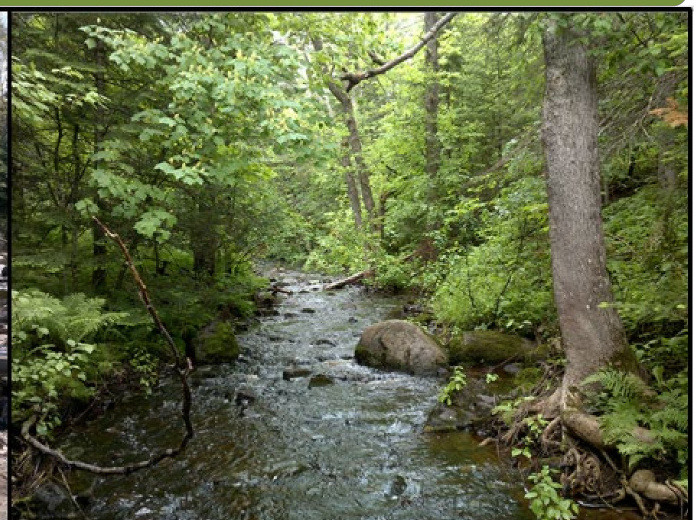
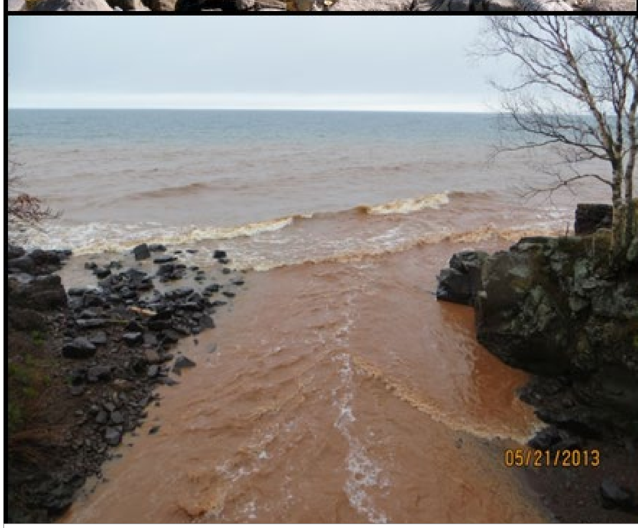
Lake Superior South Watershed Stressor Identification Report

Evaluating potential causes of degraded fish and aquatic macroinvertebrate communities in the Lake Superior South Watershed

MINNESOTA POLLUTION CONTROL AGENCY

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Authors

Jeff Jasperson (MPCA)
Jenny Jasperson (MPCA)
Tim Beaster (South St. Louis County SWCD)

Contributors/acknowledgements

Michael Harris (DNR)
Ann Thompson (South St. Louis County SWCD)
Alice Yonke (South St. Louis County SWCD)

Manuscript reviewers

Karl Koller (DNR)
Tiffany Schauls (MPCA)
Jesse Anderson (MPCA)

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Clockwise from Top Left: Bank Erosion on Beaver River near Silver Bay, Minnesota; Talmadge River near Duluth, Minnesota; Young of Year Brook Trout in East Branch Amity Creek near Duluth, Minnesota; Talmadge River entering Lake Superior during rain event near Duluth, Minnesota

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

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Executive summary

This report summarizes the principal causes, or "stressors," contributing to impaired fish and aquatic macroinvertebrate communities in three streams within the Lake Superior South 8-digit HUC watershed (Beaver River, West Branch Beaver River, and Talmadge River). Ultimately, the results of this report will be used to guide several processes, including; total maximum daily load (TMDL) development; defining the need for research and development of new water quality standards; and prioritizing additional monitoring, restoration, and protection strategies in these watersheds.

A wide-range of potential stressors were evaluated in order to increase confidence in the stressor diagnosis. Ultimately, five stressors were identified within the Lake Superior South HUC with high confidence; elevated total suspended solids (TSS), low dissolved oxygen (DO), elevated water temperatures, poor physical habitat conditions, and altered hydrology (lack of baseflow). An additional three stressors remain potential candidate causes of impairment; loss of connectivity (e.g. perched culverts), elevated ionic strength, and elevated pH. These were either unable to be eliminated based on inconclusive results, or were localized impacts in need of attention but not a prominent cause of the impaired condition. The stressor identification results for the three impaired streams are summarized below.

	Beaver River	W. Branch Beaver River	Talmadge River
Water Quality Stressors			
Total Suspended Solids (TSS)	●	X	●
Elevated Water Temperature	●	●	O
Low Dissolved Oxygen	X	●	O
Elevated pH	O	X	X
Elevated Ionic Strength	O	X	X
Hydrology			
Lack of Baseflow	X	X	●
Physical/Geomorphology			
Poor Physical Habitat	●	●	●
Loss of Connectivity	X	O	O
Key: ● = Confirmed Stressor	O = Potential Stressor/Localized Impact	X = eliminated candidate cause	

Section 7.0 and 8.0 of this report contains several recommendations for potential restoration and protection projects within the Lake Superior South 8HUC watershed. The scope of these recommendations includes several watersheds that were not identified as "impaired" in the most recent assessment process. These non-impaired watersheds were included for emphasis on protection measures or projects that have a high likelihood of success (e.g. habitat restoration/restoring connectivity on high profile trout streams).

1.0 Report purpose, process, and overview

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 81 Major Watersheds, known as the Watershed Restoration and Protection Strategy (WRAPS). A WRAPS is comprised of several types of assessments. The MPCA conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2009 and 2010. The IWM assessed the aquatic biology and water chemistry of the Lake Superior South Watershed streams and rivers. The second assessment, known as the Stressor Identification (SID) Assessment, builds on the results of the IWM. The MPCA conducted the SID data collection during follow-up monitoring that spanned the years 2011 – 2014. This document reports on the second step of a multi-part WRAPS for the Lake Superior South Watershed.

It is important to recognize that this report is part of a series, and thus not a stand-alone document. Information pertinent to understanding this report can be found in the Lake Superior South Watershed Monitoring and Assessment Report. That document should be read together with this SID Report and can be found from a link on the MPCA's webpage: https://www.pca.state.mn.us/sites/default/files/wq-ws3-04010102b.pdf.

Organization framework of stressor identification

The SID process is used in this report to weigh evidence for or against various candidate causes of biological impairment (Cormier et al. 2000). The SID process is prompted by biological assessment data indicating that a biological impairment has occurred. Through a review of available data, stressor scenarios are developed that may accurately characterize the impairment, the cause, and the sources/pathways of the various stressors (Figure 1). Confidence in the results often depends on the quality of data available to the SID process. In some cases, additional data collection may be necessary to identify the stressor(s).

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

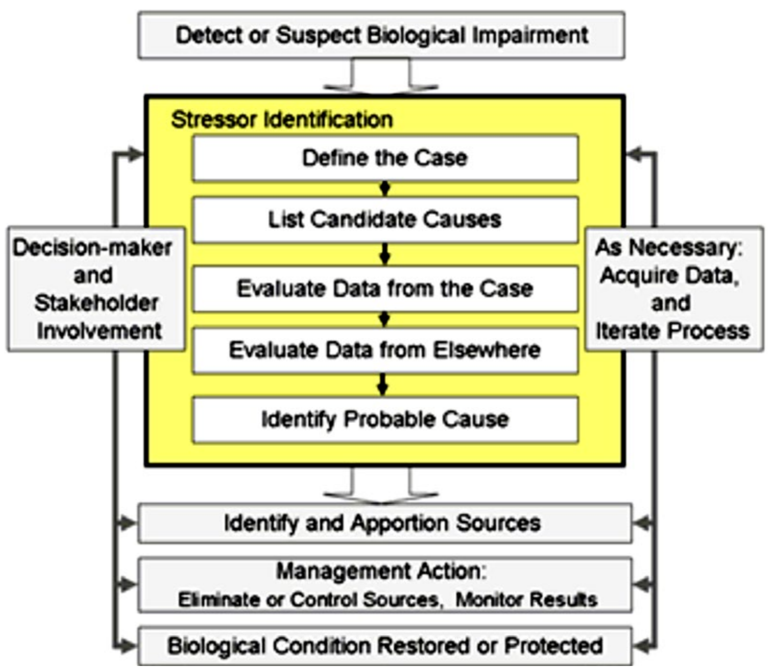
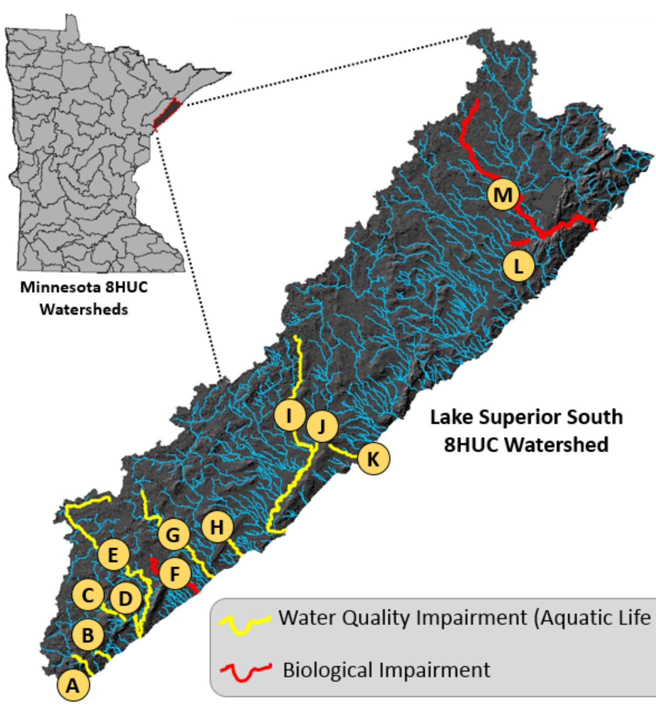


Figure 1. Conceptual diagram of the SID process for identifying the cause(s) of biological Impairment (Cormier et al 2003)

2.0 Impaired waters of the Lake Superior South 8HUC

Currently, the Lake Superior South 8HUC Watershed contains 13 stream reaches impaired for aquatic life, aquatic recreation, or both (Figure 2). Aquatic life impairments include elevated TSS/turbidity (nine impaired reaches), low DO (two impaired reaches), fish biological assessments ("bio-assessments") (three impaired reaches), and macroinvertebrate bio-assessments (one impaired reach). The aquatic recreation-based impairments in the watershed are related to E. coli concentrations in streams that exceed state water quality standards for body contact (i.e. swimming). Most of the streams impaired for TSS/turbidity have been monitored extensively over the past decade. A completed TMDL is available for the Knife River impairment (link to Knife River TMDL), and work is in progress to complete similar projects for the remainder of the TSS impairments.

This stressor identification report focuses on the three streams listed as impaired for biological measures. These streams support fish and macroinvertebrate communities that deviated significantly from those found in minimally impacted streams in the region. As a result, a decision was made to list them as impaired for failing to meet established thresholds for biological integrity. The Index of Biological Integrity, or "IBI", is the tool most commonly used by MPCA to biological condition. The three streams impaired for IBI measures in the Lake Superior South 8HUC watershed include the Beaver River (Fish IBI), the West Branch Beaver River (Fish IBI, Macroinvertebrate IBI), and the Talmadge River (Fish IBI). The Talmadge River and Beaver River are also listed as an impaired for additional water quality parameters that are associated with aquatic life (Figure 2). These water quality impairments will be discussed in some level of detail as they pertain to the the impaired biological condition, but additional analysis and reporting will be required to develop TMDLs and implementation plans for restoration.



	Stream	Impairment
A	Chester Creek	E. coli
B	Tischer Creek	E. coli
C	Amity Ck, East Br.	Turbidity
D	Amity Creek	Turbidity
E	Lester River	Turbidity
F	**Talmadge River***	Diss. Oxy., Turbidity, **Fish IBI**
G	French River	Turbidity
H	Sucker River	Turbidity
I	Knife River	Turbidity
J	Little Knife River	Diss. Oxy, Turbidity
K	Skunk Creek	E. coli, Turbidity
L	**Beaver R., West Br.***	**Fish IBI, Invertebrate IBI**
M	**Beaver River***	**Fish IBI,** Hg-W, Turbidity, pH

*Impairments in **Red** are address in this report

IBI = Index of Biological Integrity
Hg-W = Water column Mercury

Figure 2. Impaired streams of the Lake Superior South 8HUC Watershed

3.0 Candidate causes of biological stress and applicable water quality standards in Minnesota

This information provides an overview of the pathway and effects of each candidate stressor considered in the biological stressor identification process. The U.S. Environmental Protection Agency (EPA) has additional information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on its CADDIS website. The Causal Analysis/Diagnosis Decision Information System, or CADDIS, is a website developed to help scientists and engineers in the Regions, States, and Tribes conduct causal assessments in aquatic systems.

3.1 Water temperature

The factors that control stream water temperature and the biological effects of elevated temperature are complex. Stream temperature naturally varies due to:

- Air temperature
- Geological setting
- Amount of shading
- Water inputs from tributaries and springs

Human activities can increase stream temperatures through:

- Altering riparian vegetation (loss of shading)
- Urban runoff from warm impervious surfaces such as parking lots
- Agricultural runoff
- Loss of landscape water storage and thus periods of reduced stream water volume
- Direct discharges of warm wastewater to the stream

Figure 3. Cold water from a tributary spring to Brophy Creek in the Sucker River watershed near Duluth

Different organisms are adapted to and prefer different temperature ranges, and will thrive or decline based on the temperature ranges found in a stream.

Warmer water holds less DO. Water temperature also affects the toxicity of many chemicals in the aquatic environment. Algal blooms are often associated with temperature increases (EPA, 1986). Water temperature affects metabolism, and thus food and oxygen needs, and regulates the ability of organisms to survive and reproduce (EPA, 1986).

Increases in temperature due to altered landscapes can lead directly to extirpation of coldwater assemblages. Warmer water affects organisms indirectly due to the inverse relationship with DO and directly through changes in growth and reproduction, egg mortality, disease rates, and direct mortality. Macroinvertebrate species have well-known tolerances to thermal changes, and community composition of macroinvertebrates is useful in tracking the effects of increasing temperature.

Fish assemblages also change with temperature. Coldwater adapted species either leave, are unable to reproduce, or die in warmer regimes. For example, when temperatures rise near 21°C (69.6 °F), other fish can have a competitive advantage over trout for the food supply (Behnke, 1992). The temperature at which fish continue to feed and gain weight is considered their functional feeding temperatures.

The limits for brown trout growth are 4-19.5 °C (39.2-67.1 °F) (Elliott & J.A., 1995); however, for egg development, brown trout need temperatures between 0 and 15 °C (0-59 °F). According to Bell (2006), brown trout may be physiologically stressed in the thermal window of 19-22°C (66.2-71.6 °F). These temperatures are near the upper metabolic limit for trout and may affect the ability to maintain normal physical function and ability to gain weight.

Brook Trout functional feeding temperatures are between 12.7°C and 18.3°C (54.9-64.9°F) (Raleigh, 1986). They can briefly tolerate temperatures near 22.2°C (71.9°F), but temperatures of 23.8°C (74.8°F) for a few hours are generally lethal (Flick, 1991). Juvenile Brook Trout density is negatively correlated with July mean water temperatures (Hinz, 1997). Growth and distribution of juvenile Brook Trout is highly dependent on temperature (McCormick et al., (1972). For more information on the causes and effects of elevated temperature, see EPA's CADDIS website at www.epa.gov/caddis/ssr_temp_int.html.

Water quality standards

The standard for Class 2B (warmwater) waters of the state is not to exceed 5°F above natural, based on a monthly average of maximum daily water temperature. In addition, this temperature metric cannot exceed the daily average of 86°F (30°C).

The state standard for temperature in Class 2A streams is "no material increase" (Minn. R. 7050.0222, subp.2).

Types of temperature data

Both grab sample (instantaneous) and/or continuous temperature data have been collected and is available in many locations depending on the watershed. Continuous data are measured at 15-minute intervals.

Sources and casual pathways for temperature

The causes and potential sources of excess temperature are modeled at EPA's CADDIS Temperature webpage.

3.2 Dissolved oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas within the water column. Adequate DO is important to growth and reproduction of aquatic life. Oxygen diffuses into water from the atmosphere (turbulent flow enhances this diffusion) and from the release of oxygen by aquatic plants during photosynthesis. DO concentrations in streams are driven by several factors.

Large-scale factors include:

- Climate
- Topography
- Hydrologic pathways

These in turn influence smaller scale factors:

- Water chemistry
- Temperature
- Biological productivity

DO concentrations change hourly, daily, and seasonally in response to these driving factors. As water temperature increases,

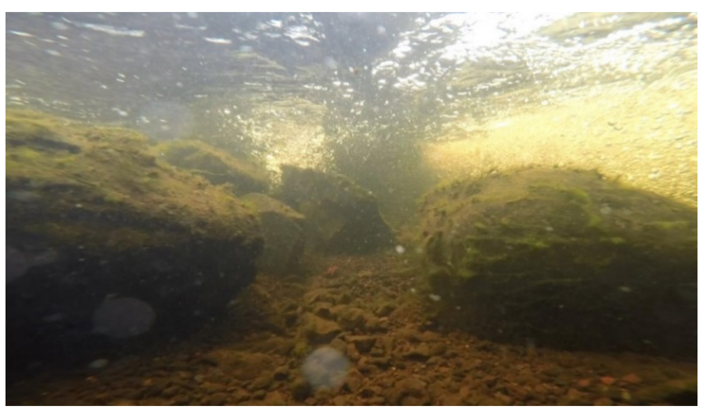


Figure 4. Oxygen diffusion within the water column

its capability to hold oxygen decreases. Low DO can be an issue in streams with slow currents, excessive temperatures, high biological oxygen demand, and/or high groundwater seepage (Hansen, 1975). In most streams and rivers, the critical seasonal conditions for stream DO usually occur during late summer when water temperatures are at or near the annual high while stream flow volumes and rates are near base flow. The critical daily period for DO is early morning, when the daily DO flux is at its minimum.

Human activities can alter many of these driving factors and change the DO concentrations of water resources. Increased nutrient content of surface waters is a common human influence, which can result in excess aquatic plant growth. This situation often leads to a decline in daily minimum oxygen concentrations and an increase in the magnitude of daily DO concentration fluctuations due to the decay of the excess organic material, increased usage of oxygen by plants at night, and their greater oxygen production during the daytime. Humans may directly add organic material by municipal or industrial effluents. These forms of pollution increase the risk of eutrophication, which can also lead to low DO.

Aquatic organisms require oxygen for respiration. Inadequate oxygen levels can alter fish behavior, such as moving to the surface to breathe air, or moving to another location in the stream. These behaviors can put fish at risk of predation, or may hinder their ability to obtain necessary food resources (Kramer, 1987). Additionally, low DO levels can significantly affect fish growth rates (Doudoroff, 1965). Fish species differ in their preferred temperature range, so alterations in water temperature (and DO) will alter the composition of fish communities.

Low DO, or highly fluctuating concentrations of DO can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975) (Nebeker, 1991). Increased water temperature raises the metabolism of organisms, and thus their oxygen needs, while at the same time, the higher-temperature water holds less oxygen. Some aquatic insect species have anatomical features that allow them to access atmospheric air, though many draw their oxygen from the water column. Macroinvertebrate groups (Orders) that are particularly stressed by low DO levels include mayflies (with a few exceptions), stoneflies, and caddisflies.

For more detailed information on DO as a stressor, see the EPA CADDIS webpage at this link.

Minnesota DO standards

The DO standard (as a daily minimum) is 5 mg/L for class 2B (warmwater) streams and 7 mg/L for class 2A (coldwater). Additional stipulations are included in this standard, detailed in the Guidance Manual for Assessing the Quality of Minnesota Surface Waters (MPCA, 2009a).

Types of dissolved oxygen data

1. **Point measurements**
   Instantaneous (one moment in time) DO data are collected and used as an initial screening for low DO reaches. Because DO concentrations can vary significantly with changes in flow conditions and time of sampling, conclusions using instantaneous measurements need to be made with caution and are not completely representative of the DO regime at a given site.
2. **Longitudinal (synoptic)**
   This sampling method involves collecting readings of DO from several locations along a significant length of the stream path in a short period of time. It is best to perform this sampling in the early morning in order to capture the daily minimum DO readings.
3. **Diurnal (continuous)**
   Continuous sampling using water quality sondes (a submerged electronic sampling device) provides a large number of measurements to reveal the magnitude and pattern of diurnal DO flux at a site.

This sampling captures the daily minimum DO concentration, and when deployed during the peak summer water temperature period, also allows an assessment of the annual low DO levels in a stream system.

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 influence the DO regime of a waterbody. Wetlands and groundwater influence can be natural sources of low DO water to a stream. 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 fluctuating DO concentrations. The conceptual model for low DO as a stressor is shown in EPA CADDIS website by following this link.

3.3 Eutrophication

Phosphorus (P), an important plant nutrient, is typically in short supply in natural systems, but human activity on the landscape often exports P to waterways, which can impact stream organisms. Nutrient sources can include:

- Agricultural runoff
- Animal waste
- Fertilizer
- Industrial and municipal wastewater facility discharges
- Non-compliant septic system effluents
- Urban stormwater runoff

Figure 5. Excessive production of algae in a stream

Phosphorus exists in several forms, with the soluble form, orthophosphorus, readily available for plant and algal uptake. While P itself is not toxic to aquatic organisms, it can have detrimental effects via other associated chemistry when levels are elevated above natural concentrations. Increased nutrients can cause excessive aquatic plant and algal growth (eutrophication), which alters physical habitat, food resources, and oxygen levels in streams. Excess plant growth increases DO during daylight hours and saps oxygen from the water during the nighttime. As plant material dies, bacterial decomposition lowers DO through absorption.

Streams dominated with submerged macrophytes experience the largest swings in DO and pH (Wilcox, 2001). Suspended algae in the water column (often measured as chlorophyll-a) also produce these effects. In some cases, oxygen production leads to extremely high levels of oxygen in the water (supersaturation), which can cause gas bubble disease in fish. The wide daily fluctuations in DO caused by excess plant growth and algae are also correlated to degradation of aquatic communities (Heiskary, 2013). Increasing primary production due to elevated nutrients can change plant species composition and cause proximate impacts to stream biology by altering food resources, altering habitat structure, or by algal toxins, in addition to higher risk for low DO situations. More information on the effects of P and related eutrophication issues can be found on EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_nut_int.html.

Water quality standards

The MPCA has developed standards for river eutrophication designed to protect aquatic life (Heiskary, 2013). River eutrophication criteria were developed for three geographic regions (Table 1). The standard is a combination of a maximum total phosphorus (TP) concentration and at least one of three related stressors above its threshold.

Table 1. River eutrophication criteria ranges by River Nutrient Region for Minnesota

Region	TP standard µg/L	Response variable		
		Chl-a µg/L	DO flux mg/L	BOD_5 mg/L
North	≤ 50	≤ 7	≤ 3.0	≤ 1.5
Central	≤ 100	≤ 18	≤ 3.5	≤ 2.0
South	≤ 150	≤ 35	≤ 4.5	≤ 3.0

Types of eutrophication data

Water samples are collected from streams and rivers throughout the state. The most common data are for TP, though orthophosphorus samples are collected in some cases. Related stressor parameters – chl-a, DO flux, five-day Biochemical Oxygen Demand (BOD_5) – are analyzed in conjunction with TP to understand potential impacts and connections.

Sources and causal pathways for eutrophication

Phosphorus is delivered to streams by wastewater treatment facilities, urban stormwater, agricultural runoff, upstream eutrophic lakes, and direct discharges of sewage. Phosphorus bound to sediments in the river channel can contribute to concentrations. Orthophosphorus is the form of P that is readily available for plant and algal uptake, and can influence excess algae suspended in the water column and submerged aquatic macrophyte growth. While orthophosphates occur naturally in the environment, river and stream concentrations may become elevated with additional inputs from wastewater treatment plants, noncompliant septic systems, and fertilizers in urban and agricultural runoff. The causes and potential sources for excess P are modeled at EPA's CADDIS Phosphorus webpage.

3.4 Flow alteration (Altered hydrology)

Flow alteration is the change of a stream's flow volume and/or flow pattern caused by anthropogenic activities, including:

- Channel alteration/Channel incision (loss of floodplain connectivity)
- Water withdrawals
- Land cover alteration
- Wetland drainage
- Agricultural tile drainage
- Impoundment

Changes in landscape vegetation, pavement, and drainage can increase how fast rainfall runoff reaches stream channels. This creates a stronger pulse of flow, followed later by decreased baseflow levels. According to the authors of a review on flow effects (Poff, 1997), "Streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems. Indeed, streamflow, which is strongly correlated with many critical physicochemical characteristics of rivers, such as water temperature, channel geomorphology, and habitat diversity, can be considered a 'master variable'..."

Reduced flow or baseflow reduction

Fish and macroinvertebrate species have many habits and traits that can either be helpful or detrimental in different flow conditions. Across the conterminous United States, (Carlisle et al, 2010) found a strong correlation between diminished streamflow and impaired biological communities. Habitat availability can be scarce when flows are interrupted, low for a prolonged duration, or extremely low, leading to decreased wetted width, cross sectional area, and water depth. Flows that are reduced beyond normal baseflow decrease living space for aquatic organisms and competition for resources increases.

Pollutant concentrations can increase when flows are lower than normal, increasing the exposure dosage to organisms. Tolerant organisms can out-compete others in such limiting situations and 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, 2012).

Changes in fish community composition are affected by species' differences in spawning behavior (Becker, 1983), flow velocity preference (Carlisle et al, 2010), and body shape (Blake, 1983). When baseflow is reduced, nest-guarding fish species increase and simple nesters, which leave eggs unattended, are reduced (Carlisle et al, 2010). Nest-guarding increases reproductive success by protecting eggs from predators and providing "continuous movement of water over the eggs, and to keep the nest free from sediment" (Becker, 1983). Active swimmers, such as the green sunfish, contend better under low velocity conditions (Carlisle et al, 2010).

Dewson et al. (2007) found the low-flow effects on macroinvertebrates were complex, and not easy to generalize. More often, the behavior called drift (using the current to be transported to a new location) increased. Many studies reported that species composition changed, and taxonomic richness generally decreased in streams experiencing prolonged low flows. Those invertebrates that filter food particles from the water column have shown negative responses to low flows. The EPA's CADDIS website (U.S.EPA, 2012) lists the responses of reduced flow as lower total stream productivity, elimination of large fish, changes in taxonomic composition of fish communities, fewer migratory species, fewer fish per unit area, and more-concentrated aquatic organisms, potentially benefiting predators.

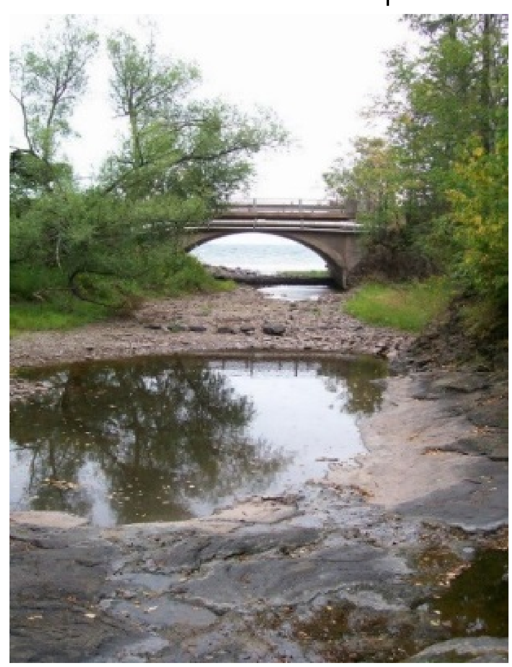


Figure 6. Stream with lack of adequate flow. Photo: Talmadge River near Duluth, MN Credit: Jesse Schomburg (MN Sea Grant)

Increased flow or channelization

Increasing surface water runoff and seasonal variability in stream flow have the potential for both indirect and direct effects on fish populations (Schlosser, 1990).

Direct effects include:

- Decreased survival of early life stages
- Potentially lethal temperature and oxygen stress on adult fish (Bell, 2006)

Indirect effects include:

- Alteration in habitat suitability
- Nutrient cycling
- Production processes
- Food availability

When flows increase, bank and bottom scouring can occur, which deepens the channel so that higher flows are now contained and no longer spill out into the floodplain. This increases the flow volume and erosive energy of water, leading to consequence such as excess sediment smothering habitat. High flows and the associated increased flow velocities can displace fish and macroinvertebrates downstream, and move habitat features like woody debris out of the stream. Woody debris and other habitat features are important as flow refugia for fish and living surfaces for clinging invertebrates. Macroinvertebrate types may shift from those species having long life cycles to shorter ones, because these species can complete their life cycle within the bounds of the recurrence interval of the elevated flow conditions (U.S.EPA, 2012). Fish species that have streamlined body forms experience less drag under high velocities and will have advantage over non-streamlined fish species (Blake, 1983).

Increased flows may directly impair the biological community or may contribute to additional stressors. Increased channel shear stresses, associated with increased flows, often cause increased scouring and bank destabilization. With these stresses added to the stream, the fish and macroinvertebrate community may be influenced by the negative changes in habitat and sediment dynamics. To learn more about flow alteration as a stressor go to the EPA CADDIS webpage here.

Water quality standards

There currently is no applicable standard for flow alteration. The standard for minimum streamflow, according to Minn. Stat. § 7050.0210, subp. 7 is:

> Point and nonpoint sources of water pollution shall be controlled so that the water quality standards will be maintained at all stream flows that are equal to or greater than the $7Q_{10}$ [the lowest streamflow for 7 consecutive days that occurs on average once every 10 years] for the critical month or months, unless another flow condition is specifically stated as applicable in this chapter.

Types of flow alteration data

Stream gaging stations are located throughout Minnesota. The outlet of each major watershed has a permanent gage that collects important long-term flow information. There are also stations at smaller scales within each watershed. The stations have differing lengths of monitoring history. If there is sufficient monitoring data, detailed hydrologic analysis can be used to help analyze for flow alteration. In addition, hydrologic models can be used to predict flows in a watershed or subwatershed when measured data are not available. An indirect determination of flow alteration can be found via geomorphological measurements, as channel form and dimensions are related to flow volumes. Information regarding the extent of tile drainage, altered watercourses, wetland storage, and water appropriations (surface and groundwater) are also used to analyze for flow alteration impacts in a watershed.

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.

3.5 Total suspended solids

Sediment and turbidity are among the leading pollutant issues affecting stream biological impairment in the United States (U.S.EPA, 2012). Recent studies in Minnesota have demonstrated that human activities on the landscape have dramatically increased the sediment entering streams and rivers since European settlement (Triplet, 2009) and (Engstrom, 2009). Sediment can come from land surfaces such as exposed soil or from unstable streambanks. The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently-vegetated pastures. Human actions on the landscape, such as channelization of waterways, riparian land cover alteration, and increased impervious surface area can cause stream bank instability leading to sediment input from bank sloughing. Although sediment delivery and transport are an important natural process for all stream systems, sediment imbalance (either excess suspended sediment or lack of sediment) can be detrimental to aquatic organisms.

Figure 7. Elevated TSS concentrations on North Shore Lake Superior tributary during spring snowmelt. Flute Reed River near Hovland, Minnesota.

As described in a review by Waters (1995), excess suspended sediments harm aquatic life through two major pathways:

- Direct physical effects on biota such as abrasion of gills, suppression of photosynthesis, and avoidance behaviors
- Indirect effects such as loss of visibility and increase in sediment oxygen demand

Elevated TSS concentrations can reduce the penetration of sunlight and can thwart photosynthetic activity and limit primary production (Munawar et al, 1991); (Murphy et al, 1981). Sediment can also increase water temperature, as darker (turbid) water will absorb more solar radiation.

Organic particles, including algae, can also contribute to TSS. Determining the type of suspended material (mineral vs organic) is important for proper conclusions about the stressor and source (erosion vs. nutrient enrichment vs. a wastewater discharge). Elevated total suspended volatile solids (TSVS) concentrations can impact aquatic life in a similar manner as suspended sediment, with the suspended particles reducing water clarity. Unusually high concentrations of TSVS can indicate excess nutrients (causing algal growth) and an unstable DO regime. More information on sediment effects can be found on EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_sed_int.html.

Water quality standards

The new TSS standard in Minnesota is stratified by geographic region and stream class due to differences in natural background conditions resulting from varied geology and biological sensitivity. There is currently no standard for TSVS in Minnesota.

Table 2. TSS standard concentrations by region

Region	TSS mg/L	Secchi tube surrogate*
North	15	40 cm
Central	30	25 cm
South	65	10 cm
Coldwater	10	55 cm

**shown here for comparison to the TSS standard*

Types of suspended sediment data

Particles suspended in the water column can be either organic or mineral. Generally, both are present to some degree and measured as TSS. TSS is determined by collecting a stream water sample, filtering it, and weighing it to determine the concentration of particulate matter in the sample. To determine the mineral component of the suspended particles, a second test is run using the same procedure except the organic material is burned off in an oven before weighing the remains, which are only mineral material.

Secchi tubes can also be used to help understand suspended sediment concentrations in streams. The secchi surrogate values for TSS are shown in Table 2.

Sources and causal pathways model for suspended sediment

High TSS occurs when heavy rains fall on unprotected soils, dislodging the soil particles, which are transported by surface runoff into the rivers and streams (MPCA and MSUM, 2009b). The soil may be unprotected for a variety of reasons, such as construction, mining, agriculture, or insufficiently vegetated land. Decreases in bank stability may also lead to sediment loss from the streambanks, often caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration, increases in impervious surfaces, and tile drainage. Part of the increased TSS at higher flows is due to resuspension of deposited sediment, which will be worse when streams have received excess sediment from banks and uplands.

Rangeland and pasture are also common landscape features in Minnesota. In some areas, the riparian corridor has been cleared for pasture and is 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 can increase the quantity and severity of bank erosion. The same effects can occur when residential yards are maintained to the edge of the stream channel. Additional causes and potential sources for increases in sediment are modeled at EPA's CADDIS Sediments webpage.

3.6 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 such as sediment, flow and DO.

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, refuge, and/or reproduction (Newcombe & MacDonald, 1991).

Figure 8. Brook trout require clean, course substrate for spawning. Photo: Knife River near Knife River, MN

Aquatic macroinvertebrates are generally affected in several ways:

- Loss of certain taxa due to changes in substrate composition (Erman, 1988)
- Increase in "drift" (an avoidance behavior) due to sediment deposition or substrate instability (Rosenberg & Wiens, 1978)
- Reductions in the quality and abundance of food sources such as periphyton and other prey items (Peckarsky, 1984)

Fish communities are typically influenced through:

- Reduction in spawning habitat or egg survival (Chapman, 1988)
- Reduction in prey items as a result of decreases in primary production and benthic productivity (Bruton, 1985); (Gray & Ward, 1982)

Specific habitats needed by a healthy biotic community can be minimized or altered by practices on the landscape by way of resource extraction, agriculture, forestry, 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). 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 because eggs become smothered by sediment and become oxygen deprived. Habitat can also be affected through direct stream projects like removing large woody debris from stream channels, which used to be a common practice. Large woody debris is important in creating habitat by causing scour pools, providing cover for fish, creating pockets of protection from faster currents, and providing a living surface for macroinvertebrates that cling to hard objects (Gurnell, 1995); (Cordova, 2007); (Magilligan F.J., 2008).

Degraded physical habitat is a leading cause of impairment in streams on 303(d) lists. According to the EPA CADDIS website, a stream provides six main features of physical habitat structure:

1. Stream size and channel dimensions
2. Channel gradient
3. Channel substrate size and type
4. Habitat complexity and cover
5. Vegetation cover and structure in the riparian zone
6. Channel-riparian interactions

Just like for terrestrial settings and those animals, aquatic population and community changes can result from decreases in availability or quality of habitat by way of altered behavior, increased mortality, or decreased reproductive success (U.S.EPA, 2012). To learn more about physical habitat go to the EPA CADDIS webpage here.

Water quality standards

Since habitat is a physical measurement, there is no water quality standard. Other measures are used to understand physical habitat limitations.

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 such as channel development, depth variability, and substrate types and conditions. These habitat metrics can then be compared for similar streams.

MPCA and Minnesota Department of Natural Resources (DNR) partners are collecting stream channel dimension, pattern and profile data at select stream locations of various sizes and biological condition. These 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. The applied river morphology method created by (Rosgen, 1996) is the accepted method of data collection by the MPCA and DNR.

Deposited sediment is visually estimated by measuring the degree to which fine material surrounds rock or woody substrate within the channel (embeddedness). Deposited sediment is also analyzed by randomly measuring numerous substrate particles (pebble count) and calculating the 50^{th} percentile particle size (D_{50}).

Sources and causal pathways for 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, urbanization, and industry can contribute to increased sedimentation, via increased erosion for example, and changes in discharge patterns, such as increased stormwater runoff and point effluent discharges. These land use activities can also lead to decreases in streambank 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 streams 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, such as increasing the prevalence of run habitats, decreasing riffle habitats, and increasing or decreasing pool habitats.

Typically, physical habitat degradation results from reduced habitat availability, such as decreased snag and riffle habitats, or reduced habitat quality, such as increased fine sediment cover. Bedded sediments are closely related to suspended sediments. Decreases in bank stability lead to sediment loss from the streambanks, causing sediment loads in the water column, and deposition on the stream bed. Bank instability is often caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration, and increases in impervious surfaces. 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. The narrative and conceptual model can be found on the EPA CADDIS webpage here.

3.7 Connectivity

Connectivity in river ecosystems generally refers to how water features are linked to each other on the landscape or how locations within a stream are connected. Connectivity also pertains to locations adjacent to a stream, such as a stream's connectivity to its floodplain. These different types of connectivity affect biology differently, do not often produce the same effects, and often times are linked to other stressors like habitat.

Longitudinal and vertical connectivity

Humans can alter the degree of connectivity within stream systems. In Minnesota, there are more than 800 dams on streams and rivers for a variety of purposes, including flood control, maintenance of lake levels, wildlife habitat, and hydroelectric power generation. Dams change stream habitat by altering streamflow, water temperature, and sediment transport (Cummins M.J., 1979), (Waters, 1995). Dams also directly block seasonal fish migration for reproduction and overwintering. Disrupted migration not only alters 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 the abundance of tolerant or undesirable species (Winston, 1991), (Santucci V.A., 2005).

DNR has conducted numerous dam removal projects in recent years, which have demonstrated benefits to fish populations. A more detailed presentation of the effects of dams on water quality and biological communities can be found in the DNR publication "Reconnecting Rivers: Natural Channel Design in Dam Removals and Fish Passage" (Aadland, 2010).

Figure 9. A perched culvert disrupting flow and fish passage on a North Shore Lake Superior tributary. Photo: Fredenberg Creek near Schroeder, MN

Culverts at road crossings can also be significant barriers to fish passage if they are installed or sized incorrectly. Culverts can be perched above the downstream water level, have too high an angle, resulting in high velocity flow which many species cannot traverse, or be undersized for the stream size, which also results in high velocity within the culvert. An excellent review of studies regarding culvert impacts to fish migration, including information specifically from Minnesota, has been conducted by the Minnesota Department of Transportation (MNDOT, 2013).

Vertical (floodplain) connectivity

Lateral connectivity represents the connection between a river and its floodplain. The degree to which lateral connectivity exists is both a time-dependent phenomenon (Tockner, 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 streams to access their floodplains (Weclomme 1979, McKeown 1984, Scheimer 2000). When a stream 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. These changes can be connected to other stressors, such as suspended sediment and habitat.

Water quality standards

There is no applicable water quality standard for connectivity impacts, though new design guidelines for culverts have been developed by Minnesota Department of Transportation for fish passage http://www.dot.state.mn.us/research/TRS/2013/TRS1302.pdf.

Types of physical connectivity data

Locations for dams are available from the DNR GIS coverage. Culvert surveys are conducted by the MPCA and DNR to determine their passage capability. Stream survey data can also indicate the degree of incision, which shows the degree of floodplain connectivity. With high degree of incision there is an associated high rate of bank failure due to increased sheer stress.

3.8 Specific conductance and ionic strength

Specific conductance refers to the collective amount of ions in the water. In general, the higher the level of dissolved minerals in water, the more electrical current can be conducted through that water. Dissolved salts and minerals occur naturally in surface waters, and biota are adapted to a natural range of ionic strengths. Aquatic organisms maintain a careful water and ion balance, and can become stressed by an increase in ion concentrations (SETAC (Society of Environmental Toxicology and Chemistry), 2004). Ions of many elements, such as calcium, sodium, and magnesium are necessary for aquatic health, but imbalances can be toxic.

Water quality standards

There is no aquatic life standard for specific conductance in Minnesota.

A standard of 1,000 µmhos/cm at 25 °C exists for Class 4 waters of the state (Minn. Stat. 7050.0224 subp. 2) that is protective of agricultural and irrigation uses, but is not an aquatic life standard.

Types of specific conductance or ionic strength data

Like other water quality parameters, specific conductance readings can be collected by deployed devices at defined time intervals, or a single, instantaneous reading taken during a site visit. Elevated conductivity can serve as a surrogate or indicator for ions in the water, such as chloride or sulfate.

Sources and causal pathways for specific conductance and ionic strength

Industry runoff and discharges, road salt, urban stormwater drainage, agricultural drainage, wastewater treatment plant effluent, and other point sources can increase ions in downstream waters. The causes and potential sources for ionic strength are modeled at EPA's CADDIS Ionic strength webpage.

3.9 pH

Acidity is measured on a scale called pH, ranging from 0 to 14. A pH of 7 is considered neutral; less than 7 is acidic, and greater than 7 is basic. Some geological material produces naturally high hydrogen ions that can leach into surface water. Photosynthesis from unnaturally-abundant plants or algae removes carbon dioxide from the water, causing a rise in pH. As pH increases, unionized ammonia (the toxic form of ammonia) increases, and can reach toxic concentrations (U.S.EPA, 2012). High or low pH effects on biology include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Values of pH outside the range of 6.5 - 9 or highly fluctuating values are stressful to aquatic life (U.S.EPA, 2012). For additional information on pH as a stressor, see EPA's CADDIS webpage: http://www.epa.gov/caddis/ssr_ph_int.html#highph.

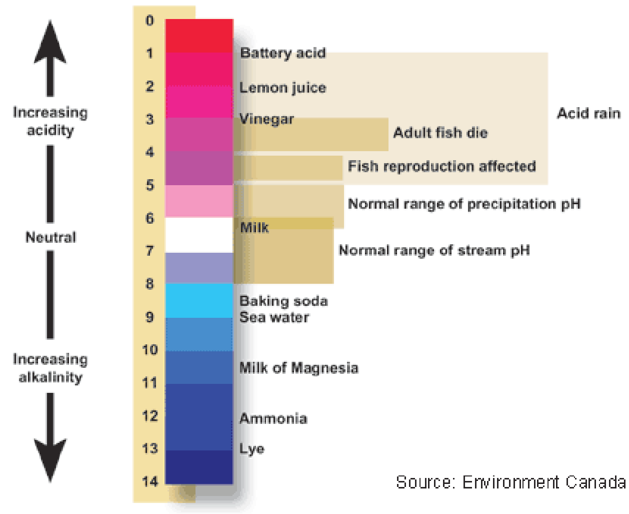


Figure 10. pH ranges of common liquids

Water quality standards

The pH standard for Class 2B (warmwater) streams is within the range of 6.5 as a daily minimum and 9.0 as a daily maximum (MN Statute 7050.0222 subp. 4).

The pH standard for Class 2A (coldwater) streams is within the range of 6.5 as a daily minimum and 8.5 as a daily maximum (MN Statute 7050.0222 subp. 4).

Types of pH data

Like DO, pH readings can be collected by deployed devices at defined time intervals, or a single, instantaneous reading taken during a site visit.

Sources and causal pathways for pH

Human effects on pH values can result from agricultural runoff, urbanization, and industrial discharges. Some geology has naturally high hydrogen ions that can leach into surface water, but it would be rare for this to be the only cause. Photosynthesis of overabundant macrophytes and algae can remove carbon dioxide from the water, causing a higher pH. Effects on biology include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Concentrations of nutrients (especially nitrogen) also play a significant part in pH dynamics, as nitrification and respiration both produce hydrogen ions (U.S.EPA, 2013). The conceptual model for pH as a candidate stressor is modeled at EPA's CADDIS pH webpage.

4.0 Methods & data analysis tools

4.1 Water temperature

Water temperature is a critical factor in shaping the distribution, abundance, and species composition of stream fishes, particularly salmonids. Many of the fish and macroinvertebrate species that serve as indicators of healthy coldwater (trout stream) habitats are extremely sensitive to changes in water temperatures and possess life history traits (feeding, reproduction, physiological processes) that are highly dependent on colder thermal regimes. These species are classified as *coldwater obligate* species. The presence/absence and abundance of these species factor heavily into fish and macroinvertebrate IBI metrics and overall IBI scores. Examples of coldwater obligate fish taxa sampled in the Lake Superior South Watershed are listed in Table 3. Also included in this table are several fish taxa often sampled from marginal coldwater streams. Several of these species also count favorably in coldwater fish IBI calculations.

Table 3. Fish species included in various coldwater IBI metrics used by MPCA

Common name	Thermal class metric	Status in Lake Superior South 8HUC
Brook Trout	Cold (Coldwater Obligate)	Abundant
Mottled Sculpin	Cold (Coldwater Obligate)	Abundant
Rainbow Trout	Cold (Coldwater Obligate)	Common
Slimy Sculpin	Cold (Coldwater Obligate)	Rare
Finescale Dace	CWSensitive (sensitive species found in coldwater streams)	Common
Longnose Dace	CWSensitive (sensitive species found in coldwater streams)	Common
Longnose Sucker	CWSensitive (sensitive species found in coldwater streams)	Rare
Pearl Dace	CWSensitive (sensitive species found in coldwater streams)	Common

Thermal tolerance & temperature values

All aquatic organisms are linked to specific thermal regimes; yet, the vast majority of the research on this topic has focused on salmonid species. The specific criteria used most to evaluate thermal regime suitability in this report are based on Brook Trout, which are the only native stream trout species in Minnesota and serve as an excellent indicator of stream and watershed health. Water temperature suitability for Brook Trout is a complex subject and many factors can significantly affect the suitability of a given stream reach for supporting this species. Examples include the duration/magnitude of exposure to given temperatures, habitat patchiness and thermal refuge areas, main stem and tributary connectivity, and local habitat characteristics (esp. pool depths).

MPCA biologists are in the process of testing several models to predict the presence and abundance of coldwater indicator species (e.g. Brook Trout) based on continuous temperature and biological data (Sandberg and Dingman, 2016, personal comm.). The temperature criteria used in these models are based on the classifications of “growth,” “stress,” and “lethal” temperature ranges commonly used by MPCA, DNR, and other water resource professionals (Table 4). Two temperature metrics emerged from the analysis as relatively strong predictors Brook Trout presence and abundance; *% Growth* (percent of temperature readings in the growth range) and *Summer Average Temperature* (mean temperature recorded between June 1 – August 31). These models were based on statewide paired temperature/biological data, and four groupings were defined in the data set (Areas 1-4) to develop generalized predictions of presence/absence and abundance (i.e. Brook Trout almost always present and in good numbers; Brook Trout may be present, generally in low numbers). These models are still in development, but a similar approach was used in this report to summarize the relationships between stream temperature data and biological metrics (see Section 4.1).

Table 4. Thermal criteria used by DNR and MPCA for Brook Trout growth, stress, and lethal temperature ranges

Classification	Temperature range (°C)	Description
Growth	7.8 to 20.0 °C	Temperature range favorable for growth
Stress	>20.0 to 25.0 °C	Stress and avoidance behaviors
Lethal	>25.0 °C	Mortality can be expected at prolonged exposure

Thermal classification of North Shore coldwater streams

Unlike the spring-fed trout streams of the southeast Minnesota Driftless Area, the hydrographs (stream flow patterns) of many northeastern Minnesota coldwater streams are heavily influenced by overland runoff, with many streams lacking a significant groundwater contribution. Although there are many miles of designated trout streams in this region, a good portion of them offer marginal habitat. This is particularly true in the stream reaches closer to Lake Superior, which often lack cover for fish and are dominated by bedrock substrate which tends to be biologically unproductive and also inhibits groundwater upwelling. Still, healthy population of Brook Trout, Sculpin sp., and other sensitive coldwater species are found in these areas if colder water and ambient air temperatures persist throughout the year.

Given the unique qualities of northeast (NE) Minnesota trout streams, a separate analysis of temperature and biological response metrics was completed. The approach used was similar to models developed by MPCA (Sandberg and Dingman, unpublished 2016), but instead of a statewide data set, stations were limited to Lake Superior South and Lake Superior North 8HUC watersheds. The data used were collected during the monitoring seasons of 2011, 2013, and 2015. In all, a total of 128 paired stream temperature and biological monitoring data points were scatter-plotted as *% Growth* vs. *Summer Average Temperature* to observe the range of coldwater stream conditions among North Shore coldwater streams. Several biological metrics, *% Brook Trout (% BKT)* and *% Coldwater* (percent of fish community comprised of "coldwater" individuals) were also incorporated into the analysis to observe relationships between temperature regime and biological response (Figures 11 and 12).

Four temperature regime categories were developed based on visual interpretations of the scatterplot results (Figures 11 and 12). Additional work is needed to justify these groupings based on statistical measures, but our objective was to stratify the results sufficiently enough for identifying general trends among North Shore data and offering a broader regional perspective on whether or not thermal conditions in the Beaver and Talmadge River Watersheds are stressful for coldwater biota. The four categorizes are described based on stream temperature measures and biological condition in Table 5.

Table 5. Four temperature regime categories developed based on visual interpretations of the scatterplot results of North Shore trout streams with temperature/fisheries data

Grouping	% temperature reading in Brook Trout growth range	Summer average temperature (C)
Area 1	90 – 100%	<17 C
Area 2	80-89%	16 – 18 C
Area 3	60-79%	17 – 20 C
Area 4	<60%	>19 C

Grouping	Description
Area 1	Brook Trout and coldwater species sometimes present, more often a mix of cool and warmwater taxa
Area 2	Can support Brook Trout and other coldwater species, often a mix of cold, cool, and warmwater taxa
Area 3	Frequently supports Brook Trout and other coldwater species, lower relative densities
Area 4	Almost always support high relative densities of Brook Trout and coldwater species

Brook Trout and other coldwater species were present at some stations in all four thermal categories, which highlights the difficulty in definitively predicting fish communities based on data from a single temperature monitoring point per reach. For example, two Brook Trout were sampled at Caribou Creek station 13LS016 in 2013, which fell into Area 1 with 42% of temperature readings in the growth range and a summer average temperature of nearly 21° C. Based on the scatterplot in Figure 11, this station should have the lowest potential to support Brook Trout of the 128 data points evaluated. Similar results can be seen in Area 1 and Area 2 of the graph in Figure 11 and 12. Localized groundwater inputs, high quality physical habitat, and access to cold tributary streams may explain why several of these stations do not agree with the overall trend.

Despite some variable results, a clear trend is apparent, with stable, cold stream temperatures resulting in a greater probability of supporting Brook Trout and other coldwater species. Ninety-five percent (20 of 21) stations included in “Area 4” (>90% temperature in BKT growth range & summer average temperature < 17 C) supported BKT and most stations had relatively high densities of that species. The majority (76% or 22/29) of stations within “Area 3” also supported Brook Trout, with slightly lower densities compared to most “Area 4” stations (Figure 11). The grouping of stations within “Area 2” shows a high level of variability, with 33 of 54 stations (62%) of them supporting Brook Trout. The stations in “Area 1” were more likely than not to be devoid of Brook Trout, and if trout were present, populations were very low. Overall, these classifications provide a broad perspective of the coldwater thermal regimes of North Shore streams and are one tool of many available to classify streams and evaluate their suitability to support coldwater species. Refer to Sections 5.3.1 (Beaver River) and 6.2.1 (Talmadge River) for a detailed evaluation of water temperature as a stressor to aquatic life in the impaired streams of the Lake Superior South watershed.

Brook Trout will move a fair distance to avoid thermal stress. It is important to note that much of the data collected for thermal regime analysis are localized observations and are not recorded year-round. The data presented here provide a broad overview of thermal conditions in many North Shore streams, but in-depth monitoring of select sub-watersheds is critical for identifying thermal refuge areas and potential fish migration patterns throughout the year.

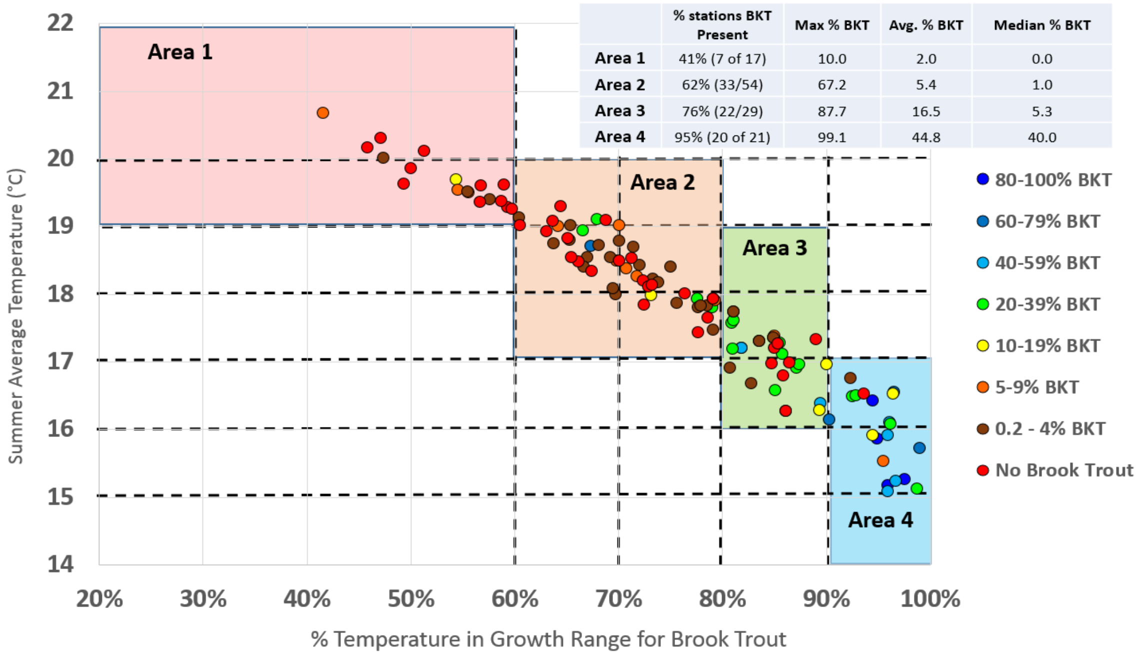


Figure 11. Scatter-plot of summer average temperature vs % of time temperature within Brook Trout growth range. Marker colors correspond to relative densities of Brook Trout sampled. Data include all Lake Superior South/Lake Superior North 8HUC stations with biological and temperature data from same season.

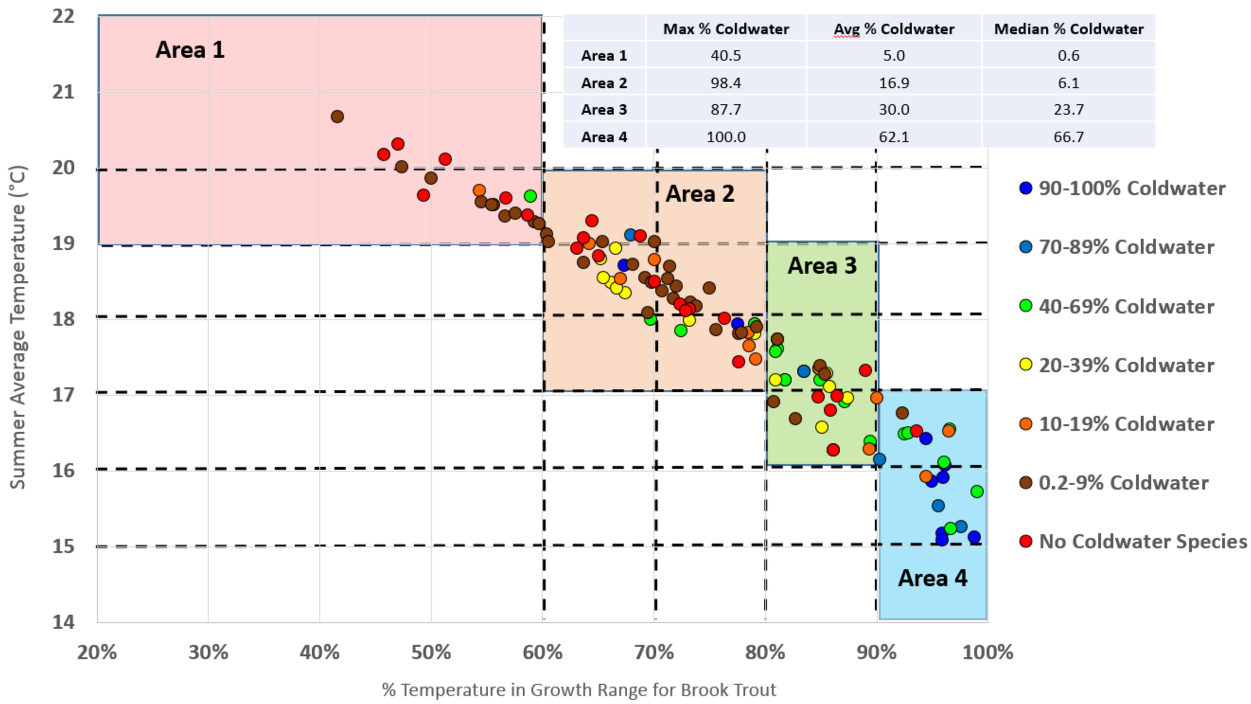


Figure 12. Scatter-plot of summer average temperature vs % of time temperature within Brook Trout growth range. Marker colors correspond to relative densities of coldwater individuals sampled. Data include all Lake Superior South/Lake Superior North 8HUC stations with biological and temperature data from same season.

4.2 Habitat and stream channel stability

Physical habitat and channel stability conditions were evaluated using three methodologies; the MSHA protocols, the Brook Trout Suitability Assessment (BTSA), and the Pfankuch Stability Index (PSI). Results from these three assessments were compiled to determine whether poor habitat conditions and channel instability were contributing to biological impairments.

MPCA Stream Habitat Assessment

MPCA biological survey crews conduct a qualitative habitat assessment using the MSHA protocol for stream monitoring sites. MSHA scores can be used to review habitat conditions such as channel development, depth variability, and substrate types and conditions. MSHA scores for stations within the Lake Superior South and Lake Superior North 8HUC Watersheds were compiled and converted into an "A-F" grading scale to represent the range of habitat conditions found within in the region. Percentile values were used to develop the grading scale for each metric and total scores. An example of this conversion is shown in Figure 13. Comparing MSHA results on a regional scale is helpful for identifying "reference conditions," which provide a benchmark that can be used to evaluate potential stressors related to physical habitat.

Percentile	Channel Morphology Score	Rating	Count
max	36	A	113
90th	31		
80th	28	B	218
70th	27		
60th	25	C	350
50th	23		
40th	21		
30th	19.7	D	190
20th	17		
10th	14	F	179
Min	1		

Figure 13. Example of MSHA metric (Geomorphology) broken into deciles and corresponding letter grades

Brook Trout Suitability Assessment

The Brook Trout Suitability Assessment (BTSA) is a modification of an assessment developed by Bidelspach (n.d.) used to assess and rank trout habitat in Colorado. The BTSA is a rapid, semi-quantitative assessment of 25 variables related to trout habitat. A review of scientific literature led to several modifications that are more pertinent to Brook Trout survival and growth. Data from Rosgen Level II/Level III surveys (Rosgen, 1996) and field observations were factored into the BTSA assessments within impaired watersheds and at numerous "reference" stations throughout the region. BTSA results from stations located on impaired stream reaches were compared to results from high quality "reference" stations to screen for habitat related stressors. A summary of the BTSA parameters, scoring system, and results in included in Appendix A.

Pfankuch Stability Index

The PSI is a rapid, semi-quantitative assessment of stream channel stability and floodplain connectivity. PSI metrics focus on three major areas, upper streambanks, lower streambanks, and channel bottom (substrate). Metric scores are combined to generate an overall score and stability rating of "unstable", "moderately unstable", or "stable". PSI stability ratings are further stratified by Rosgen stream type (Rosgen, 1996) due to the inherent differences in their resiliency to disturbance. The PSI assessments proved to be useful for evaluating channel stability on a watershed and reach scale during the course of the Stressor ID project. For a complete list of PSI results by station, refer to Appendix A.

4.3 Stable isotopes and hydrology

Stable isotopes of oxygen and hydrogen have been used to identify source waters to surface water and infer the relative contributions to surface water from ground water, soil water, and precipitation (Rodhe, 1987; De Walle et al., 1988; McDonnell et al., 1991; Wels, et al., 1991; and Harris et al., 1995). Isotopes can quantitatively and qualitatively describe mixing and track variability throughout seasons. Results for isotopes Oxygen-18 and Deuterium (Hydrogen-2) are reported in delta (δ) notation in units of ‰ relative to Vienna Standard Mean Ocean Water (VSMOW), [$\delta = (R_{sample}/R_{VSMOW} - 1) \times 1000$], where R_{sample} is the isotope ratio ($^{18}O/^{16}O$, $^{2}H/^{1}H$) of the sample and R_{VSMOW} is the isotope ratio of the standard (Schultz et al., 2011). A positive δ-‰ value indicates that the sample has more of the heavy isotope (^{18}O or ^{2}H) than the standard and a negative δ-‰ value signifies that the sample has less of the heavy isotope (^{18}O or ^{2}H) than the standard (Kendall, C. and Caldwell, 1998). A value that is more positive or negative than a reference value is described as being respectively enriched or depleted.

The global meteoric waterline ($\delta^2H = 8.17 * \delta^{18}O + 11.27$), developed by Craig (1961) defines a linear relationship between $\delta^{18}O$ and δ^2H in waters derived from precipitation worldwide however this relationship can vary geographically. A local meteoric waterline (LMWL; $\delta^2H = 8.4\ \delta^{18}O + 15.5$), developed by Jasperson (2016), defines this linear relationship for Duluth, Minnesota. Environmental conditions affecting where individual rain and snow samples fall on meteoric waterlines include air temperature, altitude, storm system origin, and amount of time that precipitation has been falling.

The position of surface waters on the LMWL is influenced by mixing of source waters including surface runoff, groundwater, and surface waters of streams, lakes, and wetlands. Surface waters that have undergone evaporation become enriched in $\delta^{18}O$ and δ^2H (Craig and Gordon, 1965; Gonfiantini, 1965). This is the result of lighter isotopes more easily entering the vapor phase and the heavier isotopes concentrating in the liquid phase. The enriched waters tend to stray from the LMWL, falling along a local evaporative line (LEL) that has a slope in the range of 4 to 6. As the fraction of water lost to evaporation increases, points increasingly and proportionately plot to the right, showing more enrichment. Evaporative losses are typically observed in streamflow where source waters have a net loss to evaporation through exposure to the atmosphere. Example source waters include flooded wetlands, shallow lakes, and stream impoundments. Less evaporative loss is expected in streamflow dominated by saturated wetlands and groundwater springs because the water has less exposure to the atmosphere.

In a precipitation-driven watershed, the intersection of the LMWL and LEL (inflow value) represents the weighted mean annual precipitation (inflow value) in a given area. An aquifer that integrates annual precipitation over several years will have a small range of values near the inflow value; whereas, stream or pond water will likely have a larger range due to the mixing of groundwater with precipitation inputs (Brooks, et al., 2013). Groundwater-dominated stream water will tend to have less evaporative losses, a tighter range, and greater inter-annual consistency than precipitation-driven streamflow.

4.4 BANCS model for streambank erosion estimates

BANCS (Bank assessment for non-point source consequences of sediment) model assessments are designed to predict stream bank erosion rates. The model uses two tools for estimating bank erosion: the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS). Characteristics of individual stream banks (Figure 15) and the distribution of energy and shear stress in the water (Figure 14) can be used to estimate an erosion rate in ft/yr using an empirically-derived curve relating BEHI and NBS (the curve used in this analysis was developed in Colorado, although recent work has been done to develop a North Shore curve. (See Lake Superior North Stressor Identification Study). The estimated erosion rate is then multiplied by the length and height of the bank to get a sediment load in cubic feet per year or, when multiplied by the density of soil, tons per year.

Additional information on this methodology can be found in *Watershed Assessment of River Stability and Sediment Supply (WARSSS)* (Rosgen, 2006).

Methods for Estimating Near-Bank Stress (NBS):
(1) Channel pattern, transverse bar or split channel/central bar creating NBS (Level I)
(2) Ratio of radius of curvature to bankfull width (Level II)
(3) Ratio of pool slope to average water surface slope (Level II)
(4) Ratio of pool slope to riffle slope (Level II)
(5) Ratio of near-bank maximum depth to bankfull mean depth (Level III)
(6) Ratio of near-bank shear stress to bankfull shear stress (Level III)
(7) Velocity profiles/Isovels/Velocity gradient (Level IV)

Converting Values to a Near Bank Stress Rating Using Method (1):
Transverse and/or central bars-short and/or discontinuous → High/Very High
Extensive deposition (continuous, cross-channel → Extreme
Chute cutoffs, down-valley meander migration, converging flow → Extreme

Figure 14. Methods for field determination of NBS used in the BANCS model. Field-based data for methods #1 and #2 were used in the Beaver River and Talmadge River assessments.

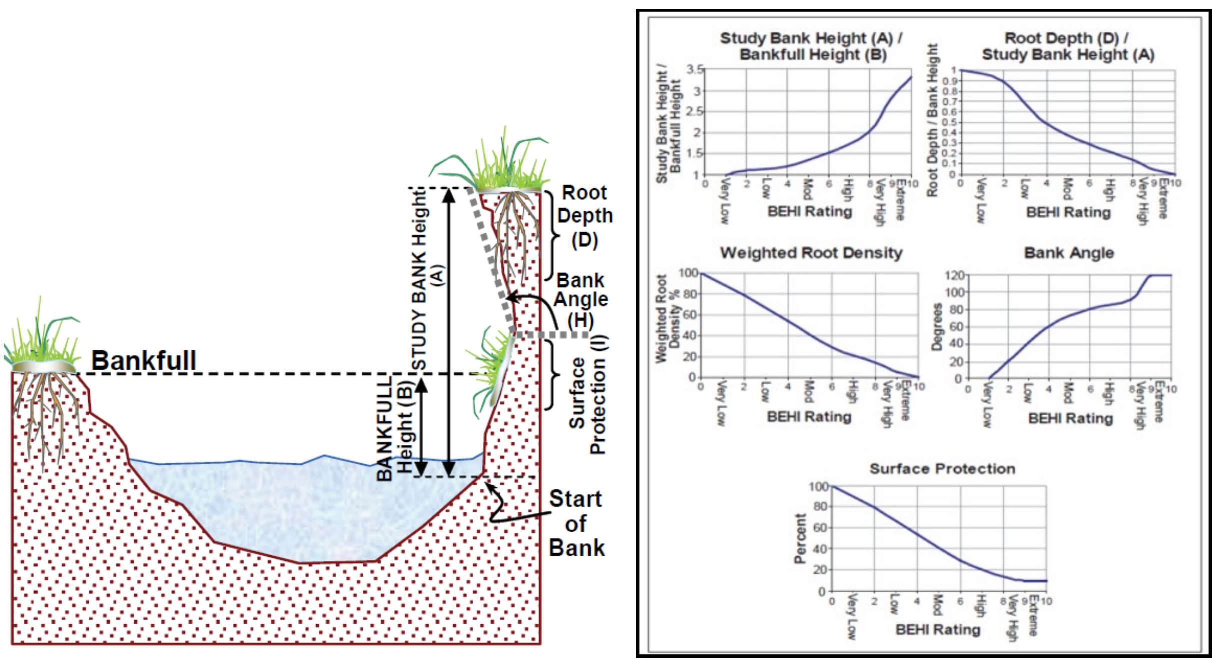


Figure 15. Bank parameters collected in the field (left) and scoring system to develop BEHI rating (right)

4.5 Tolerance indicator values

The MPCA biological monitoring staff has developed a set of tolerance indicator values (TIV) as a guidance for how tolerant various fish and macroinvertebrate taxa are to certain stressors. The TIV are calculated using the abundance weighted average of each taxon that is present in conjunction with water quality of physical conditions. For example, Central Mudminnow is a very tolerant fish species that has been observed as the dominant fish species in many streams with low DO conditions in Minnesota. As a result, this species has a TIV value for DO that indicates a very high tolerance to low DO. Each individual species is assigned a TIV value for a given stressor. Community level TIV have also been developed, which is calculated using the abundance weighted average of the tolerance values of each taxon at a station.

This report uses TIV values for the following parameters: TSS, DO, specific conductivity, nitrate, and chloride. The specific TIV values for fish and macroinvertebrate taxa of Minnesota can be provided upon request.

5.0 Beaver River

5.1 Watershed overview

The Beaver River watershed drains an area of 135 square miles in Lake County, Minnesota. Several major tributary streams enter the Beaver River, namely the West Branch Beaver River (9 square miles), Big Thirtynine Creek (24 square miles) and East Branch Beaver River (50 square miles). Notable minor tributary streams include Kit Creek, Little Thirtynine Creek, and Cedar Creek, which drains a series of lakes in the NE region of the watershed. Like the majority of streams along the North Shore, the Beaver River watershed is predominantly underlain with deposits of glacial soil, with a strip of sand, gravel, clay, and bedrock outcroppings closer to Lake Superior.

The Beaver River enters Lake Superior at the town of Beaver Bay, which is the oldest continuously occupied community on the Minnesota North Shore. The town was established in 1856 and first populated by German immigrants who constructed cabins near the mouth of the river and cleared land to build roads, grow crops, and raise cattle. These early endeavors were followed shortly after by a commercial sawmill, a grist mill, and a tannery. The Wieland Brothers sawmill became a large supplier of lumber to the region, delivering much of the material used during Duluth's population boom in the 1860's. The sawmill was eventually sold as large lumber companies began to clear cut the North Shore in the 1890's.

Throughout its early history, the area around Beaver Bay was frequented by Ojibwe affiliated with local tribes who hunted, fished, and trapped at the mouth of the Beaver River. Many Ojibwe played an influential role in settling the area – teaching immigrants how to live off the land and survive the harsh winter seasons. Chief Moquabimetem's ("Beargrease") son Eshquebe (known as John) was raised in Beaver Bay and delivered mail along the North Shore by canoe or dogsled. Today, the John Beargrease Sled Dog Marathon is an annual event that caries his namesake and follows many of the historic mail routes. As highway 61 opened along the North Shore, the community of Beaver Bay shifted its focus to becoming a tourist town. Several shops, restaurants, and lodges are still operating today.

In 1980, another prominent chapter in the history of this watershed occurred as Reserve Mining Company was ordered to stop discharging taconite tailings directly into Lake Superior. Reserve Mining began operations in Silver Bay in 1955 as a taconite pellet processing facility for iron ore mined in Minnesota's Iron Range. For every ton taconite pellets produced by the facility, two tons of waste rock (called "tailings") was left over. Over a 25-year period, as much as 67,000 tons per day of untreated tailings were discharged directly into Lake Superior under a permit issued to the facility from the State of Minnesota, forming a large delta of waste rock extending nearly a half mile into the lake (Figure 17). Other environmental concerns surfaced, including several related to the public health of area residents, and Reserve Mining was ultimately forced to cease this discharge in 1980 as part of an order issued by a federal judge.

Reserve Mining eventually continued operations by shifting the disposal of tailings from Lake Superior to an inland retention pond several miles from Lake Superior. Coarse tailings are sent by rail to the Milepost 7 tailings basin where they are used to build and maintain dams that contain the basin. The fine tailings are sent in a slurry form and deposited in the same basin via an above ground pipeline. Water from the tailings basin is either recycled and used again by the facility or treated by an on-site wastewater treatment plant and discharged to the Beaver River under a National Pollutant Discharge Elimination System and State Disposal System (NPDES/SDS) permit.

The construction of the Milepost 7 tailings basin altered the course of several major tributaries to the Beaver River (see more on this in Section 5.3.7). Other than this major shift in drainage pattern, the presence of the Milepost 7 basin in the watershed has caused few major environmental issues. One exception is a pipeline break on October 23, 2000, which spilled approximately 14,000 tons of tailings slurry, with substantial amounts flowing into the Beaver River through a nearby gully. Observations by DNR and MPCA staff following the spill revealed significant deposition of tailings slurry on stream substrates and extremely turbid water conditions. DNR and MPCA staff responding to the spill reported significant impacts to fish and macroinvertebrates and potential loss of spawning habitat (DNR Report, 2000). This spill highlights the risks involved with mining practices in this watershed, although it is highly unlikely that there are any connections between the 2000 spill and the current biological impairment.

