3.4: NO_2+NO_3 concentrations in the Wing River at two EQuIS sampling locations from 2004- 2010.

Lack of physical habitat

Habitat quality in the Wing River upstream of the Highway 210 dam; located in Hewitt, Minnesota, varies from just below fair to good. The MSHA was the main tool used for evaluating this potential stressor and the results of these habitat scores can be seen in Figure 4.3.5 below.

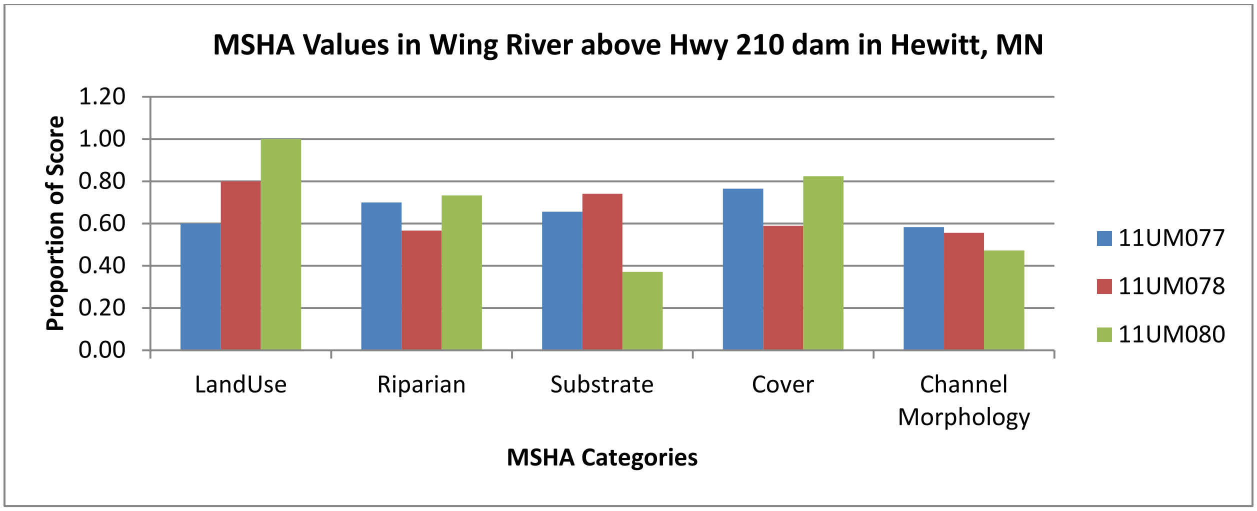


Figure 4.3.5: MSHA Values at biologically impaired sites on Wing River above the Highway 210 dam located in Hewitt, Minnesota. Site 11UM077 is the farthest downstream site while 11UM080 is the farthest upstream site.

Multiple sites on the Wing River (AUID 07010107-559) had relatively close MSHA scores. Site 11UM077 scored a 65.2, 11UM078 scored a 62.5 and site 11UM080 scored a 57. The slightly lower score in 11UM080 was caused by a lack of channel stability and general lack of pools. Only 10% of the reach was pool habitat.

Biologically, downstream Wing River fish sites are made up of a high percentage of simple lithophilic spawning fish at sites 11UM078 (58%) and 11UM077 (69%). The upstream site 11UM080 has a much lower percentage of simple lithophilic spawning fish (11.4%). These fish require clean gravel substrate for spawning. These types of spawners also tend to decrease in streams with degraded habitat. At this time, The MSHA and biological information suggest that habitat is not stressing the fish communities in this section of the Wing River at this time.

Lack of connectivity

The Wing River has a dam located at Highway 210 in Hewitt, Minnesota that is likely acting as a fish barrier.

Figure 4.3.6: Dam on the Wing River located at the intersection of Highway 210 and Highway 71 in Hewitt, Minnesota. The photo on the left is looking upstream toward dam. Photo on right is looking downstream at dam. 10/2/2013 date of photos.

Figure 4.3.6 above shows the condition and placement of the dam. This dam is approximately 1.7 feet higher than the downstream stream bottom.

July 18, 2012 photo

June 28, 2012 photo

June 13, 2013 photo

Figure 4.3.7: Photos of various flow regimes from the dam on the Wing River in Hewitt, Minnesota at Highway 210.

Photos of various flow regimes at the dam have been documented during 2012 and 2013. During flows of 30 cfs or below; the height of the dam would become a barrier to small minnow size fish. The physical jump of 1.7 feet would hinder any upstream migration. During mid-range flows as seen on June 28th, 2012 fish may be able to pass through the dam however velocities along with the drop in stream surface would still impede most small minnow size fish from passage. High flows encountered in spring and early summer would cause very high stream velocities at the dam location which would stop any upstream migration of small minnow size fish. Figure 4.3.7 above shows the dam at three differing flow regimes all of which would potentially block fish passage.

Downstream of the dam at site 11UM076 the FIBI score passed with a score of 54. Above the dam at sites 11UM077 and 11UM078 both FIBI were below the threshold of 47 and failed the FIBI. There is also a significant beaver dam located just downstream of Site 11UM077. This beaver dam is potentially acting as a fish barrier and changing the surface water slope of the stream. The beaver dam is holding back approximately 2 feet of water. The main differences in FIBI scores can be attributed to the FIBI metrics of relative abundance (%) of taxa that are darter, sculpins, and round bodied suckers (DarterSculpSucTxPct), relative abundance (%) of individuals of the dominant two species (DomTwoPct), and number of taxa that are very tolerant (Vtol). All three of these metrics scored considerably higher at the downstream site 11UM076 and increased the score by 10 points at 11UM076 which allowed it to pass the FIBI. The increase in DarterSculpSucPct at 11UM076 indicates that the Wing River is supporting this type of fish but the physical barrier of the dam is impeding fish movement. The DomTwoPct is the measure of the dominant two fish species found in the sample. The lower this percentage is the better the FIBI metric score will be. This is indicative of the distribution of fish species at the sampling locations. There were more fish species found at the downstream site (11UM076) than at the upstream locations (11UM077 and 11UM078). The Vtol metric is the number of taxa that are very tolerant. This metric score increases when the number of very tolerant fish species decreases. This indicates that the number of very tolerant fish species located at site 11UM076 is lower than at sites 11UM077 and 11UM078 which are above the dam. This would indicate that the very tolerant fish are able to survive year round in the Wing River above the dam and other fish species are not able to migrate above the dam and repopulate. Both the tolerant and very tolerant taxa numbers are higher above the dam. The numbers of fish taxa that are considered migratory are higher below the dam. There is only one fish taxon above the dam that is considered migratory and three migratory fish taxon below the dam. The dam is causing a shift in the upstream fish community that is causing the low FIBI score.

Increased bedded sediment

Channel dimension and profile survey work was conducted at three locations along the Wing River. Sites 11UM077, S007-427 and 11UM078 were surveyed using the method developed by Rosgen (Rosgen, 1996). Both of these sites are above the dam at Highway 210 and will be compared to the site below the dam (11UM077). MDNR assisted MPCA along with Local SWCD partners on conducting the surveys. Appendix C lists the detailed report on the Wing River geomorphic sampling locations performed by MDNR. Stream channel dimensions along with channel profile and substrate composition were collected at the three sampling locations. Table 4.3.2 below shows the characteristics of the channel survey inventory. Site S007-427 is immediately above the dam at Highway 210. This site was chosen to show the impact that the dam is having on the physical characteristics of the channel. The reach particle size at S007-427 is 0.27 mm and is the smallest particle size of the three surveyed reaches. Channel width at the S007-427 riffle is also over twice as wide as it is at the two reach locations that are not as severely impacted by the dam. The over widened channel cross section at S007-427 is allowing the deposition of fine particles and the stream cannot generate enough stream power to move the sediment through the system.

Table 4.3.2: Stream channel statistics for the three Wing River Rosgen channel inventory sites.

Site ID	Drainage Area (mi2)	Riffle Width (Wbkf)	Width of Flood-Prone Area (Wfpa)	Entrenchment Ratio (Wfpa/Wbkf)	Mean pool Depth to Mean Riffle Depth (dbkfp/dbkf)	Reach Particle Size (D_{50}) mm	Classification
11UM077	131	36.4	491	13.5	1.03	0.9	E5/C5
US Dam (S007-427)	124	81.3	300	3.69	1.51	0.27	C5c
11UM078	107	40.13	386	9.85	1.185	6.99	C4c

Based on Pfankuch stability rating the three surveyed reaches appears to be stable. The riparian vegetation at all three reaches were intact and the amount of bank erosion was minimal. There is not enough evidence to show that increased bedded sediment is a main stressor to the biological communities in the impaired Wing River AUID. The presence of the dam is causing localized bedded sediment issues along with over widened stream channel and loss of certain habitat features.

4.3.3. AUID summary

The Wing River lies in the far southerly portion of the Red Eye River Watershed. Land use in the impaired portion of the Wing River is predominately a mixture of agricultural cropland and rangeland, with approximately 69 registered feedlots located in the subwatershed (Figure 4.3.8). Registered feedlots range in size from small to large. The largest registered feedlots in the watershed are either turkey or chicken rearing facilities. With the large number of animal units located in this watershed there is a potential for manure runoff entering the area streams. Application of manure on frozen soil can allow the manure to directly runoff into area streams during spring rain events or snow melt conditions. Some of the feedlots are located in close proximity to area streams and if pasture areas are located along the stream corridor there is a high probability that the stream banks are eroding due to lack of riparian plant cover and animal trampling along bank tops.

Various sections of stream channel have been altered. The altered watercourse layer used to identify stream channels that have been channelized in the past is also shown on the map in Figure 4.3.8. Various headwater streams and small tributary streams to the Wing River have been altered. This can change the delivery of surface runoff by allowing the runoff to enter the streams at a faster rate than under natural conditions. This can also lead to stream bank failure due to higher peak discharges and more frequent peak stream discharges. The channelization that is present in the southern portion of the watershed appears to be designed to drain some extensive wetland areas. Many of these wetland areas are still wet meadow according to the 2010 aerial photography viewed using ArcGIS, which is a computer mapping program that allows for the viewing of aerial photography from different years that can be compared against each other.

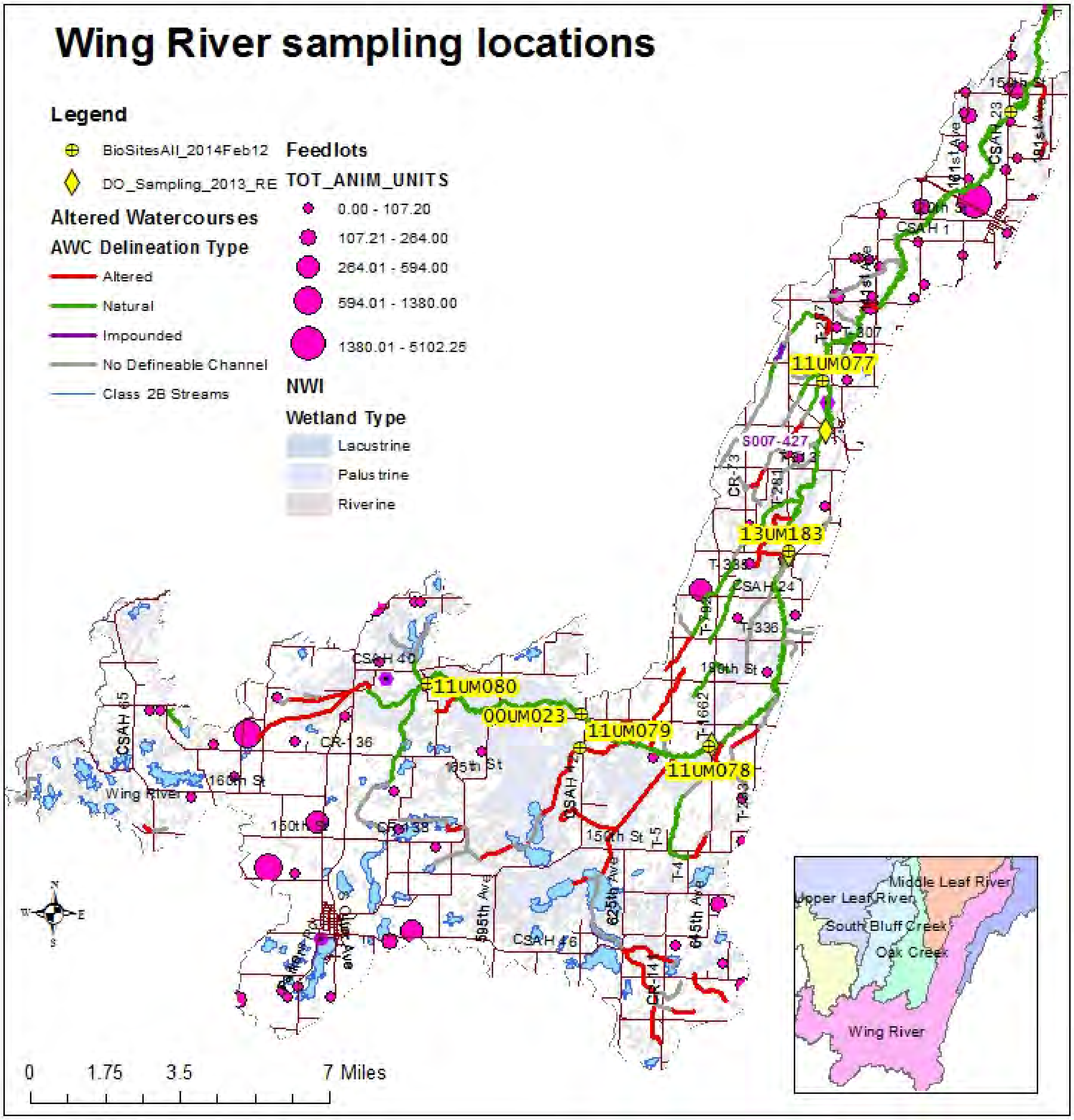


Figure 4.3.8: Wing River sampling locations along with stream channel condition upstream of the dam at Highway 210. Animal permitted feedlots and wetland area are also identified on this map.

The valley walls which confine a stream channel into a boundary condition are nearly four times as wide upstream of site 11UM078 as the valley walls are downstream of site 11UM078. The stream corridor upstream of site 11UM078 has a flatter channel slope and a wider floodplain which has extensive wetland riparian fringe. This upstream area is also the area of the stream that has some low DO concentrations that are probably driven by a combination of wetland riparian along with agricultural practices occurring in this area.

4.3.3.1. Stressor pathway discussion

The low DO coming out the headwaters of this AUID is likely a function of the land use and the landscape characteristics. The area above site 11UM080 is comprised of two large drainage ditches that join to the west of the site to form the Wing River channel. This drainage network drains some large wetland areas with interspersed agricultural row crop and some permitted feedlot facilities that range from large turkey production facilities to small cattle and sheep facilities. The increased nutrients, altered hydrology and partially drained wetland soils are all contributing to the low DO concentrations in this portion of the AUID. The elevated Nitrite-nitrate concentrations are possibly linked to the groundwater pumping that is occurring in the lower reaches of the AUID for center pivot irrigation. The nitrogen levels currently may not be high enough to cause stress to the biology but are approaching levels high enough to cause future problems. Additional information should be collected on groundwater pumping rates and concentrations of nitrite-nitrate in the shallow aquifer.

The dam at Highway 210 near Hewitt is causing a physical barrier to fish migration. This dam should be investigated and determined if removal is needed. A rock riffle structure could be installed in place of the dam which would allow for fish passage. The fish community is in better condition immediately below the dam.

4.3.3.2. Stressor conclusions

AUID 07010107-599 is 25.17 miles long and has different stressors affecting different sections of the AUID. The farthest upstream section of the AUID above sampling location 00UM023 often has DO concentrations below the Class 2B DO standard of 5 mg/L. This reach also has a fish community that is dominated by low DO tolerant fish species. As we move downstream the low DO issues are eliminated and the stream appears to be affected by a different stressor. This downstream section has a dam that is preventing fish passage during various flow regimes and the fish community is different above the dam than below the dam. The downstream fish community passes the FIBI and the upstream fish communities all have F-IBI scores below the FIBI threshold. The dam is a source of stress to the fish community. Nutrient concentrations for nitrogen are often above the ecoregion goals. The high nitrogen concentrations are linked to the high amount of agricultural land use in the watershed

4.4. Tributary to Leaf River (AUID-07010107-557)

4.4.1. Biological communities

The macroinvertebrate community in Trib. to Leaf River (07010107-557) is impaired. The macroinvertebrate IBI scored 21 points below the threshold at the one sampling location (11UM055). The macroinvertebrate community was dominated by *Hyallella sp*. (scuds) and *Physa sp*. (snails), with *Baetis sp*. (mayfly) being the third most dominant macroinvertebrate sampled. Both scuds and snails are tolerant to high sediment concentrations in the stream and can tolerate low DO concentrations. The two dominant macroinvertebrate species make up 60.1% of the sample. The three dominant macroinvertebrate species make up 73.1% of the sample. The macroinvertebrate sample was also made up of 73.7% tolerant species. The fish community at this same site scored seven points above the threshold.

4.4.2. Data analysis/evaluation for each candidate cause

Low dissolved oxygen

The water quality standard for DO is 5 mg/L as a daily minimum in Class 2B streams. Very limited data on DO has been collected in this stream AUID. On June 25, 2013 at 0810 a single DO reading was collected

(7.47) at this site. In 2013 the MPCA developed a community tolerance index value for macroinvertebrates based on tolerance values for individuals comprising the macroinvertebrate sample. Splitting the community DO index value into the different stream classes for macroinvertebrates in Minnesota is one way to identify if the community is showing signs on DO tolerance. Site 11UM055 scored a 6.63 on the DO Index Value. This value is then looked at compared to the rest of the Class3 streams in the state to determine the relative placement of the score. Table 4.4.1 below shows the statistics for all Class 3 stream macroinvertebrate community DO index values. The value of 6.63 ranks site 11UM055 in the lower 20th percentile which indicates that the macroinvertebrate community is tolerant to low DO readings. Additional early morning DO readings should be collected at this location to determine if DO is a stressor to the macroinvertebrate community.

Table 4.4.1: Class 3 macroinvertebrate DO Index Value ranked for all class 3 sites in Minnesota. The lower the value the more tolerant to low Dissolved Oxygen levels in the stream.

	DO Index Value
N of Cases	252
Minimum	5.847
Maximum	7.703
Interquartile Range	0.622
Arithmetic Mean	6.977
Standard Deviation	0.409
Method = CLEVELAND	
1.00%	5.99
5.00%	6.224
10.00%	6.396
20.00%	6.638
25.00%	6.691
30.00%	6.764
40.00%	6.898
50.00%	7.047
60.00%	7.151
70.00%	7.249
75.00%	7.314
80.00%	7.383
90.00%	7.46
95.00%	7.491
99.00%	7.649

Elevated nutrients

Elevated nutrients can have a direct effect on growth of aquatic macrophytes and peryphyton growth in streams. The limiting nutrient for plant growth is typically phosphorus. Total Phosphorus (TP) is measured to determine the concentrations in streams. TP is the concentration of all phosphorus found in the water sample and is reported as mg/L. The state standard for streams in this portion of Minnesota is 0.100 mg/L of TP. Anything above this value is excess and can cause increased plant and peryphyton growth in streams. Water samples were collected five times and analyzed for TP at site S007-429. Two of the five samples were above the 0.100 mg/L standard. Figure 4.4.1 below displays the concentration of TP along with the date of sample collection.

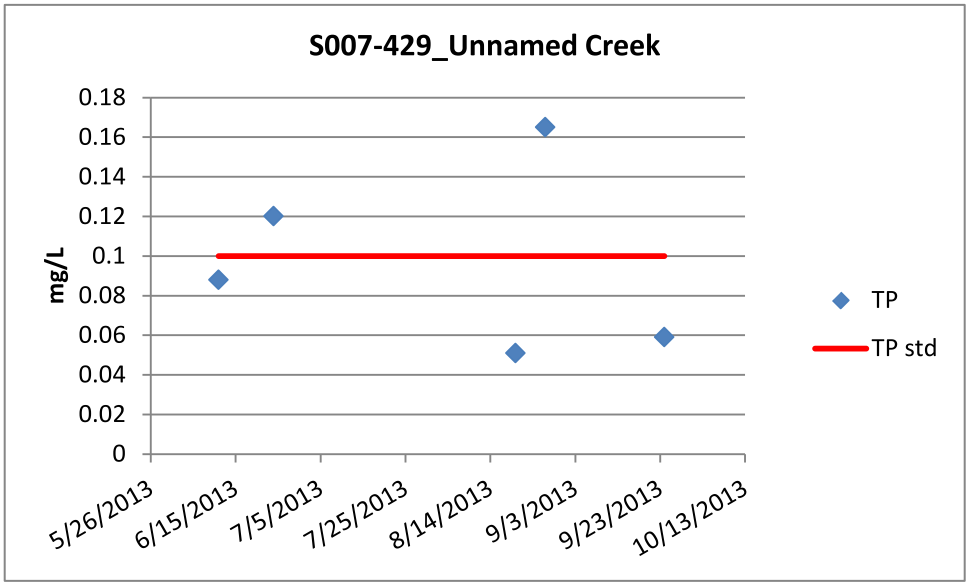


Figure 4.4.1: TP concentrations during 2013 sampling events at S007-429 in Unnamed Creek.

The elevated TP concentrations are causing an increase in stream bottom peryphyton growth. This is evident in the relatively high percentage of scrapers in the macroinvertebrate sample (17.4%). The macroinvertebrate sample was dominated by taxa richness of non-insect macroinvertebrate (nonInsect) individuals (62.4% were scuds and snails). Out of the remaining 38% of individuals that are Insects nearly half are scrapers. The insects that are considered scrapers feed by scraping peryphyton off substrate such as rock or wood. There numbers are directly influenced by the abundance of peryphyton available. Note peryphyton growth on stream channel bottom in the picture below.

Figure 4.4.2: Picture taken on 10/8/2013 during survey work

Elevated nutrients can also lead to an increase in daily DO flux which can inhibit the abundance of macroinvertebrates. Elevated nutrients can cause an increase in photosynthesis and respiration which can lead to a large daily DO fluctuation.

Increased sediment

The water quality standard for Turbidity is 25 NTU, and 30 mg/L for TSS in the Red Eye River Watershed. Excess sediment is a commonly recognized stressor in many biologically impaired streams because it can reduce habitat, cause direct physical harm, as well as reduce visibility and increase oxygen demand.

Tributary to Leaf River had seven TSS samples collected in 2013 at EQuIS site S007-429. The TSS samples were all below the 30 mg/L standard in 2013 (ranged from 1.2 to 12 mg/L) however; the dataset is small and is limited to only 2013 data. During the field survey conducted in October 2013 it was documented that there was a significant amount of bank erosion occurring in the study area. This bank erosion is active on outside bends of the river along with areas that had cattle crossing exposure. The significance of this bank erosion is difficult to link directly to the lack of macroinvertebrates at the study site. It is believed that the bank erosion is having an impact on the macroinvertebrate community. When the individual macroinvertebrates are analyzed based on tolerance metrics developed by Yuan (Yuan, 2007) and analyzed to determine tolerance to excessive sediment, the individual macroinvertebrate species show 73.1% of the sample is tolerant to excess sediment. Figure 4.4.2 below shows the individual macroinvertebrate species when ranked against sediment tolerance values developed by Yuan in 2007.

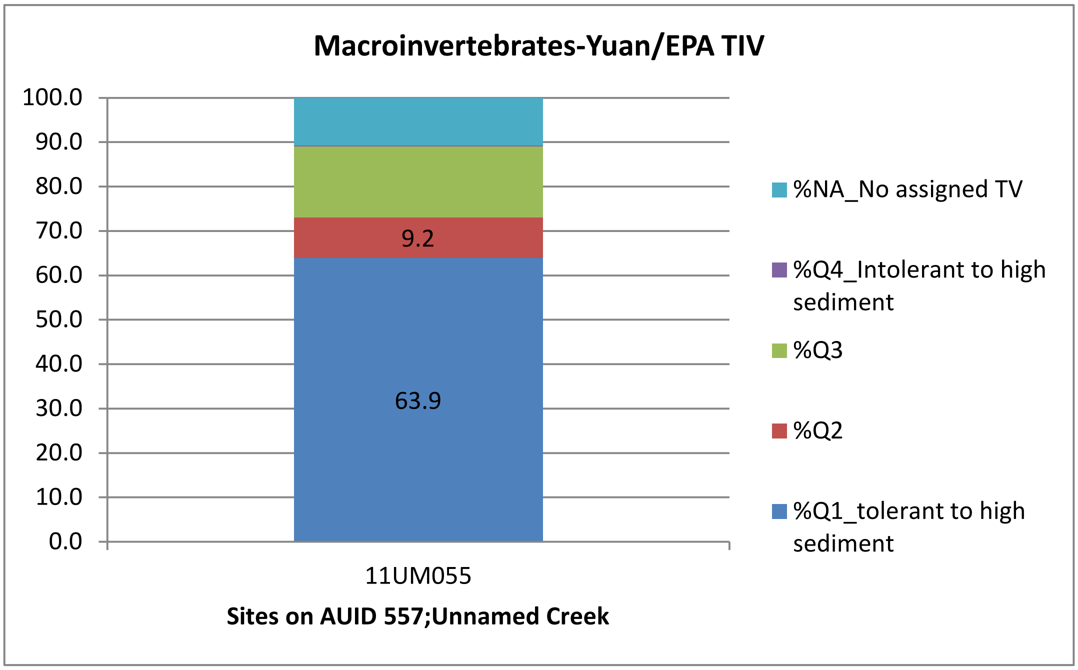


Figure 4.4.3: Tolerance to increased sediment based on TVs developed by Yuan (2007). Macroinvertebrate genera are given a TV and ranked according to quartiles. And 3.1% of genera fall below the 50th percentile for tolerance to elevated sediment.

The most abundant macroinvertebrates in the 8/25/2011 sample were snails and scuds. Both of these genera are tolerant to increased sediment levels and are responsible for the high percentage of sediment tolerant macroinvertebrates. The macroinvertebrate sample was collected from rock riffle and undercut bank. It is likely that the high number of scuds came from the undercut bank samples and their relative abundance is bringing down the M-IBI score.

The MPCA created a TSS Index value based on macroinvertebrate samples and paired TSS readings at the time of sampling. This dataset looks at the macroinvertebrate community and assigned a community index value. The community index value can then be compared to other sites in a similar macroinvertebrate class and a general sense of the community tolerance to a pollutant can be assessed. Site 11UM055 is a Class 3 stream for macroinvertebrates. Comparing all Class 3 streams throughout the state and quartiling the TSS Index value gives an indication of where the sampled macroinvertebrate community scores in relation to all other Class 3 sites statewide. Biological station 11UM055 scores in the upper 75th percentile and indicates that the community is tolerant to elevated TSS. The stream banks along this reach were actively eroding in places and contributing sediment to the stream system. The stream banks were evaluated using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model by conducting a BEHI inventory of eroding stream banks in the study reach. The stream banks in a 758 foot reach are estimated to be contributing 17 tons of sediment per year. Some of this sediment will be in the form of TSS and some will enter the system as bedload and cause the stream bed to aggrade over time. The fine colloidal particles that stay in suspension will affect the macroinvertebrates differently than the sediment that is acting as bedload. The bedload will fill interstitial spaces and cause a lack of rocky habitat over time. The TSS portion will cause gill abrasion and may smother out the macroinvertebrates. Appendix A will have the BEHI calculations along with a map showing the eroding stream bank locations. Based on the above information, elevated TSS is a stressor to the macroinvertebrate community.

Lack of physical habitat

Habitat quality in Unnamed Creek is rated as good (MSHA score of 72.7) at biological site 11UM055. The MSHA was the main tool used for evaluating this potential stressor. The fish community at this site passes the FIBI; however, the macroinvertebrate community fails the M-IBI and is listed as impaired. The clinger taxa percent (27%) was below the average amount of clinger taxa and also had a population of 74% tolerant taxa. Macroinvertebrates are sensitive to a combination of habitat and nutrient concentrations. The habitat is lacking woody debris and overhanging vegetation in the reach. The immediate land use in this particular reach is active pasture. The channel is slightly over widened and the banks are showing signs of active erosion during the 2013 channel survey inventory. Using the data that was collected during this field investigation, it is believed that lack of physical habitat is a stressor. Figure 4.4.3 and 4.4.4 below shows pictures of the 2013 channel and bank conditions at 11UM055. These photos were taken during a channel dimension and profile survey that was conducted using (Rosgen, 1996) methodology on 10/08/2013. At the time of the survey it was determined that the bank failure was significant enough to be causing filling of pools and a BANCS model was conducted (see Appendix A).

Figure 4.4.4: Photos of typical stream run section and active cattle crossing at Biological Site 11UM055.

The survey data shows that the pools are filling with fine sediment and the riffles are also aggrading over time. There is a lack of woody debris in the channel which is also an important habitat feature for macroinvertebrates. Using the additional field information that was collected it is believed that lack of physical habitat is a stressor to the macroinvertebrate community.

Figure 4.4.5: Photos of Biological Site 11UM055. Site is located in active pasture and has severe bank erosion occurring in areas.

4.4.3. AUID summary

On October 8th, 2013 a channel survey was conducted at site 11UM055 using Applied River Morphology methodology developed by Rosgen (Rosgen, 1996). The survey was conducted following a Level 2 assessment method where channel slope, pattern and profile are surveyed to classify the stream type and review physical properties of the channel. The survey collected information on approximately 1600 feet of stream channel. Figure 4.4.5 shows the location of the stream channel survey in relation to biological sampling location 11UM055. The general landscape features in this area have agricultural row crop fields located in the uplands where the land is higher in elevation and has a gentle slope. As the row crop areas approach the stream valley, the landscape slope increases and the valley is too steep to grow row crops and is generally forested with some animal pasture activity occurring in this transitional area. The stream slope is also flat in the upland areas and has a much steeper stream slope as it approaches the area that the biological sample was collected.

Channel slope was measured by surveying stream bottom features such as pool, riffle, run, and glide elevations. The stream has two different bottom slopes in the surveyed area. There was a rock structure across the channel at station 700 which caused a slope change in the channel. The channel slope upstream of the rock structure is 0.0052 ft/ft and downstream of the rock structure the stream slope is much flatter at 0.0024 ft/ft. Appendix A has the stream profile graphs for the upper and lower half of the survey along with channel cross section data and BEHI information.

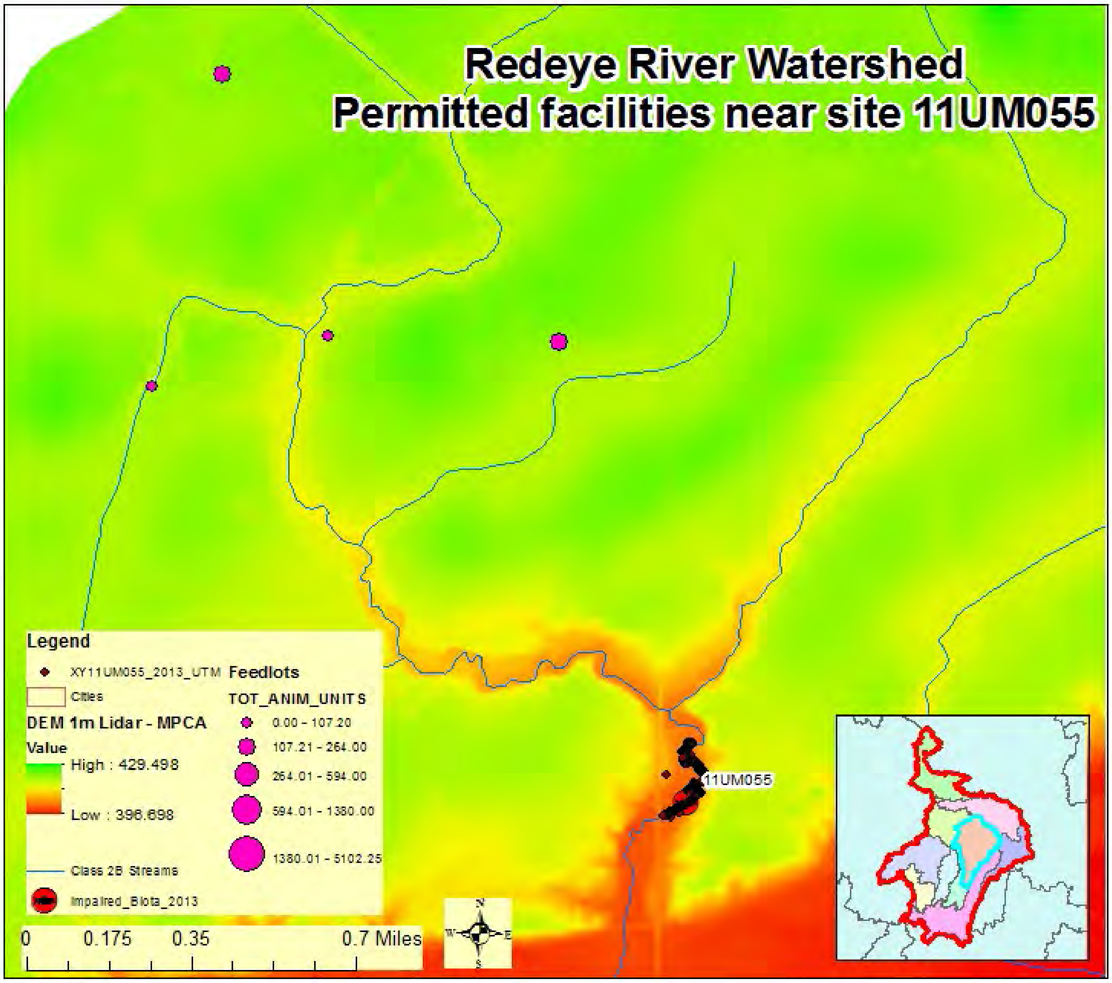


Figure 4.4.6: MPCA generated 1m Digital Elevation Map (DEM) showing slope of uplands in green where significant row crop agriculture is occurring along with the red areas indicating valley walls of stream corridor where slope is increasing. Black dots on map show surveyed area of stream at site 11UM055.

4.4.3.1. Stressor pathway discussion

The stream channel slope in the study reach was steep in the upper half of the stream section surveyed. The lower half of stream section was lower in slope (about ½ the slope of the upstream portion). The upstream portion at bankfull discharge is estimated to have 2.65 ft/sec velocities which may cause significant amounts of bank failure during bankfull discharge events. The bankfull event will occur on average every 1.5 years. So this event is common and can occur during snowmelt or heavy summer thunderstorms. The lower half of the surveyed stream reach has a lower slope and with that a lower stream velocity at bankfull discharge. The velocity in the lower section is estimated at 1.6 to 1.7 ft/sec. This is significantly lower than the upper stream section; however the bank condition in the lower stream section is more disturbed by animal access and is experiencing greater bank failure. Mid to high flow events are believed to be carrying excessive amounts of sediment into the stream. The increased sediment is causing a lack of habitat along with potential gill abrasion during high concentrations. The diurnal fluctuation of DO is believed to be tied to the increased nutrient concentrations being exported from the upland agricultural row crop production in the upland portion of the watershed. Increased nutrients are responsible for increased plant and peryphyton growth in the stream which can lead to increased photosynthesis and respiration (causing wide daily fluctuations in DO concentrations).

4.4.3.2. Stressor conclusions

The macroinvertebrate community is represented by organisms that do well in low DO conditions and high TSS conditions. The community is heavily weighted by the abundance of scuds and snails, these two species make up approximately 65% of the sample. The macroinvertebrates appear to be stressed by high TSS concentrations caused by eroding banks, upland field runoff, aggrading stream bed and lack of physical habitat (both caused by excessive sediment entering the stream through bank failure which is filling interstitial spaces and the potential for low DO concentrations.

5. Conclusions

Low DO concentrations are a common theme in the impaired AUID's throughout the Red Eye River Watershed. Review of the impaired fish and macroinvertebrate communities show that the majority of the biological communities are dominated by species that can tolerate low DO concentrations. Lack of physical habitat is also a concern to the impaired biotic communities. The habitat tool used to evaluate this stressor is the MSHA score. This score was poor to fair at the impaired stream stations sampled in each impaired AUID. Flow alteration caused by channelization and drainage is also playing an important role in the lack of biotic community structure in some AUID's. The Wing River has a low head dam located at the Highway 210 bridge which is causing limited to no fish passage during the year. Table 5.1 below lists the stressor(s) to the biotic community by stream AUID. Each AUID has multiple stressors affecting the biology.

Table 5.1: Summary of probable stressors in the Red Eye River Watershed.

		Stressors						
Stream Name	**AUID #**	**Low Dissolved Oxygen**	**Flow Alteration**	**Increased Sediment**	**Increased Bedded Sediment**	**Elevated Nutrients**	**Lack of Physical Habitat**	**Physical Connectivity**
South Bluff Creek	07010107-553	X	●		X		X	
Trib. To East Leaf Lake	07010107-554	X					X	●
Wing River	07010107-559	●	●			●		X
Trib. To Leaf River	07010107-557	●		X	●	●	X	
Union Creek	07010107-	X						

X is primary stressor

• is a secondary stressor

6. References

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7. Appendix

7.0 Appendix A

7.0.1 Summary of Rosgen Level 2 Channel Assessment 11UM055

On October 8, 2013 a channel assessment was conducted at biological monitoring location 11UM055. Below is a summary of the findings of the survey work. Figure 7.7.1 and 7.7.2 below show the channel slope differences between the upper and lower half of the surveyed reach. The reach was separated by a rock structure at station 700 which also was where the slope break occurred.

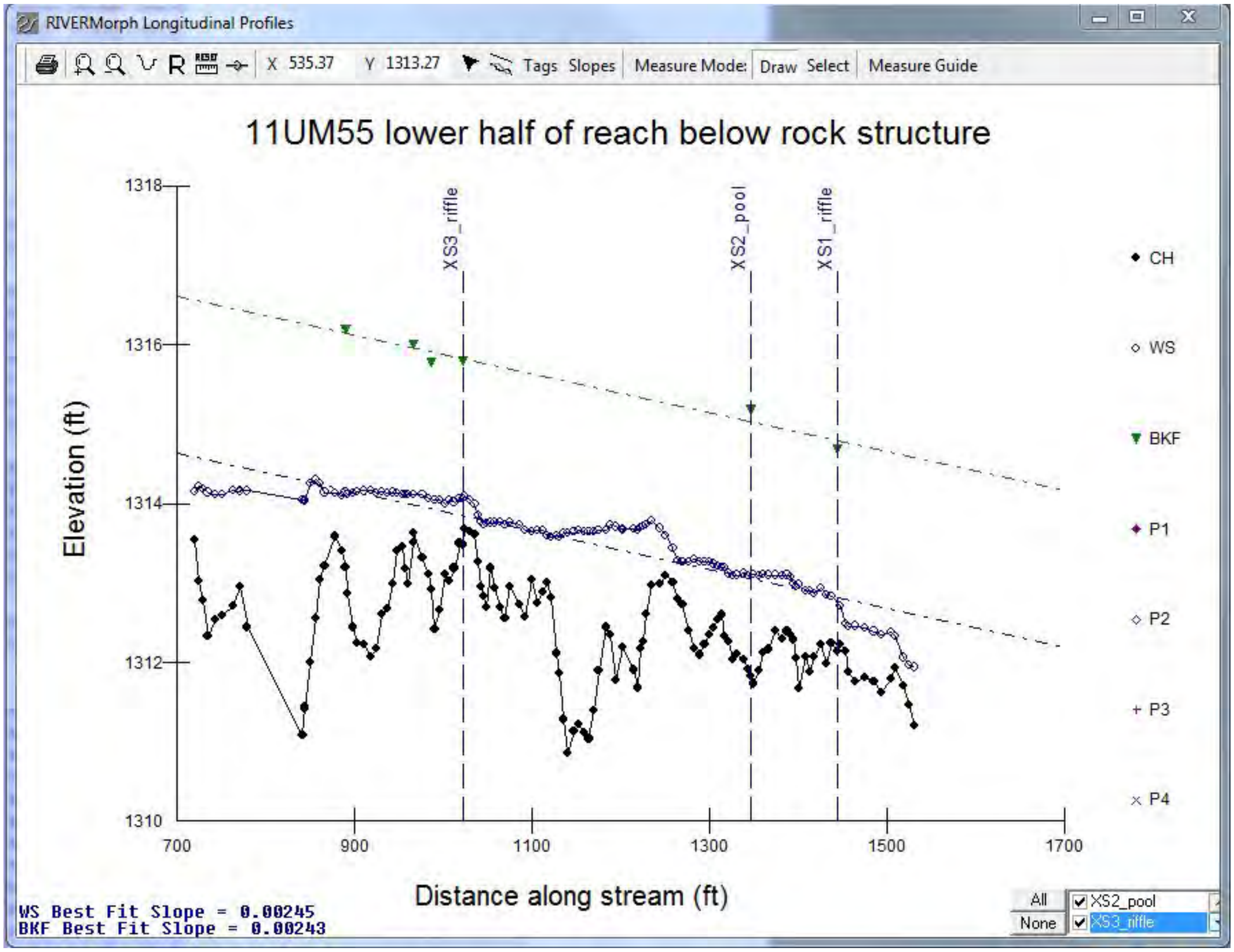


Figure 7.0.1: Lower section of channel survey at biological site 11UM055

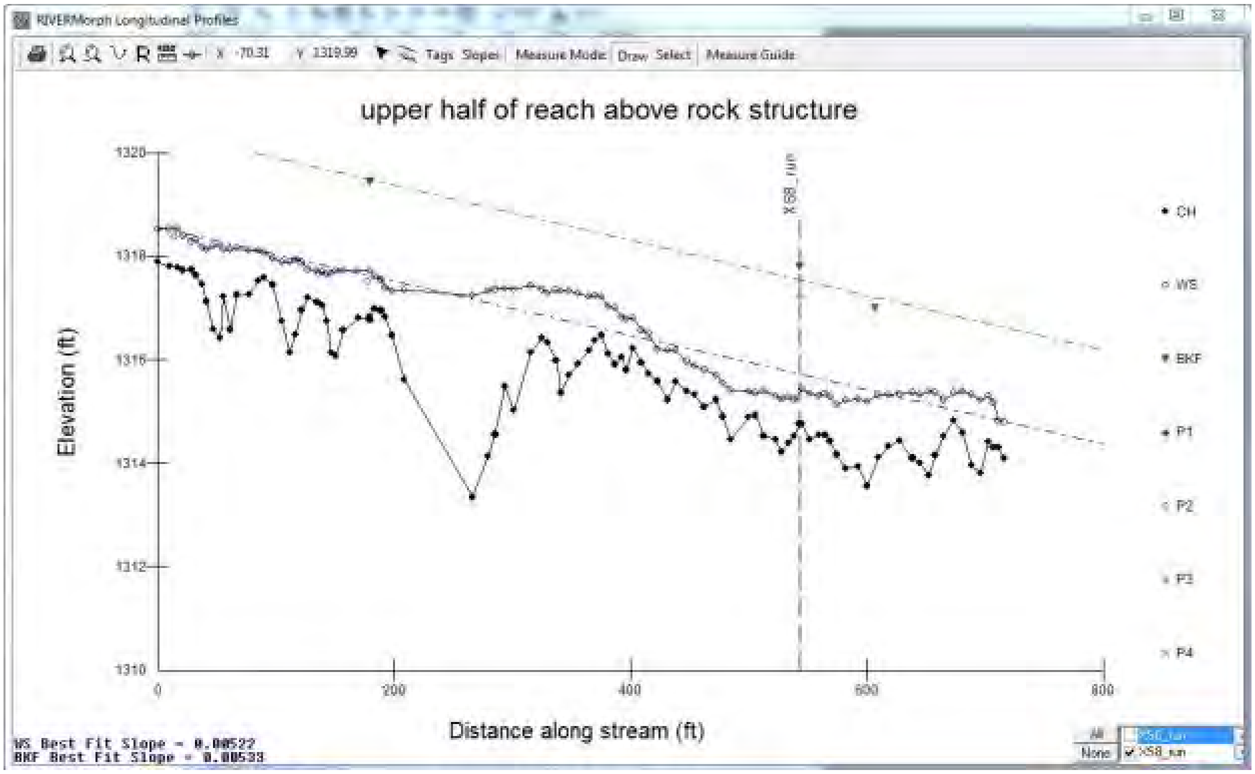


Figure7.0.2: Upper section of channel survey at biological site 11UM055. Slope is twice as steep in the upper half of the reach as it is in the lower half of the reach.

Figure7.0.3: Photos taken during channel survey on 10/8/2013. Photo on left is lower portion of reach taken from approximately 100 feet upstream of road crossing looking upstream. Photo on the right shows the rock structure that is acting as a slope change between the two streams surveyed sections. Upstream of rock structure is higher gradient and downstream is lower gradient.

Channel cross sections were collected to identify various channel characteristics. Channel dimension is important to characterize so we can interpret what is happening with the current channel. Is the channel stable or is it in a state of change that may be impacting the biological community. Cross sections were collected and a select number of cross sections were further analyzed to assess the current conditions of the channel dimensions. Table 7.7.1 shows the channel dimensions that were collected during the survey. The channel discharge and velocity were estimated using channel cross section characteristics along with slope and D84 particle size to estimate roughness. The cross section data collected suggests that the channel does not have enough stream power to move the sediment and is therefore aggrading. This is changing the stream type from a stable C to an unstable D channel.

Table 7.0.1: Riffle Cross section comparisons from three stations in the stream reach where biological sample 11UM055 was collected.

	XS1 - riffle	XS3 - riffle	XS9 - riffle
Floodprone Elevation (ft)	1317.23	1318.1	1322.14
Bankfull Elevation (ft)	1314.69	1315.79	1319.45
Floodprone Width (ft)	150	150	125
Bankfull Width (ft)	45.7	52.38	36.47
Entrenchment Ratio	3.28	2.86	3.43
Mean Depth (ft)	0.95	0.94	1.34
Width/Depth Ratio	48.11	55.72	27.22
Bankfull Area (sq. ft)	43.51	49.28	48.96
Hydraulic Radius	0.92	0.93	1.21
Estimated Velocity at Bankfull (ft/sec)	1.62	1.69	2.54
Estimated Discharge at Bankfull (cfs)	67.5	82	124
Channel Slope (ft/ft)	0.0025	0.0025	0.0054
D84 (mm)	87.8	87.8	87.8
Entranchment Ratio	3.28 (Slightly Entrenched)	2.86 (Slightly Entrenched)	3.43 (Slightly Entrenched)
Width to Depth Ratio	48.11 (Very High)	55.72 (Very High)	27.22 (Moderate to High)
Classification	C--- > D	C--- >D	C
Stable	No	No	Yes

Figure 7.0.4: Biological site 11UM055 location map of bank erosion areas used in calculation of BEHI.

Bank erosion was evident in much of the surveyed reach around site 11UM055. The relatively steep stream slope in the upper portion of the survey area can have stream velocities in the 2.6 ft/sec range during bankfull events. The velocity is high enough to cause banks to erode where adequate bank protection is not provided. In an effort to quantify how much sediment was being contributed to the stream from stream bank erosion a BANCS model was computed using the Bank Erosion Hazard Index (BEHI) method. This method looks at the height and length of the study bank along with the sheer stress placed on the bank to estimate how much sediment is annually eroding from the study bank. Figure 7.0.5 shows the areas of the stream banks that had active erosion and were used to estimate the amount of bank material annually eroding. The eroding banks were documented using the BEHI spreadsheet and annual sediment supply from the eroding banks was calculated using the Rivermorph 5.1 software package. Table 7.0.2 below lists the sites along with annual sediment supply coming from each study bank. The estimated annual sediment load coming from the 758 feet of study bank is 17.4 tons/year. Some of this sediment is being transported downstream and away from the surveyed stream section and some of this sediment is being stored in the stream and causing point bar and mid channel bar deposition.

Table 7.0.2: BEHI assessment of eroded stream banks in the surveyed reach along with the estimated sediment contribution from bank failure.