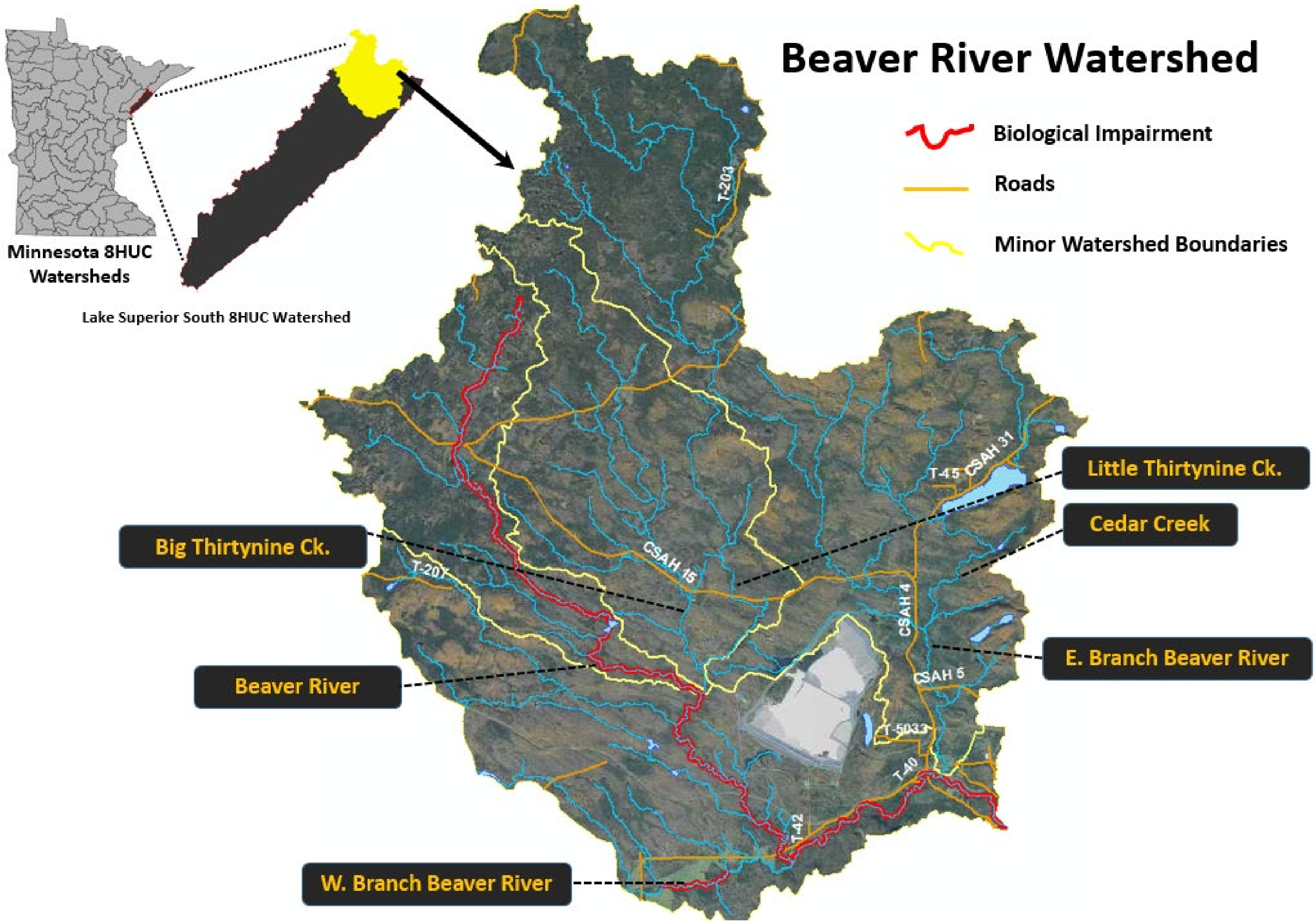


Figure 16. Beaver River 8-digit HUC watershed, minor watersheds, impaired streams, and road

Figure 17. Reserve Mining Company discharged directly into Lake Superior at Silver Bay

Figure 18. Effects of October 2000 pipeline break that spilled 10 million gallons of taconite tailings slurry into the Beaver River watershed

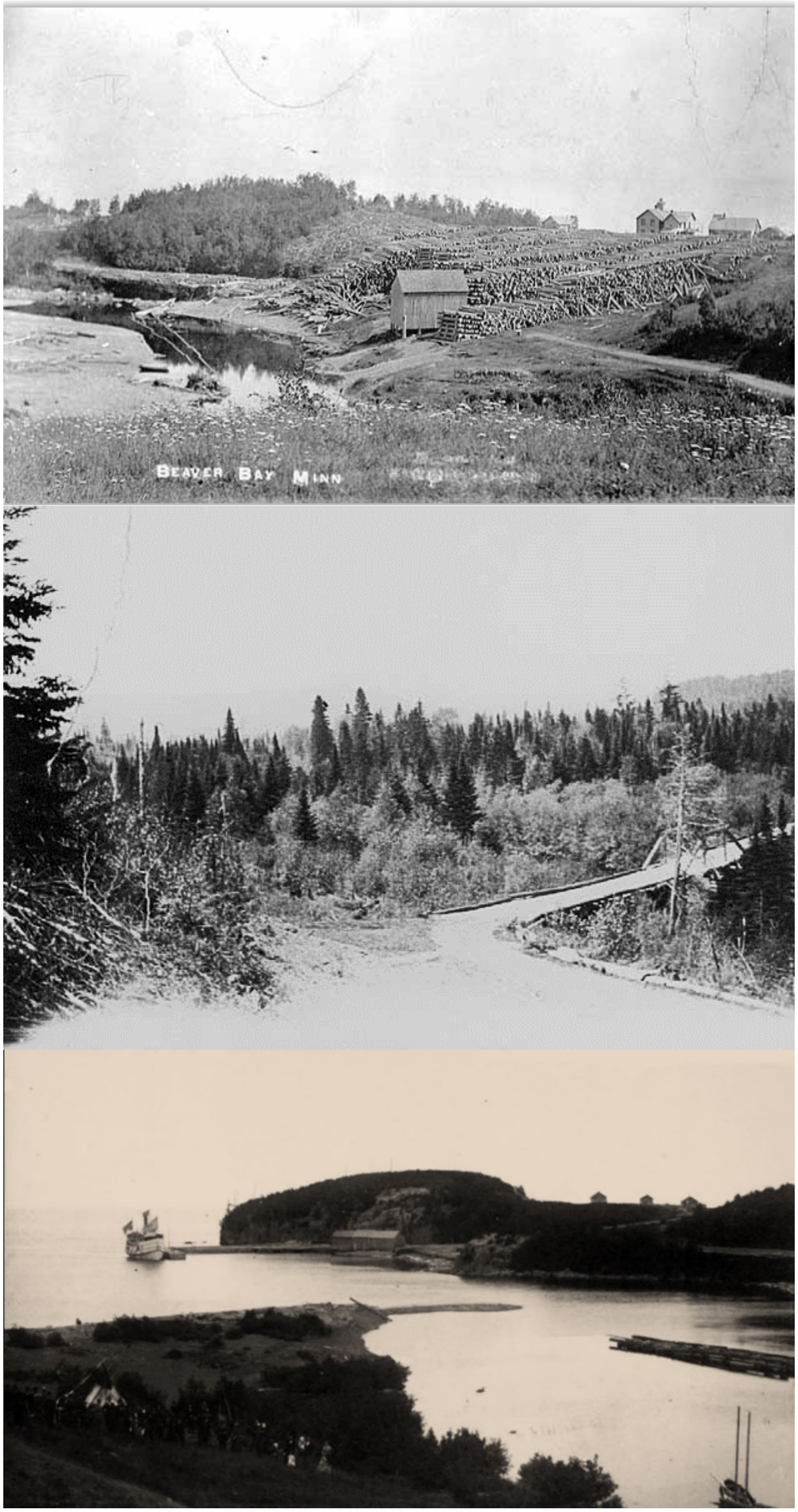


Figure 19. Historic photos of Beaver River and Beaver Bay. Top: "General View", Beaver Bay, circa 1915 *(Image: Minnesota Historical Society – Online Collections)* Middle: "Bridge Across Beaver River, two miles from Lake Superior - 1906" This is the current location of the Highway 4 bridge. Bottom: Steamer *Ossifrage* in Beaver Bay, 1888 *(Image: University of Minnesota Duluth Kathryn A. Martin Library Archives and Special Collections)*

5.2 Overview of biological data and impairments

5.2.1 Beaver River (AUID 04010102-501)

Fish Index of Biological Integrity (FIBI) scores were calculated for 11 stations on the main stem of the Beaver River (Table 6). Several of these stations were visited multiple times over the course of several years. All of the data presented in this report are from "reportable" sampling events (acceptable methods and sampling results). FIBI results ranged from a minimum score of 25 (10 points below the impairment threshold) to a maximum of 64, which is well above the threshold, and can be considered an above average FIBI result. The poorest FIBI results were somewhat localized, mostly in the headwaters and lower third of the impaired reach. An additional low FIBI result was observed at station 91LS026 just upstream of the point where the West Branch Beaver River enters the Beaver River. This location has been sampled several times, and more recent sampling (summer of 2015) resulted in more favorable FIBI result that scored above the impairment threshold.

Table 6. Summary of Beaver River biological sampling stations, results, and applicable assessment criteria (fish only). Map of stations can be found in Figure 21. Green and Bold Black text indicates IBI scores meeting aquatic life standards. Red text indicates IBI score failing to meet aquatic life standards.

Station	Drainage area (mi2)	Gradient (%)	Fish IBI class	Fish IBI result *(visit year)*	Fish IBI result *(visit year)*	Fish IBI result *(visit year)*	Standard	IBI lower confidence limit	IBI upper confidence limit
11LS027	4.6	0.8%	11	**37** *(2011)*			35	25	45
94LS007	16.0	1.3%	11	**64** *(2011)*			35	25	45
97LS010	48.6	1.0%	11	**52** *(2014)*	**45** *(1997)*		35	25	45
94LS005	54.0	0.2%	11	**41** *(2014)*			35	25	45
91LS026	54.1	0.1%	11	**25** *(2011)*	**47** *(2015)*		35	25	45
15LS061	64.2	0.8%	11	**52** *(2015)*			35	25	45
15LS060	68.8	0.6%	11	**51** *(2015)*			35	25	45
94LS003	70.9	0.2%	11	**45** *(2015)*			35	25	45
97LS055	121.7	0.1%	11	**46** *(1997)*	**41** *(1997)*		35	25	45
11LS022	121.8	0.1%	11	**35** *(2011)*	**33** *(2014)*	**29** *(2015)*	35	25	45
14LS001	122.5	1.8%	11	**31** *(2014)*			35	25	45

A total of 18 fish species were observed in the Beaver River over sampling events ranging from 1994 to 2015. Blacknose Dace were dominant at nearly all of the stations sampled, accounting for 21 – 60% of the total community depending on the station. Robust populations of Creek Chub were also ubiquitous in all of the sampling reaches. Several wetland-oriented species, such as Pearl Dace, Finescale Dace, Northern Redbelly Dace and Brook Stickleback accounted for a fair proportion of the overall community at stations located in headwaters reaches, and were also found in lower relative abundance throughout the lower river as well. Longnose Dace were abundant at monitoring stations that exhibited moderately steep gradients and an abundance of boulder/cobble substrate (e.g. 15LS061, 97LS010, 15LS060, and 14LS001).

Of particular interest to this report is the abundance and distribution of "coldwater taxa" (coldwater) within the impaired reach. Three fish species that qualify as coldwater (based on MPCA classification) were collected in the Beaver River based on the data retrieved from MPCA's biological monitoring database. These include Brook Trout (BKT), Rainbow Trout (RBT), and Mottled Sculpin. The BKT population in the Beaver River is limited in its spatial extent, and overall numbers are low relative to many North Shore streams. BKT populations in this river are sustained through natural reproduction as stocking has ceased for this species.

Rainbow Trout (RBT) were sampled in low numbers at several stations during MPCA's fish assessments. RBT are present in the river due to an active steelhead RBT management goals administered by the DNR regional office. Several characteristics of the Beaver River present challenges to DNR in their efforts to maintain a steelhead fishery. The primary limitation is the lack of quality spawning habitat available, as the distance from Lake Superior to the first barrier upstream is short (0.20 miles) and does not provide good conditions for spawning and rearing of steelhead RBT. Currently, the DNR supplements any natural reproduction with stockings of 100,000 RBT fry every other year in the East Branch Beaver River.

Mottled sculpin were present at monitoring stations throughout the length of the Beaver River. In the more recent fish surveys, higher numbers of sculpin were sampled at stations 94LS007 and 15LS061. Station 94LS007 is located in a heavily forested and undeveloped portion of the watershed. BKT were also more abundant (n=15) here than any other station sampled by MPCA. The relatively large population of sculpin sampled at 15LS061 is likely related to the input of colder water discharged from the Milepost 7 tailings basin, which joins the Beaver River just upstream of this station. No sculpin were sampled at station 15LS060, which is located immediately upstream of the Milepost 7 discharge.

5.2.2 West Branch Beaver River (AUID 04010102-578)

Fish community overview

Fish IBI results were calculated for two stations on the West Branch of the Beaver River (WBBR). Station 05LS001 is located in the headwaters of the WBBR and is not technically on the impaired reach. Even so, FIBI results were two points below the impairment threshold and are not indicative of a healthy coldwater fish community. Farther downstream, station 11LS028 was sampled two separate times (2011 and 2014) and scored below the impairment threshold in each visit. The poor results from this station provided the justification for designating this reach of the WBBR as an impaired water.

A total of 11 fish species were identified in the WBBR through MPCA's sampling efforts, which were completed in 2011 and 2014. Similar to the results from the main stem of the Beaver River, Blacknose Dace and Creek Chub were the dominant species observed at both stations on the WBBR. Common Shiner, Northern Redbelly Dace, Pearl Dace, Finescale Dace, Brook Stickleback, and Johnny Darter were present or abundant at both stations. Several species tolerant of a variety of stressors (Central Mudminnow, White Sucker, Fathead Minnow) were observed but in relatively small numbers.

The WBBR is a designated coldwater trout stream, yet no coldwater fish taxa were sampled during MPCA's sampling efforts. DNR does not stock trout in the WBBR, citing "poor water quality," low streamflow, and poor habitat conditions as characteristics that prohibit management for stream trout.

Table 7. Summary of West Branch Beaver River biological sampling stations, results, and applicable assessment criteria (fish only)

Station	Drainage area (mi2)	Gradient (%)	Fish IBI class	Fish IBI result *(visit year)*	Fish IBI result *(visit year)*	Standard	IBI lower confidence limit	IBI upper confidence limit
05LS001	2.7	1.0%	11	**33** *(2014)*		35	25	45
11LS028	4.8	0.3%	11	**30** *(2011)*	**23** *(2014)*	35	25	45

Macroinvertebrate community overview

Results from one station (11LS028) were used to assess the WBBR for macroinvertebrate IBI. The 2011 sampling of this station resulted in a MIBI score of 17 (out of 100), which is well below the impairment threshold score (32) and lower confidence limit of the impairment threshold (20) (Table 8). Only two monitoring stations of this stream class scored lower than 11LS028 within the collective Lake Superior South and Lake Superior North 8 digit HUC watersheds, both of which are urban streams located in city of Duluth (Tischer Creek and Chester Creek).

A total of 53 macroinvertebrate taxa were collected from station 11LS028. Nearly half of these were Chironomid (midge) taxa. Mayflies were abundant at this station, but most of the individuals sampled belong to genera that are considered fairly tolerant of poor physical habitat and marginal water chemistry (*Caenis* and *Proclean*). Three caddis fly taxa were present (*Leptoceridae*, *Pycnopsyche*, *Helicopsyche*). These three taxa are "facultative" in terms of their tolerance to disturbance, meaning they can be found in streams with conditions ranging from pristine to moderately disturbed. The riffle beetle *Dubiraphia* was also abundant at this station. *Dubiraphia* is considered neutral in terms of tolerance to disturbance, and prefer streams that are shallow, permanent, and relatively free of sediment. The substrate at 11LS028 is a mixture of small cobble, gravel, sand, and silt. Some of the riffles within the reach moderately embedded with fine substrates, so it is somewhat surprising that *Dubiraphia* were so abundant in this reach. Stoneflies, which are commonly sampled from high quality trout streams along the North Shore, were not collected at station 11LS028 on the WBBR.

Table 8. Summary of West Branch Beaver River biological sampling stations, results, and applicable assessment criteria (macroinvertebrates only)

Station	Drainage area (mi2)	Gradient (%)	Invert IBI class	Invert IBI result *(visit year)*	Invert IBI result *(visit year)*	Standard	IBI lower confidence limit	IBI upper confidence limit
11LS028	4.8	0.3%	8	**17** *(2011)*		32	20	44

5.3 Stressor Identification Analysis – Beaver River/West Branch Beaver River

5.3.1 Water temperature

Water temperature assessments in the Beaver River Watershed

Water temperature data were collected by MPCA and DNR staff during summers of 2011, 2013, 2014, and 2015. Most data loggers were deployed in April and May and retrieved from the stream in October, although the final analysis of the data tends to focus on the summer period from June 1 – August 31. Temperature monitoring locations were primarily selected to be co-located with biological monitoring sites. However, several loggers were deployed in non-biological monitoring locations to improve spatial coverage, investigate areas that could contribute to thermal stress, or evaluate potential coldwater refuge areas.

Stream temperatures varied considerably along the 26-mile impaired reach of the main stem Beaver River and its major tributaries. The scatter-plot graph in Figure 20 shows the distribution of temperature results for all Beaver River watershed streams monitored during the course of the Lake Superior South Assessment and Stressor Identification Study. The highlighted "Areas 1 - 4" correspond to the thermal regime groupings presented in Section 4.1. Thermal regimes in Area 3 and 4 tend frequently support Brook Trout and other coldwater species, while those in Area 1 and 2 tend to be marginal and less likely to support coldwater taxa. Many of the stations monitored on the Beaver River main stem and significant tributary streams fell into "Area 2" based on stream temperature summary statistics (Figure 20). Based on these results, a significant portion of the impaired reach offers a marginal thermal regime for supporting coldwater fish and macroinvertebrate taxa.

A small number of stations on the Beaver River, East Branch Beaver River, West Branch Beaver River, Kit Creek, and Big Thirtynine Creek supported thermal regimes in Area 3 and 4 (Figure 20). These stations very likely provide suitable water temperatures for supporting coldwater species, although other factors still may be limiting (e.g. habitat, dissolved oxygen). A small unnamed tributary to the Beaver River, which enters just upstream of station 94LS005, recorded the coldest thermal regime in the entire Beaver River drainage (Figure 20) and could serve as a coldwater refuge. No biological data were collected from this tributary, but this could be a point of emphasis for future monitoring and protection planning.

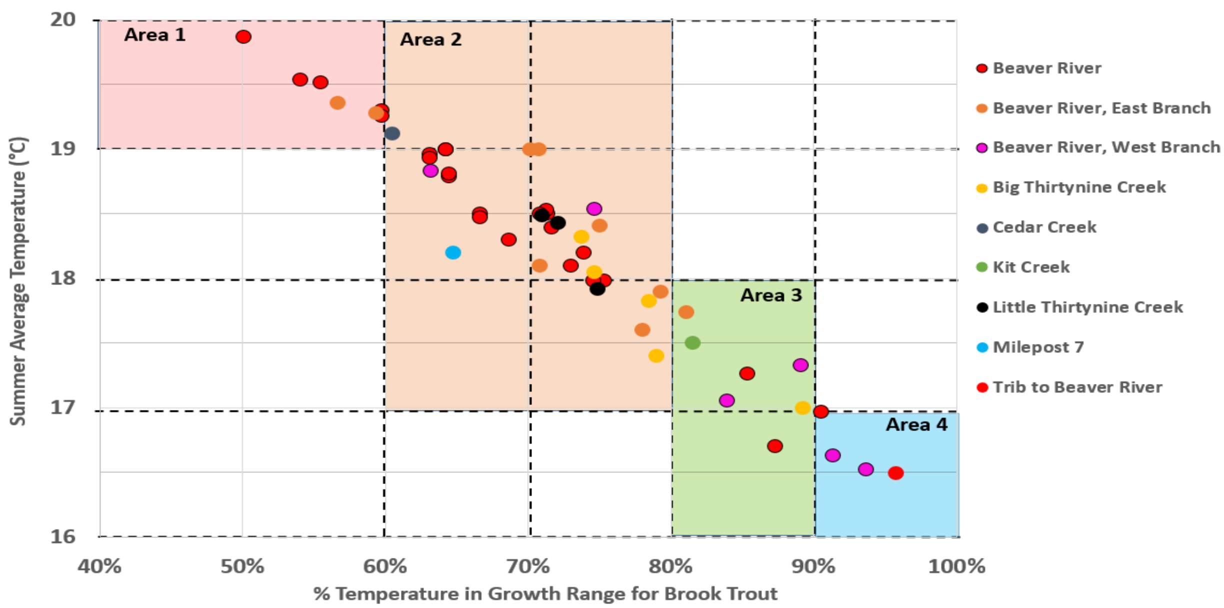


Figure 20. Plot of summer average temperature vs. percentage time in Brook Trout growth range. Data include all streams monitored in Beaver River watershed. More information on thermal regime categories in Table 9 and Section 4.1

Table 9. Criteria used for developing thermal regime groupings (Area 1-4) for North Shore coldwater streams. See Section 4.1 for more information

Grouping	% Temperature Reading in Brook Trout Growth Range	Summer Average Temperature (C)
Area 1	<60%	>19 C
Area 2	60-79%	17 – 20 C
Area 3	80-89%	16 – 18 C
Area 4	90 – 100%	<17 C

Grouping	Description
Area 1	Brook Trout and coldwater species sometimes present, more often a mix of cool and warmwater taxa
Area 2	Can support Brook Trout and other coldwater species, often a mix of cold, cool, and warmwater taxa
Area 3	Frequently supports Brook Trout and other coldwater species, lower relative densities
Area 4	Almost always support high relative densities of Brook Trout and coldwater species

Beaver River temperature summary

Only one station (11LS027) on the impaired reach of the Beaver River recorded a thermal regime in Area 3 or 4 (i.e. most suitable for coldwater taxa). Water temperatures at this location remained in the growth range for Brook Trout 85-90% of during the June – August period in 2013, 2014, and 2015. This station is located in the extreme headwaters of the river and historic fisheries data show the presence of a small Brook Trout population in this reach, though they were not sampled during the most recent biological surveys completed by MPCA in 2011. DO concentrations and water levels at this station are both marginal, likely due to the small drainage area feeding this particular reach. Although water temperatures remained cold throughout the summer, the lack of overwintering habitat and DO limitations are likely diminish Brook Trout survivability in this section of the Beaver River.

Downstream from station 11LS027 to the Highway 3 crossing (station 94LS005), water temperatures can be classified “fair” in terms of supporting coldwater taxa. Stream temperatures varied very little among the three monitoring stations in this reach, as all of them recorded temperatures in the growth range for Brook Trout between 70 – 75% of the time during the summer months (June – August). Water temperatures were in the “stress” range for Brook Trout 25 – 30% of the time, but the lethal temperature limit was rarely exceeded (<1%). Despite warmer water temperatures relative to the Beaver River headwaters, several of the stations located in this long, roadless reach continue to support small populations of naturally reproducing Brook Trout. Additional coldwater indicator species, Mottled Sculpin and Longnose Dace, were also sampled in good numbers. This reach offers high quality physical habitat conditions, deep pools for overwintering, and suitable DO concentrations. These characteristics, combined with the cool-cold thermal regime, appear to offer suitable conditions for Brook Trout survival and reproduction.

Water temperatures in the lower third of the Beaver River (Highway 3/Station 94LS005 to Lake Superior) were the warmest in the watershed and can be classified as marginal to poor for supporting coldwater taxa. Temperature data were collected at five locations in this reach – four on the Beaver River and one additional station on the tributary that serves as the outlet of the Milepost 7 tailings basin (Figure 21). Stream temperatures from the Beaver River stations were in the growth range for Brook Trout 46% – 71% of the time during the summer monitoring periods (Stress Range 24% – 49%; Lethal 1% – 8%). The Milepost 7 tributary station was the only location that did not have temperature values exceeding the lethal threshold.

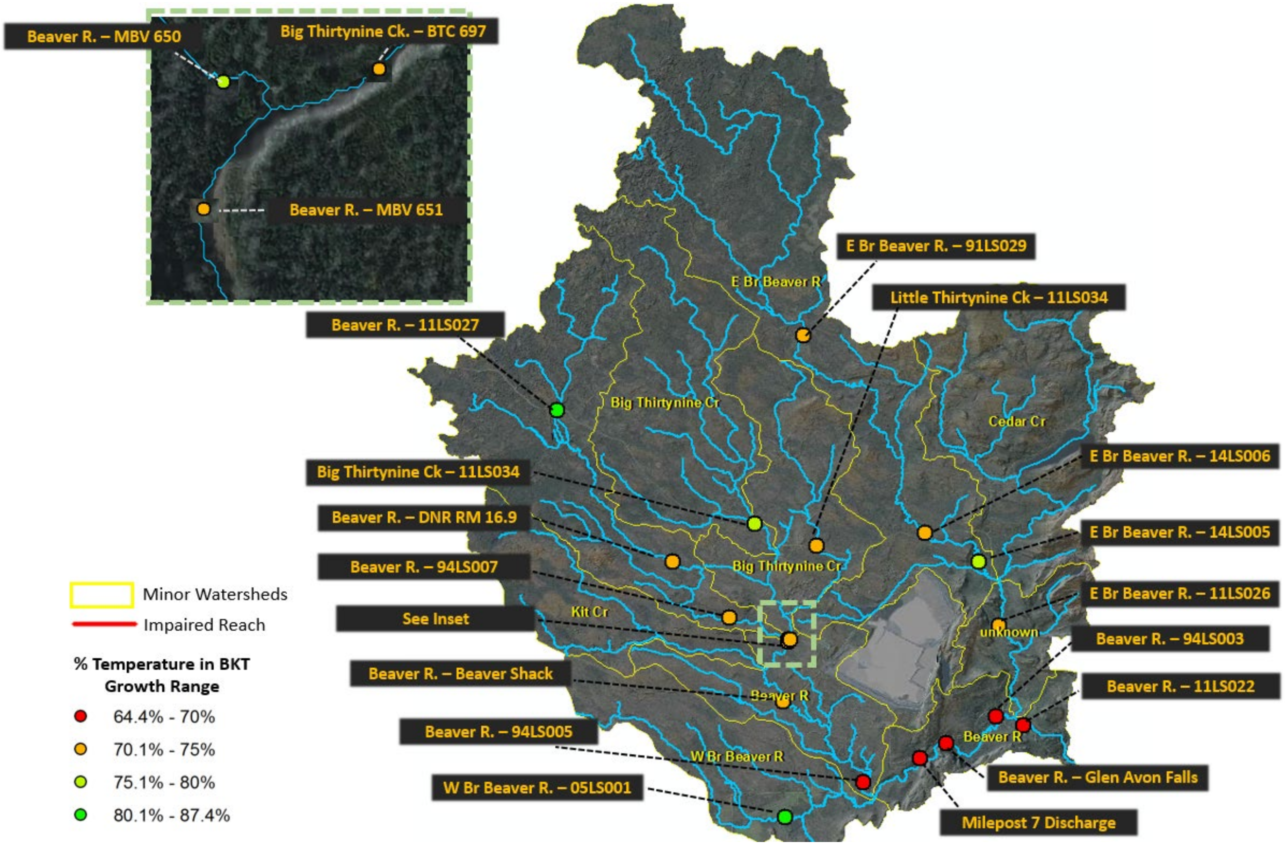


Figure 21. Percent of temperature readings in Brook Trout growth range for Beaver River watershed monitoring locations; June 1 – August 31, 2013

West Branch Beaver River temperature summary

Continuous stream temperature data were collected at five locations on the West Branch Beaver River (WBBR) during the SID monitoring period (2011 – 2015). The results show a thermal regime that is highly fragmented, with some reaches showing favorable temperatures for coldwater taxa and others with thermal regimes that are marginal to poor. Stations 11LS028 and 05LS001 offer summer stream temperatures comparable to quality coldwater streams in the region Station 11LS028 plotted in Area 3 (see Table 9) in years 2013 & 2014, while station 05LS001 plotted in Area 4 in 2014 and 2015. However, low streamflow, habitat conditions (11LS028 only), and sub-optimal DO concentrations limit the potential for these stations to support Brook Trout despite the colder water temperatures.

Warmer water temperatures were observed in the lower reaches of the WBBR as it approaches its confluence with the Beaver River. The stream channel in this particular reach is wider and shallower than upstream, and numerous beaver dams and areas of stream channelization result in sluggish or stagnant flow conditions. Only partial data records (missing June measurements) are available but temperatures were in the growth range for Brook Trout in 53% - 75% of the recorded measurements. Temperatures were in the “stress” range for Brook Trout 25% - 44% of the time, and lethal thresholds were exceeded 0.2% - 5% of the period of record depending on the station.

Suitable temperatures for coldwater taxa are present in the WBBR, but appear to be limited to be highly localized. Areas with lower width to depth ratios, moderate stream slope, overhanging vegetation, and unimpeded flow are correlated with suitable coldwater thermal regimes in this watershed. Our data suggests that stream temperatures in the lower two miles of the WWBR are marginal to poor for supporting coldwater taxa.

Figure 22. Percent of temperature readings in Brook Trout growth range for West Branch Beaver River watershed monitoring locations; June 1 – August 31, 2013

Biological response to water temperature

Biological response to thermal stress was evaluated using several metrics that are instrumental in calculating fish IBI scores. Metric results from stations on the impaired reach of the Beaver River were compared to the 25th percentile, median, and 75th percentile values from North Shore coldwater streams with good to excellent fish IBI scores (above the upper confidence limit of impairment threshold) (Table 11). Significant departure from these "reference" values can indicate symptoms of stress due to a particular parameter. Metric names and descriptions are listed in Table 10.

Three coldwater fish species were sampled from the Beaver River based on reportable monitoring data from 1997 to 2015. These include Brook Trout, Rainbow Trout (actively stocked by DNR), and Mottled Sculpin. At least one coldwater taxa was sampled in 11 out of 16 reportable sampling visits (69%), with mottled sculpin as the most ubiquitous coldwater species sampled. Brook Trout were sampled from three stations (94LS007, 97LS055, 11LS022, and 15LS061) but in extremely low numbers, with the exception of 94LS007 (n=15). Older, non-reportable DNR data also Brook Trout present at 91LS025, which is located near the headwaters just upstream of County State Aid Highway (CSAH) 15. Rainbow Trout are actively stocked by DNR, and were present in the lower third of the river. Many high quality North Shore coldwater streams support only one or two coldwater taxa. Based on this metric, the Beaver River is comparable to many high quality streams. However, there are only a few stations on the 26-mile impaired reach that supported more than a single coldwater taxa.

A more significant departure from high quality coldwater streams is apparent when looking at measures related to the relative abundance of coldwater individuals compared to warmwater or coolwater species in the fish community sampled. These data are summarized by several metrics in Table 11; *ColdPct*, *CWIntolerantPct*, and *CWSensitivePct*. Only two Beaver River stations (94LS007 and 15LS061) scored above the median values of the reference streams and a significant majority of the stations scored below the 25th percentile value for the reference streams (Table 11). Blacknose Dace and Creek Chub were highly dominant at most Beaver River monitoring stations, and the relative abundance of "coldwater" individuals was between 0 - 10% at many stations.

Fish IBI (FIBI) scores are negatively influenced by a high richness or abundance of "tolerant" and/or "pioneer" species. Central Mudminnow and Fathead Minnow are two tolerant species sampled with some regularity in the Beaver River. For the most part, these species were present in low numbers, but Fathead Minnow were relatively abundant at station 11LS022, which led to some of the lowest overall FIBI scores on the impaired reach. Water temperatures at this location were the warmest in the watershed and poor physical habitat conditions are present within this reach. "Pioneer" fish species recolonize or dominate disturbed streams. Creek Chub is a pioneer species often found in degraded North Shore trout streams or those limited by natural background conditions. This species was dominant at many Beaver River stations. In fact, all stations with the exception of 11LS027 had metric values for pioneer taxa that compared unfavorably to high quality reference streams.

Table 10. Coldwater IBI metrics used to evaluate biological response to elevated water temperature

Metric name	Metric description
Cold	Taxa richness of coldwater species
ColdPct	Relative abundance (%) of individuals that are coldwater species
CWIntolerantPct	Relative abundance (%) of individuals that are considered Intolerant in coldwater streams
CWSensitivePct	Relative abundance (%) of individuals that are considered Sensitive in coldwater streams
CWTolPct	Relative abundance (%) of individuals that are considered Tolerant in coldwater streams
PioneerTxPct	Relative abundance (%) of taxa that are pioneers

Table 11. Comparison of several coldwater fish IBI metric results between Beaver River monitoring stations and high quality reference streams.

Station	Stream	Visit	Cold	CWSensitivePct	CWIntolerantPct	ColdPct	CWTolPct	PioneerTxPct
11LS027	Beaver River	2011	O	--	--	--	--	-
94LS007	Beaver River	2011	↑	-	-	+	O	--
97LS010	Beaver River	1997	--	--	-	--	O	--
97LS010	Beaver River	2014	O	-	-	--	O	--
94LS005	Beaver River	2014	O	--	-	--	--	--
91LS026	Beaver River	2011	--	--	--	--	--	--
91LS026	Beaver River	2015	O	--	--	--	--	--
15LS061	Beaver River	2015	O	-	+	--	-	--
15LS060	Beaver River	2015	O	-	-	-	O	--
94LS003	Beaver River	2015	O	--	--	--	-	--
97LS055	Beaver River	1997	O	--	--	--	--	--
97LS055	Beaver River	1997	↑	--	--	--	-	--
11LS022	Beaver River	2011	O	--	--	--	--	--
11LS022	Beaver River	2014	O	--	--	--	--	--
11LS022	Beaver River	2015	O	--	--	--	--	--
14LS001	Beaver River	2015	--	-	-	--	O	--

Key: Metric Result Compared to Reference Streams	
below 25th percentile	--
25th percentile - Median	-
Median - 75th Percentile	+
above 75th Percentile	↑
Equal to Median	O

Sources of thermal loading in the Beaver River Watershed

Geomorphology, channel stability, and riparian conditions vary significantly along the 26-mile impaired reach of the Beaver River. These features have direct and indirect linkages to thermal loading and can influence the capacity of a given stream reach to support coldwater biota. Upstream of its confluence with Big Thirtynine Creek, the free-flowing (non-beaver dam impounded) channels have low to moderate width-to-depth ratios and generally maintain a stable pattern, profile, and dimension over time. Riparian vegetation along this section is predominantly intact and provides significant shading. Station 94LS007 (Figure 23, photo #1), one of the few reaches to support wild Brook Trout, is a prime example of optimal channel stability and riparian condition in this watershed.

Downstream of the Big Thirtynine Creek confluence, the Beaver River increases substantially in size, and areas of channel instability are evident and well-documented (see Section 5.3.7). Mass wasting of stream banks and bluffs has resulted in channel widening, aggradation and braiding (Figure 23, photo #2). Riparian shading is more limited due to the increase in width-to-depth ratio, and increased channel incision (down-cutting) in this reach has resulted in decreased connectivity between the river and its floodplain. A decrease in floodplain connectivity means less floodplain water storage, a lower water table, and ultimately less infiltration and groundwater recharge. This scenario is likely initiating the warming trend in water temperatures that continues from this point in the watershed down to Lake Superior.

Upstream of the point at which Milepost 7 discharge enters, the Beaver River exhibits an extremely high width-to-depth ratio. During summer baseflow conditions, water depth is typically less than 0.5 feet, and channel width ranges from 40-60 feet (Figure 23, photo #3). These conditions intensify warming due to direct solar radiation. Temperature comparisons between stations 91LS026 (Highway 3) and 15LS061 (200 feet upstream Milepost 7 outlet) show similar average temperatures, but the daily fluctuation in temperature is noticeably higher at 15LS061 which supports solar radiation as a source of warming. Very few signs of channel instability are present within this reach, as streambanks are stable, riparian conditions are relatively undisturbed, and the river appears to be connected to its floodplain in most areas.

Near its confluence with the East Branch Beaver River, stream gradient decreases and the Beaver River remains wide, but depth increases due to several riffles that provide grade control and maintain moderate water depths (Figure 23, photo #4). The lack of overhead cover (canopy trees) and exposure to sunlight is a likely source of thermal loading in this reach, although the increase in water depth may minimize these effects to some degree. Clay streambanks are more common in this reach and water clarity tends to be lower due to the suspension of fine particles. This increase in turbidity may also promote higher rates of thermal loading.

Figure 23. Examples of stream channel condition along the Beaver River. Conditions in photos 2-4 lead to warmer water temperatures.

Milepost 7 Basin

The Milepost 7 taconite tailings basin continuously discharges to the Beaver River approximately 4.75 miles upstream of Lake Superior. During low flow conditions, this discharge accounts for a considerable portion of the streamflow (see Section 5.3.8) and influences various water quality parameters and physical properties, including water temperature. Stream temperature data were collected from Beaver River stations immediately upstream and downstream of the discharge point during the course of the Stressor Identification monitoring period. Temperature data were also collected from the discharge channel upstream of its confluence with the Beaver River. Currently, stream temperature is not one of the parameters regularly monitored as part of the discharge permit. Considering that this discharge flows into a designated trout stream, a temperature monitoring component should be a future consideration during permit re-issuance.

Water temperature of the Milepost 7 discharge was monitored continuously during the 2013 open water season. The summer average temperature (June 1 – August 31) was 18.2 °C. Temperatures were within the growth range for Brook Trout 64.7% of the time over that period (stress range 35.3%, lethal range 0.0%. These results are comparable to Beaver River temperature data upstream (station 91LS026) and downstream (station 94LS003) of the discharge point. Additional temperature loggers were installed in the Beaver River in the immediate vicinity of the discharge on July 11, 2013. During this monitoring period, the continuous discharge from the Milepost 7 tailings basin significantly reduced the daily temperature flux observed in the Beaver River downstream of the outfall (Figure 24 and 25). Daily maximum and minimum temperatures downstream of the discharge were often several degrees cooler during the daylight hours and warmer during nightfall than observations upstream of the discharge.

The “dampening” effect of the discharge reduced the percentage of time that temperatures at the downstream station were in the “lethal” range for Brook Trout. However, temperatures were in the “stress” range slightly more often below the discharge due to the same effect.

Biological data collected from stations above and below the Milepost 7 discharge show differences that may be linked to the thermal regime alterations. Mottled Sculpin were sampled in good numbers (n=16) below the Milepost 7 discharge but were absent from the sampling reach upstream. The higher daily maximum temperatures (26-29° C) observed upstream of the discharge may limit or eliminate the potential for this species to establish in this location. A single Brook Trout was sampled above the Milepost 7 discharge at station 15LS061 in 2015, but none were sampled downstream. Brook Trout are known to move long distances in response to temperature change and have the ability to do so in this reach of the Beaver River. The composition of coldwater macroinvertebrate taxa upstream and downstream of the discharge was very similar. *Epeorus* (Little Maryatt mafylies) and *Glossosoma* (Saddle-case caddisflies) were sampled at both locations, but an additional sensitive coldwater species, *Boyeria grafiana* (Ocellated Darner dragonfly), was collected downstream of the discharge. This dragonfly is currently on Minnesota’s list of Species of Special Concern.

The influence of the Milepost 7 discharge on water temperatures in the lower Beaver River extend several miles downstream, and likely all the way to the outlet into Lake Superior. Continuous monitoring data from 2015 show how daily temperature values and patterns at station 11LS022 (approximately 3.5 river miles downstream of the Milepost 7 discharge) are in close agreement with results from just below the discharge point (station 15LS060) (Figure 25). Temperature values from all monitoring stations in the lower third of the Beaver River (all stations shown in Figure 25) exceeded the stress and lethal temperature thresholds for Brook Trout with regularity in late July and early August.

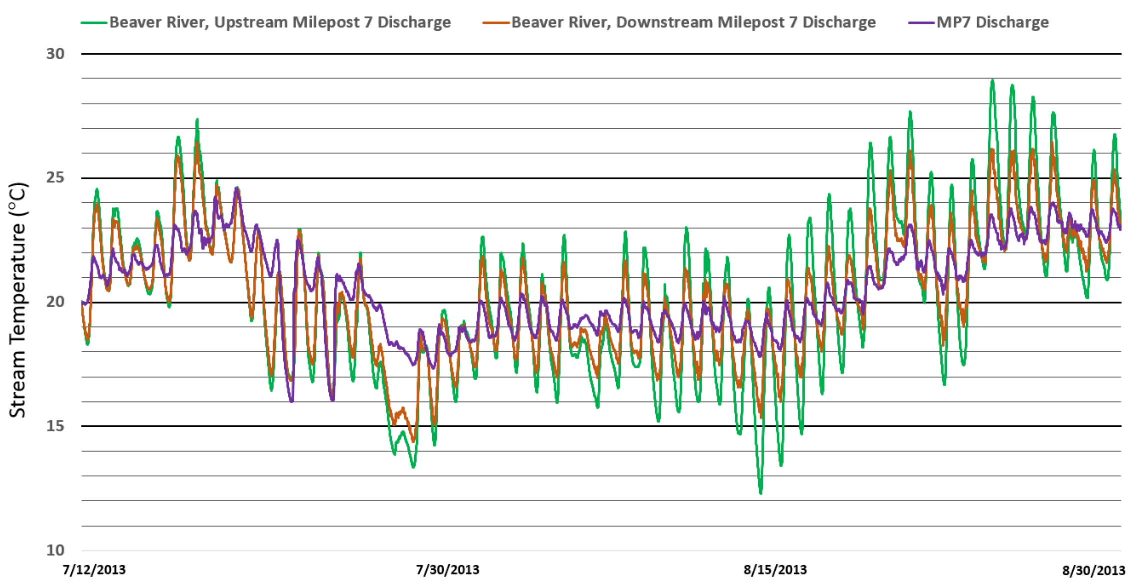


Figure 24. July-August 2013 temperature data from the Beaver River and Milepost 7 discharge. The discharge from Milepost 7 basin dampens the diurnal (daily) temperature flux in the Beaver River downstream of the discharge point.

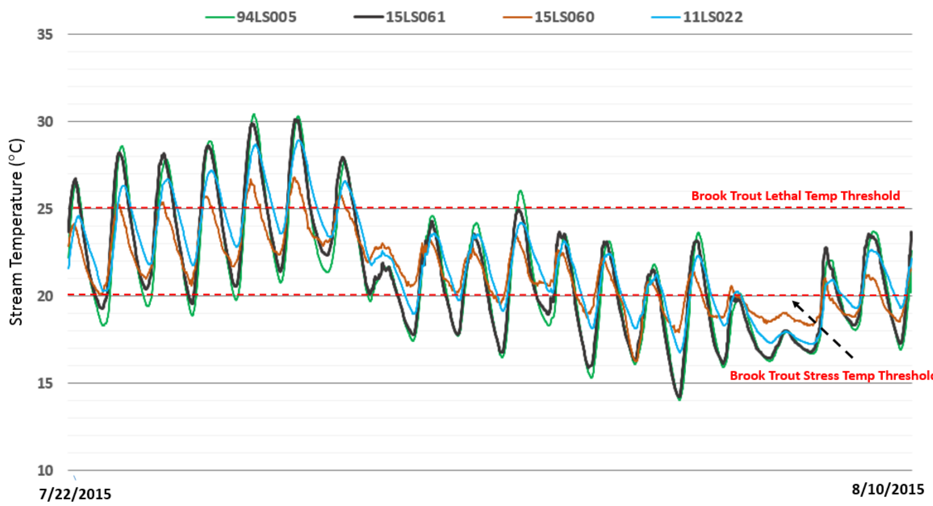


Figure 25. Late July - Early August 2015 temperature results from the lower third of the Beaver River main stem.

Summary: Is water temperature a stressor in the Beaver River/West Branch Beaver River?

Water temperatures in the headwaters and upper half (upstream of Big Thirtynine Creek confluence) of the impaired reach of the Beaver River are suitable for Brook Trout and other coldwater species. Stream temperatures in the headwaters are particularly favorable, although habitat and DO may be limiting. Brook Trout remain in self-sustaining populations at several monitoring locations in the upper half of the watershed, although temperatures are relatively warm compared to the highest quality trout streams in the region. Additional monitoring and protection efforts are warranted in the upper Beaver River watershed to maintain the current thermal regime and quality physical habitat.

Downstream of Highway 3, water temperatures more frequently exceed the “stress” and “lethal” thresholds for Brook Trout. Several factors likely contribute to the warmer temperatures observed in this portion of the river, including decreased canopy cover due to channel enlargement and a higher susceptibility to warming due to turbid water conditions. A general lack of significant coldwater tributary streams in the lower watershed is also a major limitation, as few refuge areas are accessible to resident fish populations in this reach.

The Milepost 7 taconite tailings basin discharge has a significant influence on the thermal regime of the lower Beaver River during low flow periods. However, this discharge does not appear to be a major source of thermal loading. Temperature readings from the discharge and surrounding areas are similar, and marginal to poor temperature ranges for coldwater taxa were frequently observed well upstream of the discharge point.

Elevated water temperature should be considered a stressor and contributing cause of the fish IBI impairment downstream of the Highway 3 crossing. Additional monitoring and modeling work is recommended to better understand the processes contributing to thermal loading, but one of the principal factors appears to be a change in stream and valley characteristics (higher channel width-depth ratio and less entrenched valley) that are driven in part by natural background conditions. Restoration projects aimed at restoring channel stability, shading, and floodplain connectivity may help to provide colder water temperatures.

Water temperature is also a stressor in the West Branch Beaver River. Suitable temperature ranges for coldwater taxa were observed in the headwaters of this stream but temperatures were significantly warmer in the lower half of the watershed. Warming appears to be driven a combination of natural background conditions and anthropogenic disturbances.

5.3.2 Low dissolved oxygen

Beaver River dissolved oxygen data

Dissolved oxygen (DO) data were collected intermittently at seven monitoring stations along the length of the Beaver River. YSI sondes were deployed to continuously record DO concentrations at these stations for durations of one to five weeks during mid-summer months when conditions are generally most limiting to suitable DO levels. Spot measurements were also collected at these locations during various flow conditions, but continuous data will be relied on more heavily for stressor identification, as it more accurately represents the range of conditions fish and macroinvertebrates are exposed to over the course of the summer.

DO concentrations in the Beaver River were generally adequate for supporting Brook Trout and other coldwater aquatic life. Concentrations fell slightly below the 7 mg/L DO standard at several locations, but typically for short durations of six to eight hours. The only prolonged period of sub-7 mg/L DO was observed at station S007-357 in July/August of 2015. A minimum DO concentration of 5.16 mg/L was observed during this period, and the DO concentration remained below 7 mg/L for over 70 hours. This monitoring station is located near the headwaters of the river and low streamflow conditions are regularly observed. Diurnal (24-hour) fluctuation in DO concentrations at this station were routinely the lowest of all the monitoring stations, and the lower DO levels observed at this station are likely the result of natural factors (low flow conditions and upstream wetlands) as opposed to nutrient enrichment.

DO concentrations briefly fell below the 7 mg/L standard at several other stations in the middle reaches of the Beaver River. Several of these stations are prone to low streamflow conditions in the summer months, which are exacerbated by stream channels that are extremely wide and shallow (high width/depth ratio) and lack shading from direct sunlight (see middle and right photos in Figure 26). All sub-7 mg/L measurements within these reaches were recorded during the months of July and August. During these periods, the river was at baseflow and air and water temperatures were near their annual maximums. Despite these factors, DO minimums in the middle and lower reaches of the river never dropped below 6.22 mg/L. Given the minimum concentrations were only slightly below the standard and exposures were short in duration, low DO is not a likely cause of the fish IBI impairment in the Beaver River.

High daily fluctuation in DO concentrations (DO flux) is another pathway that can stress fish and macroinvertebrate communities. The MPCA's Nutrient Criteria for Rivers (Heiskary, 2013) includes DO flux as one of the stressor variables. For the "Northern Nutrient Region" the DO flux stressor threshold value was set at 3 mg/L, meaning that any result above that value can be a sign of river eutrophication (excess nutrients) and can stress sensitive aquatic life. A DO flux of greater than 3 mg/L was observed at two stations on the Beaver River, S007-967 and S007-354. Maximum DO flux observed at these sites ranged from 3.08 – 3.22 mg/L, but average values over the course of the two to four week monitoring period were all below 3 mg/L.

The Beaver River receives a continuous discharge from the Milepost 7 taconite tailings basin near river mile 4.5. On average, this discharge provides around 50% of the baseflow to the lower Beaver River during dry periods. In terms of DO concentrations and flux, the addition of the Milepost 7 discharge has a stabilizing effect, dampening the daily maximums and minimums by approximately 1 mg/L on both ends. This affect is clearly shown in Figure 27, where S007-967 represents conditions just upstream of the discharge, and S007-968 approximately 400 feet downstream. Also shown on this graph is the DO profile for station S007-970 (@ North Shore Trail/Superior Hiking Trail bridge) approximately 3.3 miles downstream of the where the Milepost 7 discharge enters the Beaver River. The dampening effect of the discharge on DO concentrations is no longer evident at this station, and DO minimums, maximums, and daily flux are very similar to conditions observed upstream of the Milepost 7 discharge.

Figure 26. Lower DO concentrations were observed in the headwaters of the Beaver River (left photo), and briefly fell below the 7 mg/L standard at several other stations in the middle reaches of the Beaver River. Several of these stations are prone to low streamflow conditions in the summer months, which are exacerbated by stream channels that are extremely wide and shallow (high width/depth ratio) and lack shading from direct sunlight (middle and right photo)

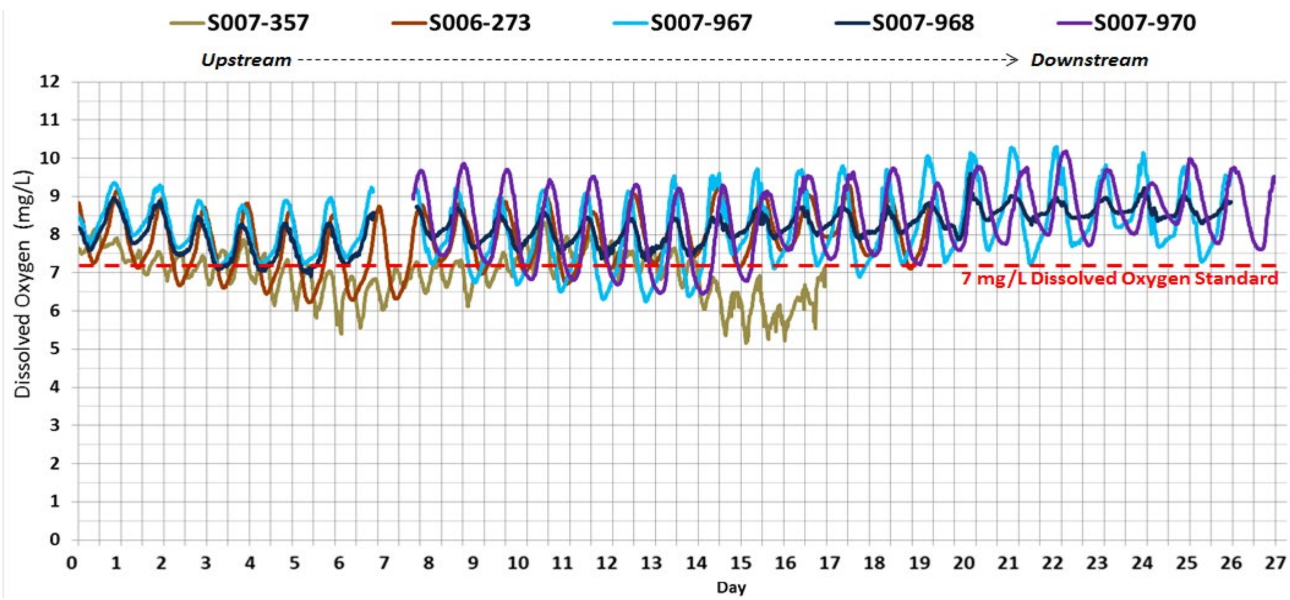


Figure 27. Continuous DO profiles from Beaver River monitoring stations; 7/14/15 – 8/11/15

Sources and pathways of low dissolved oxygen/high dissolved oxygen flux

Nutrients and productivity

Although a number of nutrients are required for plant growth, phosphorous and nitrogen are generally given the most attention, as research identifies these as limiting nutrients in aquatic systems (Dodds 2006, Dodds & Cole 2007). Total phosphorus (TP) is the primary causal variable used by MPCA to evaluate river eutrophication (Heiskary, 2013). Samples for TP have been collected at numerous locations along the Beaver River, and several stations have extensive records dating back to the late 1970's. For this report, more contemporary results were used (year 2000-2015) to evaluate TP levels in the river and their effect on DO concentrations.

The four stations with the most extensive data sets for TP are summarized in Table 12. TP concentrations exceeded the 0.055 mg/L standard at several stations, but the rate of exceedance was less than 10% of the samples. The highest TP values were observed at a station near Glen Avon Falls and another approximately 1.8 miles downstream at Highway 4. No exceedances of the TP criteria were observed at S004-234, which is located at the mouth of the Beaver River. Only 10 TP results are available for this station, which presents uncertainties in fully evaluating nutrient concentrations at this location. Similarly, a relatively small data set exists for the upper half of the river, but TP concentrations are expected to be well below the 0.055 mg/L standard based on the few samples that have been taken.

Biochemical oxygen demand (BOD) and chlorophyll-a (Chl-a) are two "response variables" used in the MPCA's river eutrophication standard. There are no Chl-a data available for the Beaver River. BOD data are available for several stations from samples collected in August of 2015. Results from station S006-273 (Beaver River at Highway 3) and S007-357 (Beaver River at Highway 15) were below the lab detection limit of 1.5 mg/L. Samples from locations farther downstream, including S007-968, S007-967, and S007-955 were all slightly higher, ranging from 1.8 – 2.0 mg/L. Each of these results is slightly above the BOD response variable criteria of 1.5 mg/L listed in the MPCA's River Nutrient Criteria (Heiskary, 2013). The increased BOD concentrations observed at these locations are spatially co-located with the highest TP results observed in the river. However, TP concentrations were well below the 0.055 mg/L standard in August 2015 sampling event, even as BOD concentrations exceeded the stressor variable threshold of the nutrient standard (1.5 mg/L).

Table 12. Summary of TP results at four monitoring stations on the Beaver River and comparison to MPCA's River Nutrient Standards for TP.

Station	# Samples	% Exceeding nutrient criteria (0.055 mg/L)	TP maximum (mg/L)	TP minimum (mg/L)	TP average (mg/L)
S006-273	6	0%	0.022	0.004	0.010
S000-252	41	5%	0.142	0.007	0.021
S004-955	44	7%	0.092	0.004	0.024
S006-234	10	0%	0.033	0.016	0.023

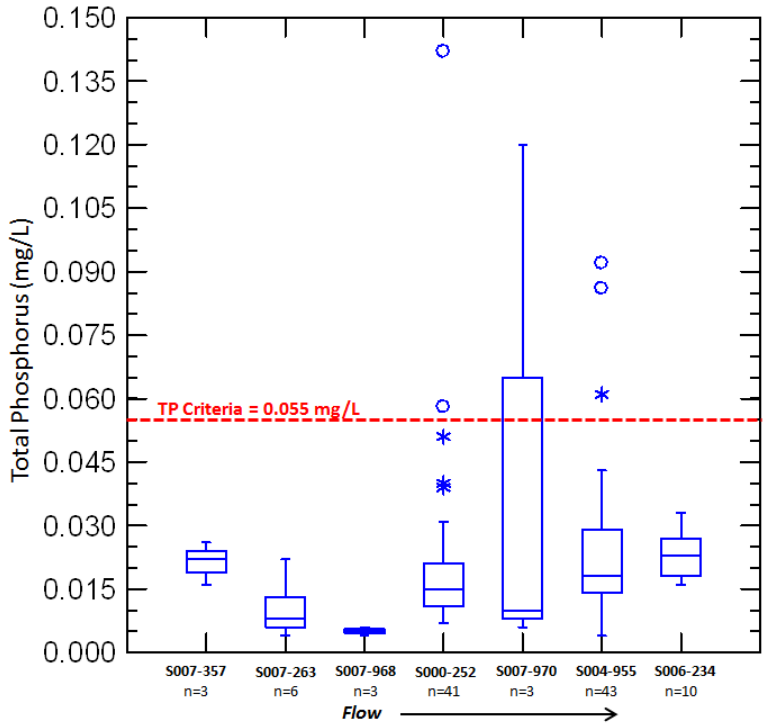


Figure 28. Summary of Beaver River TP results for monitoring stations with three or more sampling events

Table 13. Summary of TP results and other parameters associated with DO and river eutrophication

Sample date	Station	Total phosphorus (mg/L)	Biological oxygen demand (mg/L)	Chemical oxygen demand (mg/L)	Dissolved organic carbon (mg/L)
8/19/15	S006-273	0.008	< 1.5	28	n/a
8/18/15	S007-357	0.022	< 1.5	n/a	16.2
8/10/15	S006-273	0.004	< 1.5	n/a	n/a
8/10/15	S007-968	0.004	*1.8*	n/a	n/a
8/10/15	S007-967	0.005	*2.0*	n/a	n/a
8/10/15	S007-955	0.010	*1.9*	n/a	n/a
River nutrient standard (North)		**0.055**	**≤1.5**	**n/a**	**n/a**

Values in **BOLD/*italics*** exceed river nutrient criteria values *Laboratory holding times exceeded. Results are approximate.

Biological response to low dissolved oxygen and/or dissolved oxygen flux

A total of 18 species of fish have been observed in the Beaver River in the course of sampling by MPCA and DNR between the years of 1991 and 2015. Blacknose Dace, Creek Chub, Longnose Dace and Common Shiner are rather ubiquitous in the river and have often dominated the assemblage within a given sampling reach. These species are commonly found in streams and rivers with ample DO concentrations for supporting a variety of warm and coolwater species. They also have the ability to withstand lower DO concentrations than many sensitive species that require relatively higher DO concentrations (e.g. Brook Trout). Species that are highly tolerant of low DO concentrations were present in the Beaver River (Fathead Minnow, Central Mudminnow, Brook Stickleback) in relatively small populations. Brook Trout, which are intolerant of low DO concentrations, were only observed at a few locations, primarily in the upper half of the watershed.

In general, the fish community of the Beaver River is fairly diverse and can be categorized as fairly neutral in terms of tolerance to DO-related stress. Yet, due to the lack of low DO intolerant taxa, the fish community dissolved oxygen "Tolerance Indicator Value" (DO TIV) results are relatively low throughout the Beaver River compared to results from high quality monitoring stations along the North Shore of Lake Superior. Nearly all of the DO TIV results from the Beaver River were between 7 – 8, which resulted in many sites falling below the 25th percentile value of the high quality streams (Figure 29). The presence of Brook Trout at station 94LS007 and 15LS061 resulted in high DO TIV scores comparted to other Beaver River stations.

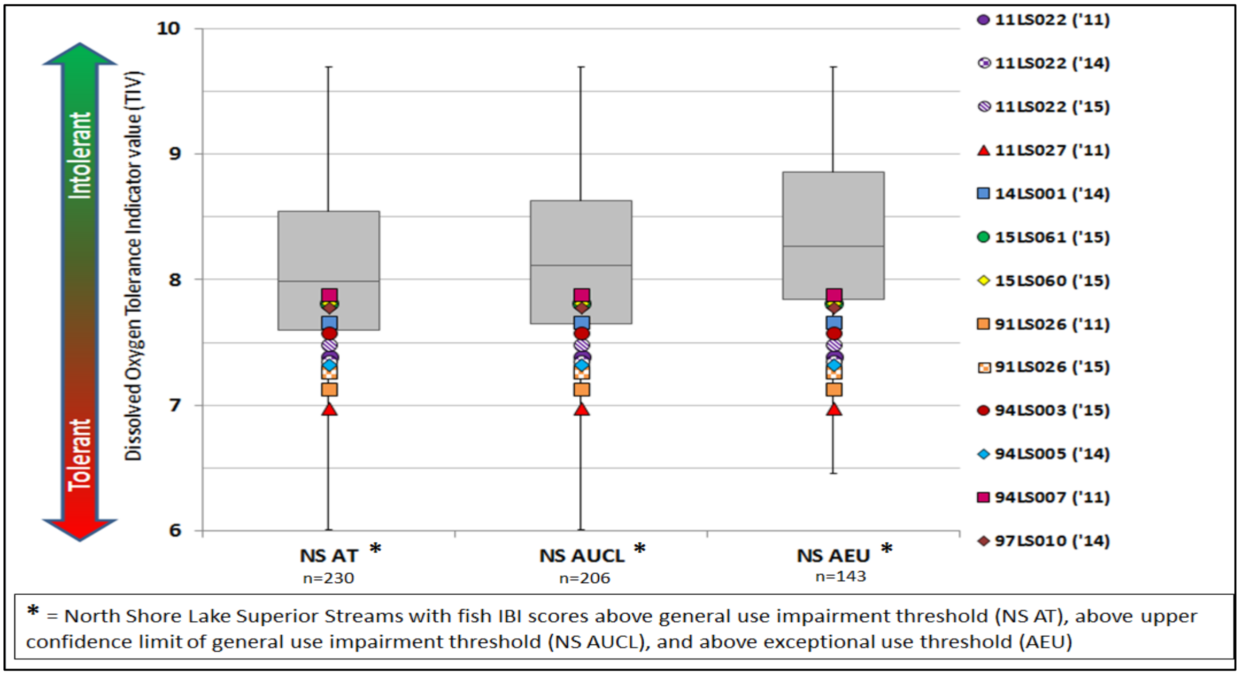


Figure 29. DO TIV for Talmadge River biological monitoring stations compared to results from comparable high quality reference stations. See Section 4.5 for TIV development.

Summary: Is low dissolved oxygen a stressor in the Beaver River?

The majority of the data collected suggest that DO concentrations in the Beaver River are suitable for supporting coldwater fish. During mid-summer low flow periods, DO concentrations occasionally fall below the 7 mg/L standard, particularly near the headwaters where low flows are common and wetland influences are prominent. Low minimum DO concentrations may be somewhat limiting to sensitive coldwater taxa around the Highway 15 crossing and upstream of that point. Brook Trout are commonly sampled in fairly good numbers several miles downstream and also down near the North Shore snowmobile trail crossing, which suggests that the lower DO concentrations observed near Highway 15 do not extend too far downstream.

Daily DO flux exceeded 3.0 mg/L in several of the monitoring periods, but was more commonly in the range of 1.5 mg/L. Moderate growths of periphyton algae have been observed near the stream gauging station at times, but the TP results and DO flux data do not suggest that eutrophication is resulting in persistent conditions that are stressful for aquatic life. Dissolved oxygen flux is a parameter to keep close watch on in this system during future monitoring efforts as climate change increases water and air temperatures.

The fish community of the Beaver River is neutral in terms of tolerance levels to low DO. DO TIV results do not compare favorably to the vast majority of the high quality coldwater streams on the North Shore.

However, the potential for confounding stressors must be considered, as water temperature data and habitat conditions in much of the Beaver River are marginal for many of the same species that are intolerant of lower DO. Low DO tolerant species were not common at most monitoring locations. Low dissolved oxygen and DO flux are not considered a primary cause of fish impairment in the Beaver River.

West Branch Beaver River

Dissolved oxygen data were collected at five monitoring stations along the length of the WBBR. YSI sondes were deployed to continuously record DO concentrations at these stations for periods of one to five weeks during mid-summer months, which tends to be the period that is most limiting to suitable DO levels. Our monitoring effort placed a high priority on collecting data from the biological monitoring reach (station S007-363/11LS028) and also targeted areas of the WBBR that are frequently impounded or hydrologically altered by beaver activity.

Dissolved oxygen in the WBBR varied considerably between monitoring stations, and was highly influenced by streamflow and beaver dam impoundments. DO concentrations were regularly below 2 mg/L for long durations of time at monitoring stations located immediately downstream of beaver impoundments (S007-947/S007-364). Diurnal (24-hour or daily) DO flux at these locations was also very low and responded more to pulses of streamflow than primary production within the stream. A representative example of this response to precipitation can be seen in the DO profile for station S007-364 in Figure 31. DO concentrations rapidly increase following several large rain events that occurred during this monitoring period.

DO concentrations within free-flowing, non-impounded reaches of the WBBR were more favorable for aquatic life, yet still fell below the 7 mg/L DO standard with regularity. Five continuous DO profiles were collected within the impaired biological monitoring reach (S007-364 / 11LS028) between the years of 2013-2015. DO concentrations were sub-7 mg/L for a significant percentage of the total time during each monitoring period; 36%, 56%, 76%, 88%, and 59%. These results clearly show that DO concentrations within this reach regularly fail to meet the minimum DO standard used for coldwater (trout) streams in Minnesota (7 mg/L). Our data suggest DO conditions in the WBBR are poor for supporting Brook Trout and other sensitive fish species as well as DO-sensitive aquatic macroinvertebrates.

Dissolved oxygen flux rates (daily maximum – daily minimum) in the WBBR significantly exceeded the MPCA's River nutrient criteria value for northern Minnesota (3 mg/L). Elevated DO flux in streams can be symptomatic of excess nutrients and unnaturally high primary productivity. In the WBBR, flux rates greater than 3 mg/L were observed at biological monitoring station 11LS028 and 05LS001, as well as the majority of the other non-biological monitoring sites that were sampled. Several monitoring stations in the lower WBBR exhibited extremely high DO flux rates of >7 mg/L. Within these lower reaches, streamflow is often stagnant and habitat and water chemistry are heavily influenced by vegetation commonly associated with wetlands. Beaver dams, poorly designed/installed culverts, and the wetland-nature of this area are all factors contributing to the high DO flux observed in this reach. Additional information related to the various sources and pathways contributing to elevated DO flux/Low DO is offered later in this section.

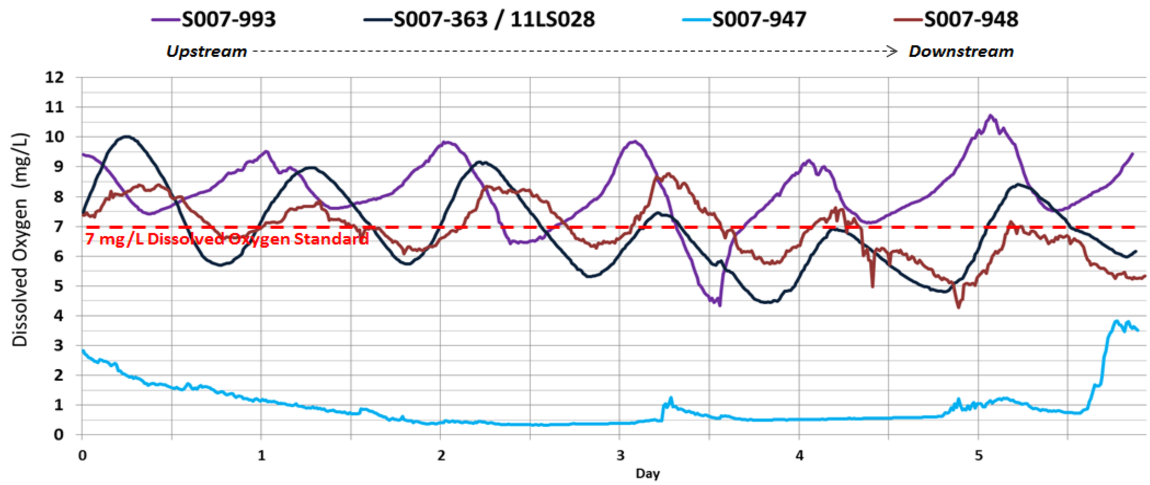


Figure 30. Dissolved oxygen profile collected in the West Branch Beaver River 7/18/14 – 7/24/14

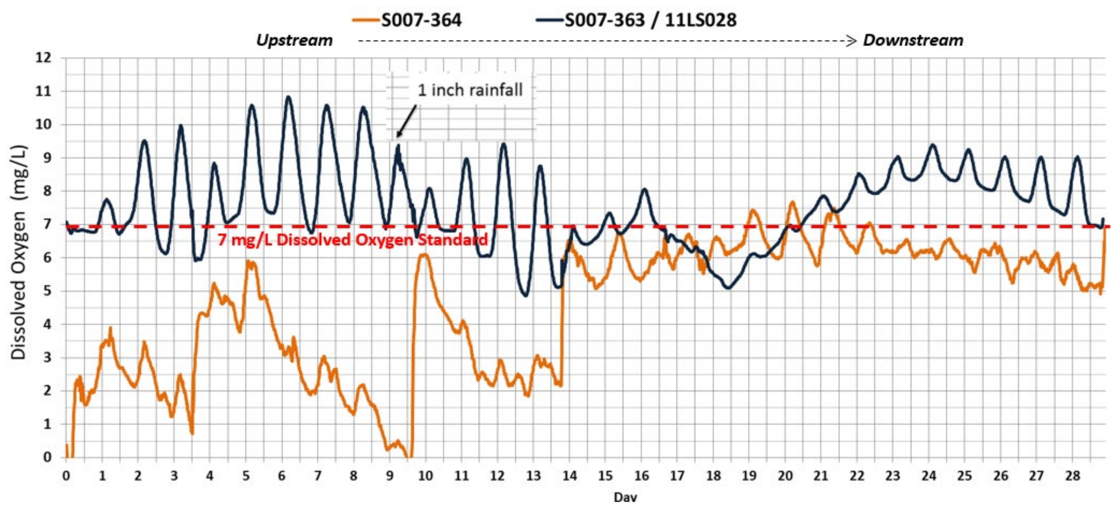


Figure 31. Dissolved oxygen profile collected in the West Branch Beaver River 8/19/15 – 9/17/15

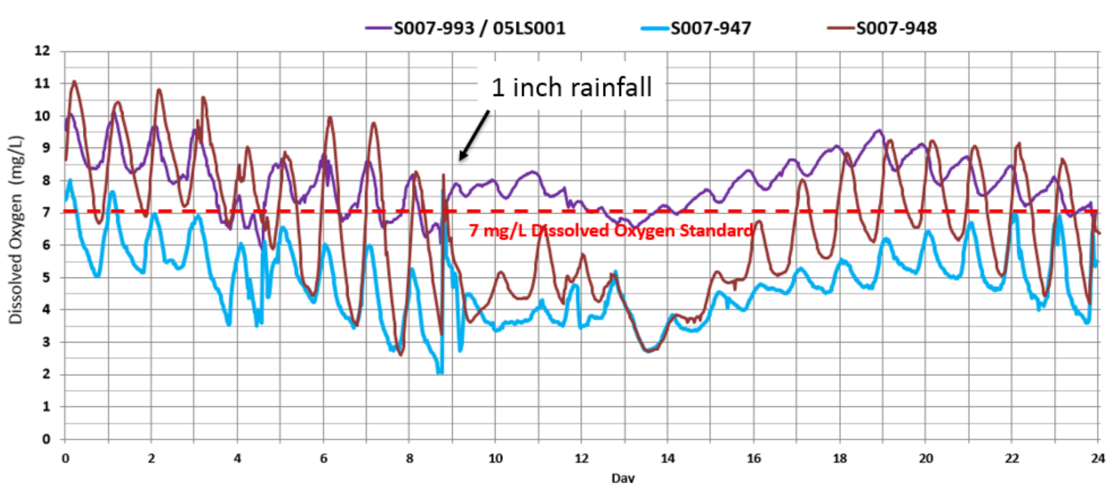


Figure 32. Dissolved oxygen profile collected in the West Branch Beaver River 8/24/15 – 9/17/15

Biological effects of low dissolved oxygen

The fish community of the WBBR is dominated by species that are found in streams with cool to warm temperatures and moderate levels of DO, such as Blacknose Dace, Creek Chub, Common Shiner, and Johnny Darter. Northern Redbelly Dace and Pearl Dace were also present and/or abundant at all WBBR stations. These two minnow species are commonly associated with wetland and/or headwater stream habitats and are found in streams with a wide range of DO concentrations. Several species that known to be tolerant of low DO conditions were observed in the WBBR, including Brook Stickleback, Central Mudminnow, Fathead Minnow, and White Sucker. These species were not dominant in any of the stream reaches sampled, although Brook Stickleback and White Sucker were relatively abundant at several stations.

The fish community TIV results provide further evidence that DO concentrations in the WBBR may be suitable for many cool and warmwater species, but marginal to poor for supporting more sensitive coldwater fish and macroinvertebrate taxa. The fish community DO TIV results for WBBR stations were well below the 25th percentile when compared to the results from North Shore coldwater streams with good to excellent biological integrity scores (Figure 33). Many of the streams with more favorable DO TIV results support species not observed in the WBBR, such as Brook Trout, sculpin spp., and Longnose Dace. The lack of these species in the WBBR, coupled with the presence of several that are tolerant of low DO, resulted in DO TIV results that rank poorly compared to other streams in the region.

Macroinvertebrate data from station 11LS028 (the only station sampled on the WBBR) share similarities to the fish results in that very few DO-sensitive taxa were present. Riffle beetle (*Optioservus*) and the non-biting midge *Brillia* were the only “low DO intolerant” taxa observed, and combined, individuals from these two taxa accounted for only 1% of the total individuals sampled. On the contrary, over 30% of the macroinvertebrate taxa observed at 11LS028 can be considered either “tolerant” (20%) or “very intolerant” (10%) of low DO concentrations. The air-breathing snail *Helisoma* was the most abundant of these low DO tolerant taxa. Other low DO tolerant taxa present that were abundant at this station include the amphipod *Hyalella* and the non-biting midge *Paramerina*. The macroinvertebrate community DO TIV result for station 11LS028 scored well below the 25th percentile when compared to the results from North Shore coldwater streams with good to excellent biological integrity scores (Figure 34).

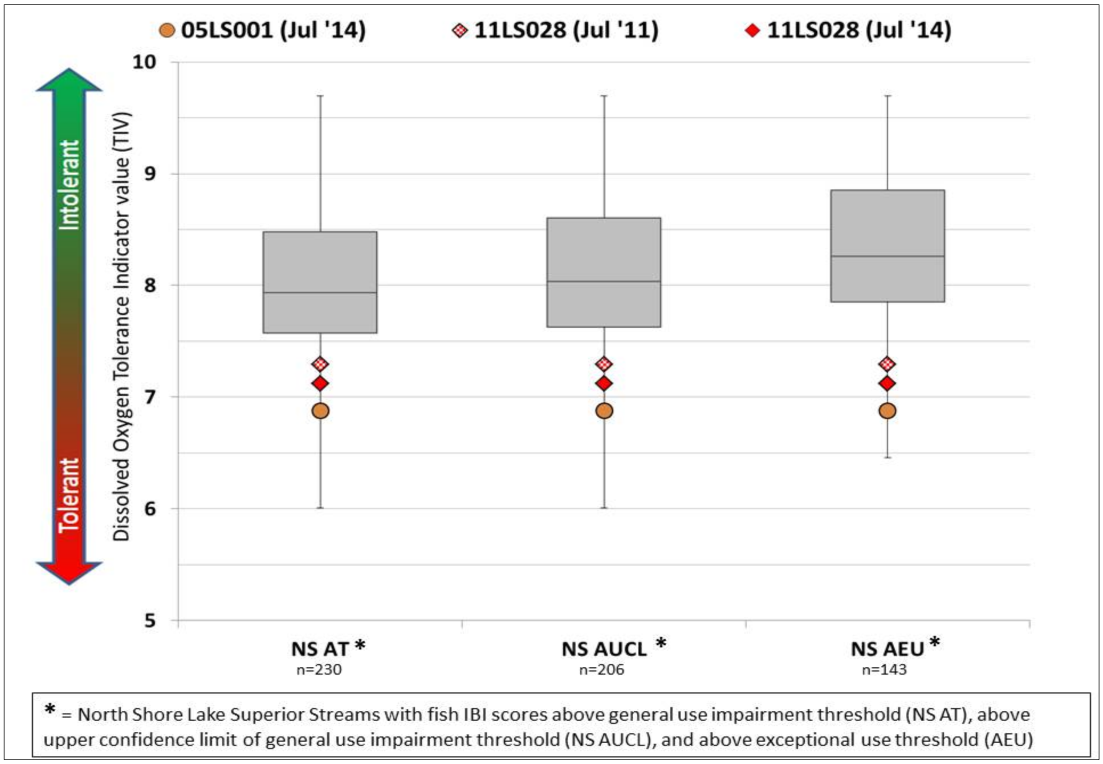


Figure 33. Fish tolerance indicator values (TIV) for DO at Talmadge River biological monitoring stations compared to results from comparable high quality reference stations. See Section 4.5 for TIV development

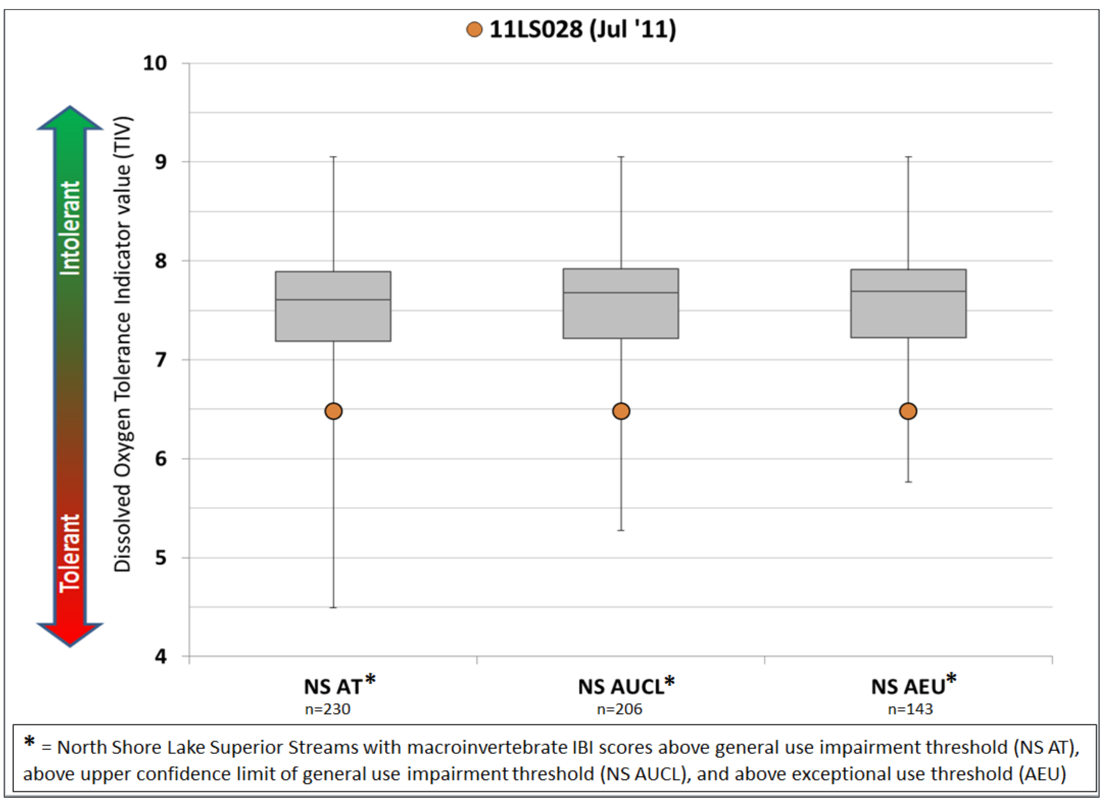


Figure 34. Macroinvertebrate TIV for DO at Talmadge River biological monitoring stations compared to results from comparable high quality reference stations. See Section 4.5 for TIV development

Sources and pathways of low dissolved oxygen

Wetlands

Wetlands provide valuable ecosystem services and are beneficial for maintaining and improving water quality conditions in lakes and rivers. However, depending on the type of wetlands present and their hydrologic connectivity to nearby streams, they can be a source of conditions that are limiting (e.g. low DO) to some forms of aquatic life. Wetlands were identified as the dominant source and pathway of low DO stressors in nearby watersheds in Northeastern Minnesota (Jasperson et al., 2016). Wetlands are a common feature of the WBBR watershed, accounting for over 26% of the total land area. The vast majority of these wetlands are considered “woody wetlands,” which are defined as areas of forest or shrub land that are “periodically saturated with or covered with water.”

Bourdaghs (2015) visited several stream locations on the WBBR with the goals of determining the prevalence of wetland characteristics within the stream channels, providing background information on how adjacent wetlands may be influencing stream conditions, and assessing the condition of vegetation in adjacent riparian wetlands. Both landscape scale data and on the ground monitoring were used to determine the hydrogeomorphic (HGM) classes of riparian wetlands at the monitoring sites. Bourdaghs (2015) concluded that the riparian wetland area for the majority of the WBBR can be classified as Amnicon-Fluvaquents soil type, which have mineral surface profiles (silt-loam) developed from clayey till parent materials. This soil series was confirmed on-site at biological monitoring station 11LS028. As the soils had mineral surface profiles and are frequently flooded. The adjacent riparian wetlands are best HGM classed as riverine, as riverine wetlands are typically receiving water from frequent flooding, they are not supplying the stream with low DO water over prolonged periods as slope or flat HGM wetlands would.

The following conclusions were reached by Bourdaghs (2015) in terms of the relationships between wetlands and stream conditions in the WBBR:

- One site (S007-947 – see Figure 37) has wetland characteristics within the channel. These characteristics likely extend both up and downstream from the site.
- The vegetation within the reach at S007-947 is dominated by a native species (*Equisetum palustre*) that only occasionally forms such dense stands, and the community is considered to be in good condition.
- The stream (WBBR) is providing the predominant water source to the wetlands, as opposed to the wetlands continuously supplying the stream with water.
- Adjacent riparian wetlands are in fair condition, though are very close to being in good condition.

Altered streamflow/Low streamflow

Low streamflow resulting from climactic events, hydrological alterations, or natural background conditions can have profound effects on the DO regime of a stream or river. As streamflow recedes, the water column can lose oxygen or experience changes in diurnal DO patterns due to a lack of reaeration (less turbulence), increases in water temperature, and increased productivity (e.g. algae growth). In this section we evaluate the potential for these factors to limit DO in the WBBR.

A quick review of precipitation and air temperature data for the period of 2013-2015 (the duration of this study) show no significant aberrations from the historical records. The year biological data were collected from the watershed for the initial assessments (2011) was a dry year, ranking between the 10th and 20th percentile of the modern record (50th percentile is equivalent to the "median", a measure of central tendency, Minnesota Climatology Working Group). All of the DO data collected for the stressor identification portion of this study were collected during years of normal to slightly above average rainfall, therefore seasonal drought can be eliminated as a cause of the low DO values observed. A more in-depth analysis of regional climate trends would be required to link low DO levels in the WBBR to global climate change.

Road crossings, beaver dams, and stream channelization are all factors that affect the hydrology and physical pattern and profile of the WBBR. Several large beaver dams were observed on the WBBR over the course of this study. Historical aerial photos of the area taken in 1940 reveal that some of these dams were present in nearly the same location over seventy-five years ago. The most recent aerial photos (2016) show a higher number of dams in the middle to lower portions of the WBBR in comparison to 1940, although the increase in dams is rather minimal. The potential for beaver dams to impact water quality and habitat conditions in the WBBR is not due to the number of dams, but rather their size, location, and the small size of the WBBR itself. Two large beaver dams were observed within the reaches of the WBBR evaluated for this study. Streamflow was typically stagnant downstream of these dams during site inspections (Figure 36). DO concentrations were significantly lower below beaver impoundments, particularly during lower flow conditions.

Several road crossings with poorly designed and/or failing culverts are impeding flow and could have a role in the low DO concentrations observed. Crossings at North Alger Grade (headwaters of WBBR), CSAH 3, and Buck Mountain Road are undersized have an impact on hydrology in this watershed. Beaver dams have been constructed near the CSAH 3 and Buck Mountain Road crossings and are prone to seasonal flooding during snowmelt and significant rainfall events.

Nutrients and productivity

Total phosphorus concentrations in the WBBR were below the applicable TP standard of 0.055 mg/L at most sampling locations. The exception was station S007-364, which exceeded the TP standard in two of the four samples collected. This particular station is located just downstream from a very large beaver dam impoundment (see Figure 38). TP is one of several WQ parameters negatively impacted from the impoundment of the stream at this location (temperature and DO being others). Very low DO concentrations (0.5 – 2.0 mg/L) were regularly observed downstream of this impoundment, which likely results in releases of TP into the stream from bottom sediments.

Samples from the WBBR were also collected for biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). BOD is included as a "response variable" in MPCA's river nutrient criteria, with the target value being 1.5 mg/L for streams in the northern nutrient region (Heiskary, 2012). BOD concentrations in the WBBR exceeded 1.5 mg/L in 6 out of 8 samples collected concurrently with continuous DO measurements. The highest BOD values occurred immediately downstream of the large beaver pond at station S007-364. COD was only sampled a single time in August of 2015, and the results were nearly identical at stations S004-364 (below beaver dam at Highway 3) and S007-363 (biological monitoring station 11LS028) which is located approximately one mile downstream. TOC results were only obtained during one sampling event, and increased in a longitudinal pattern from upstream to downstream. The largest increase in TOC was observed below the large beaver dam at Highway 3.

Figure 35. Samples collected upstream of large beaver dam at biological monitoring station 05LS001 (bottle 1 and far right photo) vs. immediately downstream of beaver dam (bottle 2). Note showing increase in staining due to organics.

Figure 36. A beaver dam upstream of station S007-947 reduces streamflow and influences the DO regime in this reach. These photos were taken from the same location November 14, 2015 looking upstream (left) and downstream (right) near the beaver dam.

Figure 37. Channelized reach of the WBBR adjacent to Highway 3. This reach is downstream of a beaver dam and water levels are frequently very low. Marsh horsetail (*Equisetum palustre*) covers much of the stream channel in the summer and fall

Figure 38. Aerial photo (left) and photo from Highway 3 (right) showing large beaver pond. DO concentrations were significantly lower downstream of the pond compared to free-flowing reaches upstream and 1+ miles downstream.

Table 14. Summary of TP results and other parameters associated with DO and river eutrophication

Sample date	Station	Total phosphorus (mg/L)	Biological oxygen demand (mg/L)	Chemical oxygen demand (mg/L)	Total organic carbon (mg/L)
7/23/2014	S007-993	0.013	1.5		12
7/23/2014	S007-364	0.053	***2.7***		17.3
7/23/2014	S007-992	0.023	0.7		17.9
7/23/2014	S007-947	0.030	***1.9***		19.6
8/10/2015	S007-364	***0.086***	***2.5****		
8/10/2015	S007-363	0.017	***2.4****		
8/19/2015	S007-364	***0.069***	***2.5****	55	
8/19/2015	S007-363	0.026	***2.1****	57	
9/17/2015	S007-993	0.020			
9/17/2015	S007-364	0.021			
9/17/2015	S007-363	0.040			
9/17/2015	S007-947	0.049			
9/17/2015	S007-948	0.026			
River nutrient standard (North)		0.055	≤1.5	n/a	n/a

Values in **BOLD/*italics*** exceed river nutrient criteria values
*Laboratory holding times exceeded. Results are approximate.

Summary: Is low dissolved oxygen a stressor in the West Branch Beaver River?

The water quality and biological data provide adequate evidence for diagnosing low DO as a stressor in the impaired reach of the West Branch Beaver River. Prolonged periods of very low DO (less than 2 mg/L) were observed frequently below several of the large beaver ponds that are present year-round. More suitable DO concentrations were observed in free-flowing reaches, including several of the biological monitoring sites. However, DO concentrations were found to drop below the 7 mg/L DO standard frequently and for long durations. The fish and macroinvertebrate community include very few sensitive taxa that are commonly observed in quality coldwater habitats.

DO concentrations are influenced by a variety of factors in the WBBR watershed. Seasonally low streamflows, warmer water temperatures, and the low stream gradient contribute to lower DO concentrations which are unsuitable for sensitive fish and macroinvertebrate taxa. Several large beaver ponds are also a major driver of low DO concentrations in the WBBR, as monitoring results show negative changes in water quality parameters and significant decreases in DO downstream of these ponds.

5.3.3 Specific conductivity (Ionic strength)

Elevated specific conductivity (ionic strength) was identified as a candidate stressor in the Beaver River based on the presence of several point source dischargers in the watershed, as well as existing data that show a departure from reference conditions for Lake Superior tributary streams (Figure 39). Water quality and biological data are evaluated in this section to determine if elevated ionic strength is contributing to the fish IBI impairment in the Beaver River.

Data summary

Both point (one-time, instantaneous "grab" sample) data and continuous monitoring results for ionic strength are available for evaluating this stressor. Point data are available for 15 monitoring stations on the Beaver River, and the period of record is extensive at several of these sites (1973-2015). The point sample results clearly show that ionic strength is elevated compared to other Lake Superior tributary streams along the North Shore (Figure 39). Median conductivity values in the Beaver River are somewhat comparable to the North Shore reference streams, but the >75th percentile values and extreme outliers are unique to this watershed (Figure 39) and are cause for concern in terms of causing undesirable changes in aquatic communities. The continuous discharge from the Milepost 7 tailings basin causes a pronounced increase in specific conductivity (Figure 39).

Continuous specific conductivity data were recorded for periods of one to three weeks during low to moderate flow conditions in the summers of 2013, 2014, and 2015. Results from stations upstream of the Milepost 7 discharge were typically between 100-200 µS/cm, with the exception of S006-273 during the August 2013 monitoring period, when slightly higher readings (200-300 µS/cm) were recorded. The continuous monitoring data highlight the changes in ionic strength that occur downstream of the Milepost 7 tailings basin discharge. Specific conductivity readings immediately downstream of the Milepost 7 discharge ranged from a low of around 350-400 µS/cm during wet periods to a high of 800-825 µS/cm during low flows (Figure 40 and 41). On August 4, 2015 the Milepost 7 discharge was reduced to zero for approximately 10 hours. The graph in Figure 41 shows the specific conductivity readings immediately downstream of the discharge point decreasing quickly towards natural background levels, and rising sharply once the discharge resumed.

Specific conductivity levels in the Beaver River gradually decrease downstream of Milepost 7 discharge, particularly below the confluence with the East Branch Beaver River (EBBR). If specific conductivity is altering biological communities in the Beaver River, the strongest symptoms of stress should be in the reach between the Milepost 7 discharge and EBBR confluence, and a gradient of impact should exist with decreasing effects in the downstream direction. The gradient of biological effect will be evaluated in detail in the "Biological Response to Elevated Ionic Strength" section on page 58.

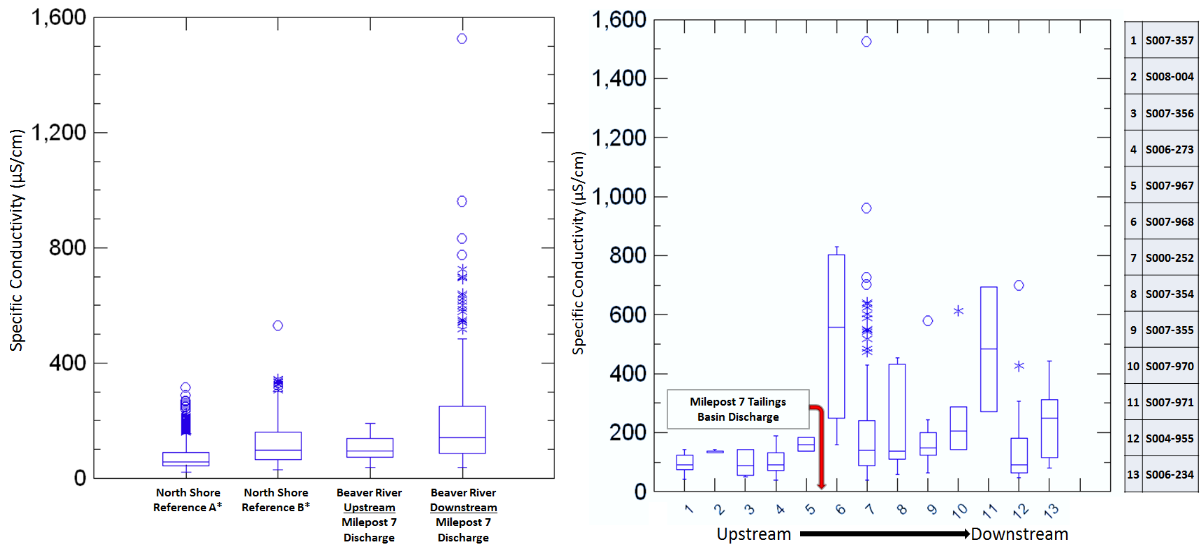


Figure 39. Summary of specific conductivity results in the Beaver River compared to other North Shore streams

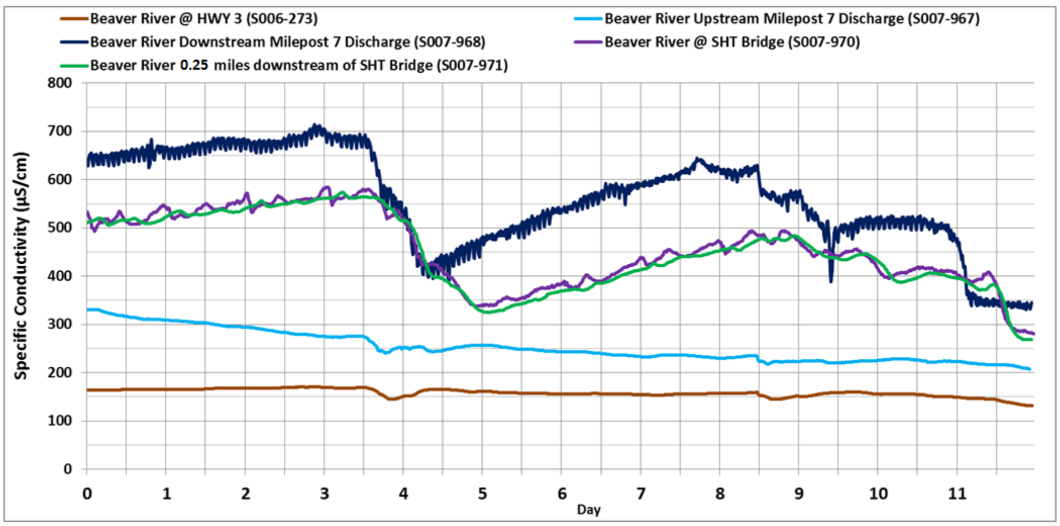


Figure 40. Continuous specific conductivity data from the Beaver River, collected 8/7/14 – 8/19/14

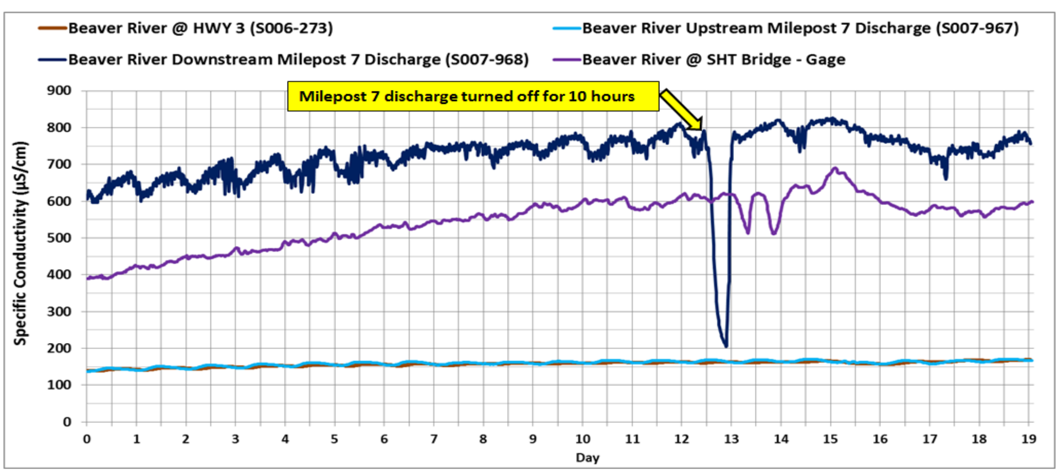


Figure 41. Continuous specific conductivity data from the Beaver River, collected 7/22/15 – 8/10/15

Sources and pathways contributing to elevated ionic strength

Treated wastewater is discharged to the Beaver River from the Milepost 7 Tailings basin at a nearly continuous rate of 5-10 cubic feet per second. Among other effects on water quality, this discharge increases the ionic strength of the Beaver River through loading of sulfate, chloride, sodium, fluoride, and other ions. Winter sampling results during extreme baseflow conditions highlight the changes in water chemistry downstream of the discharge point. The most significant changes (based on percentage increase) seen during winter baseflow were in chloride, bromide, sodium, sulfate, and fluoride. Despite some rather significant changes in water chemistry, there were no recorded violations of WQ standards for any parameter. There are currently no aquatic life-based water quality standards for ionic strength or sulfate.

As a condition of the permit to discharge, specific conductivity of the Milepost 7 effluent is monitored on a regular basis. On average, conductivity levels of the discharge are between 750 - 800 µS/cm, with a maximum 900 – 1000 µS/cm, and a minimum of 600 – 650 µS/cm. A summary of the discharge monitoring results is shown in Figure 46.

The Beaver Bay wastewater treatment pond (WWTP) is the other potential source of elevated ionic strength in this watershed. Specific conductivity is not among the list of parameters monitored by this facility per its permit requirements. Monitoring results from the Stressor Identification Study did not show any increase in ionic strength downstream of the WWTP discharge point. This facility discharges very few times annually, typically during the spring and fall seasons, and there is a good chance that releases from the ponds occurred outside of the MPCA's continuous monitoring periods. In comparison to the Milepost 7 discharge, the WWTP does not appear to be a significant driver of elevated ionic strength in the Beaver River. Also, it is unlikely that the WWTP discharge would have a prolonged effect on ionic strength due to the short duration and infrequent nature of the releases from the treatment ponds.

Figure 42. Beaver River upstream (left photo) and downstream (right photo) of Milepost 7 basin discharge point

Biological response to elevated ionic strength

Elevated ionic strength was identified as a potential stressor downstream of the Milepost 7 discharge. A total of six biological monitoring stations are located in the "impacted" reach, including one station immediately downstream of the discharge point (15LS060). Three monitoring stations are located a short distance upstream of the discharge and can be considered "control" stations.

Overall fish IBI scores show no consistent response to the increases in ionic strength below the Milepost 7 discharge. Immediately upstream of the discharge, a fish IBI score of 52 (17 points above impairment threshold) was recorded from a 2015 sampling event at station 15LS061. Station 15LS060, located immediately downstream of the discharge, was sampled on the same day (July 1, 2015) and scored a 51 on the IBI. A comparison of the fish assemblage between the two stations shows a high degree of similarity. Species found above the discharge but not below include Brook Trout (only one individual sampled) and Central Mudminnow. Mottled Sculpin and Northern Redbelly Dace were collected only at the station downstream of the discharge. Both stations were highly dominated by Blacknose Dace and Longnose Dace (84 – 87% of total fish community). At the time of fish sampling, specific conductivity was 91 µS/cm upstream of the discharge and 352 µS/cm downstream. One month later during the macroinvertebrate sampling, the readings were much higher and showed a higher degree of separation in sp. conductivity values (197 µS/cm upstream; 1041 µS/cm downstream).

Moving downstream away from the Milepost 7 discharge, fish IBI scores vary considerably, but show a downward trend. The three lowest fish IBI scores recorded on the Beaver River were from the two downstream-most stations (11LS022 and 14LS001) and another station upstream of the Milepost 7 discharge. These stations are not spatially co-located with the most elevated specific conductivity readings in the watershed and the decrease in fish IBI scores appear to be linked to other stressors, namely water temperature and physical habitat. These results provide further evidence against elevated ionic strength as a main cause of the fish IBI impairment.

Fish community TIV for ionic strength were tightly clustered into two groups (Figure 43). One group had TIV results that were higher (more tolerant of elevated ionic strength) than 75% of the reference streams used for comparison. This group included two stations downstream of the Milepost 7 discharge (11LS022 and 94LS003), and one station 1.5 miles upstream of the discharge (91LS026). A station (11LS027) located near the headwaters of the river, which are relatively undisturbed, also had a TIV result that exceeded the 75th percentile value of many of the reference streams. These results suggest that the TIV results are influenced by confounding stressors and are unrelated to changes in ionic strength in the Beaver River.

Macroinvertebrate IBI (MIBI) scores from the stations above and below the Milepost 7 both meet the general use standard for coldwater streams and do not indicate impairment. The MIBI score at station 15LS060 (immediately below the discharge) of 56.0 is above the exceptional use standard (52), and slightly higher than results from 15LS061 (47.6; just downstream of discharge). Despite the lower MIBI scores, there are some differences between the two stations that may be related to the sharp increase in specific conductivity observed in this reach of the river. A larger number of macroinvertebrate taxa were sampled upstream of the discharge than below (43 at 15LS061; 38 at 15LS060) and a wider gap was observed in the number of POET taxa sampled (25 upstream, 18 downstream). Larvae from several sensitive caddisfly, stonefly, and dragonfly taxa were sampled upstream of the discharge, but were not found immediately downstream. The sampling sites are very similar in terms of physical habitat, but have different temperature and water chemistry characteristics due to the discharge.

As with the fish data, there are many inconsistencies in the ionic strength stressor-response results in the macroinvertebrate community. Macroinvertebrate community TIV were calculated for Beaver River monitoring stations using taxa-specific tolerance values, weighted by relative abundance. Based on the TIV results, the most tolerant macroinvertebrate assemblage in terms of specific conductivity was observed at station 91LS026. This station is located several miles upstream of the Milepost 7 discharge, where specific conductivity readings are generally between 100-200 µS/cm and comparable to healthy, high quality coldwater streams in the region. The TIV values directly above (15LS061) and below (15LS060) the Milepost 7 discharge were almost identical, indicating very little change in macroinvertebrate community tolerance to ionic strength between these two stations. As a whole, the TIV results for Beaver River monitoring stations were slightly higher than the majority of the high quality stations in the same MIBI class (Northern Coldwater). However, the lack of co-located cause and effect weakens the case for elevated ionic strength as a cause of impairment.

Summary: Is elevated ionic strength a stressor?

Despite the significant increase in ionic strength downstream of the Milepost 7 discharge, there are inconsistencies in the stressor-response data that weaken the case for ionic strength as a primary cause of the fish impairment. The fish assemblages and IBI scores are very similar upstream and downstream from the affected area, and the stations with the poorest fish IBI results are well above or well below the discharge point. The effects of elevated conductivity on the fish community may be less apparent in the vicinity of the Milepost 7 discharge due to the relatively high quality physical habitat found in that reach.

Elevated ionic strength can be eliminated as a stressor due to the lack of a biological response at the most impacted stations. Specific conductivity levels in the lower Beaver River are highly elevated compared to un-impacted, reference quality North Shore streams. However, there are other stressors in the Beaver River watershed that show a more consistent linkage to the impaired condition (e.g. elevated water temperature, poor physical habitat).

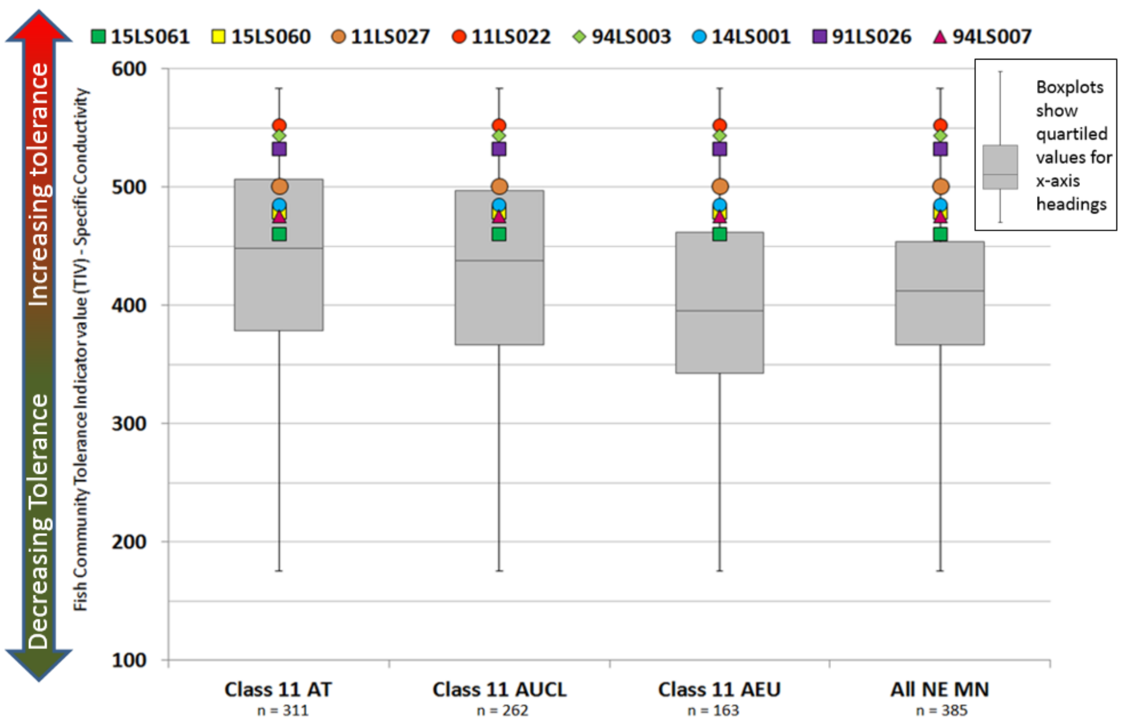


Figure 43. Collection of box-plot distribution graphs comparing biological response data from Beaver River to results from other Class 11 (Northern Coldwater) biological monitoring stations * See Section 4.5 for explanation of TIVs. AUCL = Stations scoring above upper confidence limit of FIBI threshold; AT = Stations scoring above FIBI threshold; AEU = Stations scoring above exceptional use criteria; ALL NE MN = All Northeast Minnesota biological monitoring.

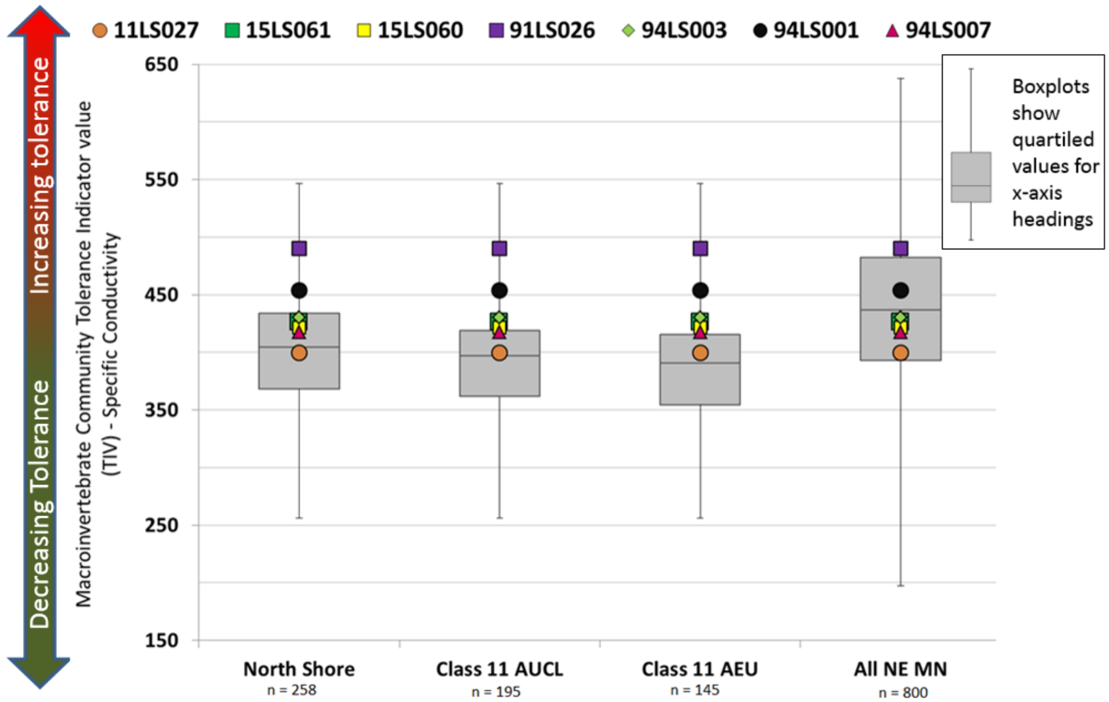


Figure 44. Collection of box-plot distribution graphs comparing biological response data from Beaver River to results from other Class 11 (Northern Coldwater) biological monitoring stations * See Section 4.5 for explanation of TIVs. AUCL = Stations scoring above upper confidence limit of FIBI threshold; AT = Stations scoring above FIBI Threshold; AEU = Stations scoring above exceptional use criteria; ALL NE MN = All Northeast Minnesota biological monitoring stations.

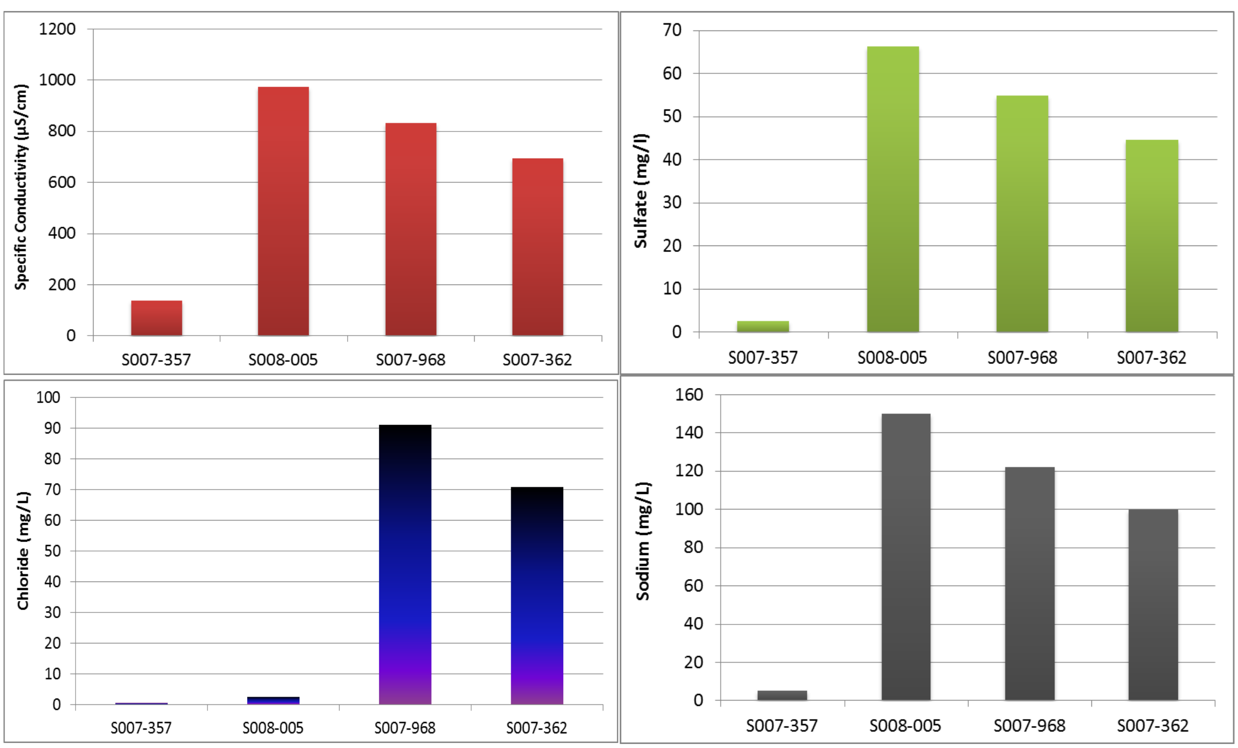


Figure 45. Sampling results from baseflow sampling during February of 2015. Milepost 7 discharge enters the Beaver River upstream of S008-005. Stations arranged in upstream to downstream order from left to right.

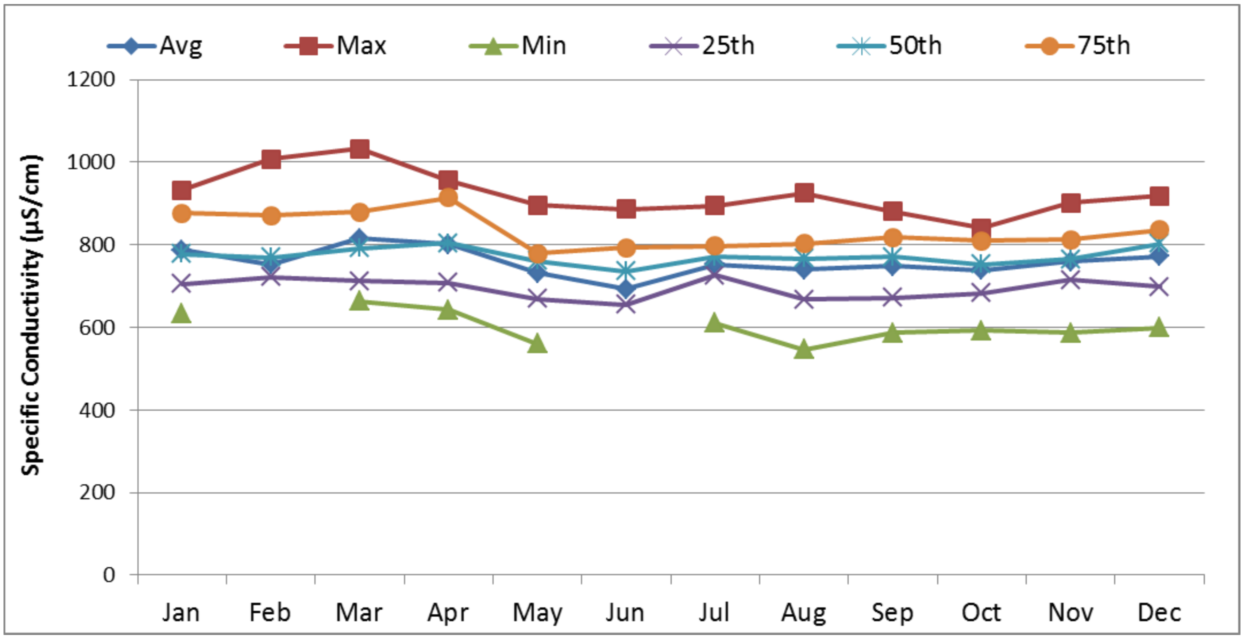


Figure 46. Summary of specific conductivity levels of Milepost 7 Tailing Basin discharge to Beaver River

5.3.4 pH

The Beaver River was listed as impaired for elevated pH during the 2002 water quality assessment process. Although the entire reach was listed (AUID 04010102-501- Headwaters to Lk Superior), the impairment designation was in response to elevated pH levels that were only observed in the lower third of the river. Due to the existing impairment and the presence of several point source discharges in the watershed, elevated pH was identified as a potential cause of the fish IBI impairment.

Data summary

Both point (one-time, instantaneous "grab" sample) data of pH and continuous monitoring results are available for evaluating pH concentrations and their potential impact on aquatic life. Point sampling results span many years of sampling (1973–2015) and provide robust data for a small selection of stations on the river, the majority of which are within a river mile or two of the Beaver River's outlet into Lake Superior. The continuous pH data were collected during the course of the Stressor Identification Study (2013-2015) and provide a short-term record of pH conditions at sites of high interest (e.g. upstream/downstream of point source discharge areas, spatial coverage of the watershed).

Point sample pH results are summarized in Table 15. The pH maximum standard for coldwater trout streams (8.50) was exceeded at three of the stations at a relatively low rate (5-15% of samples). For a stream to be considered impaired, at least 10% of the samples must violate the pH standard, with a minimum of 20 representative measurements needed for an assessment. These criteria were met at three stations, with station S006-273/S007-362 falling just one sample short. Among these four stations with relatively large data sets, only station S006-273/S007-362 did not record one ore more violations of the pH standard. This particularly station is the lone station in this set that is located upstream of the Milepost 7 taconite tailings pond discharge. A maximum pH of 9.08 was observed at station S000-252 in late November of 2009.

Table 15. Summary of pH sampling results for Beaver River monitoring stations

Drainage Area (sq. mi.)	EQUIS	# Obs.	pH Max	pH Min	pH Avg	# > pH Standard	% > pH Standard
4.7	S007-357	8	7.63	6.30	7.03	0	0%
16.3	S008-004	2	7.72	7.19	7.46	0	0%
40.2	S007-356	5	7.47	7.00	7.16	0	0%
53.9	S006-273/S007-362	19	8.06	6.83	7.30	0	0%
64.1	S007-967	2	8.39	7.99	8.19	0	0%
68.8	S007-968	4	8.43	7.79	8.11	0	0%
69.2	S000-252	301	9.08	6.20	7.80	26	9%
70.9	S007-354/S007-355	13	8.29	7.10	7.55	0	0%
121.8	S007-970	5	8.37	7.34	7.84	0	0%
122.7	S004-955	20	8.73	6.84	7.66	1	5%
123.0	S006-234	20	8.53	7.06	8.08	3	15%

Several noteworthy observations can be gathered from the continuous data. First, the discharge entering from the Milepost 7 tailings basin has a stabilizing effect on the pH levels in the Beaver River. Upstream of the Milepost 7 discharge at stations S007-967 (and also S006-273, to a lesser extent) the daily fluctuation in pH is much more pronounced (approx. 0.7 units) compared to data from downstream of the discharge point (S007-968, S007-354, S007-971) (Figure 47). When the Beaver River is at low flow, the Milepost 7 discharge accounts for a significant portion (up to 50%) of the flow from the discharge point downstream to Lake Superior. As a result, the pH regime (as well as temperature, DO, and conductivity) of the river downstream of this point is closely linked to the conditions of the effluent leaving Milepost 7 tailings pond area. The effect of the Milepost 7 discharge on pH can be clearly seen between Day 12 and Day 13 of the data presented in Figure 47 (top graph). The discharge from the tailings basin was reduced to zero on August 14, 2015 for approximately 10 hours, and the pH results from the Beaver River below Milepost 7 showed an immediate response.

Violations of the maximum pH standard (8.50) were observed at locations upstream and downstream of the Milepost 7 discharge during continuous monitoring profiles. The highest rate of standard exceedance occurred at a station located immediately upstream of the Milepost 7 discharge point (S007-967). The standard was exceeded at this station approximately 10-11% of the time and for relatively short durations (average of about two hours) during afternoon/evening hours (Figure 47). Immediately downstream of the Milepost 7 discharge, pH levels of the Beaver River were right at the maximum standard of 8.50, yet rarely exceeded that value. A few river miles downstream, more regular exceedances of the pH standard were observed at station S007-354 (Beaver River at CR-4).

In Figure 47 (bottom graph), a significant difference in pH is evident between stations at the “CSAH 3” and “Upstream of Milepost 7” monitoring stations. The West Branch Beaver River enters between these two stations, but data collected from this tributary showed pH levels comparable to, if not lower than results from Beaver River at CSAH 3. The cause of the increase in pH between CSAH 3 and Upstream of Milepost 7 monitoring stations is unclear, but could be related to an increase in primary production, as DO concentrations at the two stations show a similar trend.

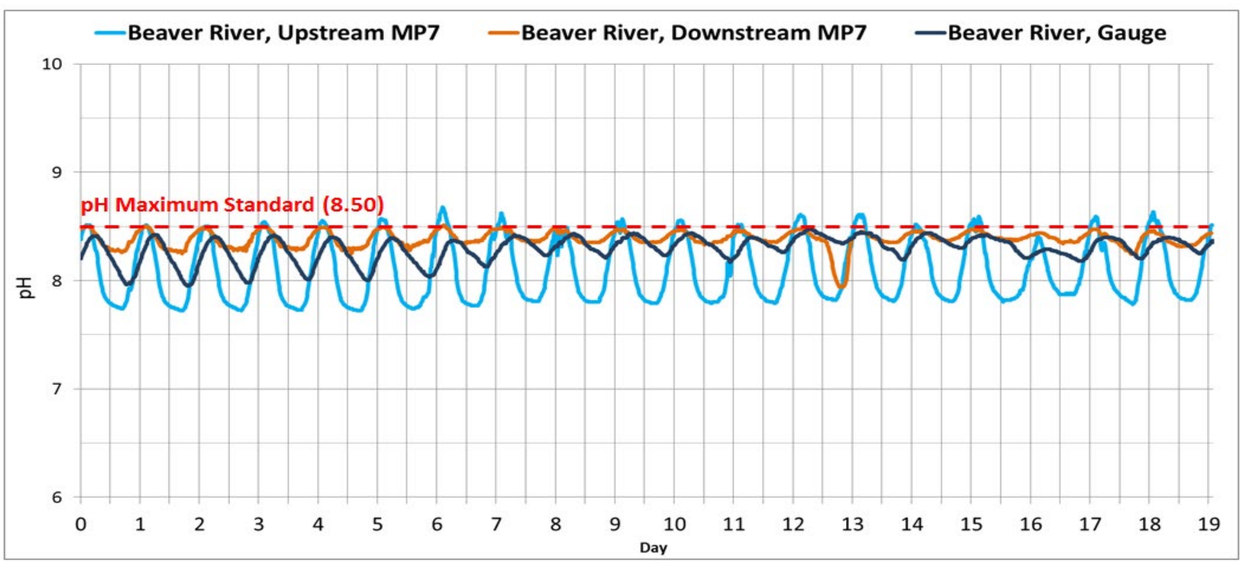
The upper Beaver River has a pH closer to 7.00, which reflects the prominent wetlands that exist in this portion of the watershed. Throughout the upper half of the watershed, pH levels are well within the suitable range for Brook Trout and other sensitive fish species found in coldwater streams.

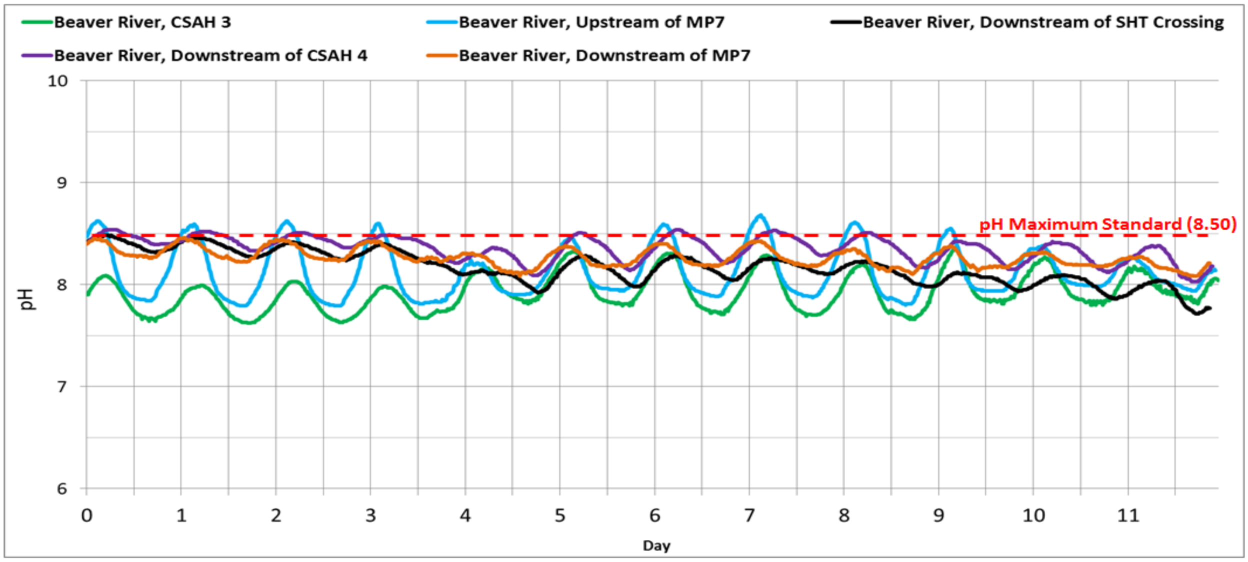
Sources of elevated pH

Milepost 7 Taconite Tailings Basin

The Beaver River receives treated wastewater from the Milepost 7 taconite tailings basin at an average rate of 6 cubic feet per second (cfs). During low flow periods, this wastewater discharge can account for up to 54% of the baseflow (see Section 5.3.8) in the lower Beaver River and alters water chemistry conditions. The wastewater treatment process at the outlet of the basin regulates the pH of the effluent to comply with discharge permit requirements. A summary of effluent monitoring results is provided in Table 16. Average monthly maximum pH values of the effluent ranged from 7.37 – 7.61, and overall monthly maximum pH ranged from 7.80 – 8.40. Based on the monitoring data associated with the discharge permit, the pH of the treated effluent from Milepost 7 basin complies with pH standards for coldwater streams. Additionally, the pH of the effluent is, at times, lower than that of the Beaver River upstream of the discharge point based on continuous monitoring data.

Groundwater sampling was not completed during the Stressor Identification monitoring period, but should be considered for future studies of the Beaver River watershed. Groundwater contamination due to seepage from the Milepost 7 basin or other sources is one possible explanation of the high pH levels upstream of the Milepost 7 discharge. A series of groundwater monitoring wells positioned around the basin are regularly monitored by Cliffs-Erie as part of the wastewater discharge permit. Data from monitoring wells located down gradient from the basin show higher pH levels than those located up gradient (Figure 48). Stations GW 001, GW 011, and GW 012 are located down gradient of the basin and samples collected from these stations regularly exceeded the 8.50 pH standard. A few of the stations up gradient of the basin exceeded the pH standard on very rare occasions, however, the vast majority of the pH readings from these stations are well below the standard. The hydrologic connectivity between these groundwater wells and the nearby Beaver River is unknown and would require more detailed monitoring to evaluate in detail.





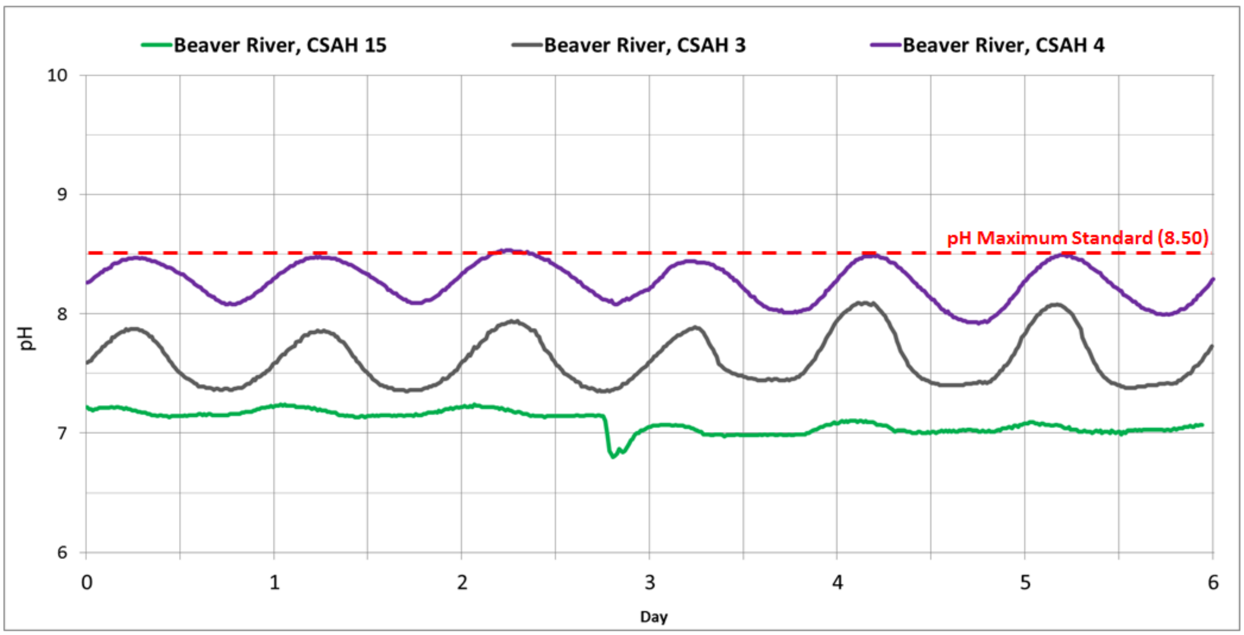


Figure 47. Continuous pH monitoring results for several Beaver River stations; *top:* 7/22/2015 – 8/10/2015, *middle:* 8/7/2014 – 8/19/2014, *bottom:* 8/16/2013 – 8/22/2013

Table 16. Monthly Maximum pH of Effluent Discharged to Beaver River from Milepost 7 Taconite Tailings Basin based on monitoring data collected between the years 2000 – 2015.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg.	7.37	7.46	7.49	7.44	7.55	7.44	7.54	7.59	7.57	7.62	7.53	7.62
Max	7.80	8.40	7.80	7.80	8.10	8.00	7.80	7.90	7.90	8.30	7.90	8.40
Min	6.41	6.50	7.00	6.61	7.02	6.60	7.22	7.22	7.17	7.17	6.76	6.82
25th	7.23	7.31	7.39	7.33	7.40	7.30	7.47	7.46	7.41	7.50	7.40	7.50
50th	7.40	7.58	7.50	7.40	7.49	7.45	7.50	7.60	7.60	7.60	7.57	7.60
75th	7.60	7.68	7.65	7.63	7.70	7.63	7.63	7.73	7.75	7.75	7.70	7.80

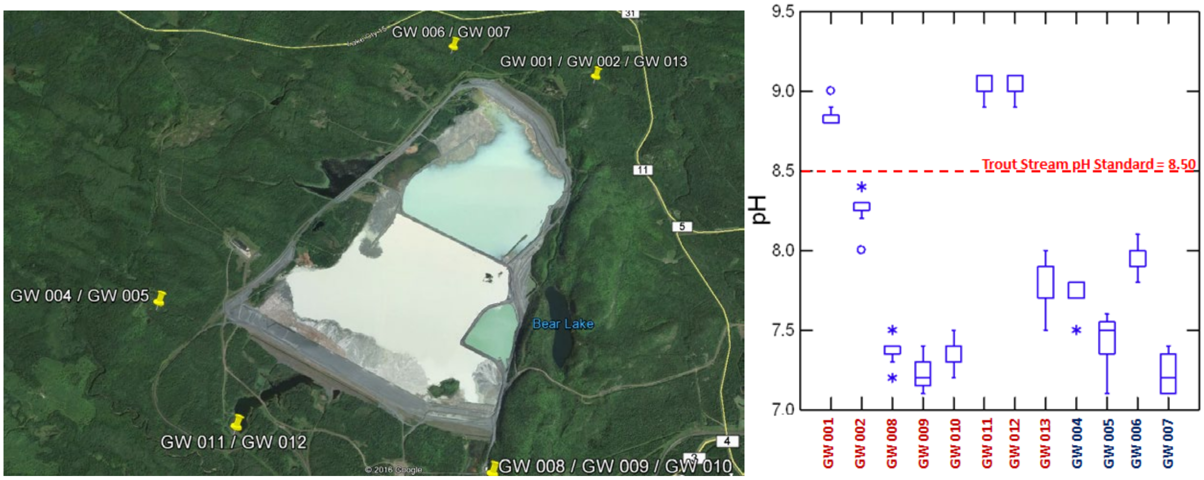


Figure 48. Location of groundwater monitoring wells in the vicinity of Milepost 7 taconite tailings basin (left); and monitoring results for pH (right)

Beaver Bay Wastewater Treatment Ponds

The wastewater treatment ponds (WTP) for the city of Beaver Bay discharge treated wastewater into the Beaver River several miles upstream of its outlet into Lake Superior. The pH levels of the river are already elevated at this point, and monitoring results suggest that the WTP discharge does not have a negative impact on pH. Effluent monitoring data shows an average pH of 7.40 (n=152; min = 5.90; max = 8.70). Only 1 out of 152 measurements (0.6%) of the effluent readings have exceeded the 8.50 maximum pH standard. Based on the effluent monitoring results and the intermittent nature of the discharge from the WTP, it is unlikely that this source plays a major role in the elevated pH concentrations observed in the Beaver River.

Primary productivity/West Branch Beaver River

Photosynthesis from abundant plant or algae growth removes carbon dioxide from the water, causing a rise in pH. Many reaches of the lower Beaver River are shallow and sun-exposed, which create favorable conditions for abundant algae growth and/or aquatic macrophytes. The limiting factor for most streams and lakes in terms of productivity is phosphorous, and the Beaver River does, at times, carry higher phosphorous concentrations in its lower reaches from station S000-252 downstream to Lake Superior (Figure 28 in Section 5.3.2). Significant mats of periphyton algae (attached to submerged rocks) have been observed near the streamflow gaging station, but are not a common feature in other reaches of the Beaver River.

The West Branch Beaver River (WBBR) joins the main Beaver River between the two monitoring stations that show the most drastic increases in maximum pH and pH flux. Due to the numerous wetland areas and beaver dams in the WBBR watershed, the pH level of this stream tends to be lower than the main stem of the Beaver River. The highest pH observed in the WBBR was 8.12 (July 23, 2014), and the average pH observed in this tributary stream is around 7.10 (n=40). These monitoring results suggest that the WBBR is not a direct cause of elevated pH levels in the Beaver River.

The majority (86%) of the total phosphorous (TP) results from the WBBR were below the river nutrient criteria standard of 0.055 mg/L (with the exception of several samples collected below a large beaver impoundment). However, diurnal DO flux was elevated (> 6.70 mg/L) during August of 2015 near the mouth of the WBBR at station S007-948. It is possible that these conditions in the WBBR are influencing DO and pH levels 1.5 miles downstream at Beaver River station S007-967, which is just upstream of where the Milepost 7 discharge enters.

Biological response to elevated pH

Laboratory studies indicate that Brook Trout are somewhat tolerant of wide range of pH values (3.5 – 9.8) (Daye and Garside, 1975), but the optimal range appears to 6.50 – 8.00 (Raleigh, 1986). A pH of 8.00 was exceeded with regularity in the Beaver River from Highway 3 downstream to Lake Superior and may contribute to the lack of naturally reproducing Brook Trout in this reach. The presence/absence of Brook Trout is not an adequate metric for diagnosing high pH as a stressor in this watershed given the presence of other stressors that are widely known to reduce Brook Trout abundance and distributions (temperature, habitat, TSS/turbidity).

Stressor information from the EPA states that the effects high/low pH levels are not specific enough to be symptomatic. However, some documented effects of high/low pH on aquatic life include decreased growth and reproduction, decreased biodiversity, and damage to skin, gills, eyes, and organs. Fish biodiversity in the Beaver River ranged from 7 - 13 species depending on the station, with the lowest richness at 94LS004, 91LS027, and 94LS003. These stations are located in a 2-3 mile reach downstream of the Milepost 7 discharge. An extensive data set for pH exists for this reach and 9% (26 of 301) observations exceed the 8.50 standard. Physical habitat is in relatively good condition in this reach and is not likely a limiting factor. Although taxa richness was lower in this reach, several sensitive species were present in large numbers, including Longnose Dace and Mottled Sculpin. The Milepost 7 discharge does not appear to have a direct impact on fish taxa richness immediately below the discharge point, as taxa richness is very similar just above (15LS061) and below (15LS060) the discharge point (Figure 49).

There is no history of fish suffering from severe skin or organ damage in the Beaver River. Some sporadic DELT (deformities, eroded fins, lesions, tumors) abnormalities were recorded within the river system during sampling events, but the majority of these instances were cases of "black spot" (*neascus*), which is common and not linked to pH levels. Four of the fish collected in summer 1997 from station 97LS055 were affected by deformities and lesions, but these represented approximately 0.5% of the total population sampled.

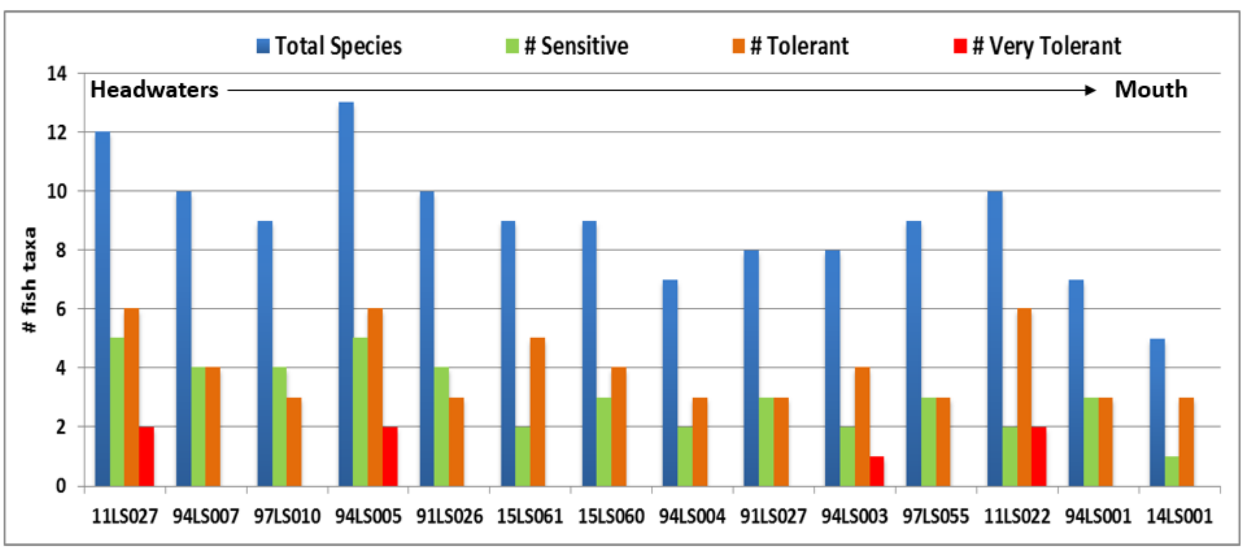


Figure 49. Fish taxa richness observed at Beaver River biological monitoring stations. Stations are arranged upstream to downstream order from left to right.

Summary: Is elevated pH a stressor in the Beaver River?

Stream pH levels in the middle and lower reaches of the Beaver River are elevated and violate Minnesota water quality standards. The cause(s) of the elevated pH levels remain unclear, but possible sources include stream eutrophication (esp. from West Branch Beaver River), seepage of untreated wastewater from the Milepost 7 tailings basin, and/or inputs from local geologic conditions. The direct discharge of treated wastewater from the Milepost 7 tailings basin and city of Beaver Bay WWTP do not appear to be directly responsible for raising pH levels in the Beaver River. Both of these facilities are regularly monitoring treated wastewater, and results show a good compliance record with their discharge permits.

Biological response to elevated pH levels is inconclusive. There are no major changes in the fish community that can be linked to an altered pH regime with high confidence due to the presence of confounding stressors (e.g. temperature, turbidity, habitat). Fish IBI scores and community data do not respond in a consistent manner to changes in pH. Additional monitoring should be pursued during the TMDL development process to determine the cause(s) of elevated pH in the Beaver River. Provided that water quality data exceeds state standards on a regular basis, elevated pH should remain a candidate cause for impairment, but there is not a definitive linkage to the fish IBI impairment based on the data reviewed during the SID process.

5.3.5 Physical habitat

Physical habitat conditions were evaluated using two methodologies; the MSHA protocols, developed by MPCA and used statewide by biological monitoring crews; and a Brook Trout Suitability Assessment (BTSA) developed by the authors. The BTSA is a modification of an assessment developed by Bidelspach (n.d.) used to assess and rank trout habitat in Colorado. Details on each of these methods are covered in Section 4.2 and Appendix A.

Results of Habitat Assessments: West Branch Beaver River

MSHA metric results for the NE Region of Minnesota were compiled and sorted into decile distributions to develop a letter grade (A-F) scale for each metric. A statewide MSHA data set was used to develop the scale for the "Riparian" metric due to a lack of variability in the results for NE Minnesota. More information on the development of the MSHA grading scale is located in Section 4.2. MSHA results are available for two stations on the WBBR, 11LS028 and 05LS001. The fish and macroinvertebrate IBI results from 11LS028 were the basis for the impairment listing, although scores at 05LS001 were also below the impairment threshold.

The BTSA results for station 11LS028 on the West Branch Beaver River were compared to a reference reach in order to identify any limiting factors related to physical habitat. The reference reach used for comparison (Little Gooseberry River - station 11LS004) is a stable reach of the same stream and valley type, Rosgen E5/valley type X (Rosgen, 1996), and scored favorably in fish and macroinvertebrate IBI assessments. A complete comparison of BTSA results between these two stations is shown in Figure 50.

Limiting habitat conditions in impaired reach
(1) Channel morphology

MSHA grades for channel morphology ranged from C- (station 11LS028) to C+ (station 05LS001). Poor attributes contributing to the lower grade at station 11LS028 include a slightly incised stream channel and a lack of variability in water depth. Compared to the reference reach used, station 11LS028 had a higher with to depth (W/D) ratio at low flow (Figure 50). A high W/D ratio is the result of a wide, shallow channel that lacks a well-defined "inner-berm." These conditions result in poor low-flow habitat and can render streams more vulnerable to warming and sedimentation.

Maximum depth and width depth ratio are critical variables with proven relationships to fish abundance, size, and species distribution. Nuemann and Wildman (2002) found that Brook Trout density increased with greater habitat unit depth and decreasing width to depth ratio. These two variables had some of the strongest relationships with adult trout density among all of the physical habitat variables tested by the authors. A few deep pools were present within the sampling reach at 11LS028, but shallow water during dry periods result in marginal to poor channel conditions for supporting Brook Trout and other fish species that are dependent on cover and sufficient water depths.

(2) Cover and woody debris

A lack of large woody debris (LWD) cover, or fish cover in general, was another limiting factor identified in the impaired reach of the West Branch Beaver River (WBBR). Most of the riparian corridor along the WBBR consists of alder, dogwood, small willows, and grasses. Few inputs exist for large woody debris as a habitat feature. Fine woody debris (often called fine particulate organic matter or FPOM) was also a limiting factor that emerged from comparing station 11LS028 to the reference reach (Figure 50). MSHA results for cover corroborated the BTSA findings, giving the impaired reach a grade of "C" for fish cover. Some cover is present within this reach due to some undercut banks and aquatic vegetation. Streams of the E channel type in broad, lacustrine valleys often have less LWD as cover due the wetland/wet meadow riparian vegetation (forbs/shrub). However, the reference channel has retained some LWD features due to fewer disturbances in the riparian corridor and superior channel stability (Figure 51).

LWD and other types of fish cover are critical components of healthy trout streams, and the availability of these cover types have been shown to positively affect adult and sub-adult Brook Trout density (Nuemann and Wildman, 2002; Dechenes and Rodriguez, 2007). The shallow water depths and lack of in-stream cover elements within the impaired reach of the WBBR are a limiting the potential of this stream to support trout and other species that are cover dependent. Other factors such as low streamflow and low DO are perhaps more critical deficiencies related to coldwater habitat within this reach, but the lack of LWD and cover affects all aquatic life, fish, macroinvertebrates, and other organisms that inhabit riparian areas.

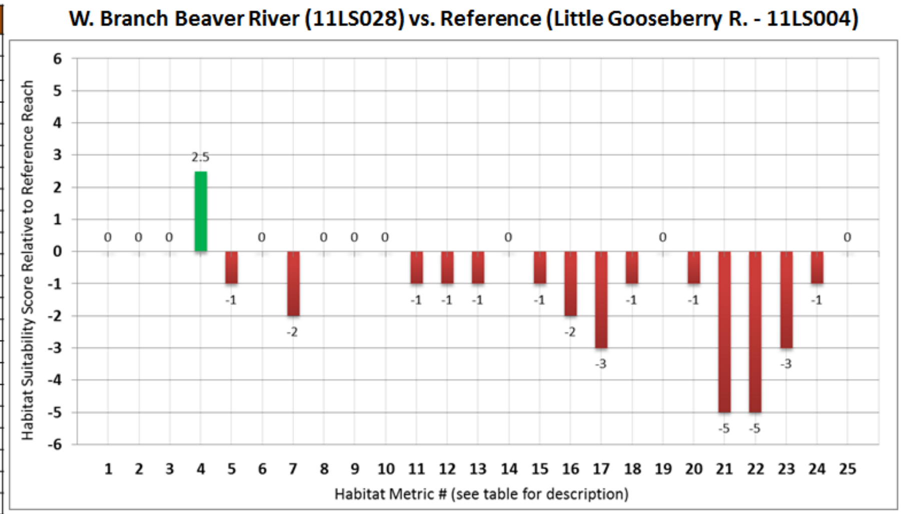
(3) Low flow

Low streamflow has been previously cited as a significant limitation for supporting Brook Trout and other sensitive coldwater biota in the WBBR (DNR, 2005). Water levels during the summer and early fall periods are often extremely low, although we did not observe any intermittent stream conditions during the course of this study (2011-2015). DNR has observed intermittent flows along the upper reaches of the WBBR in previous investigations (DNR, 2005). Although no quantitative flow measurements were collected, the low flow habitat available in the reference reach was far superior to the conditions observed at 11LS028 (see metric #21 in Figure 50).

Several ecological models and scientific journal articles clearly show the importance of adequate base flow for maintaining a healthy coldwater assemblage. Base flow, which is considered the lowest annual flow condition, typically occurs during dry periods in late summer, fall, and winter seasons. The Brook Trout Habitat Suitability Index Model (Raleigh, 1982) considers a base flow that exceeds 55% of the average annual daily flow as "excellent", 25 to 50% as "fair", and < 25% "poor" for maintaining quality trout habitat (adapted from Wesche 1974; Binns and Eiserman 1979). No flow data are available for the WBBR, but based on the minimal discharge observed in the channel during summer and fall months, the base flow rating within the impaired reach is likely "poor," or "fair" at best.

Streams with very low baseflow are vulnerable to "anchor ice" conditions or freezing solid. In regions with extremely cold climates, like Northeastern Minnesota, one of the major factors limiting salmonid densities may be the amount of adequate overwintering habitat rather than summer rearing habitat (Bustard and Narver 1975). Adequate base flow is important for maintaining water depth during the winter months, and preventing the formation of anchor ice.

#	Metric
1	Floodplain Connectivity
2	Water Temperature
3	Gravel Substrate
4	Fine Substrates and Embeddedness
5	Algae on the Gravel Substrates
6	Aquatic Vegetation
7	Bank Erosion
8	Bank Habitat
9	Longitudinal Connectivity
10	Deep Pools
11	Morphological Energy Dissipation
12	Riffle Complexity
13	Riffle Length
14	Beaver Dams
15	Side Channel Habitat
16	Channel Width to Depth Ratio
17	Low Flow Width to Depth Ratio
18	Hyporheic Exchange
19	Riparian Vegetation
20	Vegetative Shade
21	Flow rates at Low-Flow
22	Large Woody Cover
23	Fine Woody Debris
24	Riffle-Pool Ratio
25	Presence of Predator Species



Critical Limitations: **(#22)** Large Wood/Cover; **(#21)** Flow Rates at Low Flow
Other Limitations: **(#23)** Fine Woody Debris; **(#17)** Low Flow width/depth ratio

Figure 50. Comparison of BTSA metric scores between station 11LS028 on the West Branch Beaver River and a high quality reference stream of the same stream and valley type (Little Gooseberry River – station 11LS004).

Figure 51. The reference E5 channel at Little Gooseberry River station 11LS004 (left photo) has a lower width to depth ratio at low flow and more fish cover compared to the impaired reach of the West Branch Beaver River (right photo, station 11LS028).

(4) Substrate

Results related to stream substrate condition varied among the assessment methods used. The MSHA ratings for substrate were graded "C" and "D" due to fairly high levels of substrate embeddedness. On the contrary, the data from a particle size analysis (Wolman, 1954) completed during a detailed survey of this reach show a high relative percentage of gravel (85%), and fairly low percentages of sand (5%) and silt (15%). Particle size data were used to compare substrate conditions between 11LS028 and the reference reach using the BTSA metrics. The two reaches had equal scores for the amount of gravel present, but embeddedness scores were slightly more favorable within the impaired reach of the WBBR. Overall, it can be concluded that substrate conditions are not ideal at station 11LS028, but other stressors such as low streamflow and lack of cover may be more limiting than substrate conditions. Substrate conditions may also be highly variable depending on the extent of high water events or drought. The vast majority of substrate within the reach is composed of smaller gravels, silt, and sand, which can be mobile at fairly low current velocities. It should be noted that other reaches of the WBBR are much more impacted by silt, particularly the areas near beaver dams or where stream gradient is lower.

Compared to high quality reference stations, the impaired reach of the WBBR supports lower measures of fish and macroinvertebrate taxa that require clean, coarse substrate and riffle habitat. The only "riffle-dwelling" fish species observed in the impaired reach was White Sucker, which are found in a variety of habitat types and conditions. Riffle-dwelling species commonly observed in high quality coldwater streams in the region, such as Mottled Sculpin, Longnose Dace, and Brook Trout, were not observed in the impaired reach or any other location on the WBBR.

Several macroinvertebrate metrics offer further evidence of marginal substrate conditions in the impaired reach. The percentage of "clinger" macroinvertebrate taxa (cling to hard surfaces) present within the impaired reach was significantly lower than the 25th percentile value observed in high quality North Shore coldwater streams (Figure 52). The percentage of "sprawler" taxa (sprawl on fine substrates) was greater than the 75th percentile value observed in high quality North Shore coldwater streams (Figure 53). The biological response data provide clear supporting evidence of marginal substrate conditions as a contributing cause of impairment.

Results of Habitat Assessments: Beaver River

MSHA results are available for 10 stations on the impaired reach of the Beaver River. Overall, MSHA results ranged from a low grade of "D" at station 94LS005 to a high grade of "A" at stations 94LS007, 15LS061, 15LS060, and 15LS061 (Table 17). This wide range in MSHA results illustrates the highly variable physical habitat conditions that exist along the 26-mile impaired reach of the Beaver River. The four stations with an MSHA grade of B+ or higher are located primarily on stream reaches within moderately entrenched valleys, with stream slopes between 0.5 – 2.2% and riparian corridors dominated by mature forest (i.e. B, Bc channel types). The poorest MSHA scores were observed at stations with lower stream gradient (0.06 – 0.2%) and slightly entrenched valleys. Out of the five MSHA categories (channel morphology, substrate, cover, riparian condition, land-use) the lowest metric scores at stations with poor habitat pertained to substrate conditions, in-stream cover, and channel morphology.

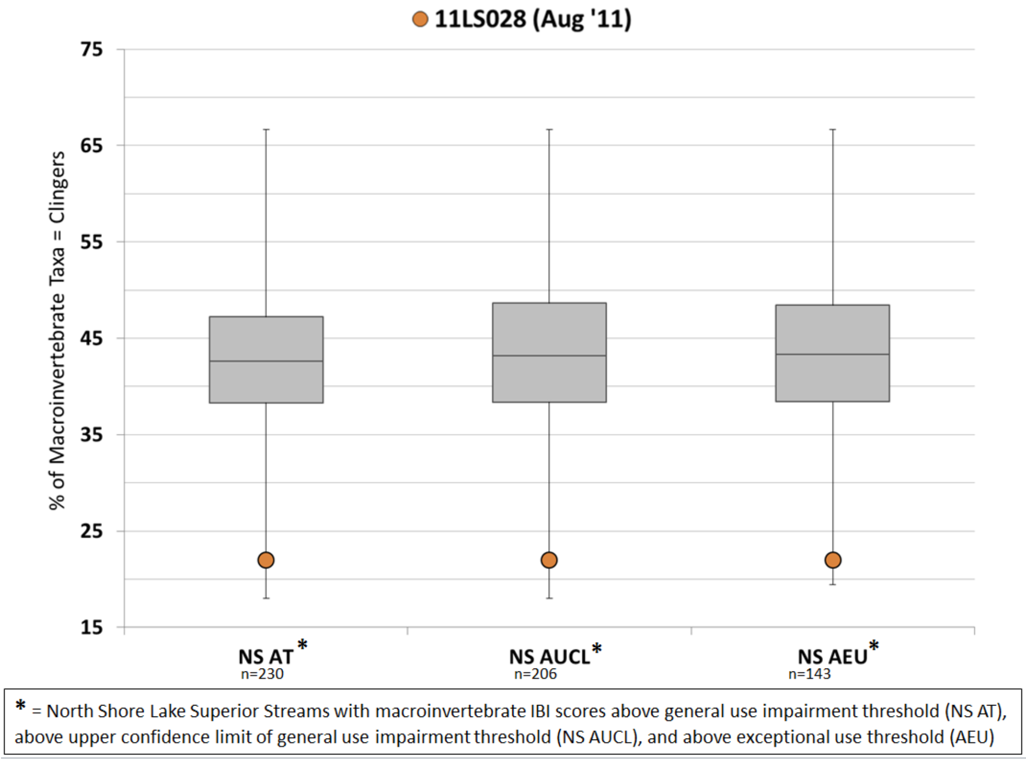


Figure 52. % Clinger macroinvertebrate taxa observed at West Branch Beaver River station 11LS028 compared to results from high quality reference streams

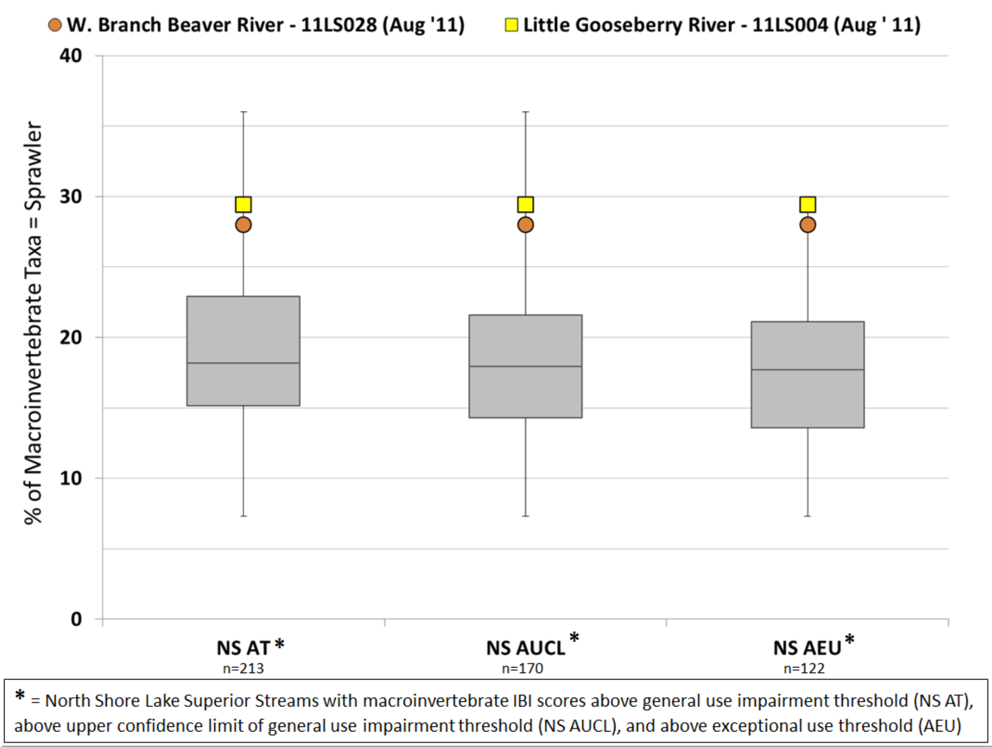


Figure 53. % sprawler macroinvertebrate taxa observed at West Branch Beaver River station 11LS028 and Little Gooseberry River 11LS004 compared to results from high quality reference streams

Table 17. Summary of habitat and channel stability assessments for the Beaver River

River	Station	MSHA Score (0-100)	MSHA Grade (A-F)*	BTSA Score	Fish IBI REL GU**	Pfankuch Stability Index Rating	Potential Habitat Stressor?
Beaver R.	11LS027	72	C	n/a	+2	Good/Stable	NO
Beaver R	MN DNR RM 16.9	n/a	n/a	103 (Good)	n/a, BKT#	Good/Stable	NO
Beaver R.	94LS007	90	A	99 (Good)	+29	Good/Stable	NO
Beaver R.	Beaver Shaq	n/a	n/a	79 (Fair)	n/a	Fair/Mod. Unstable	YES
Beaver R.	97LS010	72	C	n/a	+10 / +17	Poor/Unstable	YES
Beaver R.	94LS005	64	D	80 (Fair)	+6	Fair/Mod. Unstable	YES
Beaver R.	91LS026	74	C+	n/a	-10 / +12	Fair/Mod. Unstable	YES
Beaver R.	15LS061/15LS060	88	A	n/a	+17 / +16	Good/Stable	NO
Beaver R.	94LS003	87	A	n/a	+10	Fair/Mod. Unstable	NO
Beaver R.	97LS055	69	C	n/a	+11 / +6	Fair/Mod. Unstable	YES
Beaver R.	11LS022	67	C	72 (Poor)	0 / -2 / -6	Poor/Unstable	YES
Beaver R.	14LS001	84	B+	n/a	-4	Good/Stable	NO

*See section BLANK for grading scale ** Fish Index of Biological Integrity Score relative to general use impairment threshold (35)
BKT# No IBI score calculated due to difference in methods, but wild Brook Trout regularly present

Brook Trout Suitability Assessment (BTSA) data were collected from four biological monitoring stations on the Beaver River. These stations were chosen from the larger list of sites because they represented the range of habitat types and quality present on the impaired reach. BTSA results for the chosen stations were compared to a reference reach in order to identify any limiting factors related to physical habitat. The reference reaches selected for comparison are from high-quality biological monitoring stations of the same stream and valley type (Rosgen, 1995) as the impaired Beaver River locations. A list of the reference reaches used for each impaired station is included in Appendix C.

Portions of the impaired reach of the Beaver River offer good quality physical habitat for trout and other coldwater fish and macroinvertebrate taxa. BTSA results from stations located within stable reaches do not show a high rate or degree of departure from results obtained at the reference stations (Figure 55). For some BTSA metrics (e.g. deep pools, large woody cover), scores were higher within the stable areas of the Beaver River compared to the reference data. These findings indicate that other stressors (primarily water temperature) are limiting the potential for a coldwater fish community in areas of the impaired reach that exhibit high quality fish habitat.

In contrast, data from other biological monitoring stations show a clear departure from reference conditions, and a high probability for a fish community shift caused by habitat degradation. Biological monitoring stations 97LS010, 94LS005, 91LS026, 97LS005, and 11LS022 were flagged as locations on the impaired reach with potential habitat related stressors (Table 17). BTSA data are available for two of these stations (94LS005 & 11LS022), as well as one additional station ("Beaver Shaq") where biological data were not collected. Comparing the BTSA metric scores from these impacted reaches against applicable reference reach data reveal critical habitat limitations, which include; high water temperatures, bank erosion, lack of Hyporheic exchange (groundwater), riffle-pool ratio, cover, fine substrates and embeddedness, and lack of side channel habitat (Figure 54). Water temperature (5.3.1) and bank erosion (Section 5.3.7) are discussed in detail in other sections of this report, but the remaining habitat limitations will be evaluated further in this section as a potential cause of impairment.