Stream:	**11UM055_Unnamed Cr, Reach - Reach 1**				Location:		
Graph Used:			Total Stream Length (ft):	**758**		Date:	**10/8/2013**
Observers:	**cgj**		Valley Type:	**V**		Stream Type:	**C 4**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1. **BEHI2**	**Low**	**Low**	**0.042**	**54.0**	**1.3**	**2.93**	**0.00260**
2. **BEHI3**	**Moderate**	**Low**	**0.168**	**54.0**	**1.3**	**11.79**	**0.01050**
3. **BEHI4**	**Moderate**	**Low**	**0.168**	**55.0**	**1.3**	**12.01**	**0.01050**
4. **BEHI5**	**Moderate**	**Moderate**	**0.282**	**40.0**	**1.3**	**14.66**	**0.01770**
5. **BEHI6**	**Moderate**	**Moderate**	**0.282**	**37.5**	**1.3**	**13.75**	**0.01770**
6. **BEHI7**	**Low**	**Low**	**0.042**	**20.0**	**1.3**	**1.09**	**0.00260**
7. **BEHI8**	**Moderate**	**Moderate**	**0.282**	**28.0**	**1.3**	**10.27**	**0.01770**
8. **BEHI9**	**Low**	**Low**	**0.042**	**49.0**	**1.3**	**2.66**	**0.00260**
9. **BEHI10**	**Moderate**	**Moderate**	**0.282**	**35.0**	**1.3**	**12.83**	**0.01770**
10. **BEHI11**	**Moderate**	**High**	**0.473**	**59.0**	**1.3**	**36.28**	**0.02960**
11. **BEHI12**	**Moderate**	**Low**	**0.168**	**23.0**	**1.3**	**5.02**	**0.01050**
12. **BEHI13**	**Low**	**High**	**0.239**	**32.0**	**1.3**	**9.94**	**0.01500**
13. **BEHI14**	**High**	**Extreme**	**2.261**	**46.0**	**1.3**	**135.21**	**0.14150**
14. **BEHI15**	**Low**	**Moderate**	**0.100**	**64.0**	**1.3**	**8.32**	**0.00630**
15. **BEHI16**	**Moderate**	**High**	**0.473**	**33.0**	**1.3**	**20.29**	**0.02960**
16. **BEHI17**	**Moderate**	**High**	**0.473**	**105.0**	**1.3**	**64.57**	**0.02960**
Sum erosion subtotals in Column (7) for each BEHI/NBS combination					**Total Erosion (ft^3/yr)**	**361.62**	
Convert erosion in ft^3/yr to yds^3/yr {divide Total Erosion (ft^3/yr) by 27}					**Total Erosion (yds^3/yr)**	**13.39**	
Convert erosion in yds^3/yr to tons/yr {multiply Total Erosion (yds^3/yr) by 1.3}					**Total Erosion (tons/yr)**	**17.41**	
Calculate erosion per unit length of channel {divide Total Erosion (tons/yr) by total length of stream (ft) surveyed}					**Unit Erosion Rate (tons/yr/ft)**	**0.0230**	

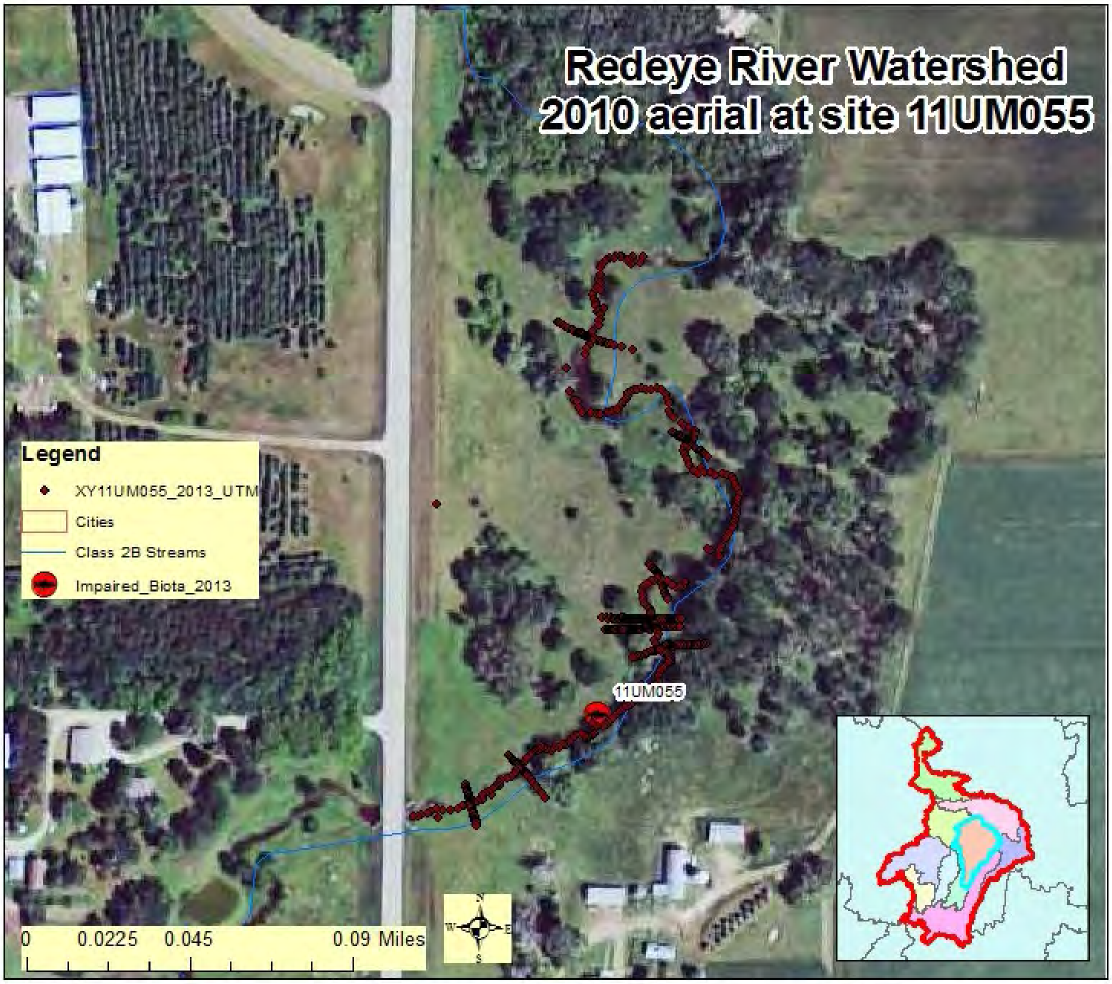


Table 7.0.3: 2010 aerial photo of surveyed stream reach at biological site 11UM055. Land use is study stream section is actively being lightly grazed. Riparian vegetation is grasses with shallow root depth and low root density. This is causing some stream banks to actively erode.

7.1 Appendix B: Lines of evidence scoring of candidate causes

Figure 7.1.0.1: Scoring of Candidate Causes for South Bluff Creek

	South Bluff Creek (AUID 07010107-553)			
	Scores of Candidate Causes			
Types of Evidence	Low DO Concentration	Flow Alteration	Increased Bedded Sediment	Lack of Physical Habitat
Spatial/temporal co-occurrence	++	+	+	+
Temporal sequence	++	+	+	+
Field evidence of stressor-response Causal pathway	++	+	+	+
Evidence of exposure, biological mechanism	NE	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	+++	+	++	++
Symptoms	+	0	+	+
	Evidence using data from other systems			
Mechanically plausible cause	+	+	+	+
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	+	+	++	+
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	NE	NE	NE	NE
	Multiple lines of evidence			
Consistency of evidence	+++	+	+++	++
Explanatory power of evidence	+++	+	++	++

Key to candidate cause scoring

Rank	Meaning	Caveat		Rank	Meaning	Caveat
+++	Convincingly supports	But other possible factors		-	somewhat weakens support	But association does not necessarily reject as a cause
++	Strongly supports	But potential confounding factors		--	strongly weakens	But exposure or mechanism possibly missed
+	Some support	But association is not necessarily causal		---	Convincingly weakens	But other possible factors
0	Neither supports or weakens	(ambiguous evidence)		NE	No evidence available	

Figure 7.1. 0.2: Scoring of Candidate Causes for Tributary to East Leaf Lake

	Trib. to East Leaf Lake (AUID 07010107-554)		
	Scores of Candidate Causes		
Types of Evidence	**Low DO Concentration**	**Physical Connectivity**	**Lack of Physical Habitat**
Spatial/temporal co-occurrence	+	+	+
Temporal sequence	+	+	+
Field evidence of stressor-response Causal pathway	++	0	+
Evidence of exposure, biological mechanism	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE
Verified or tested predictions	+++	+	++
Symptoms	+	0	+
	Evidence using data from other systems		
Mechanically plausible cause	+	0	+
Stressor-response in other lab studies	NE	NE	NE
Stressor-response in other field studies	+	+	+
Manipulation experiments at other sites	NE	NE	NE
Analogous stressors	NE	NE	NE
	Multiple lines of evidence		
Consistency of evidence	++	+	++
Explanatory power of evidence	+++	+	++

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	But other possible factors
++	Strongly supports	But potential confounding factors
+	Some support	But association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	somewhat weakens support	But association does not necessarily reject as a cause
--	strongly weakens	But exposure or mechanism possibly missed
---	Convincingly weakens	But other possible factors
NE	No evidence available	

Figure 7.1. 0.3: Scoring of Candidate Causes for Wing River

	Wing River (AUID 07010107-559)			
	Scores of Candidate Causes			
Types of Evidence	Low DO Concentration	Flow Alteration	Elevated Nutrients	Physical Connectivity
Spatial/temporal co-occurrence	++	+	+	++
Temporal sequence	+	+	+	+
Field evidence of stressor-response Causal pathway	+	0	0	+
Evidence of exposure, biological mechanism	NE	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	++	+	+	++
Symptoms	+	0	+	+
	Evidence using data from other systems			
Mechanically plausible cause	+	+	+	+
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	+	0	+	+
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	NE	NE	NE	NE
	Multiple lines of evidence			
Consistency of evidence	++	+	+	+++
Explanatory power of evidence	++	+	+	++

Key to Candidate Cause Scoring

Rank	Meaning	Caveat
+++	Convincingly supports	But other possible factors
++	Strongly supports	But potential confounding factors
+	Some support	But association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	somewhat weakens support	But association does not necessarily reject as a cause
--	strongly weakens	But exposure or mechanism possibly missed
---	Convincingly weakens	But other possible factors
NE	No evidence available	

Figure 7.1. 0.4: Scoring of Candidate Causes for Tributary to Leaf River

	Trib. To Leaf River (AUID 07010107-557)			
	Scores of Candidate Causes			
Types of Evidence	**Low DO Concentration**	**Increased Sediment**	**Increased Bedded Sediment**	**Lack of Physical Habitat**
Spatial/temporal co-occurrence	++	++	+	+
Temporal sequence	+	+	+	+
Field evidence of stressor-response Causal pathway	+	+	0	+
Evidence of exposure, biological mechanism	NE	NE	NE	NE
Field experiments/ manipulation of exposure	NE	NE	NE	NE
Laboratory analysis of site media	NE	NE	NE	NE
Verified or tested predictions	++	+	+	+
Symptoms	+	+	+	++
	Evidence using data from other systems			
Mechanically plausible cause	+	+	+	+
Stressor-response in other lab studies	NE	NE	NE	NE
Stressor-response in other field studies	+	+	+	+
Manipulation experiments at other sites	NE	NE	NE	NE
Analogous stressors	NE	NE	NE	NE
	Multiple lines of evidence			
Consistency of evidence	++	++	+	+
Explanatory power of evidence	+	+	+	+

Key to candidate cause scoring

Rank	Meaning	Caveat
+++	Convincingly supports	But other possible factors
++	Strongly supports	But potential confounding factors
+	Some support	But association is not necessarily causal
0	Neither supports or weakens	(ambiguous evidence)
-	somewhat weakens support	But association does not necessarily reject as a cause
--	strongly weakens	But exposure or mechanism possibly missed
---	Convincingly weakens	But other possible factors
NE	No evidence available	

7.2 Appendix C: MDNR Stream Geomorphic Assessment Report

The following report in Appendix C was provided by the MDNR staff in Detroit Lakes, Minnesota. It is a report on the current stream classification system developed by Rosgen.

Site Wing River 11UM078

Introduction

Site 11UM078 is located on the Wing River, approximately 5½ miles southwest of Bertha, Minnesota. It is in Otter Tail County, next to the county boundary line shared with Todd County. According to USGS StreamStats, the drainage area is approximately 107 mi^2 (Figure 1).

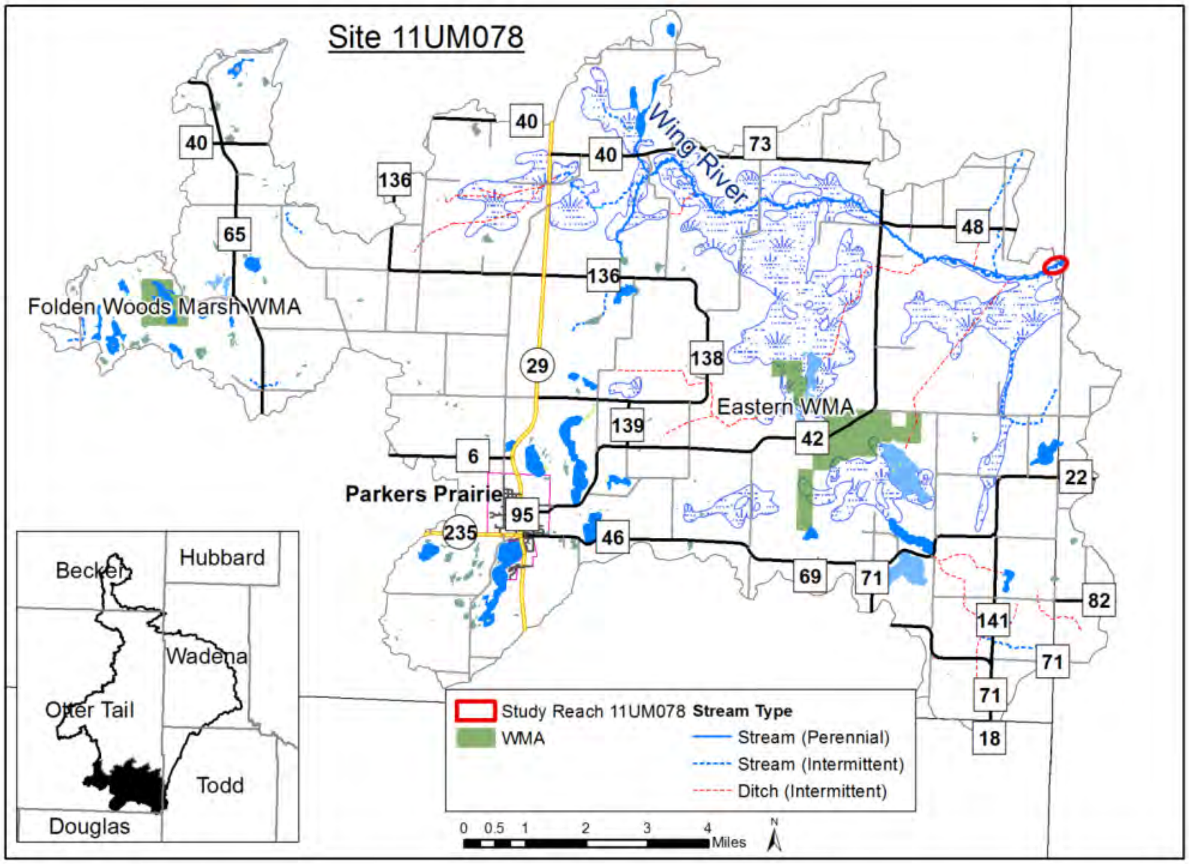


Figure 1: Upstream watershed to site 11UM078. This watershed delineation was created with the USGS StreamStats online tool.

Based on the NLCD 2011 data, the dominant land cover types within this subwatershed are cultivated crops (34.6%), deciduous forest (16.8%), hay/pasture (15.2%), and emergent herbaceous wetlands (14.2%). The wetland complexes are primarily located near the waterways, specifically the Wing River. The deciduous forest land cover is predominantly located in the western portion, around the Folden Woods Marsh WMA and along the perimeter of the wetland complexes.

Station map

Figure 2 is an aerial view of site 11UM078. Cross-section locations are denoted on the image.

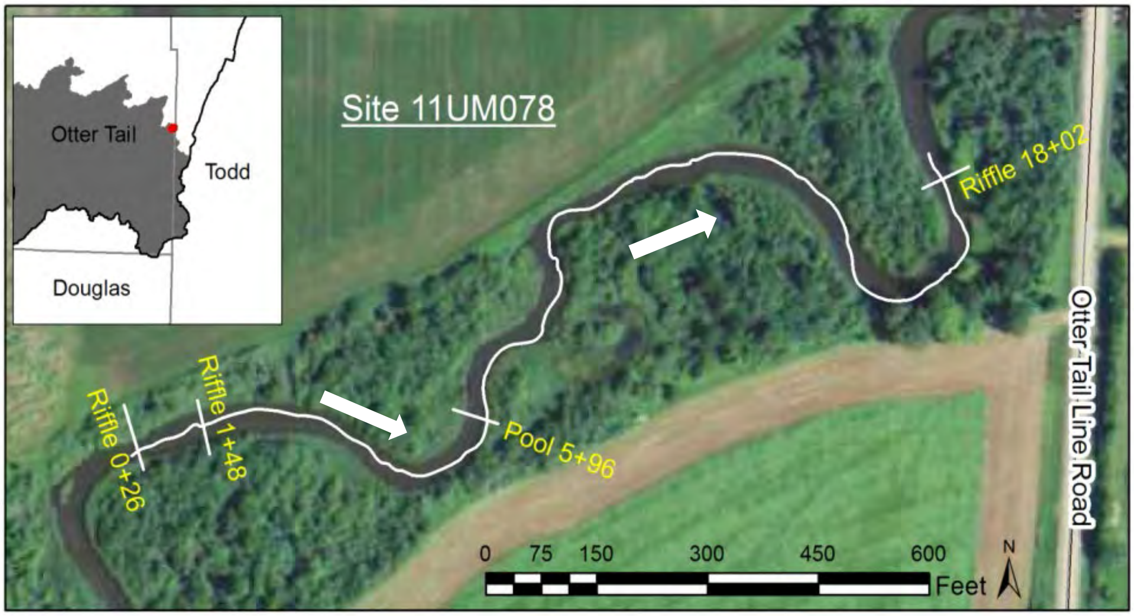


Figure 2: Aerial image of site 11UM078. (Source: 2013 Farm Service Agency Image)

Longitudinal profile

Figure 3 is the longitudinal profile of site 11UM078. The water surface slope was 0.00037 and the bankfull slope was 0.00040.

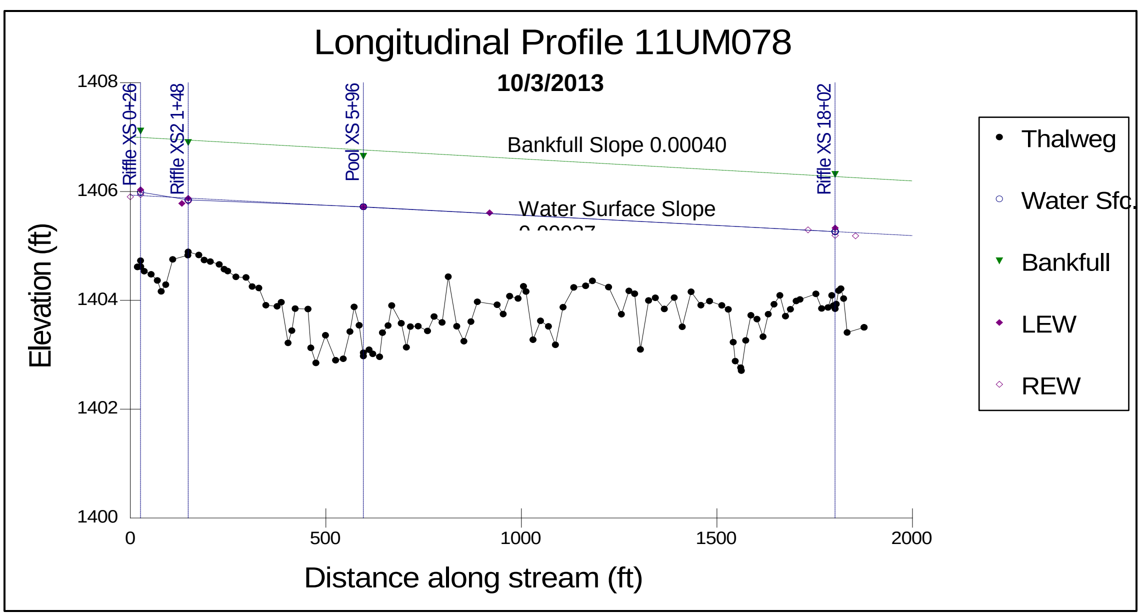


Figure 3: Longitudinal profile of site 11UM078

Riffle 0+26

The most upstream cross-section was riffle 0+26. The bankfull channel width was 38.46 ft and the mean depth was 1.88 ft (Figure 4). The maximum depth at bankfull was 2.38 ft Well-vegetated bankfull benches were present on both sides of the channel. Bankfull flows and higher have access to the floodplain and the channel was not incised at this location.

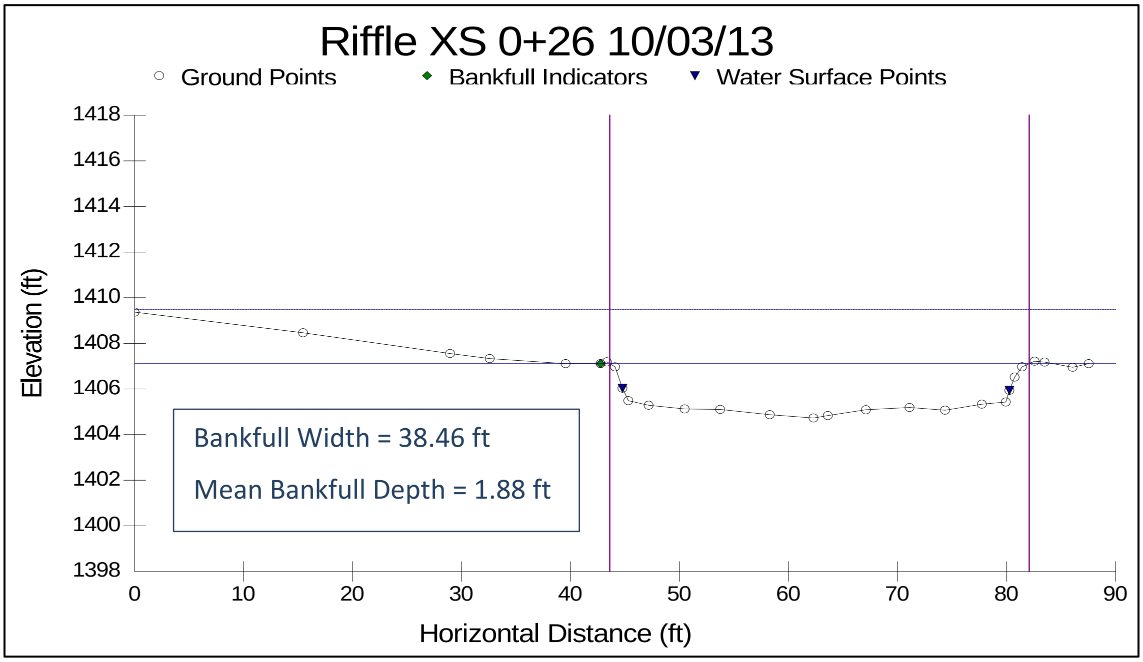


Figure 4: Riffle cross-section at 0+26.

The left bank had thick willow shrubs growing near the water and the right bank was vegetated with reed canarygrass (*Phalaris arundinacea*) (Figure 5). A pebble count was completed at riffle location 0+26. Figure 6 shows the particle size distribution. The particle sizes ranged from silt/clay up to cobble (180 mm). The dominant particle type present at this cross-section was gravel, making up 57.55% of the total sample. The D_{84} at riffle 0+26 was 87.49 mm. Bankfull shear stress and movable particle size was estimated at 0.05 lb/sq ft and 15.6 mm.

Figure 5: Photo of the left bank at riffle cross-section 0+26.