Limiting habitat conditions in impaired reach

(1) Lack of cover

A lack of cover features for fish (e.g. large wood, boulders, undercut banks, aquatic vegetation) was identified as a habitat limitation in several impacted reaches of the Beaver River. Overall, the riparian corridor along impaired reach is in fairly good condition and the forested upper banks do provide a source of large wood for fish cover. However, bed aggradation (excess deposits of gravel, sand, cobble) has caused channel widening in some areas, and much of the potential fish cover is lost as streambanks erode and trees/logs are transported downstream by high flows, ending up congregated in large debris jams spaced too widely apart to offer consistent cover for fish. The historic logging of mature stands of cedar and white pine within the riparian corridor has likely reduced the quality and stability of large woody cover in this river system. The input of large, old growth trees to streams has shown positive contributions to grade control, retainment of spawning gravel, and fish cover in moderate to high gradient streams.

LWD and other types of fish cover are critical components of healthy trout streams, and the availability of these cover types have been shown to positively affect adult and sub-adult Brook Trout density (Nuemann and Wildman, 2002; Dechenes and Rodriguez, 2007). The few biological monitoring stations that support wild Brook Trout populations on the impaired reach (DNR river mile 16.9 and MPCA 94LS007) have superior ratings and scores for fish cover compared to stations that have no recent record of supporting a Brook Trout population. Monitoring stations with poor ratings for fish cover are dominated by fish species that are not cover dependent, such as Creek Chub, Longnose Dace, and Blacknose Dace. Although there are certainly other factors influencing the distribution of trout and other coldwater fish species in the watershed, the lack of available cover at several stations is a contributing cause to low fish IBI scores.

(2) Fine substrates and embeddedness

Substrate conditions are highly variable along the 25-mile impaired reach of the Beaver River. Sixty-percent (6/10) of the MPCA's biological monitoring stations have a MSHA grade for substrate that is B+ or higher, with five of the stations receiving an "A" grade based on MSHA scores. In general, these are the stations with steeper gradient (ranging from 0.7% to 1.8%) and fairly entrenched valleys. These characteristics are conducive to transporting sediment, thus keeping substrate conditions relatively clear of excess fines that could potentially embed gravel, cobble, and other coarse bed material. Substrate conditions are not as favorable at several stations with lower gradient (0.08 – 0.2%), especially in areas located immediately downstream of reaches with high stream power and erosion risk. Examples include 94LS005 and 91LS026, which appear to be aggrading (accumulating sand and silt) due to sediment inputs from upstream that exceed sediment transport capacity. Several mid-channel bars were noted at station 94LS005, which is a good indicator that sediment inputs are exceeding sediment transport capacity in this reach (Figure 61).

Quality spawning habitat for trout consists of clean gravels where steady, moderate flows of cold water continually supply oxygen to the eggs and keep the redd ("nest") free of sand and silt. A significant amount of gravel substrate material is available within many of the biological monitoring stations, even those that produced poor fish IBI scores. This claim is supported by the BTSA results for the "Gravel Substrate" metric, for which scores from the impacted Beaver River sites did not depart from the reference stations used for comparison. However, comparisons of BTSA scores for "fine substrate and embeddedness" reveal that more of the gravels within the impacted reaches of the Beaver River are embedded with sand/silt, leading to inferior spawning conditions and riffle habitat. In addition to degrading spawning habitat, excess deposits of sand and silt can also inhibit groundwater exchange and reduce width the depth ratio as channel dimensions become wider and shallower.

A noticeable shift in the fish community of the Beaver River can be observed in response to changes in stream gradient and substrate conditions. Riffle dwelling fish species such as Mottled Sculpin and Longnose Dace account for a higher percentage of the overall fish community at stations exceeding 1% slope (16 – 37% riffle dwelling individuals) and those between 0.5 – 0.85% slope (8 – 37% riffle dwelling individuals) compared to stations with gradient less than 0.2% (2 – 16% riffle dwelling individuals).

A similar pattern is observed at these stations for other fish metrics that respond to substrate quality, such as the percentage of fish that are benthic insectivores. The natural variability of these stream reaches must be taken into account when evaluating the fish community, resulting IBI scores, and the potential of these stations to meet established criteria.

Fine substrates and embeddedness are limiting the physical habitat at select stations on the Beaver River. In general, the impacted areas are those that are lower in gradient with significant sediment inputs (bank erosion) upstream or within the impacted reach itself. Reduced habitat quality due to sedimentation is a stressor in this watershed, and implementation activities should focus on reducing bank erosion and improving sediment transport capacity in reaches that with significant bed aggradation. These include stations 94LS005, 91LS026, 97LS055, and 11LS022.

(3) Low flow width/Depth ratio and inner berm area

Low flow channel width/depth (w/d) ratio and inner berm area are key components for maintaining quality habitat during the critical summer and winter periods. High w/d ratio channels at low flow are more susceptible to warming during summer low flows, and are also more likely to develop anchor ice or freeze solid during the winter season. The w/d ratio at bankfull stage (approximately 1.1 - 1.5 year flood) for most Beaver River sites fell within the normal range for the stream type as defined by Rosgen (1995). However, during baseflow (extreme low flow) conditions, many of the impacted Beaver River stations developed higher w/d ratios (based on mean depth and wetted width). BTSA metric scores for low flow w/d ratio were slightly inferior at Beaver River stations compared to reference sites (Figure 50).

The inner berm defines the shape of the low flow channel. Figures 56 and 57 depict two cross-sections collected at 94LS005 and how channel dimension and inner berm relate to thalweg (deepest part of channel) definition and depth at low flows. Cross-section "XS2-Riffle", located within the biological sampling reach (Figure 56), has a wider and shallower low flow channel than a more stable riffle cross-section ("XS100 – Upstream") that was surveyed in a more stable reach located several meander lengths upstream (Figure 57). In addition to poor low flow habitat, inner berm dimensions like those of "XS2-Riffle" are less likely to route sediment under moderate to high flows, thus making these areas more prone to sediment deposition and aggradation.

(4) Side channel habitat

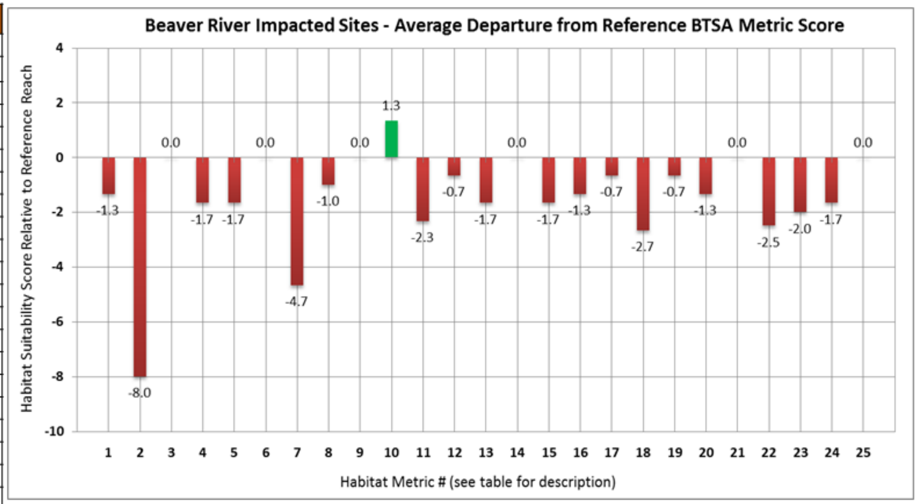
Side channel habitat provides protected rearing areas for juvenile Brook Trout as well as refuge for larger fish during floods. High quality side channel habitat has connectivity to the main channel flow, plentiful cover (tree limbs, cobble/boulder, aquatic veg), and adequate shading to prevent water temperature increases. Impacted areas of the Beaver River (esp. stations 94LS005, 11LS022) scored poorly in the BTSA metric related to side channel habitat. Minimal side channel habitats were available in these stream reaches. Where present, they were generally filled in with fine sediment, lacked cover, and were exposed to direct sunlight. The photos in Figure 62 provide an example of quality side channel habitat from Cascade River station 13LS043 contrasted with poor side channel habitat at Beaver River station 94LS005.

Summary: Are physical habitat conditions a stressor in the Beaver River?

Several locations on the impaired reach of the Beaver River provide marginal to poor physical habitat for trout and other sensitive fish species. Poor MSHA and BTSA scores in the categories of substrate condition, cover, geomorphology (low flow w/d ratio & short riffle lengths), and side-channel habitat confirm several of the limiting factors contributing to low coldwater fish IBI scores. Habitat degradation in the Beaver River is rather localized, occurring in areas with lower stream gradient and high sediment supply (bank erosion) within the reach or immediately upstream of the impacted area.

Degraded physical habitat is a contributing stressor at stations 97LS010, 94LS005, 91LS026, 97LS055, and 11LS0022. The remaining biological monitoring stations on the impaired reach offer adequate physical habitat conditions for supporting trout and other sensitive coldwater fish species. Poor physical habitat should be listed as a stressor based on the conditions observed in the lower half of the impaired reach.

#	Metric
1	Floodplain Connectivity
2	Water Temperature
3	Gravel Substrate
4	Fine Substrates and Embeddedness
5	Algae on the Gravel Substrates
6	Aquatic Vegetation
7	Bank Erosion
8	Bank Habitat
9	Longitudinal Connectivity
10	Deep Pools
11	Morphological Energy Dissipation
12	Riffle Complexity
13	Riffle Length
14	Beaver Dams
15	Side Channel Habitat
16	Channel Width to Depth Ratio
17	Low Flow Width to Depth Ratio
18	Hyporheic Exchange
19	Riparian Vegetation
20	Vegetative Shade
21	Flow rates at Low-Flow
22	Large Woody Cover
23	Fine Woody Debris
24	Riffle-Pool Ratio
25	Presence of Predator Species



Critical Limitations: **(#2)** Water Temp.; **(#7)** Bank Erosion; **(#18)** Hyporheic Exchange; **(#24)** Riffle-Pool Ratio
Other Limitations: **(#22/#23)** Large Woody Cover/Fine Woody Debris; **(#4)** Fine Substrates and Embeddedness **(#15)** Side Channel Habitat

Figure 54. Comparison of BTSA results from "impacted" Beaver River vs. comparable high quality reference stations

#	Metric
1	Floodplain Connectivity
2	Water Temperature
3	Gravel Substrate
4	Fine Substrates and Embeddedness
5	Algae on the Gravel Substrates
6	Aquatic Vegetation
7	Bank Erosion
8	Bank Habitat
9	Longitudinal Connectivity
10	Deep Pools
11	Morphological Energy Dissipation
12	Riffle Complexity
13	Riffle Length
14	Beaver Dams
15	Side Channel Habitat
16	Channel Width to Depth Ratio
17	Low Flow Width to Depth Ratio
18	Hyporheic Exchange
19	Riparian Vegetation
20	Vegetative Shade
21	Flow rates at Low-Flow
22	Large Woody Cover
23	Fine Woody Debris
24	Riffle-Pool Ratio
25	Presence of Predator Species

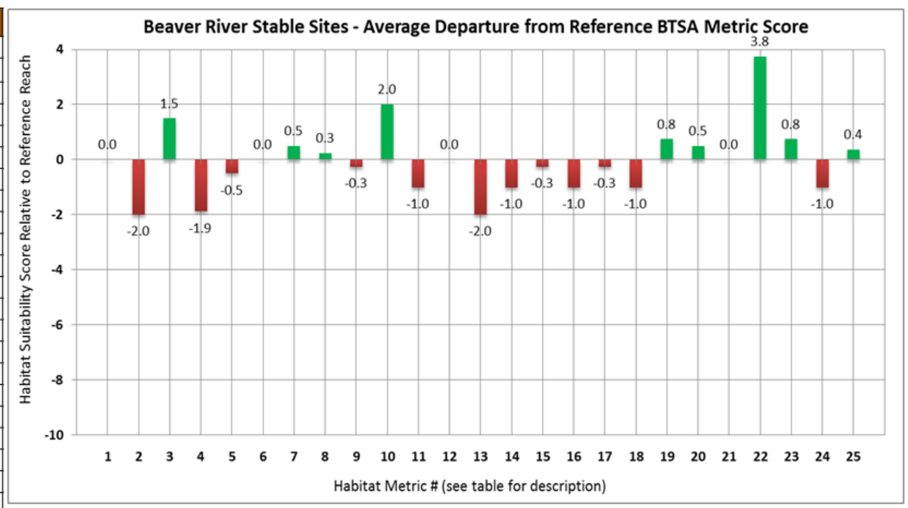


Figure 55. Comparison of BTSA results from "stable" Beaver River stations vs. comparable high quality reference stations

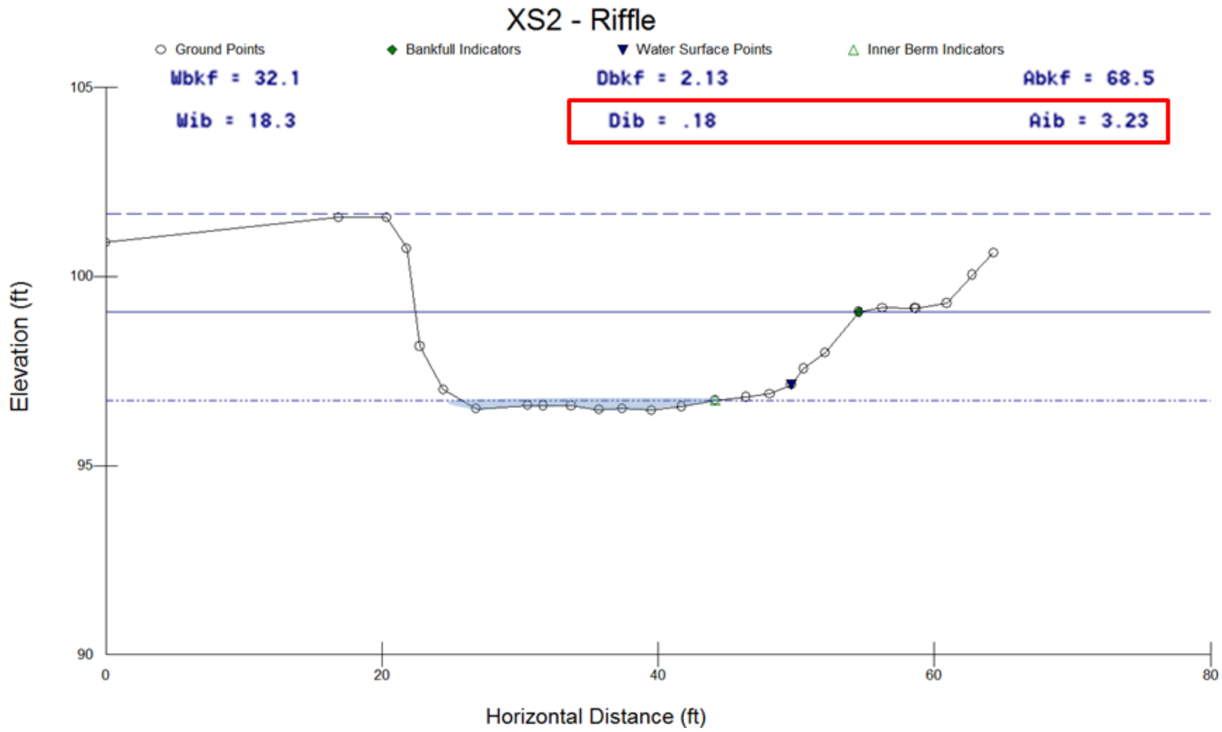


Figure 56. Riffle cross-section at biological monitoring station 94LS005 with high width to depth ratio at low flows and lack of inner berm. These channel conditions offer poor habitat at low flow and are prone to sedimentation (accumulation of sand/silt on streambed).

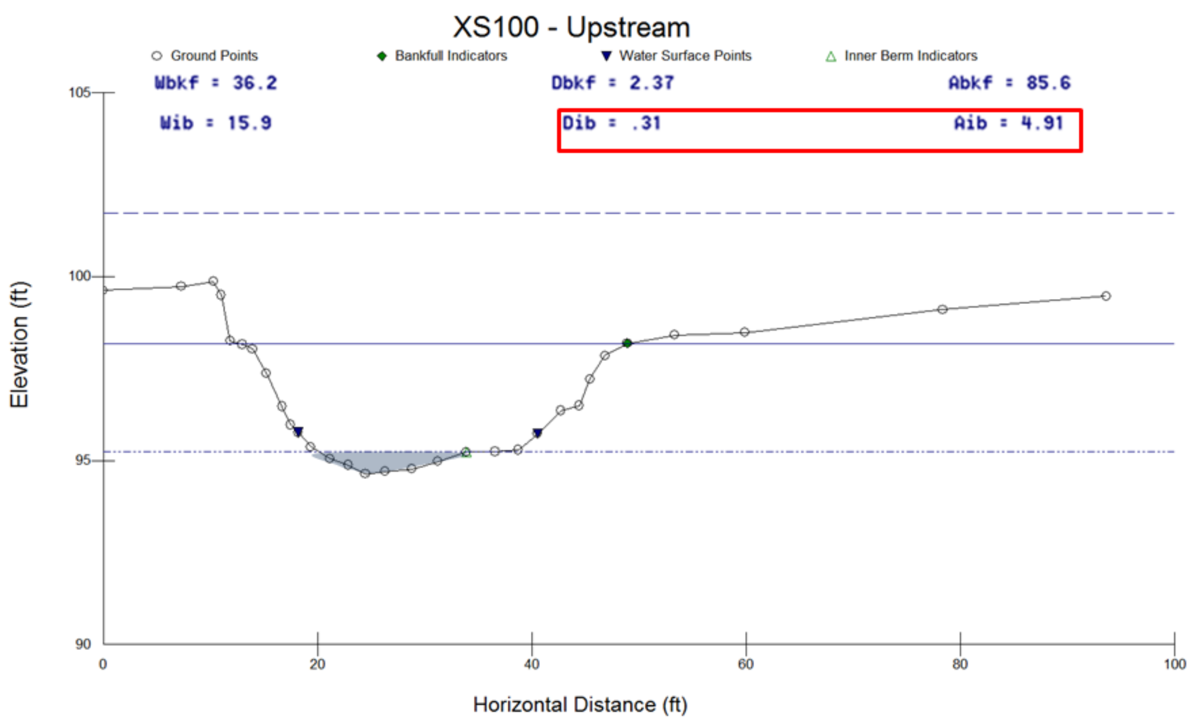


Figure 57. Riffle cross-section with lower width to depth ratio at low flows and well established inner berm. These channel conditions offer better habitat at low flow and are less prone to sedimentation (accumulation of sand/silt on streambed).

Figure 58. Impaired reach of Beaver River (left photo; station 94LS005) showing lack of fish cover at low compared to reference reach (right photo; Two Island River station 98LS028).

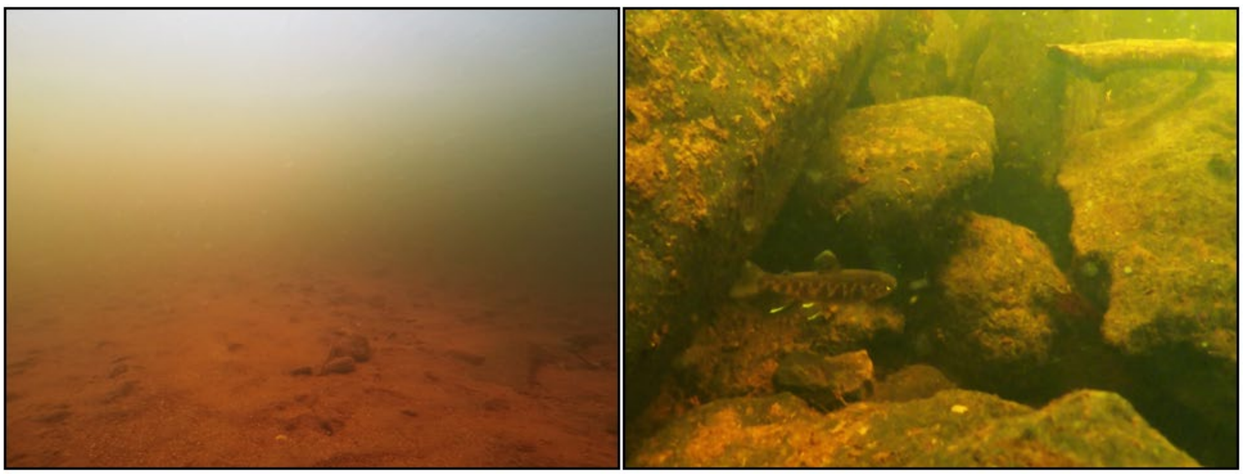


Figure 59. High level of substrate embeddedness observed at station 94LS005 (left photo) compared to quality substrate observed upstream at 94LS007 (right photo). Fish in the photo on right is a young of year or age-1 wild Brook Trout observed during a snorkel survey.

Figure 60. (Left photo) Streambed aggradation (excess deposits of gravel, sand, cobble) has caused channel widening in some areas of the Beaver River. Large woody cover congregates in logjams. (Right) Stable stream channels route sediment more effectively, and maintain suitable width/depth rations and retain in-stream cover.

Figure 61. Mid-channel bar (left) and side bars (right) showing accelerated sediment deposition at Beaver River station 94LS005. These are indicators of channel aggradation as sediment inputs exceed transport capacity of the channel.

Figure 62. (Left) Minimal side channel habitats were available within impacted areas of the Beaver River. Where present, they were generally filled in with fine sediment, lacked cover, and were exposed to direct sunlight. (Right) An example of quality side channel habitat from Cascade River station 13LS043.

5.3.6 Connectivity – Impediments to aquatic organism passage

Stream ecosystems are high complex, as fish movement, habitat heterogeneity, and life-stage dependent habitat requirements interact to influence fish populations at the watershed scale (Fausch et al., 2002) (Figure 63). The ability of fish and other aquatic organisms to move freely within streams plays a key role in assuring that all of the critical habitat components of a species are met, particularly those that are highly sensitive and may have stringent requirements to carry out their life cycles.

Until recently, researchers believed that Brook Trout and other stream resident salmonids were rather sedentary by nature (Gerking, 1959; Clapp et al., 1990). Recent studies have concluded that long-range movements are relatively common within stream resident Brook Trout populations. Gowan and Fausch (1996) observed that 59% and 66% of marked Brook Trout moved at least 50 meters, and movements between 2000 – 3400 m (1.2 – 2.1 miles) were also detected, even though the tracking period lasted only several months. In the upper Cheat River basin in West Virginia, adult Brook Trout commonly undertake large-scale movements between mainstem areas and tributaries for the purposes of spawning, feeding, and refugia from elevated water temperatures (Petty et al., 2012).

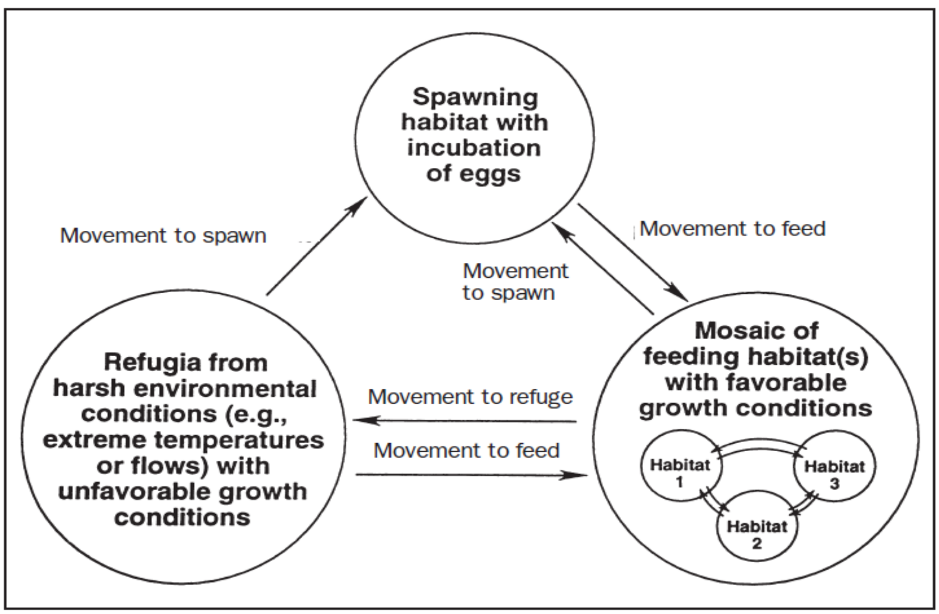


Figure 63. The basic life cycle of stream fish with emphasis on patterns of habitat use and migration (from Schlosser, 1991)

The concept of "scale" is an important consideration in assessing the importance connectivity in a watershed. Fausch et al. (2002) provides a framework of 5 scales that are an integral part of a watershed ecosystem; "Microhabitat" (10^{-1} – 10^{0}), "Channel Units" (10^{1}), "Reaches" (10^{1} – 10^{3}), "Segments" (10^{3} – 10^{5}), and "Drainage Basins" (10^{5} – 10^{6}). The author contends that the intermediate scales (Channel Units, Reaches, Segments) encompass the stream habitat features and ecosystem services that are most critical for understanding fish populations. Of course, the critical scale for research, protection, and restoration efforts vary considerably depending on the target species involved. The Beaver River is a designated trout stream with management goals of sustaining a wild Brook Trout within a significant portion of the middle to upper river segments, and a wild Steelhead Rainbow Trout population in the lower reach up to the first barrier falls (0.2 miles upstream from Lake Superior) (see map in Figure 63a). The "Reach" and "Segment" scales are suitable for evaluating the impact that stream connectivity has on these two focus species.

Elevated water temperatures and low streamflow are two limiting factors that create marginal conditions for coldwater fish in the Beaver River and other North Shore streams. Maintaining year-round connectivity between larger rivers and small, cool/coldwater tributary streams is critical for survival of salmonids within watersheds that offer marginal coldwater habitat. In some cases, coldwater refugia is located within larger rivers themselves, in areas where groundwater seeps are prevalent.

Connectivity assessment in the Beaver River Watershed

Potential and verified impediments to fish migration were identified through a combination of aerial photo analysis and field reconnaissance. Barriers identified included both natural features (waterfalls, beaver dams) and anthropogenic changes that have occurred in the watershed (road crossing culverts). Although some uncertainty remains for several areas, all of the barriers inventoried were classified as "partial/seasonal barriers" or "complete barriers" to fish migration. The scope of this assessment includes the Beaver River main stem from Lake Superior to CSAH 15, the West Branch Beaver River, and the East Branch Beaver River up to the barrier waterfall near Pipeline Road.

Natural barriers

Natural barriers are moderately abundant in the watershed in the form of impassable waterfalls and beaver dams. Eight major falls were identified on the Beaver River, with many smaller falls and drops present that may be barriers to some species under extreme low/high flow conditions. Several large waterfalls are located just upstream from mouth of the Beaver River, which effectively ends the migration of lake-run fish approximately 0.2 miles upstream from Lake Superior. Several additional waterfalls are located within the next several river miles in the upstream direction on both the Beaver River and East Branch Beaver River (Figure 63a, creating a river segment that is rather dissected by impassable barriers.

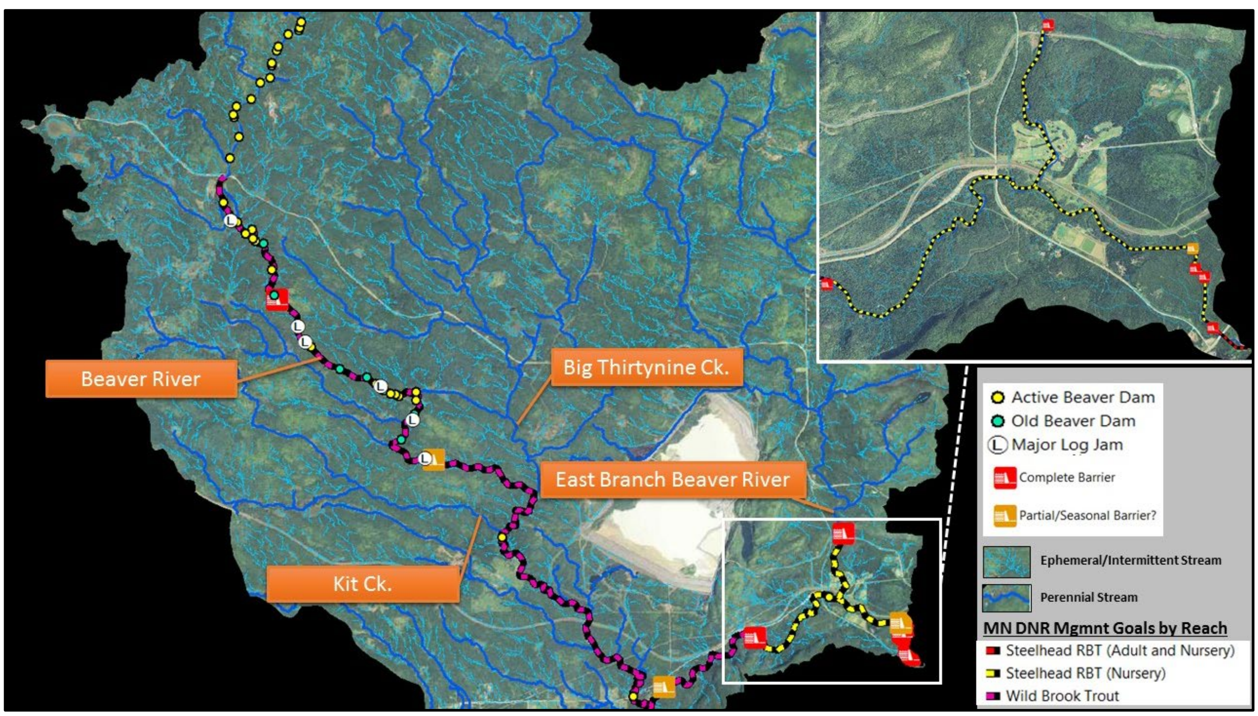


Figure 63a. Overview of verified and potential barriers to fish migration in the Beaver River Watershed. Also shown are DNR management designations by stream reach, and log-jam/beaver dam areas that are affecting habitat and water chemistry. 2013 imagery was used for analysis.

Further adding to the fragmented nature of this river segment is the lack of sizeable tributary streams. The lower four miles of the Beaver River, as well as the East Branch Beaver River below Pipeline Road falls, are not fed by any perennial streams that could serve as potential refugia for coldwater fish during critical baseflow periods. Fish within this lower river segment are subjected to high suspended sediment concentrations, poor to fair physical habitat conditions, and water temperatures that frequently exceed the threat and lethal threshold values for coldwater fish. There are no tributary streams in this segment providing temporary refuge from stressful conditions.

Upstream of Glen Avon falls, the Beaver River is less fragmented by barriers and is joined by several significant tributaries that offer additional habitat and refugia. Brook Trout and other resident fish species are capable of migrating long distances in these stream segments for the purposes of refugia, reproduction, feeding, and other factors. Kit Creek, Big Thirtynine Creek, and an unnamed tributary (Township 55/Range 8W/Section 7) are key coldwater tributaries that may provide refuge and spawning habitat in the upper Beaver River watershed.

Beaver dams and major log jams are fairly common in the middle to upper reaches of the Beaver River, and throughout the impaired reach of the West Branch Beaver River. Although the majority of these features do not represent physical barriers to fish movement, they can have a profound impact on physical and chemical conditions in streams (e.g. increase in fine substrates, lower DO, higher water temperatures), thereby creating restricted movements and fragmented populations. Water quality and habitat stressors linked to beaver dams are discussed in more detail in the DO and habitat sections of this report. The location of beaver dams (both active and old dam sites) and logjams are shown in Figure 63a.

<u>Non-natural barriers</u>

Road – stream intersections were inspected throughout the Beaver River drainage to identify improperly sized/set culverts, with an emphasis on those that may act as barriers to fish migration. A total of 32 crossings were assessed (2 bridges, 30 culverts), including sites on the Beaver River, East Branch Beaver River, West Branch Beaver River (WBBR), Big Thirtynine Ck, and several major and minor tributaries to those streams. We found 14 of 30 (47%) of the culverts evaluated were not sized properly to handle frequent high water events and/or maintain channel stability near the crossing over time. Undersized culverts also create velocity barriers for many fish species due to higher water velocities and turbulence within the culvert compared to those that are properly sized to handle high flows.

Only two undersized culverts were identified on the impaired stream segments of the Beaver River and WBBR. Brook Trout have been sampled near the undersized culvert on the Beaver River, which is located in the headwaters of the river near biological monitoring stations 11LS027 and 91LS025. The undersized culvert at this location could make fish passage more difficult under high flow conditions, but it is not a complete barrier, and is likely passable for most of the year. The undersized culvert on the WBBR is located at the upstream end of the impaired biological monitoring station (11LS028) and is likely a barrier during high flows, but is passable at moderate to low flow conditions.

Only 2 out of the 30 culverts observed in the greater Beaver River watershed were perched at the outlet, and the perch heights were low (0.2 – 0.3 feet). Both of the perched culverts observed were in the headwaters areas of small tributary streams, both of which tend to be somewhat intermittent in flow, and have no formidable link to the impaired condition of the Beaver River main stem.

Overall, culverts at stream crossings are not a significant contributor to the fish impairments in the Beaver River and West Branch Beaver River. Aside from the two crossings on the impaired stream segments discussed above, the vast majority of the perched and/or undersized culvert crossings are concentrated in the headwaters of high quality tributary streams, the majority of which are disconnected from the impaired reach by natural barriers (waterfalls). The undersized and perched culverts in the headwaters of the watershed should be evaluated further to determine whether there are any localized impacts that can be alleviated through culvert replacement or retrofitting.

Figure 64. Numerous waterfalls are present in the Beaver River watershed, several of which are natural barriers to fish migration

Figure 65. Major log-jams are fairly common in the upper and middle reaches of the Beaver River

Figure 66. Active (right) and inactive (left) beaver dams affect water quality and stream channel/floodplain conditions throughout the Beaver River watershed

Biological response to loss of connectivity

The significance of longitudinal connectivity varies depending on the life history traits of the species inhabiting the watershed of interest. Brook Trout (and other sensitive coldwater fish) have a critical need for access to cold water and suitable habitat for spawning, feeding, and surviving harsh environmental conditions. The migration rates of Brook Trout within larger watersheds (e.g. Beaver River) have been linked to maximum summer water temperature and distance from a known coldwater source, and individuals within larger main stem rivers migrate at a higher rate than those in smaller tributaries (Petty et al., 2012). Based on these findings, the ability of fish to move freely within the Beaver River watershed is critical given that many stream segments show elevated water temperatures and relatively poor habitat conditions. As previously mentioned, the migratory distance of Steelhead Rainbow Trout from Lake Superior is extremely limited (0.2 miles) by impassable waterfalls. Biological data used for assessment purposes were collected from stations upstream of this barrier, and therefore the connectivity discussion in this report focuses primarily on resident fish.

Upstream of Glen Avon Falls, there are very few permanent barriers to fish migration. Many miles of the Beaver River, as well as numerous second and third order tributary streams are accessible to fish populations within this river segment. Wild Brook Trout populations are present in this region of the watershed and have access to a variety of habitat types and refugia. On the contrary, the fish community inhabiting the reach of the Beaver River downstream of Glen Avon Falls and the impassable falls on the East Branch Beaver River are without a single refuge by way of a sizeable tributary, and are exposed to conditions that can be considered fair to poor for sensitive coldwater fish for long durations of time. The lack of coldwater refugia in the lower reaches of the Beaver River is a critical limitation, but cannot be improved through any restoration activities.

The West Branch Beaver River (WBBR) is fragmented by numerous beaver dams and an undersized culvert at Beaver Valley Road could prevent some fish species from migrating upstream under high flow conditions. The biological effects of habitat fragmentation in the WBBR are not likely stressing the current fish community, as most of the species observed in this stream are relatively short lived and are not known to migrate long distances. Biological data from the six monitoring stations show a high degree of similarity in terms of fish species and distributions. However, as land-use changes occurred in the watershed over time (logging, road construction), increased habitat fragmentation has potentially led to the loss of sensitive coldwater species (e.g. Brook Trout) in this sub-watershed. Most of the development in this sub-watershed occurred nearly a century ago.

Summary: Is loss of connectivity a cause of fish impairment in the Beaver River/West Branch Beaver River?

The Beaver River is fragmented by several impassable waterfalls, as well as partial/seasonal barriers in the form of beaver dams, log jams, and smaller "step" waterfalls. A lack of connectivity between main stem and tributary streams is certainly one of the limiting factors facing coldwater fish communities in this watershed. A <u>lack</u> (not "loss") of connectivity should be considered one of the stressors in this system, but no major restoration activities are recommended as all of the permanent barriers are natural features of the landscape.

Connectivity concerns in the West Branch Beaver River include an undersized and damaged culvert at station 11LS028 and several large beaver dams. Replacing the culvert at 11LS028 with one that is sized to better accommodate high flows and promote fish passage is recommended.

5.3.7 Elevated total suspended solids (TSS)/Turbidity

Sources and pathways of sediment in the Beaver River watershed

The Beaver River watershed has experienced many changes in land cover over the last century. Old-growth forests were clear-cut and many regions were impacted by forest fires in the early 1900s. Today forests have regenerated as predominantly aspen and birch rather than the white and red pines that were once present throughout the watershed. Along with changes to forest type, the Beaver River watershed has also experienced an increase in road density and stream crossings, residential expansion, and changes to the landscape caused by mining practices and transportation. Each of these alterations to the landscape has affected sediment and hydrologic pathways in the Beaver River watershed.

Roads and road ditches

Roads and road ditches within a watershed act as direct and indirect sources of suspended sediment to the river. Roads and road ditches move water across the landscape quickly indirectly increasing sediment input by increasing the peak flows of the river (Wemple 1994). Roads and road ditches within the Beaver River watershed are not as abundant as in other watersheds and therefore probably do not contribute as much sediment to the stream. The Beaver River watershed has a density of 0.43 miles of road per square mile of watershed. This density is similar to other less developed watersheds along the North Shore and much less than developed watersheds closer to the city of Duluth (e.g. Talmadge River, Lester River).

Watershed changes

The Beaver River watershed has experienced changes in watershed area and tributary confluence locations that have potentially caused channel instability. Before the Milepost 7 tailings basin was constructed in the late 1970's, Big Thirtynine Creek and Little Thirtynine Creek flowed south through the valley just west of Bear Lake, entering the main Beaver River at river mile 8.9. In the 1970's Reserve Mining Company was forced to stop dumping tailings in Lake Superior and find a suitable basin site inland. The Big Thirtynine Creek valley was chosen and stream channels were redirected away from the valley to make room for the basin. The new Big Thirtynine Creek was diverted into the main Beaver River 3.7 miles upstream of its previous confluence (Figure 67), essentially doubling the drainage area at stream mile 12.6 of the Beaver River.

This change in watershed size led to a significant increase in water volumes and velocities causing channel widening, incision, and stream bank and bed erosion. Lane's stream balance equation illustrates the effects of increased water volumes on channel instability and erosion (Appendix D). The balance shows sediment volume and size, and stream discharge and steam slope (i.e. water velocity). Each of these variables are interrelated; if one changes all others must adjust resulting in a possible impacts to stream stability. Aggradation (excess deposition of sediment on the stream bed) results if changes occur that reduce the stream's sediment transport capacity– if sediment size increases, volume of sediment increases, volume of discharge decreases, or stream slope decreases. Degradation (channel incision or downcutting) occurs if the stream is overly capable of moving its sediment (stream slope or discharge *increase* or the particle size or amount of sediment *decreases*).

Lane's balance shows that channel degradation and enlargement is the likely impact of increased watershed size between stream miles 8.9 and 12.6. We can estimate the degree of channel enlargement using the regional channel geometry curve developed by the authors for the Beaver River watershed (see Appendix E). As stated before, the watershed area at the present Beaver/Big Thirtynine confluence more than doubled as a result of Milepost 7 construction and rerouting Big Thirtynine Creek. The pre- Milepost 7 basin drainage area of the Beaver River at the present confluence site was 16.33 miles^2. The regional curve predicts a bankfull cross-sectional area of 48.6 ft^2 for that watershed size. The post-basin drainage area at the confluence is now 40.16 miles^2 with a predicted bankfull cross-sectional area of 93.9 ft^2.

The amount of sediment generated by channel enlargement can be estimated by multiplying the predicted increase in cross-sectional area by the length of stream between the present confluence and the original confluence (3.7 miles or 19,536 ft). The confluence of Kit Creek within the reach affects the predicted increase in cross-sectional area downstream, but after adjusting for that this calculation produces a potential sediment yield of almost 27,600 cubic yards, or roughly 36,000 tons.

Figure 67 shows the pre- and post-tailings basin drainage areas and predicted channel dimensions for the Beaver River between the current Big Thirtynine mouth and the Milepost 7 outlet (S007-598). A proportion of the sediment generated by channel enlargement is large enough to be categorized as bedload, therefore we would expect to see aggradation and instability downstream. We would also expect to see embeddedness in downstream reaches due to the vast amount of sand and silt that is being generated by this channel enlargement process. Several reaches downstream of this impacted area were cited as having poor physical habitat due to aggradation and substrate embeddedness (see Section 5.3.5).

Channel instability/Bank erosion

The Beaver River is impaired for turbidity, and we hypothesized that a large percentage of the sediment loading is coming from eroding banks in unstable reaches. Much of this instability can be linked to landscape changes and human disturbance (Riedel, 2004). In addition to the aforementioned watershed alterations related to the tailings basin construction, these changes include turn-of-the-century logging which cleared many areas along the North Shore, leading to an increase in snowmelt and rainfall runoff rates, a decrease in vegetation transpiration rates, and subsequent increases in peak flows within the Beaver River and its tributaries (Riedel, 2005).

This increase in flows has caused the river channel to begin an evolutionary process in which the channel is changing form in order to adjust to increased flow events. As the river adapts to these increased flow events it incises, widens, aggrades, and overall stream bank and bed erosion increases. When the bed or bank material consists of finer particles (clay and silt) the erosion can result in extremely high TSS concentrations when mobilized by moderate to high flows.

Many areas of channel instability and bank erosion were observed in the Beaver River but were located in specific regions of the watershed. The upper half of the watershed consisted of mostly Rosgen “B” and “E” stream types. These streams were observed to be mostly stable (Figure 69) perhaps due to the lack of recent disturbance or the relative resilience of the stream types, which are both very efficient at transporting sediment but also resistant to degradation. Stream banks were densely vegetated and the channels were well connected to their floodplains. The areas of observed channel instability were predominantly in southern half of the watershed (Figure 70).

Stream reaches identified as significant sediment sources include: 1) Beaver River from the Big Thirtynine confluence to the West Beaver confluence, 2) Beaver River from Glen Avon Falls to the Superior Hiking Trail crossing (94LS001), 3) East Branch Beaver River downstream of Lake County Highway 15, and 4) Cedar Creek downstream of Cedar Creek Road. Within some of these reaches there were sections of stable, functioning channel which were more resistant to degradation due to the presence of bedrock (most were “A” and “B” stream types). Stream banks were mostly well vegetated, but the vegetation was failing to hold stream banks in place because the stream had cut down below the rooting depth and exposing erodible alluvium. Following the trend seen in many North Shore rivers, the most unstable reaches were mostly “C” and “F” channels and are going through the evolutionary process mentioned above.

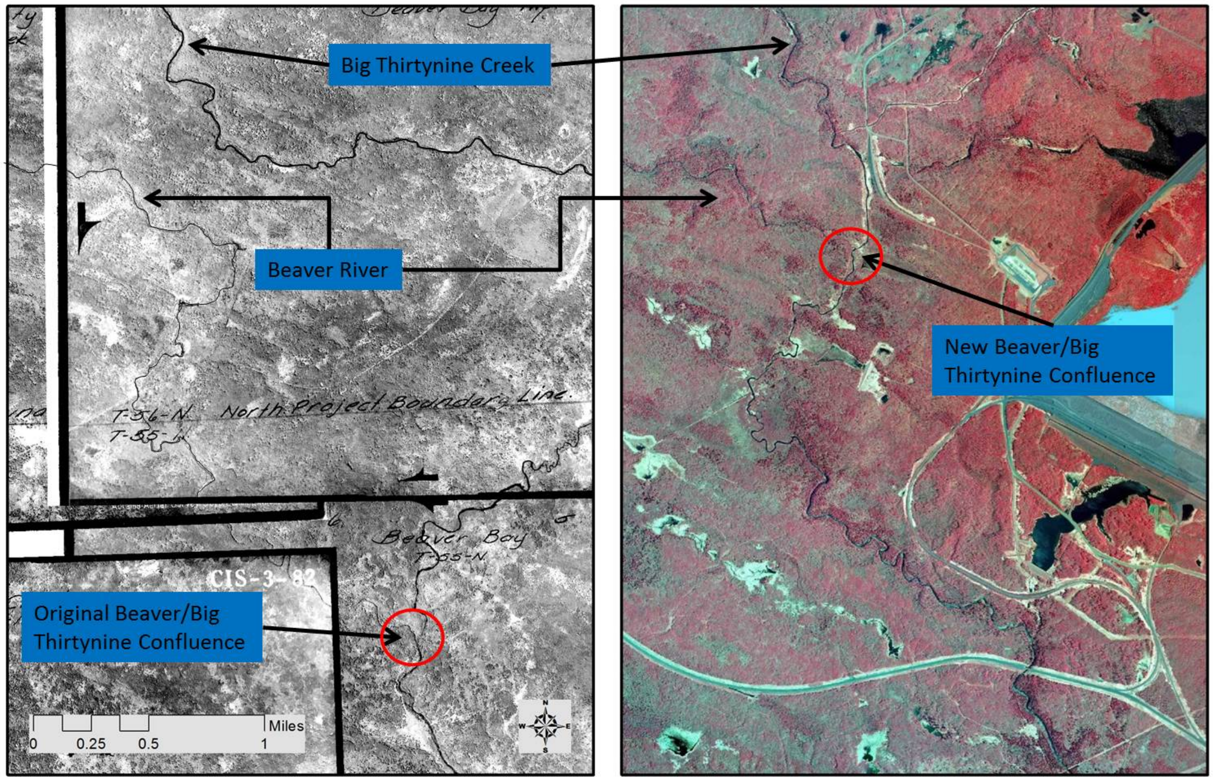


Figure 67. At left, historical photos from 1939 showing the original confluence near the bottom of the photo. At right, aerial photo from 2009 showing the current confluence location 3.7 miles further upstream.

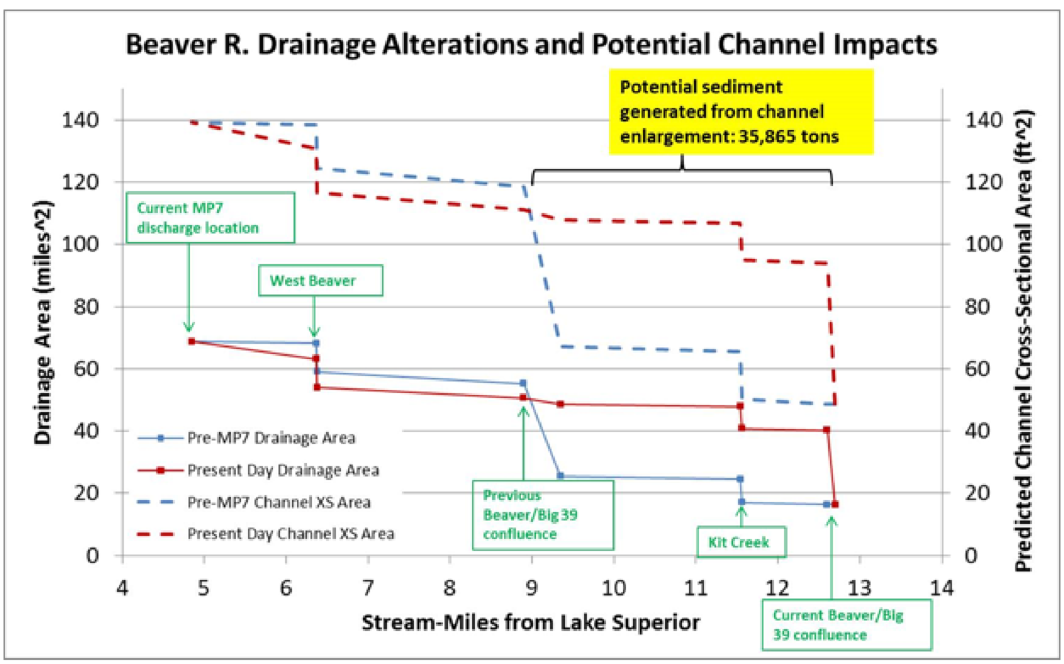


Figure 68. Pre- and post-tailings basin drainage areas and predicted channel dimensions for the Beaver River. The solid lines show the longitudinal change in drainage area as a result of Milepost 7 basin construction. Above the original Big 39 confluence, the basin construction caused a marked increase in drainage area in the main stem Beaver. Below that point, there is a slight decrease due to tailings basin runoff being redirected downstream to the current Milepost 7 discharge location. Dashed lines show the corresponding longitudinal change in channel cross-sectional area for the same reach of the Beaver River. The predicted increase in cross-sectional area potentially generated up to 36,000 tons of sediment from bed and bank erosion.

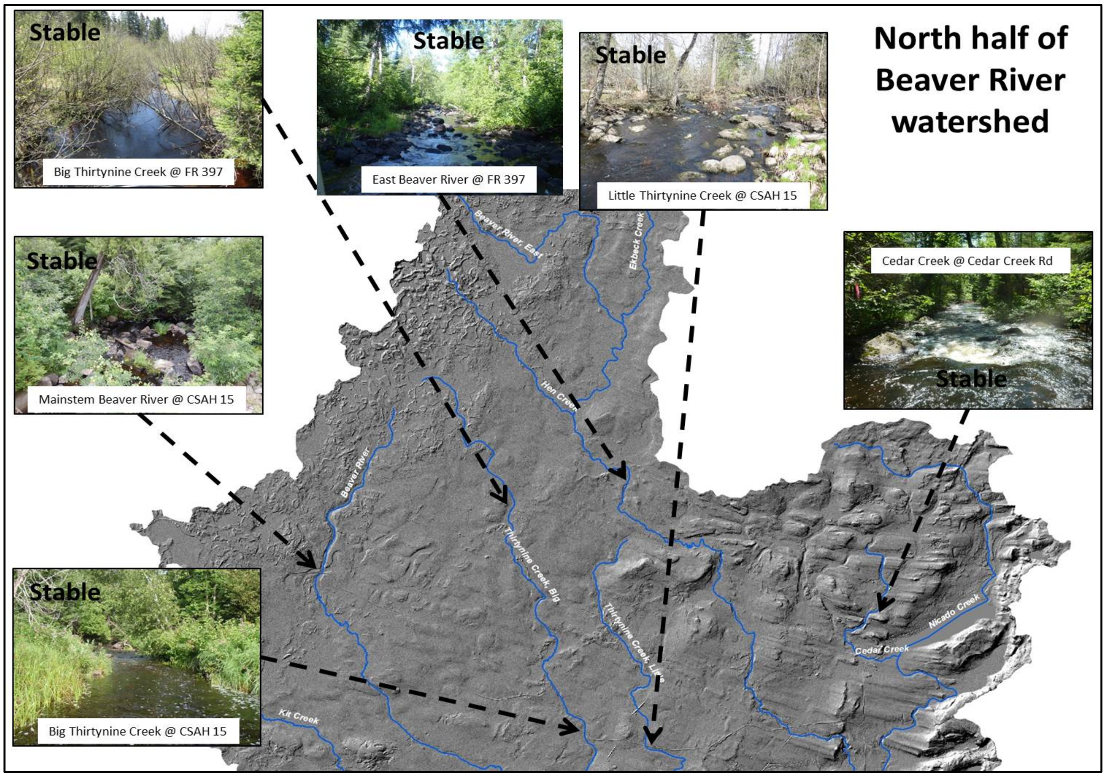


Figure 69. Photos showing representative stream banks in the upper half of the Beaver River watershed. Stream reaches are almost entirely stable, with only a few isolated areas of erosion.

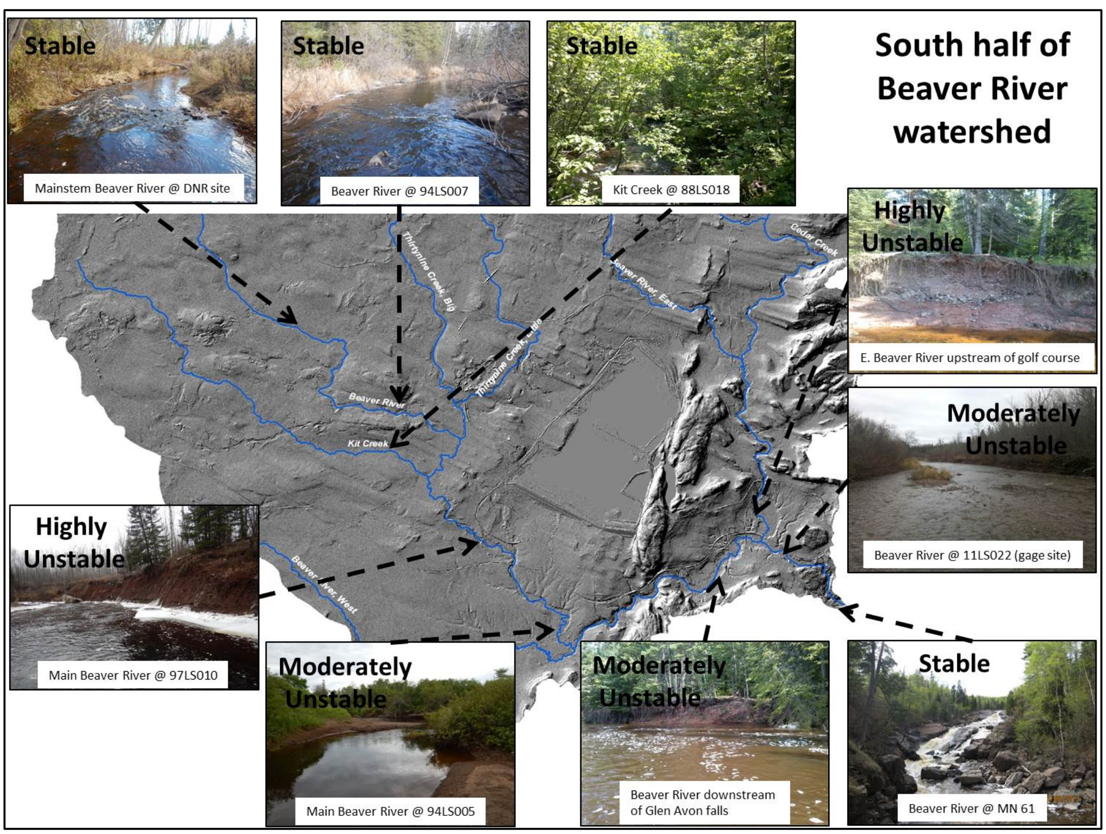


Figure 70. Photos showing representative stream banks in the southern half of the Beaver River watershed. Highly unstable reaches are present near 97LS010 and in the Silver Bay golf course.

Total suspended solids (TSS): Response to seasonal change & streamflow

The streams along the North Shore of Lake Superior are prone to rapid and significant changes in streamflow and TSS concentrations. The spring snowmelt and moderate to heavy rainfall events (>1") generate considerable runoff in these watersheds. Steep stream slopes, unstable streambanks/bluffs, and erosion-prone soils result in considerable sediment loading during these events. The streamflow and water chemistry changes caused by these events are characteristically "high magnitude, short duration, low frequency". Based on continuous turbidity measurements recorded at the stream gauging station on the Beaver River in 2015, summer rain events caused rapid increases in turbidity that receded rather quickly (2-3 days) (Figure 72 and 73). Rainfall events of 0.5 – 3.6" inches in August and September of 2015 resulted in elevated turbidity levels 4x-10x higher than the class 2A standard of 10 NTU. Turbidity concentrations during summer baseflow conditions hovered around 10 NTU water quality standard.

Continuous turbidity data are not available for snowmelt conditions in the Beaver River watershed. In a typical snowmelt year, streams run high and turbid from runoff beginning in March or April and begin receding towards summer low flow conditions during the month of June. Spikes in streamflow and turbidity are common throughout the spring season due to saturated soil conditions and lack of vegetation on the landscape. Given all of these factors, it is clear that the greatest risk of TSS-related stress to aquatic life occurs during spring and early summer. This statement is supported by the seasonal analysis of TSS and streamflow data presented in Appendix F.

TSS load duration analysis

Load duration curves address the likelihood of equaling or exceeding a given pollutant load at a location. Water quality and flow data are used to quantify the pollutant loading to this location from the watershed area upstream. Over the past decade, these curves have been widely used in the development of TMDLs in Minnesota and other US States. The load duration curve approach relies on setting a desired pollutant concetration, which is typically an established water quality standard, in this case 10 mg/L TSS (standard for coldwater trout streams in Minnesota). The resulting curve is the maximum pollutant load that can be observed at the site to meet water quality standards based on the given flow condition.

A TSS load duration curve was developed for the Beaver River using streamflow and water chemistry data from 2014-2015 (Figure 74). Additional flow and water quality data were collected in 2016, but final results were not available for the writing of this report. The load duration curve shows TSS loadings exceeding the TMDL allocation most frequently during high flow (90^{th} percentile and greater Mean Daily Flow) and during "Moist Conditions" (i.e. moderately high flows à 60^{th}-90^{th} percentile Mean Daily Flow). A very small number of exceedances also occur during mid-range flows, dry conditions, and low flow, but TSS loads mostly comply with water quality standards during these flow conditions. The TSS load duration curve provides further evidence that TSS-reductions are needed during high flow events and that exposures of aquatic life to elevated TSS concentrations are short in duration.

Longitudinal trends in total suspended solids

TSS and Secchi tube data were collected at numerous locations on the main stem Beaver River and major tributaries to identify areas of increased erosion and sediment delivery. Data collected between years 2008 and 2015 were used to develop longitudinal summaries for these stations (Appendix G).

Results show an increase in TSS and decrease in Secchi Tube data towards the mouth of the Beaver River. Several sites both exceeded the standards more than 10% of the time and had an adequate number of samples to support the existing TSS/turbidity impairment. However, many of the stations do not have sufficient numbers of samples, and results may be somewhat biased due to event-based sampling (rain/snowmelt events). Overall, the main stem of the Beaver River had the highest TSS values and lowest Secchi Tube readings. The Big Thirtynine Creek watershed showed the most favorable results, with no transparency exceedances and low percentages of event-based TSS concentrations above the 10 mg/L standard. All four sampling sites within the West Beaver River watershed had high exceedance levels but the low number of event-based samples makes it difficult to draw any conclusions about TSS trends. Results from the East Branch show an increase in TSS concentrations and a decrease in Secchi Tube readings in downstream reaches compared to upstream, especially downstream of CSAH 4.

Monitoring data from a snowmelt event in May 2013 was used to develop a longitudinal picture of TSS during periods of high flow. For each sampling site, the increase in TSS concentration was divided by the corresponding inc rease in drainage area from the next upstream sampling site (Figure 76). The resulting metric (mg/L/mile^2) helps to pinpoint the stream reaches and sub-watersheds that are contributing a disproportionate amount of suspended sediment to the river. The results were somewhat surprising, in that the highest contributing sub-watershed was the Cedar Creek catchment between Lax Lake Road and Cedar Creek Road. This creek supports a wild Brook Trout population and a mostly undisturbed watershed. Several beaver impoundments are located further upstream, and some signs of channel instability (extensive point bar development, mid-channel bars) are evident in the aerial photos near the impoundments. These areas may be contributing to the higher than expected TSS concentrations observed at the sampling station. Suspended organic material entering the stream from Lax Lake may also explain some of the higher TSS concentrations, but no data are available for the volatile suspended solids.

The East Beaver River drainage area between CSAH 15 and CSAH 5 was contributing a relatively high (~3.3 mg/L/mile^2) concentration of TSS, which correlates well with the observed bank and channel instability in those reaches. The unnamed sub-watershed in the WBBR was also contributing a comparatively high TSS concentration of 3.6 mg/L/mile^2. Most of the headwater catchments were predictably contributing a low TSS concentration, except for the upper Beaver River sub-watershed, which (similar to the aforementioned Cedar Creek catchment) may have been due to suspended organic debris during snowmelt. The Beaver River sub-watershed between the Big Thirtynine confluence and CSAH 3 was contributing a very low TSS concentration of 1.1 mg/L/mile^2. This was unexpected due to the observed channel instability in this reach. One possible explanation for this may be that the sediment eroding from the stream banks has a high bedload component, which would not show up in TSS samples.

Figure 71. Examples of Beaver River at various flows and TSS concentrations during 2015, looking downstream from flow gaging station.

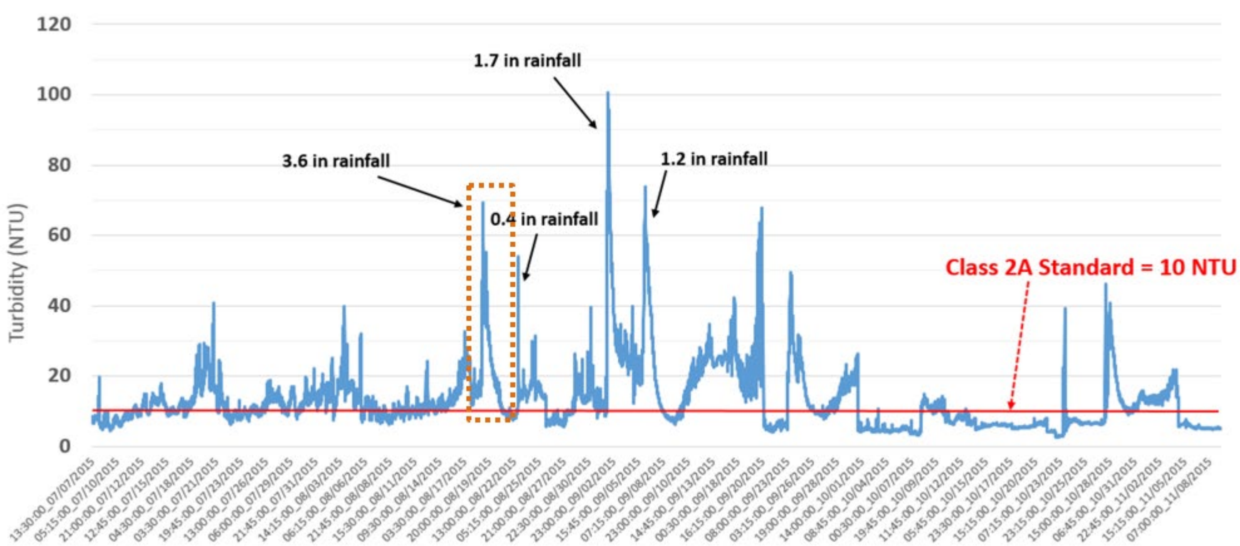


Figure 72. Continuous turbidity results for 7/7/15 – 11/8/15 at the Beaver River gaging station (S004-955). Area highlighted by orange box shown in detail in Figure 73.

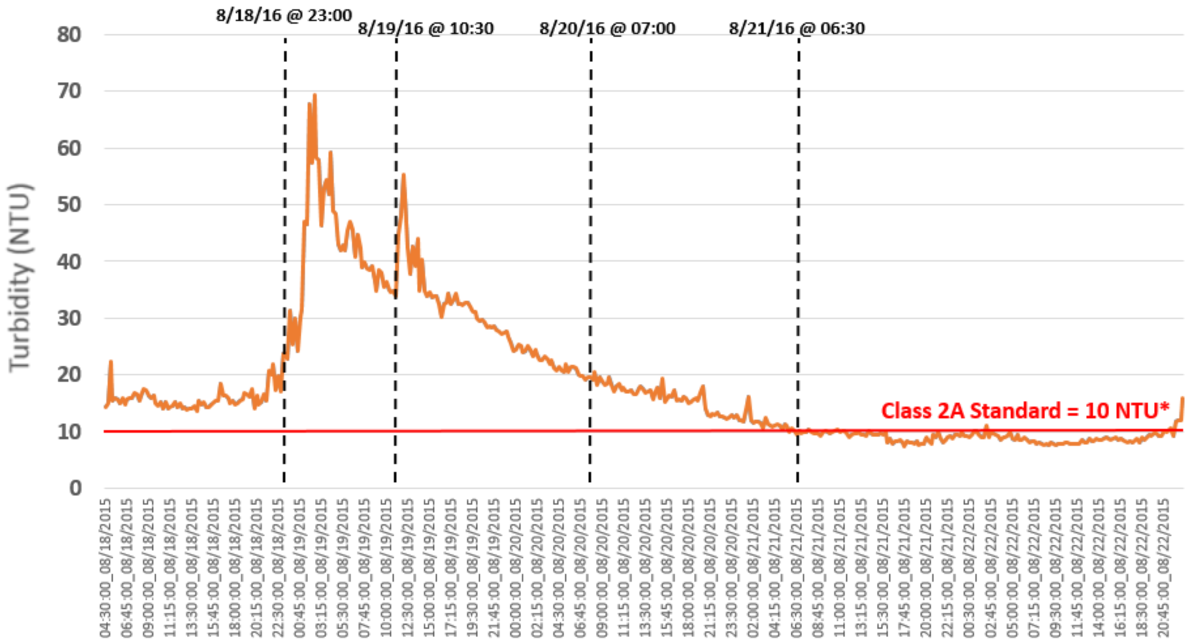


Figure 73. Duration and magnitude of a turbidity spike at Beaver River station S004-955 caused by a rainfall event in 2015

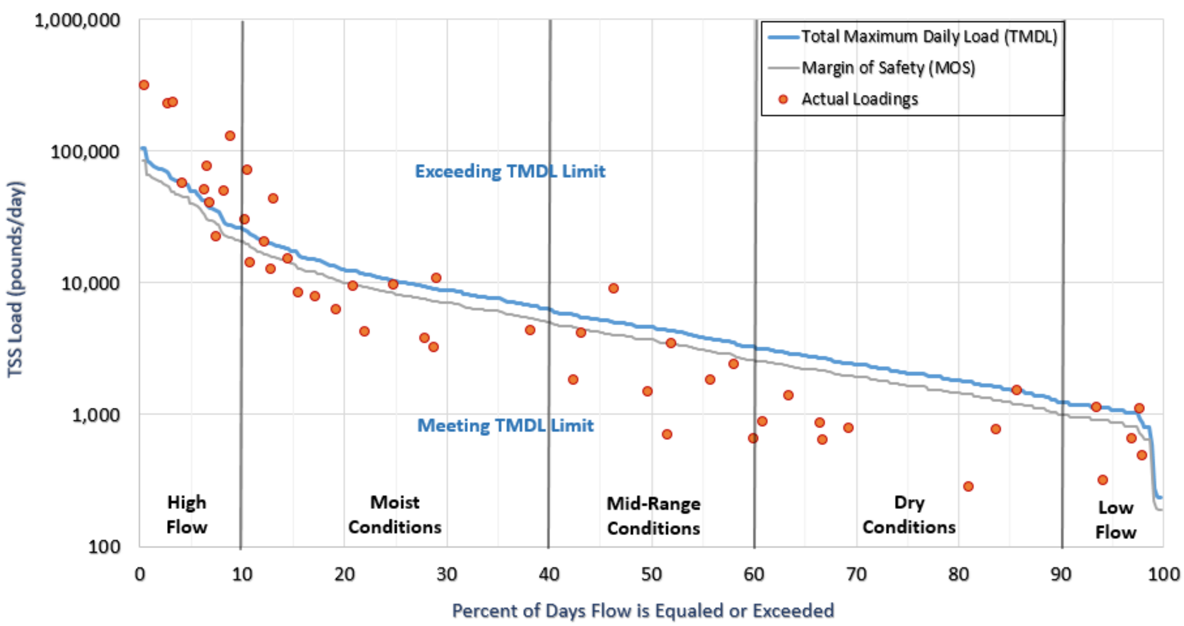


Figure 74. Total suspended solids (TSS) load duration curve for Beaver River based on 2014-2015 monitoring data from station S004-955. Additional flow/TSS monitoring data will be incorporated for TMDL development.

Table 18. Summary of TSS load duration curve results by flow range

Flow Range (% of days equaled or exceeded)	**Flow range (cfs)**	**# TSS samples**	**# TSS samples >10 mg/L**	**Percent of TSS samples >10 mg/L**
High (0-10%)	Above 481	10	9	90%
Moist conditions (10-40%)	481 - 118	17	4	24%
Mid-range conditions (40-60%)	118 - 61	8	1	13%
Dry conditions (60-90%)	61 - 23	9	0	0%
Low flow (90-100%)	23 - 4	5	1	20%

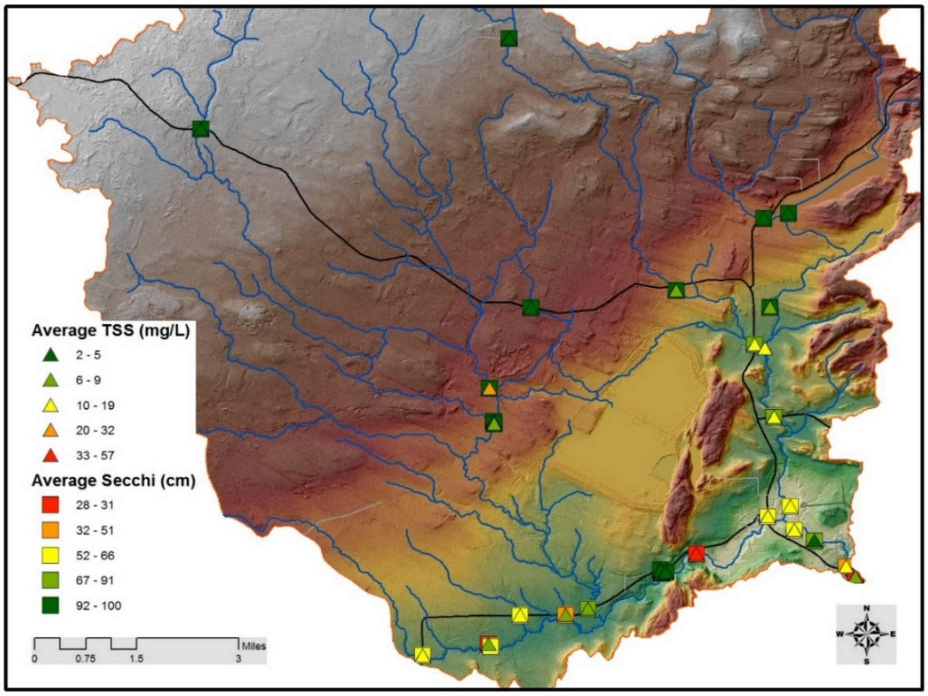


Figure 75. Average TSS and Secchi tube values at sampling sites in the Beaver River watershed

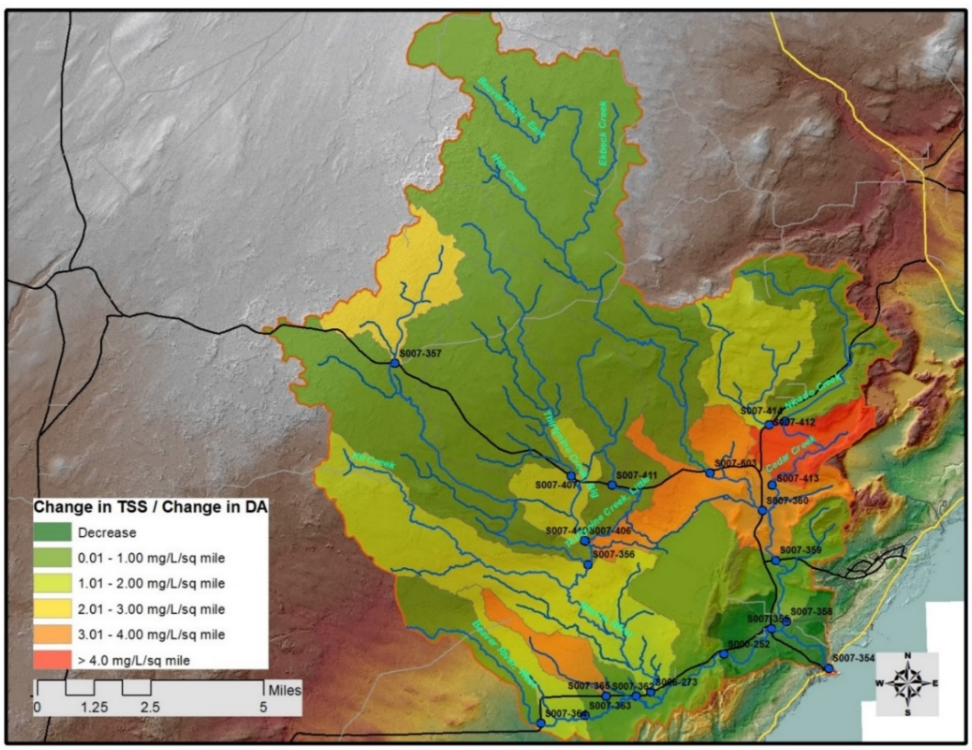


Figure 76. Map showing the Beaver River sub-watersheds and stream reaches that are contributing a disproportionate amount of suspended solids. TSS concentrations in Cedar Creek may be the result of suspended organic material originating in Lax Lake.

Beaver River BANCS analysis

BANCS (Bank Assessment for Non-point source Consequences of Sediment) assessments are meant to predict stream bank erosion rates. The model uses two tools for estimating bank erosion: the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS). Characteristics of individual stream banks and the distribution of energy and shear stress in the water can be used to estimate an erosion rate in ft/yr using an empirically-derived curve relating BEHI and NBS (the curve used in this analysis was developed in Colorado, although recent work has been done to develop a North Shore curve). The estimated erosion rate is then multiplied by the length and height of the bank to get a sediment load in cubic feet per year or, when multiplied by the density of soil, tons per year.

A detailed BANCS study was performed on the mainstem of the Beaver River from the mouth to about a mile upstream of the 97LS010 biosite. The whole mainstem was not assessed due to time contraints. TSS sampling indicated that the East Beaver River was also contributing high amounts of suspended sediment, so that system from the mouth to CSAH 15 was also included as well as the lower reach of Cedar Creek. The predicted erosion rates in tons/ft/year are shown in Figure 77.

The results of this study show that a large reduction in sediment load could be accomplished by implementing restoration projects on a comparatively small length of the river. The BANCS model predicts that 19.5% of the sediment load is coming from about 2.2% of the stream length for the stream reaches we analyzed. These banks have predicted erosion rates of about 0.36 tons/feet/year, or 720 lbs of sediment per foot of channel every year. Eighty-one percent of the sediment supply is being sourced in C channels, with the highest erosion rates coming from transitional reaches with slopes between 0.5 - 1.0%.

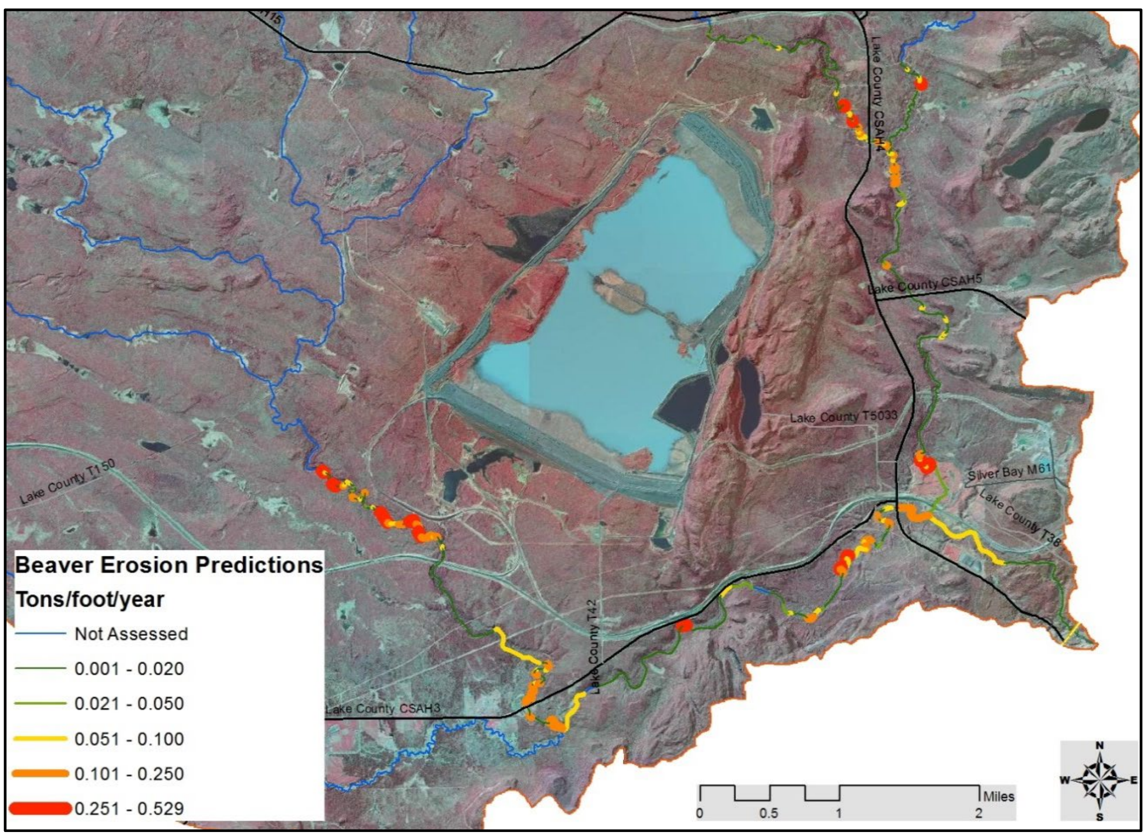


Figure 77. Map of the Beaver River showing predicted erosion rates in tons/ft/yr

Figure 78. Representative streambanks from an unstable, highly erosion prone reach (left) and a stable, very low erosion prone reach (right). Both of these sites were located between Glen Avon Falls and the Highway 4 crossing of the Beaver River.

Biological response to elevated TSS/Turbidity

MPCA biologists have developed TSS TIVs for all of the fish species found in Minnesota. The TIVs were developed using statewide biological and water chemistry data sets, and are based on the presence, absence, and/or relative abundance of fish taxa found in various water quality conditions. More information on the development and use of TIVs can be found in 4.5. For the purpose of evaluating various stressors in this report, TIV values were broken up into percentiles and fish taxa were classified as highly sensitive, moderately sensitive, slightly sensitive, neutral, slightly tolerant, moderately tolerant, or highly tolerant. These categories are used in this section to evaluate the general tolerance of the Beaver River fish community to elevated TSS concentrations.

DNR and MPCA staff completed fisheries surveys at 10 locations on the Beaver River between the years 1991 -2015. A total of 18 fish species were observed in the river over this period. Half of the species sampled (n=9) can be considered “neutral” in terms of their association with turbid/high TSS conditions in Minnesota streams. In other words, these species are observed in streams with a wide range of TSS concentrations and are not useful for stressor diagnosis. About 22% (4/18) of the species sampled in the Beaver River can be considered “slightly sensitive” to elevated TSS concentrations, while around 6% (1/18) are classified as “moderately sensitive”, and 22% (4/18) as “highly sensitive”. Examples of highly sensitive fish species sampled include Brook Trout, Longnose Dace, Mottled Sculpin, and Rainbow Trout (stocked by DNR). No TSS “tolerant” fish species were sampled in the Beaver River, although several of the species classified as “neutral” (e.g. White Sucker, Fathead Minnow) are known to occupy streams with higher TSS/turbidity levels. A summary of the fish species sampled, relative abundance, and respective TSS-tolerance categories are included in Table 19.

TSS concentrations along the Beaver River show a strong longitudinal trend of increasing concentrations with increasing drainage area. As a result, the duration/magnitude of exposure to elevated TSS varies considerably among the biological monitoring locations. Therefore, a gradient of impact to the fish community would be expected if TSS is acting as a primary stressor. The main stem of the river can be divided into three segments based on generalized TSS conditions gleaned from monitoring data; “Upper Beaver River” (Headwaters to Big Thirtynine Creek confluence: Low TSS concentrations), “Middle Beaver River” (Big Thirtynine Creek confluence to Glen Avon Falls: Moderate TSS concentrations), and “Lower Beaver River” (Glen Avon Falls to Lake Superior: High TSS concentrations). As previously mentioned, TSS concentrations in this river system are closely linked with river stage, so the TSS levels listed above reflect the more adverse conditions resulting from high flow events.

Biological monitoring stations within the upper Beaver River and middle Beaver River tended to support a higher relative number of individuals that are sensitive to increases in TSS (Figure 79). Wild Brook Trout are common near station 94LS007 within this reach and have been observed at other stations in this segment as well. The Lower Beaver R. segment, which is frequently turbid and experiences large spikes in TSS during rain events, supported a higher relative percentage of fish with “neutral” tolerance and fewer “highly sensitive” and “moderately sensitive” individuals. These trends in the fisheries data are correlated with changes in TSS, but other stressors diagnosed in this report (e.g. physical habitat, temperature) are capable of causing similar symptoms in the fish community.

Several TSS-sensitive fish species (Longnose Dace, Mottled Sculpin) are regularly sampled in the lower Beaver River despite TSS concentrations in this reach that frequently exceed WQ standards. A very small number of Brook Trout have also been sampled in this reach over the years, but observations of this species could be due to stocking of the East Branch Beaver River upstream, as little to no natural reproduction has been observed. The presence of several sensitive fish species in the lower Beaver River suggests that the magnitude and duration of TSS exposure is not severe enough to cause a complete shift in the fish community towards highly tolerant taxa. Yet, in combination with other documented stressors (habitat degradation, elevated water temperatures), elevated TSS concentrations cannot be eliminated as a potential stressor considering the much more favorable conditions in the upstream portion of the watershed.

Table 19. Fish species sampled in Beaver River and general tolerance to elevated TSS/turbidity. Tolerance classes are based on MPCA's TIVs.

TSS Tolerance Category	Species Present in Beaver River (A = Abundant, C = Common, P = Present, R = Rare)
Highly Sensitive	Rainbow Trout (P – stocked); Mottled Sculpin (P); Longnose Dace (C); Brook Trout (P);
Moderately Sensitive	Northern Redbelly Dace (C)
Slightly Sensitive	Blacknose Dace (A); Finescale Dace (P); Largemouth Bass (R); Blacknose Shiner (R);
Neutral	White Sucker (N); Pearl Dace (P); Johnny Darter (C); Iowa Darter (R); Fathead Minnow (P); Creek Chub (A); Common Shiner (A); Central Mudminnow (P), Brook Stickleback (C);
Slightly Tolerant	None
Moderately Tolerant	
Highly Tolerant	

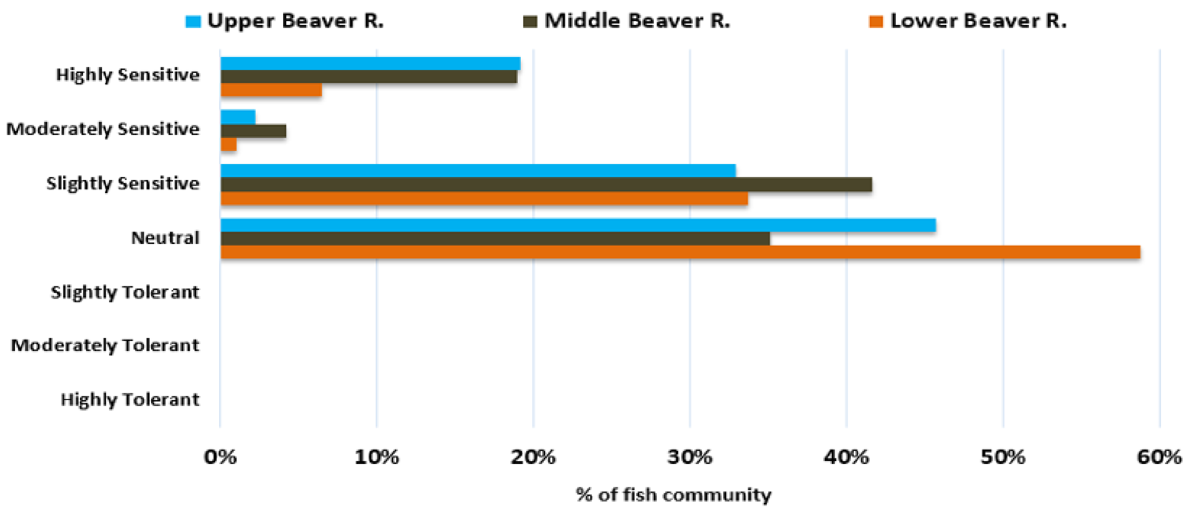


Figure 79. Summary of Beaver River fish community data by TSS sensitivity and relative location on the main stem

Summary: Is elevated TSS a cause of fish impairment in the Beaver River/West Branch Beaver River?

The Beaver River is currently listed as impaired for elevated TSS concentrations and turbidity. Analysis of existing water chemistry data reveals elevated TSS concentrations during high to mid-range flows. The areas of the stream most impacted by TSS and turbidity are located in the lower half of the impaired reach. The diversion of Big Thirtynine Creek was into the main Beaver River 3.7 miles upstream of its previous confluence essentially doubled the drainage area at stream mile 12.6 of the Beaver River. This change in the drainage network may play a significant role in causing channel widening, incision, and stream bank and bed erosion downstream of this point.

The presence of several sensitive fish species in the lower Beaver River suggests that the magnitude and duration of TSS exposure is not severe enough to cause a complete shift in the fish community towards highly tolerant taxa. Yet, in combination with other documented stressors (habitat degradation, elevated water temperatures), elevated TSS concentrations cannot be eliminated as a potential stressor considering that elevated TSS/turbidity concentrations are spatially linked (co-located) with some of the lowest fish IBI scores in the watershed. The causal relationship between TSS and the impaired conditions is not extremely strong, but TSS is considered a stressor in this system based on the current impairment listing for that parameter, and the lack of sensitive coldwater taxa in the reaches most impacted by elevated TSS.

5.3.8 Altered hydrology

The Beaver River (AUID=04010102-501) is 23 miles long and extends from the outlet at Lake Superior (602 feet AMSL) to the headwaters (1965 feet AMSL) in the North Shore Highlands. The 123 mi^2 watershed is located in the Lake Superior South basin. Main tributaries to the Beaver River include the West and East Branch Beaver Rivers, Kit Creek, Big Thirtynine Creek, and Little Thirtynine Creek. Wetlands and lakes cover 30% of the watershed area, with five named lakes greater than 10 acres in size. The largest lake, Lax Lake, is 295 acres in size and outlets through a solid concrete drop inlet to Nicado Creek in the eastern watershed. Nicado Creek discharges to Cedar Creek approximately 250 downstream of the outlet. The remaining four lakes are smaller and range from 13 to 43 acres in area. The West Branch Beaver River is approximately eight miles long and has a drainage area of nine mi^2. It consists of three AUIDs and the middle reach (AUID = 04010102-577, length = 1.62 mi) is listed as impaired. Wetlands cover 25% of the watershed and there are no lakes.

The landscape of the Beaver River watershed consists primarily of glacial drift deposits of the Superior lobe overlaying bedrock. A prominent end moraine covers the northern section of the watershed, whereas the lower watershed is formed from a ground moraine. Soil types range from sand and gravel to clay with coarser soils often associated with end moraine features of the headwaters and finer soils prominent in the lower watershed. In general, groundwater storage is shallow due to the thick clay soils, shallow depth to bedrock, and lack of deep aquifers. Other North Shore of Lake Superior studies (Ostazeski & Schreiner, 2004; Jasperson, 2016) have shown that pockets of subsurface storage, where they exist, are often associated with the headwaters, coarse glacial deltaic sediments, and the toe-slope of high relief (upland drainage) features. The steepest topography in the Beaver River watershed is found in the end moraine hills and ridges of the headwaters and the stream-dissected bedrock features of the eastern watershed. The remaining watershed, including the entirety of the West Branch Beaver drainage has a more gently rolling terrain formed in clay tills. Highland flutes (drumlins) cover much of the mid-watershed, and consist of clayey soils over bedrock.

Development is primarily located in the lower third of the watershed and includes the Northshore Mining's Milepost 7 taconite tailings pond (1600 acres), several municipal ponds (< 20 acres), and the Silver Bay Golf Course (50 acres). In the West Beaver River sub-watershed, development includes the Silver Bay Municipal Airport (160 acres) and a few hundred acres of hay/pasture land. Rural development is dispersed. Streams mostly remain in a natural state with the exception of the diversions of Big Thirtynine and Little Thirtynine Creeks that occurred in the 1970s during the construction of the Milepost 7 tailings pond. The pond discharges to the Beaver River approximately 4.5 miles upstream from the mouth at Lake Superior. Stream alterations significantly altered upstream drainage areas and stream length in given reaches of Big Thirtynine Creek, Little Thirtynine Creek, and the Beaver River. Milepost 7 discharge effects on streamflow are described below.

The Beaver River hydrology is flashy, particularly in the lower watershed where stream gradients steepen. The low-permeability soils, lack of lakes, and shallow depth-to-bedrock contribute to high surface runoff rates resulting in fast, turbulent streamflow following precipitation events. MPCA stream gage H02006003 was operated at sample station MBV 696 during years 2011 to present. The hydrograph for this station (years 2011-2015) is displayed in Figure 82. Daily flows range from less than 1 cfs to 4890 cfs during the period of record. Bankfull flows were estimated using streamflow data and survey data. Estimates range between 1400 to 2000 cfs at 1.3-year reoccurrence intervals, primarily occurring during snowmelt and high-intensity rain events. It is typical for flows of less than 20 cfs to occur during the late summer.

Flow duration curves and stream flashiness

Flow duration curves can be used to interpret the flashiness of a stream system, with sharp curvature indicating fast changes in discharge. Figure 118 in the Talmadge Hydrology section of the report compares flow duration curves, normalized by bankfull discharge, for multiple streams along the North Shore. Streams included include lake-dominated systems such as Poplar River and Brule River, wetland dominated systems such as Big Sucker Creek and Baptism River, and systems that generally lack surficial storage such as Amity Creek and Talmadge River. Because the flashiness of Beaver River compared to other streams was not as obvious in Figure 118 as it was for the Talmadge River, a second step of aligning normalized curves at the upper threshold of mid-range flows was taken to further analyze curvature (Figure 80).

This analysis indicated that Beaver River is flashier than the lake-dominated Poplar River and Brule River, but is less flashy than Talmadge River and Amity Creek for all flow regimes. These findings can be explained by an increase in lake storage in the Brule and Poplar Rivers and the overall lack of storage in lakes and wetlands in Amity and Talmadge, compared to Beaver River. When compared to Big Sucker Creek, Beaver River duration curves are very similar in shape for high flows, but Sucker Creek has noticeably less slope indicating more sustained flows during dry and low flow conditions. Because percent surficial storage in Beaver River and Big Sucker Creek is approximately equal, this indicates that Big Sucker Creek has greater groundwater contributions to streamflow than the Beaver River during dry periods. Compared to Baptism River, Beaver River is flashier during high flow periods, but similar in slope for mid-range and dry conditions .

A difference in slope is observed in the low flow regime of 95-100% exceedence, where the Baptism slope steepens as Beaver River slope remains unchanged. This difference may be due to increased uncertainties in data at the very low end of the respective rating curves used to compute low flow output for these stations. However, our data shows that the Milepost 7 point source discharge sustains Beaver River streamflow above a set level (~7cfs) within this regime as described further below in this report section. This could factor into the difference between Beaver and Baptism River curves in the low flow regime.

Flow magnitude of the Beaver River is greater at all flow regimes than flow rates observed in the streams with noticeably smaller (>69% reduced area) drainages. These include Amity Creek, Talmadge River, and Big Sucker Creek. Beaver River flow magnitude is less for all flow regimes than flows recorded on Brule River which has two times the drainage area. Beaver River flows are greater than Poplar and Baptism at higher discharges, while Baptism and Beaver River flows are less than Poplar at lower discharges. This relationship between Poplar and Beaver River flow magnitudes can be explained by the hydrograph buffering that occurs with increased lake storage found in the Poplar River drainage.

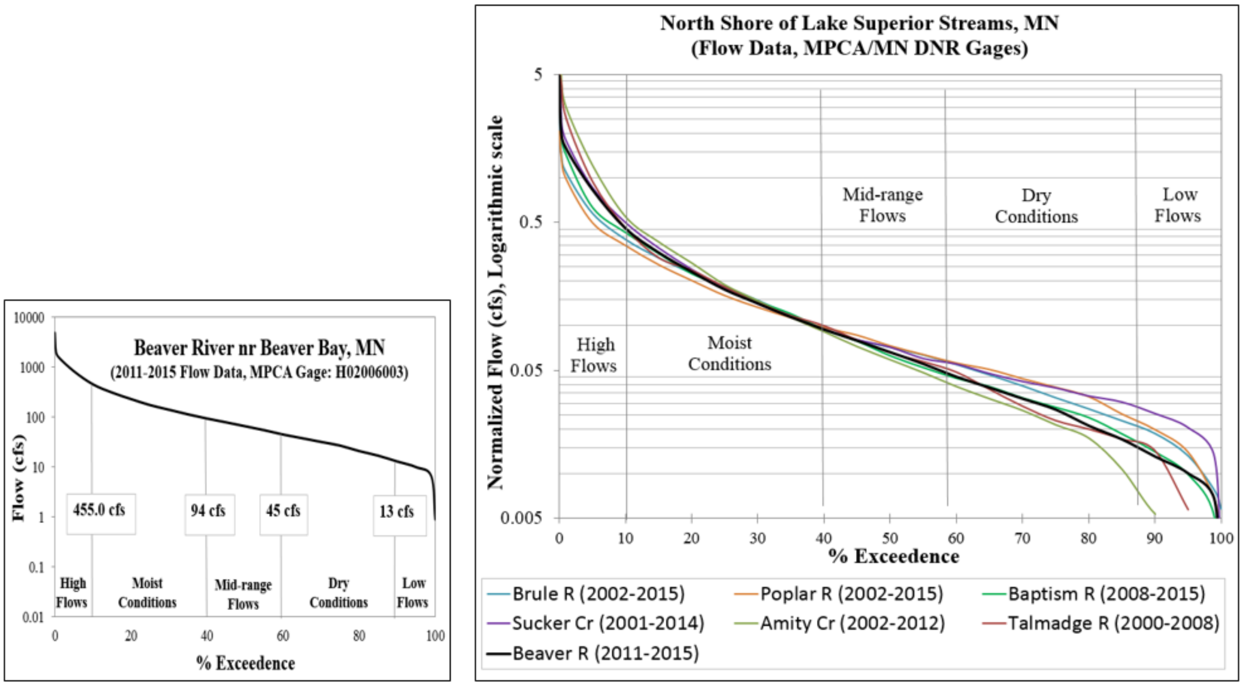


Figure 80. The flow duration curve developed for the Beaver River stream gage identifis five flow regimes (left). The flow duration curve was compared to curves developed for other North Shore tributaries (right). Curves were normalized by dividing by bankfull discharge; and were aligned at the the 40% exceedence to compare curvature for different flow regimes.

Point discharge influence on the stream hydrograph

Records for Milepost 7 point discharge SD001 were analyzed for years 2000 to 2015. The data show annual discharge rates have increased over the period of record, particularly the latter half (2008-2015), resulting in an overall increase in annual discharge volume (Figure 81). Discharge rates range from 4.8 to 8.0 cfs over the period of record. To compare seasonal variation in discharge, the two time periods (first and second half of record) were separated and monthly rates were compared within and between each time period. Monthly rates were relatively constant with a median value of 5.3 cfs and seasonal range of 1 cfs for the 2000-2007 record. The general trend showed an increase in discharge from spring to late summer. The 2008-2015 data had an increased median flow rate of 8 cfs, a seasonal range of 2cfs, and showed no noticeable seasonal trend.

Point discharge effects on streamflow can be seen in gage records during several periods (September 2011 and August 2015) when the Milepost 7 water treatment plant was shutdown. Water levels at the flow gage decreased by 0.20 to 0.40 feet within 24-hours during both time periods. During the September 2011 event, the stream levels rebounded six days later following the re-start of the treatment facility. In 2015, the plant remained down for an extended period. Levels rebounded prior to the plant re-start and following multiple large rain events. Estimated declines in discharge corresponding to the drop in 2015 levels was 7.8 cfs, based on the flow-discharge relationship established at the gage station. The plant reported 7.7 cfs discharge one month prior to the shutdown, supporting our estimate. Stream flow at the gage was 13.4 cfs prior to levels receeding. This indicates that Milepost 7 discharge (SD001) was contributing approximately 58% of baseflow at the gage station, located 2 miles downstream from the discharge, during August 2015 baseflow and prior to the plant shutdown. Rating curves were not as well developed for season 2011, but new analysis of flow records similarly estimate that SD001 was contributing 56% flow in September 2011 prior to the plant shutdown.The extent of change in flows over the full hydrograph pre- and post-development of Milepost 7 is unknown due the absence of stream flow data pre-construction.

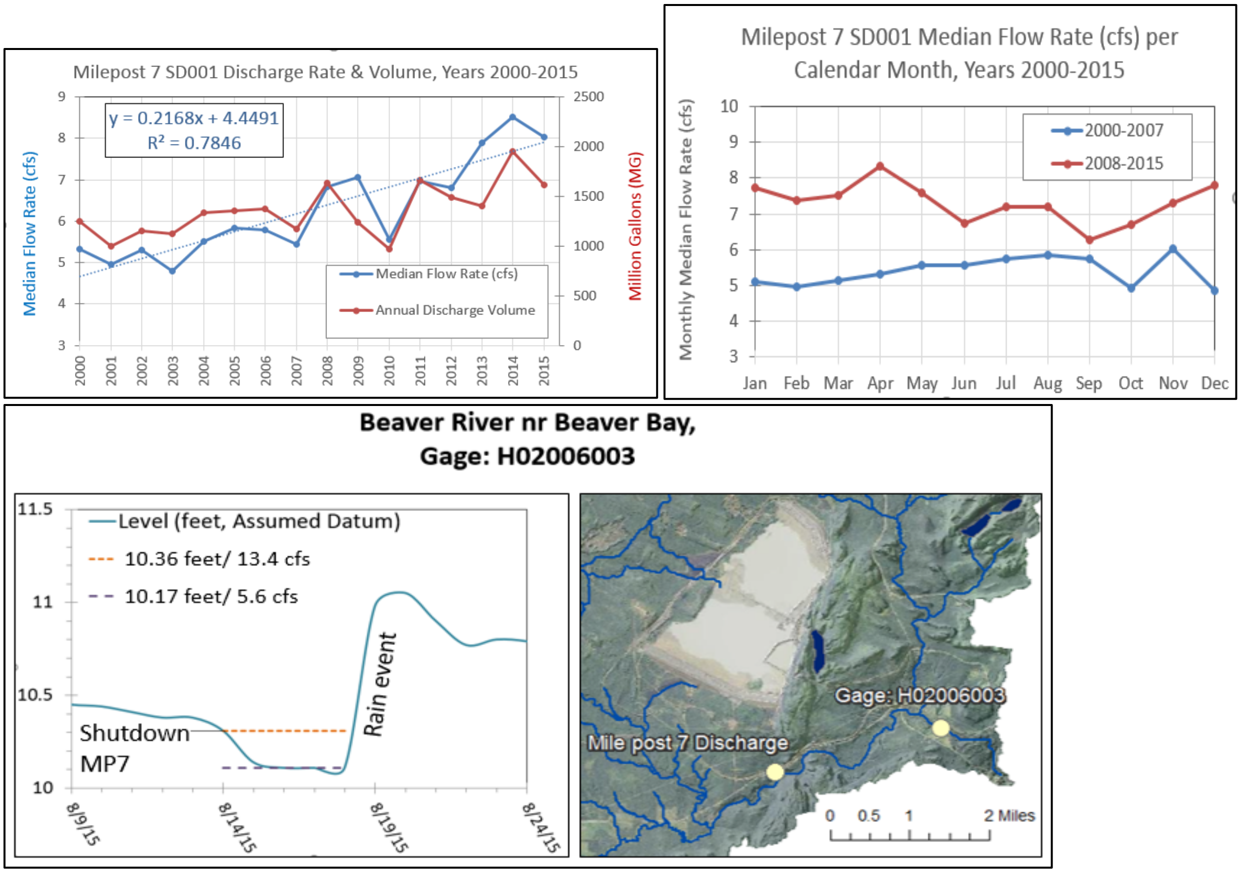


Figure 81. Milepost 7 Discharge records show an increase in discharge volume over the 2000 – 2015 period of record (upper left). Median flow rates were higher in years 2008-2015 than the previous half of record (upper right). The discharge is located approximately 2 miles upstream of the gage and upstream of the East Branch Beaver River confluence with the Beaver River (lower right). A decrease in levels was recorded at the gage in August 2015 when the discharge was temporarily shut-down (lower left).

Watershed isotope characterization

Stable isotopes of oxygen and hydrogen are used to identify source waters to surface water and infer the relative contributions to surface water from ground water, soil water, and precipitation. Isotopes can quantitatively and qualitatively describe mixing and track variability throughout seasons. Detailed discussion on the application and methods of isotopic analysis of oxygen-18 ($\delta^{18}O$) and deuterium ($\delta^{2}H$) in hydrologic applications are located in Section 4.3 of this report. This includes the use of the local meteoric water line (LMWL), local evaporative line (LEL), and inflow value (δI), which is the intersection of the two lines. Theoretically, the inflow value is the signal representing weighted mean annual precipitation in precipitation-driven watersheds.

Stream water samples were collected from twenty-one sample stations dispersed throughout the Beaver River watershed in years 2013-2015. The highest temporal frequency of sampling was conducted on the mainstem Beaver River, West Branch Beaver River, and Cedar Creek. Additional streams in which sampling occurred at an equal or lesser frequency included East Br. Beaver River, Big and Little Thirtynine creeks, and a tributary to West Branch Beaver River. Waterbody signatures were collected for Lax Lake outlet at Nicado Creek station NCC 699 and the Milepost 7 tailings pond at the discharge. The samples were submitted to the Biometeorology Lab at the University of Minnesota and University of Waterloo Environmental Isotope Laboratory for analysis of ^{18}O and ^{2}H. Results are shown in Figures 83 and 84.

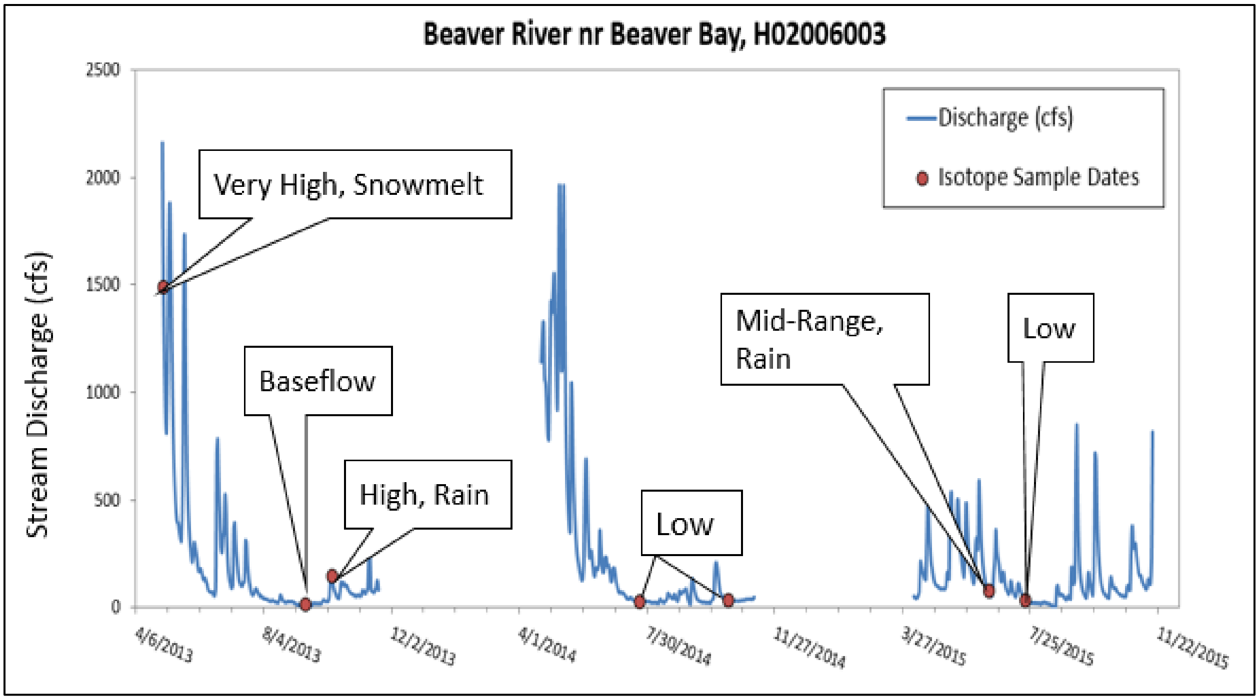


Figure 82. Isotops samples were collected for various flow regimes in 2013-2015.

Streamflows ranged from 13 to 1490 cfs at the Beaver River gage for discrete sample events which captured high to dry condition flow regimes (Figure 82). The term baseflow was used to differentiate the September 2013 event which was barely above the low flow regime threshold from other dry condition sample events. Hydrographs for years 2013 and 2014 show a large stream discharge response to snowmelt, reaching flows of approximately 2000 cfs for each snowmelt peak and remaining at very high levels into mid-May. Snow totals for winter season 2014-2015 was approximately one-third of the totals for the two previous winters and resulted in an insignificant 2015 spring season peak in discharge. Alternatively, rainfall in September of 2015 resulted in multiple very high flow events that were not observed in the dry summer months of August and September in seasons 2013 and 2014.

Groundwater signals in streamflow

The estimated inflow value for Beaver River is -11.3‰ $\delta^{18}O$ based on the intersection of the LMWL and LEL (Figure 83). To develop the LEL ($\delta^2H = 5.3\ \delta^{18}O - 19$, $r^2 = 0.88$), isotope signatures of 32 samples showing losses to evaporation were used. Evaporation primariy was observed in data collected during dry-condition events including the September baseflow event, which clearly shows the highest evaporative effects on stream water. No stations show a consistantly dominant groundwater signal throughout the year. Due to lack of inter-annual consistency in signals at stations, a range of $\delta^{18}O$ values was defined for consideration of relatively “stronger” or “deeper” groundwater influence in stream water in this analysis. The set range was detemined in consideration of $\delta^{18}O$ inflow values derived for three Lake Superior South subwatersheds: Amity Creek (δ I = -10.8‰), Talmadge River (δ I = -10.4‰), and Beaver River (δ I = -11.3‰). With consideration of the error range (2 x 0.2‰) for $\delta^{18}O$, the groundwater range was set at -11.7 to -10.0‰. Results falling outside this range do not necessarily indicate that groundwater is not contributing to stream flow. If subsurface storage is extremely shallow, groundwater signals may change with filling and flushing of the shallow water table during moderate to very high rain events and may show depletion during snowmelt and enrichment following large summer storm events. A site with more stable readings within the groundwater range would suggest a deeper storage zone where annual waters reside long enough to become well-mixed.

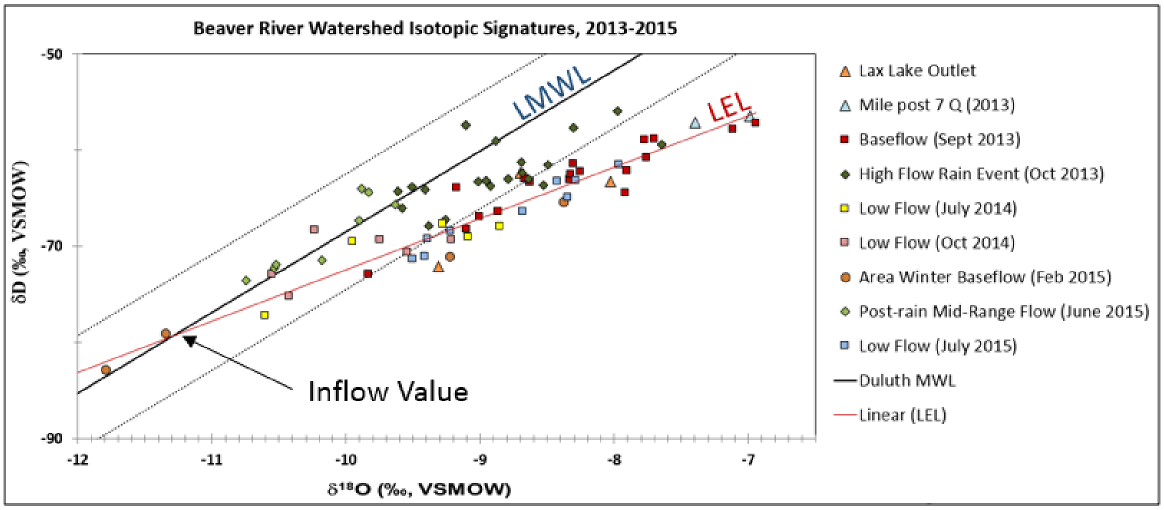


Figure 83. Isotope signatures of all samples were evaluated against athe LMWL developed for Duluth. The sample results were used to develop a LEL and estimate the inflow value (intersection of the two lines).

The most distinct groundwater signals observed in Beaver River Watershed stream samples were from samples collected in February 2015. During the winter event, samples were collected at four locations on mainstem Beaver River, two upstream of Milepost 7 discharge and two downstream. The two upstream stations (MBV 615 in the headwaters and MBV 670 in the mid-watershed) show no evaporative loss and are within -0.1 and -0.5‰ $\delta^{18}O$ of the inflow value. The February 2015 sample results suggest that groundwater dominates streamflow in the upper Beaver River during under-ice conditions of winter as would be expected.

The differences from the inflow value suggest well mixed groundwater storage conditioning the stream in the mid-watershed at MBV 670 and more depleted fall or winter precipitation comprising the water table at the headwaters station MBV 615. The evaporative signals found in the two lower watershed stations for the February sample event indicates that sources of flow other than groundwater are comprising under-ice streamflow at stations MBV 685 and MBV 696 (gage station). These sources are discussed in more detail below in the upper and lower Beaver River Minor Watersheds Hydrogeology Section. Additional groundwater signals were found in streamflow in discrete reaches during July 2014, October 2014, and June 2015 dry to mid-range flow events. Eleven percent of the total watershed samples fell within the set groundwater range. Of those samples, only one sample collected on Cedar Creek was taken during the more evaporative months of July through September. The other eight were collected in February, June, and October. The lack of signals within this range during the dry and hot summer months indicates that deep subsurface storage is lacking in this watershed.

Surficial and point sourcewaters

Surficial sourcewaters sampled included the Milepost 7 basin point discharge (Milepost 7 SD001) and the Lax Lake outlet sampled at downstream Nicado Creek station NCC 699. Milepost 7 was sampled in March and September of 2013, representing late winter and late summer conditions. The $\delta^{18}O$ signal range (0.4‰) was tight (Figure 84) and showed relatively high evaporative enrichment. Lax Lake outflow was collected at Nicado Creek station NCC 699 which is located just downstream of the Lax Lake outlet. It was sampled in May, September, and October of 2013, capturing snowmelt, baseflow, and high flow conditions. The $\delta^{18}O$ signal range was also small at 1.28 and most clearly showed evaporation in two of three samples. As compared to 15 other sites that were sampled during the same three events, the next tightest ranges were found at Cedar Creek stations CRC 685 and Fortythree Creek station CRC 650 with respective $\delta^{18}O$ ranges of 3.32 and 4.31‰. Lax Lake and Fortythree Creek inputs to Cedar Creek is investigated more in the East Branch Beaver Minor Watershed section below.

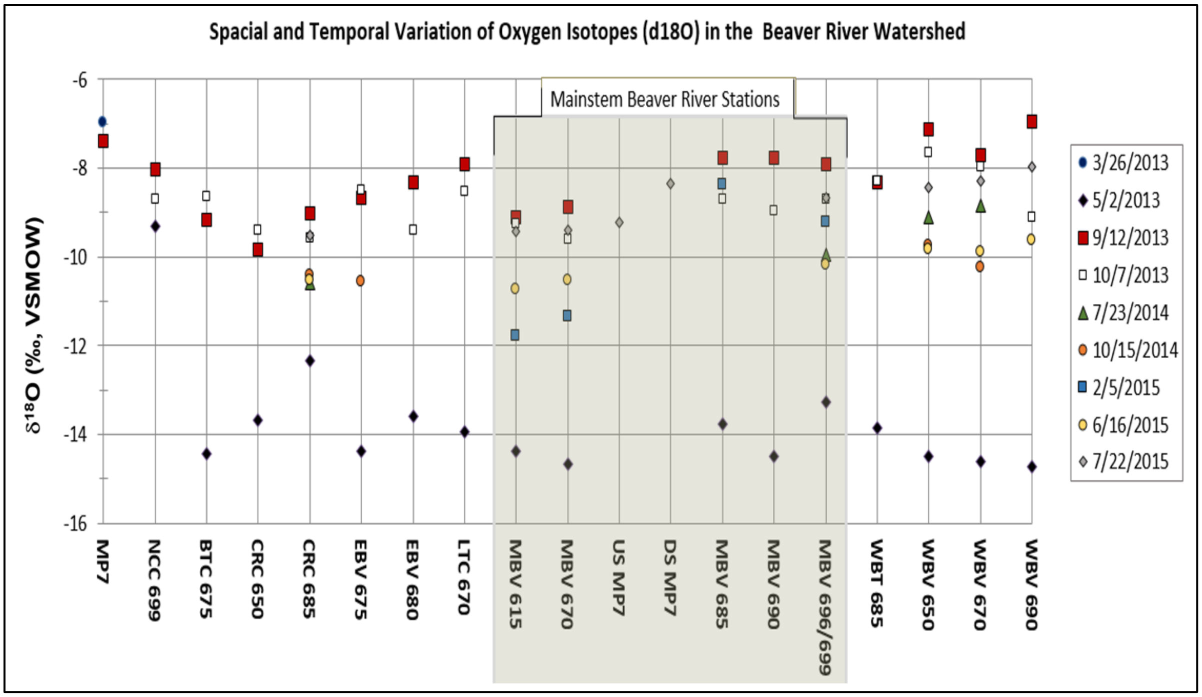


Figure 84. Oxygen-18 results ($\delta^{18}O$) for Beaver River Watershed stations that were sampled at a minimum for the snowmelt, baseflow, and rain events of 2013. Data for additional stations that were samples less are not shown in this plot. Sourcewaters sampled include Milepost 7 discharge (Milepost 7) and Lax Lake outflow (NCC 699). The estimated groundwater range is -11.7 to -10.0‰.

East Branch Beaver HUC-12 Minor Watershed Hydrogeology

The East Branch Beaver River and its tributaries including Hen Creek, Fortythree Creek, Nicado Creek, and Cedar Creek drain this HUC-12 watershed. Topography in the drainage is steep compared to the greater watershed (Figure 85). Steep abrupt features of end moraine deposits are found in the headwaters; and the steep topography of glacially scoured and stream dissected bedrock is present in the middle and lower portions of this drainage. Lax Lake and scattered wetlands are located in depressions of this steeper terrain. Groundwater, Lax Lake, and wetlands are the primary sourcewaters in this watershed.

Isotope Sampling was conducted on Fortythree Creek (CRC 650), Cedar Creek, (CRC 680), and multiple locations on East Branch Beaver River. The majority of the stations were sampled three times with additional sampling done at CRC 685 (seven samples) and EBV 675 (four samples) and lesser sampling at several East Branch stations (EBV 635, EBV 660, and EBV 697). Sites with more frequent sampling captured at a minimum a high flow snowmelt event, a moderate flow summer rain event, and late summer baseflow.

Isotope results show that the criteria for groundwater was met in July 2014, October 2014, and June 2015. These were dry to mid-range flow events in which very few stations were sampled, limiting analyses to some extent. Noticeable groundwater signals were met for all three events at the Cedar Creek station CRC 685. East Branch Beaver River station EBV 675 was sampled during the October 2014 event and also showed groundwater influence. This station is located just upstream of the Cedar Creek-East Branch Beaver River confluence showing that groundwater was also present in the rolling terrain and non-lake portion of this drainage. It is typical for stream signals to fall within the groundwater range during non-storm event conditions in October when evaporation and transpiration rates decline and groundwater levels begin to rebound.

Groundwater and lake inputs to Cedar Creek

Of all stream stations sampled under snow, rain, and baseflow conditions, Cedar Creek had the tightest $\delta^{18}O$ range (3.3‰) compared to the median (5.8‰) and maximum (7.7‰) values (Figure 84). The Cedar Creek station is located 2.8 miles downstream of Lax Lake and less than one mile upstream of its confluence with East Branch Beaver River. A tight $\delta^{18}O$ range (4.3‰) on Fortythree Creek station CRC 650 that is located in the Cedar Creek headwaters upstream of Lax Lake indicates that signal stability also occurs in the headwaters of this system, upstream of the lake. A marginal evaporative signal was measured on Fortythree Creek during the September baseflow as it plotted within the error bars of the LMWL and 0.8 ‰ less enriched than the next cluster of points along the LEL. This indicates that groundwater stabilizes the streamflowflow at this station. The Fortythree Creek station was not sampled during other dry condition events. For the three events in which it was sampled (snowmelt, baseflow, and October rain event of 2013), the composition at CRC 685 was compared to Fortythree Creek and Lax Lake signals. We estimated percent contributions to Cedar Creek stream flow from Lax Lake using a simple linear mixing model. We assumed that Fortythree Creek represents the upstream sourcewater contributions to CRC 685 and Nicado Creek station NCC 699 represents lake outflow. Lake outflow contributions to CRC 685 were less than upstream source water contributions for all three events. The lake contributions would be 32% during snowmelt, 44% during baseflow, and 11% during the October rain event. These are all likely over-estimates as localized inputs from wetlands and groundwater were ignored. Based on photos of the lake outlet weir, 44% during baseflow particularly may be an overestimate as lake levels were likely below the weir. Because signals occurred in the groundwater range during dry conditions of July 2014 and October 2014, these data suggest that lake inputs through surficial pathways may not be a primary source of flow to Cedar Creek during dry conditions. Although lake inputs to the stream through subsurface pathways may be sourcing flow. Another possible source of the evaporatively enriched waters observed during the baseflow sampling is nearby wetlands, located between the lake and the sample station.

Late summer, Low flow source waters

Watershed-wide, samples showed marginal to high evaporative enrichment during the late summer September 2013 sampling. Streamflow was near low flow conditions with the last high flow rain event occurring two months earlier. Maximum monthly air temperatures for the year were reached in June, July, and August; just prior to this sampling event. Fortythree Creek signal plots closest (< 0.2‰, $\delta^{18}O$) to the groundwater threshold. Cedar Creek CRC 685 plots within the next cluster at slightly higher evaporative enrichment. The majority of East Beaver River stations show a more evaporative signal than Cedar Creek. Positioning along the LEL indicates moderate losses on East Branch Beaver River when compared to all greater watershed sites. Likely, a mix of wetlands and groundwater contribute flow to all of these streams under baseflow conditions. The placement of signatures along the LEL during late summer suggests that groundwater is most dominant at Fortythree Creek whereas wetlands play a greater role in contributing flow to East Branch Beaver River under the same climatic conditions. Compared to the greater watershed, Fortythree Creek and Cedar Creek are among sites with the highest groundwater contributions during low flow periods.

Storm event souce waters

During snowmelt of 2013, streams were sampled during high flow (1490 cfs) conditions. All stream samples with the exception of Cedar Creek CRC 685 fell within the -14.7 to -13.2‰ $\delta^{18}O$ range due to isotopically depleted snowmelt waters contributing to streamflow. The increased enrichment (-12.3‰, $\delta^{18}O$) at station CRC 685 is due to snowmelt inputs (32% flow) from Lax lake. Signal comparison at surrounding stations (NCC 699, CRC 685, EBV 675, and EBV 680) suggest that lake contributions to Cedar Creek's downstream receiving waters diminished longitudinally and were indistinguishable from event flow meaured elsewhere in the watershed at downstream East Branch stations EBV 680 and EBV 697.

Rain event waters mixed into streamflow throughout the greater watershed was observed during the October 2013 sampling through non-evaporative enrichment. Forty-three Creek, Cedar Creek, and two East Branch Beaver plot in a cluster with one Beaver River station (MBV 670) on the LMWL at less enrichment than other watershed stations. This suggests that less event water was mixed in streamflow of this minor watershed compared to the greater watershed. Either less direct runoff was influencing flow at these stations and/or more mixing of groundwater with event water was occurring. Greater post-storm enrichment relative to other stream stations in this minor watershed were observed at EBV 675 and EBV 697. EBV 697 is located in a golf course where increased surface runoff might be expected due to the sparsely vegetated landscape and potential tiling.

East Branch Beaver River and Milepost 7 Basin's North Ditch

The unique signal at EBV 675 compared to immediate upstream and downstream reaches of the East Branch Beaver River is not specific to the October 2013 rain event. It is also observed during the the May 2013 snowmelt event and September 2013 baseflow event. Isotope signals at EBV 675 plot closer to signals observed on Big and Little Thirtynine Creeks than longitudinally adjacent stations on the East Branch Beaver River. The unique signal may be related to the hydrologic functions and storage areas found in the Highland Flutes (drumlin)-wetland landscape that drains to station EBV 675. These flutes are also present in Big and Little Thirtynine Creek drainages. Another possible influence on flow is a ditch (Figure 85) located at the north end of the Milepost 7 basin. The ditch drains 2 mi^2 of the Highland Flutes landscape just north of the basin and enters the East Branch system 800 feet upstream of EBV 675. Increased drainage efficiency in the area due to the ditch could cause a localized change in signal in this reach of the East Branch Beaver River. Because Big and Little Thirtynine creeks historically flowed through this area, it is also possible that subsurface substrate and flow pathways play a role.

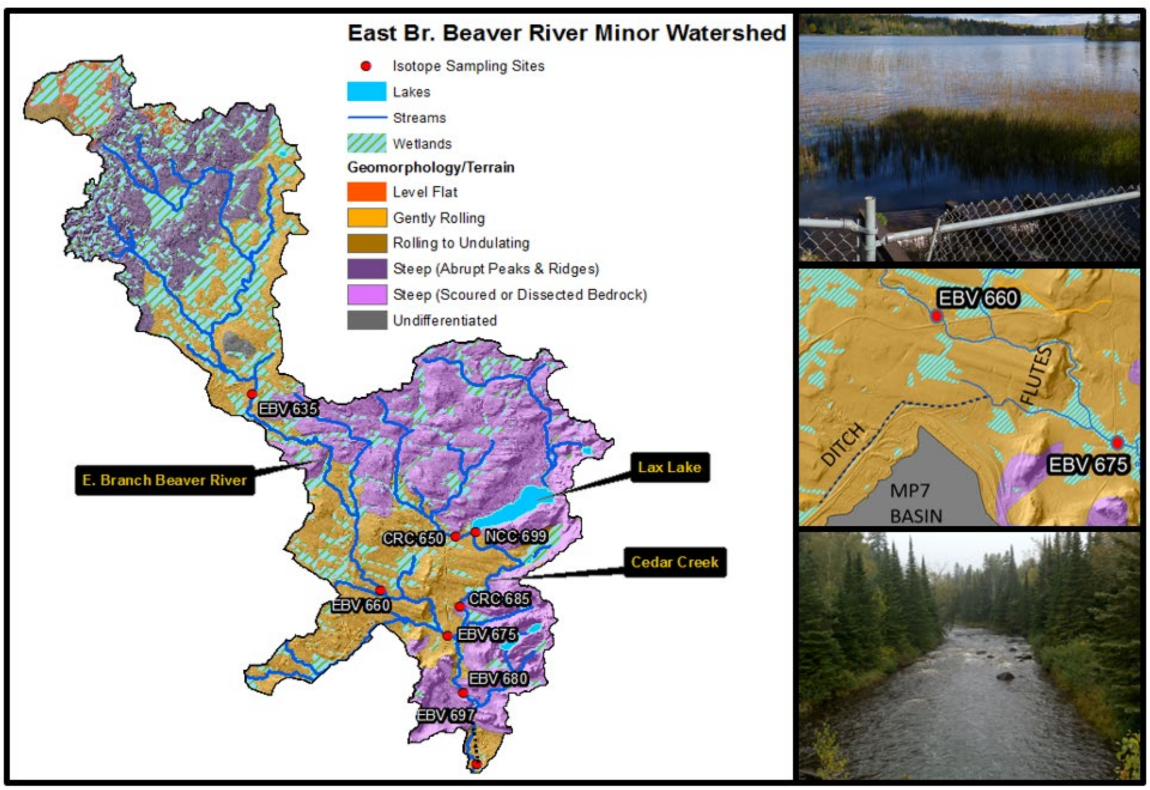


Figure 85. (Left) East Branch Beaver River Minor Watershed showing isotope sampling stations, hydrologic features, and geology. (upper right) Lax Lake outlet structure. (Middle Right: Highland flutes and diversion ditch near station EBV 675. (lower right) East Branch Beaver River at station EBV 680, located at CSAH 11 crossing.

Big Thirtynine and Little Thirtynine Creeks hydrogeology

Big and Little Thirtynine Creeks are the main stream channels in this subwatershed with several smaller unnamed tributaries draining wetlands in a gently rolling landscape of the Northshore Highlands (Figure 86). Highland flutes are scattered through the watershed, becoming more prominent in the southern part of the drainage. Steep topography exists only in pockets, located at end moraine peaks and ridges in the headwaters and a scoured bedrock peak on the eastern side of the midwatershed. Rerouting of these streams around the Milepost 7 basin is discussed above and in other sections of this report. Landuse/cover is primarily forested and road density is extremely low.

Isotope Sampling was conducted at several locations on Big Thirtynine and Little Thirtynine Creeks with three events (snowmelt, late summer baseflow, October rain) sampled at stations BTC 675 and LTC 675 and less frequent sampling conducted elsewhere. No specific sourcewaters were sampled in this watershed due to the absence of lakes or point source discharges. Isotopes were used to analyze subsurface verses surficial (wetland and runoff) flow inputs within the system.

Late summer, low flow source waters

During September 2013 baseflow sampling, Big Thirtynine creek station BTC 675 is the only station that clearly falls along the LMWL rather than the LEL. It plots 0.9‰ $\delta^{18}O$ from the groundwater range, but relative to the greater watershed shows minimal loss to evaporation while plotting within a cluster of sites that show seasonal groundwater influence. Since no evaporative signature is present in the signal, we believe the primary sourcewater is groundwater. The datum plots 2.4‰ $\delta^{18}O$ to the right of the inflow value which indicates that the aquifer is not deep enough to store well-mixed annual precipitation. The residence time is likely much shorter than a year. Increased enrichment at headwater site BTC 625 indicates higher percent flow coming from wetlands in the headwaters portion of the drainage, differing from the subsurface signal observed downstream. More evaporative enrichment is seen in the Big Thirtynine Creek headwater signal compared to the upper Beaver River (MBV 615) headwater signal for the same baseflow event. This shows more wetland influence on flow in the Big Thirtynine Headwaters than other headwater areas. A smaller percent area covering end moraine features and station distance from steeper moraine features may explain the greater wetland influence in Big Thirtynine Creek headwaters compared to upper Beaver River headwaters. Little Thirtynine Creek station LTC 670 shows greater evaporation during baseflow than all other Big and Little Thirtynine Creek stations. Because the wetland density and type is uniform through the uniform landscape, we suspect the increase in evaporation in late summer may be due to two small beaver dams located on the channel just 400 and 800 feet upstream of the sample station.

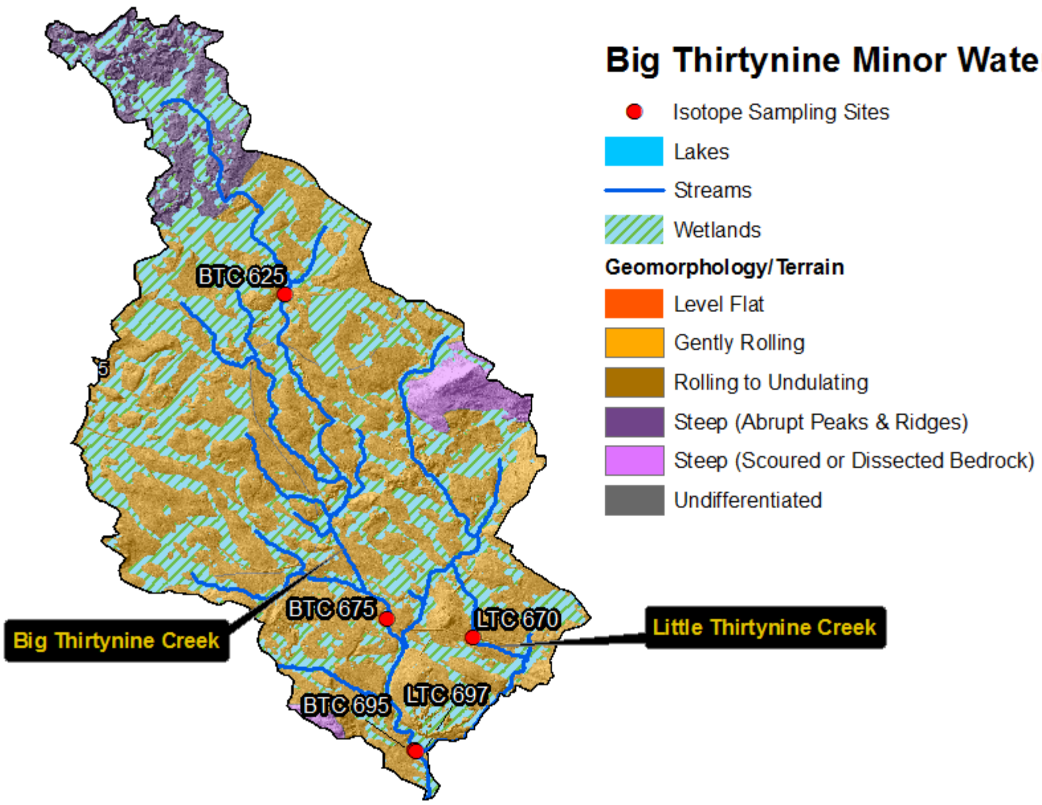


Figure 86. Big Thirtynine Creek Minor Watershed showing isotope sampling stations, hydrologic features, and geology.

Storm event source waters

Samples collected during the rain event in October 2013, show moderate enrichment from event water mixing into Big and Little Thirtyine Creeks when compared to watershed-wide stations. Sites LTC 670 and BTC 625 that showed higher evaporative losses during baseflow due to beaver dam and/or wetland influences became less evaporatively enriched as event water mixed into the system during the October storm event. Contrary, station BTC 675, which had a stronger subsurface signal during baseflow became slightly more enriched with the addition of storm event flow.

West Branch Beaver River hydrogeology

The West Branch Beaver River is a smaller catchment located within the Lower Beaver River HUC-12 minor watershed. Because of the impairment on this branch, the catchment was separated out for detailed analysis of isotope hydrology. The West Branch Beaver River is the main stream channel in this subwatershed with several small unnamed tributaries draining wetlands fron the north and upland features from the south. The gently rolling glacial landscape has very few high-relief features with areas of pronounced topography isolated in the far north and along the southern border of the catchment (Figure 87). Development and agricultural lands are located adjacent to the stream channel in the lower west-to-east flowing reaches. A prominent beaver dam is located immediately upstream of station WBV 650 at the highway culvert crossing. West Branch Beaver River station WBV 690 is located in a naturally-vegetated in-stream wetland complex as determined through analysis of soils and vegetation.

Isotope sampling was conducted at several locations on West Branch Beaver River and on an unnamed tributary that enters between the two downstream West Branch stations (Figure 87). Mainstem sample locations included outflow from a beaver dam (WBV 650), a site on the impaired AUID (WBV 670), and an in-stream wetland complex (WBV 690) that is located just upstream of the confluence with the

Beaver River. Station WBT 685 is located on the largest tributary which drains wetlands from the north. No specific sourcewaters were sampled in this watershed due to the absence of lakes or point source discharges. Isotopes were used to analyze subsurface verses surficial (wetland and runoff) flow inputs within the system. Samples were collected for snowmelt, October rain, and September baseflow events of 2013 and additional sampling occurred on the three West Branch Beaver sites.

Late summer, low flow source waters

The greatest $\delta^{18}O$ range of all greater watershed stations was 7.77‰ at station WBV 690 (Figure 84), which is a stream segment located in a wetland complex and holds in-channel vegetation that would typically be found in a wetland environment. Compared to all stations, the mainstem West Branch Beaver River stations are some of the most evaporatively enriched sites during dry to low flow conditions and the most influenced by storm event runoff. Maximum evaporation in the watershed was observed during the September 2013 baseflow sampling. The three mainstem West Branch Beaver stations had the greatest evaporative signal of all sampled sites. Mainstem site WBV 690 and WBV 650 noticeably plot to the right of all other values and are the only stations to show more percent fraction water loss to evaporation than the Milepost 7 basin in September 2013. The tributary signal at WBT 685 is moderately evaporative. Flow at the sample site during collection was stagnant. High evaporative losses at WBV 650 are expected due to the 0.5 acre beaver pond immediately upstream of the sample site. Smaller beaver dams are present upstream of the WBV 690 site, but the dams are much smaller in size with negligible water ponded behind. Evaporative signal at this location is likely due to the shallow wetland conditions of the stream channel and upstream contributing wetlands, but may also be affected by the smaller dams. The baseflow signal at WBV 670 shows that evaporative enrichment occurs in the mid-reach, but not to the extent that it occurs in reaches where beaver dams and wetland connectivity are present. Overall higher losses on this branch indicate that wetland storage is the primary source of flow during dry to low flow periods.

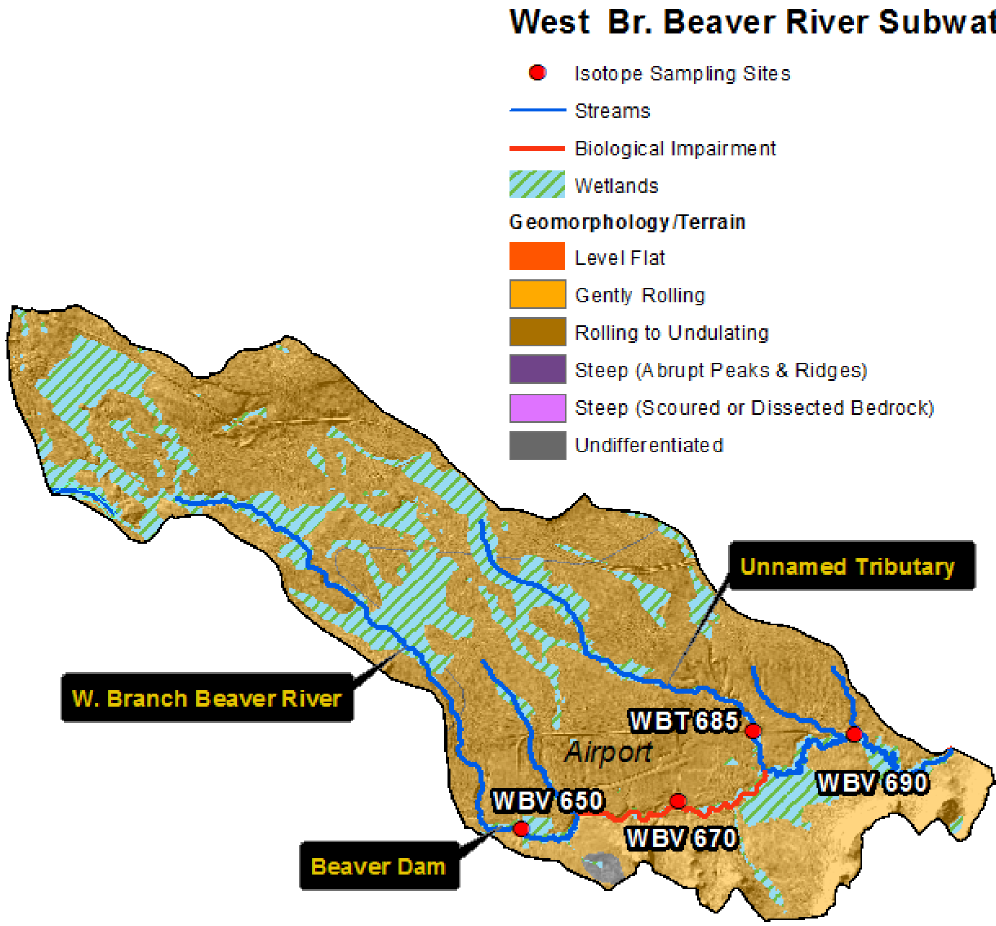


Figure 87. West Branch Beaver River subwatershed showing isotope sampling stations, hydrologic features, and geology. West Branch Beaver River is a smaller catchment located within the Lower Beaver River Minor (HUC-12) Watershed.

Early to mid-summer source waters

Evaporation is also observed for samplings in July 2014 (29 cfs) and July 2015 (36 cfs), both to a lesser extent than the September 2013 baseflow sampling. The average $\delta^{18}O$ value for the respective samplings were -9.07‰ and -8.22‰ compared to the -7.51‰ mean value for the September event. In all three evaporative events, West Branch Beaver River sites show high evaporative losses relative to the greater drainage. Immediately downstream of the Milepost 7 Discharge SD001 is the one locational exception where evaporation is within the range of that observed at West Branch sites. The increase in evaporation in September compared to July under dry conditions is expected as the fraction of evaporative losses in wetlands and beaver dams would increase with time during the hot and dry months of summer. The July samplings of 2014 and 2015 were done on the 23rd and 21st days of the month. Difference in evaporation might be due to differences in summer air temperatures with June and July 2015 air temperatures approximately 3 degrees higher in year 2015 compared to 2014. Also, 2015 was a very low snowpack year which means that the less melt water contributed to wetland and groundwater storage at the start of the season. This would cause more initial enrichment in storage than years where more depleted meltwater mixed into the system. Depending on residence time, this could affect July signals. In both July events, evaporative losses increase with distance downstream. The evaporative effects of the beaver dam at WBV 650 are more significant in the September 2013 baseflow data than July data.

Storm event source waters

Data show that non-evaporative enrichment due to storm event runoff is a driver in this watershed, both at mid-range and high flows. During the June 2015 mid-range flow (75 cfs) event, West Branch Beaver station were sampled as well as three Beaver River stations and Cedar Creek. Samples were collected 10 days after a high flow event. While other watershed signals cluster within the well-mixed groundwater threshold, the West Branch sites plot to the right. This indicates higher percent storm event waters in streamflow in the West Branch catchment. This could be due to a slow release of rain waters from wetlands following the event, but could also suggest that initial storage in the watershed was less than the other minor watersheds and did not sustain a spring season signal with the addition of rain water.

Greater spread or variable enrichment of water at West Branch stations is observed during the October 2013 stormflow event (148 cfs). Pre-event waters did not appear present in the wetland complex of station WBV 690 as it plots 2.2‰ $\delta^{18}O$ to the left of the September water collected at the station and shows no evaporative signature. Rain water was not sampled during this event so the isotopic signature of precipitation is unknown. We do know that the greatest change from September signatures occurred here when compared to data collected from twenty-one other stations. This indicates that source waters were most changed from the pre-event condition at this station. Flushing of pre-event water and storage of new event water in wetlands connected to WBV 690 may have occurred one day earlier during peak flows. More enrichment is observed at upstream stations WBV 670 and WBV 650, but the change in signal from September is less. Water from station WBV 650 shows slight evaporation in the signal and plots within 0.5‰ $\delta^{18}O$ of the September sample. Water from WBV 670 plots within 0.3‰ $\delta^{18}O$ of the September sample, but has no evaporative signal. The degree of change from September water at at these stations is more ambigious. Signs of sustained evaporation at WBV 650 in October 2013 indicates that pre-event waters stored behind the beaver dam remained present following the rain event. The beaver pond at WBV 650 is approximately one half acre in size and appears to be relatively deep. Mixing of event waters throughout the entire depth profile may not occur during a moderate flow event due to the pool dimensions. Time-intensive sampling in future monitoring could provide a clearer intrepretation of stream-response to event flow in this reach of the system.

Upper and lower Beaver River Minor Watersheds hydrogeology

The Mainstem Beaver River and its tributaries drain the greater watershed. The larger tributaries are discussed in the preceeding sections. The upper Beaver River and Lower Beaver River HUC-12 Watersheds are shown below in Figure 88. Although the West Branch Beaver River catchment is part of the Lower Beaver River HUC-12, it was excluded from Figure 88 as it was discussed in detail above. For continued discussion, we distinguish three stream segments of the Beaver River as individual stream sections and refer to them as follows: upper reach, Mid-reach Beaver River, and Lower reach with endpoints of the reaches defined by dashed lines in Figure 88. The upper reach is drained by wetlands and steep end moraine feautes and has one moderately sized tributary draining wetlands and undulating feaures from the west. Sample station MBV 615 is located in the headwaters of this reach. The Mid-reach receives waters from Big Thirtynine Creek from the east; and Kit Creek and an unnamed tributary drain wetlands and undulating features from the west. West Branch Beaver River enters the Beaver River near the downstream boundary of this reach that is shared with the Lower reach. Station MBV 670 is located in the Mid-reach and is located just upstream of inflow from West Branch Beaver River. The Lower reach receives flow inputs from upstream, West Branch Beaver River, Milepost 7 point source discharge, and East Branch Beaver River.

Isotope Sampling was conducted at six primary locations on the mainstem Beaver River. The upper reach and mid-reach each have one sampling station, MBV 615 and MBV 670 respectively. A higher number of sampling stations in the Lower Reach was intended to differentiate waters from the various inputs. Four primary stations were located in the Lower Reach. Additionally, the Beaver River immediately upstream and immediately downstream of Milepost 7 SD001 was sampled one time in July 2015 during dry conditions. This is the only event in which a sample was collected between the West Branch Beaver confluence and Milepost 7 discharge. In the 1.5 mile section of stream from the mouth of the Beaver River, data from two locations (MBV 696 and MBV 699) were collected. Three events in 2013 were sampled at location MBV 699. The 2014 and 2015 samples were collected from MBV 696. Based on their location (downstream of all major inputs) in the watershed, their results were combined in the data interpretation, representing the lower 1.5 miles of the river. Inconsistencies in sampling at all stations for all events limits data interpretation to some degree, but the majority of these stations were sampled four to five times each.

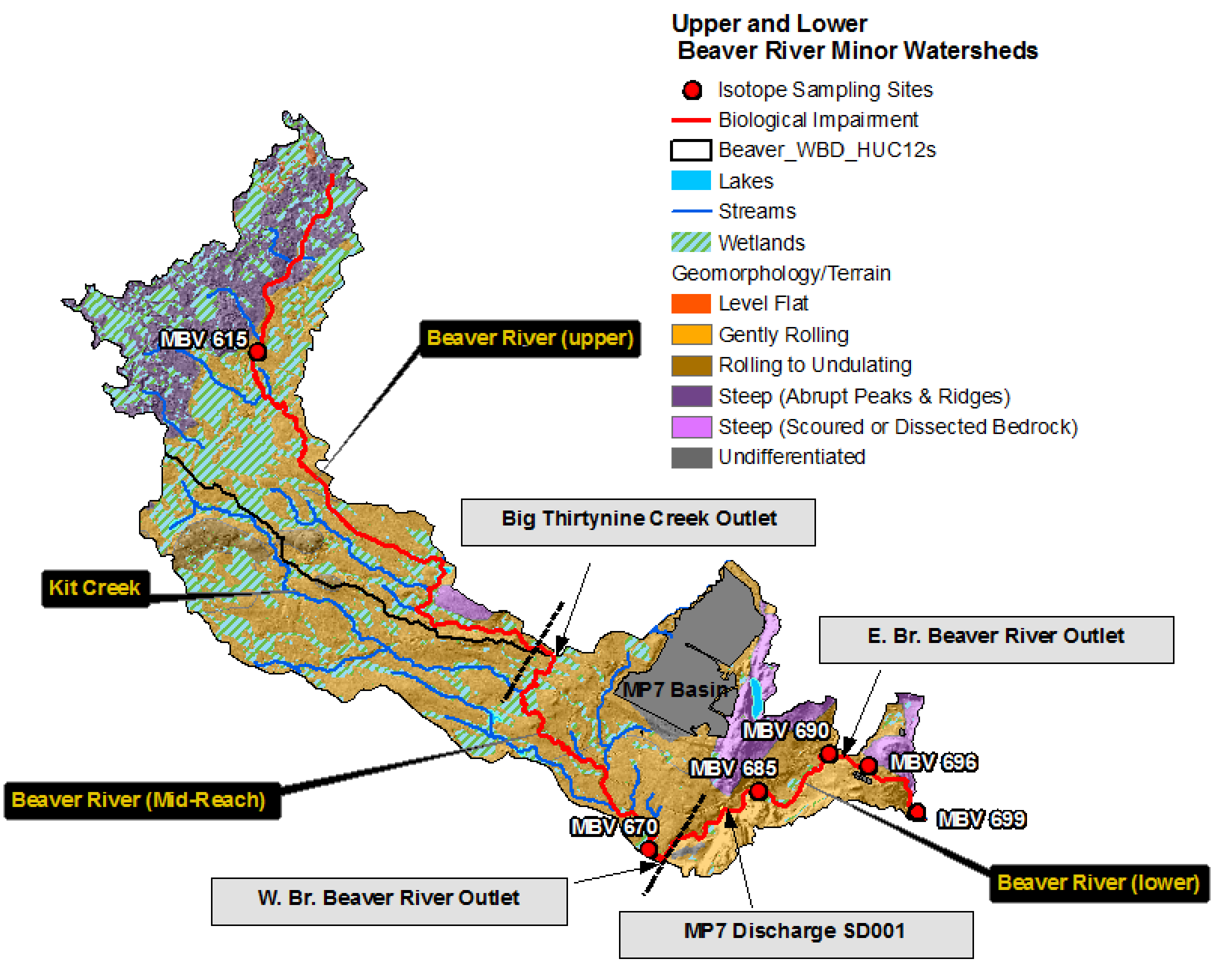


Figure 88. Upper and lower Beaver River Minor Watesheds showing isotope sampling stations, hydrologic features, and geology. The watershed boundary between the upper and minor drainage is depicted by a solid black line. The stream is divided into three reaches for data interpretations. The boundaries are depicted by dashed black lines. West Branch Beaver River,a smaller catchment located within the lower Beaver River Minor (HUC-12) watershed, is not included as it was mapped above.

Water composition change in the Lower Beaver River

Isotope data results for mainstem Beaver River show a noticeable change in water composition between Mid-Reach station MBV 670 and Lower-Reach stations for multiple samplings (Figure 89). The change is first and most prominently observed from signals measured at MBV 685. Compared to the upper and mid-reaches, water in the lower Beaver River is generally more enriched. The enrichment can be evaporative or non-evaporative in nature depending on the climatic and flow conditions of sampling. This indicates that the source of change in water composition in the Lower-Reach is dependent on climate and flow.

Waters in the Lower-Reach showed evaporative losses in streamwater for the following dry and low flow conditions: February 2015 (under-ice), July 2015 (Q = 36 cfs), September 2013 (Q = 13 cfs), and October 2014 (Q = 36 cfs). Upper and mid-Reach samples showed no signs of evaporation in February 2015, marginal evaporation in July 2015, and less percent evaporation in September 2013. The upper and mid-reaches were not sampled in October 2014, but several tributaries were including West Branch Beaver River, East Branch Beaver River, and Cedar Creek. West Branch Beaver River is typically one the most evaporative sites due to the wetland influence. A mid-reach station on this tributary showed no evaporative losses in streamflow and plotted within the groundwater range in October 2014. Marginal evaporation was observed above the West Branch beaver pond, but was less than that observed in the Lower Beaver River. East Beaver River and Cedar Creek also showed a groundwater signal. Compared to greater watershed sampling, Lower Beaver River had the most evaporative signal; and during a month when evaporative losses in wetland and stream signals typically are marginal to absent in this region.

Investigating source water inputs and the change in water composition

The Upper-Reach and Mid-Reach sites plotted near the groundwater inflow value for the February sampling, clearly showing a dominant groundwater signal during ice-conditions. Evaporation was observed in the Lower Reach sites during this sample event. Comparing signals at two Lower reach stations for the February event shows that station MBV 685 had noticeably more (1‰, $\delta^{18}O$) evaporative losses than at the downstream gage station (MBV 696). Primary source waters that could initiate the evaporative signature between the Mid-reach station MBV 670 and and Lower-reach station MBV 685 include West Branch Beaver outflow and Milepost 7 discharge. The reduction in evaporation between MBV 685 and the downstream gage most likely is linked to inputs coming from the East Branch Beaver River drainage as it is another main tributary to the gaged reach.

In addition to the routine sampling stations, two additional samples were collected immediately upstream and downstream of the Milepost 7 discharge during the July 2015 sample event. The additional data showed that just upstream of Milepost 7, the stream water composition does not appear different from the Mid-Reach water as it clusters within error range of the Upper and Mid-Reach signals. Just downstream of Milepost 7, the signal shifts up the evaporative line 0.88‰ $\delta^{18}O$, showing the most evaporative signal in the mainstem for this event. Data from the additional stations shows that the evaporative signal frequently observed in the Lower reach is not due to mixing from West Branch Beaver River outflow. It indicates that the Milepost 7 basin is causing the shift in water composition. Similar to the February event, the evaporative signal is slightly diminished at the downstream gage station from that observed downstream of Milepost 7 and likely is the result of East Branch Beaver River mixing into mainstem flow upstream of the gage.

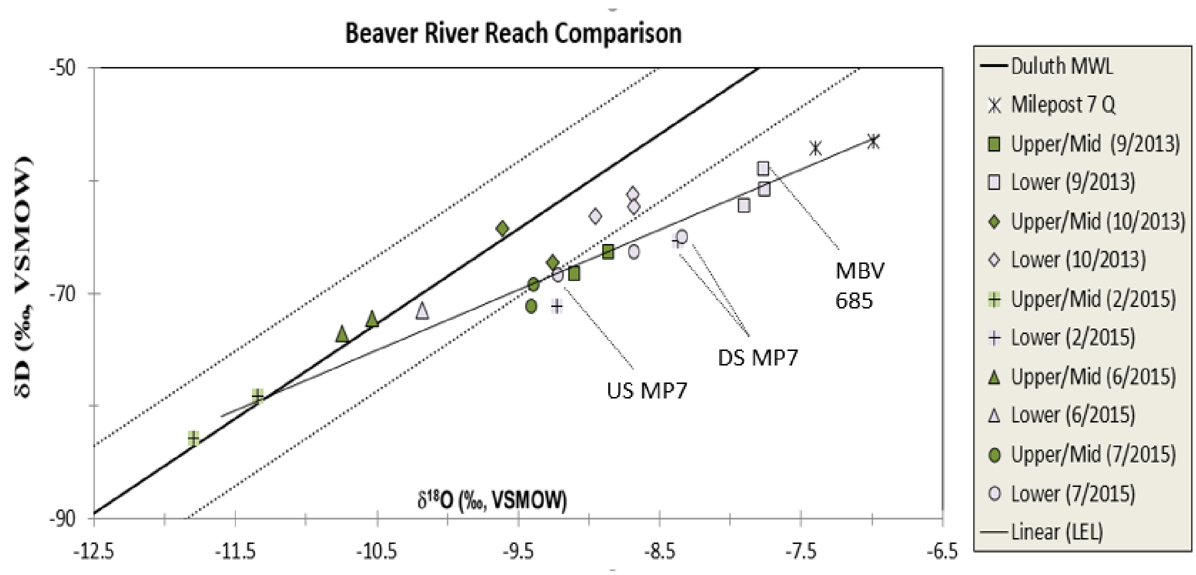


Figure 89. Isotope signatures for sample stations located on the mainstem Beaver show a difference in water composition that occurs between the Upper/Middle reaches and the Lower reach. Greater evaporative and non-evaporative enrichment is observed in the lower reach.

Late summer, low flow source waters

In September of 2013, the highest evaporation is observed in the system which is a typical observation for late summer samples. Respective to all samples collected in the greater system, the Upper and Mid-Reaches of the mainstem plot at a lower level of evaporation near Cedar Creek and Big Thirty Nine Creek signals and marginally outside of the error bars of the LMWL. This stream grouping is indicative of areas with more seasonal groundwater mixing. The Lower Reach stations plot >1‰ $\delta^{18}O$ further to the right along the LEL from the Upper and Mid-Reach signatures. Only waters collected on West Branch Beaver River and the outfall of Milepost 7 show more evaporation. Records indicate that Milepost 7 was discharging approximately 5.72 cfs in September 2013. This would account for 44% discharge computed at the gage station; and a higher percent fraction of flow in the section of mainstem that is located between Milepost 7 and the East Branch Beaver River outflow. An isotopic linear mixing model was used to further estimate percent contributions from Milepost 7 in this stretch of stream near station MBV 685. We assumed that Mid-Reach Beaver River and Milepost 7 discharge were the primary input waters at station MBV 685, and that West Branch Beaver River contributed little to no flow (based off of the July 2015 isotope results). The discharge estimate of this simplistic model is that Milepost 7 was contributing up to 75% flow volume at station MBV 685 during the September baseflow event. Likely the contribution was less since only two sourcewater were accounted for in the model. Localized wetlands or hyporheic exchange may also play a lesser role. This estimate provides a range (44-75%) for percent contribution in the reach of stream immediately downstream of the discharge. Slightly reduced evaporative enrichment was observed at the gage once again.

Storm event source waters

In addition to the February sample results, groundwater signals were again observed in the Upper and Mid-Reaches during the June 2015 sampling (Q = 75 cfs). Flows were high (Q = 600 cfs), just ten days prior to sampling due to a early summer rain event. Signals in the Upper and Mid-Reaches plot in a cluster with Cedar Creek station CRC 685, falling within the groundwater range. The Lower reach of Beaver River was sampled at the gage station. This sample also falls within the set groundwater threshold, but shows slightly more enrichment than the Upper and Mid-Reaches. Twenty-six stream stations along the North Shore were sampled for this event; and 80% of the stations show less enrichment than MBV 696. West Branch Beaver River was among the 20% that showed more. Groundwater signal are typical for this time of year as the $\delta^{18}O$ data range (-11.56, -9.49‰) and median value (-10.56‰) of the North Shore of Lake Superior tributary dataset shows.