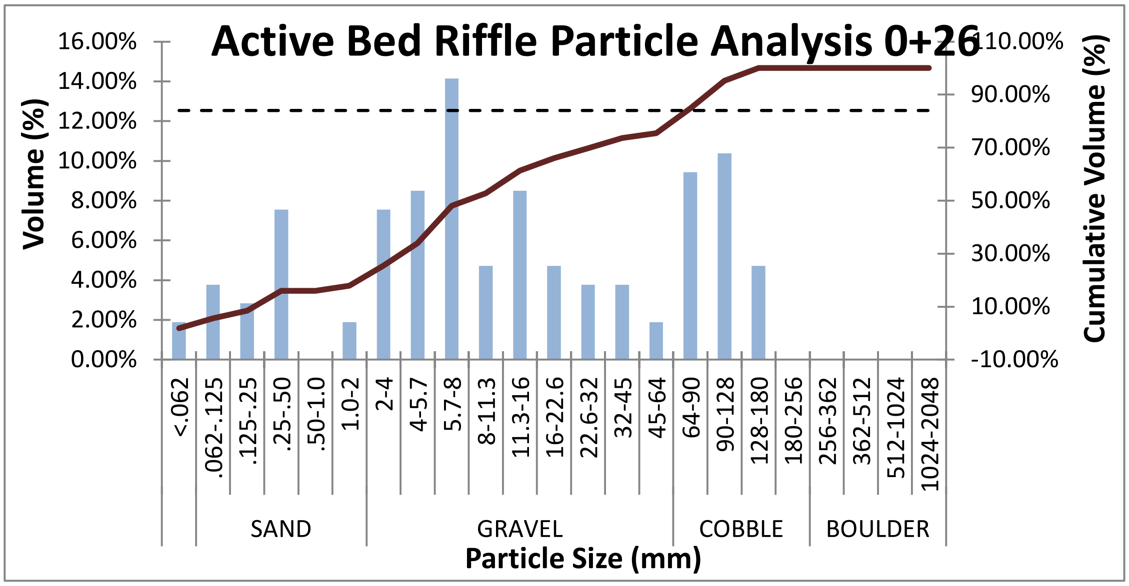


Figure 6: Pebble count results for riffle cross-section 0+26.

Riffle 1+48

The second riffle along the longitudinal profile was very similar to the riffle cross-section at 0+26. The width of the channel at bankfull was 45.94 ft, and the mean depth was 1.79 ft (Figure 7). The maximum depth at bankfull was 2.01 ft. Adequate bankfull benches were also present at this cross-section. Bankfull flows and higher had access to the floodplain and channel incision was not evident.

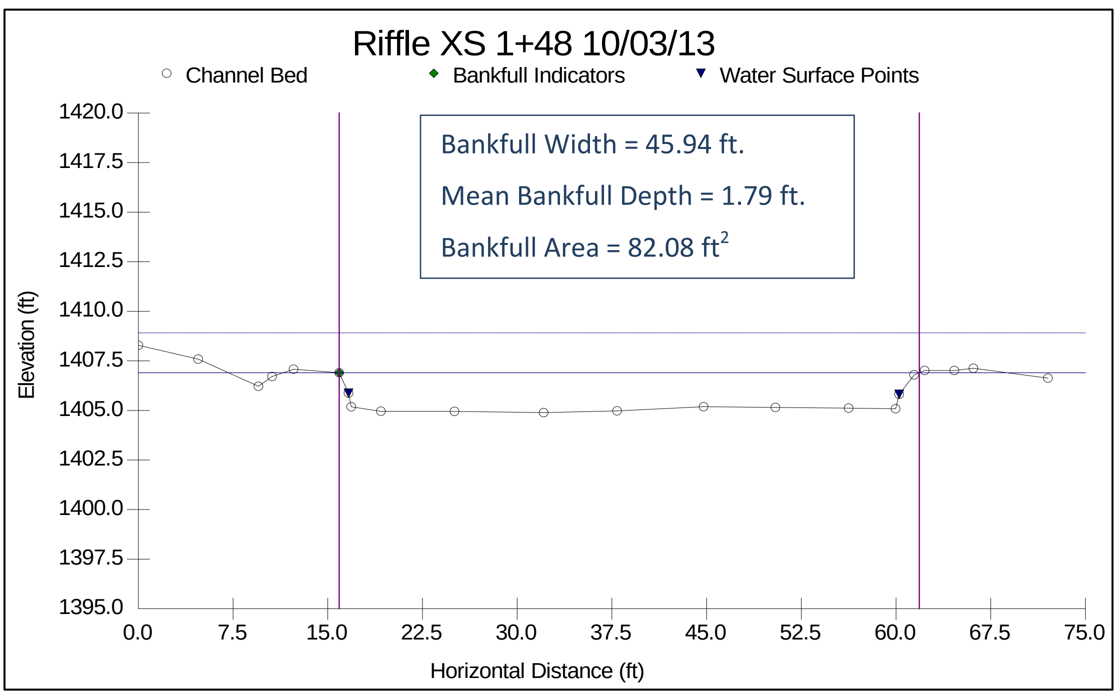


Figure 7: Riffle cross-section at 1+48.

POOL 5+96

A pool cross-section was completed at 5+96 along the longitudinal profile. The width of the channel at bankfull was 35 ft and the mean depth was 2.24 ft (Figure 8). The maximum depth at bankfull was 3.61 ft.

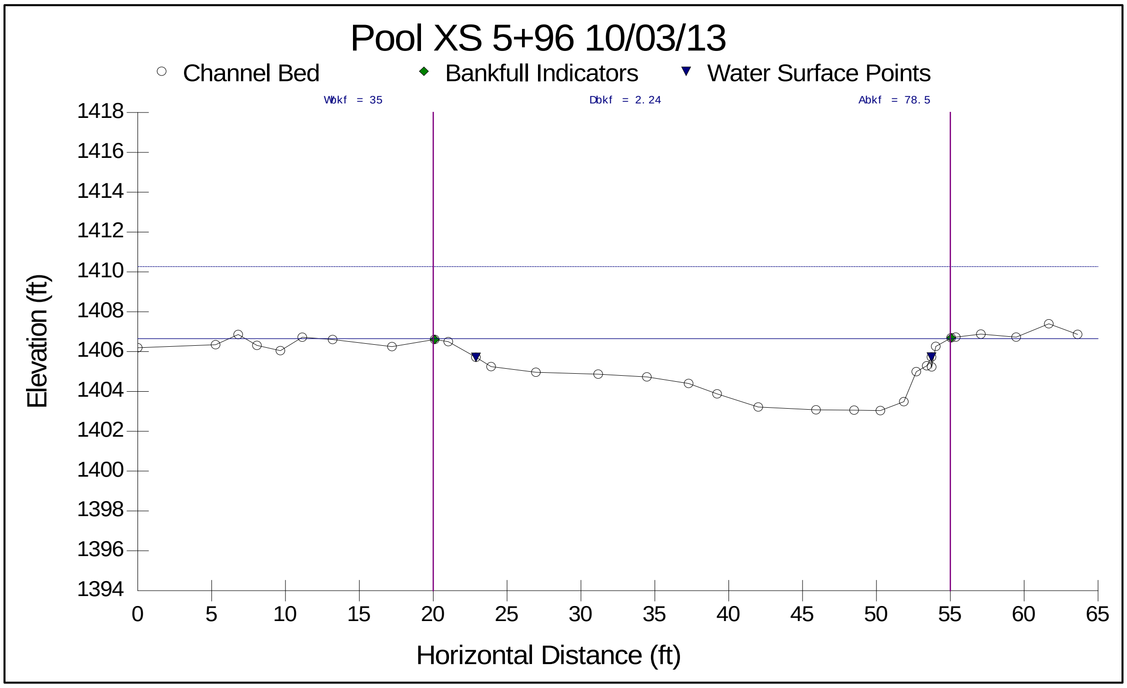


Figure 8: Pool cross-section at 5+96.

Figure 9: Photo of the left bank at pool cross-section 5+96. (photo taken on 10/03/2013)

Both banks at this cross-section were vegetated with thick reed canarygrass (Figure 9). A pebble count was completed at pool 5+96, and particle sizes ranged from silt/clay to cobble (Figure 10). The dominant particle types present were sand and gravel, making up 37.61% and 55.96%, respectively. Bankfull shear stress and movable particle size were 0.05 lb/sq ft and 17.1 mm. The high percentage of bed material less than 17 mm, and in particular fine sand, shows a possible lack of pool scour or capacity to move an abundance of fine depositional materials.

However, no bar or pavement/sub-pavement sample was collected to calculate an estimate of sediment competence or ability to entrain the largest particle delivered from the upstream watershed. In addition, no sediment transport capacity estimates were computed.

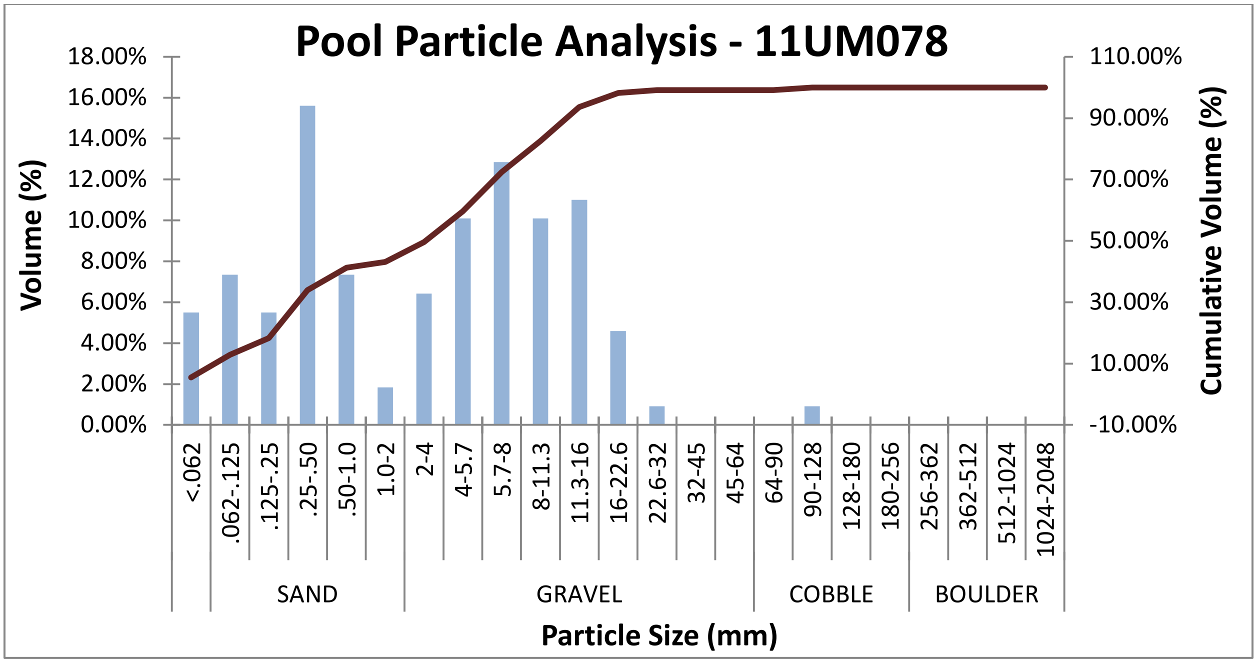


Figure 10: Pebble count results for pool cross-section 5+96.

Riffle 18+02

A riffle cross-section was completed near the end of the study reach (18+02). The width of the channel at bankfull was 35.98 ft, and the mean depth was 2.01 ft (Figure 11). The maximum bankfull depth was 2.47 ft. Adequate bankfull benches were also present at this cross-section.

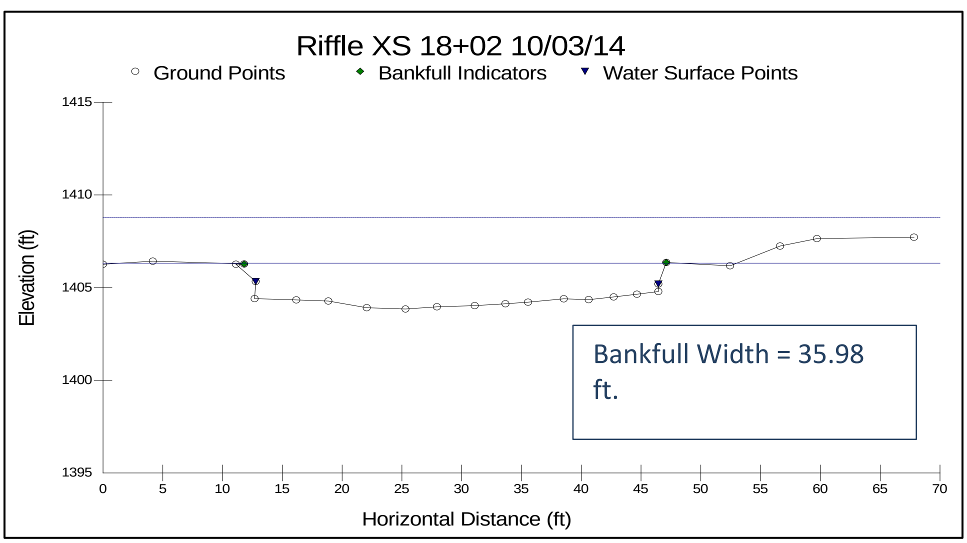


Figure 11: Riffle cross-section at 18+02.

The banks at this cross-section location were vegetated with reed canarygrass, as well as other herbaceous species including goldenrod and *Carex spp*. (Figure 12). Dense alder was present above the bankfull elevation. A pebble count was completed at this riffle location (18+02). The particle sizes ranged from silt/clay up to boulder (511.99 mm). The dominant particle type present at this cross-section was gravel (Figure 13). The D_{84} at riffle 18+02 was 105.84 mm. Bankfull shear stress and movable particle size were estimated from the Rosgen Colorado data set at 0.05 lb/sq ft and 15.6 mm.

Figure 12: Photo at riffle cross-section 18+02. Photo taken on 10/03/2013)

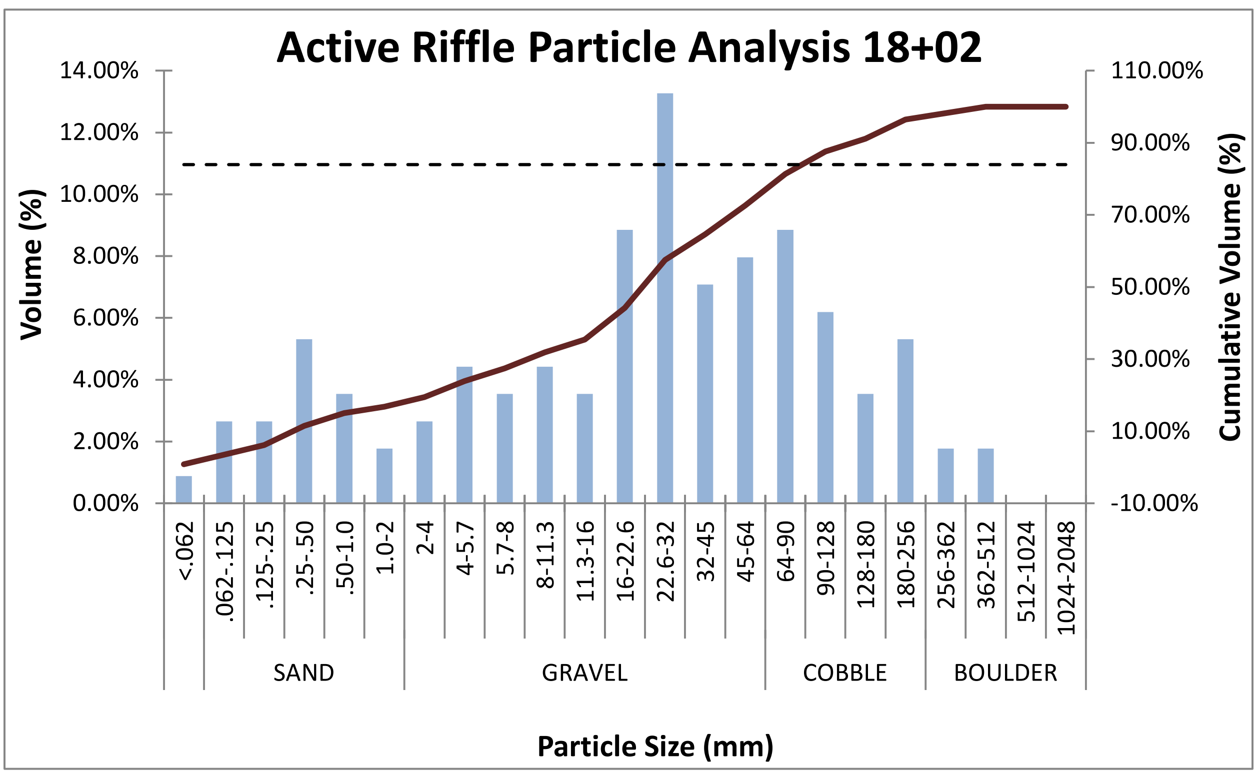


Figure 13: Pebble count results at riffle cross-section 18+02.

Classification

The Rosgen stream type through study reach 11UM078 was active riffle at station 0+26.

The input variables used for classification came from the C stream types are generally described as low gradient, meandering streams with depositional point bars on the inside bends. The $_{c-}$ denotes that the gradient of the stream is less than 0.001, and the 4 means a gravel bed.

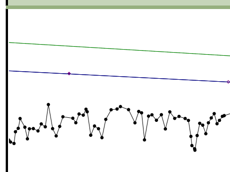
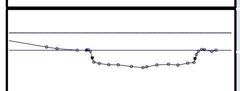
C4 stream types are very sensitive to disturbance; however, they have a good response to recovery when the disturbance is removed. This stream type is very dependent on robust stream bank vegetation to remain stable.

Study reach 11UM078 was classified as a stable $C4_{c-}$ stream. The modified (by stream type) Pfankuch stability rating on 10/03/2013 was 62. A good, or stable, rating range for a C4 is 70-90. The lower the Pfankuch rating, the more stable the study reach. This rating of 62 is very stable for a C4 stream.

The riparian area, including most of the meander belt, at site 11UM078 had diverse plant communities and appeared to be in excellent condition (Figure 14). The herbaceous layer covered about 50% of the riparian zone, with reed canarygrass as the dominant species. Understory shrubs made up about 35% of the cover and were a mix of speckled alder, willow species, and redosier dogwood. A few trees were present within the riparian zone including willow, bur oak, American elm, and box elder.

Figure 14: Bottle Gentian (*Gentiana andrewsii*) plant near riffle cross section 18+02. (Photo taken on 10/03/2013

Table 1: Stream site 11UM078 was classified as a $C4_{c-}$ (Table 1).

	STREAM TYPE	C4c-
	VALLEY TYPE	VIIIc
	Slope	0.0004
	Entrenchment Ratio	12.61
	Width/Depth Ratio	20.46
	Sinuosity	2.57
	Channel Material (D_{50})	6.99 mm (GRAVEL)

A pebble count was completed for the entire reach at site 11UM078 (Figure 15). The dominant particle size was gravel (65.03%). Clay, silt, sand, and cobble particles were tallied as well. The D_{50} was 6.99 mm, which classifies out as a small gravel dominant stream.

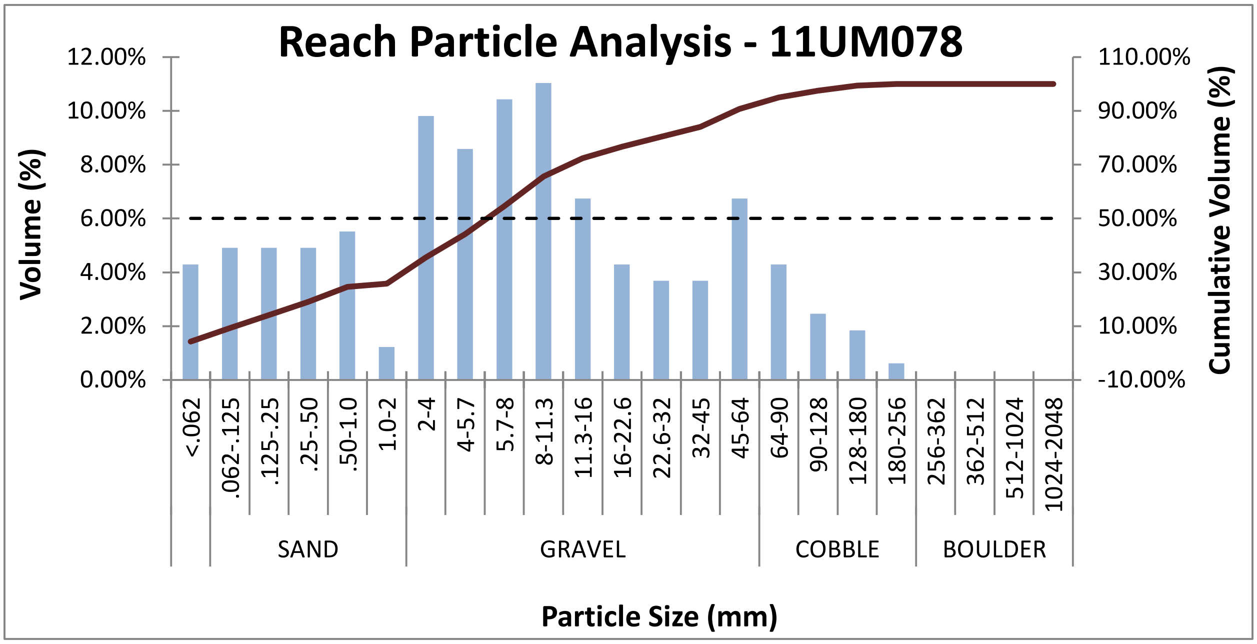


Figure 15: Pebble count results for entire study reach.

Summary

The dimensional variability between riffle cross-sections was minor (Table 2). Riffle cross-section 1+48 was slightly wider than riffle cross-sections, 0+26 and 18+02, but their mean depths were within 0.22 ft of each other. Riffle 1+48 also had the largest cross-sectional area at 82.08 ft^2.

CHANNEL MORPHOLOGY & DIMENSIONLESS RATIOS

Stream: Wing River | **Site: 11UM078**
Observers: Dave Friedl, Lori Clark, & Julie Aadland | **Date: 10/03/2013**

Riffle Dimensions	Mean	Min	Max	Dimensionless Ratios	Mean	Min	Max
Riffle Width (W_{bkf})	40.13	35.98	45.94	Width of Flood-Prone Area (W_{pfa})	386	297	485
Mean Riffle Depth (d_{bfk})	1.89	1.79	2.01	Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})	21.34	17.9	25.67
Maximum Riffle Depth (d_{max})	2.29	2.01	2.47	Max Riffle Depth to Mean Riffle Depth (d_{max} / d_{bkf})	1.21	1.12	1.27
Riffle Cross-Sectional Area (A_{bkf}) (ft^2)	75.56	72.17	82.08	Entrenchment Ratio (W_{fpa} / W_{bkf})	9.85	6.47	12.61
Pool Dimensions							
Pool Width (W_{bkfp})	34.97	34.97	34.97	Pool Width to Riffle Width (W_{bkfp} / W_{bkf})	0.871	0.871	0.871
Mean Pool Depth (d_{bfkp})	2.24	2.24	2.24	Mean Pool Depth to Mean Riffle Depth (d_{bkfp} / d_{bkf})	1.185	1.185	1.185
Maximum Pool Depth (d_{maxp})	3.61	3.61	3.61	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})	1.039	1.039	1.039
Pool Cross-Sectional Area (A_{bkfp}) (ft^2)	78.48	78.48	78.48	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	1.91	1.91	1.91

Table 2: Summary of study reach 11UM078 channel morphology.

Only one pool cross-section was completed along study reach 11UM078. Pool habitat may be affecting aquatic habitat in this assessment reach, with pools being generally short (39 ft average), fairly widely spaced (212 ft), and mean pool depth only slightly deeper than riffles (ratio of 1.19). Particle size of bed materials in the pool, riffles, and reach indicated a possible lack of scour, capacity, or competence to move the largest particles available and a possible trend toward moderate deposition.

Bank erosion estimates

The BANCS model (Rosgen, 1996) was used to estimate streambank erosion rates. The left image of Figure 16 represents the estimated annual rate of streambank erosion (ft/yr). Input variables to estimate this rate include bank height, root depth, root density, bank angle, surface protection, soil particles, possible stratification of soil profile, and proximity of the thalweg to each bank. Rates for this study reach ranged from 0.00 – 0.32 ft per year. Several lengths along this study reach showed evidence of deposition, and therefore a rate of erosion was not calculated at those locations. The Colorado curve was used for these estimates. Other erosion rate curves are available that would yield different estimates but the Colorado rate is a good starting point. Eventually, enough data points will be estimated and validated from stream bank sites in Minnesota to develop local erosion rate curves.