Non-evaporate enrichment observed in rain event (148 cfs) samples collected in October of 2013 indicate event-water mixed in streamflow throughout the watershed. The Mid-reach station MBV 670 plotted along the LMWL at lesser enrighment than other sites. Forty-three Creek, Cedar Creek, and several East Branch Beaver sites plot in a cluster near this point indicating less event water in streamflow than the rest of the watershed at these stations. Either less direct runoff was influencing flow at these stations and/or more mixing of groundwater with event water was occurring. Lower Reach stations show more enrichment than the Upper and Lower watersheds, however there are no clear trends between isotope enrichment and locational variables such as drainage area, geology, or subwatershed groupings, making analysis somewhat ambiguous. Neither rain or direct runoff water was collected therefore the event water signal is unknown. Because this was not a hot summer rain event, precipitation may not have been highly enriched as the data indicates through lack of enrichment and trends. Change in $\delta^{18}O$ values between September and October 2013 samples was also analyzed. Lower and Mid-Reach Beaver River stations fall within the third and fourth percentile of the seventeen stream stations sampled or show relatively higher change from baseflow conditions compared to all stations.

Beaver River hydrogeology summary

Flow gage analysis produced 1.3-year recurrence intervals, a flow duration curve, and combined with point source discharge records, information on the influence of Milepost 7 discharge on streamflow. Flow duration curves showed that the Beaver River is a flashy watershed. When compared to other streams along the North Shore, it was less flashy to smaller systems near Duluth, but flashier than the lake-fed streams further northeast. Comparison of Beaver River to Baptism River and Big Sucker Creek shows that flow stability is more complex than just looking at drainage area and percent lakes and wetlands. Beaver River appears less stable than Big Sucker Creek on the lower end of the curve indicating that a lower proportion of groundwater may be contributing to streamflow in Beaver River. The slightly more stable low flows observed in Beaver River compared to its neighboring watershed, the Baptism River, may be related to the influence of Milepost 7 point source discharge on streamflow. Point source discharge effects on streamflow were evaluated using permit discharge records and streamflow records. During multiple periods when the Facility was nonoperational, 0.20 to 0.4 foot decreases in water level and 7.8 cfs drop in stream discharge occurred. We estimate that Milepost 7 was providing 58% baseflow when operational in August of 2015.

Hydrologic characterization was possible through analysis of isotopes ^{18}O and ^{2}H. Evaluation of evaporative and non-evaporative isotope signals identified the presence of surficial and subsurface source waters in streamflow. Dominant groundwater signals were absent during the hot dry summer months of July to September, although some stations noticeably had more subsurface mixing in streamflow compared to others. Lack of dominant groundwater in this watershed differs from that observed in regional studies conducted on Amity Creek and Talmadge River. This may be due to more surficial inputs in the Beaver River watershed including higher wetland density and the influence of lakes, ponds, and the Milepost 7 basin. This also could indicate lack of seeps from pockets of deeper storage in the Beaver River watershed when compared to other Lake Superior tributary drainages.

The data infer that groundwater mixing in streamflow in this watershed is most prominent in Cedar Creek, Fortythree Creek, Big Thirtynine Creek, and the upper and mid-watershed reaches of the Beaver River. Steeper topography of end moraine features or glacially scoured and stream dissected bedrock appear to be common features in upland drainages of these locations. This includes steeper topography in the headwaters, eastern watershed, and discrete features in the far western drainage. Under dry conditions, mixing of groundwater and wetland inputs seem to be occurring at all stations. Isotope data showed that West Branch Beaver River has a relatively high loss rate to evaporation during dry conditions, believably due to the dominant role that wetlands play in storing event waters in this catchment. Beaver dams also show highly evaporative signals during the summer months. A large dam on West Branch Beaver River only partially mixes with event waters during an early fall high flow event and shows high losses to evaporation in late summer. Smaller dams on Little Thirtynine Creek also appear to be enhancing evaporative losses in stream water during the summer.

A change in water composition under dry to low flow conditions occurs on the Beaver River between stations MBV 670 and MBV 685. The stations are respectively located in the middle and lower reaches of the impaired stream AUID. The addition of a mainstem isotope station during the July 2015 sampling showed that West Branch Beaver River outflow to Beaver River was not the source of this change. Isotopic signals in Beaver River showed negligible change from upstream to downstream of the West Branch confluence during a July sampling. We believe this means that flow from West Branch Beaver River to Beaver River is insignificant during dry conditions. A change in the stream composition was observed upstream and downstream of the Milepost 7 discharge, with a noticeable increase in evaporation in samples collected downstream of the discharge point. An evaporative signal is also present at the gage during dry conditions, but diminishes slightly from that observed immediately downstream of the point discharge. The hydrology data shows that Milepost 7 contributes up to 54% flow at the gage in August of 2015 when 13 cfs recorded at the gage. Gage records recorded a 0.25 to 0.40 foot drop in water levels and 7 cfs decline in streamflow when the Facility temporarily shut down on two separate occasions during the study. We believe that additional inputs from the East Branch Beaver drainage and/or hyporheic exchange make up the remaining 25% streamflow at the gage. Incorporation of the less enriched and more groundwater-influenced water of the East Branch drainage would explain the slightly diminished evaporative signal at the gage compared to immediately below the point discharge.

Lax Lake contributions to receiving waters is seasonally variable. These data suggest Cedar Creek has greater upstream, subsurface, and local inputs (combined) than surficial lake outflow inputs during all flow regimes. However, groundwater and Lax lake contribute to the stable composition measured through isotopes at the downstream Cedar Creek sample station. Using isotopes, we roughly estimate that the lake provides 32% flow to downstream Cedar Creek during snowmelt, 11% during a summer rain event, and up to but likely less than 44% contributions during late summer baseflow. Data suggest that the groundwater component in Cedar Creek streamflow is comparatively high under dry conditions relative to the greater watershed. This is most apparent during July and October months.

Future management for protecting hydrologic function

This data highlights areas where stream composition appears more stable due to groundwater inputs and lake inputs. It also identifies areas where wetlands play a key role in the hydrologic functions of the system. These critical hydrologic inputs and storage areas should be considered in future watershed management and protection efforts in the watershed. Our data suggests that water from the Milepost 7 basin contributes over half of the flow to this system and changes the stream composition in the downstream reaches of the Beaver River during dry periods. This should be considered when evaluating stream water chemistry in the lower system. Finally, isotope data suggests that generally strong groundwater inputs are scarce in this drainage. Although seasonal and mixed groundwater signals were observed in streamflow, no dominant groundwater seeps were found at the locations samples in this watershed. This differs from study results of nearby Lake Superior tributaries, Talmade River and Amity Creek, and may be due to less percent landscape in steep features, lack of deep subsurface sediments, or greater wetland storage. The lack of strong groundwater inputs in this watershed may limit stream temperature and low flow capacities that are critical for coldwater biota to thrive. Preservation of existing groundwater inputs in this watershed is critical for maintaining a coldwater habitat.

5.4 Beaver River Watershed Stressor Identification Summary

Stressor identification results for the Beaver River fish impairment are presented in Table 20. Refer to the section number listed in the right column of the table to review the evidence used to diagnose or eliminate the various stressors that were evaluated for this impairment.

Table 20. Summary of stressor identification results for the Beaver River fish IBI impairment

Candidate cause	Result	Section
Elevated water temperature	•	**5.3.1**
Low dissolved oxygen	X	**5.3.2**
Elevated ionic strength (Specific conductivity)	○	**5.3.3**
pH	○	**5.3.4**
Poor habitat	•	**5.3.5**
Loss of connectivity	○	**5.3.6**
Elevated total suspended solids/Turbidity	•	**5.3.7**
Altered hydrology	○	**5.3.8**

Key: **• = confirmed stressor** ○ = **potential stressor X = eliminated candidate cause**

5.5 West Branch Beaver River Watershed Stressor Identification Summary

Stressor identification results for the West Branch Beaver River fish and macroinvertebrate impairment are presented in Table 20. Refer to the section number listed in the right column of the table to review the evidence used to diagnose or eliminate the various stressors that were evaluated for this impairment.

Table 21. Summary of stressor identification results for the West Branch Beaver River fish and macroinvertebrate IBI impairment

Candidate cause	Result	Data analysis section
Elevated water temperature	X	**5.3.1**
Low dissolved oxygen	•	**5.3.2**
Poor habitat	•	**5.3.5**
Loss of connectivity	○	**5.3.6**
Elevated total suspended solids/Turbidity	○	**5.3.7**
Altered hydrology	○	**5.3.8**

Key: **• = confirmed stressor** ○ = **potential stressor X = eliminated candidate cause**

6.0 Talmadge River: Impaired reach (AUID 04010102-508)

6.1 Overview of biological data

Fish community overview

Reportable fish IBI results were calculated for two stations on the Talmadge River, both of which are located near the mid-point of the 6.17 mile impaired reach. Several other stations were sampled by DNR, but due to differences in methodology, FIBI scores cannot be calculated for those visits. Data from these non-reportable sampling efforts will still be considered during SID analysis. Attributes for the two MPCA stations (gradient, drainage area, etc.) are listed in Table 22. The original station used for assessment purposes, 11LS038, was sampled twice (2011 and 2013).

FIBI results for all visits were well above the upper confidence interval of the impairment threshold (Table 22). Based on the FIBI scores alone, these results would indicate full support of the designated use for this stream (coldwater aquatic life) and a high quality coldwater fish assemblage. However, additional tools are regularly used to evaluate the biological integrity of a stream and can result in contrasting conclusions. In the case of these Talmadge River stations, the Biological Condition Gradient (BCG) results suggested an impairment despite the relatively good FIBI results. Blacknose Dace and Creek Chub were highly dominant at both stations and sensitive taxa were poorly represented in both abundance and taxa richness. Ultimately, the assessment team decided to list the Talmadge River as impaired based on the low BCG scores and the fact that other impairments currently exist for this reach (Turbidity, Low DO).

Figure 90. Biological monitoring stations 11LS038 (left) and 13LS110 on the Talmadge River

Only five fish species were sampled by MPCA between the two monitoring stations. In addition to the large population of Blacknose Dace and Creek Chub sampled at both locations, Pearl Dace, Iowa Darter, and Brook Stickleback were sampled in low numbers at 11LS038. The Talmadge River is a designated coldwater trout stream, yet no coldwater fish taxa were observed during MPCA's sampling efforts. Coldwater species such as Rainbow Trout and Coho Salmon have been sampled during DNR surveys conducted in the early 2000's. A single Brook Trout was sampled by DNR in 2001 at station 01LS001, located at the river's mouth at Lake Superior. With the exception of stocked Rainbow Trout, no salmonid species have been sampled upstream of the natural barrier falls at river mile 1.1.

Table 22. Talmadge River biological monitoring stations and fish IBI summary

Station	Drainage area (mi2)	Gradient (%)	Fish IBI class	Fish IBI result *(visit year)*	Standard	IBI lower confidence limit	IBI upper confidence limit
11LS038	5.12	2.4%	11	53	35	25	45
11LS038	5.12	2.4%	11	51	35	25	45
13LS110	5.44	2.6%	11	50	35	25	45

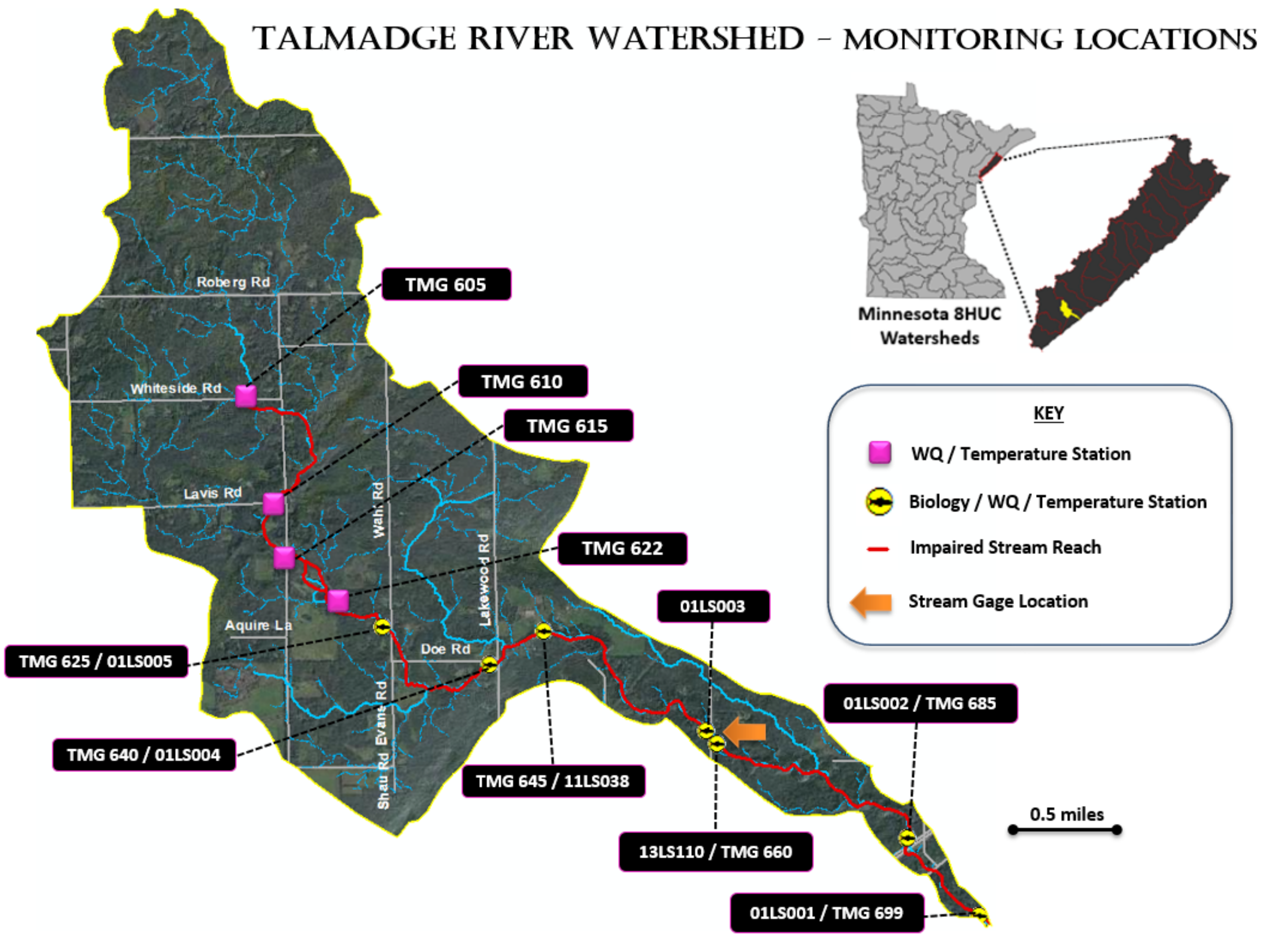


Figure 91. Talmadge River watershed monitoring stations and impaired reach

6.2 Stressor Identification analysis for the Talmadge River

6.2.1 Water temperature

Water temperature data used in this analysis were collected during summers of 2013, 2014, and 2015. Temperature loggers were installed in April and May and retrieved from the stream in October, although data analysis for the purpose of stressor identification tends to focus on the summer period from June 1 – August 31. Temperature monitoring locations were primarily selected to be co-located with biological monitoring sites. However, several loggers were deployed in non-biological monitoring locations in order to improve spatial coverage, investigate areas that could contribute to thermal stress, or evaluate potential coldwater refuge areas.

A summary of the temperature data is presented in Table 23 along with statistics related to critical temperature thresholds for Brook Trout. Some of the stations have partial records due to temperature probe malfunction or installations that occurred after June 1st. Six out of the eight stations recorded temperatures within the growth range for Brook Trout for greater than 80% of the monitoring periods. The two stations that dropped below this mark were located on the same reach, just downstream from the Duluth Retriever Club Impoundment. These two stations are significant outliers in the watershed in terms of water temperature.

Talmadge River temperature data from 2013 and 2015 are plotted in Figure 93. The highlighted "Areas 1 - 4" correspond to the thermal regime groupings presented in Section 4.1 (Methods Section). Thermal regimes in Area 3 and 4 frequently support Brook Trout and other coldwater species, while those in Area 1 and 2 tend to be marginal and less likely to support coldwater taxa. Most of the Talmadge River stations plotted in Area 3 or 4, which indicates that suitable temperature ranges were present for Brook Trout and other coldwater species during these monitoring seasons. The coldest temperatures in the watershed were observed in headwaters areas (TMG 610/TMG 615) and lower reaches (01LS002, Highway 61 to Lake Superior) (Figure 93). As mentioned previously, significantly warmer water temperatures were observed at station TMG 622, which is located immediately downstream of the Duluth Retriever Club Impoundment. This station plotted well within "Area 1" based on 2015 temperature data with water temperatures frequently exceeding Brook Trout stress threshold (56.3% of monitoring period) and lethal threshold (15% of the monitoring period).

During the course of this study (2011-2015), the warmest water temperatures were consistently observed downstream of the Duluth Retriever Club pond, which is formed by a low-head wooden/earthen dam with a concrete spillway. A permit was issued to construct the dam in 1957 and today an approximately 4.5 acre reservoir exists in the headwaters of this designated trout stream. At the time of permit issuance, it was determined that the dam and impoundment would have "no serious effect to the stream" (State of Minnesota Conservation Department Correspondence, 1957). A state of Minnesota official made this determination based on "knowing the stream and the little angling it gives in this particular area." No water quality or biological data were collected prior to the dams' construction and a complete lack of biological data remains for the stream reach above and below the Retriever Club impoundment.

Continuous monitoring data clearly show the warming effect caused by the impoundment. Loggers were placed above and below the pond in 2015 to compare stream temperatures throughout the summer season (June 1 – August 31). Average water temperature below the pond was 4.6 °C warmer than the upstream station. Water temperature downstream of the pond exceeded the stress and lethal thresholds for Brook Trout at a much higher frequency and longer durations. Maximum temperatures below the pond exceeded 30°C (Figures 96, 97). The maximum instantaneous temperature difference between the upstream and downstream stations was 8.18 °C, which occurred on June 19, 2015.

The increase in stream temperature caused by the Retriever Club pond appears to be fairly localized. Data collected in August of 2015 show warmer temperatures below the pond (TMG 622), but approximately 1.5 miles further downstream at station 11LS038, stream temperatures were very comparable to those observed upstream of the pond (TMG 615) (Figure 97). Several small tributary streams enter the Talmadge downstream of the retriever pond and contribute colder water to the stream when flowing. Additional groundwater inputs appear to enter the river in the vicinity of Highway 61 down to the confluence with Lake Superior. Temperature data collected during the course of this study consistently show colder temperatures in this lower reach near Lake Superior.

Table 23. Summary of Talmadge River temperature results for 2013, 2014, and 2015 by monitoring station. Stations are arranged in upstream to downstream order, top to bottom.

River	Station	Year	% Record	Summer Avg	July Avg	% Growth*	% Stress^	% Lethal#	% No Growth##
Talmadge R.	TMG 610	2014	60%	n/a	n/a	97%	3%	0%	0%
Talmadge R.	TMG 610	2015	96%	16.0	17.2	100%	0%	0%	0%
Talmadge R.	TMG 615	2013	100%	14.9	15.9	100%	0%	0%	0%
Talmadge R.	TMG 615	2015	96%	17.2	18.7	82%	16%	1%	0%
Talmadge R.	TMG 622	2015	96%	21.8	23.6	26%	56%	15%	0%
Talmadge R.	01LS005	2014	65%	n/a	n/a	79%	21%	0%	0%
Talmadge R.	01LS004	2013	100%	16.9	18.6	84%	16%	0%	0%
Talmadge R.	TMT 650	2013	87%	n/a	16.4	97%	3%	0%	0%
Talmadge R.	11LS038	2013	100%	16.8	18.1	86%	14%	0%	0%
Talmadge R.	11LS038	2014	64%	n/a	n/a	91%	9%	0%	0%
Talmadge R.	13LS110	2013	100%	17.0	18.2	86%	13%	0%	0%
Talmadge R.	13LS110	2014	65%	n/a	n/a	89%	11%	0%	0%
Talmadge R.	01LS002	2013	100%	17.4	17.9	91%	9%	0%	0%

***** % of time in Brook Trout growth range (7.8 C – 20 C) **^** % of time in Brook Trout Stress range (20 C - 25 C)
# % of time above Brook Trout Growth lethal temperature (25 C) ## % of time with temperatures below Brook Trout growth range

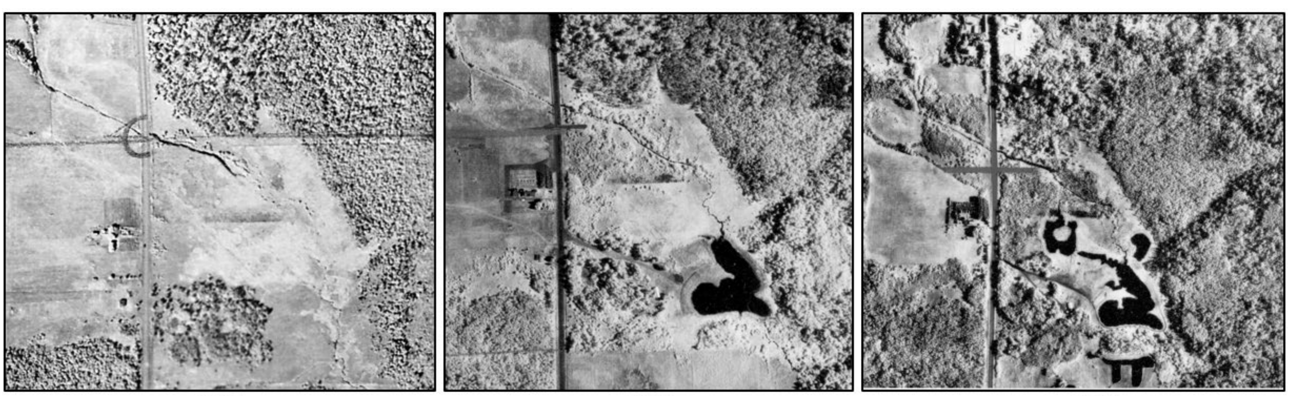


Figure 92. Historic aerial photos showing the Talmadge River prior to the Retriever Club Pond (left); approximately 3-4 years after construction of the dam (middle); and additional ponds added prior to 1981 (right)

Table 24. Criteria used for developing thermal regime groupings (Area 1-4) for North Shore coldwater streams. See Section 4.1 for more information

Grouping	% Temperature reading in Brook Trout growth range	Summer average temperature (C)
Area 1	<60%	>19 C
Area 2	60-79%	17 – 20 C
Area 3	80-89%	16 – 18 C
Area 4	90 – 100%	<17 C

Grouping	Description
Area 1	Brook Trout and coldwater species sometimes present, more often a mix of cool and warmwater taxa
Area 2	Can support Brook Trout and other coldwater species, often a mix of cold, cool, and warmwater taxa
Area 3	Frequently supports Brook Trout and other coldwater species, lower relative densities
Area 4	Almost always support high relative densities of Brook Trout and coldwater species

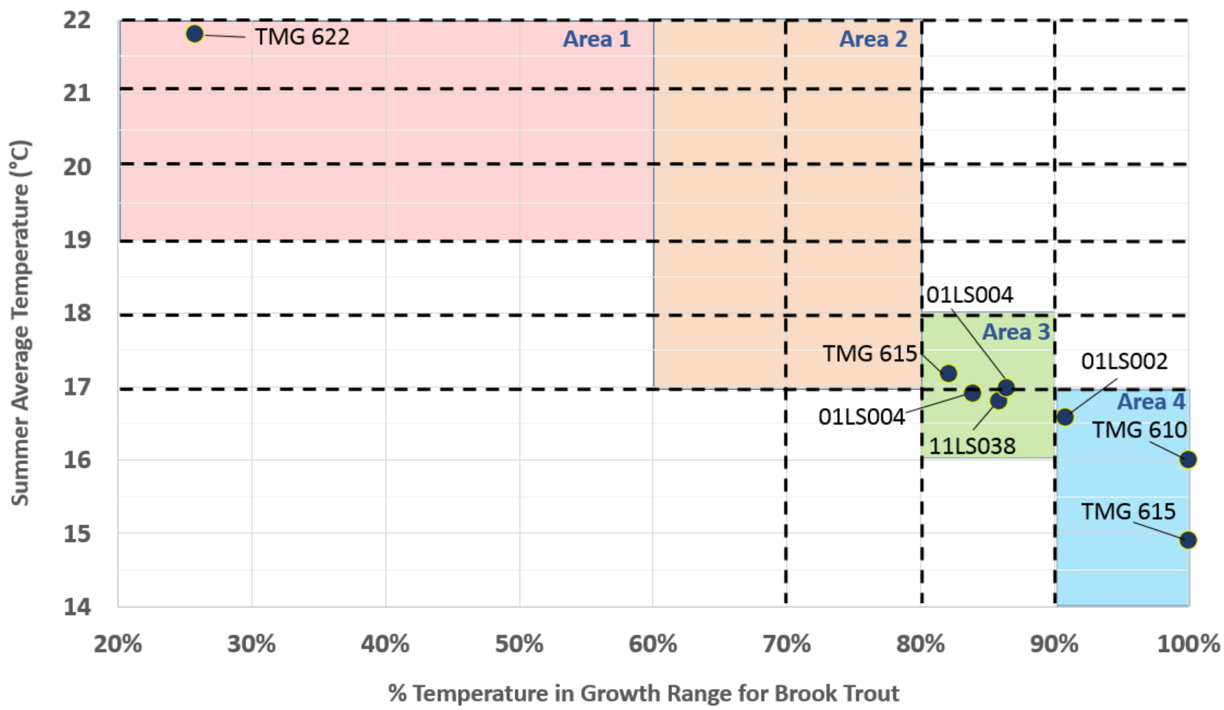


Figure 93. Plot of summer average temperatures vs. % time in Brook Trout Growth Range for Talmadge River stations. More information on thermal regime categories (Areas 1-4) in Table 24 and Section 4.1

Figure 94. 1. Upper Talmadge River near Lavis Road. This station sustained temperatures within the "growth" range for Brook Trout 97% (2014 season) and 100% (2015 season) of the time during the June 1-Aug 31 monitoring period. 2. The Duluth Retriever Club pond, approximately 4.5 acres in size. In 2015, the summer average water temperature was 4.6 °C warmer downstream of the impoundment compared to an upstream monitoring location (17.2°C vs 21.1°C). 3. Despite the low flow conditions in the Talmadge River (shown here at station 11LS038), water temperatures remained within the growth range for Brook Trout >80% of the summer at almost all of the monitoring stations during this study.

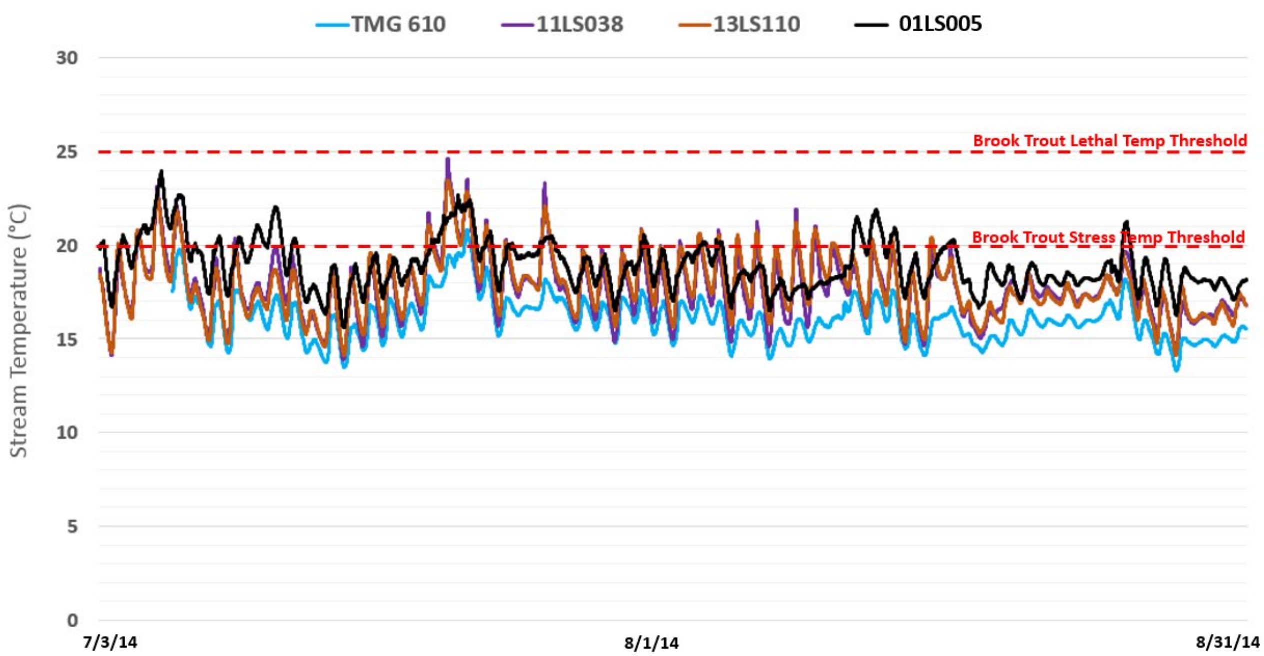


Figure 95. Continuous temperature results from four Talmadge River monitoring stations; 7/3/14 – 8/31/14

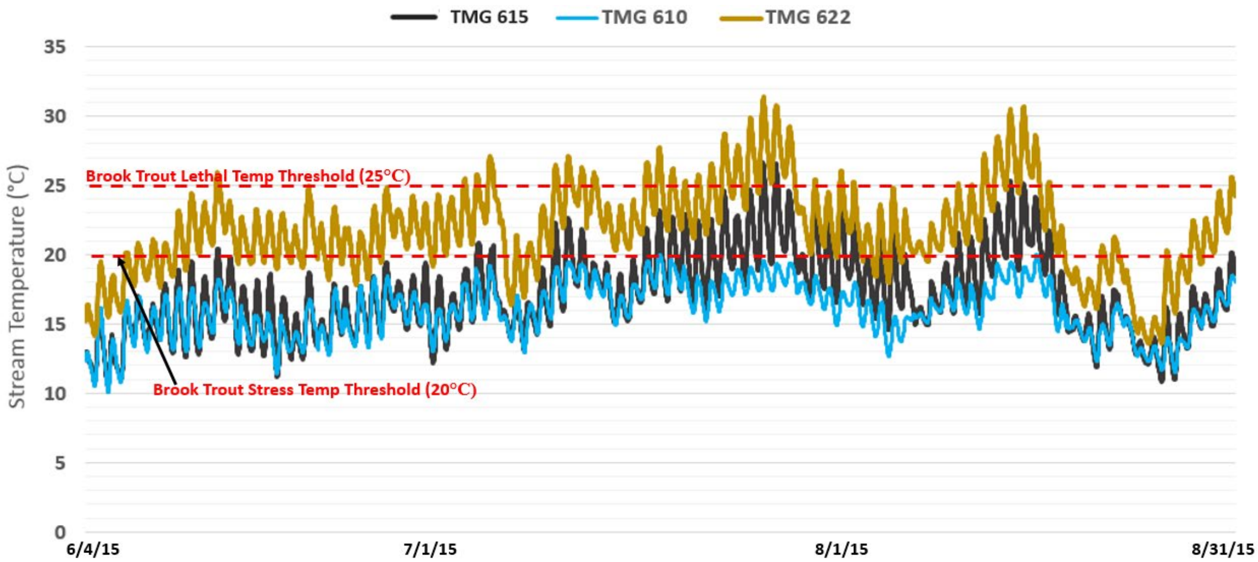


Figure 96. Continuous temperature results from three Talmadge River monitoring stations; 6/4/15 – 8/31/15

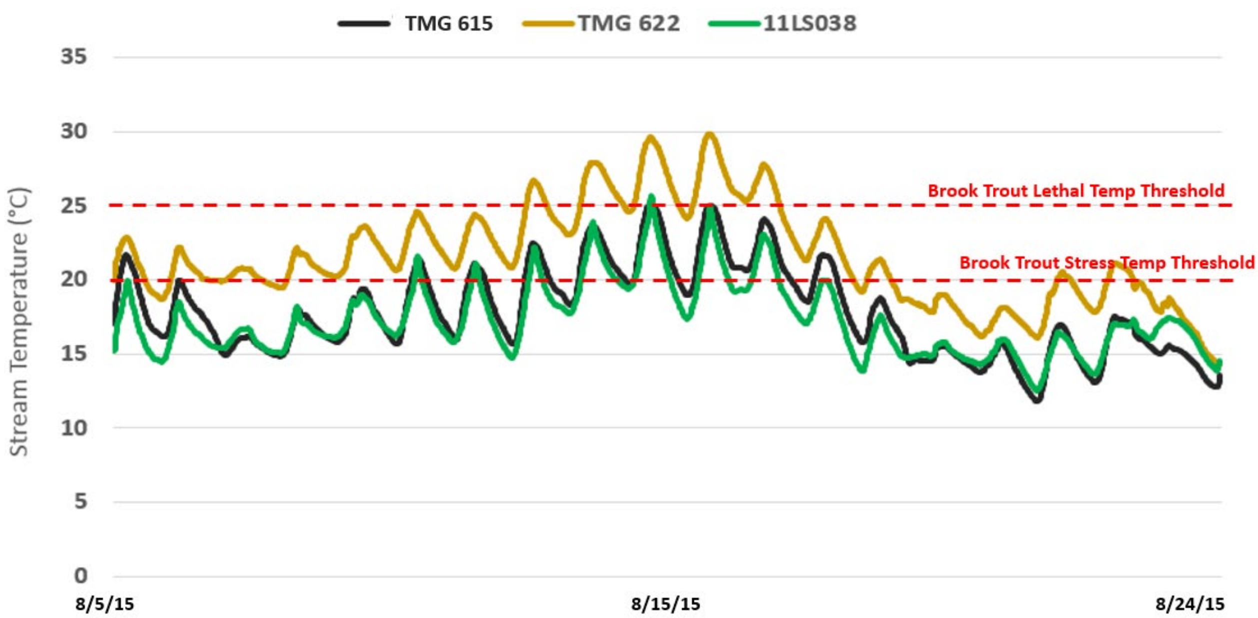


Figure 97. Continuous temperature results from three Talmadge River monitoring stations; 8/5/15 – 8/24/15

Biological response to water temperature

Historically, three coldwater fish species have been sampled from the Talmadge River; Brook Trout, Rainbow Trout (actively stocked by DNR), and Coho Salmon (previously stocked by DNR). Brook Trout and Coho Salmon are not commonly sampled and are present in low numbers, if at all. Rainbow Trout sampled upstream of the ledge rock barrier at river mile 1.1 are the result of DNR stocking efforts. These fish are routinely stocked by DNR with the goal of increasing the number of adult Steelhead that return to the lower Talmadge River to spawn. Steelhead Rainbow Trout annually migrate from Lake Superior into river and utilize the lower reaches for spawning and rearing. There is no record of Brook Trout upstream of the barrier at river mile 1.1, although several areas appear to provide adequate habitat and water temperatures to support this species.

No coldwater species were collected during the most recent sampling efforts by MPCA. Sampling occurred at two stations, 11LS038 and 13LS110, both of which are upstream of the natural barrier falls and therefore exclude migratory species entering from Lake Superior. Creek Chub, a "pioneer" species in coldwater streams, was the dominant species sampled at both of these stations. Pioneer species tend to dominate habitats that are frequently disturbed or altered. Blacknose Dace were also highly dominant in the upper Talmadge. Combined, Creek Chub and Blacknose Dace accounted for 85 – 100% of the fish population at the three monitoring stations. Other species present included Pearl Dace, Brook Stickleback, and single Iowa Darter individual at 11LS038. Pearl Dace was the only species sampled above the barrier falls that is associated with colder North Shore streams.

No fish or macroinvertebrate data are available for the Talmadge River upstream of the Duluth Retriever Club pond. Stream temperatures in this reach were consistently colder than areas downstream of the pond, and physical habitat conditions may be more suitable for supporting trout (lower width-depth ratio, deep pools, undercut/shaded streambanks). Although there are no records showing that Brook Trout ever inhabited this portion of the stream, additional monitoring work could be done to document the current fish assemblage and assess potential for (re)introducing Brook Trout to this area of the watershed. Given the small drainage area of this watershed, these headwaters areas may be vulnerable to low DO concentrations and low streamflow conditions. Therefore, additional monitoring is recommended before any restorations actions are taken in this portion of the watershed.

Summary: Is water temperature a stressor in the Talmadge River?

Most reaches of the Talmadge River maintained temperatures suitable for Brook Trout and other coldwater taxa during the course of this study (2013-2015). Temperatures were within the "growth" range for Brook Trout roughly 80-100% of the summer, with the colder temperature regimes being located in the headwater and near Lake Superior. Water temperatures were significantly warmer within a 0.50 – 0.75-mile reach immediately downstream of the Duluth Retriever Club impoundment. Stream temperatures frequently exceeded "stress" and "lethal" thresholds for Brook Trout within this reach, but relatively cold temperatures returned to some degree further downstream.

The fish assemblage was similar at all stations and did not show a strong response to temperature differences. Creek Chub and Blacknose Dace were highly dominant and coldwater species were rare or absent. With the exception of stocked trout and migratory salmonid species. (Rainbow Trout, Coho Salmon) entering from Lake Superior, there are no records showing that a robust, naturally-reproducing trout (or other coldwater species) population has ever existed in the Talmadge River. Currently, there are no biological monitoring data available upstream of the Retriever Pond, which is a portion of the watershed that may be suitable for coldwater species based on temperature monitoring results.

Elevated stream temperatures limit coldwater potential immediately downstream of the Retriever Pond, but there is not strong evidence to suggest that this stressor is a major driver of the impaired condition throughout the length of the river. Marginal to poor physical habitat conditions, flashy hydrology, and elevated levels of total suspended solids (TSS) and sedimentation are limiting biological integrity in this watershed on a much larger scale. Modifications of the Retriever Pond, such as constructing an off channel pond and designing a free-flowing river channel to circumvent the impoundment, would likely lead to colder water temperatures downstream of the impoundment (see Section 7.1.4).

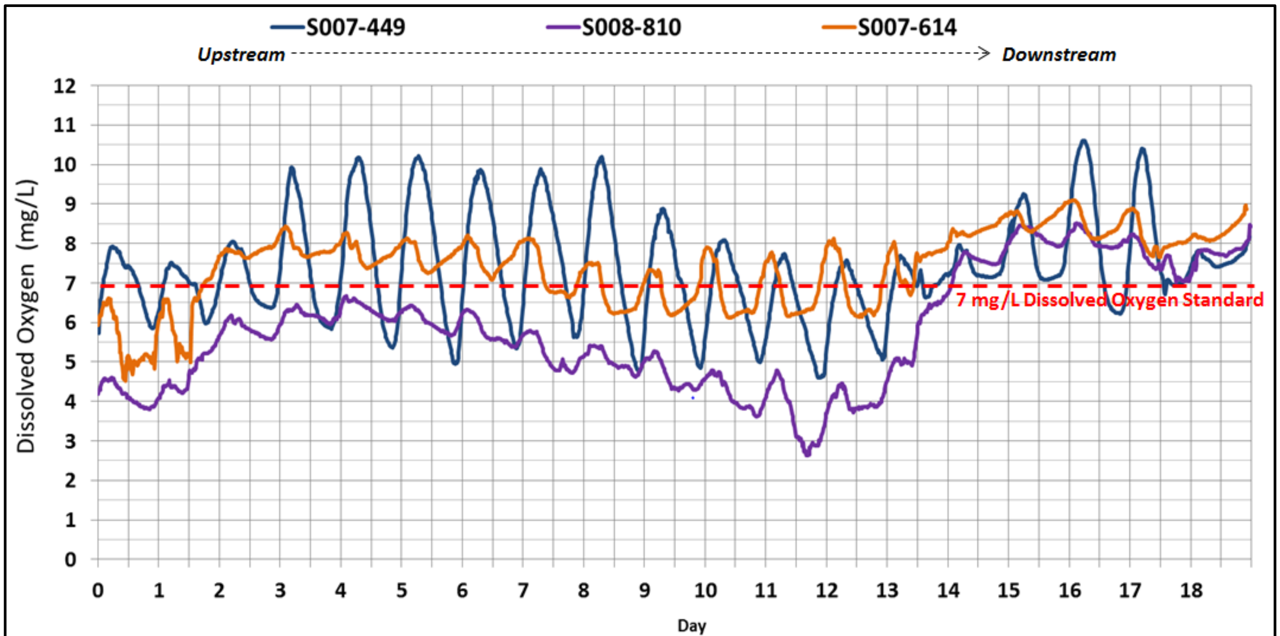
6.2.2 Low dissolved oxygen

The Talmadge River was added to the list of impaired waters in 1996 for failing to meet the DO standard of 7 mg/L at one station near its confluence with Lake Superior. As part of the stressor identification project, additional DO data were collected from six locations along the Talmadge River to evaluate whether or not concentrations are suitable for supporting coldwater fish and macroinvertebrate communities. YSI sondes were deployed at these stations intermittently for durations of one to four weeks during the months of June through September in 2013 and 2015. Spot measurements were also collected at these locations during various flow conditions, but continuous data will be relied on more heavily for stressor identification, as it more accurately represents the range of conditions fish and macroinvertebrates are exposed to over the course of the summer.

DO concentrations below the 7 mg/L standard were observed with regularity in the upper reaches of the Talmadge River. During the summer of 2015, an emphasis was placed on collecting DO data upstream and downstream of a 3.5 acre reservoir created by an earthen dam (see Section 6.2.1 for background on this structure). Very low DO concentrations (2.17 mg/L) and long durations (at least 14 days) of sub-7 mg/L DO levels were observed at station S008-810 immediately downstream of the reservoir outlet (Figure 98). During the same period, DO concentrations upstream of the reservoir were higher, ranging from 4.59 – 10.60 mg/L, but were still marginal to poor for sensitive aquatic life that depend on water with higher DO content. Approximately 1.5 miles downstream from the reservoir at biological monitoring station 11LS038 (a.k.a. S007-614), DO concentrations appeared to recover to some degree from the negative effects of the reservoir, but remained marginal for trout and other sensitive aquatic off and on throughout the 18-day monitoring period. The monitoring data from July 2015 show similar trends, although DO minimums are higher and the two stations downstream of the reservoir rarely fall below 7 mg/L.

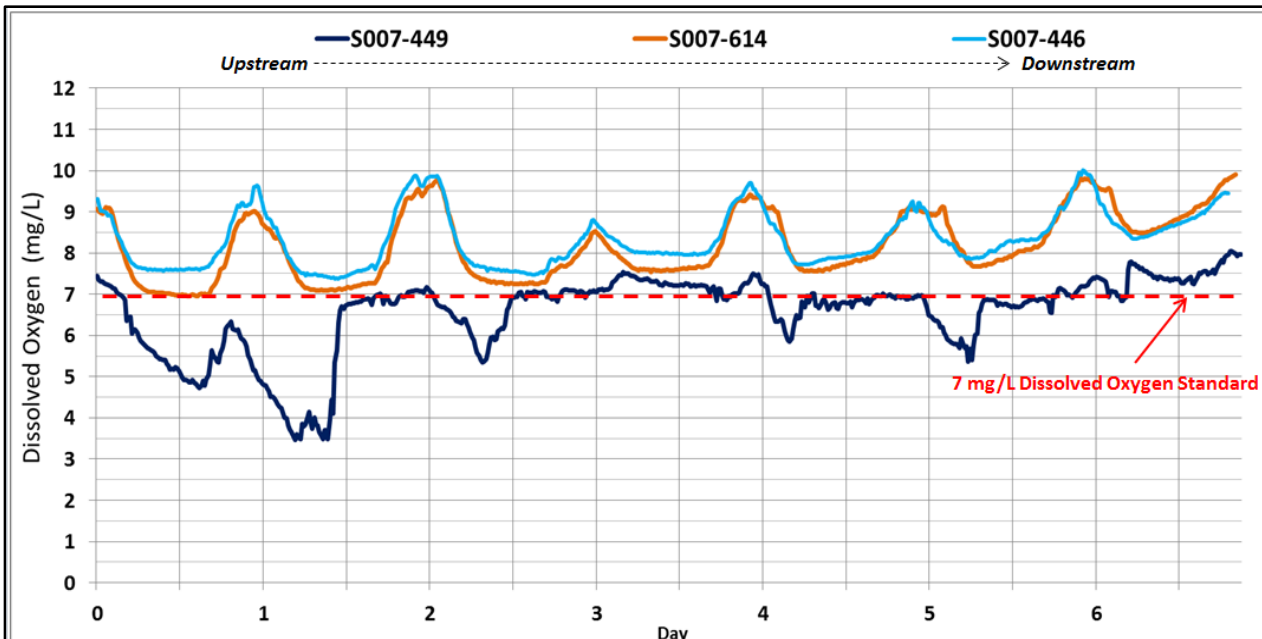
DO concentrations during the 2013 monitoring year were more favorable for supporting trout and other sensitive aquatic life. Higher than normal rainfall and cooler air temperatures resulted in DO concentrations that remained above the 7 mg/L standard at all stations for nearly the entire 17.5 days of continuous monitoring data collected. Low streamflow conditions were present in late August and September of 2013. Photos of biological monitoring station 11LS038 during this period of low flow are shown in Figure 97. No DO data are available for the date that these photos were taken, but measurements collected on August 12, 2013 during fish community assessments were adequate (9.25 mg/L). In addition, continuous monitoring data from September show suitable DO concentrations at this station.

Figure 97. Low flow conditions at Talmadge River biological monitoring station 11LS038 in September of 2013. Despite the low flows, DO concentrations were adequate when sampled from shallow pools.



	Results Summary		DO Max/Min		DO Flux Summary		Comparison to WQ Standard		
Station	# of Readings	# hours	Min (mg/L)	Max (mg/L)	Average (mg/L)	Max (mg/L)	% Readings Below	Avg. Duration below (hours)	Max Duration below (hours)
S007-449	1822	456	4.59	10.6	3.31	5.45	38%	9	17
S008-810	1824	456	2.63	8.51	1.05	2.17	74%	338	338
S007-614	1817	454	4.51	9.09	0.93	2.69	30%	15	42

Figure 98. Talmadge River continuous DO data 8-5-2015 through 8-23-2015



	Results Summary		DO Max/Min		DO Flux Summary		Comparison to WQ Standard		
Station	# of Readings	# hours	Min (mg/L)	Max (mg/L)	Average (mg/L)	Max (mg/L)	% Readings Below	Avg. Duration below (hours)	Max Duration below (hours)
S007-449	660	165	3.47	8.04	2.05	3.69	62%	14	37
S007-614	657	164	6.95	9.91	2.14	2.52	2%	2	3
S007-446	653	163	7.38	10.02	0.89	2.49	0%	0	0

Figure 99. Talmadge River continuous DO data 9-6-2013 through 9-11-2013

High daily fluctuation in DO concentrations (DO flux) is another pathway that can stress fish and macroinvertebrate communities. The MPCA's River Nutrient Criteria (Heiskary, 2013) includes DO flux as one of the stressor variables. For the "Northern Nutrient Region" the DO flux stressor threshold value was set at 3 mg/L, meaning that any result above that value can be a sign of river eutrophication (excess nutrients) and can negatively impact sensitive aquatic life. DO flux exceeded 3 mg/L at station S007-449 during two separate continuous monitoring periods in July and August of 2015, when daily flux values were 4.89 mg/L and 5.45 mg/L, respectively. The August 2015 results are shown in Figure 98, with the period of higher DO flux occurring between days three and nine in the profile. This reach of the Talmadge River is low in gradient and often impounded by beaver dams, which results in sluggish streamflow and higher productivity during summer low flow periods.

Sources and pathways contributing to low dissolved oxygen and/or high DO flux

Grab samples for TP, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) were collected in conjunction with the August 2015 continuous DO monitoring. The reservoir created by the earthen dam had a clear impact on several water quality parameters. Temperature increased by 4 degrees (F), TP concentrations increased from 0.018 mg/L to 0.052 mg/L, BOD concentrations increased from <1.5 mg/L to 3.4 mg/L, and COD concentrations rose from 29 to 44 mg/L (Figure 100 and Table 25). These changes in water quality all contribute to the significant drop in DO concentrations that are observed below the reservoir.

Nearly 32% (44 out of 139) of the TP results from the Talmadge River exceed the 0.055 mg/L threshold set by the MPCA's River Nutrient Criteria. The majority of the TP results are from station S001-755, which is co-located with an inactive stream gaging station, and sits in the lower fourth of the watershed. The only "response variable" data associated with this station are DO flux measurements collected during the summer of 2013. The maximum DO flux values recorded during this period were in the range of 1.5 to 2.1 mg/L, which is below the 3 mg/L threshold established by the RNC as an indicator of possible river eutrophication. Air temperatures in the summer of 2013 were below average and precipitation levels were above normal. As a result, the DO flux values from 2013 may be somewhat lower than years with warmer water temperatures and lower streamflow. Additional data are needed to determine if the elevated TP concentrations observed at this station are contributing to stream eutrophication.

On average, TP concentrations are highest during snowmelt conditions in months of March and April. Much of the increase in TP can be attributed to suspended sediment, which also tends to reach its annual peak during this period. Several reaches of the lower Talmadge River are prone to bank erosion and release large amounts of sediment during higher flow. Intense rain events during the summer months can also drive TP concentrations to very high levels due to the release of sediment from streambanks. The highest TP value on record is 0.337 mg/L from a July 8, 2002, sampling event during which 2.87 inches of rain fell in the watershed.

The 3.5 acre Duluth Retriever Club pond has a clear effect on nutrient dynamics and stream productivity in the upper reaches of the Talmadge River. Total phosphorous, BOD, COD, and water temperature all showed increases downstream of the ponds during an August 2015 sampling event (Figure 100). TP concentrations increased from 0.018 mg/L upstream of the pond to 0.052 mg/L downstream; BOD from <1.5 mg/L to 3.4 mg/L; and COD from 29 mg/L to 44 mg/L. TP and BOD criteria have been incorporated into Minnesota's water quality rules (TP as a standard, and BOD as a response variable for productivity). The TP results downstream of the pond are narrowly below the 0.055 mg/L TP standard for the northern nutrient region. However, the BOD result of 3.4 mg/L was much higher than the "seasonal average" threshold of 1.5 mg/L used in the river nutrient criteria. These results indicate a substantial increase in oxygen demand as the Talmadge River courses through the complex of ponds in this portion of the watershed. The negative effects on dissolved concentrations are well documented in the continuous monitoring data.

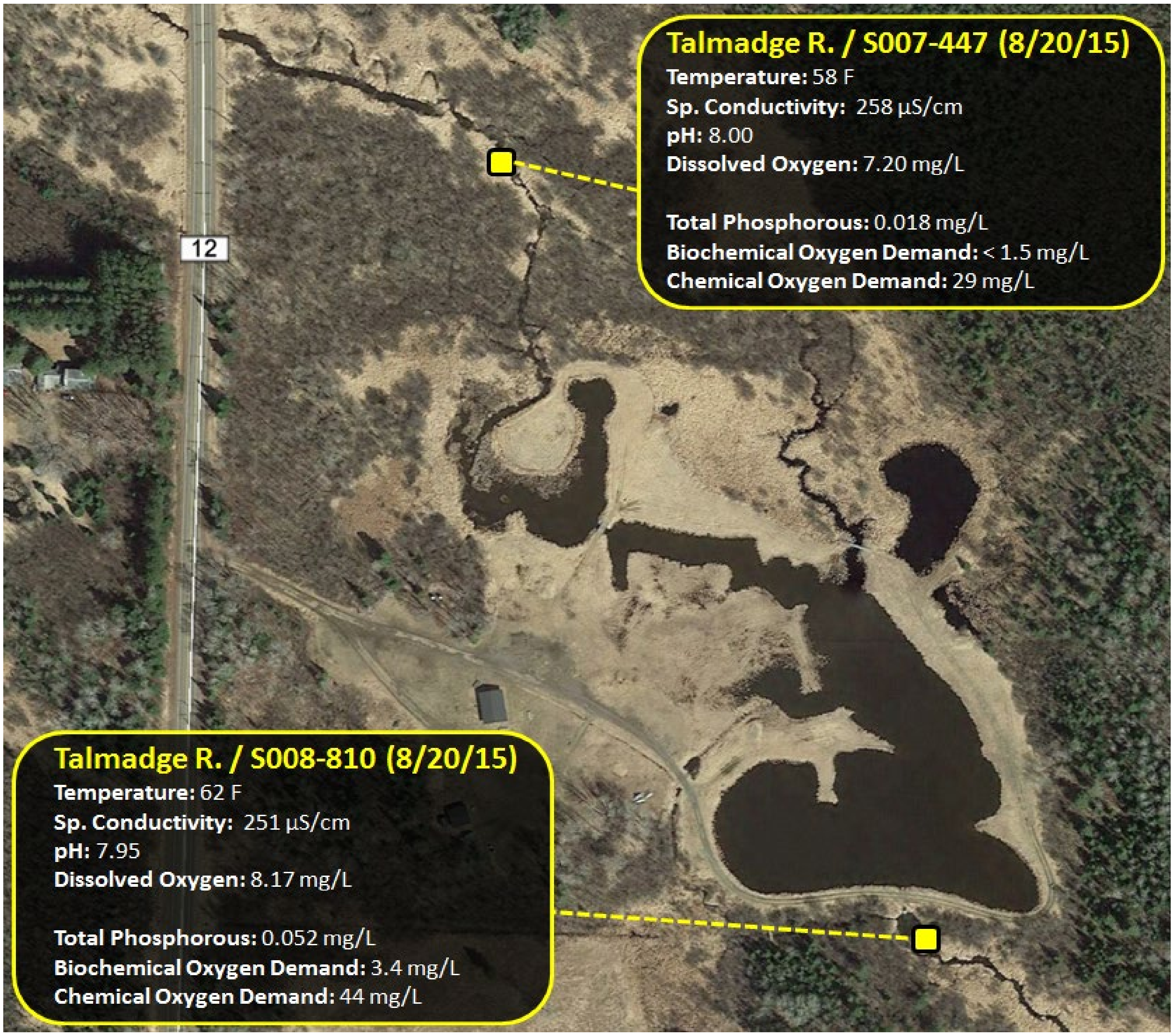


Figure 100. Summary of 8/20/15 sampling effort above and below the Duluth Retriever Club pond on the Talmadge River

Table 25. Summary of TP results and other parameters associated with DO and river eutrophication

Sample date	Station	Total phosphorus (mg/L)	Biological oxygen demand (mg/L)	Chemical oxygen demand (mg/L)
8/20/15	S007-449	0.018	<1.5	29
8/20/15	S008-810	0.052	3.4	44
8/20/15	S007-614	0.022	2.3	39
River nutrient standard (North)		0.055	≤1.5	n/a

Biological response to dissolved oxygen stress

MPCA sampled fish at two stations (11LS038 and 13LS110) during the most recent biological assessments of the Talmadge River in 2011 and 2013. Very low taxa richness was observed at both stations and none of the species present are highly sensitive or tolerant of low DO concentrations. Creek Chub and Blacknose Dace were sampled in very large numbers relative to the other species present (Pearl Dace, Brook Stickleback, Iowa Darter). In general, the species observed in the Talmadge River are found in coolwater streams with moderate levels of DO. Fish community DO TIV results for these monitoring stations fall between the 25th percentile and the median values observed in high quality coldwater streams along the North Shore of Lake Superior (Figure 101).

Due to the lack of DO tolerant and/or sensitive species, the fish community data are not highly useful for diagnosing or eliminating low DO as a stressor. Both of the monitoring stations sampled by MPCA were in the mid to lower reaches of the river, which exhibits steep gradient with several small waterfalls. These features may help to maintain fair to moderate DO concentrations in this reach during critical low flow periods. Additional biological monitoring in the headwaters of the Talmadge River, especially above and below the impoundment, could be useful for further evaluating fish community response to lower DO concentrations. DO concentrations as low as 2.17 mg/L have been observed downstream of the impoundment, which could stress more sensitive taxa and cause a shift in the fish community towards more tolerant taxa.

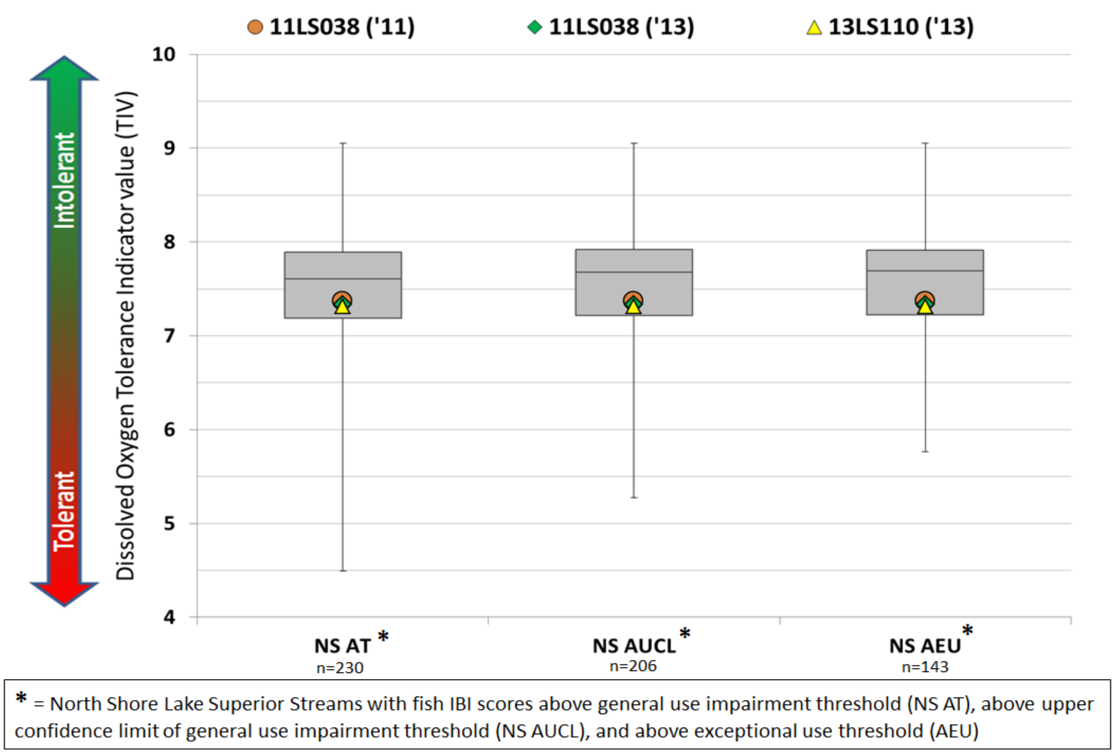


Figure 101. DO TIV for Talmadge River biological monitoring stations compared to results from comparable high quality reference stations. More information on TIV values is located in Section 4.5

Summary: Is low dissolved oxygen a stressor in the Beaver River?

Dissolved oxygen conditions in the Talmadge River vary considerably depending on sampling location and ambient conditions such as air temperature and rainfall. The most recent monitoring data suggest that DO concentrations in the middle to lower reaches of the river are suitable for supporting sensitive coldwater fish, as DO concentrations generally exceeded 7 mg/L in these locations. However, data from other locations on the Talmadge River show less favorable conditions for Brook Trout and other sensitive aquatic biota. DO concentrations in the upper reaches of the river dropped well below 7 mg/L for long durations. This may be caused in part by several natural background conditions, including wetlands and beaver impoundments. Yet, there are several anthropogenic disturbances in this area that negatively affect DO. The ditching and straightening of the river near Lester River Road has reduced riffle habitats, which provide oxygen to the stream via turbulence and reaeration. In addition, the reservoir created by the earthen dam just downstream of Lester River Road has been shown to increase TP, BOD, and water temperatures. All of these changes negatively affect DO concentrations and create stream conditions that are less suitable for sensitive aquatic life.

Low DO concentrations can be diagnosed as a stressor in the Talmadge River, but the extent of the impact is likely limited to the reach between the headwaters and Lakewood Road. Downstream from this point, the vast majority of the data show suitable DO concentrations. TMDL investigations and restoration activities should focus on the role that ditches, dams, streamflow alteration, water temperature, and climate have on DO in this river system.

6.2.3 Poor physical habitat

Physical habitat methods

Physical habitat conditions were evaluated using two methodologies; (1) MSHA protocols, where were developed by MPCA and used statewide by biological monitoring crews; and (2) Brook Trout Suitability Assessment (BTSA) developed by the authors. The BTSA is a modification of an assessment developed by Bidelspach and Geenen (2011) that was used to assess and rank trout habitat in Colorado. Details on each of these methods can be found in Section 4.2 and Appendix A. MSHA metric results for the NE Region of Minnesota were compiled and sorted into decile distributions to develop a letter grade (A-F) scale for each metric. A statewide MSHA data set was used to develop the scale for the "Riparian" metric due to a lack of variability in the results for NE Minnesota. More information on the development of the MSHA grading scale can be found in Appendix B.

Results of habitat assessments

MSHA results are available for two stations on the impaired reach of the Talmadge River. Other habitat assessment data (BTSA & Pfankuch Stability Index) were collected at two additional stations. A summary of total MSHA scores and letter grades for these stations can be found in Table 26. Individual metric scores and letter grades for each station are included in Appendix B. Overall, MSHA results ranged from a low grade of "C" at station 13LS110 to a high grade of "A" at station 11LS038. Metrics with sub-optimal scores at station 13LS110 were related to fish cover (7/18; grade "F") and channel morphology (23/36; grade "C").

BTSA results further support lack of cover and unstable geomorphic conditions at 13LS110 as a limiting factor. Overall, station 13LS110 received a BTSA score of 70 out of a possible 138, for a rating of "poor." Compared to a high quality reference reach (McCarthy Creek, 11LS007) of the same channel type (C3), station 13LS110 departed greatly from the reference reach in categories related to "large wood/cover", "bank erosion", "flow rate at low flow", and "water temperature." Other limiting factors with less severe, but still significant departure from reference conditions included "floodplain connectivity" and "deep pools".

BTSA results from Talmadge River station 11LS038 were much more favorable than 13LS110. The total score at 11LS038 was 28 points better (98) and resulted in a BTSA rating of "good." BTSA metric results for station 11LS038 were not compared to a reference reach of the same stream type because of the high degree of channel stability observed. Stream channel and physical habitat conditions at 11LS038 are already near or at their potential, and restoration activities are not recommended along this reach.

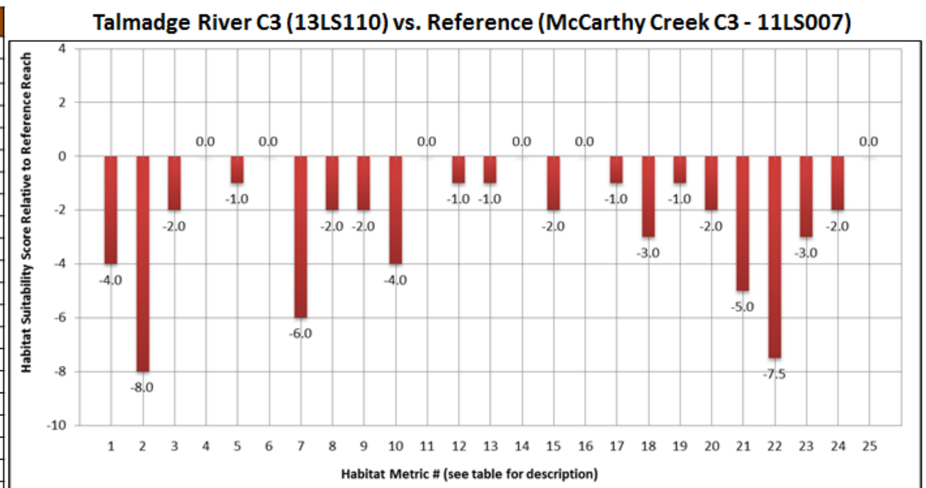
However, the limited stream flows observed throughout the entire Talmadge River system during mid-summer and early fall months often limit the available habitat at this location. Stressors related to hydrology are covered in detail in Section 6.2.6.

Table 26. Summary of physical habitat and stream channel stability results for Talmadge River biological monitoring stations

River	Station	MSHA Score (0-100)	MSHA Grade (A-F)*	BTSA Score	Fish IBI REL GU**	Pfankuch Stability Index Rating	Potential Habitat Stressor?
Talmadge R.	LESTER RIVER RD.	n/a	n/a	97 (Good)	n/a	Fair / Mod. Unstable	NO
Talmadge R.	01LS005	n/a	n/a	82 (Fair)	n/a	Good / Stable	NO
Talmadge R.	11LS038	87	A	98 (Good)	+18 / +16	Good / Stable	NO
Talmadge R.	13LS110	71	C	70 (Poor)	+15	Poor / Unstable	YES

*See section BLANK for grading scale ** Fish Index of Biological Integrity Score relative to general use impairment threshold (35)
BKT# No IBI score calculated due to difference in methods, but wild Brook Trout regularly present

#	Metric
1	Floodplain Connectivity
2	Water Temperature
3	Gravel Substrate
4	Fine Substrates and Embeddedness
5	Algae on the Gravel Substrates
6	Aquatic Vegetation
7	Bank Erosion
8	Bank Habitat
9	Longitudinal Connectivity
10	Deep Pools
11	Morphological Energy Dissipation
12	Riffle Complexity
13	Riffle Length
14	Beaver Dams
15	Side Channel Habitat
16	Channel Width to Depth Ratio
17	Low Flow Width to Depth Ratio
18	Hyporheic Exchange
19	Riparian Vegetation
20	Vegetative Shade
21	Flow rates at Low-Flow
22	Large Woody Cover
23	Fine Woody Debris
24	Riffle-Pool Ratio
25	Presence of Predator Species



Critical Limitations: **(#2)** Water Temperature; **(#7)** Bank Erosion; **(#22)** Large Wood/Cover; **(#21)** Flow Rates at Low Flow

Other Limitations: **(#1)** Floodplain Connectivity; **(#10)** Deep Pools

Figure 102. Comparison of BTSA metrics results for Talmadge River station 13LS110 and McCarthy Creek station 11LS007.

Limiting habitat conditions in impaired reach

(1) Lack of cover

A lack of cover features for fish (e.g. large wood, boulders, undercut banks, aquatic vegetation) was identified as a habitat limitation in several of the more impacted reaches of the Talmadge River. Areas of severe bank erosion and channel widening have decreased the amount and quality of stable structure suitable for fish cover. The low streamflow conditions commonly observed in the impaired reach throughout much of the summer and early fall compound this problem, as much of the available cover along the streambanks and/or within the stream channel is above the water surface, or does not provide adequate water depth. Two historic rain events in the summer of 2012 caused severe bank and bluff erosion in the middle to lower sections of the Talmadge River. Many large trees and rootwads entered the river during these storms and were deposited in the stream channel or along banks. Although this added structure provides fish cover, it cannot be considered “stable” cover given that much of it moves during higher flows and is contributing to further erosion and channel widening.

LWD and other types of fish cover are critical components of healthy trout streams, and the availability of these cover types have been shown to positively affect adult and sub-adult Brook Trout density (Nuemann and Wildman, 2002; Dechenes and Rodriguez, 2007). The dominant fish species in the impaired reach (Creek Chub, Blacknose Dace) are not considered cover dependent, and are often found in shallow, sun-exposed areas of streams. Although there are certainly other factors limiting the distribution of trout and other coldwater fish species in the Talmadge River watershed, the lack of available cover at several stations is a contributing cause to low fish IBI scores. An increase in baseflow would increase the amount of cover that can be utilized by fish during periods of moderate to low streamflow.

(2) Lack of deep pools

BTSA results identified a lack of deep pools as a limiting factor at the majority of Talmadge River monitoring stations. The exception to this trend is the Lester River Road site and station 11LS038, which both received a "fair" score for pool depth. Stations located in the mid to lower reaches of the river (13LS110 and 01LS003) lack deep pools aside from the occasional plunge pool below small waterfalls. Long stretches of wide, shallow water exist within sampling reach 13LS110 and elsewhere in the lower Talmadge.

Deep pools are critical for survival and growth of adult trout on several levels. During summer periods of low streamflow, Brook Trout prefer deep, low current velocity areas of the stream and a strategy of minimizing risks and energy costs rather than maximizing forage gain (Sotiropoulos et al., 2006; Anglin and Grossman, 2013). Brook Trout > age 1 have also shown a preference for deep, slow-moving water beneath overhead cover during the winter months (Cunjak and Power, 1986). Deep pools provide critical overwintering habitat for trout in Northeastern Minnesota streams, a region with frigid temperatures, relatively low groundwater inputs to streams, and flashy hydrology. Anchor-ice and/or complete freezing of the water column have been cited for eliminating or reducing trout populations in several streams in this region (DNR).

The fish community present in the Talmadge River reflects the lack of quality pool habitat available. Several salmonid taxa have been sampled near the mouth of the river at station 01LS001. The deep pool at the confluence with Lake Superior provides refuge, both in terms of depth and thermal regime. Discounting Rainbow Trout that are regularly stocked by DNR, the river is dominated by Creek Chub and Blacknose Dace, which are relatively short-lived and are habitat generalists. Like many of the stressors discussed in this report, the lack of pool habitat in this river system is directly linked to the minimal streamflow that occurs regularly in the summer and fall.

(3) Bank erosion

Bank erosion was identified as a stressor pathway through BTSA assessment results. Bank erosion is not a direct stressor to aquatic life, but is linked to several of the habitat stressors discussed in this section (high width/depth ratio, lack of cover, pool depth). The issue of bank erosion along the Talmadge River is discussed in detail in Section 6.2.5.

(4) Width to depth ratio

Low flow channel width/depth (w/d) ratio and inner berm area are key components for maintaining quality habitat during the critical summer and winter periods. High w/d ratio channels at low flow are more susceptible to warming during summer low flows and are more likely to develop anchor ice or freeze solid during the winter season. Several of the photos in Figure 104 depict the high w/d ratio of station 13LS110 during summer low flow periods. Channel widening and aggradation processes, particularly in response to the two flood events in the early summer of 2012, have resulted in a channel that is over-widened and offers marginal to poor habitat for sensitive fish.

Summary: Habitat conditions a stressor in the Talmadge River?

The Talmadge River offers a range of conditions along its length, but the majority of its physical habitat can be considered marginal to poor for supporting trout and other coldwater fish taxa. The upper half of the river, from the headwaters through station 11LS038 on McDonnel Road, is generally stable and could offer decent physical habitat if several other stressors were addressed (low DO, impoundments, altered hydrology). On the contrary, the reach from Cant Road down to Minnesota Highway 61 has been more impacted and habitat conditions are marginal to poor, and made worse by the lack of suitable streamflow during dry periods.

Poor physical habitat is a contributing stressor to the fish impairment in the Talmadge River. Improving the hydrological regime to support better baseflows would have immediate positive effects on habitat conditions. Still, channel instability throughout most of the lower half of the river is resulting in habitat conditions that are unfavorable for sensitive coldwater fish.

Figure 103. Examples of bank erosion and lack of pool habitat at Talmadge River station 13LS110

Figure 104. Examples of channel instability leading to high width to depth ratio and habitat loss at station 13LS110 on the Talmadge River

6.2.4 Connectivity – Impediments to aquatic organism passage

Connectivity assessment in the Talmadge River Watershed

Potential and verified impediments to fish migration were identified through a combination of aerial photo analysis and field reconnaissance. Barriers identified included both natural features (waterfalls, beaver dams) and anthropogenic changes that have occurred in the watershed (e.g. road crossing culverts). A level of uncertainty remains in terms of the ability of fish to pass certain features, but for the purposes of this report, all of the barriers inventoried were classified as “partial/seasonal barriers” or "complete barriers" to fish migration. The spatial setting of this assessment included the Talmadge River main stem from Lake Superior to Whiteside Road (Township Road 2716) and major tributary streams in the watershed.

<u>Natural barriers</u>

The Talmadge River is a high gradient stream with many bedrock drops and small waterfalls. A ledgerock waterfall located 1.1 miles upstream from Lake Superior inhibits upstream migration of trout and salmon entering the river from Lake Superior. Several other waterfalls located both upstream and downstream of river mile 1.1 act as seasonal barriers to resident fish during periods of low and high streamflow. Seven complete or partial/seasonal barrier waterfalls were identified on the impaired reach, all of which are located in the lower half of the Talmadge River's course to Lake Superior. As a result, fish habitat in the lower river is highly fragmented, which could prevent migration of resident fish into critical refuge areas (deep pools, groundwater upwelling areas) when stream conditions are marginal.

Beaver dams were relatively non-existent in the vast majority of the Talmadge River watershed during the years of the SID study (2012 – 2015). Several beaver dams, some old and some active, were observed in low gradient stream segments in the headwaters of the watershed. Due to the low density of beaver dams the fact that they are located in the extreme headwaters of the watershed, beaver activity is not a primary contributor to the impaired condition. Beaver are a native species in the region and their population and rate of activity in the Talmadge River watershed appears to be comparable to many of the high quality watersheds along the North Shore of Lake Superior.

<u>Non-natural barriers</u>

Non-natural barriers observed in the Talmadge River included constructed impoundments and road culverts that were poorly designed, poorly installed, degraded to due wear and tear, or all of the above. Several examples of these non-natural barriers and their locations within the watershed are shown in Figure 105. Two-thirds of the culverts assessed (12/18 or 66%) were determined to be too narrow (i.e. narrower than bankfull width). Culverts that are narrower than bankfull (1.5 year flood stage) width are often barriers to migration due to water velocities within the culvert that exceed swimming ability of many fish species. In addition, improperly sized culverts can disrupt sediment transport processes and degrade habitat and water quality conditions near the crossing.

Culvert outlet elevations perched above the stream bottom ("perched culverts") also act as barriers to migrating fish and other aquatic organisms. Of the 18 culverts evaluated in the Talmadge River watershed, six (33%) were determined to be perched. Four of the perched culverts were located on the Talmadge River main stem (Note: one has since been fixed, photo #4 in Figure 105), while the other two were located on tributaries with ephemeral streamflow and limited habitat potential. Three of culverts on the main stem remain perched and should be strongly considered for restoration projects aimed at improving connectivity.

One of the perched culverts is located under Highway 61 (#1 in Figure 105), within a reach of the river that is managed primarily for migratory Steelhead Rainbow Trout. Restoring this culvert to promote fish passage would enhance access to spawning and rearing habitats in this stream segment under all streamflow conditions. Another perched culvert is located in the headwaters of the river (just upstream of the Lavis Road/Lester River Road. intersection) in a segment that consistently displayed the coldest water temperatures and relatively good habitat conditions. Repairing the perched culvert on Lester River Road would reconnect approximately one mile of quality habitat and coldwater refugia upstream of the crossing to the 0.3 of quality habitat on the downstream side.

The culvert located at the outlet of the Duluth Retriever Club pond is also perched (photo #2 in Figure 105) and presents a barrier to resident fish populations. Physical habitat conditions upstream and downstream of this barrier are in fair to good condition, although water temperatures tend in the immediate area tend to be too warm to support coldwater species much of the year. If connectivity were restored, fish would have the ability to move into the quality habitat and coldwater refuge area observed near the Lavis Road crossing. Restoration work to restore connectivity above and below the pond would involve removal of the earthen dam or creating a new bypass channel around the impoundment. In addition to restoring connectivity, the removal of the impoundment would also improve DO conditions, reduce evaporative water loss, and lower water temperatures downstream.

Biological response to loss of connectivity

The negative impacts of habitat fragmentation are difficult to evaluate with the current biological monitoring data set. Monitoring locations along the Talmadge River are spaced relatively far apart and most of the stations have been sampled in different years. The most suitable data for evaluating the impacts of connectivity loss are supplied by a fisheries survey completed by DNR in 2001. This survey included five stations, with the most downstream station at river mile 0.1 and the upper-most station located at river mile 5.3 at Wahl Road. Overall, fish taxa richness was very low in the 2001 sampling, with only six fish species observed. Rainbow Trout were observed at all stations, but solely due to active stocking programs operated by DNR. A single Brook Trout and Coho Salmon were observed at station 01LS001 which is located just upstream from the confluence with Lake Superior. This reach tends to have colder water temperatures and can support more species (esp. coldwater species) per connectivity with Lake Superior.

Figure 107 shows a schematic diagram of the 2001 survey locations, species observed, and relative positions of natural and non-natural barriers. The majority of the species sampled in the Talmadge River were found at all monitoring stations with a few exceptions. Brook Trout and Coho Salmon were observed at station 01LS001 but were not present 0.5 miles upstream at station 01LS002, or at any other station sampled. The culvert under Highway 61 between 01LS001 and 01LS002 is undersized, slightly perched, and lacks natural substrate, conditions which present a barrier to fish passage at certain stream flows. Brook Trout and Coho Salmon have not been routinely sampled in the river and restoring connectivity between these two stations would not necessarily result in a significant increase in coldwater IBI scores. In general, the 2001 fisheries data suggest that the non-natural and natural barriers in the watershed are not significantly altering fish species composition, as there is little variation between monitoring stations.