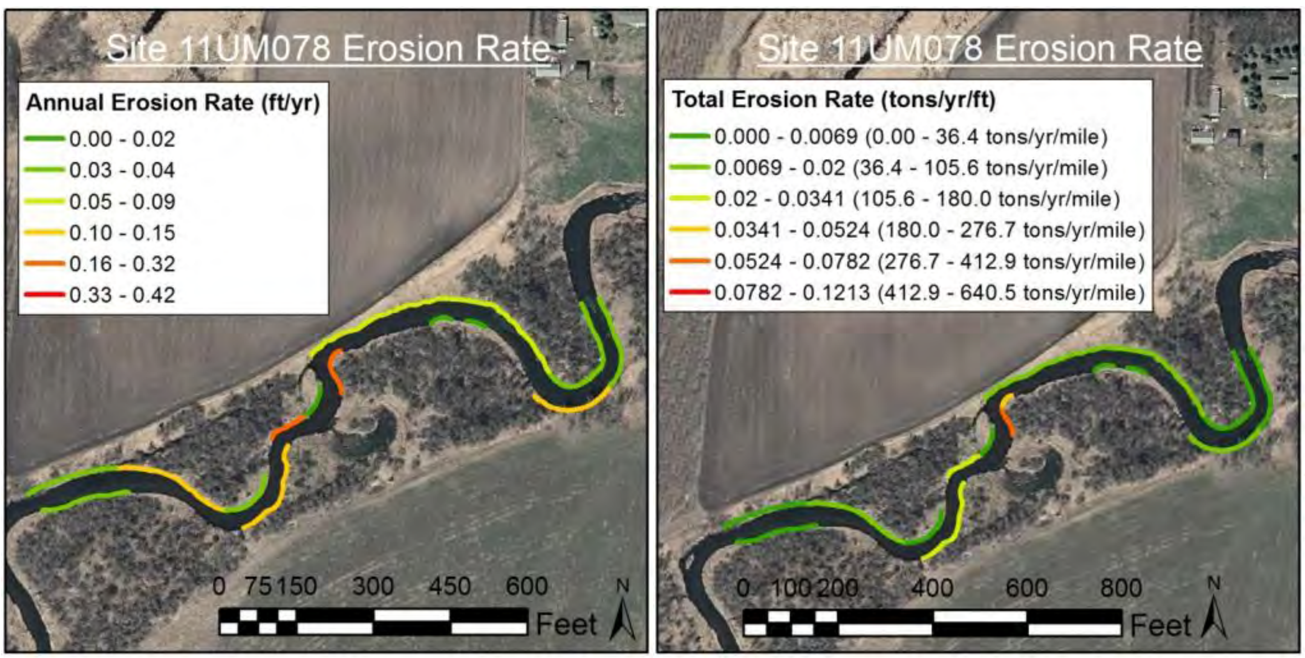


Figure 16: Estimated bank erosion rate (ft/yr) and total erosion rate (tons/yr/ft) at site 11UM078.

The majority of the study reach was at or below 0.15 ft/yr. The area with the 0.32 ft/yr rate was near the middle of the reach. A small waterway flows into the river and at higher flows this may be applying higher shear stress to the bank at this location. Based on aerial photography, this waterway appears to be a straight line connection from upstream. Total annual bank erosion from the study reach was estimated at 30.5 tons (about 3, 10 yd^3 dump trucks) or 96 tons per mile (about 7, 10 yd^3 dump trucks). Only the portion of the eroded bank sediment smaller than 0.063 mm would suspend as washload and the balance would deposit as bedload, including a sand component that would suspend during high flows and otherwise deposit on the bed. Future validation of actual erosion rates will occur from re-surveying cross sections, repeating bank profile studies, LiDAR, and aerial photography comparisons. No validations were completed for this study.

The right image of Figure 16 represents the total volume of annual erosion, which is calculated by multiplying the erosion rate by the length and height of each estimated section. The streambanks with the higher total erosion rate had the higher Bank Erosion Hazard Index (BEHI) scores and/or higher banks than the streambanks with the lower total erosion losses (Table 3).

Table 3: Site 11UM078 BANCS Erosion Estimate using Colorado curve data.

Stream: **Wing River**				Location: **Reach - 11UM078**			
Graph Used: **Colorado**		Total Stream Length (ft): **1675.8**				Date: **10/3/2013**	
Observers: **D. Friedl, L. Clark, J. Aadland**		Valley Type: **VIII**				Stream Type: **C 4c-**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1. **031-032 LB**	**Low**	**Low**	**0.036**	**179.2**	**1.7**	**10.55**	**0.00280**
2. **030-031 LB**	**Moderate**	**Low**	**0.153**	**231.6**	**2.4**	**83.25**	**0.01730**
3. **029-030 LB**	**Low**	**Low**	**0.036**	**119.8**	**1.7**	**7.06**	**0.00280**
4. **027-028 LB**	**Moderate**	**Moderate**	**0.253**	**77.0**	**2.8**	**54.57**	**0.03410**
5. **026-027 LB**	**Low**	**Very High**	**0.000**	**68.4**	**1.5**	**0.00**	**0.00000**
6. **023-024 LB**	**Moderate**	**Very Low**	**0.092**	**375.0**	**2.5**	**86.43**	**0.01110**
7. **022-023 LB**	**Moderate**	**Very Low**	**0.092**	**184.2**	**2.0**	**33.97**	**0.00890**
8. **021-022 LB**	**Low**	**Low**	**0.036**	**103.2**	**1.7**	**6.08**	**0.00280**
9. **020-021 LB**	**Low**	**Low**	**0.036**	**14.8**	**1.7**	**0.87**	**0.00280**
10. **019-020 LB**	**Low**	**Low**	**0.036**	**143.6**	**1.7**	**8.46**	**0.00280**
11. **149-150 RB**	**Low**	**Low**	**0.036**	**172.7**	**2.5**	**15.41**	**0.00430**
12. **153-154 RB**	**Low**	**Very High**	**0.323**	**66.4**	**4.1**	**87.99**	**0.06380**
13. **154-155 RB**	**Low**	**Very High**	**0.323**	**31.3**	**2.5**	**25.31**	**0.03890**
14. **156-157 RB**	**Low**	**Very Low**	**0.017**	**44.4**	**2.5**	**1.90**	**0.00210**
15. **158-159 RB**	**Low**	**Very Low**	**0.017**	**39.9**	**2.0**	**1.36**	**0.00160**
16 **160-161 RB**	**Moderate**	**Low**	**0.153**	**174.6**	**2.7**	**72.11**	**0.02000**
17 **161-163 RB**	**Low**	**Low**	**0.036**	**46.9**	**2.5**	**4.19**	**0.00430**
18 **151-152 RB**	**Low**	**High**	**0.151**	**201.6**	**4.0**	**121.76**	**0.02910**
19 **163-164 RB**	**Low**	**Low**	**0.036**	**130.7**	**2.5**	**11.67**	**0.00430**
20 **164-end RB**	**Low**	**Low**	**0.036**	**6.7**	**2.1**	**0.50**	**0.00360**

Velocity and discharge

Velocity and discharge estimates between the two riffle cross-sections (0+26 and 18+02) were very similar. The hydraulic slope used was 0.0004. For reference, the discharge estimates from the online USGS StreamStats tool for the 1.5 year recurrence intervals was 201 cfs.

Table 4: Velocity and discharge estimates for riffle 0+26.

BANKFULL VELOCITY & DISCHARGE

Stream: Wing River
Observers: Dave Friedl, Lori Clark, & Julie Aadland
Location: Site 11UM078
Date: 10/03/2013

Riffle Cross-section:	Riffle 0+26	
D84 of Active Bed:	87.49	Dia. (mm)
Bankfull Slope:	0.0004	
Drainage Area:	107	Mi^2

Estimation Methods	Bankfull Velocity		Bankfull Discharge	
Manning Limerinos n	1.201	ft / sec	86.988	CFS
Darcy-Weisbach	1.17	ft / sec	84.715	CFS
U/U*	1.12	ft / sec	81.48	CFS
Stream Type (C4, small with vegetative influence)	1.105	ft / sec	80.035	CFS

Table 5: Velocity and discharge estimates for riffle 18+02.

BANKFULL VELOCITY & DISCHARGE

Stream: Wing River
Observers: Dave Friedl, Lori Clark, & Julie Aadland
Location: Site 11UM078
Date: 10/03/2013

Riffle Cross-section:	Riffle 18+02	
D84 of Active Bed:	105.84	Dia. (mm)
Bankfull Slope:	0.0004	
Drainage Area:	107	Mi^2

Estimation Methods	Bankfull Velocity		Bankfull Discharge	
Manning Limerinos n	1.143	ft / sec	82.49	CFS
Darcy-Weisbach	1.194	ft / sec	86.152	CFS
U/U*	1.05	ft / sec	76.07	CFS
Stream Type (C4, small with vegetative influence)	1.106	ft / sec	79.82	CFS

Site Wing River 11UM077

Introduction

Site 11UM077 is located on the Wing River, approximately 1 mile northwest of Hewitt, Minnesota. It is in Todd County, just downstream of the Hewitt dam. According to the USGS StreamStats online tool, the drainage area is approximately 131 mi^2 (Figure 17).

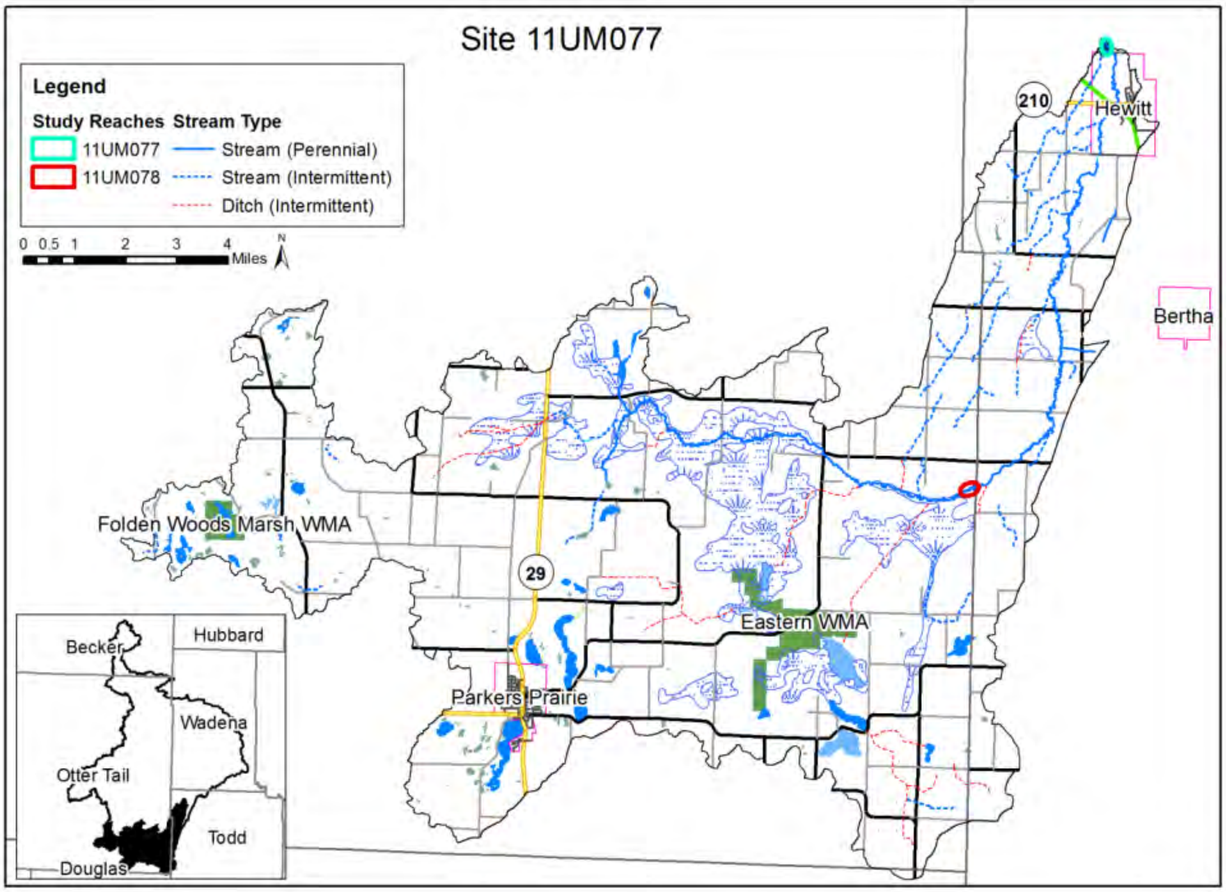


Figure 17: Upstream watershed of site 11UM077.

Based on the NLCD 2011 data, the dominant land cover types within this subwatershed are cultivated crops (34.9%), hay/pasture (17.4%), deciduous forest (17.3%), and emergent herbaceous wetlands (12.1%). The wetland complexes are primarily located near the waterways, specifically the Wing River. The deciduous forest land cover is predominantly located in the western portion, around the Folden Woods Marsh WMA and along the perimeter of the wetland complexes.

Station map

Figure 18 is an aerial view of site 11UM077. Cross-section locations are denoted on the image. At approximately 8+75 ft on the longitudinal profile the water became too deep to wade due to a beaver dam 450 ft downstream. A short longitudinal profile section was completed near the beaver dam and a cross-section was completed at the first riffle (14+11) just downstream of the beaver dam.

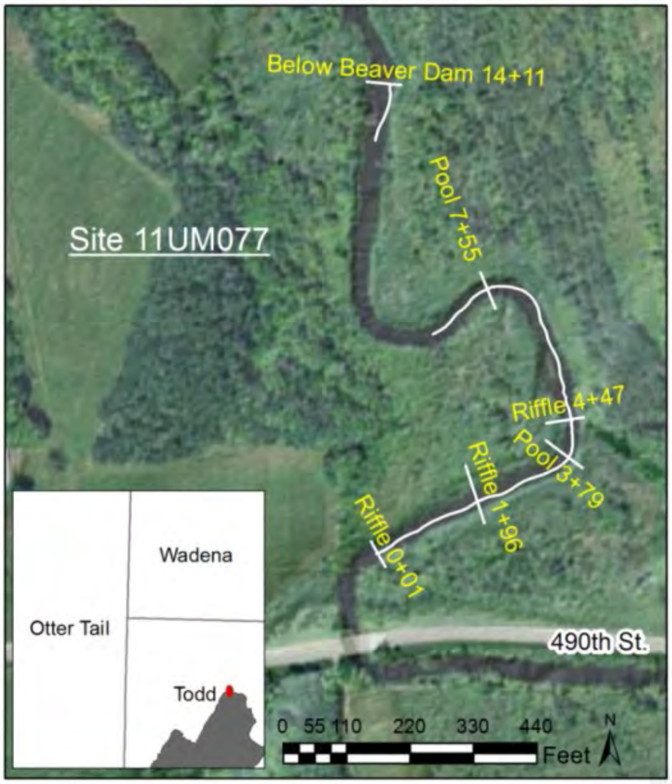


Figure 18: Aerial image of site 11UM077. (Source: 2013 Farm Service Agency Image.)

Longitudinal profile

Figure 19 is the longitudinal profile of site 11UM077. A beaver dam between stationing 13+00 and 14+00 was backing up water through the entire study reach. The slope of the water surface through most of the reach was 0.00013, measured from the beginning of the long pro to the top of the beaver dam. The slope used for the hydraulic relations was the 0.00063 bankfull slope, which reflects the actual energy slope before the recent construction of the beaver dam.

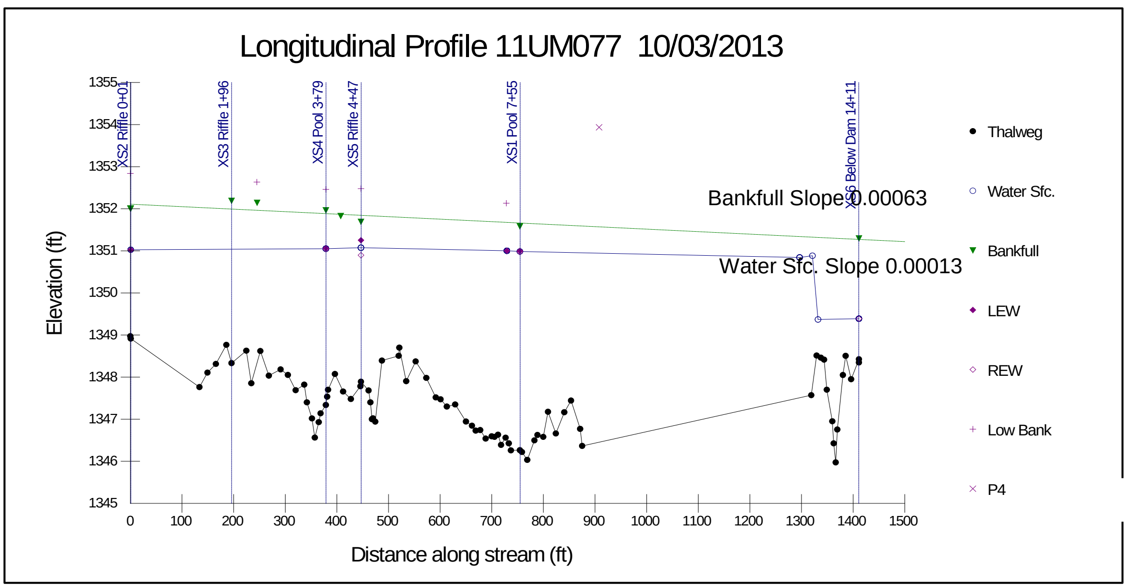


Figure 19: Longitudinal profile of site 11UM077.

Due to the recent construction of the beaver dam, deposition was occurring throughout the reach, which may not have been the case when the reach was sampled for fish and macroinvertebrates. This reach was in a state of transition due to the beaver dam and energy slope change. Since the beaver dam was new, removal of the beavers and dam would result in a quick recovery to pre-dam conditions and positive aquatic habitat response. Several tentative bankfull calls made in the field were determined to be a low terrace and are denoted on the figure as purple plus signs.

Riffle 0+01

The most upstream cross-section was a riffle at station 0+01. The bankfull channel width was 38.63 ft and the mean depth was 2.4 ft (Figure 20). The maximum depth at bankfull was 3.1 ft. Bankfull shear stress and movable particle size was estimated from the Rosgen Colorado data-set, and was 0.09 lb/sq ft and 25.8 mm.

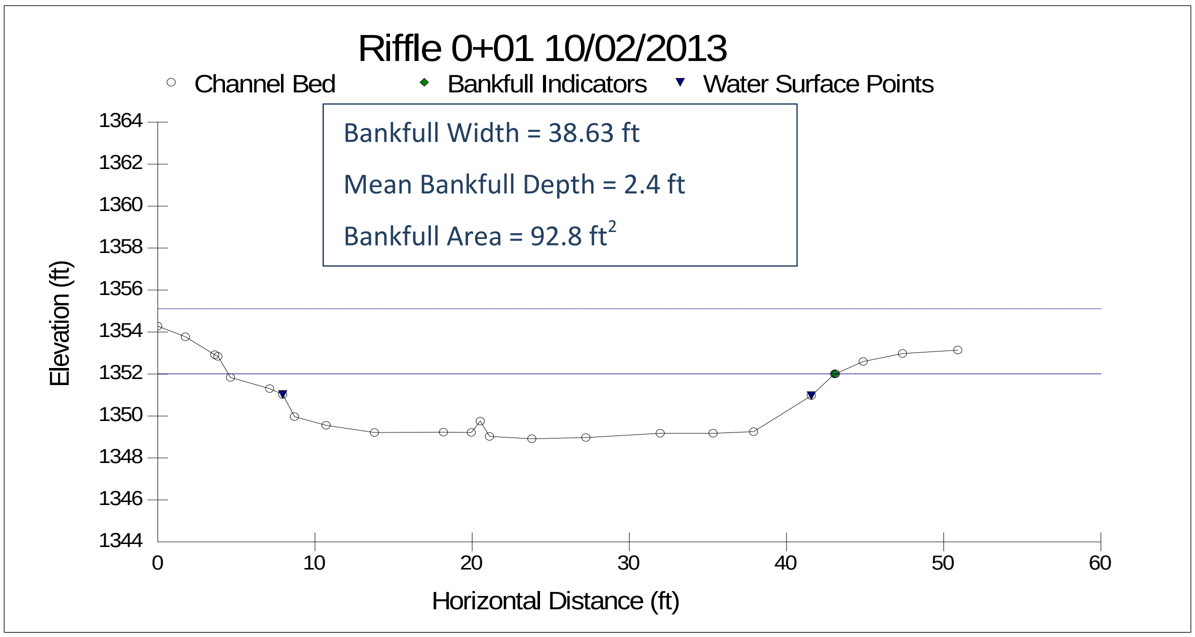


Figure 20: Riffle 0+01 cross-section.

A pebble count was completed at riffle location 0+01. A wide size range of particles were measured at this location (Figure 21). Sizes range from silt/clay up to boulder (1023.94 mm). At the next downstream riffle cross-section the largest particle size measured was 11.3 mm, which was likely influenced by aggradation from the beaver impoundment. Though just 165 ft downstream of a road crossing, this cross-section had a steeper gradient and was moving larger particles, influencing the particle size distribution. It was also out of the influence of the beaver impoundment. The D_{84} at riffle 0+01 was 217.62 mm. The particle size distribution at this riffle was the only cross-section data set that produced realistic velocity and discharge estimates.

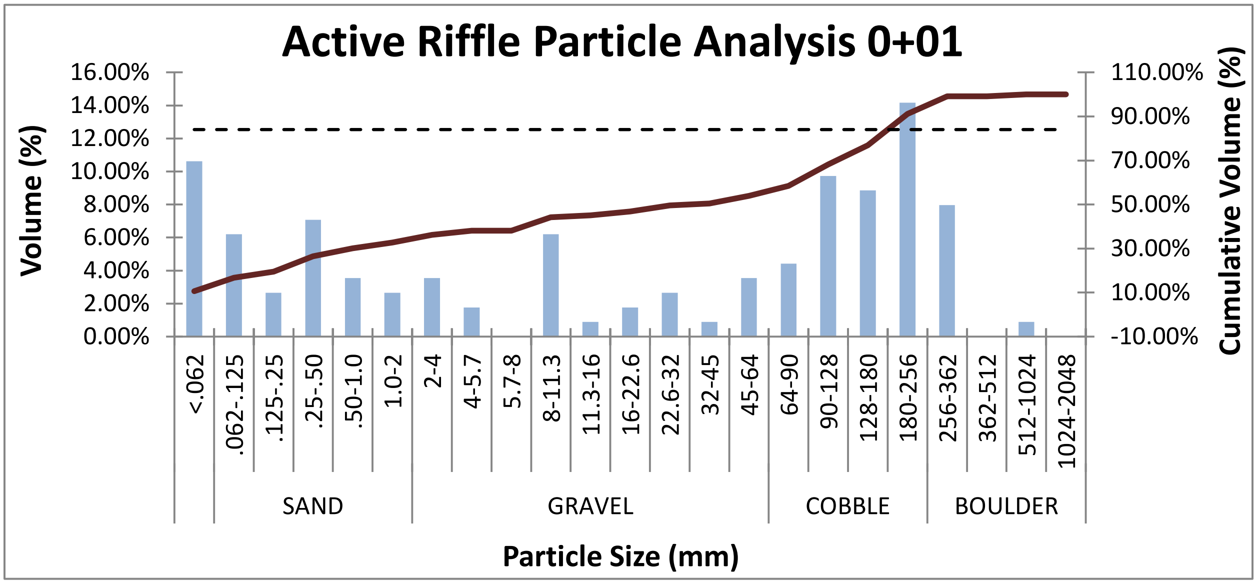


Figure 21: Pebble count results from riffle cross-section 0+01.

Riffle 1+96

The second cross-section completed on this reach was a riffle, 196 ft downstream from the start of the study reach. The bankfull width of the channel was 40.2 ft and the mean depth was 3.17 ft (Figure 22). The maximum bankfull depth was 3.86 ft. Well-vegetated bankfull benches were present on both sides of the channel (Figure 23). Bankfull or greater flows had access to the floodplain and the channel was not incised, allowing healthy floodplain function and storage.