Barriers to migration in this watershed may not be a major factor in terms of species distribution. However, given the small drainage area and inherent risks involved with habitat fragmentation of small streams (intermittent flow, low DO, limited physical habitat), it is important to evaluate the effects of all barriers, especially those that can be removed with stream restoration and/or infrastructure improvements. Enhancing connectivity in this watershed will increase resiliency to many of the changes forecasted with a changing climate in NE Minnesota.

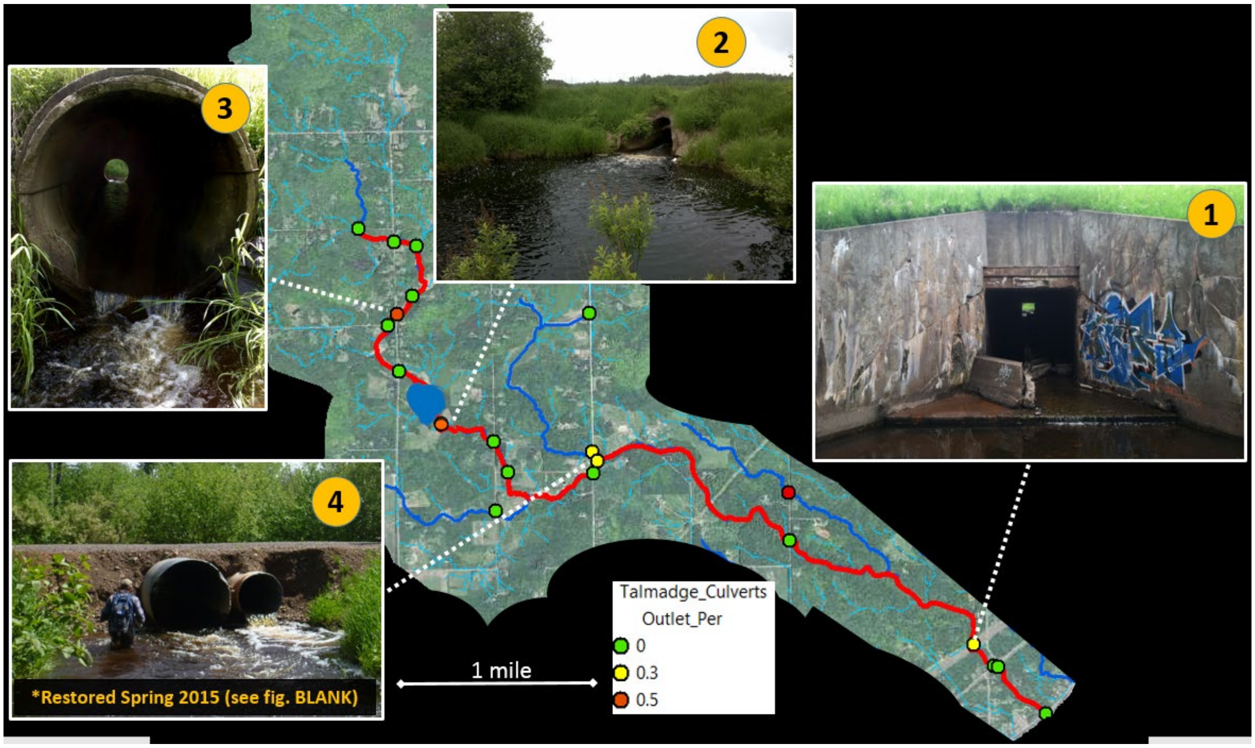


Figure 105. Examples of human-caused obstructions to fish passage in the Talmadge River watershed

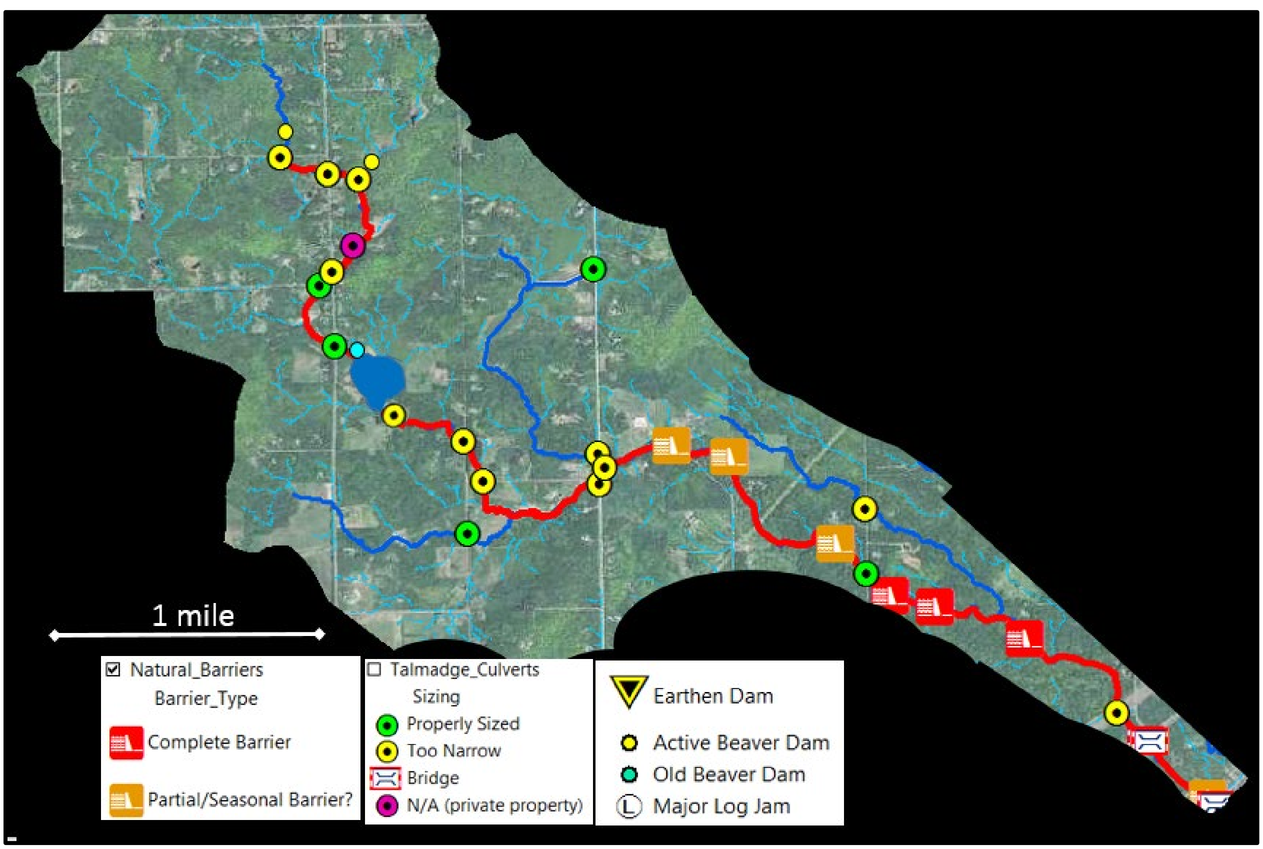


Figure 106. A comprehensive map of potential and verified barriers to fish passage in the Talmadge River watershed

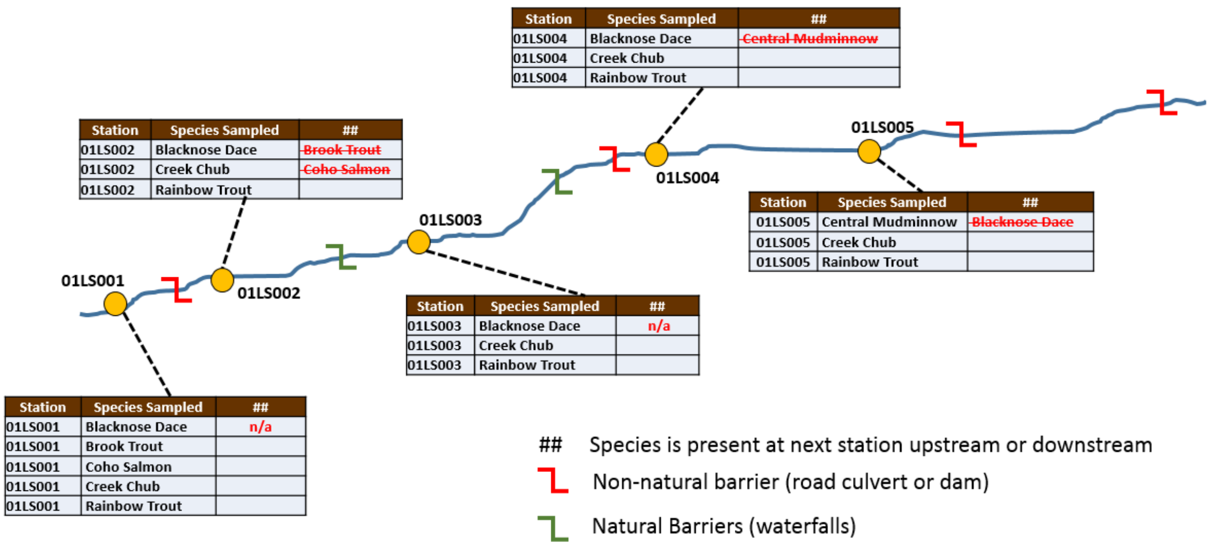


Figure 107: Schematic diagram of the 2001 fisheries survey locations, species observed, and relative positions of natural and non-natural barriers. The majority of the species sampled in the Talmadge River were found at all monitoring stations with a few exceptions

Summary: Is loss of connectivity a cause of fish impairment in the Talmadge River?

Bedrock waterfalls, undersized and/or perched culverts, and an earthen dam limit connectivity and contribute to habitat fragmentation within the Talmadge River watershed. The biological data available do not show a high degree of change in species composition between stations that are separated by natural and/or non-natural barriers. Targeted sampling above and below identified barriers during critical conditions (e.g. low flow/high water temperatures) would be valuable for understanding the impact of barriers in the watershed and for prioritizing restoration activities. Other stressors such as high water temperatures and low streamflow have a stronger impact on the fish community and the impaired condition. However, implementation activities to replace undersized/perched culverts and reduce the negative effects of the Retriever Pond could improve access to thermal/habitat refuge areas located near the Lavis Road crossing.

6.2.5 Elevated total suspended solids/Turbidity

Sources and pathways of sediment in the Talmadge River watershed

(1) Roads and road ditches

Road ditches can serve as indirect sources of sediment by shunting water from the landscape to the stream as quickly as possible. Speeding the delivery of runoff to the stream channel increases peak flows (Wemple 1994), which can initiate channel degradation, instability and bank erosion. Using the Department of Transportation 2008 public road layer, we developed a road density metric (# road miles/watershed area). The Talmadge River watershed has the densest road and ditch network of any of its rural Duluth Area neighbors at 2.33 miles of road for every square mile of drainage area. For comparison sake the Brule River, which many consider to be one of the most pristine watersheds on the North Shore, has only 0.33 miles of road for every square mile of drainage. The relatively dense road and ditch network in the Talmadge River watershed is increasing the drainage efficiency of the landscape and potentially causing impacts to the stream channel.

Roads and road ditches can also serve as *direct* sources of suspended sediment. Overland flow carries finer particles off unpaved road surfaces into ditch networks and eventually into the stream. Coarser particles, such as coarse sands and gravels, can make their way into the stream if the road is in close proximity. Ditches themselves can also have erosion problems which deliver sediment directly to the stream. Headcuts can often develop when road ditches are not properly designed or when culverts are not set properly. A ditch will respond to a headcut the same way a stream will; incising, widening, and delivering large amounts of suspended sediment downstream.

Two such headcuts were noted in a watershed immediately adjacent to the Talmadge River. While none were directly observed in the Talmadge River watershed itself, it is likely that similar problems exist in that watershed. Ditch "cleaning" was another common issue observed in this area. In an effort to increase the water transport capacity of ditches, road maintenance crews often carve trapezoidal channels and remove sediment-trapping vegetation. The result is a steeper channel with no vegetation to hold the soil in place. It is difficult to quantify the sediment inputs resulting from such actions, but the impact that these cleanings can have on water quality and suspended sediment is dramatic. Figure 108 shows some examples of road and ditch networks providing a potential direct source of sediment to the Talmadge River.

(2) Channel instability/Bank erosion

Channel instability is common on the north shore of Lake Superior, especially in the watersheds near Duluth. The Talmadge River is impaired for turbidity, as are the neighboring Amity/Lester, French and Sucker River watersheds. It is hypothesized that a large percentage of the sediment loading in these turbidity impaired streams is coming from eroding banks.

In the Talmadge River, areas of channel instability and bank erosion were observed mostly between the McDonnell Road biological monitoring site (11LS038) and the Highway 61 expressway. These reaches of the river mark the transition between the low gradient, unconfined headwater reaches and the very confined bedrock-controlled stretches near Lake Superior. This area also lies just below the historic Glacial Lake Duluth beach line where clay soils are common and rivers tend to be more incised and sensitive to human disturbance. Stream types in this area alternate between Rosgen "B" channels, which are mostly stable, and Rosgen "C" channels, which often show signs of vertical and lateral instability in the form of bank erosion and channel filling (Rosgen, 1996). C-type channels are less efficient at transporting sediment than B channels because they generally have flatter slopes, higher width/depth ratios, and are not as entrenched – meaning that as flows increase the water tends to spread out its energy onto a wider floodplain (reducing sediment transport capability). An observed trend in many North Shore streams is that the C channel types tend to be the most unstable in incised rivers with excess sediment supplies.

Seasonal variation in total suspended solids

Similar to many other streams near Duluth and along the North Shore, the Talmadge River generally appears turbid during high flow events and clearer during low flow. The highest TSS concentrations are mostly limited to these high flow events. Figure 110 shows TSS and Secchi data relating to discharge and time of year at the Talmadge River gage station (S001-755). Paired TSS and maximum daily discharge data (top left) from 2001 through 2008 clearly show the positive relationship between flow and TSS concentration.

The vast majority (90%) of samples that met the coldwater TSS standard of 10 mg/L were taken during days when the maximum discharge was 50 cfs or less. The relationship between discharge and TSS concentration is not perfect however and contains some interesting variation. For example, a flow of 9.6 cfs on April 11, 2003 produced a TSS concentration of 25 mg/L, more than double the TSS standard. A very similar flow (10.9 cfs) a year later on April 12, 2004 produced a TSS concentration of 1.2 mg/L that easily met the standard. In general, there was more variation in TSS concentrations at lower flows under 50 cfs, including a notable grouping of high concentrations under 20 cfs.

Figure 108. Examples of potential sediment sources from the road and ditch network in the Talmadge River watershed. Top left: sand and gravel entering the stream from a poorly designed road crossing. Top right: a headcut on a ditch in a neighboring watershed. Bottom left and right: water quality impacts from ditch "cleaning" efforts.

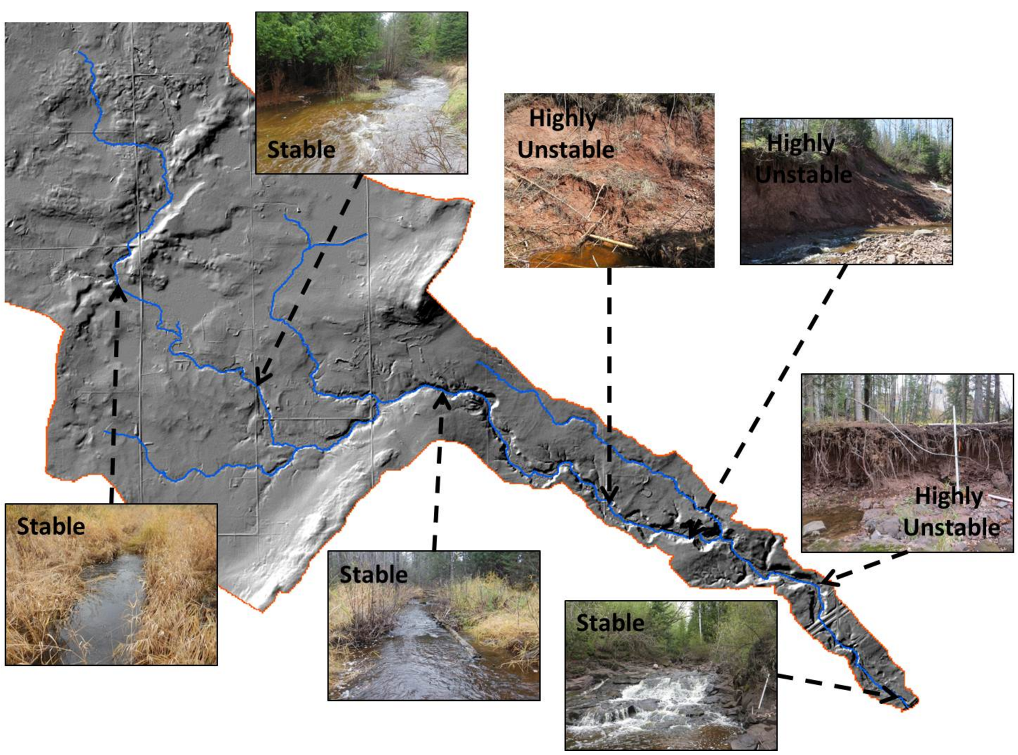


Figure 109. Photos showing representative stream banks along the Talmadge River. Bank erosion is mostly occurring in the transitional reaches below 11LS038 and above the Highway 61 Expressway. Elsewhere the river is generally stable.

TSS concentrations increased more reliably as flows increased above ~50 cfs. The same could be said of the Secchi transparency data (top right), in which greater flows tended to produce lower transparency values with the exception of an anomalous grouping of very low transparency readings at flows under 35 cfs. In fact, about 50% of readings that exceeded the standard were taken at flows under 50 cfs, which is about half the bankfull flow and occurs on a very regular basis. There was no discernible seasonal trend in either the anomalous TSS or Secchi results, suggesting that natural runoff and erosion patterns are probably not the culprit. The Talmadge River watershed is small and somewhat sensitive to disturbance due to its geologic setting. It is possible that human disturbances in the watershed such as construction activities or ditch cleaning may temporarily increase turbidity levels independent of flow conditions.

There is a fairly strong seasonal influence on Talmadge River flows and TSS concentrations. Predictably, the highest average monthly flows (taken from 2001-2008 gage data) were during March and April, when snowmelt often occurs in the Duluth area. Average flows were lowest during July, August, and September, when base flow conditions usually dominate. The average TSS concentrations by month strongly mirrored the average discharge values (Figure 110, bottom left). Similarly, there was a strong negative relationship between average monthly discharge and average Secchi tube reading (bottom right). This serves as further evidence of the robust seasonal TSS trend in the Talmadge River.

TSS load duration analysis

Load duration curves address the likelihood of equaling or exceeding a given pollutant load at a location. Water quality and flow data are used to quantify the pollutant loading to this location from the watershed area upstream. Over the past decade, these curves have been widely used in the development of TMDLs in Minnesota and other US States. The load duration curve approach relies on setting a desired pollutant concentration, which is typically an established water quality standard (in this case 10 mg/L TSS). The resulting curve is the maximum pollutant load that can be observed at the site to meet water quality standards based on the given flow condition.

A TSS load duration curve was developed for the Talmadge River using streamflow and water chemistry data from 2001-2008. It is important to note several potential limitations with this data set. First, the data used are pre-2012 flood, an event which had a profound negative impact on channel stability conditions in the Talmadge River. In addition, the location of the flow/WQ monitoring station for the Talmadge River (1.9 miles upstream of Lake Superior) was chosen for its suitability as a flow gaging station, and does not capture sediment/flow contributions from several highly unstable reaches downstream.

TSS loadings exceeded the TMDL allocation most frequently during high flow (90th percentile and greater mean daily flow) and during “moist conditions” (i.e. moderately high flows à 60th-90th percentile mean daily flow) (Figure 111). No exceedances were observed during mid-range flows, dry conditions, and low flow, although several data points would likely be within the margin of safety that is typically calculated during TMDL development. The TSS load duration curve provides further evidence that TSS-reductions are needed during high flow events and that exposures of aquatic life to elevated TSS concentrations are short in duration.

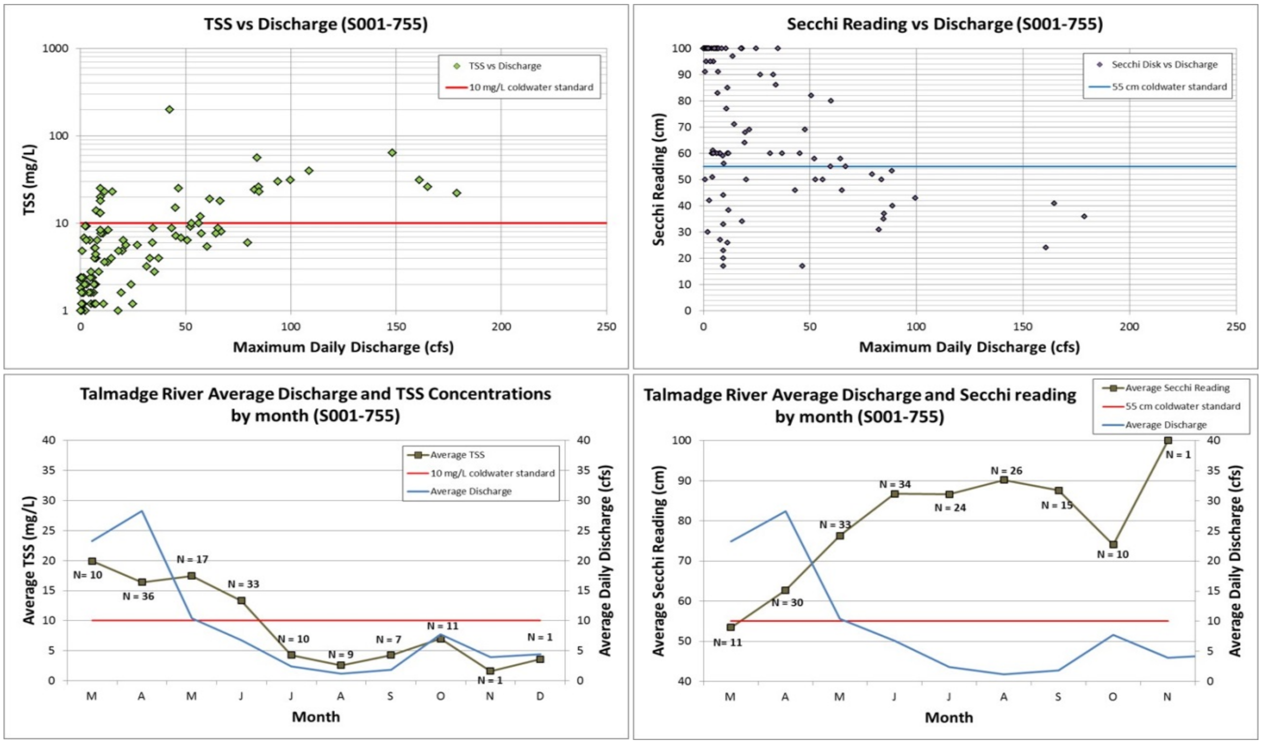
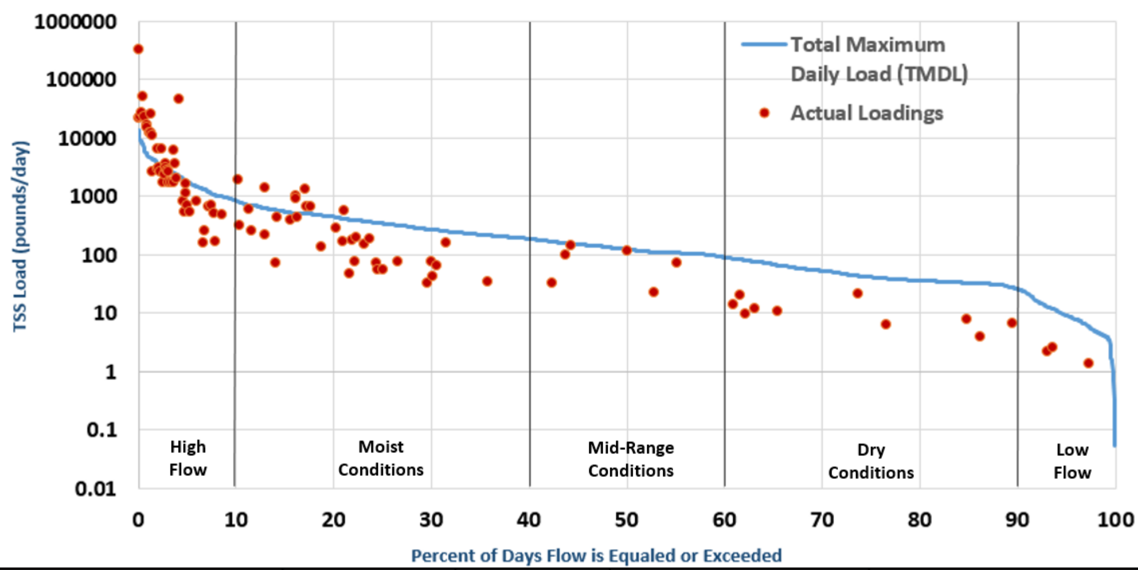


Figure 110. Talmadge River TSS data from the Talmadge River, plotted by month



Flow Range (% of Days Equaled or Exceeded)	Flow Range (cfs)	# TSS Samples	# TSS Samples > 10 mg/L	Percent of TSS Samples >10 mg/L
High (0-10%)	≥16	46	18	39%
Moist Conditions (10-40%)	3.5 - 16	35	8	23%
Mid-Range Conditions (40-60%)	1.7 – 3.5	9	0	0%
Dry Conditions (60-90%)	0.5 – 1.7	16	0	0%
Low Flow (90-100%)	0.0 – 0.5	6	0	0%

Figure 111. TSS load duration curve developed for the Talmadge River using 2001 – 2008 data from station S001-755

Longitudinal trends in total suspended solids

TSS and Secchi disk data from 2006 – 2014 (Table 26) show that the TSS and the Secchi transparency standards are being exceeded more than 10% of the time for all of the sites with at least 10 suitable samples (highlighted in red). Many of the sites with less than 10 samples also have a greater than 10% exceedance rate (highlighted in yellow), although almost all of those samples were event-based and should not be construed as typical for the wide range of flows and conditions in the river. These event-based samples were meant to pinpoint sediment sources – see further discussion below. The data from S001-755 support the TSS impairment for the Talmadge River. Nine out of thirty-three (27%) samples exceeded the coldwater TSS standard, with the average concentration more than doubling the 10 mg/L threshold. The Secchi tube readings at that site exceeded the coldwater standard of 55 cm in 19 out of 111 samples (17%), although the average reading was clearer than the standard at 85 cm. The Secchi data near the mouth (S005-468) were similar, with 18% of the 88 readings less than the standard and an average reading of 80 cm.

During periods of high flow streams often exhibit higher levels of turbidity. The larger discharges during snowmelt and storm events increase stream power and erode stream banks more than periods of low flow. For this reason, conducting longitudinal TSS sampling during these events is vital to locating stream reaches that serve as sources of suspended sediment in a watershed. Monitoring data from four early season snowmelt or rain events in 2013 and 2014 were used to develop longitudinal summaries of TSS and Secchi Tube data for the Talmadge River (Table 26). The results show that TSS concentrations generally increase from upstream to downstream. There were large increases in average TSS from S007-447 to S007-614 (16.7 to 31.1 mg/L) and from S007-614 to S001-755 (31.1 to 60.9 mg/L). The largest increase by far though was from Cant Road (S001-755) to the Highway 61 Expressway (S007-446), where the average TSS concentration from those four sampling events increased from 60.9 mg/L to 158.2 mg/L. At those same set of four sites, the average Secchi tube transparency correspondingly decreased from 75cm -> 61cm -> 50.3cm -> 29.8cm.

For each sampling site, the increase in average TSS concentration was divided by the corresponding increase in drainage area from the next upstream sampling site (Figure 114). The resulting metric (mg/L/mile^2) helps to pinpoint the stream reaches and sub-watersheds that are contributing a disproportionate amount of suspended sediment to the system. The results show that the sub-watershed between the Highway 61 expressway (S007-446) and Cant Road (S007-755) and the sub-watershed of the tributary crossing Cant Road (S007-450) both were contributing an extreme concentration of at least 100 mg/L/mile^2 during the four sampling events. This longitudinal data lines up well with the observed bank and channel instability in those reaches and supports the hypothesis that most of the suspended sediment in the Talmadge River is being sourced from stream banks.

Figure 112. Results and appearance of May 21, 2013 TSS samples collected longitudinally from upstream (left) to downstream (right)

Table 26. Longitudinal TSS and Secchi Tube average values and percent standard exceedances for Talmadge River monitoring stations. Red Highlights = # samples and exceedance rate

Talmadge River TSS and Secchi Summary

Flow

		TSS				Secchi		
Site (*Co-located Biosite*)	Site Description	# of Samples	Average (mg/L)	% Exceeding Standard	Drainage Area (miles^2)	# of Samples	Average (cm)	% Exceeding Standard
S007-449	TALMADGE R AT LESTER R RD	4	7	0%	2.74	4	100	0%
S007-448 (*01LS005*)	TALMADGE R AT WAHL RD	4	7	25%	3.16	4	91	0%
S007-447 (*01LS004*)	TALMADGE R AT LAKEWOOD RD	4	17	50%	4.11	4	75	25%
S007-614 (*11LS038*)	TALMADGE R NW OF MCDONNELL RD	2	31	50%	5.13	2	61	50%
S001-755 (*13LS110*)	TALMADGE R AT CO RD 281	33	21	27%	5.42	111	85	17%
S008-003	TALMADGE R (TALMADGE CK), W OF FLYNN RD AND UPSTR OF TRIB MOUTH, N OF DULUTH, MN	1	10	100%	5.53	1	76	0%
S007-446 (*01LS002*)	TALMADGE R AT CSAH-61 EXPRESSWAY	4	158	75%	5.87	4	30	75%
S005-468	TALMADGE R, 100 YDS BELOW MN-61, 6 MI NE OF DULUTH				5.96	88	80	18%
S007-445 (*01LS001*)	TALMADGE R AT CSAH-61, 10.7 MI NE DULUTH, MN	4	159	100%	5.96	4	31	75%
Tributaries								
S007-450	UNN STR AT CANT RD	4	21	50%	0.10	4	59	50%
S007-984	UNN STR (TALMADGE R TRIB) TO TALMADGE R, UPSTR OF CONFLU WITH TALMADGE R, W OF FLYNN RD AND N OF DULUTH, MN. T51N R13W S24	1	25	100%	0.19	1	21	100%
S007-451	UNN STR AT LAKEWOOD RD	4	28	100%	0.83	4	76	25%

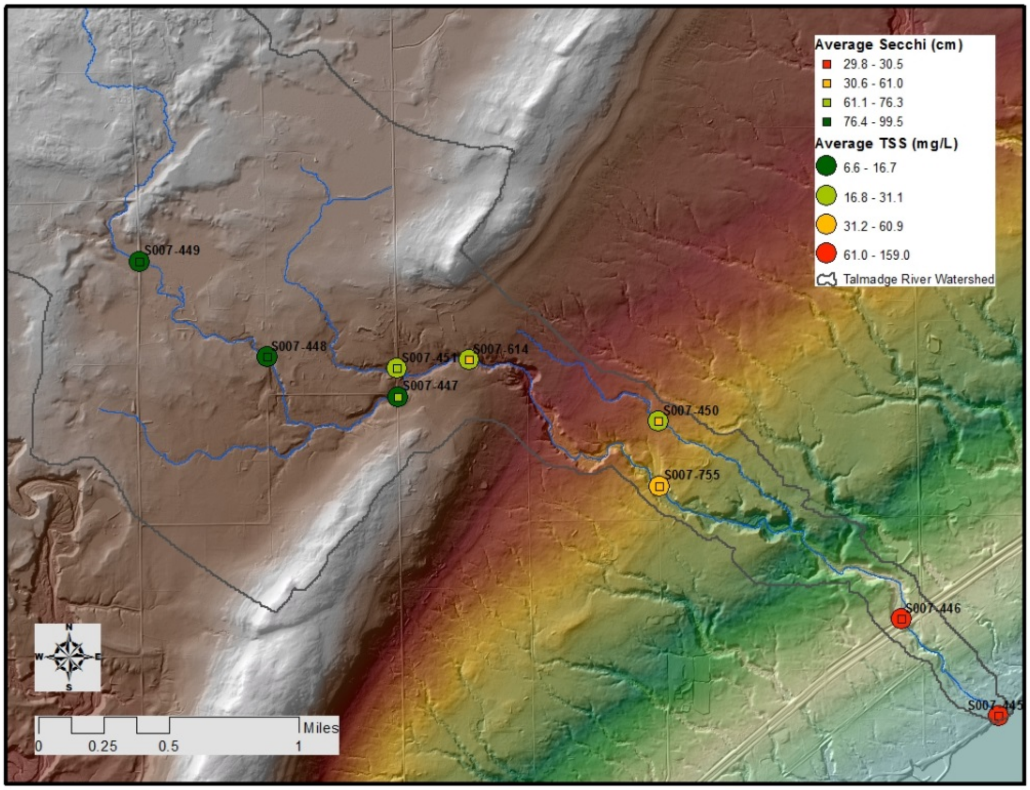


Figure 113. Map of average TSS and Secchi tube values longitudinal sampling sites on the Talmadge River

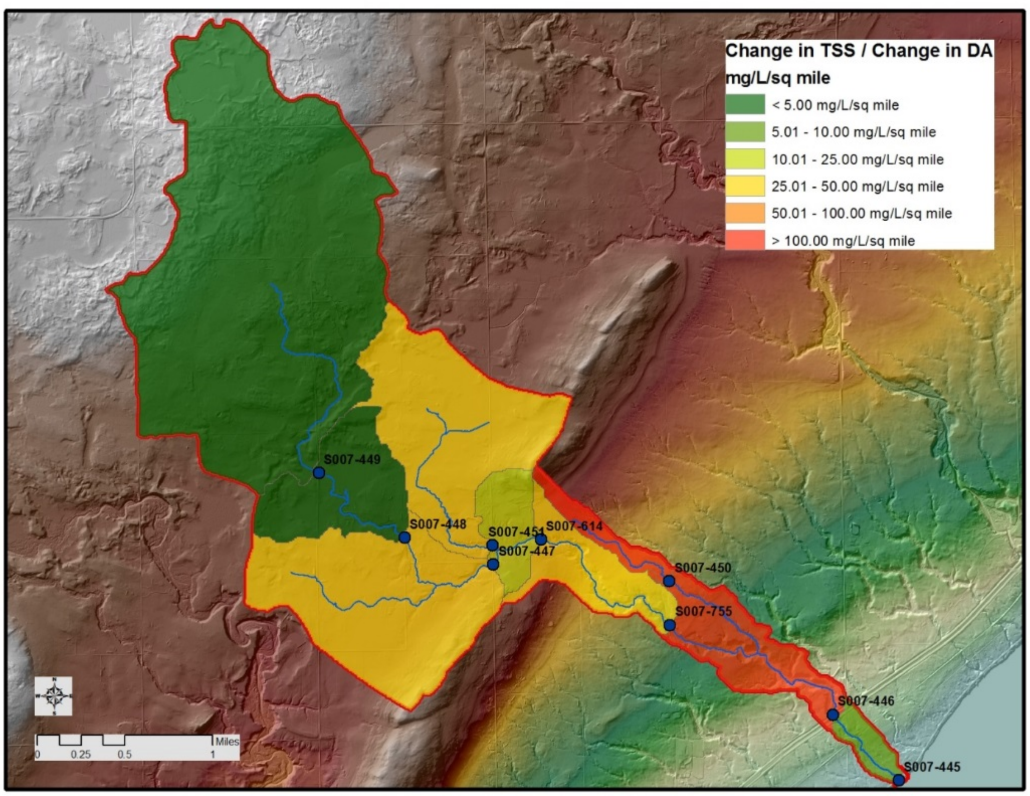


Figure 114. Map showing the Talmadge River sub-watersheds and stream reaches that are contributing a disproportionate amount of TSS

Talmadge River BANCS analysis

A detailed BANCS analysis (see Section 4.4 for methodology) was performed on the mainstem of the Talmadge River from the mouth to the Lavis Road crossing. The whole mainstem was not assessed because earlier synoptic TSS sampling indicated that a negligible amount of sediment was being supplied from the headwaters above Lester River Road. The three main tributaries to the Talmadge River were not assessed due to time constraints. Figure 115 shows the results from the BANCS analysis. Predictably, most of the estimated sediment supply is taking place in the same reaches where TSS concentrations disproportionately increased and where bank and channel instability were observed (McDonnell Road to Highway 61 expressway).

The results of this analysis suggest that a large reduction in sediment load could be accomplished by restoring a relatively small percentage of the river. This assessment predicts that, for the stream reaches we analyzed, 43% of the sediment load is coming from about 2.5% of the stream length. These banks have predicted erosion rates of about 0.35 tons/feet/year, or 700 lbs of sediment per foot of channel every year. Eighty-one percent of the sediment supply is being sourced in C channels, with the highest erosion rates coming from transitional reaches with slopes between 1.0-1.5%.

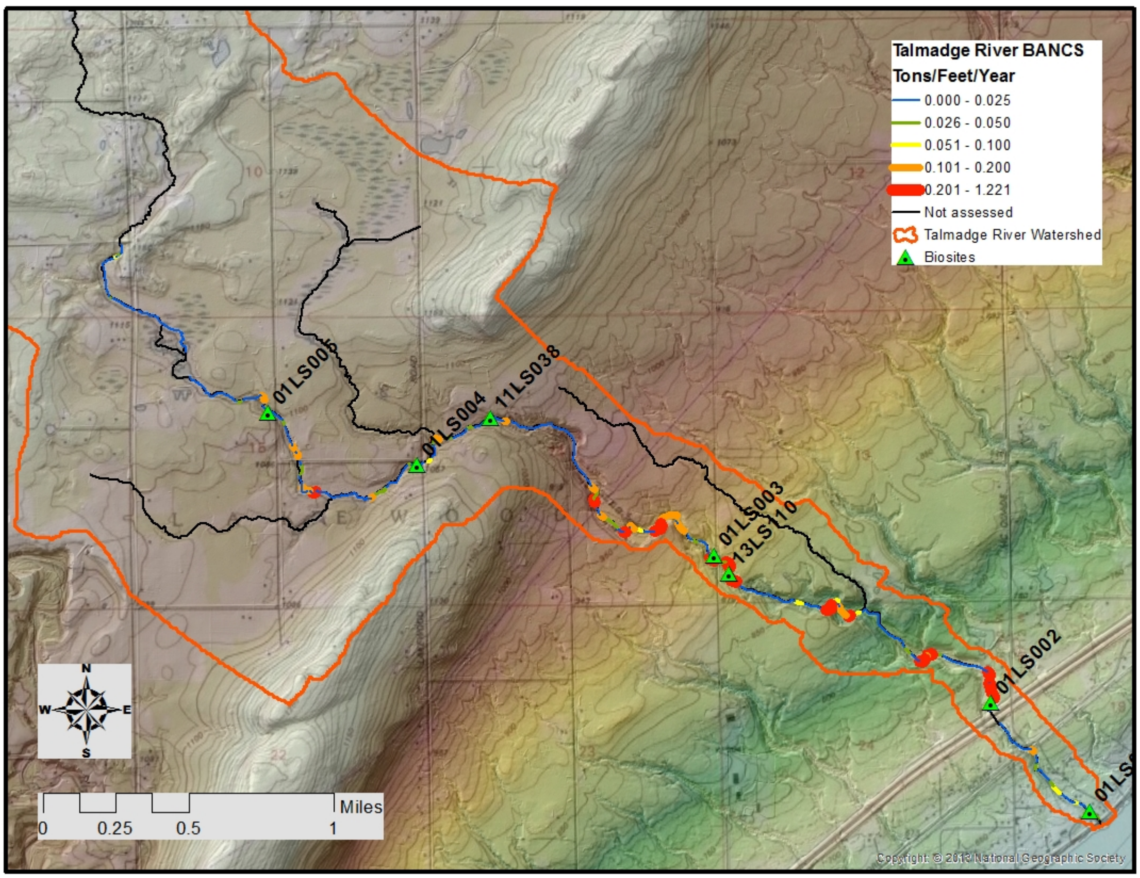


Figure 115. Map of Talmadge River showing predicted erosion rates in tons/foot/year

Biological effects of elevated TSS

MPCA biologists have developed TSS TIVs for all of the fish species found in Minnesota. The TIVs were developed using statewide biological and water chemistry data sets, and are based on the presence, absence, and/or relative abundance of fish taxa found in various water quality conditions. More information on the development and use of TIVs can be found in Section 4.5. For the purpose of evaluating various stressors in this report, TIV values were broken up into percentiles and fish taxa were classified as highly sensitive, moderately sensitive, slightly sensitive, neutral, slightly tolerant, moderately tolerant, or highly tolerant. These categories are used in this section to evaluate the general tolerance of the Beaver River fish community to elevated TSS concentrations.

DNR and MPCA staff completed fisheries surveys at seven locations on the Beaver River between the years 2001 -2013. A total of nine fish species were observed in the river over this period. Over half of these species (n=5) can be considered “neutral” in terms of their association with turbid/high TSS conditions in Minnesota streams. In other words, these species are observed in streams with a wide range of TSS concentrations and are not all that useful for stressor diagnosis. Examples of these species found in the Talmadge River include Creek Chub (Abundant), Pearl Dace (Present), and Brook Stickleback (Rare). Several highly sensitive fish species were sampled in small populations by DNR in 2001 surveys completed well below the migratory fish barrier falls. Rainbow Trout, Brook Trout, and Coho Salmon, and Rainbow Trout (stocked by DNR) were present in these surveys, but were not observed above the migration barrier in recent sampling efforts. No TSS “tolerant” fish species were sampled in the Talmadge River. A summary of the fish species sampled, relative abundance, and respective TSS-tolerance categories are included in Table 27.

TSS concentrations along the Talmadge River show a strong longitudinal trend of increasing concentrations with increasing drainage area. As a result, the duration/magnitude of exposure to elevated TSS varies considerably among the biological monitoring locations. Therefore, a gradient of impact to the fish community would be expected if TSS is acting as a primary stressor. Two biological monitoring stations recently sampled by MPCA, 11LS038 (sampled 2011 and 2013) and 13LS110 (sampled 2013), provide an opportunity to observe if a gradient of impairment exists.

Station 11LS038 is located in a stable reach of the river, and sediment inputs upstream of this point are minimal. On the contrary, station 13LS110 is located at the stream gaging station within an unstable reach and downstream of areas producing high sediment loads. TSS concentrations at this station frequently exceed the 10 mg/L water quality standard during periods of high streamflow. The fish community at these stations is fairly similar, both dominated by Blacknose Dace and Creek Chub. These were the only two species sampled at 13LS110. Three additional species were observed at station 11LS038; Pearl Dace, Iowa Darter, and Brook Stickleback. Although these species are not known to be highly intolerant of TSS, several of them are indicators of healthy streams. Based on these results, there is potentially a gradient of impact related to TSS in the Talmadge River. Other factors, particularly physical habitat, may be partially responsible for the slight change in fish community as well.

Overall, specific symptoms of impairment related to TSS are difficult to decipher based on the Talmadge River fish community. A few sensitive species are present in extremely small populations that may be sustained only through stocking efforts and/or connectivity with Lake Superior. TSS-tolerant species are also absent, which is not surprising considering the exposures to potentially harmful TSS concentrations are rain/snowmelt driven and are short in duration.

Table 27. Fish species sampled in Beaver River and general tolerance to elevated TSS/turbidity. Tolerance classes are based on MPCA's TIVs.

TSS Tolerance Category	Species Present in Talmadge River (A = Abundant, C = Common, P = Present, R = Rare)
Highly Sensitive	Rainbow Trout (P – stocked); Brook Trout (R), Coho Salmon (R)
Moderately Sensitive	None
Slightly Sensitive	Blacknose Dace (A)
Neutral	Pearl Dace (P); Creek Chub (A); Central Mudminnow (R), Brook Stickleback (R)
Slightly Tolerant	
Moderately Tolerant	None
Highly Tolerant	

Summary: Is elevated TSS a cause of fish impairment in the Talmadge River?

The Talmadge River is currently impaired for turbidity. The results obtained through stressor identification monitoring support this impairment listing, particularly on the basis of the water quality measures. Extremely high TSS concentrations (up to 520 mg/L; WQ standard is 10 mg/L) were observed from the Cant Road crossing down to Lake Superior during rain/snowmelt events in the spring. Summer and fall rain events also cause TSS concentrations to exceed state water quality standards for aquatic life. During low to moderate flows, TSS concentrations are generally below the 10 mg/L standard, although some exceedances have also been observed during lower flows.

The fish community is dominated by species common to marginal coldwater streams along the North Shore (Blacknose Dace, Creek Chub). Very few species were sampled during the most recent electrofishing surveys. The lack of species richness in the Talmadge River could be due to a variety of limitations in this watershed – poor habitat, occasional low DO, flashy hydrology, and/or large spikes in TSS during higher flows. Turbidity/TSS has been extensively studied in this watershed and a TMDL is needed to address the current impairment for that parameter. Directly linkages to the biota impairment are difficult to derive given the possibility of confounding stressors mentioned above. but TSS/turbidity should be considered a stressor given that the sources of sediment (bank erosion, roads) and the resulting habitat loss are major issues in this watershed.

6.2.6 Altered hydrology

The Talmadge River watershed, a 5.9 mi^2 (3786 acre) drainage within the Lake Superior South Basin, is a primarily-forested watershed with fragments of rural development, scrub/shrub, and open land/pasture landuse dispersed throughout. The stream Assessment Unit ID (AUID) is 6.2 miles long and extends northwest from the outlet at Lake Superior (602 feet AMSL) to a culvert crossing at Whiteside Road, Lakewood Township, Saint Louis County, Minnesota. Much of the landscape is drained through 55 additional miles of unclassified drainage ways that flow to the Talmadge River. Unclassified stream segments and the drainage boundaries of primary tributaries to the Talmadge River are identified in Figure 117 along with stream sample stations. Lakes are absent in the watershed. Wetlands cover 11% of the total drainage area and are primarily located in the upper half of the watershed. In addition, private ponds ranging from 0.1 to 0.5 acres in size are scattered throughout the headwaters region. Altered watercourse data created by the MPCA through aerial imagery shows that little to no stream channel alterations have occurred. Any alterations of flow in this watershed is due to changes in landuse and cover.

The headwaters form in a prominant end-moraine (1280 to 1400 feet AMSL) of the Superior Lobe and consists of forested and scrub/shrub wetlands dispersed throughout. The headwaters supply critical flow to the system, draining approximately 47% of the total watershed area. Generally, headwater soils are moderately well-drained with coarser well-drained high relief features and finer wetland soils scattered throughout. Shallow depth to groundwater is observed through the relative abundance of private ponds. The upper watershed landcover is primarily forest, scrub shrub, and wetland with rural development scattered throughout.

Decreased relief and finer soils contribute to a changed hydrologic characterization found in the drift complex of the mid-watershed. Geographic breaks from the upper and lower watershed regions are linearly oriented northeast to southwest respectively downstream of station TMG 615 and downstream of station TMG6 40. Tributary drainages and near-channel wetlands supply flow to this mid-watershed area. The dominant soil type is somewhat poorly drained. One well-drained high relief feature is oriented northeast to southwest along the downstream border of the mid-watershed and drains to a moderately well-drained stream floodplain near stations TMG 640 and TMG 645. Several large saturated wetland complexes are mapped in this region. A stream impoundment, built on the Talmadge River at a private recreation facility in the 1960s, forms an in-channel pond (retriever pond) that is 2.9 acres in size and located just upstream of TMG 625. Overhead cover is lacking in the openlands surrounding the pond. Mid-watershed landcover shows an increase in rural development and open land/pasture compared to the overall watershed.

The upper boundary of the lower watershed is found along a prominent sill oriented northeast to southwest and intersecting the Talmadge River near station TMG 645. Downstream of this feature, wetlands are scarce and the stream transitions to a steep-gradient channel, flowing through bedrock outcrops and steep clay walls to Lake Superior. The drainage area is small compared to the mid and upper watershed regions. The long and narrow shape of the lower watershed in addition to shallow depth to bedrock limits deep or longer-term subsurface storage capacity. The high-relief valley walls along the stream discharge subsurface waters to the stream following snowmelt and rain events. Drainage T6 which contains negligible wetlands enters the Talmadge River in this lower portion of the watershed. Soils are mostly somewhat poorly drained. Landcover is primarily forest with a pocket of open land/pasture near the upper boundary and some rural development scattered throughout.

The Talmadge River hydrology is flashy, meaning that water levels rise and fall very rapidly, particularly in the mid-to-lower watershed where it flows at steep gradients through clay till and bedrock towards Lake Superior. The low-permeability soils and bedrock in the watershed contribute to increased surface runoff rates resulting in fast, turbulent streamflow following precipitation events. Bankflow flows are estimated at 100 cfs and occur at approximately 1.3-year reoccurrence intervals, primarily occurring during snowmelt and high-intensity rain events. In general, groundwater storage is shallow due to the thick clay soils, shallow depth to bedrock, and lack of deep storage, particularly in the lower watershed. Wetlands are the primary source of storage. It is typical for flows of less than 1 cfs to occur during the late summer of a normal climate year. Stream depths are shallow throughout much of the system during dry periods. During low and very low flow periods flows can become interstitial, with stranded pools of water hydraulically connected by slow moving subsurficial waters. Contrast of low and high flow conditions in the lower reaches of the watershed is shown below in the images of Figure 119 .

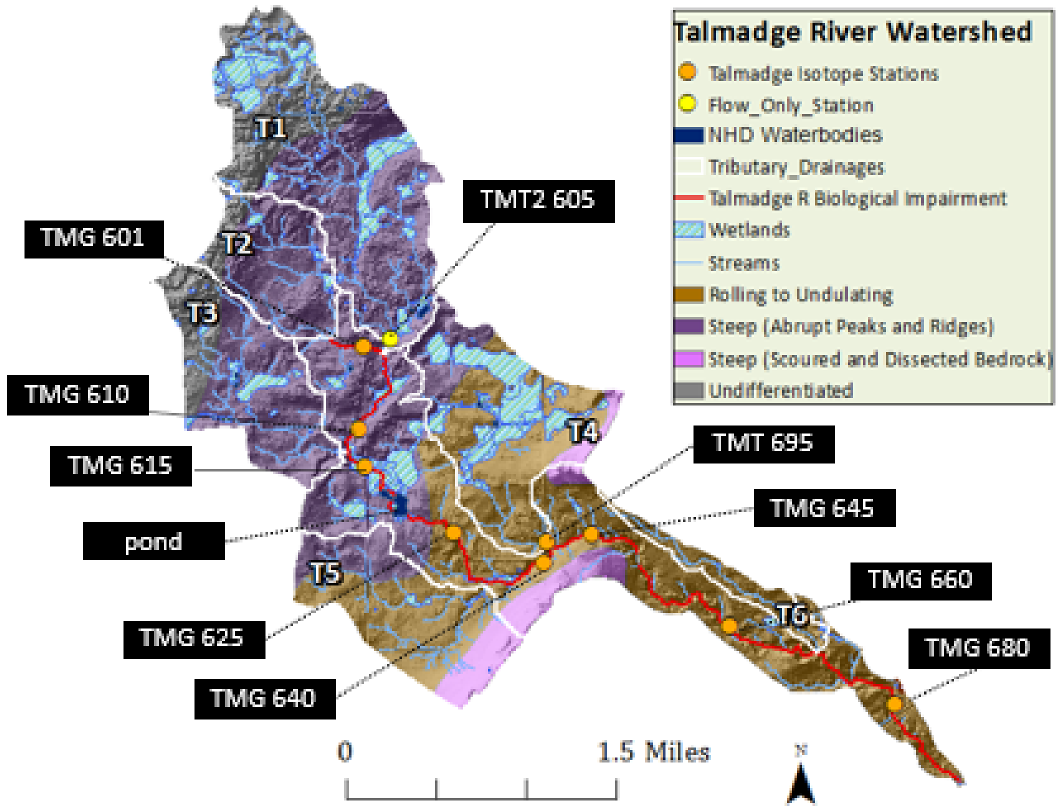
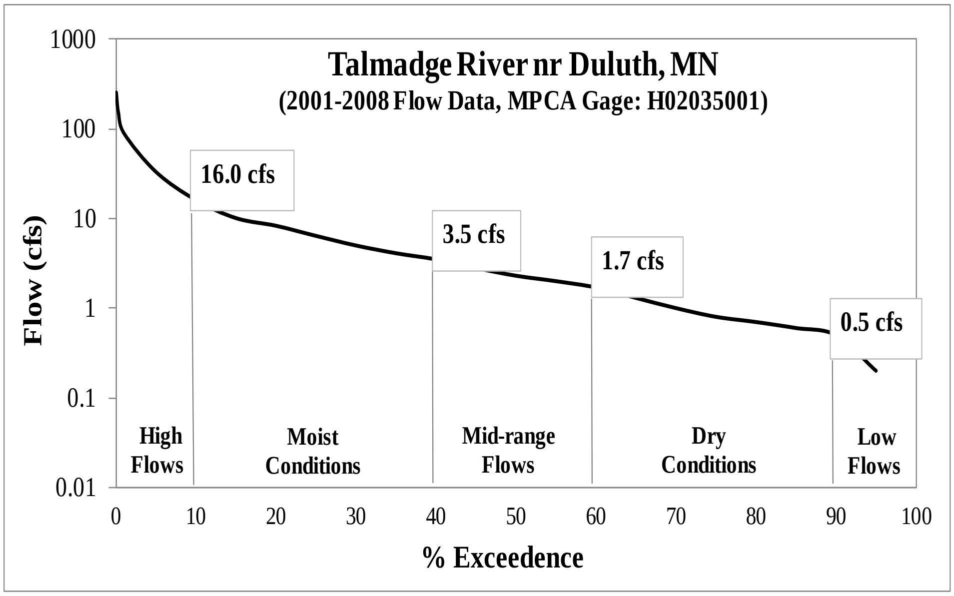
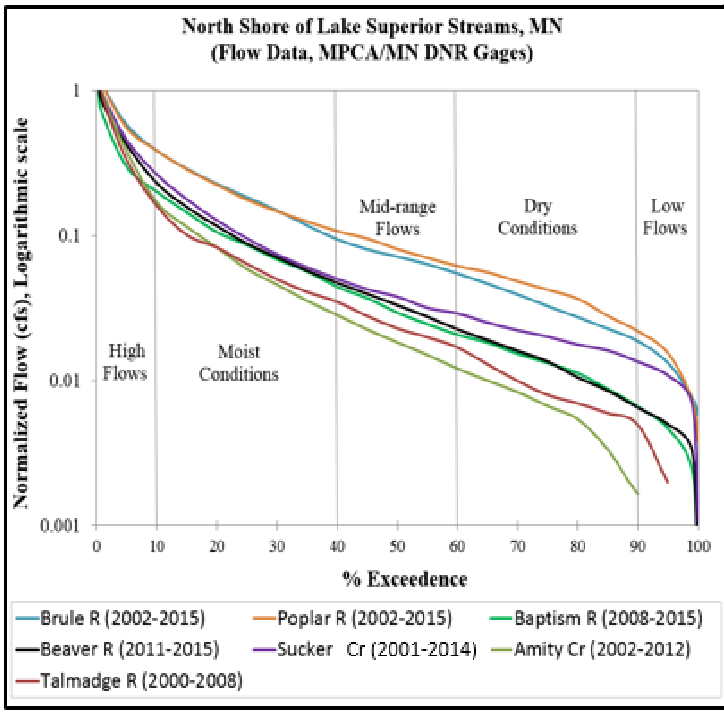


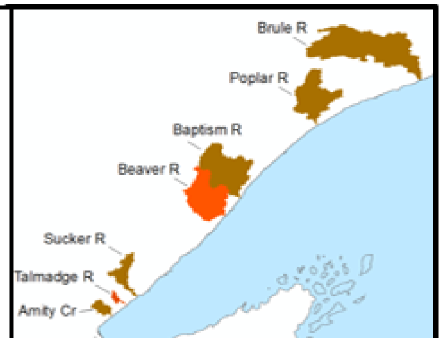
Figure 117. Tributary drainages, streams, wetlands, sample stations, and stream impoundment (pond) in the Talmage River Watershed. Geomorphology and terrain delineation is from University of Minnesota-Duluth Geology Department, 1997.

Flow duration curves and stream flashiness

An MPCA stream gage was operated on Cant Road at sample station TMG 660 during years 2001 to 2008. Daily flows range from 254 cfs to less than 0.10 cfs during the gaged period. The flow duration curve, showing the percent of time that a given discharge was exceeded, is displayed logarithmically in Figure 118 and is compared to other North Shore streams. Flow duration curves can be used to interpret the flashiness of a stream system, with greater concavity or sharp curvature indicating fast changes in discharge. The Talmadge duration curve shows that discharges in the range of 16 to 254 cfs occur less than 10% of the time. The remaining 90% of the year, flows remain below 16 cfs and approach zero at less than 0.5 cfs for 10% of the record. Flow duration curves, normalized by bankfull discharge, for various gaged streams along the shore are displayed in Figure 118. The steep curvature of the Talmadge River plot compared to other North Shore gages indicates that it is flashy compared to other systems. Amity Creek, another respectively small watershed located just outside of Duluth, similarly shows flashy curvature and also approaches zero discharge during the low flow regime. The wetland area to drainage area ratio of these two watersheds is one-third of that calculated for the other watersheds analyzed; and they have little to no storage in lakes. With less surficial storage, the ability to retain water on the landscape during high runoff events and supply flow during dry periods is greatly reduced and therefore flashier hydrology is expected. With the smallest drainage area of all streams, Talmadge River also has the overall lowest flows.







Stream Name	Drainage Area (mi2)	% Lakes	% Wetlands
Talmadge	5.9	0.0	10.8
Amity	16.5	0.3	9.3
Sucker	37.7	0.4	27.2
Beaver	123.0	0.6	29.5
Baptism	138.4	0.9	25.8
Poplar	113.3	7.5	21.4
Brule	265.2	9.6	16.8

Figure 118. Flow duration curve for the Talmadge River, identify five flow regimes (upper). Flow duration comparison of North Shore tributaries shows the relative flashiness of the Talmage River (lower). Curves are normalized by dividing by bankfull discharge. Talmadge watershed has low drainage area and percent area in wetland and lakes compared to other North Shore tributaries (rower right).

Figure 119: Contrast of low and high flow conditions in the lower reaches of the Talmadge River watershed. Stranded pools are seen under low flow conditions of year 2013 (lower right).

Watershed streamflow characterization

Longitudinal flow data collection

Stream flow measurements were collected using a Sontek Flowtracker at eight locations, including seven of the isotope sample stations and Tributary T1 at a location immediately upstream of the confluence with the Talmadge River. Flow measurements were collected within a four hour period on June 2, 2016. The area had received daily rainfall amounts of 0.1 to 0.5-inches eight of the ten previous days. Flow augmentation by groundwater discharge of upland drainage and post-event storage was likely based on timing of sampling. A groundwater-surface water study on an area stream in Lake Superior South watershed showed that during the spring season shallow groundwater discharge from subsurface storage within the floodplain can last into mid-June (Jasperson, 2016); and post-event rainfall release time can last up to 16 days in mid-to-late summer.

Tributary drainages were delineated for each flow sample location using U.S. Geological Survey Stream Stats web application. Change in flow and change in flow per change in unit drainage between sample stations were computed. Higher uncertainties in the measurements were caused by the rapid measurement technique used to decrease time between flow measurements to better simulate flow within the system during a snap-shot in time. Uncertainties are primarily due to lack of verticals in each cross-sectional measurement which was the result of narrow stream channels and the rapid measurment technique.

Longitudinal discharges, uncertainties, and drainage areas are are found in Table 28. Based on the flow (3 cfs) measured at TMG 660 (historic gage station H02035001), the stream was under mid-range flow conditions for the longitudinal survey. Discharge per unit area of drainage between stations was used as an indicator of flow inputs within the watershed. Headwater stations TMT2 605 and TMG 601 were summed to calculate flow, error, and drainage area at the confluence of Tributary 1 and the Talmadge River. They are the furthest upstream stations therefore discharge per unit drainage area was computed directly for each individual station. Higher discharge per unit area gains between flow stations are observed at sites TMT2 605 (Tributary 1) and TMG 615 (Talmadge River), indicating strong flow contributions to the system from Tributary T1 and source waters between stations TMG 610 and TMG 615. A moderately higher value is also observed for TMG 680 (Talmadge River), but because the increase in flow observed at this station is approximately equal to the cumulative uncertainties of station TMG 680 and the next upstream station TMG 660, error may be affecting the value. Similarly, the negative discharge per unit area value for station TMG 610 is likely due to measurement error relative to flow increase in combination with the small change in drainage area used in the calculation. Lower discharge per drainage area results are observed at stations TMG 601, TMG 610, TMG 625, and TMG 640. The lower value at TMG 610 is expected since no additional tributaries enter the system between this location and the upstream confluence of Talmadge River and Tributary T1.

Table 28. Measured flow and calculated drainage area at each sample station; and calculated flow increase and discharge-drainage area ratio between sample stations.

Station	Flow (ft^3/s)	Error (+/-) (ft^3/s)	Drainage Area (mi^2)	Δ Flow (ft^3/s) *from upstream station*	Δ Drainage Area (mi^2) *from upstream station*	Δ Discharge/Drainage Area ($ft^3/s/mi^2$) *from upstream station*
TMT2 605 *[1]	1.19	0.13	1.31			0.91
TMG601 *[2]	0.07	0.03	0.56			0.13
SUM *[1 & 2]	1.26	0.16	1.87			
TMG610	0.96	0.21	2.02	-0.31	0.15	-2.06
TMG615	1.68	0.17	2.75	0.72	0.73	0.99
TMG625	1.88	0.36	3.17	0.20	0.42	0.47
TMG640	2.20	0.19	4.11	0.32	0.94	0.34
TMG660	3.00	0.32	5.42	0.80	1.31	0.61
TMG680	3.36	0.2	5.86	0.36	0.44	0.82

Isotope sample collection

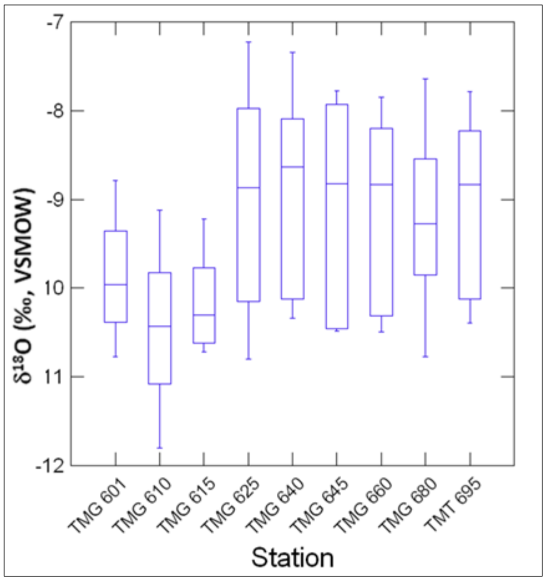
Stream isotope samples were collected from nine sample stations dispersed throughout the Talmadge River watershed (Fig. 117) in years 2014-2015. Eight sample locations were located on the main stem and one station (TMT 695) was located on Tributary T4 at just upstream of the confluence with the Talmadge River. Baseflow conditions were targeted, but post-rain event mixing was observed in select sample events. Samples were collected in August and October of 2014 and monthly June to September of 2015. Samples were submitted to the University of Waterloo Environmental Isotope Laboratory for analysis of stable isotopes of oxygen-18 and deuterium.

Stable isotopes (^{18}O and ^{2}H) of stream water were evaluated for placement with respect to the local meteoric water line (LMWL), range of values, and inter-annual consistency. Local evaporative lines (LELs) were evaluated for events in which samples strayed in a linear relationship outside the error bars 2σ (2 x maximum reported standard deviation) of the LMWL and with lesser slope. Stream samples showing no evaporative loss and clustering in a tight range near the interesection of the LMWL and LEL (inflow value) are considered representative of groundwater-dominated streamflow. Locations with higher evaporative loss were further evaluated using landuse, landcover, and hydrologic features to assess the natural or anthropogenic condition of evaporative source waters. Spacial and temporal variability of signals was used to interpret seasonal and locational variability in groundwater-surface water interactions in the Talmade River watershed.

Isotope results

Isotope samples collected throughout the watershed reflected three primary conditions: groundwater-dominated baseflow, wetland/pond inputs to baseflow, and post-rain surface water runoff inputs to streamflow. Evaporative and non-evaporative enrichment from the inflow value was used to interpret sourcewater inputs. Non-evaporative enrichment observed in September 2015 sample results show storm-event mixing with resident stream water as points plot to the right of the graph while still aligning along the LMWL. This differs from evaporative signatures which plot to the right of the graph, but tend to stray from the LMWL at a lesser slope along the LEL. Evaporative loss signatures are observed in August 2014, July 2015, and August 2015 data, indicating that surficial sourcewaters (wetlands) were discharging to streamflow in given reaches of the system during the drier summer months.

October 2014 and June 2015 data show non-evaporative signals in streamflow throughout the entire watershed as points cluster near the inflow value located at the intersection of the LMWL and LEL (Figure 120). The intersection, representative of seasonally-mixed precipitation in watershed storage is located at $\delta^{18}O$ equal to -10.40 ‰ in 2014 and -10.50 ‰ in 2015. Scatter from the intersection is within +/- 0.65 ‰ for the two events. Data suggests that marginal evaporative losses could be starting to appear at station TMG 680 in June of 2015. A groundwater study (Jasperson, 2016) on nearby Amity Creek of Duluth, Minnesota showed that groundwater discharge to the stream following the snowmelt season continues into mid-to-late June. Additionally, maximum monthly air temperatures, initiating evaporative processes, typically occur in July to September months. By October, the mean monthly air temperature for the Duluth area is 44°F and trees begin to lose their leaves. These reduce evaporative effects on surface waters and decrease transpiration. Groundwater levels tend to rebound. The non-evaporative signals in stream waters throughout the watershed during June and October sample events can be explained by the timing of these climatic conditions.



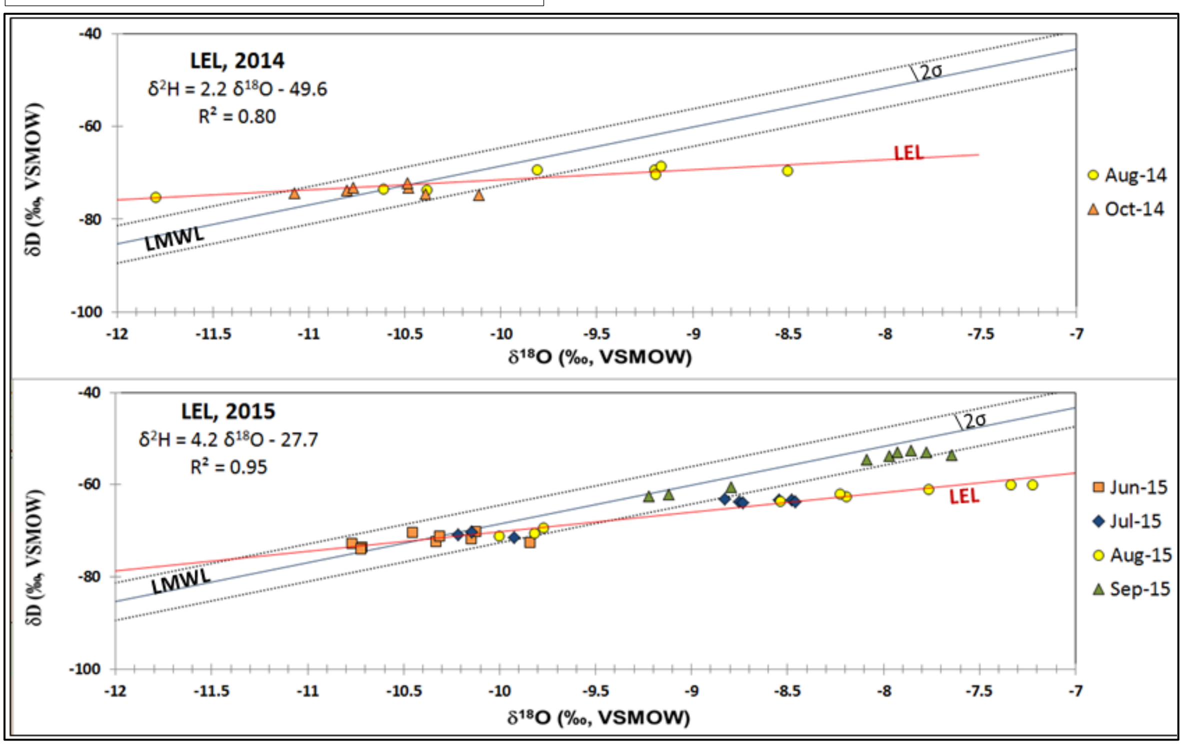


Figure 120. (top) Box plot of oxygen-18 isotopes measured in waters at Talmage River sample stations. (bottom) Isotope signatures of samples collected in 2014 and 2015 and LEL for each year.

During the dry summer months (July – August), data show locational variability of isotope signatures within the watershed (Figure 120). Stations TMG 601, TMG 610, and TMG 615 have a more depleted (negative) signal than greater watershed locations and plot near the inflow value ($\delta^{18}O$ = -10.45 +/- 0.6 ‰). The tightest ranges are observed at stations TMG 601 and TMG 615 (Figure 120), indicating a stable source of flow at these stations. Marginal loss to evaporation is observed at these locations in August 2015 and zero loss to evaporation is observed in August 2014. Based on the lack of evaporative signature during the summer months, we believe a primary source of flow in these upper reaches is subsurface storage, June through October. The source of the highly depleted signature for the TMG 610, August 2014, sample is unknown. The isotope signal skews towards winter precipitation. Because the sample was collected in August, this suggests the presence of a seep from a larger or deeper aquifer. Other North Shore locations in which similarly depleted signals have been observed in late summer include McCarthy Creek, a spring to Brophy Creek, Thompson Creek, and a tributary to the Flute Reed River.

Typically, September baseflow samples would show the highest evaporative losses. The regional area received 1-2 inches of rain just ten days prior to the September sample event. Our September samples show the presence of enriched water in streamflow and verify that we did not sample baseflow conditions. Event water was present in streamflow however, the percent contribution varied spatially within the watershed. Less storm water enrichment was present in the headwater stream samples than observed in the mid and lower-watershed reaches. Sample waters from TMG 610 and TMG 615 plot 1‰ $\delta^{18}O$ to the left of downstream samples, approximately mid-way between the downstream waters and the inflow value. This indicates that groundwater and event water more evenly mix in streamflow in the headwaters, whereas more event water dominates streamflow in the mid and lower watershed under these conditions.

Evaporative signatures are present in July and August data for all sample stations including and downstream of station TMG 625. The greatest evaporative losses are observed in August 2015 samples. The evaporative signal infers wetlands and shallow pond release to streamflow since these are the primary source of surficial waters in the watershed. Evaporative losses and the spread between points along the LEL are greatest in July 2015. Evaporative losses in stream water were particularly high at stations TMG 625 and TMG 640 and then decreased longitudinally downstream for the July 2015 event. In August 2014 and July 2015, less evaporative losses are observed compared to August 2015. In July 2015, all middle and downstream watershed stations cluster together showing moderate loss. In August 2014, the greatest loss is seen at TMG 640 and the least (marginal) evaporative loss is seen at the furthest downstream station, TMG 680. Seasonally, TMG 680 has a narrow isotope signal range compared to the remaining middle and lower watershed stations.

Talmadge River hydrogeology summary

Groundwater inputs

Headwater stations TMG 601, TMG 610, and TMG 615 have isotope signatures indicating groundwater contributions during the entire sample period. Although similar signals are observed, flow data shows that percent flow volume to the system varies within the headwater tributary drainages. Based on flow data (Table 28) collected at stations TMT 2 605 (Tributary T1) and TMG 601 (Talmadge T2), the T1 drainage supplies the majority of flow to the upmost reaches of the Talmadge River and contributes 35% of total flow measured at the furthest downstream station TMG 680. Similarly, both a dominant groundwater isotope signal and a noticeable increase in flow volume per drainage area is observed at station TMG 615. Field observations during multiple seasons and years confirm that streamflow noticeably increases to a perennial state moving downstream from station TMG 601 to TMG 615. Flow measured at TMG 615 accounts for 50% of the total flow measured at the furthest downstream station TMG 680. Headwater tributary T3 enters the system between stations TMG 610 and TMG 615 and may contribute to the increased groundwater inputs observed in this reach. High-relief coarse-grained features and near-channel wetlands may also supply subsurface flow. In-channel springs at the sample site were observed during summer field visits.

Dry season wetland inputs

July and August isotope data show that evaporative loss signal in the stream water is introduced between stations TMG 615 and TMG 625. The strong groundwater signal observed at TMG 615 diminishes between these stations. The evaporative loss signals observed at TMG 625 indicate mixing of wetland and pond surface waters into the streamflow. Spacial variability in evaporative loss is the most apparent in the August 2015 sampling. Stations TMG 625 and TMG 640 show the greatest loss. Evaporative surface waters that drain to these reaches include the retriever pond and wetlands that are located along the mainstem and withiin tributary drainage T5. The wetlands however are classified as saturated wetlands which hold water below the surface throughout most of the growing season; and strong losses to evaporation would not be expected. Saturated wetlands are found throughout the watershed and do not result in high evaporative losses in the rest of the system. Generally, in this part of the watershed, overhead channel cover is decreased and percent openlands is increased which provides an ideal environment for higher evaporation rates relative to the overall system. The retriever pond is surrounded by unforested open land and flow through the impounded area tends to be stagnant during low flow periods.

Dry season hyporheic exchange

The decrease in evaporative loss with longitudinal distance towards Lake Superior from stations TMG 625 and stations TMG 640 during highly evaporative conditions are likely due to hyporheic exchange of surface water and near-channel shallow groundwater. In addition, a decrease in wetland density in the lower reaches likely plays a role. Although deep groundwater storage in the lower watershed is unlikely due to the shallow depth to bedrock, shallow storage and interflow from upland infiltration is present. Groundwater seeps can be seen along stream banks. Water storage in the shallow aquifer likely fluctuates throughout the season and can be sourced from infiltration of precipitation and from losing stream or above-bankfull conditions where stream water recharges subsurface storage. Non-rain event sampling shows that station TMG 680, the furtherst downstream station, has a narrow isotope signal range compared to the remaining middle and lower watershed stations. The narrower range and decreased evaporative losses at this station suggest that the exchange with groundwater is stronger in this reach of the lower watershed. However, compared to headwater stations, the groundwater contribution is quite less. Flows gradually increase with downstream distance and increasing drainage area in the middle and lower watersheds. The influence of wetlands and ponds is observed in isotope data, particularly in the mid-watershed.

Storm event source waters

The watershed was sampled ten days after a 2-inch summer rain event and flows were in the mid-range flow regime. Isotope data show that more groundwater is mixed with storm runoff waters in the headwaters compared to a higher percent event water in the middle and lower watershed drainages. Lower watershed stations show higher event water contributions than mid-watershed stations TMG 625 and 640. Storm water enrichment increases longitudinally downstream from station TMG 645 to TMG 680 and may be related to drainage area of upland storage. Tributary TMT 695 also has a high runoff contribution and likely is related to the high density of wetlands in the upstream drainage. We believe these data infer that wetlands play an important role in storage and release of summer rain water in this system.

Future management for protecting hydrologic function

This data highlights headwater reaches where seasonal stream composition is more stable due to groundwater inputs. Flow and isotope data show that headwater tributaries T1 and T3 contribute the most flow to the system and that groundwater is a dominant source there even during the dry months of summer. Additionally, in-channel springs were identified near station TMG 615. These critical hydrologic inputs should be considered in future watershed management and protection efforts in the watershed.

Evaporative losses are observed in the middle and lower watersheds during dry periods, indicating that wetlands are more dominant contributors of summer flow in the middle and lower reaches. Wetlands play a key role in the release of summer rain event waters, particularly in mid-watershed tributary TMT 695. Without adequate flows during dry periods, severely degraded habitat for aquatic life can result from lack of flow connectivity. Fish can become stranded in fragmented pools. Photographs show that interstitial flow and stranded pools occurred in the summer of 2013. Our data show that wetland storage and slow release of high flow waters occurs in this watershed, most prominently in tributary T4. Protection of these critical wetland areas is recommended.

Hyporheic exchange helps supplement summer flows in the lower watershed and appears to increase longitudinally downstream. Post-rain event, a slight increase in rain waters with longitudinal downstream distance indicates that rain waters are slowly released from upland storage of infiltrated precipitation. Protection of riparian areas should be considered in future protection efforts in the watershed.

Maximum evaporative losses in the system are observed downstream of the retriever pond impoundment in August 2015. The hydrologic effects of stream impoundments in watershed drainages should be further studied and seriously considered prior to permitting and construction. Our data suggests that even small structures can impact the water budget in a small drainage.