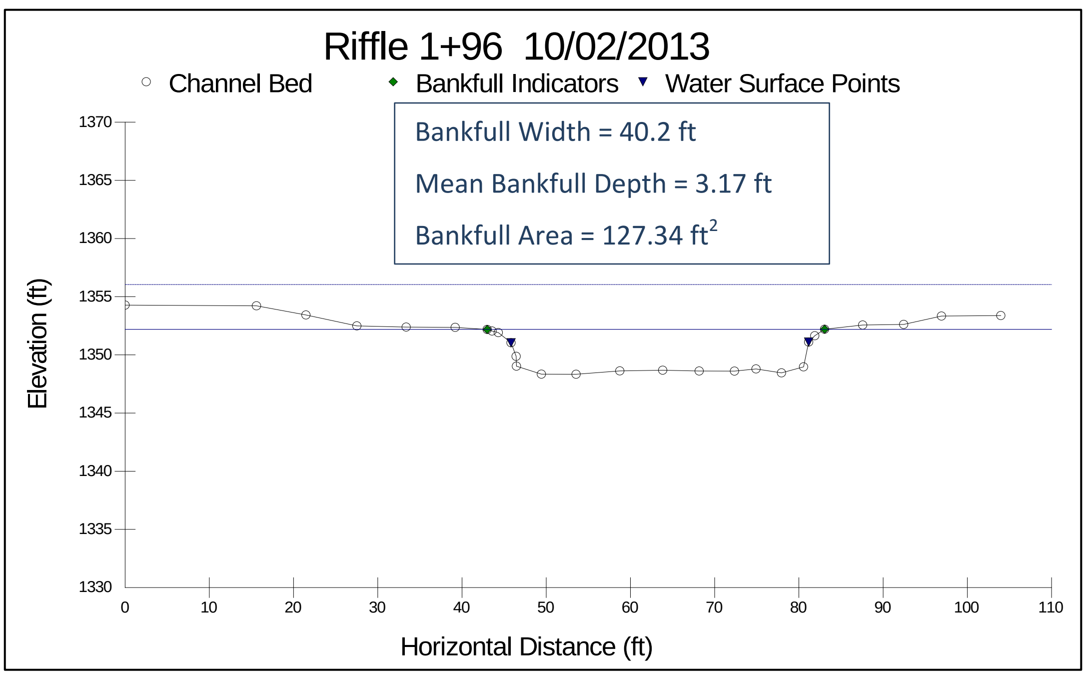


Figure 22: Riffle cross-section at 1+96.

Vegetation on both the left and right banks at riffle 1+96 was predominantly thick reed canarygrass (Figure 23). Sporadic willow shrubs were found above the bankfull elevation.

Figure 23. Photo taken at approximately stationing 2+50, looking upstream.

A pebble count was completed at riffle 1+96 (Figure 24). The dominant particle type present at this cross-section was sand, making up 56.44% of the total distribution. There were no larger cobbles and boulders at this location, like those found at riffle 0+01. The D_{84} at riffle 1+96 was 3.26 mm. At the bankfull indicator slope of 0.00063, shear stress and movable particle size was estimated at 0.11 lb/sq ft and 30.7 mm. The water surface energy slope of .00013 created by the beaver dam was likely the cause of the smaller particle sizes observed at this cross section and the rest of the riffle and reach particle size distributions downstream to the beaver dam. Excess fines appeared at this riffle as a result.

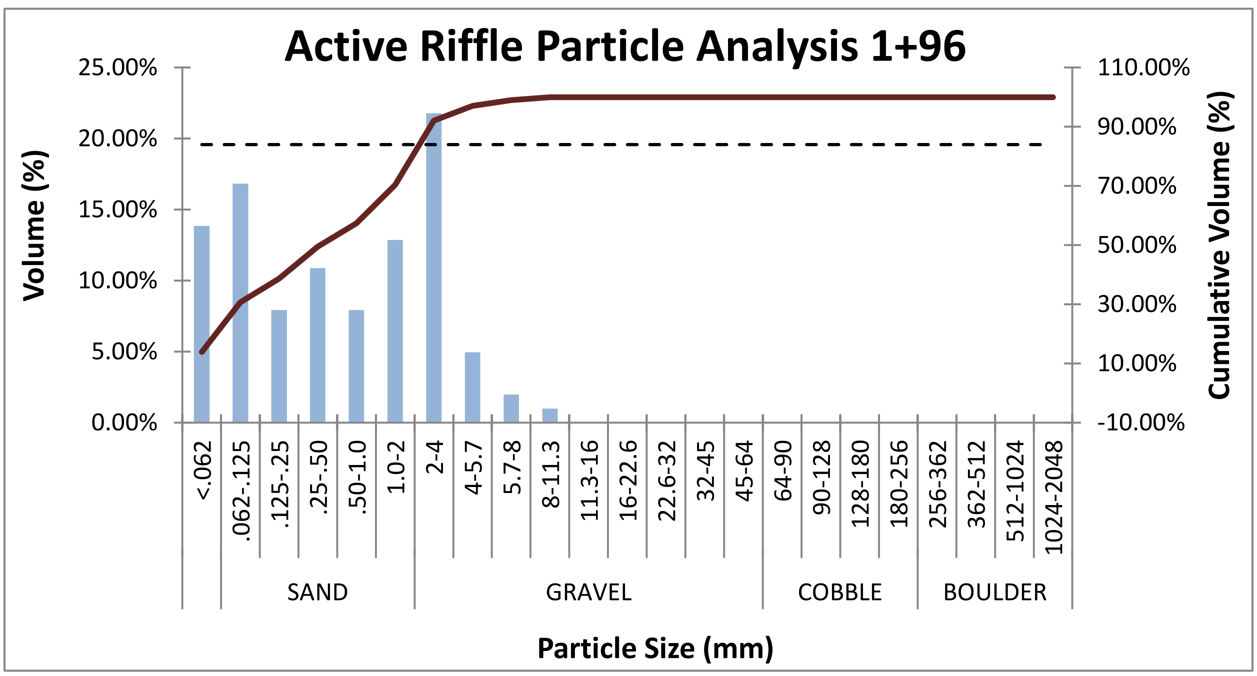


Figure 24: Pebble count results at riffle cross-section 1+96.

Pool 3+79

A pool cross-section was located 379 ft downstream from the beginning of the longitudinal profile. The width of the channel at bankfull was 32.31 ft and the mean depth was 3.32 ft (Figure 25). The maximum depth at bankfull was 4.62 ft. The pool cross-section was just downstream of the lowest point of the pool (see Figure 19) and approaching the transition into a glide. It was not included in the summary ratios.

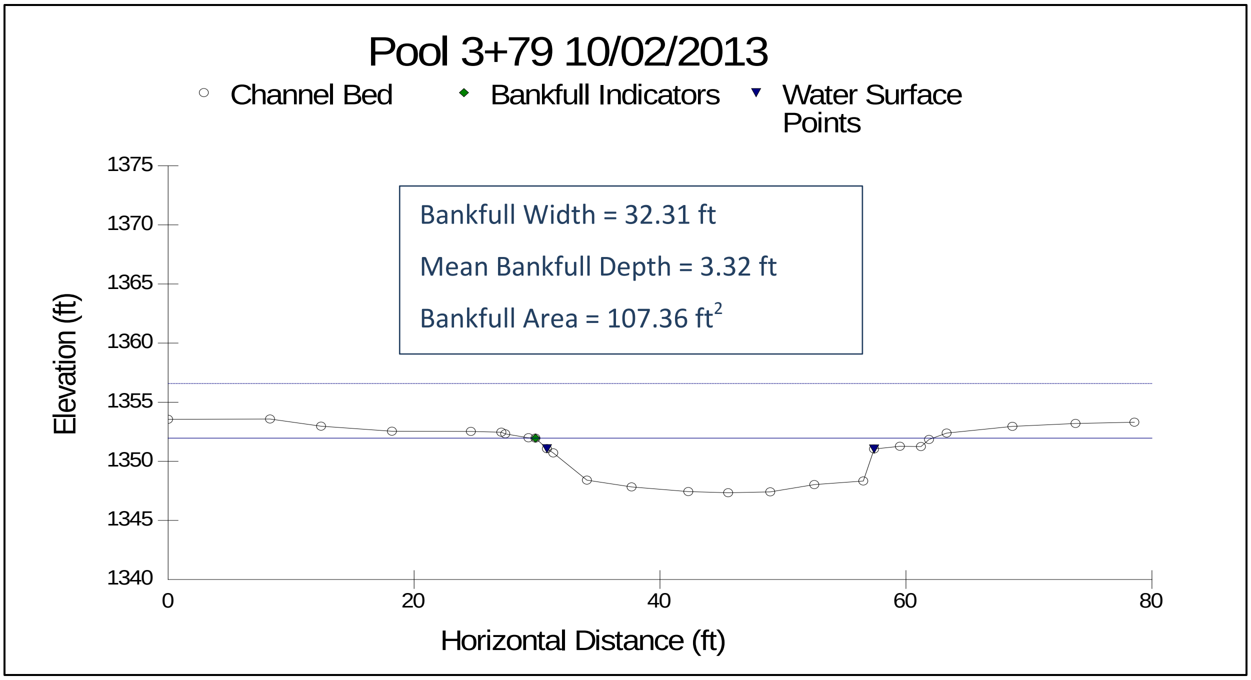


Figure 25: Pool cross-section at 3+79.

Riffle 4+47

A shorter riffle was present between the meander where pool cross-section 3+79 was located and a mid-channel bar (Figure 26).

The width of the channel at this riffle cross-section was 30.48 ft and the mean depth was 2.89 ft (Figure 27). The maximum depth at bankfull was 3.8 ft.

Figure 26. Mid-channel depositional bar 75 feet downstream of riffle cross-section at stationing 4+47.

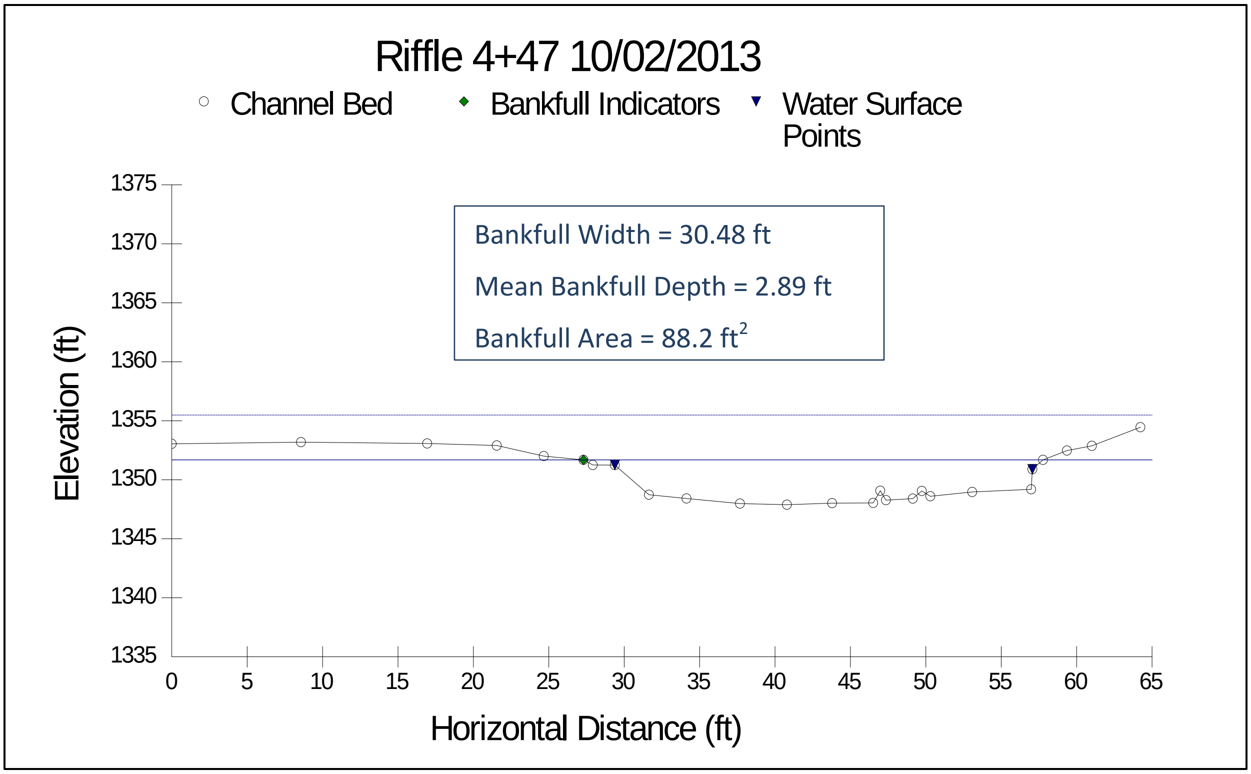


Figure 27: Riffle cross-section 4+47.

Pool 7+55

A pool cross-section was located 755 ft downstream from the beginning of the longitudinal profile. Reed canarygrass was still the dominant plant species on the banks, but additional species, such as goldenrod, were present along this cross-section (Figure 28). The right bank had a more diverse plant community than the left bank. The width of the channel at bankfull was 40.2 ft and the mean depth was 2.89 ft (Figure 29). The maximum bankfull depth was 5.32 ft.

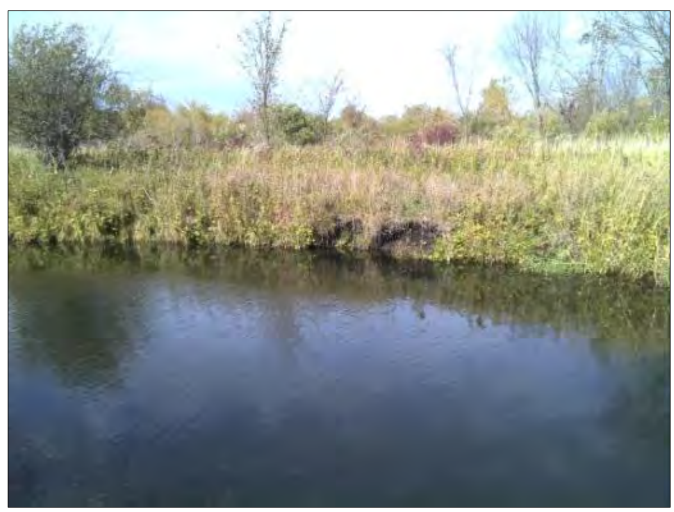


Figure 28: Photo of right bank near pool cross-section 7+55. (photo taken on 10/03/2013)

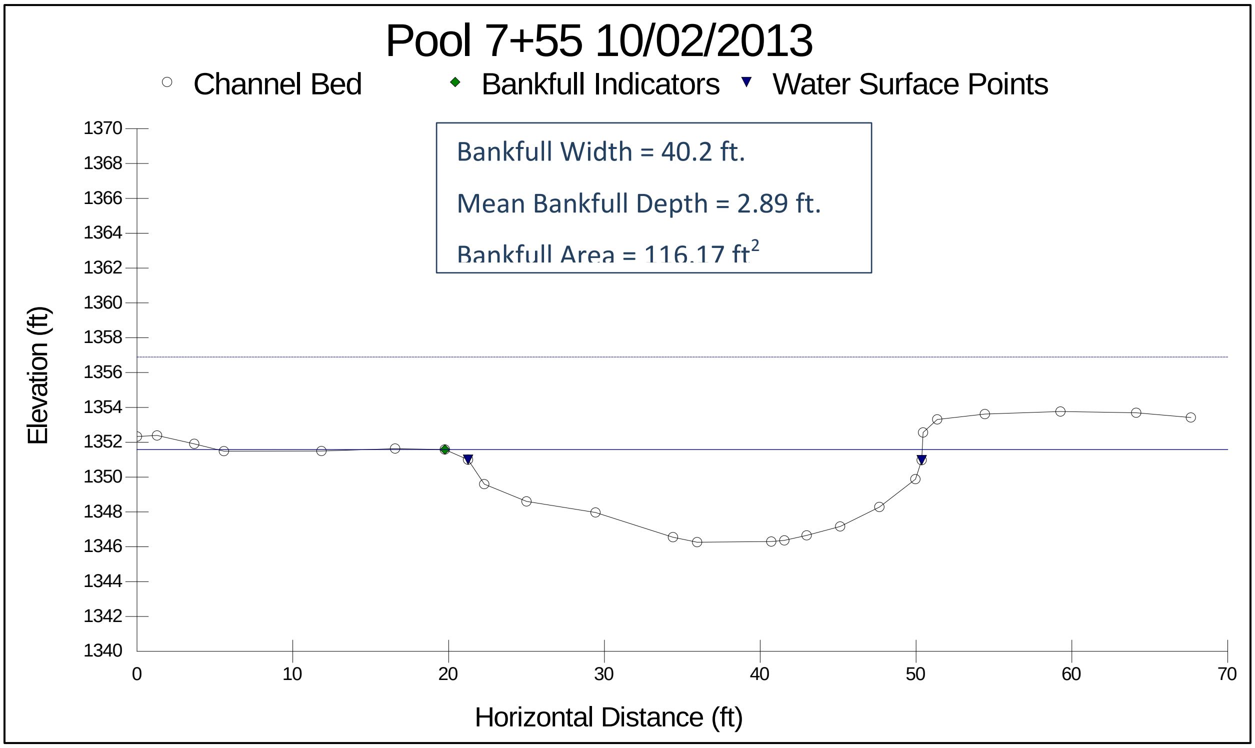


Figure 29: Pool cross-section at stationing 7+55.

Below Beaver dam cross-section 14+11

A cross-section was completed at the first riffle just downstream of the beaver dam (Figure 30). The channel was wider and shallower at this location with a bankfull width and mean depth of 48.16 and 2.40 ft (Figure 31). The maximum depth at bankfull was 2.95 ft. Since this riffle was not representative of the upstream study reach, the data from this cross-section was not included in the summary ratios.

Figure 30: Looking upstream, photo of beaver dam. (Photo taken on 10/02/2013)

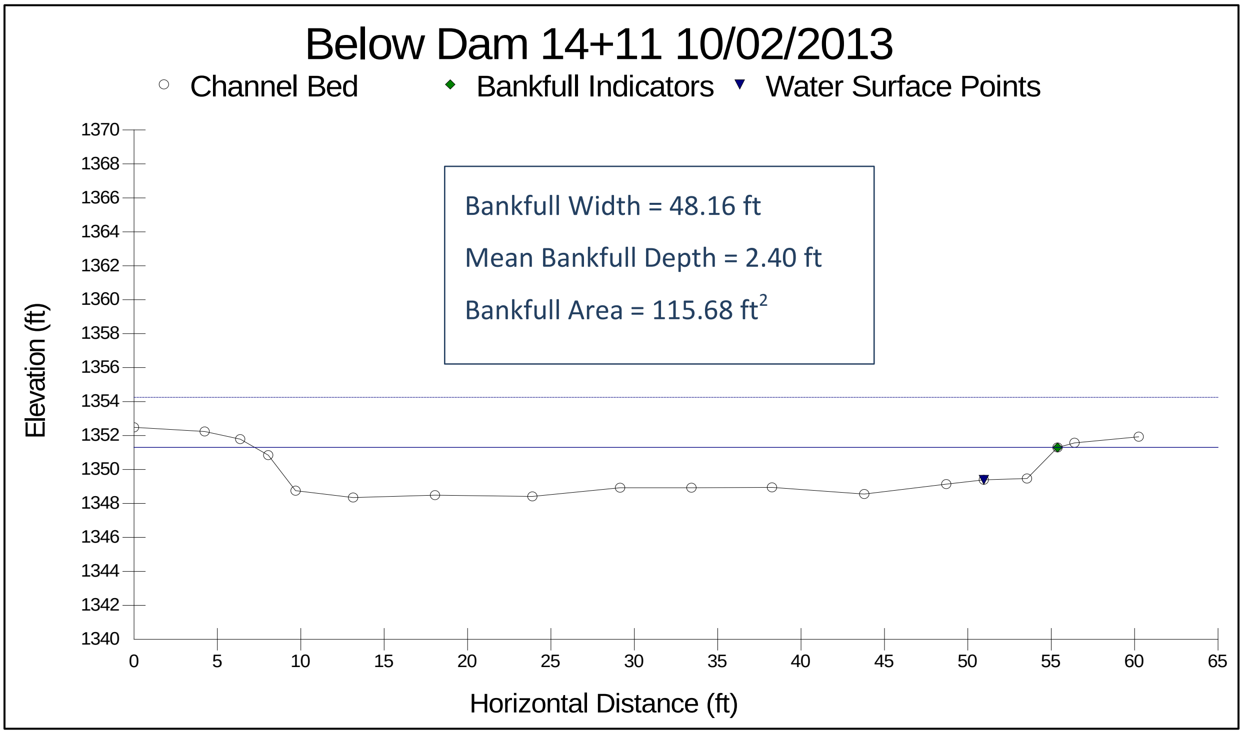


Figure 31: Cross-section below beaver dam at stationing 14+11.

Classification

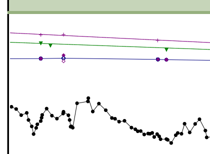
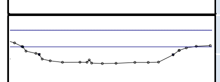
The Rosgen stream type through study reach 11UM077 was classified as a borderline E5/C5 (Table 6). E stream types are generally described as low gradient, meandering riffle/pool sequence streams. They are very efficient at moving sediment and water through the channel with very little deposition. C stream types have a higher width/depth ratio (>12) and depositional point bars develop on the inside bends of the meanders. Like E stream types, the gradient through this reach was low (<0.02).

Both E and C stream types are very sensitive to disturbance; however, they have a good to fair response to recovery when the disturbance is removed. Both are also very dependent on robust stream bank vegetation to remain stable.

Study reach 11UM077 is a stable E5/C5 stream. The modified (by stream type) Pfankuch stability rating on 10/02/2013 was 72. A good, or stable, rating range for E5 stream types is 50-75, and for a C5 is 70-90.

The riparian vegetation boundary conditions of this study

Table 6. Input variables for stream classification.

	STREAM TYPE	**E5 / C5**
	VALLEY TYPE	**VIIIc**
	**Slope**	**0.00063**
	**Entrenchment Ratio**	**13.13**
	Width/Depth Ratio	**12.68**
	**Sinuosity**	**1.92**
	Channel Material (D_{50})	**0.9 mm (SAND)**

reach was critical to the stability of this waterway. The herbaceous layer covered about 50% of the riparian zone, with reed canarygrass as the dominant species. Understory shrubs made up about 20% of the cover and were a mix of willow species and redosier dogwood. A few trees were present within the riparian zone. A white pine tree planting was adjacent to the river near riffle cross-section 4+47. Box elder trees were speckled throughout the riparian zone from natural regeneration.

A pebble count was completed along the entire reach of the longitudinal profile (Figure 32). The dominant particle sizes measured were sand and small gravels, making up 51.4% and 14.95%, respectively. The larger cobble and boulder particle sizes were concentrated at the beginning of the reach. The D_{50} was 0.9 mm, which classifies out as a sand dominant stream. Finer particles appeared to be present in higher volumes than ideal for this study reach, a result of the fairly recent beaver dam, change in energy slope, and aggradation of finer particles due to the impoundment.

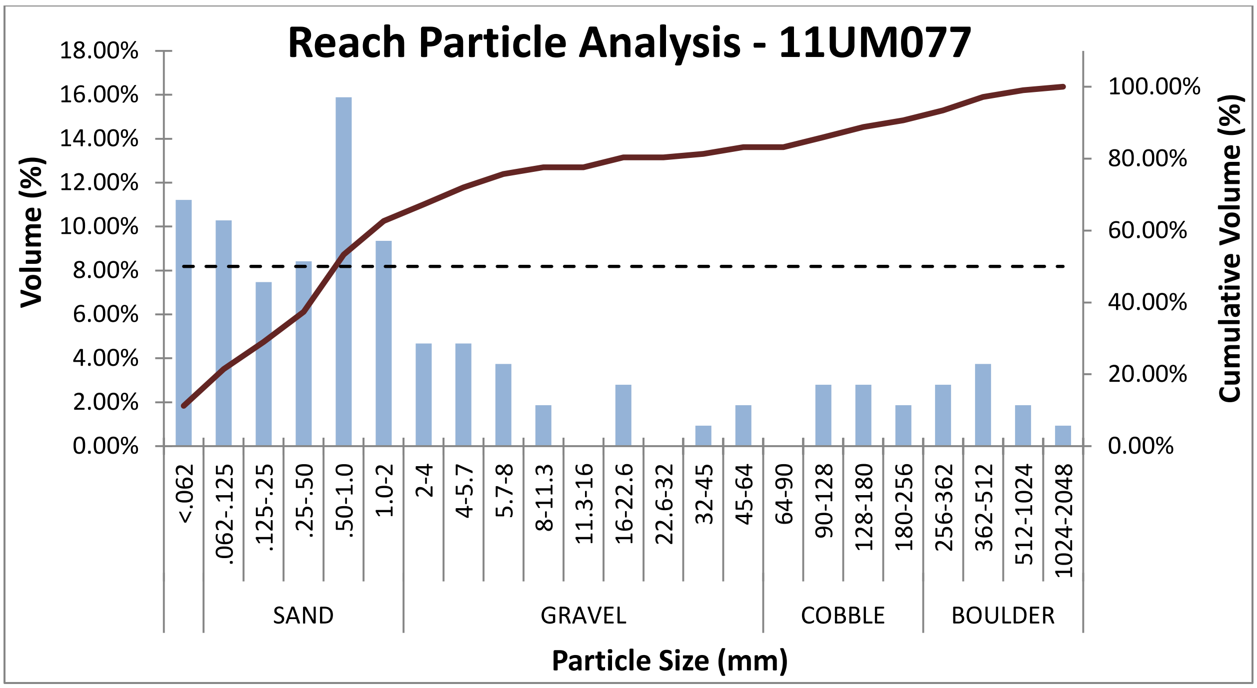


Figure 32: Pebble count results for the entire study reach 11UM077.

Summary

Table 7 records a summary of the channel morphology at site 11UM077. There was some dimensional variability across riffle cross-sections and only one pool (7+55) was used for pool dimensions.

Table 7: Summarization of channel morphology at site 11UM077

CHANNEL MORPHOLOGY & DIMENSIONLESS RATIOS

Stream: Wing River | **Site: 11UM077**

Observers: Dave Friedl, Lori Clark, & Julie Aadland | **Date: 10/02/2013**

Riffle Dimensions	Mean	Min	Max	Dimensionless Ratios	Mean	Min	Max
Riffle Width (W_{bkf})	36.4	30.5	40.2	Width of Flood-Prone Area (W_{pfa})	491	422	528
Mean Riffle Depth (d_{bfk})	2.82	2.4	3.17	Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})	13.1	10.6	16.1
Maximum Riffle Depth (d_{max})	3.59	3.1	3.86	Max Riffle Depth to Mean Riffle Depth (d_{max} / d_{bkf})	1.28	1.22	1.32
Riffle Cross-Sectional Area (A_{bkf}) (ft^2)	102.8	88.2	127.3	Entrenchment Ratio (W_{fpa} / W_{bkf})	13.5	13.1	13.9
Pool Dimensions							
Pool Width (W_{bkfp})	40.2	40.2	40.2	Pool Width to Riffle Width (W_{bkfp} / W_{bkf})	1.1	1.1	1.1
Mean Pool Depth (d_{bfkp})	2.89	2.89	2.89	Mean Pool Depth to Mean Riffle Depth (d_{bkfp} / d_{bkf})	1.03	1.03	1.03
Maximum Pool Depth (d_{maxp})	5.32	5.32	5.32	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})	1.13	1.13	1.13
Pool Cross-Sectional Area (A_{bkfp}) (ft^2)	116	116	116	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	1.89	1.89	1.89

Bank erosion estimates

The BANCS model was used to estimate streambank erosion rates. The left image of Figure 33 represents the estimated annual rate of streambank erosion. Input variables to estimate this rate include bank height, root depth, root density, bank angle, surface protection, soil particles, possible stratification of soil profile, and proximity of the thalweg to each bank. Rates for site 11UM077 ranged from 0.04 – 0.42 ft per year. The Colorado curve was used for these estimates. The majority of the study reach was at or below 0.15 ft/yr. The lower end on the right bank had the higher estimates (0.25 – 0.42 ft/yr) and smallest radius of curvature for the reach.

The right image of Figure 33 represents the total volume of annual erosion, which is calculated by multiplying the erosion rate by the length and height of each estimated section. The right bank had slightly higher bank heights, which would explain the slightly higher total erosion rates along the right bank (Table 8). Overall, these were very low estimated rates of erosion and total erosion loss.

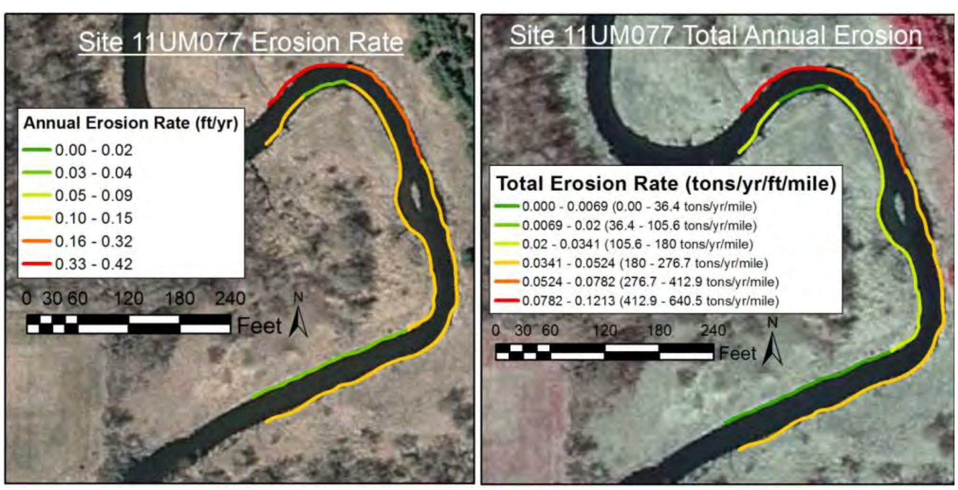


Figure 33: Estimated bank erosion rate (ft/yr) and total erosion rate (ft/yr) at site 11UM077.

Table 8: BANCS Model erosion estimates for site 11UM077, using Colorado curve data.

Stream: Wing River				Location: Reach - 11UM077			
Graph Used: Colorado		Total Stream Length (ft): 710				Date: 10/2/2013	
Observers: D. Friedl, L. Clark, J. Aadland			Valley Type: XIII			Stream Type: E5/C5	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	BEHI rating (Worksheet 3-11) (adjective)	NBS rating (Worksheet 3-12) (adjective)	Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)	Length of bank (ft)	Study bank height (ft)	Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)	Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}
1. 006-007 LB	Low	Low	0.036	201.7	4.0	28.80	0.00690
2. 007-008 LB	Moderate	Low	0.153	136.5	4.0	83.54	0.02950
3. 008-009 LB	Moderate	Low	0.153	48.8	3.0	22.40	0.02210
4. 009-010 LB	Moderate	Low	0.153	155.4	4.0	95.10	0.02950
5. 010-011 LB	Moderate	Low	0.036	58.9	3.5	7.36	0.00600
6. 011-012 LB	Moderate	Low	0.153	70.1	4.0	42.90	0.02950
7. 013-014 RB	Moderate	High	0.420	12.2	5.5	28.18	0.11120
8. 014-015 RB	Moderate	High	0.420	32.2	5.5	74.38	0.11120
9. 016-017 RB	High	Low	0.250	151.0	6.5	245.38	0.07820
10. 017-007 RB	Moderate	Low	0.153	271.9	5.0	207.97	0.03680
11. 015-016 RB	Moderate	High	0.420	69.9	6.0	176.15	0.12130
12. 017-start RB	Moderate	Low	0.153	177.2	5.0	135.56	0.03680

Velocity and discharge

Velocity and discharge estimates varied widely depending on the active bed riffle used, estimation method, and hydraulic slope value used. The slope used for estimating velocity was 0.00063, which was based on bankfull features through the reach. For comparison, the 1.5 year recurrence interval discharge estimate from the online USGS StreamStats tool was 259 cfs, which may not show good agreement with estimated velocity and discharge for this station. A stream gage exists approximately 7.5 miles downstream; however, the period of record was too short to calculate an annual peak recurrence interval analysis.

Table 9: Velocity and discharge estimates for riffle 0+01.

BANKFULL VELOCITY & DISCHARGE

Stream: Wing River | **Location: Site 11UM077**

Observers: Dave Friedl, Lori Clark, & Julie Aadland | **Date: 10/02/2013**

Riffle Cross-section:	Riffle 0+01		Bankfull Slope:	0.00063	
D84 of Active Bed:	217.62	Dia. (mm)	Drainage Area:	131	Mi^2

Estimation Methods	Bankfull Velocity		Bankfull Discharge	
Manning Limerinos n	1.335	ft / sec	123.888	CFS
Darcy-Weisbach	1.292	ft / sec	119.852	CFS
U/U*	1.22	ft / sec	113.44	CFS
Stream Type (C5, small with vegetative influence)	1.175	ft / sec	109.04	CFS

The particle size distribution at riffle 0+01 was the only cross-section data set that produced velocity and discharge calculations that seemed reasonable and matched the velocities calculated at 11UM078, while accommodating the larger drainage area (Table 9). The velocity and discharge estimates for other riffles from this reach were all deemed too high. The water surface energy slope of .00013 created by the beaver dam was likely the cause of the smaller particle sizes observed at this cross section and the rest of the riffle and reach particle size distributions downstream to the beaver dam, which affected roughness and velocity calculations, giving unrealistic discharge estimates.

Site Leaf Lake Tributary 11UM065

Introduction

Site 11UM065 is located on a small tributary that flows into East Leaf Lake, approximately 3 miles west-northwest of Deer Creek, Minnesota. It is in Otter Tail County, just west of 530th Avenue. According to the online USGS StreamStats tool, the drainage area is approximately 16 mi^2 (Figure 34).

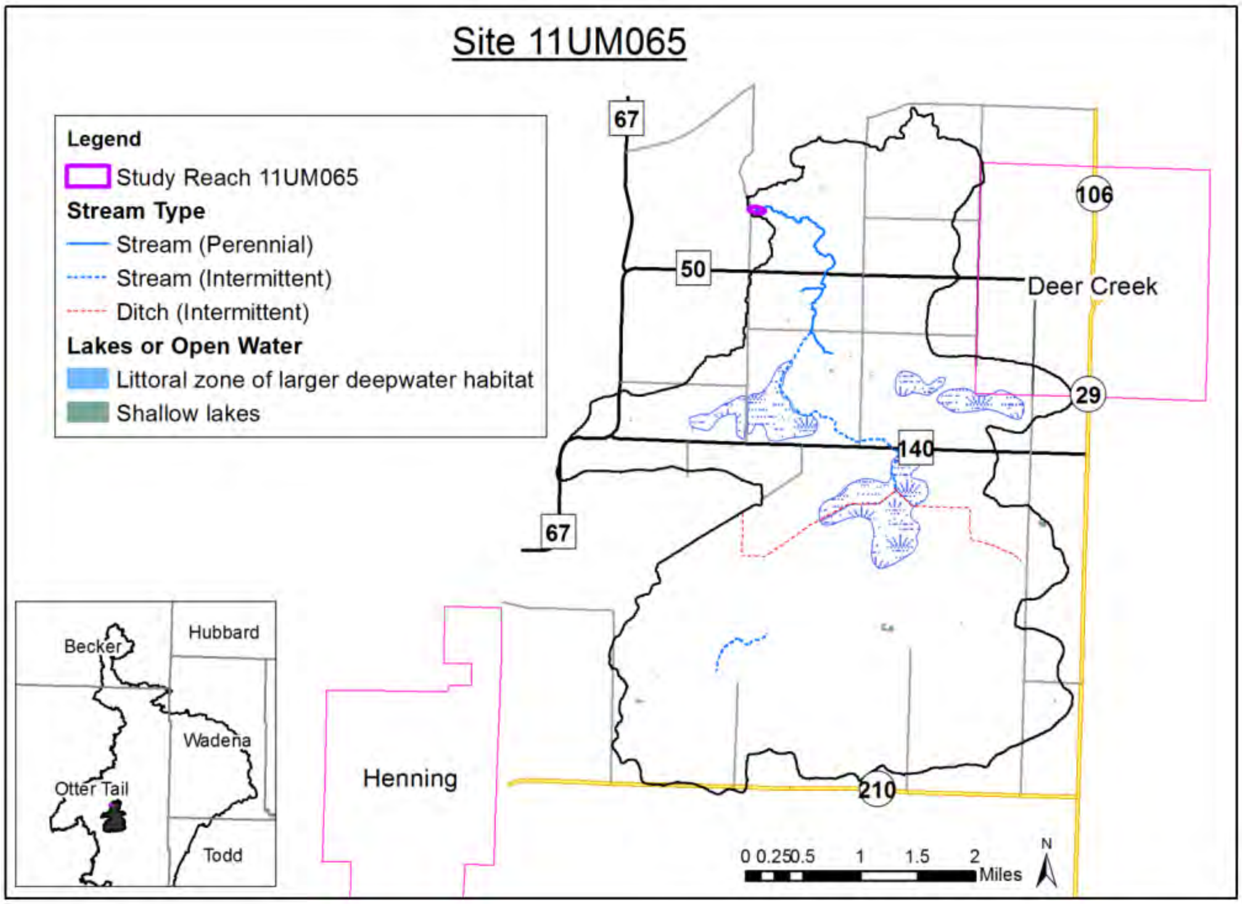


Figure 34: Drainage area for site 11UM065. This watershed delineation was created with the USGS StreamStats online tool.

Based on the NLCD 2011 data, the dominant land cover types within this subwatershed are cultivated crops (26.1%), deciduous forest (22.6%), and hay/pasture (22.4%). The deciduous forest land cover is predominantly south of County Road 140. Woody wetlands are scattered in this forest cover as well. The cultivated crops and hay/pasture land cover types are interspersed throughout the northern portion of this drainage area and along the perimeter of the southern portion. Just downstream of site 11UM065, this specific tributary flows through another large wetland complex.

Station map

Figure 35 is an aerial view of site 11UM065. Cross-section locations are denoted on the image.

Figure 35: Aerial image of site 11UM065.

Longitudinal profile

Figure 36 shows the longitudinal profile from site 11UM065. The stream bed slope from head-of-riffle to head-of-riffle was at 0.00227. The bankfull indicators at cross sections that provided the highest confidence resulted in a slope line of 0.00192. It seemed reasonable to use 0.002 as the energy slope for velocity and discharge calculations. The water surface slope was 0.00057 but may have been influenced by the road crossing downstream, which appears to have an undersized culvert based on the scour pool downstream of the road. The pool cross-section at stationing 1+85 was located in a hammer head pool. The tight radius of curvature at this location was causing the water to scour out a deep, wide pool, relative to the rest of the study reach.

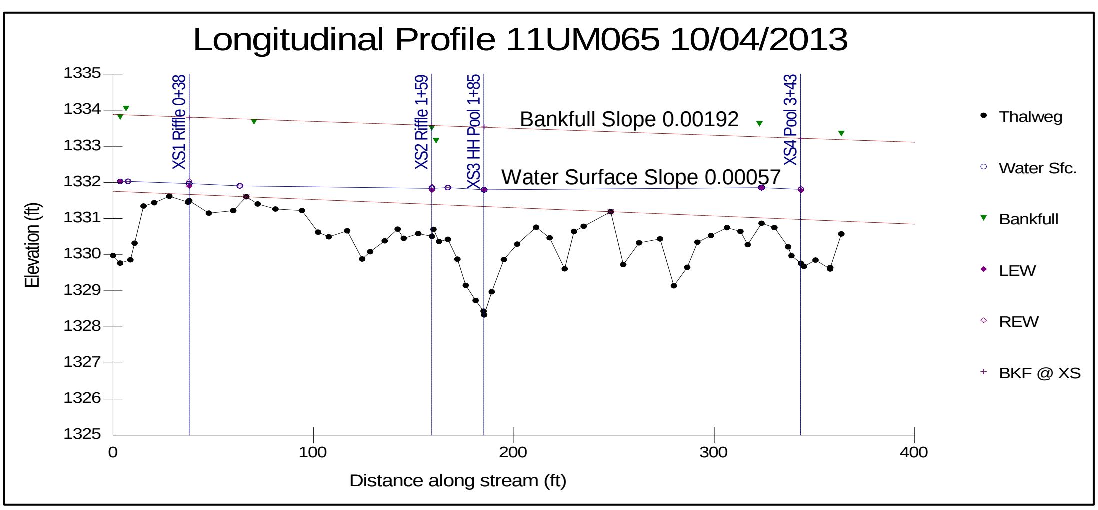


Figure 36: Longitudinal Profile of site 11UM065.

Riffle 0+38

The most upstream cross-section was a riffle at 0+38. The width of the channel at bankfull was 9.38 ft and the mean depth was 1.86 ft (Figure 37). The maximum depth at bankfull was 2.30 ft.

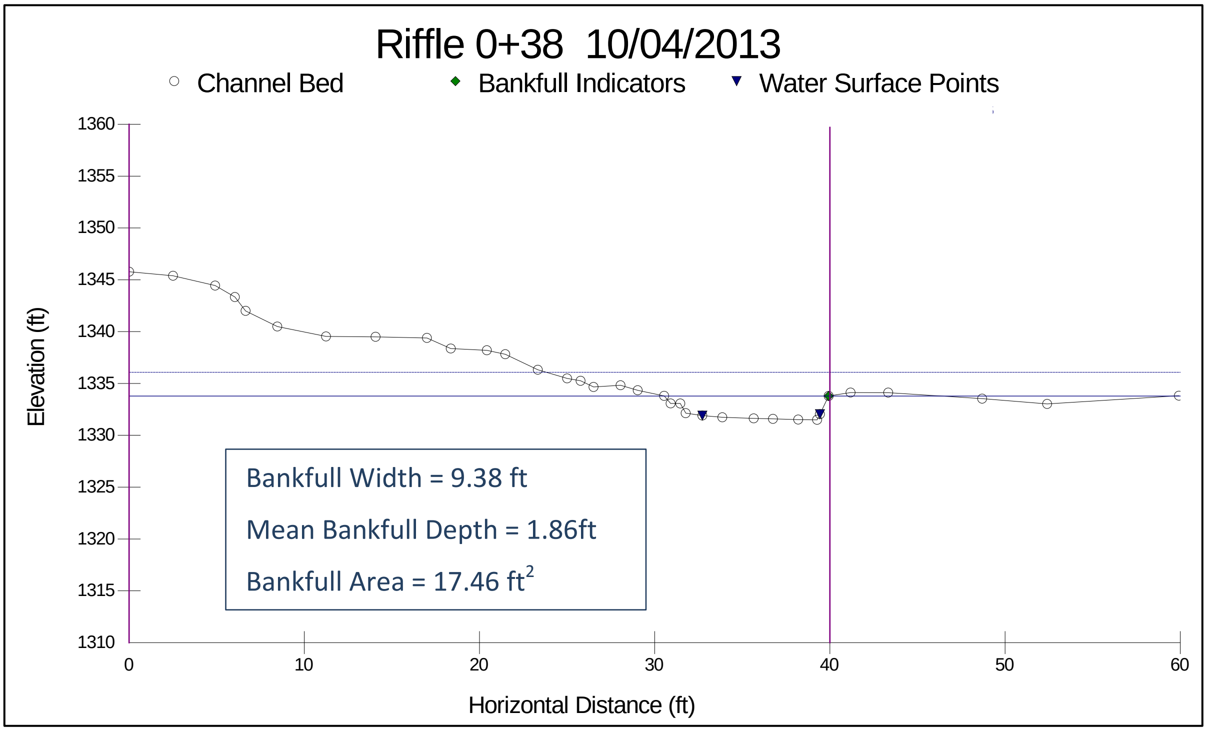


Figure 37: Riffle cross-section located at longitudinal profile station 0+38.

The streambank at this cross-section location was well vegetated with reed canarygrass (Figure 38). Shrub species, including speckled alder, were present above bankfull on the left bank. A pebble count was completed at riffle location 0+38. Figure 39 shows the particle size distribution that ranged from silt/clay up to cobble. The dominant particle type present at this cross-section was gravel, making up 76.47% of the total sample. The D_{84} at riffle 0+38 was 14.21 mm.

Figure 38: Photo of riffle cross-section 0+38.
Photo was taken from the left bank, looking north.

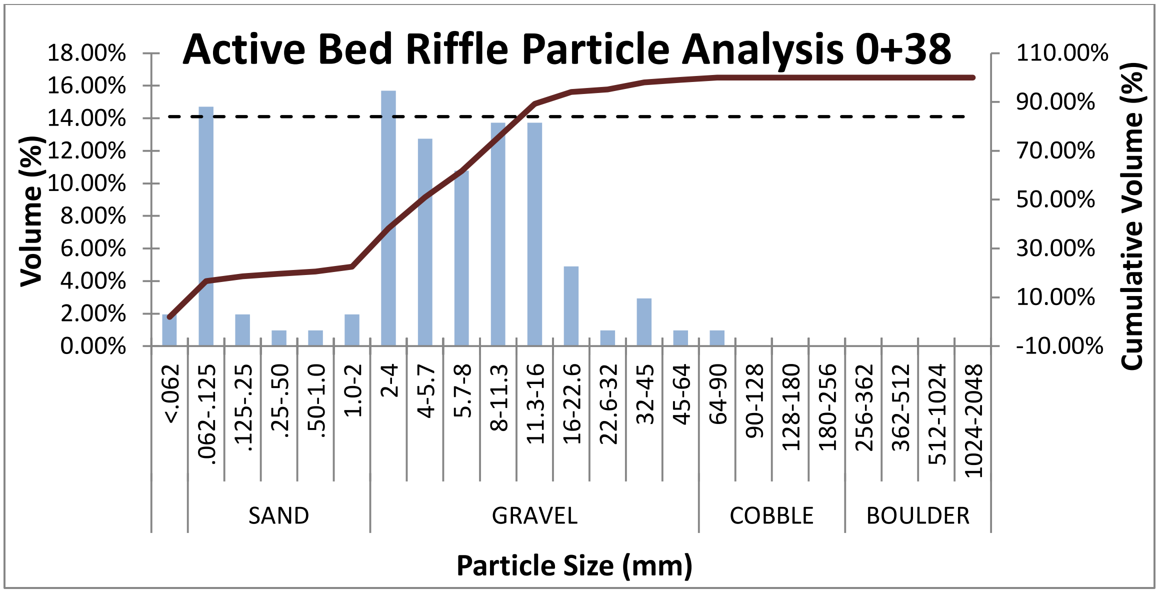


Figure 39: Pebble count results for riffle cross-section 0+38.

Riffle 1+59

The second cross-section was also at a riffle. The width of the channel at bankfull was 8.2 ft and the mean depth was 2.44 ft (Figure 40). The maximum depth at bankfull was 3.08 ft. Significant sand dunes were present on the channel bed at this cross-section location. The heights of the dunes were measured as a surrogate for a pebble count. The height ranged from 2-32 mm. The D_{84} of the sand dune heights was 23.23 mm.

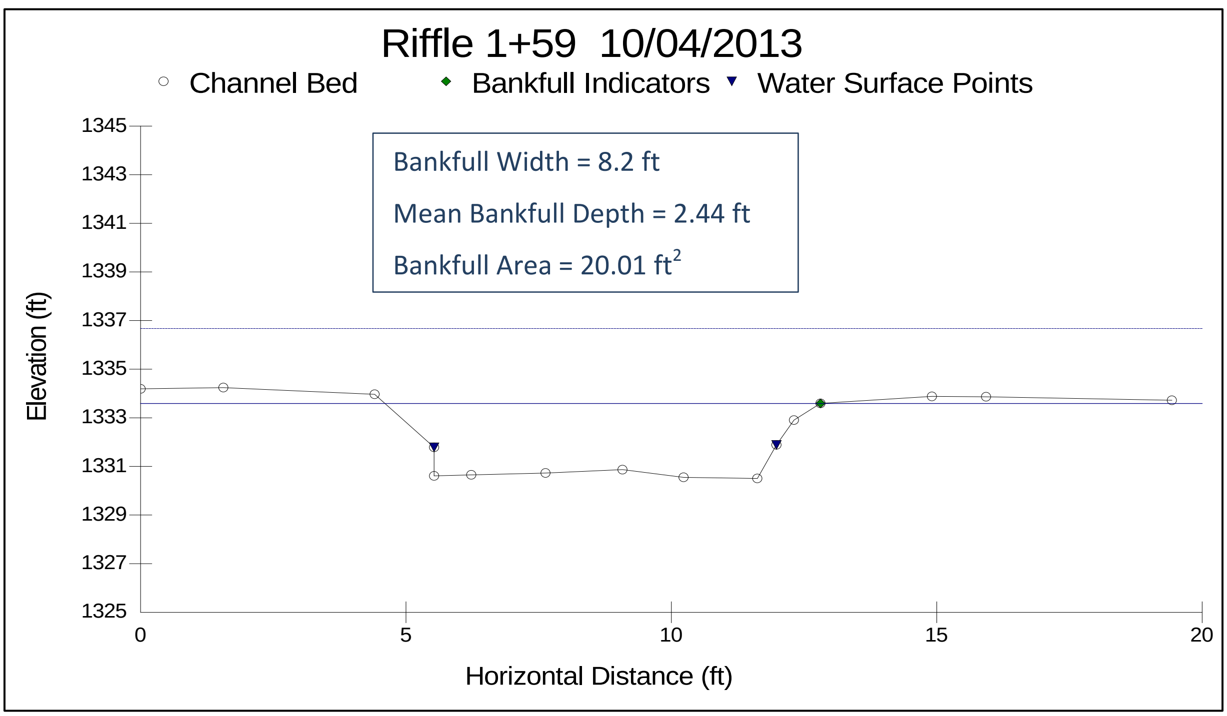


Figure 40: Riffle cross-section at station 1+59.

Pool 1+85

The pool located at station 1+85 had a very tight radius of curvature, which created a wide, deeply scoured pool. This type of pool is sometimes referred to as a hammer head pool, due the shape of the meander. The width of the channel at bankfull was 18.22 ft, and the mean depth was 3.02 ft (Figure 41). The maximum depth at bankfull was 5.21 ft.

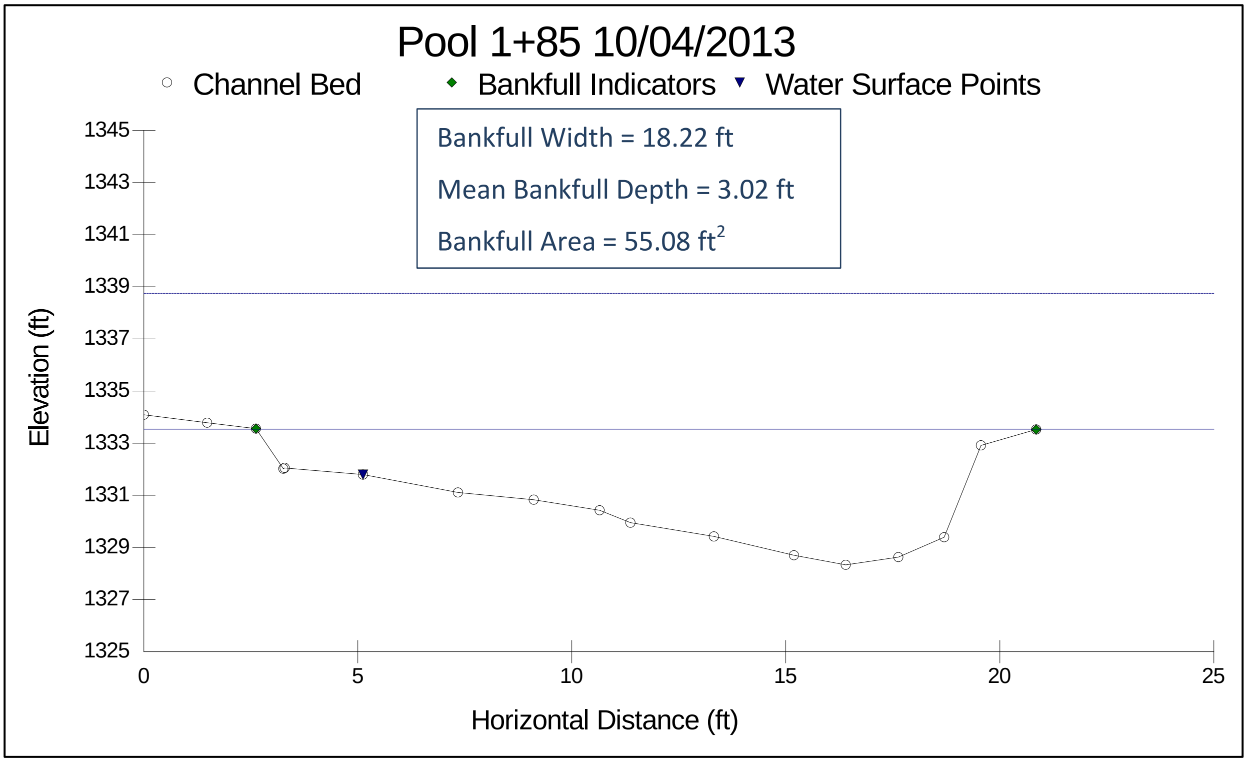


Figure 41: Pool cross-section at station 1+85.

Figure 42 is a photo taken from the upstream end of the pool, looking downstream. The dominant plant species present at this cross-section was reed canary grass.

Figure 42: Photo of hammer head pool at station 1+85.

Pool 3+43

A pool cross-section was completed near the end of this study reach. The width of the channel at bankfull was 13.7 ft and the mean depth was 1.95 ft (Figure 43). The maximum depth at bankfull was 3.45 ft.

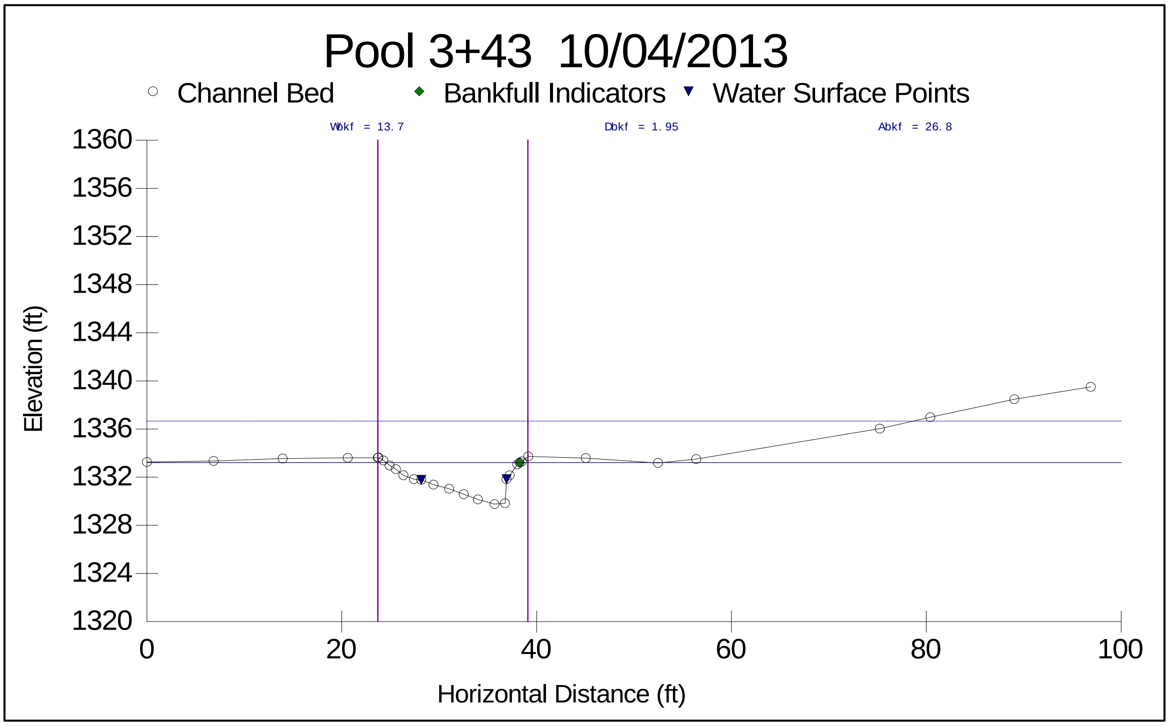


Figure 43: Pool cross-section at stationing 3+43.

Figure 44: Photo taken near the end of study reach 11UM065, looking back upstream.

The streambank at this cross-section location was well vegetated with reed canarygrass (Figure 44). Most of the study reach looked like this area. Duckweed and a *Ranunculus* species were found in pockets near the streambank.

Between pool 1+85 and pool 3+43 there were a few areas of thick shrub growth along the streambank, and some woody debris was collecting in the stream along this stretch.

Classification

The stream at study reach 11UM065 was given a Rosgen stream type E5 classification (Table 10). E stream types generally have wide accessible floodplains and are typically highly sinuous. They also have low gradients and low width to depth ratios. They are very efficient at moving sediment and water through the channel with very little deposition.

Due to the low width/depth ratio, E stream types need robust vegetation on and near the stream banks. They are very sensitive to disturbance; however, they also have the ability to recover when the disturbance is removed.

Study reach 11UM065 was a classified as a stable E5 stream. The modified (by stream type) Pfankuch stability rating was 69. A good, or stable, rating range for an E5 stream type is 50-75. Very little deposition was seen at this site.

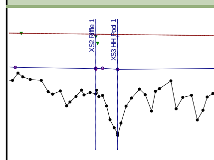
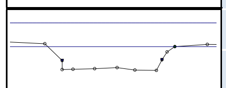
	STREAM TYPE	**E5**
	VALLEY TYPE	**VIIIc**
	**Slope**	**0.002**
	**Entrenchment Ratio**	**22.6**
	Width/Depth Ratio	**5.04**
	**Sinuosity**	**1.49**
	Channel Material (D_{50})	**0.81 mm (SAND)**

Table 10: Input variables for stream classification

Figure 45: Photo of study Reach 11UM065 (10/04/2013)

The plant community immediately adjacent to the banks and within the riparian zone is critical to the stability of this tributary (Figure 45). The herbaceous layer covered about 50% of the riparian zone, with reed canarygrass as the dominant cover. Understory shrubs made up about 30% of the cover and were a mix of willow species, speckled alder, hawthorn, and redosier dogwood. Trees were present in the riparian zone and most were found on the south side of the tributary and appear to have been planted over 50 years ago. The dominant tree species included box elder, white spruce, and basswood.

A study reach pebble count was completed (Figure 46) and the dominant particle sizes measured were sand and small gravels, making up 56.36% and 39.09%, respectively (Figure 47). A small amount of silt/clay and boulder-sized material were measured. The larger particle sizes were concentrated in one location along the reach, at around station 0+50 to 1+50. At this location the channel was close to a steep valley wall and the boulders may have fallen out of the valley wall or from a rock pile near the edge of the adjacent field.

Figure 46: Approximately 120 ft from start of long profile.

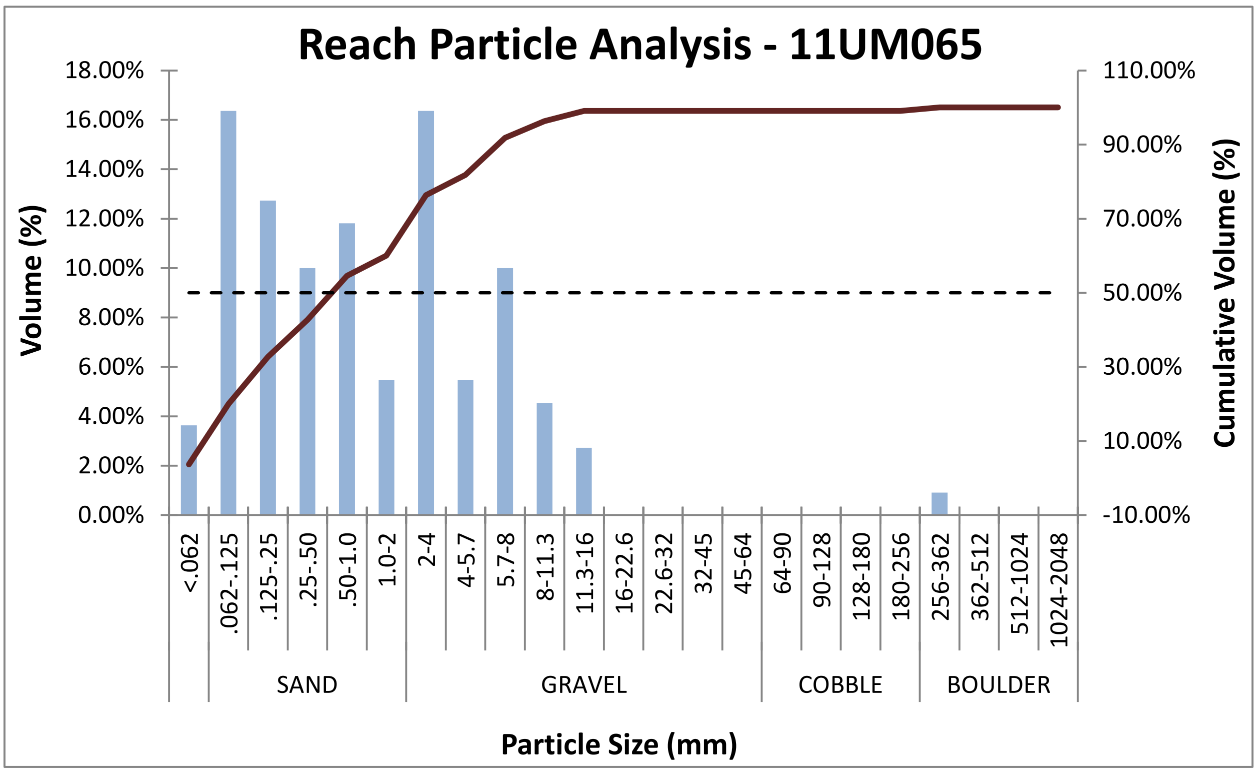


Figure 47: Pebble count results for entire study reach at site 11UM065.

Summary

Table 11 is a summary of select channel morphology dimensions and dimensionless ratios for study reach 11UM065. The mean width to depth ratio was very low (mean 4.2) and the gradient was low (slope of 0.002). The width of the valley at the floodprone elevation (approximately two times maximum bankfull riffle depth) was sufficient to give this reach a large entrenchment ratio and this study reach has a low degree of vertical containment. The reach was classified as an E5 stream type.

The hammer head pool at 1+85 heavily influenced the dimensionless ratios. The width at the pool cross-sections was approximately twice as wide as at the riffles. Typical of stable E stream types, the pools were also deeper and had larger cross-sectional areas than the riffles. The hammer head pool created the best pool habitat in the reach.

Table 11: Summary of channel morphology at site 11UM065.

CHANNEL MORPHOLOGY & DIMENSIONLESS RATIOS

Stream: Unnamed Tributary to East Leaf Lake **Site: 11UM065**
Observers: Dave Friedl, Lori Clark, & Julie Aadland **Date: 10/04/2013**

Riffle Dimensions	Mean	Min	Max	Dimensionless Ratios	Mean	Min	Max
Riffle Width (W_{bkf})	8.79	8.2	9.38	Width of Flood-Prone Area (W_{pfa})	220	212	228
Mean Riffle Depth (d_{bfk})	2.15	1.86	2.44	Riffle Width/Depth Ratio (W_{bkf}/ d_{bkf})	4.2	3.36	5.04
Maximum Riffle Depth (d_{max})	2.69	2.3	3.08	Max Riffle Depth to Mean Riffle Depth (d_{max}/ d_{bkf})	1.25	1.24	1.26
Riffle Cross-Sectional Area (A_{bkf}) (ft^2)	18.74	17.46	20.01	Entrenchment Ratio (W_{fpa} / W_{bkf})	25.2	22.6	27.81
Pool Dimensions							
Pool Width (W_{bkfp})	15.97	13.71	18.22	Pool Width to Riffle Width (W_{bkfp}/ W_{bkf})	1.82	1.56	2.07
Mean Pool Depth (d_{bfkp})	2.49	1.95	3.02	Mean Pool Depth to Mean Riffle Depth (d_{bkfp}/ d_{bkf})	1.16	0.91	1.41
Maximum Pool Depth (d_{maxp})	4.33	3.45	5.21	Pool Area to Riffle Area (A_{bkfp} / A_{bkf})	2.19	1.43	2.94
Pool Cross-Sectional Area (A_{bkfp}) (ft^2)	40.94	26.79	55.08	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	2.01	1.61	2.42

Bank erosion estimates

The BANCS model was used to estimate streambank erosion rates. The left image of figure 48 represents the estimated annual rate of streambank erosion (ft/yr). Input variables used to estimate this rate included bank height, root depth, root density, bank angle, surface protection, soil particles, stratification of soil profile; and the depth and proximity of the thalweg to eroding banks. Erosion rates for site 11UM065 ranged from 0.09 – 0.42 ft/yr. The majority of the study reach had erosion rates less than 0.25 ft/yr. The Colorado curve was used for these estimates. The outside bends had the highest annual erosion rates (0.38 – 0.42 ft/yr). The hammer head pool erosive study bank height and tight radius contributed to a higher erosion rate estimate for that location. The location on the left bank (facing downstream) with the higher erosion rate had extensive shrub growth near the streambanks. The amount of woody debris in the channel at this location was directing some flow towards the streambank, which was contributing to a higher erosion rate.

The right image of figure 48 represents the total annual sediment contribution from bank erosion, which was calculated by multiplying the erosion rate by the length and height of each similar bank segment. The outside banks with the higher annual erosion rates had a higher estimated volume of erosion (Table 12). Overall, these were low erosion rate and total erosion loss estimates.

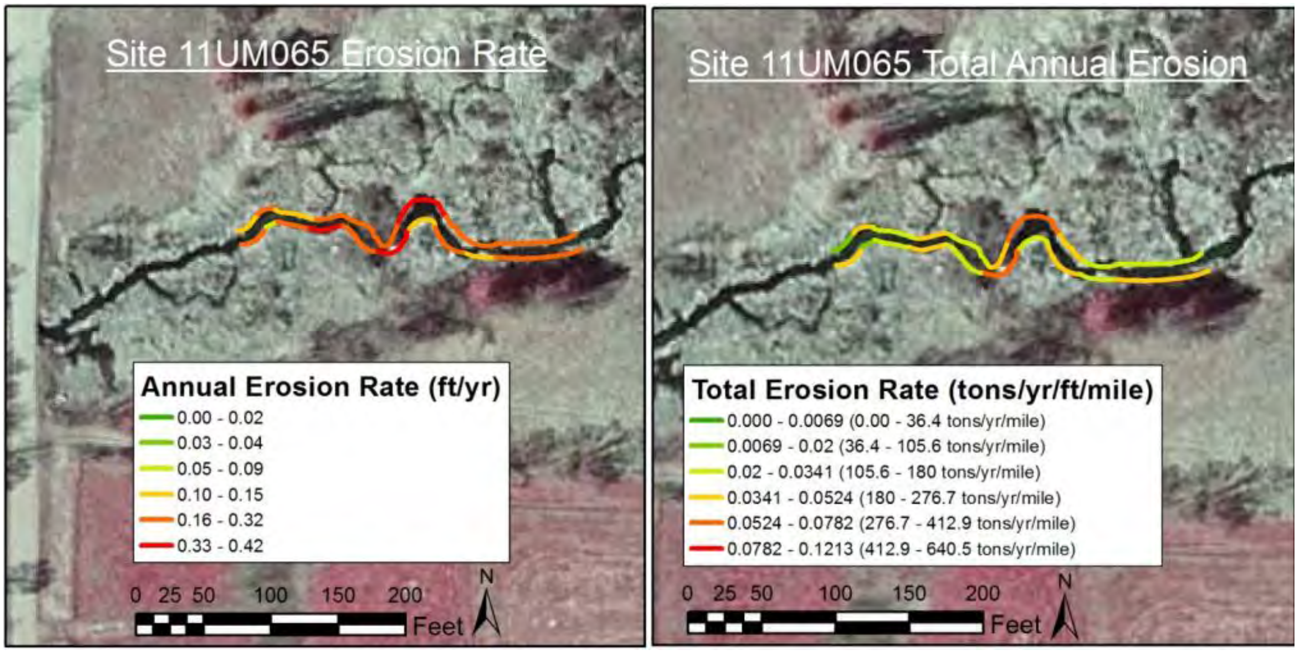


Figure 48: Estimated bank erosion rate (ft/yr) and the total erosion rate (tons/yr) for study reach 11UM065.

Table 12: BANCS Model erosion estimates for site 11UM065, using Colorado data.

Stream: **Leaf LakeTrib**				Location: Reach - 11UM065			
Graph Used: **Colorado**		Total Stream Length (ft): **303.63**				Date: **10/4/2013**	
Observers: **D. Friedl, J. Aadland, L. Clark**		Valley Type: **XIII(c)**				Stream Type: **E 5**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Station (ft)	**BEHI rating (Worksheet 3-11) (adjective)**	**NBS rating (Worksheet 3-12) (adjective)**	**Bank erosion rate (Figure 3-9 or 3-10) (ft/yr)**	**Length of bank (ft)**	**Study bank height (ft)**	**Erosion subtotal [(4)×(5)×(6)] (ft^3/yr)**	**Erosion Rate (tons/yr/ft) {[(7)/27] × 1.3 / (5)}**
1. **033-034 LB**	**High**	**Low**	**0.250**	**24.2**	**3.3**	**19.96**	**0.03970**
2. **033-034 RB**	**Moderate**	**Low**	**0.153**	**20.3**	**2.3**	**7.13**	**0.01690**
3. **034-035 LB**	**Moderate**	**Very Low**	**0.092**	**9.6**	**2.4**	**2.13**	**0.01070**
4. **034-035 RB**	**High**	**Low**	**0.250**	**15.2**	**4.4**	**16.53**	**0.05240**
5. **035-036 LB**	**High**	**Low**	**0.250**	**26.6**	**2.5**	**16.62**	**0.03000**
6. **035-036 RB**	**Moderate**	**Low**	**0.153**	**28.8**	**3.0**	**13.22**	**0.02210**
7. **036-037 LB**	**High**	**Moderate**	**0.380**	**22.3**	**2.7**	**22.88**	**0.04940**
8. **036-037 RB**	**High**	**Low**	**0.250**	**24.3**	**4.1**	**24.91**	**0.04940**
9. **037-038 LB**	**High**	**Low**	**0.250**	**33.8**	**2.6**	**21.97**	**0.03130**
10. **037-038 RB**	**Moderate**	**Moderate**	**0.253**	**37.9**	**2.7**	**25.89**	**0.03290**
11. **038-039 LB**	**Moderate**	**High**	**0.420**	**34.6**	**3.7**	**53.77**	**0.07480**
12. **038-039 RB**	**Moderate**	**Moderate**	**0.253**	**24.9**	**3.0**	**18.58**	**0.03590**
13. **039-040 LB**	**Moderate**	**Low**	**0.153**	**25.0**	**3.0**	**11.48**	**0.02210**
14. **039-040 RB**	**High**	**Moderate**	**0.380**	**50.3**	**4.2**	**80.21**	**0.07680**
15. **040-041 LB**	**High**	**Low**	**0.250**	**31.4**	**2.9**	**22.77**	**0.03490**
16 **040-041 RB**	**High**	**Low**	**0.250**	**24.7**	**3.2**	**19.74**	**0.03850**
17 **041-042 LB**	**High**	**Low**	**0.153**	**23.9**	**3.3**	**11.86**	**0.02390**
18 **041-042 RB**	**Moderate**	**Moderate**	**0.253**	**23.1**	**2.7**	**15.46**	**0.03230**
19 **042-start LB**	**High**	**Low**	**0.250**	**64.5**	**3.0**	**48.35**	**0.03610**
20 **042-start RB**	**High**	**Low**	**0.250**	**59.9**	**2.8**	**41.92**	**0.03370**

Velocity and discharge

Velocity and discharge estimates from riffle cross-sections 0+38 and 1+59 were similar (Table 13), but lower than the one and a half year recurrence interval discharge estimate of 81 cfs from the online USGS StreamStats tool. The slope used for calculations was 0.002, which was obtained from bankfull indicators and bed features (riffle head to riffle head) along the reach.

BANKFULL VELOCITY & DISCHARGE

Stream: Unnamed Tributary to East Leaf Lake | **Location: Site 11UM065**
Observers: Dave Friedl, Lori Clark, & Julie Aadland | **Date: 10/04/2013**

Riffle Cross-section:	Riffle 0+38		Bankfull Slope:	0.002	
D84 of Active Bed:	14.21	Dia. (mm)	Drainage Area:	15.6	Mi^2

Estimation Methods	Bankfull Velocity		Bankfull Discharge	
Manning Limerinos n	3.58	ft / sec	62.49	CFS
Darcy-Weisbach	4.16	ft / sec	72.64	CFS
U/U*	3.4	ft / sec	59.37	CFS
Stream Type (small with vegetative influence)	1.56	ft / sec	27.19	CFS

Table 13: Velocity and discharge estimates for riffle 0+38.

The velocity and discharge estimates for riffle 1+59 were similar to riffle 0+38 (Table 14). As mentioned, the pebble count at riffle 1+59 was completed by measuring sand dune heights.

BANKFULL VELOCITY & DISCHARGE

Stream: Unnamed Tributary to East Leaf Lake | **Location: Site 11UM065**
Observers: Dave Friedl, Lori Clark, & Julie Aadland | **Date: 10/04/2013**

Riffle Cross-section:	Riffle 1+59		Bankfull Slope:	0.002	
D84 of Active Bed:	23.23	Dia. (mm)	Drainage Area:	15.6	Mi^2

Estimation Methods	Bankfull Velocity		Bankfull Discharge	
Manning Limerinos n	3.49	ft / sec	69.86	CFS
Darcy-Weisbach	4.55	ft / sec	91	CFS
U/U*	3.27	ft / sec	65.53	CFS
Stream Type (small with vegetative influence)	1.67	ft / sec	33.38	CFS

Table 14: Velocity and discharge estimates for riffle 1+59.