6.3 Talmadge River Watershed stressor identification results

Stressor identification results for the Talmadge River fish impairment are presented in Table 29. Refer to the section number listed in the right column of the table to review the evidence used to diagnose or eliminate the various stressors that were evaluated for this impairment.

Table 29. Summary of stressor identification results for fish IBI impairment on the Talmadge River

Candidate cause	Result	Section
Elevated water temperature	X	6.2.1
Low dissolved oxygen	•	6.2.2
Poor habitat	•	6.2.3
Loss of connectivity	○	6.2.4
Elevated total suspended solids/Turbidity	•	6.2.5
Altered hydrology	•	6.2.6

Key: **• = confirmed stressor ○ = potential stressor X = eliminated candidate cause**

7.0 Recommendations for restoring impaired watersheds

7.1 Talmadge River Watershed Projects

7.1.1 Re-meander channelized headwaters reach

Approximately 1,500 feet of the Talmadge River is channelized in the vicinity of Lester River Road. Based on historic aerial photos, the ditching of this reach occurred prior to 1939. The current stream channel has recovered some natural features (slight bends, short riffles, some pools) but still functions predominantly like a ditch and offers marginal habitat conditions. Given the colder water temperatures observed in this portion of the Talmadge River, this reach is a candidate for a restoration project to restore channel stability, increase floodplain connectivity, and improve physical habitat conditions. No biological monitoring has been completed within this reach. A more complete survey of this area is recommended prior to developing any plans for restoration.

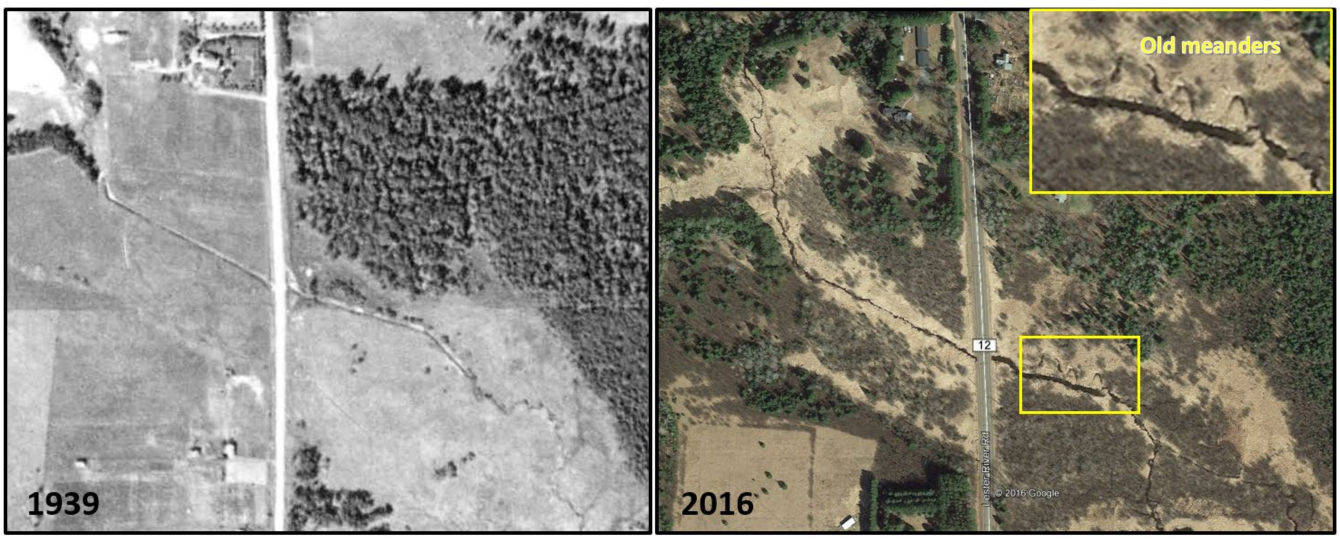


Figure 121. Comparison of potential project site before channelization in 1939 (left) and current channelized condition (right)

7.1.2 Fix undersized/perched culverts

Several culverts in the Talmadge River watershed were found to be undersized and/or perched. These poorly designed or deteriorated crossings are a detriment to aquatic organism passage and are causing localized channel instability and habitat loss. Three priority culverts to replace are shown in Figure 122. Of the three shown, the crossing at Highway 61 is likely the highest priority for replacement given that it is a known impediment to the Steelhead Rainbow Trout that migrate up the Talmadge River in the Spring and Fall. Culvert replacement plans should adhere to the MESBOAC design procedure and other guidance published in this 2011 report:

(DNR 2011; http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html)

MESBOAC stands for:

Match culvert width to bankfull stream width

Extend culvert length through the side slope toe of the road

Set culvert slope the same as the stream slope

Bury the culvert

Offset multiple culverts

Align the culvert with the stream channel

Consider headcuts and cutoffs

Figure 122. Examples of fish passage barriers in the Talmadge River watershed in need of restoration

7.1.3 Restore/protect wetlands

Flow alteration is a probable stressor to aquatic life in the Talmadge River watershed. Limited baseflow and a "flashy" hydrological regime (rapid increases/decreases in streamflow) are creating stressful conditions for aquatic life during the summer and late fall seasons. Efforts to restore and protect wetlands in this watershed are one method of attenuating runoff and potentially increasing baseflow.

7.1.4 Duluth Retriever Club restoration

The impoundment of the Talmadge River at the Duluth Retriever Club property is degrading stream conditions upstream and downstream of the pond. The detrimental effects caused by the pond include elevated stream temperatures, lower DO concentrations, streamflow reductions, loss of physical habitat, and loss of stream connectivity. One potential remedy to these impacts is a restoration project that bypasses flow around the ponds through a "natural" channel during low to moderate flow conditions. The natural channel design would mimic undisturbed or "reference" conditions observed elsewhere in this portion of the watershed. Reducing the overall size of the ponds to reduce thermal loading and evaporation losses is another consideration that should be discussed.

7.1.5 Bank stabilization and stream channel restoration

Areas of significant bank and bluff erosion exist on the Talmadge River between McDonnell Road and the Highway 61 expressway (see examples in Figure 124). Sediment inputs from this reach are the primary driver of the current TSS/turbidity impairment and cause stress to aquatic life through various pathways. The streambank erosion assessments and predictions detailed in Section 6.2.5 should be consulted to prioritize potential bank stabilization or reach-scale restoration projects that would reduce sediment loading from these sources. A reach-scale restoration project has already been completed near Highway 61 to reduce bank erosion and improve physical habitat (Figure 125).

Figure 124. Significant bank erosion and bluff failure in the lower Talmadge River. A large portion of the TSS load was predicted to originate from this reach during BANCS model assessments, and sampling of TSS verified those predictions.

Figure 125. Before and after pictures of a stream channel/floodplain restoration project completed on the lower Talmadge River. The photo on right was taken shortly after the completion of the project. Native grasses, plants, and trees were planted in the floodplain.

7.1.6 Road and ditch management

The Talmadge River watershed contains a relatively high percentage of land in residential development due to its close proximity to the city of Duluth. As a result, many road networks are present, and some deliver significant sediment loads to the river during snowmelt and heavy precipitation events (see Section 6.2.5). Several "cleaning" efforts observed by the authors appeared to leave roadside ditches prone to erosion. Road ditches along Flynn Road and near the McDonnel Road dead end are two that could be further assessed and possible restored.

http://www.lakesuperiorstreams.org/stormwater/toolkit/contractor/resources/DitchGuide_SeaGrant.pdf

7.1.7 Talmadge River Headwaters: Additional monitoring and protection strategies

Cold water temperatures (suitable for Brook Trout) and good physical habitat exist in the Talmadge River upstream of Lester River road. Unfortunately, no biological monitoring data (fish/macroinvertebrates) were collected in this reach during the watershed assessment or stressor identification efforts. Low streamflow conditions, DO, and barriers to fish movement (culverts) are three factors that may limit the ability of sensitive aquatic life to inhabit this reach. Additional monitoring is recommended for this reach in order to inventory the current biological condition, establish management goals, and steer protection efforts in this relatively undisturbed portion of the Talmadge River watershed.

7.2 Beaver River Watershed Projects

7.2.1 Stream channel restoration

Streambank and bluff (valley wall) erosion introduce a significant amount of excess sediment to the Beaver River annually (see Section 5.3.7). Excess sediment degrades physical habitat, impairs water quality, and reduces biological integrity. Many miles of unstable and erosion prone streambanks are present in the watershed, and prioritizing areas for restoration requires merging several data sets (geomorphology, biology, water quality, habitat) to determine logical places to direct funding and other resources. Location of the sediment sources within the watershed also needs to be factored in, as projects with many miles of stable (low sediment supply) reaches upstream are a lower risk for failure and require little or no maintenance over time.

Additional discussion is warranted on this topic given the high cost and risk associated with stream restoration projects of this magnitude. Several potential areas for discussion are presented in below in figure 126. Area #1 is located at the confluence of Big Thirtynine Creek and the Beaver River. This location represents the upstream-most point on the Beaver River where symptoms of channel instability occur. Lateral channel migration, bank erosion, and mid-channel/diagonal bar within this reach are indicators of aggradation (excess sediment deposition) and channel widening. Water temperatures tend to remain fairly cold within this reach and may be suitable for supporting Brook Trout, although no data are available to confirm their presence. An additional benefit of restoring this reach is the close proximity of major tributary streams (Big Thirtynine Creek, Little Thirtynine Creek, Kit Creek) that are in good condition. Restoration efforts near these streams creates a centrally located corridor of quality stream conditions.

Area #2 (Figure 126) is 3-4 miles downstream of Area #1 within a reach that has much steeper slope and a slightly more confined valley. Indicators of stream channel instability at this location include streambank/valley wall erosion, channel widening and braiding, and extensive and rapid bar development. Signs of localized degradation (channel incision or “down-cutting”) and aggradation (filling) are visible within this reach. This portion of the river is a major source of sediment which ends up accumulating on the streambed farther downstream around Area #3 (see Figure 126).

Potential project Area #3 is located at upstream of CSAH 3 at biological monitoring station 94LS005. This reach is approximately 1.8 river miles downstream of Area #2. Stream gradient decreases substantially within this reach, and as a result, a significant portion of the sediment generated from streambank and valley wall erosion upstream settles out and deposits on the streambed. Accelerated bar development, bank erosion, mid-channel and diagonal bars, and a shift towards finer substrate materials are common indicators of channel instability found within this reach. Physical habitat conditions are limited due to the abundance of fine substrates (mostly sand) and it appears that water depths are reduced during low flows due to streambed aggradation (#3 – Figure 126).

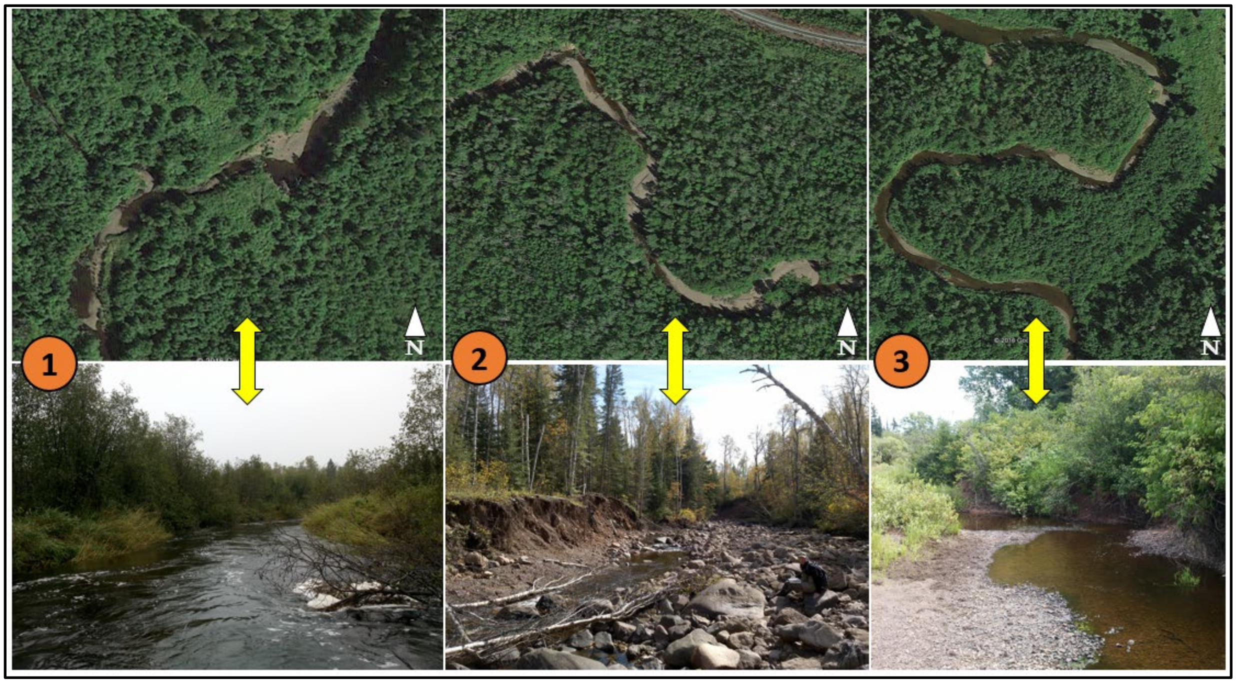


Figure 126. Areas of channel instability and habitat loss within the impaired reach of the Beaver River. These areas could be further evaluated as potential restoration sites.

7.2.2 Reduce impacts from trails (ATV, Glen Avon Falls)

Roads, trails, and parking lots can introduce sediment from complete failure, loss of road fill, surface erosion, and ditch-line erosion. Several roads and trails are contributing sediment to streams within the Beaver River watershed. Although these sources are rather minor compared to sediment loading from streambank erosion, the maintenance and/or repair of failing roads and trails target a preventable problem and can be cost-effective. One potential project area is the access road to Glen Avon falls off CSAH 3. The access road is an unmaintained off-road trail that is composed of clay soils and courses down a steep grade to the Beaver River at the top of the falls (Figure 127). During rain events and snowmelt periods this access road develops gullies that carry sediment downslope and into the river. Implementation funding could be used to stabilize and revegetate this area and provide easier access to view the falls.

Sediment delivery to the Beaver River is also occurring via ATV trails in the watershed. A sediment plume was observed entering the river from gullies originating on the trail (Figure 128). These sediment sources are not significant in comparison to bank erosion and natural gullies and ravines that exist in the watershed. However, they are preventable with additional maintenance and planning.

Figure 127: Surface erosion and sediment delivery at parking area at Glen Avon Falls. A parking area and hiking trail could be developed for better access and reducing sediment delivery and impacts to the riparian area.

Figure 128. Runoff from ATV trail entering Beaver River at station S007-971

8.0 Recommendations for restoring/protecting non-impaired watersheds

8.1 Protection of high quality coldwater watersheds

The Lake Superior South Major Watershed contains many miles of high quality coldwater streams that support naturally reproducing populations of native Brook Trout and other sensitive aquatic life. In addition, a number of streams in this watershed also support seasonal runs of Steelhead Rainbow Trout, Brown Trout, and salmon. All coldwater streams are deserving of protection based on their sensitivity to disturbance, but several priority areas are highlighted below due to their exceptional quality and ecological significance to the region.

8.1.1 McCarthy Creek

McCarthy Creek is a designated trout stream with a watershed area of 5.32 square miles that encompasses portions of St. Louis and Lake Counties. MPCA sampled one station on this stream (11LS017) in 2011. Brook Trout were sampled in extremely high numbers (n=112, 0.747 Brook Trout/meter) compared to other North Shore streams. Water temperature remained in the "growth range" for Brook Trout 98-99% of the time during the summer season (June-August), making it one of the coldest streams in the entire Lake Superior Basin based on available data. In addition to the robust population of wild Brook Trout, the sample also contained young-of-year Rainbow Trout, which indicates the use of this stream by migratory Steelhead (entering from the Knife River) as a spawning and rearing area. Brook Trout were also observed spawning at the confluence of McCarthy Creek and the Knife River, likely due in part to the coldwater inputs from McCarthy Creek.

The McCarthy Creek watershed is predominantly forested (56%) with areas of pasture/hay agriculture and cleared areas due to timber harvesting. Given the outstanding value of this resource as native Brook Trout habitat, and its importance to the Steelhead population of the Knife River, protection measures should be implemented in this watershed to prevent degradation of this critical habitat area.

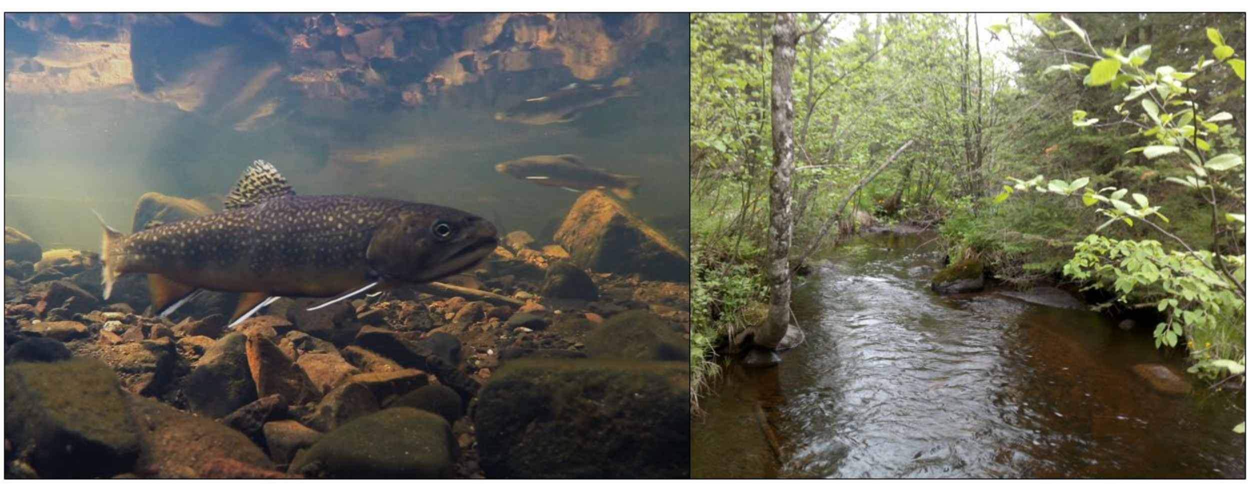


Figure 129: Wild Brook Trout spawning in the Knife River near its confluence with McCarthy Creek (left). Station 11LS017 on McCarthy Creek (right) had one of the highest densities of Brook Trout observed in North Shore streams.

8.1.2 East Branch Amity Creek

The majority of the Amity Creek watershed lies within the city limits of Duluth, Minnesota. Land-uses uses are a mix of residential, rural-residential, light industrial (gravel mining), and undeveloped forested land. Some portions of this watershed provide moderate to heavy recreational use due to its scenic qualities, trout fishing opportunities, and numerous parks with hiking and mountain biking trails. The Amity Creek drainage consists of the East Branch, West Branch, and Amity Creek, although some maps combine the West Branch as part of Amity Creek. Of these three major drainages, the East Branch offers the coldest water temperatures and provides much of the baseflow to the system due to significant groundwater upwelling and wetland storage (Jasperson, 2015).

The East Branch of Amity Creek Watershed is a productive coldwater stream with a robust population of naturally reproducing native Brook Trout. Water temperatures and Brook Trout numbers in this stream are comparable or superior to many of the highest quality streams in less developed areas of the North Shore and surrounding area (Table 30). A Brook Trout spawning assessment was completed in the fall of 2014 along approximately three miles of the East Branch, where 186 areas of spawning activity (clusters of "redds" e.g nests) were observed, a density of 62 per mile, compared to nine per mile on the main stem of Amity Creek (Figure 130). Several of the spawning areas observed on the main stem of Amity Creek were located at its confluence with the East Branch, likely due to the coldwater inputs from this tributary. The results of the spawning assessment clearly illustrate the importance of the East Branch as a spawning and rearing area for wild Brook Trout.

Protection option #1: Duluth Natural Areas Program designation

In 2002, the city of Duluth established the Duluth Natural Areas Program (DNAP) to protect and preserve the natural heritage of the city and surrounding area. Several areas of the city have since received permanent protection under DNAP based on the presence of unique ecological features. The DNAP program covers both public and private land parcels with the goal of protecting the "best remaining examples of viable natural areas representative of the Duluth area" including "special species areas" and "geologic landform areas."

Protection planning for Duluth's twelve trout streams should be a priority under the efforts highlighted above. Many of the trout streams that course through city lands are negatively impacted by urban runoff, fragmented by road crossings, and offer marginal physical habitat and temperate regimes for coldwater fish. East Branch Amity Creek is an exception to this in many regards:

- Large corridors of undeveloped public land
- Priority protection area is already in public ownership, and located upstream of densely developed urbanized areas
- Significant groundwater sources and wetlands maintain cold temperatures and suitable stream flows (Jasperson, 2015)

The area proposed for protection under DNAP is located within the undeveloped, sixty-acre Janette Pollay Park, which was established in 1914 (Figure 131). The city park currently provides some level of protection from development, but permanent protection measures are recommended as population growth in this area of the Amity Creek watershed is projected to occur. Other current and potential threats to ecological integrity of this area include gravel mining and riparian forest impacts due to the presence of emerald ash borer in the region.

Based on available data, East Branch Amity Creek represents one of the best remaining habitats for wild Brook Trout within the city limits of Duluth. This stream segment warrants protection under DNAP based on these attributes and the abundance of public land and recreational interests in the watershed. A partnership of State and local agencies could provide the monitoring and management support required under the DNAP guidelines.

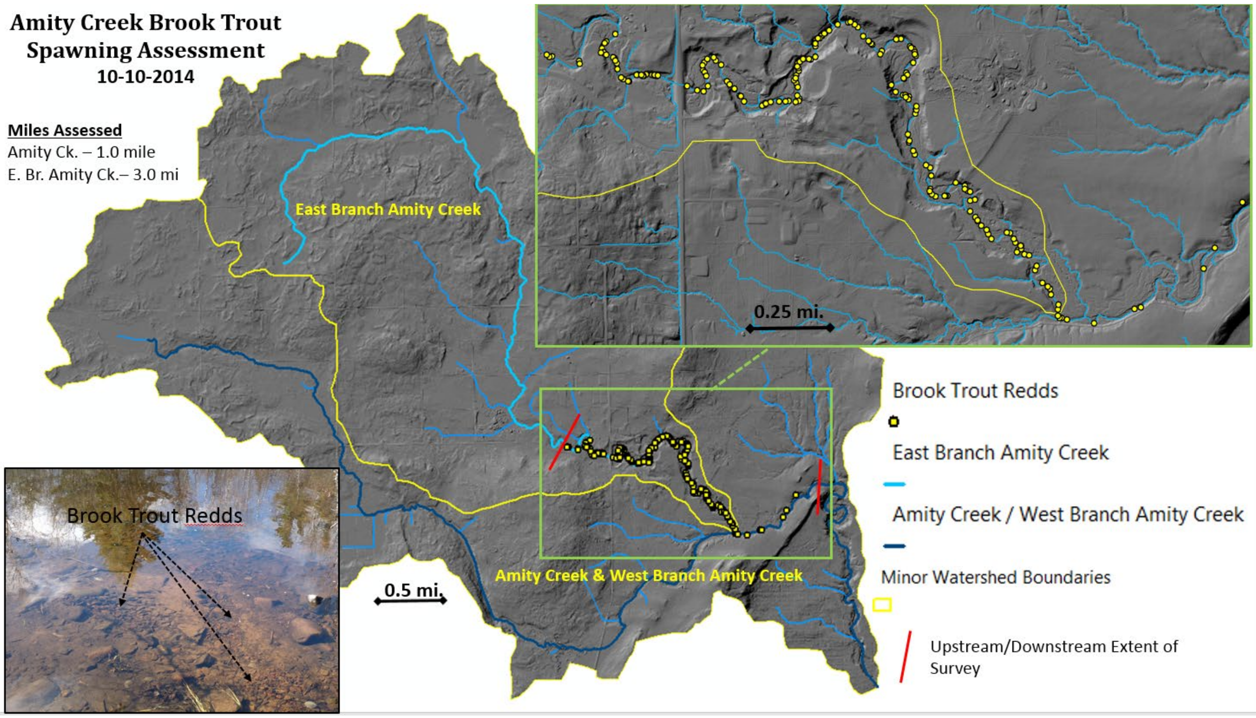


Figure 130. Results of Amity Creek/East Amity Creek Brook Trout spawning assessment completed in fall of 2014

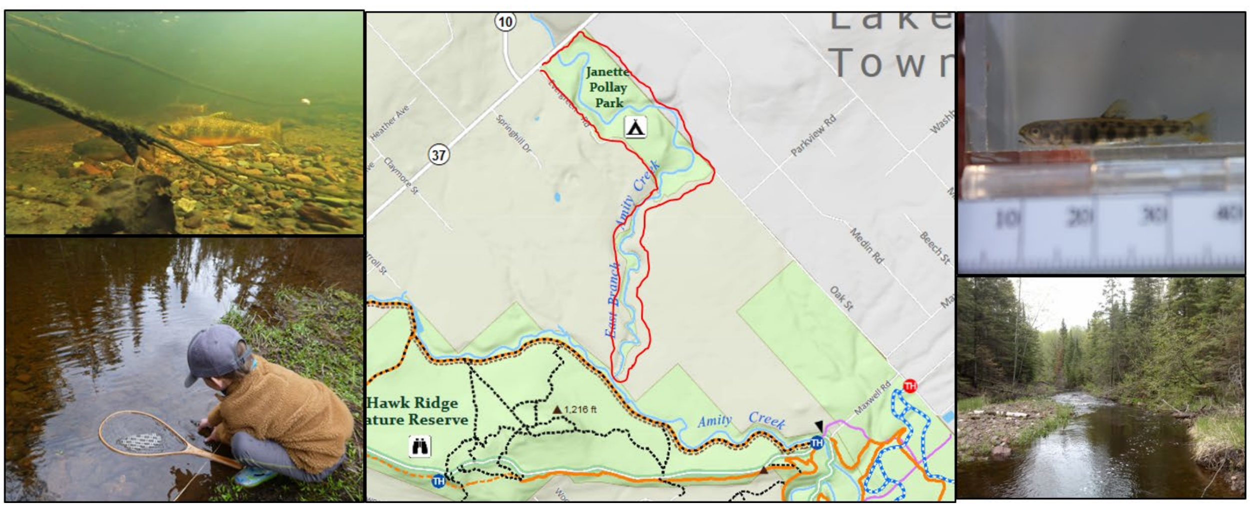


Figure 131. Priority protection area proposed for DNAP (area outlined in red in center map). Other photos highlight ecological and recreational significance of this area; Brook Trout spawning (top left), recreational catch and release fishing (bottom left); young-of-year Brook Trout recently hatched from stream (top right); stream reach within proposed protection area (lower right)

Table 30. Top fifteen biological monitoring stations in terms of Brook Trout density (# BKT/meter sampled). Data includes all reportable sampling visits to coldwater streams in St. Louis River, Lake Superior South, and Lake Superior North 8 HUC watersheds between 2009-2014 (n=95). Stations on several streams sampled in these watersheds were eliminated from the analysis due to potential biases from stocked trout.

Rank (n=95)	Stream name	Station	Visit date	Distance sampled (m)	# Brook Trout sampled	BKT/meter	Batch weight (g)
1	Kadunce River	13LS050	8/27/2013	221	214	0.968	4006
2	McCarthy Creek	11LS007	8/9/2011	150	112	0.747	3222
3	Cascade River	13LS013	9/4/2013	350	175	0.500	6279
4	Devil Track River	13LS046	9/4/2013	280	116	0.414	5247
5	**Amity Creek, East Branch**	**97LS038**	**6/20/2011**	**158**	**55**	**0.348**	**3124**
6	Little Devil Track River	97LS073	9/17/2013	150	50	0.333	1765
7	Big Sucker Creek	97LS089	8/31/2011	262	86	0.328	3038
8	Junco Creek	13LS006	8/22/2013	175	47	0.269	2059
9	Kimball Creek	13LS011	8/13/2013	134	33	0.246	471
10	Heartbreak Creek	97LS075	8/15/2013	220	52	0.236	1551
11	Elbow Creek	05LS005	8/7/2013	175	41	0.234	1824
12	Captain Jacobson Creek	11LS017	7/28/2011	150	31	0.207	902
13	Brophy Creek	10EM141	6/22/2010	157	30	0.191	763
14	Manitou River	98LS030	9/19/2013	420	79	0.188	2797
15	Cascade River	95LS013	9/5/2013	420	76	0.181	3200
80	Amity Creek	11LS036	6/20/2011	245	2	0.008	186

Protection option #2: Designate funds for stream restoration

The "Amity Creek Stressor Identification Report" produced by Jennings and Geenen (2016) documented sources of sediment loading and potential stream restoration projects within the Amity Creek watershed. Severeal reaches of East Branch Amity Creek were identified as major sediment sources, and areas of degraded physical habitat were observed due to channel and bluff instability. East Branch Amity Creek may be a priority area for stream restoration funding due based on its cold thermal regime and abundance of gravel suitable for spawning. Several conceptual restoration designs for East Branch Amity Creek and main stem Amity Creek can be found in the report cited above.

8.1.3 Captain Jacobson Creek

An in-depth study of the Captain Jacobson Creek biological monitoring site 11LS017 was included as part of the larger coldwater trout stream study performed by the authors between 2013 and 2015. The site had one of the healthiest fish communities of all the sites in the study with a fish IBI score of 90. To add to the biological data collected by the MPCA in 2011, data was collected for the other four of the five components of stream and watershed health, including temperature (water quality), longitudinal profile and cross sections (geomorphology), bankfull discharge estimates and stable isotope analysis (hydrology), and a culvert assessment (connectivity).

The results of the study suggest that the healthy biological community in Captain Jacobson Creek is mostly the result of relatively stable hydrology and excellent water quality. Preliminary isotope data analysis indicate lower groundwater inputs than other study sites on the North Shore, but temperatures remained within the "growth range" for Brook Trout 92% of the time during the summer of 2015.

In addition, the bankfull discharge estimates derived from the geomorphology survey indicate that the watershed is less flashy than other watersheds on the North Shore. The BKF Discharge/Drainage Area ratio for Captain Jacobson Creek at this site is 13 cfs/mile^2. This ratio is much lower compared to the Knife River watershed as a whole (21 cfs/mile^2), indicating that Captain Jacobson Creek has greater potential to infiltrate rain and snowmelt and slowly release it as groundwater.

This study also shows that the other two components that influence biology (connectivity and geomorphology) have been degraded by human activities and threaten the biology in the system. The evidence points to the crossing at St. Louis County CSAH 41 being the main culprit at this site (Figure 132). A DNR crossing assessment was completed for this crossing. The main issue is that the culvert is extremely undersized. The stream has a bankfull width of 20 feet, taken from a stable riffle away from the influence of the culvert. The culvert is only 6 feet wide, giving it a culvert/bankfull width ratio of only 0.3 (6/20). This puts this crossing in the bottom 5% of crossings assessed in the area by the South St. Louis SWCD. The culvert is so narrow that it is causing reach-wide geomorphic impacts on the stream and its ability to transport water and sediment. During flood events undersized openings like this tend to pond water on the upstream side, increasing head pressure and drastically increasing water velocities on the downstream end. This increased velocity and erosive power (called the shotgun effect) often removes all sediment from inside the culvert and scours the channel bed immediately downstream of the culvert. This creates a plunge pool.

Over time the stream bed can lower enough that the culvert becomes perched. At the same time that the stream is made overly-capable of transporting sediment on the downstream side, the stream is actually losing its capability to transport sediment on the upstream side of the culvert. The culvert bottleneck ponds water during flood events, reducing velocities and stream power. Aggradation is often the result – especially if the stream is moving moderate amounts of bedload. As part of a vicious cycle, aggradation causes stream channels to become wider and shallower, further reducing their ability to move sediment and leading to more aggradation. Aquatic habitat is often poor in this state of disequilibrium, with pools filling in and spawning substrate constantly being smothered with fine sediment.

All of the impacts of a narrow culvert described above were observed in Captain Jacobson Creek up and downstream of CSAH 41. Foremost among these impacts were: 1) a large plunge pool and an incised, eroding channel downstream of the culvert, 2) an outlet perch and lack of in-culvert substrate creating a complete fish barrier, and 3) a braided channel due to aggradation upstream of the crossing. There were no direct measurements of the degree of channel incision on the downstream side, but visual observations of eroding banks on both sides of the channel suggest that the channel is incised. The perch height was estimated at 0.5' at low flows. The perch height, complete lack of substrate and 0.1' water depth within the culvert points to the culvert being a complete upstream migration barrier to all fish species at most flows. A cross-section taken just upstream of the culvert shows the degree of channel aggradation taking place there (Figure 134). Extensive gravel deposits are causing channel braiding and the channel has a very high width/depth ratio of 166.

It is evident that the crossing at CSAH 41 is causing degradation to the geomorphology and connectivity of the system and is a prime candidate for replacement. Replacing the culvert with a bridge or culvert that matches bankfull width would have a two-pronged effect. First, it would restore the sediment transport balance to the stream channel. Over time the excess sediment built up above the crossing would pass through and the stream channel would find a new stable equilibrium. More importantly, replacing the culvert would restore passage to almost four miles of headwaters habitat for fish and other aquatic organisms.

The four components of watershed health that drive biological condition need to be fully functioning in order for the biological community in Captain Jacobson Creek to maintain its health into the future. The current sole reliance on stable flows and cold water decreases the resiliency of the biota in Captain Jacobson Creek, especially in the face of climate change and its expected impact on flows and temperatures. Restoration of the connectivity and geomorphology of this system by replacing the CSAH 41 crossing is an excellent opportunity to ensure that this remains a high quality resource for many years to come.

Figure 132. Captain Jacobson Creek crossing at CSAH 41

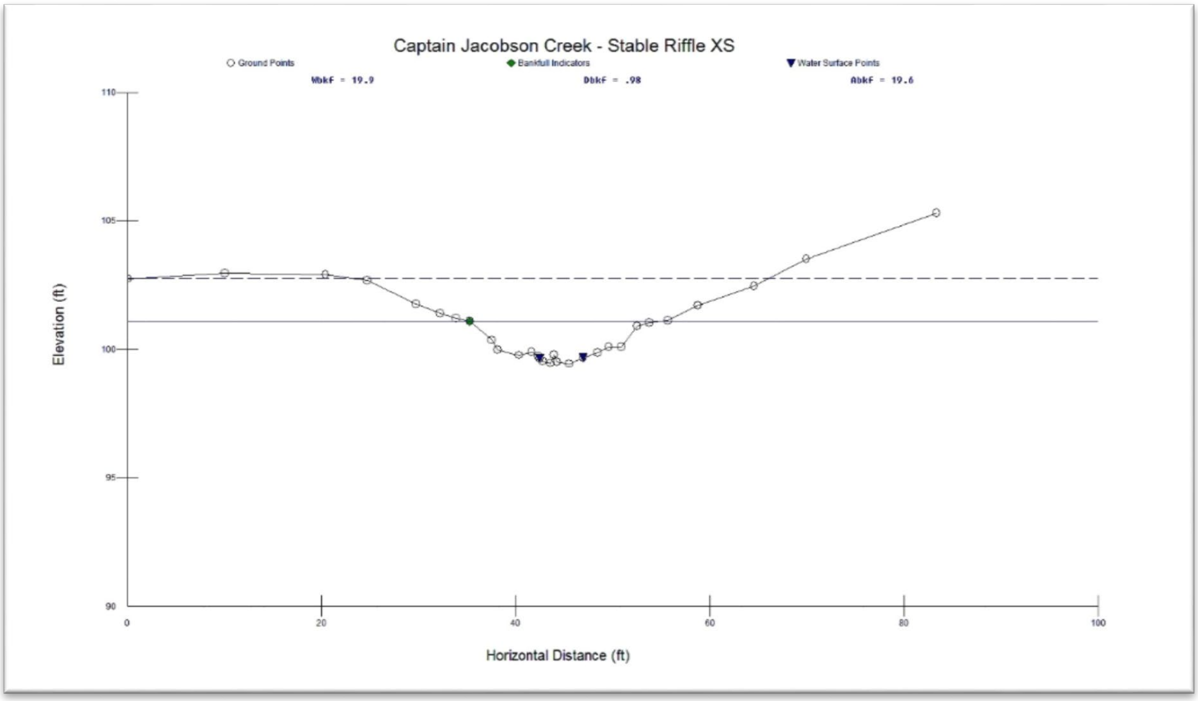


Figure 133. Cross-section of a stable riffle on Captain Jacobson Creek

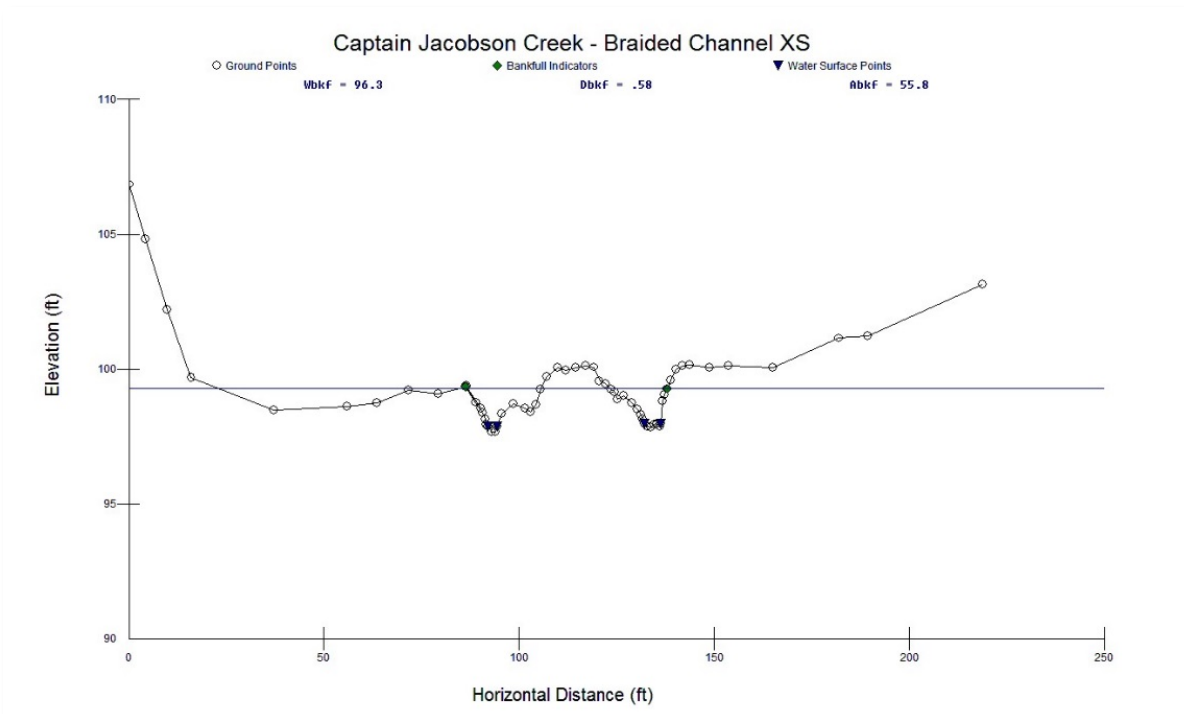


Figure 134. Cross-section taken just upstream of CSAH 41 showing braided channel

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Appendix A

Example of a Brook Trout Suitability Assessment (BTSA) form completed for the Beaver River. Metrics are listed on the left, and values, scores, multipliers listed middle and right.

Brook Trout Suitability Matrix

#	Category	Variable	0 points		1 points		2 points		3 points		Multiplier	Score
1	Floodplain Connectivity	Bank Height Ratio	3.0		2.0		1.5		1.0	3	2.00	6
2	Water Temperature	Average number of days above 21 degrees water temperature on an annual basis	28		14		7		1		1.33	0
3	Gravel Substrate	Substrate within the Spawning range for BKT (3-80 mm; Duff 1980)	5%		10%		25%	2	50%		1.00	2
4	Fine Substrates and Embeddedness	% of riffle and glide area comprised of fine particles < 3mm	75%		50%		25%		5%	3	1.00	3
5	Algae on the Gravel Substrates	% Large Gravels and Cobbles covered with Algae	50%		25%		10%	2	5%		1.00	2
6	Aquatic Vegetation	% of Riffle with Aquatic Vegetation	25%		10%		5%		1%	3	1.00	3
7	Bank Erosion	lbs of Bank Erosion per linear foot	0.90		0.09		0.04		0.009	3	2.00	6
8	Bank Habitat	Percent of Pools with Stable Undercut Banks, Boulders, or LWD	5%		25%		50%	2	75%		1.00	2
9	Longitudinal Connectivity	% of Channel with fish migration barriers at Low-Flow to Bankfull Flow	10%		1%		0.1%		0.01%	3	1.00	3
10	Deep Pools	Max Depth Water in Pools at Low-Flow (ft)	0.5		1.0		2.0	2	3.0		3.00	6
11	Morphological Energy Dissipation	Pool - Pool Spacing Ratio Relative to Reference Reach	3.0		2.0		1.5	2	1.0		1.00	2
12	Riffle Complexity	Number of Habitat units within Riffle	1		2		3		4	3	1.00	3
13	Riffle Length	Riffle Length Ratio Relative to Reference Reach	3.0	0	2.0		1.5		1.0		1.00	0
14	Beaver Dams	Average # of Beaver Dams per 100 ft	0.5%		0.1%		0.05%		0.01%	3	1.00	3
15	Offline Beaver Dams	% of Beaver Dams in the Reach that are off-line	10%	0	25%		75%		100%		1.00	0
16	Side Channel Habitat	Average # of Side Channel Habitats within a Reference Meander Wavelength	0.01		0.1		0.25	2	1.0		1.00	2
17	Channel Width to Depth Ratio	WDR Ratio Relative to Reference Reach	3.0		2.0	1	1.5		1.0		1.00	1
18	Low Flow Width to Depth Ratio	WDR Ratio Relative to Reference Reach Inner Berm Channel	3.0		2.0		1.5	2	1.0		1.00	2
19	Hyporheic Exchange	% Riffle that has Upwelling, Loose Gravels or noticeable groundwater exchange	1%		10%	1	25%		50%		1.00	1
20	Riparian Vegetation	% Riparian Vegetative Cover	10%		25%		50%		75%	3	1.00	3
21	Vegetative Shade	% of Channel with Vegetative Shade and cover	10%		25%		50%	2	75%		1.00	2
22	Flow rates at Low-Flow	Stream Types, Ephemeral, Intermittent or Perennial	Ephemeral		Intermittent		Impaired		Perennial	3	2.00	6
23	Large Woody Cover	Average # LWD habitat features within a reference meander wavelength	<1, or excessive (log jams / flow deflectors / sediment traps)		1		2	2	more than 3		2.00	4
24	Fine Woody Debris	Relative abundance of fine woody debris (brush, branches, tree tops, fine roots, in-stream vegetative cover)	absent or very scarce		spotty		moderate	2	very common		1.50	3
25	Riffle-Pool Ratio	Ratio of riffle to pool habitat available	defined riffles or pools		2:1 ratio	1	1.5 to 1 ratio		riffle/pool		1.00	1
26	EPT Taxa	Optional: % Dominant in Common EPT Species with Reference	20%		40%		60%		100%		1.00	0
27	Presence of Brook Trout	Optional: only score if BKT fish sampling data is availablefor the reach	None		Low Population		Average Population		High Population		1.50	0
28	Presence of Predator Species	Optional: only score if fish sampling data is available for the reach	High Population		Population		Population		None		1.50	0
			Poor: 0 - 26		Fair: 27 - 54		Good: 55 - 82		Excellent: >83		Total	66
	Stream:	Beaver River										
	Reach:	94LS007 Downstream B	Stream Type:		B3							

Below: BTSA results for all North Shore streams used in this report.

Location/Site:	Stream:	Stream Type:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	New Rating	Final Total		
11LS007	McCarthy Creek	C4	6	24	6	5	3	3	6	2	3	8	3	2	3	3	2	3	3	3	2	3	15	7.5	4.5	3	4.5	Excellent	127.5		
13LS011	Kimball Creek	B3	6	24	4	7.5	3	3	6	2	2	8	3	3	3	3	3	3	3	3	3	3	15	2.5	1.5	1	4.5	Excellent	120		
13LS013	Cascade River	C3	6	8	6	7.5	2	3	6	2	3	12	3	3	3	3	3	3	3	3	3	1	15	5.0	4.5	1	4.5	Excellent	113.5		
13LS043	Wanless Creek	E4	6	24	6	5	3	3	6	1	3	4	1	3	1	3	0	3	3	1	3	3	15	5.0	4.5	2	4.5	Excellent	113		
97LS075	Heartbreak Creek	B3	6	24	4	7.5	3	3	4	1	3	4	3	3	2	3	2	3	3	3	3	2	15	2.5	3	1	4.5	Excellent	112.5	Excellent	112-140
98LS028	Two Island River	C4	4	16	6	5	3	3	6	2	3	8	2	1	3	3	3	3	1	3	3	2	15	5.0	4.5	3	4.5	Excellent	112	Good	96 - 111
02LS004	Silver Creek	C4	6	16	4	7.5	3	3	4	2	3	8	3	2	3	3	3	3	3	3	2	1	15	2.5	3	3	4.5	Good	110.5	Fair	75-95
DNR 16.93	Beaver River	B3c	6	16	6	5	3	3	6	2	3	4	3	3	3	2	0	3	3	1	3	3	15	2.5	4.5	1	4.5	Good	105.5	Poor	0-74
97LS038	E. Branch Amity Creek	F4	4	24	6	5	0	2	2	2	3	8	1	1	1	3	1	1	0	3	2	3	15	5.0	4.5	3	4.5	Good	104		
94LS007 (US)	Beaver River	C4	6	8	4	5	2	3	6	2	3	12	2	3	0	3	2	3	3	1	3	2	15	5.0	3	1	4.5	Good	101.5		
11LS030	Gooseberry River	E4	6	16	4	0	3	3	6	0	3	8	3	2	3	3	3	3	3	1	3	3	15	0.0	4.5	1	4.5	Good	101		
DNR 16.93	Beaver River	C4	6	16	6	5	3	3	4	1	2	8	1	1	1	0	3	1	3	2	3	1	15	7.5	3	1	4.5	Good	101		
11LS004	Little Gooseberry	E5	6	16	4	0	3	0	6	2	3	4	3	1	3	3	2	3	3	1	3	2	15	5.0	4.5	3	4.5	Good	100		
10EM141	Brophy Creek	E5	6	16	0	0	3	0	4	3	3	8	3	1	3	2	3	3	3	3	3	3	15	5.0	4.5	2	3	Good	99.5		
98LS028	Two Island River	B3c	6	16	4	7.5	3	3	6	1	3	4	3	3	3	3	0	3	3	2	2	2	15	0.0	1.5	1	4.5	Good	99.5		
11LS038	Talmadge River	B3c	6	16	6	5	3	3	6	1	0	8	3	1	3	3	0	3	3	1	3	2	10	2.5	3	2	4.5	Good	98		
94LS007 (DS)	Beaver River	B3	6	8	4	7.5	2	3	6	2	3	8	2	3	0	3	2	1	2	1	3	2	15	5.0	3	1	4.5	Good	97		
Lester Road	Talmadge River	E4	4	16	6	5	2	3	4	2	3	8	3	0	1	2	0	2	3	2	2	1	15	2.5	3	3	4.5	Good	97		
88LS016	Cabin Creek	C3	6	8	4	5	3	3	6	3	3	4	0	1	2	3	2	2	0	1	3	2	15	7.5	4.5	3	4.5	Fair	95.5		
11LS023	Cedar Creek	B3	6	8	2	7.5	3	3	6	1	3	4	3	3	3	3	2	3	3	1	3	2	15	0.0	3	1	3	Fair	91.5		
11LS017	Captain Jacobson Creek	C4	2	24	6	7.5	2	3	4	2	1	0	0	1	0	3	2	0	0	2	3	3	10	2.5	1.5	1	4.5	Fair	85		
01LS005 (Bc reach)	Talmadge River	B3c	2	8	6	7.5	2	3	6	1	1	4	3	1	3	3	1	3	3	1	1	3	10	2.5	1.5	3	4.5	Fair	84		
01LS005 (B reach)	Talmadge River	B3	6	8	6	5	2	3	4	1	1	4	3	1	3	3	1	3	3	1	1	3	10	2.5	1.5	1	4.5	Fair	81.5		
13LS034	Hockamin Creek	B3c	6	8	0	0	1	3	6	2	3	4	2	3	3	3	2	1	3	1	3	2	15	2.5	1.5	1	4.5	Fair	80.5		
11LS002	Encampment River	F1b	6	16	4	7.5	1	2	6	0	0	4	3	0	3	0	0	3	3	0	3	2	10	0.0	0	2	4.5	Fair	80		
94LS005	Beaver River	C4	4	8	6	5	1	3	0	1	3	12	0	1	0	3	1	2	3	0	2	0	15	2.5	1.5	1	4.5	Fair	79.5		
Beaver Shaq	Beaver River	C3	4	8	4	7.5	2	3	0	1	3	8	1	1	2	3	0	2	2	1	2	0	15	2.5	1.5	1	4.5	Fair	79		
13LS052	Woods Creek	F4b	2	24	6	5	3	3	0	0	0	0	1	1	0	3	0	1	2	2	2	2	10	2.5	1.5	2	4.5	Fair	77.5		
97LS010	Beaver River	C3/4b	4	8	6	7.5	2	3	0	1	3	4	2	1	1	3	0	1	2	1	2	0	15	2.5	1.5	2	4.5	Fair	77		
11LS028	West Beaver River	E4	6	16	0	2.5	2	0	4	2	3	8	2	0	2	3	1	1	0	0	3	1	10	0.0	1.5	2	4.5	Poor	74.5		
11LS022/94LS001	Beaver River	C4c-	4	0	6	5	0	3	2	1	3	12	0	2	2	3	3	1	0	0	2	0	15	0.0	3	0	4.5	Poor	71.5		
13LS110 / 01LS003	Talmadge River	C3	2	16	4	5	2	3	0	0	1	4	3	1	2	3	0	3	2	0	1	1	10	0.0	1.5	1	4.5	Poor	70		
98LS026	Crow Creek	E4	2	8	0	0	3	3	2	1	3	8	1	1	1	3	0	3	3	0	2	0	10	0.0	1.5	3	4.5	Poor	63		

Appendix A (continued)

Pfankuch Stability Index Form

Stream		Location:		Valley Type:		Observers:		Date:	

Location	Key	Category	Excellent Description	Rating	Good Description	Rating	Fair Description	Rating	Poor Description	Rating
Upper banks	1	Landform slope	Bank slope gradient <30%.	2	Bank slope gradient 30–40%.	4	Bank slope gradient 40–60%.	6	Bank slope gradient > 60%.	8
Upper banks	2	Mass erosion	No evidence of past or future mass erosion.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly yearlong.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
Upper banks	3	Debris jam potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	8
Upper banks	4	Vegetative bank protection	> 90% plant density. Vigor and variety suggest a deep, dense soil-binding root mass.	3	70–90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50–70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species and less vigor indicating poor, discontinuous and shallow root mass.	12
Lower banks	5	Channel capacity	Bank heights sufficient to contain the bankfull stage. Width/depth ratio departure from reference width/depth ratio = 1.0. Bank-Height Ratio (BHR) = 1.0.	1	Bankfull stage is contained within banks. Width/depth ratio departure from reference width/depth ratio = 1.0–1.2. Bank-Height Ratio (BHR) = 1.0–1.1.	2	Bankfull stage is not contained. Width/depth ratio departure from reference width/depth ratio = 1.2–1.4. Bank-Height Ratio (BHR) = 1.1–1.3.	3	Bankfull stage is not contained; over-bank flows are common with flows less than bankfull. Width/depth ratio departure from reference width/depth ratio > 1.4. Bank-Height Ratio (BHR) > 1.3.	4
Lower banks	6	Bank rock content	> 65% with large angular boulders. 12"+ common.	2	40–65%. Mostly boulders and small cobbles 6–12".	4	20–40%. Most in the 3–6" diameter class.	6	<20% rock fragments of gravel sizes, 1–3" or less.	8
Lower banks	7	Obstructions to flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed.	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
Lower banks	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12–24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
Lower banks	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate deposition of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges. Surfaces smooth and flat.	2	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
Bottom	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, i.e., 35–65% mixture range.	3	Predominantly bright, > 65%, exposed or scoured surfaces.	4
Bottom	12	Consolidation of particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	4	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
Bottom	13	Bottom size distribution	No size change evident. Stable material 80–100%.	4	Distribution shift light. Stable material 50–80%.	8	Moderate change in sizes. Stable materials 20–50%.	12	Marked distribution change. Stable materials 0–20%.	16
Bottom	14	Scouring and deposition	<5% of bottom affected by scour or deposition.	6	5–30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30–50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
Bottom	15	Aquatic vegetation	Abundant growth moss-like, dark green perennial. In swift water too.	1	Common. Algae forms in low velocity and pool areas. Moss here too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perennial types scarce or absent. Yellow-green, short-term bloom may be present.	4
			Excellent Total =		Good Total =		Fair Total =		Poor Total =	

Stream type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstab	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+

Stream type	DA3	DA4	DA5	DA6	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	G1	G2	G3	G4	G5	G6
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107
Fair (Mod. unstab	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+

Grand Total =	
Existing Stream Type	
*Potential Stream Type	
Modified channel stability rating =	

*Rating is adjusted to *potential* stream type, not existing stream type

Appendix A (continued)

Summary of Pfankuch Stability Assessment results used in this Stressor Identification report. See example form on previous page for metric descriptions and scoring.

			Pfankuch Metric (see Worksheet 3-10 in Rosgen, 1996)																
Location/Site:	Stream:	Stream Typ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Rating
11LS022/94LS0	Beaver River	C4c-	8	9	2	9	4	8	2	12	14	3	3	6	12	18	3	113	Poor (Unstable)
94LS005	Beaver River	C4	6	9	4	7	2	7	4	11	12	3	3	6	12	18	3	107	Fair (Mod. unstable)
94LS007 (DS)	Beaver River	B3	4	3	2	3	1	2	2	4	4	1	1	2	4	6	3	42	Good (Stable)
94LS007 (US)	Beaver River	C4	2	3	4	3	1	6	2	4	4	2	1	2	4	6	2	46	Good (Stable)
97LS010	Beaver River	C3/4b	6	9	6	9	4	4	8	12	12	3	4	4	12	18	3	114	Poor (Unstable)
Beaver Shaq	Beaver River	C3	6	8	6	9	3	5	6	12	12	2	3	4	8	12	3	99	Fair (Mod. unstable)
DNR 16.93	Beaver River	B3c	6	3	4	3	1	2	2	4	8	1	2	2	8	6	3	55	Good (Stable)
DNR 16.93	Beaver River	C4	2	3	4	3	2	4	6	6	8	2	3	4	8	12	2	69	Good (Stable)
11LS027	Beaver River	C3b	2	3	2	6	2	4	2	4	4	2	1	2	4	6	2	46	Good (Stable)
91LS026	Beaver River	C4	6	9	4	9	2	7	4	12	12	3	3	6	8	14	3	102	Fair (Mod. unstable)
15LS061/15LS0	Beaver River	B3	2	6	2	6	2	2	2	4	8	1	1	2	8	12	2	60	Good (Stable)
97LS055	Beaver River	C4/5	8	9	4	9	3	6	2	12	12	3	3	6	12	18	3	110	Fair (Mod. unstable)
14LS001	Beaver River	B2	4	3	2	3	1	2	2	4	4	1	1	2	4	6	2	41	Good (Stable)
94LS003	Beaver River	C4	6	6	4	6	2	6	2	8	12	3	3	4	8	18	3	91	Fair (Mod. unstable)
10EM141	Brophy Creek	E5	2	3	4	3	1	8	2	6	4	1	1	2	8	12	2	59	Good (Stable)
88LS016	Cabin Creek	C3	2	3	8	3	3	4	4	4	4	2	1	2	4	12	1	57	Good (Stable)
11LS017	Captain Jacobson	C4	2	6	6	6	2	6	5	10	12	2	3	6	8	18	3	95	Fair (moderately unstabl
13LS013	Cascade River	C3	4	3	2	3	1	4	4	4	4	1	1	2	4	12	1	50	Good (Stable)
11LS023	Cedar Creek	B3	5	3	3	3	1	2	2	4	4	1	1	3	4	6	1	43	Good (Stable)
98LS026	Crow Creek	E4	8	9	4	6	3	8	6	12	8	3	3	4	12	18	3	107	Poor (Unstable)
97LS038	E. Branch Amity C	F4	6	9	6	9	3	5	6	14	10	2	2	4	8	12	2	98	Fair (Mod. unstable)
11LS002	Encampment Rive	F1b	6	7.5	2	6	2	2	2	4	8	1	1	2	4	6	2	55.5	Good (Stable)
11LS030	Gooseberry River	E4	4	3	4	3	1	6	2	4	4	2	2	4	4	12	2	57	Good (Stable)
97LS075	Heartbreak Creek	B3	4	3	4	3	2	4	4	6	8	2	2	4	8	12	4	70	Fair (Mod. unstable)
13LS034	Hockamin Creek	B3c	4	3	4	3	1	2	2	4	4	1	1	2	4	6	3	44	Good (Stable)
13LS011	Kimball Creek	B3	6	3	2	3	2	2	2	6	8	1	2	2	4	10	1	54	Good (Stable)
11LS004	Little Gooseberry	E5	1	1	4	3	1	8	0	4	10	1	2	2	6	6	1	50	Good (Stable)
11LS007	McCarthy Creek	C4	2	3	4	6	1	4	4	4	4	2	2	2	4	6	3	51	Good (Stable)
02LS004	Silver Creek	C4	4	3	4	9	1	6	2	6	4	1	2	2	8	8	3	63	Good (Stable)
11LS038	Talmadge River	B3c	4	3	4	3	2	3	4	4	8	1	1	2	4	12	1	56	Good (Stable)
Lester Road	Talmadge River	E4	6	9	4	9	3	8	5	9	8	2	3	4	8	12	3	93	Fair (Mod. unstable)
01LS005 (Bc re	Talmadge River	B3c	2	6	6	6	1	4	4	6	4	3	3	2	8	12	3	70	Fair (Mod. unstable)
01LS005 (B rea	Talmadge River	B3	4	3	2	6	1	3	2	4	4	2	2	2	4	6	1	46	Good (Stable)
13LS110 / 01LS	Talmadge River	C3	8	12	6	9	4	4	6	16	12	3	3	6	12	24	4	129	Poor (Unstable)
98LS028	Two Island River	C4	4	3	4	3	2	8	4	6	8	3	2	4	8	12	2	73	Good (Stable)
98LS028	Two Island River	B3c	6	3	4	3	1	2	2	4	4	3	1	2	4	6	1	46	Good (Stable)
13LS043	Wanless Creek	E4	4	3	6	3	1	4	4	4	4	2	2	4	8	12	2	63	Good (Stable)
11LS028	West Beaver River	E4	2	6	4	6	1	8	4	6	4	2	1	4	8	12	1	69	Good (Stable)
13LS052	Woods Creek	F4b	8	9	6	9	4	6	6	12	12	3	4	4	12	18	2	115	Poor (Unstable)

Appendix B

Minnesota Stream Habitat Assessment (MSHA) scores for Northeastern Minnesota divided into a letter grade scoring system. "Count" is the number of stations that fell into each letter grade category.

Percentile	Total MSHA Score	Rating	Count
max	95.6	A	106
90th	84.7		
80th	81.0	B	210
70th	77.5		
60th	73.7	C	316
50th	70.0		
40th	66.8		
30th	62.3	D	208
20th	57.5		
10th	49.8	F	210
Min	21.5		

Percentile	Land-Use Score	Rating	Count
N/A	5	A	811
N/A	4	B	100
N/A	3	C	71
N/A	2	D	37
N/A	0-1	F	31

Percentile	Cover Score	Rating	Count
max	18	A	119
90th	16		
80th	15	B	225
70th	14		
60th	13	C	330
50th	12		
40th	12		
30th	11	D	186
20th	9		
10th	7	F	190
Min	0		

Percentile	Channel Morphology Score	Rating	Count
max	36	A	113
90th	31		
80th	28	B	218
70th	27		
60th	25	C	350
50th	23		
40th	21		
30th	19.7	D	190
20th	17		
10th	14	F	179
Min	1		

Percentile	Substrate Score	Rating	Count
max	27.0	A	137
90th	24.0		
80th	22.9	B	179
70th	21.9		
60th	20.6	C	317
50th	19.4		
40th	17.9		
30th	15.1	D	219
20th	12.0		
10th	9.0	F	198
Min	2.0		

Percentile	Riparian Score	Rating	Count
max	15.0	A	374
90th	13.0		
80th	12.0	B	238
70th	11.5		
60th	11.0	C	384
50th	10.0		
40th	9.0		
30th	8.5	D	30
20th	7.5		
10th	6.0	F	24
Min	-1.0		

Appendix B (continued)

West Branch Beaver River MSHA results and letter grade scores

Composite MSHA Score

River/Stream	Station	Visit Date	MSHA Score (0-100)	Grade (A - F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	69.7	C	Poor substrate conditions, but riparian corridor and channel morphology ratings were average to good
W. Branch Beaver River	11LS028	7/27/2011	66.2	D	Slightly incised stream channel; coarse substrates embedded by fine sediment; grazing in riparian corridor

* *See section BLANK for background information on grading scale*

Channel Morphology

River/Stream	Station	Visit Date	MSHA Score (0-36)	Grade (A-F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	25	C +	Connected to floodplain, low w/d ratio, good cover
W. Branch Beaver River	11LS028	7/27/2011	22	C -	Slightly incised and over-widened channel

* *See section BLANK for background information on grading scale*

Substrate

River/Stream	Station	Visit Date	MSHA Score (0-28)	Grade (A - F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	16.7	D	Gravel/cobble substrates embedded by sand
W. Branch Beaver River	11LS028	7/27/2011	18.7	C	Coarse substrates lightly embedded with sand and silt

* *See section BLANK for background information on grading scale*

Cover

River/Stream	Station	Visit Date	MSHA Score (0-18)	Grade (A - F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	12	C	Some undercut banks and woody cover, pools lacking
W. Branch Beaver River	11LS028	7/27/2011	12	C	Some undercut banks and woody cover, pools lacking

* *See section BLANK for background information on grading scale*

Riparian

River/Stream	Station	Visit Date	MSHA Score (0-14)	Grade (A - F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	12	B	Relatively undisturbed wet meadow with alder
W. Branch Beaver River	11LS028	7/27/2011	10	C	Wet meadow, grazed intermittently by horses

* *See section BLANK for background information on grading scale*

Land Use

River/Stream	Station	Visit Date	MSHA Score (0-5)	Grade (A - F)*	Notes & Comments
W. Branch Beaver River	05LS001	7/7/2014	4.5	B	Hay fields and powerline crossing, otherwise dominated by alder and tall grasses
W. Branch Beaver River	11LS028	7/27/2011	3.5	C	Hay field and fenced pasture, otherwise dominated by alder and tall grasses

* *See section BLANK for background information on grading scale*

Appendix B (continued)

Beaver River MSHA results and letter grade scores

Channel Morphology

River/Stream	Station	MSHA Score (0-36)	Grade (A-F)*
Beaver River	11LS027	23	C
Beaver River	94LS007	32	A
Beaver River	97LS010	19	D
Beaver River	94LS005	25	C
Beaver River	91LS026	25	C
Beaver River	15LS061/15LS060	30	B+
Beaver River	94LS003	28	B
Beaver River	97LS055	22	C
Beaver River	11LS022	20	D+
Beaver River	14LS001	27	B

Substrate

River/Stream	Station	MSHA Score (0-28)	Grade (A-F)*
Beaver River	11LS027	15	D
Beaver River	94LS007	24	A
Beaver River	97LS010	24	A
Beaver River	94LS005	17	D+
Beaver River	91LS026	21	C+
Beaver River	15LS061/15LS060	27	A
Beaver River	94LS003	27	A
Beaver River	97LS055	23	B+
Beaver River	11LS022	20	C
Beaver River	14LS001	27	A

Cover

River/Stream	Station	MSHA Score (0-18)	Grade (A-F)*
Beaver River	11LS027	15	B
Beaver River	94LS007	15	B
Beaver River	97LS010	9	D
Beaver River	94LS005	9	D
Beaver River	91LS026	12	C
Beaver River	15LS061/15LS060	15	B
Beaver River	94LS003	16	A
Beaver River	97LS055	8	F
Beaver River	11LS022	12	C
Beaver River	14LS001	15	B

Appendix B (continued)

Beaver River MSHA results and letter grade scores

Riparian			
River/Stream	Station	MSHA Score (0-14)	Grade (A-F)*
Beaver River	11LS027	14	A
Beaver River	94LS007	14	A
Beaver River	97LS010	10	C
Beaver River	94LS005	8	D
Beaver River	91LS026	11	C
Beaver River	15LS061/15LS060	11	C
Beaver River	94LS003	11	C
Beaver River	97LS055	11	C
Beaver River	11LS022	11	C
Beaver River	14LS001		

Land Use			
River/Stream	Station	MSHA Score (0-5)	Grade (A-F)*
Beaver River	11LS027	5	A
Beaver River	94LS007	5	A
Beaver River	97LS010	5	A
Beaver River	94LS005	5	A
Beaver River	91LS026	4	B
Beaver River	15LS061/15LS060	5	A
Beaver River	94LS003	5	A
Beaver River	97LS055	4	B
Beaver River	11LS022	4	B
Beaver River	14LS001	5	A

Composite MSHA Score			
River/Stream	Station	MSHA Score (0-100)	Grade (A-F)*
Beaver River	11LS027	72	C
Beaver River	94LS007	90	A
Beaver River	97LS010	72	C
Beaver River	94LS005	64	D
Beaver River	91LS026	74	C+
Beaver River	15LS061/15LS060	88	A
Beaver River	94LS003	87	A
Beaver River	97LS055	69	C
Beaver River	11LS022	67	C
Beaver River	14LS001	84	B+

Appendix B (continued)

Talmadge River MSHA results and letter grade scores

Channel Morphology

River/Stream	Station	MSHA Score (0-36)	Grade (A-F)*
Talmadge River	11LS038	30	B+
Talmadge River	13LS110	23	C

Substrate

River/Stream	Station	MSHA Score (0-28)	Grade (A-F)*
Talmadge River	11LS038	24	A
Talmadge River	13LS110	24	A

Cover

River/Stream	Station	MSHA Score (0-18)	Grade (A-F)*
Talmadge River	11LS038	13	C
Talmadge River	13LS110	7	F

Riparian

River/Stream	Station	MSHA Score (0-14)	Grade (A-F)*
Talmadge River	11LS038	15	A
Talmadge River	13LS110	12.5	B+

Land Use

River/Stream	Station	MSHA Score (0-5)	Grade (A-F)*
Talmadge River	11LS038	5	A
Talmadge River	13LS110	5	A

Composite MSHA Score

River/Stream	Station	MSHA Score (0-100)	Grade (A-F)*
Talmadge River	11LS038	87	A
Talmadge River	13LS110	71	C

Appendix C

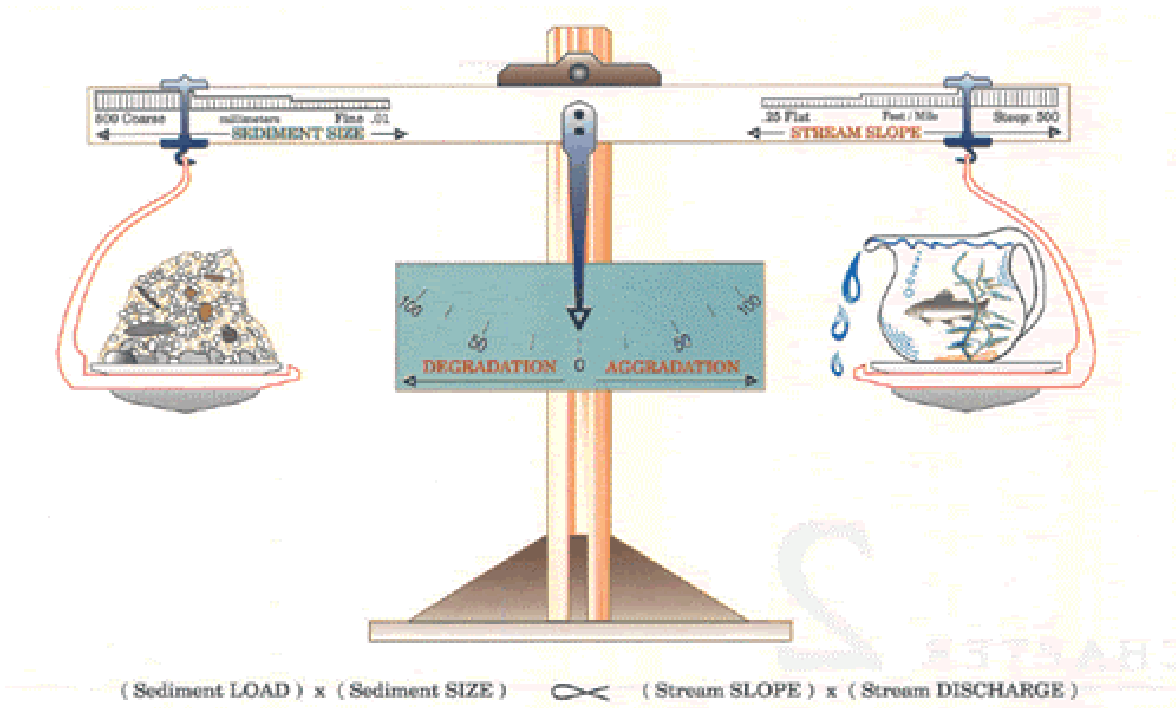
List of reference reaches used for physical habitat and channel stability analysis

River	Reach	Current Stream Type	Stable?	Potential Stream Type	Stream Type Letter	Watershed Area	Width	Reference Stream to Use
E Br Amity Ck	97LS038	F4	N	C4	C	7.62	38.19	McCarthy
Hockamin Creek	13LS034	B3c	Y	B3c	Bc	15.65	31.9	Two Island
Beaver R	ATV DNR Site	B3c	Y	B3c	Bc	9.63	21.2	Two Island
Beaver R	ATV DNR Site	C4	N	C4	C	9.63	25.61	Silver
Beaver R	94LS007	B3	Y	B3	B	15.95	34.6	Cedar
Beaver R	Shaq	C3	N	C3	C	48.3	45.41	Cascade
Beaver R	94LS005	C4	N	C4	C	53.4	32.15	Two Island
Beaver R	11LS022	C4c-	N	C4c-	C	122	82.27	Silver
Beaver R	94LS007	C4	Y	C4	C	15.95	33.65	Silver
Brophy Ck	10EM141	E5	Y	E5	E	2.53	11.06	Brophster
Captain Jacobson Ck	11LS017	C4	N	C4	C	5.11	21.84	McCarthy
Cascade R	13LS013	C3	Y	C3	C	53.63	42.91	Cascade
Cedar Creek	11LS023	B3	Y	B3	B	14.5	27.18	Cedar
Wanless	13LS043	E4	Y	E4	E	3.58	13.63	Little Gooseberry
Crow R	98LS026	F4	N	E4	E	3.89	16.73	Little Gooseberry
Crow R	98LS026	E4	N	E4	E	3.89	13.47	Little Gooseberry
Woods Creek	13LS052	F4b	N	B3	B	2.05	25.55	Kimball
Encampment R	11LS002	B1c	Y	B1c	Bc	15.89	28.5	Two Island
Encampment R	11LS002	F1b	Y	F1b	F	15.89	28.3	Encampment
Encampment R	11LS002	F3	N	C3	C	15.89	46.4	Silver
Gooseberry R	11LS030	E4	Y	E4	E	13.81	22.97	Gooseberry
Heartbreak Ck	97LS075	C3	N	C3	C	14.27	40.51	Silver
Heartbreak Ck	97LS075	B3	Y	B3	B	14.27	25.3	Cedar
Kimball Ck	13LS011	B3	Y	B3	B	13.64	23.52	Kimball
Little Gooseberry R	11LS004	E5	Y	E5	E	9.87	18.6	Little Gooseberry
Cabin Creek	88LS016	C3	Y	C3	C	13.25	42.5	Silver
McCarthy Ck	11LS007	C4	Y	C4	C	3.6	18.88	McCarthy
Silver Ck	02LS0004	C4	Y	C4	C	9.23	26.06	Silver
Talmadge R	Lester River Rd	E4	N	E4	E	2.75	11.46	Brophster
Talmadge R	Wahl Rd	B3	Y	B3	B	3.16	18.4	Kimball
Talmadge R	Wahl Rd	B3c	Y	B3c	Bc	3.16	20.6	McDonnell
Talmadge R	McDonnell	B3c	Y	B3c	Bc	5.13	23.05	McDonnell
Talmadge R	Gage Site	C3	N	C3	C	5.42	24.67	McCarthy
Talmadge R	Upstream of hwy 61	F4	N	B4c	Bc	5.86	50.92	McDonnell
Two Island R	98LS028	B3c	Y	B3c	Bc	11.5	20.63	Two Island
Two Island R	98LS028	C4	Y	C4	C	11.5	22.8	Silver
West Beaver R	11LS028	E4	N	E4	E	5.15	12.06	Little Gooseberry

- Denotes Reference Reach

Appendix D

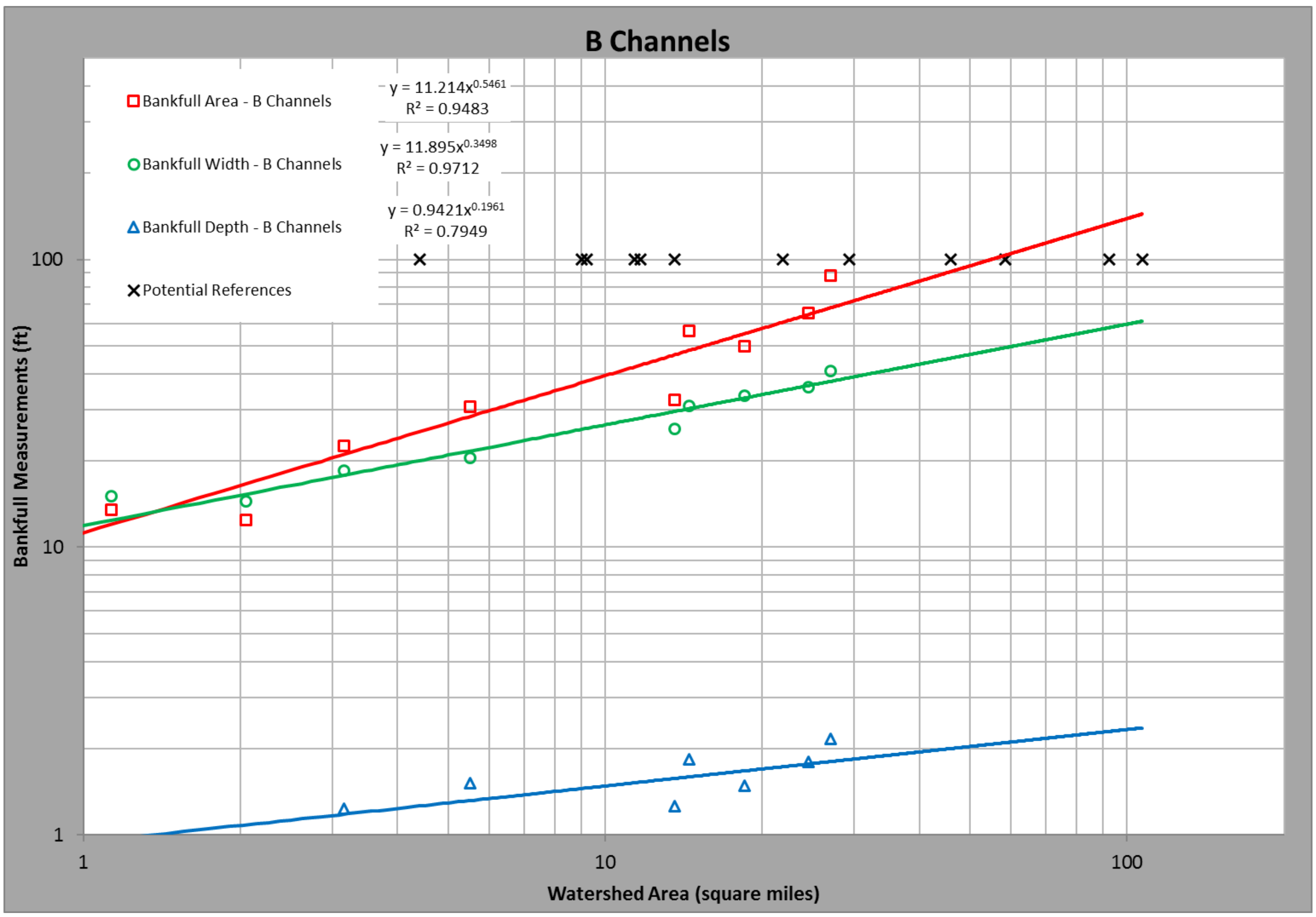
Lane's Balance shows the relationship between stream discharge and slope and sediment load and size. Source: E.W. Lane, The importance of fluvial morphology in hydraulic engineering, 1955.



Appendix E

"B" Channels

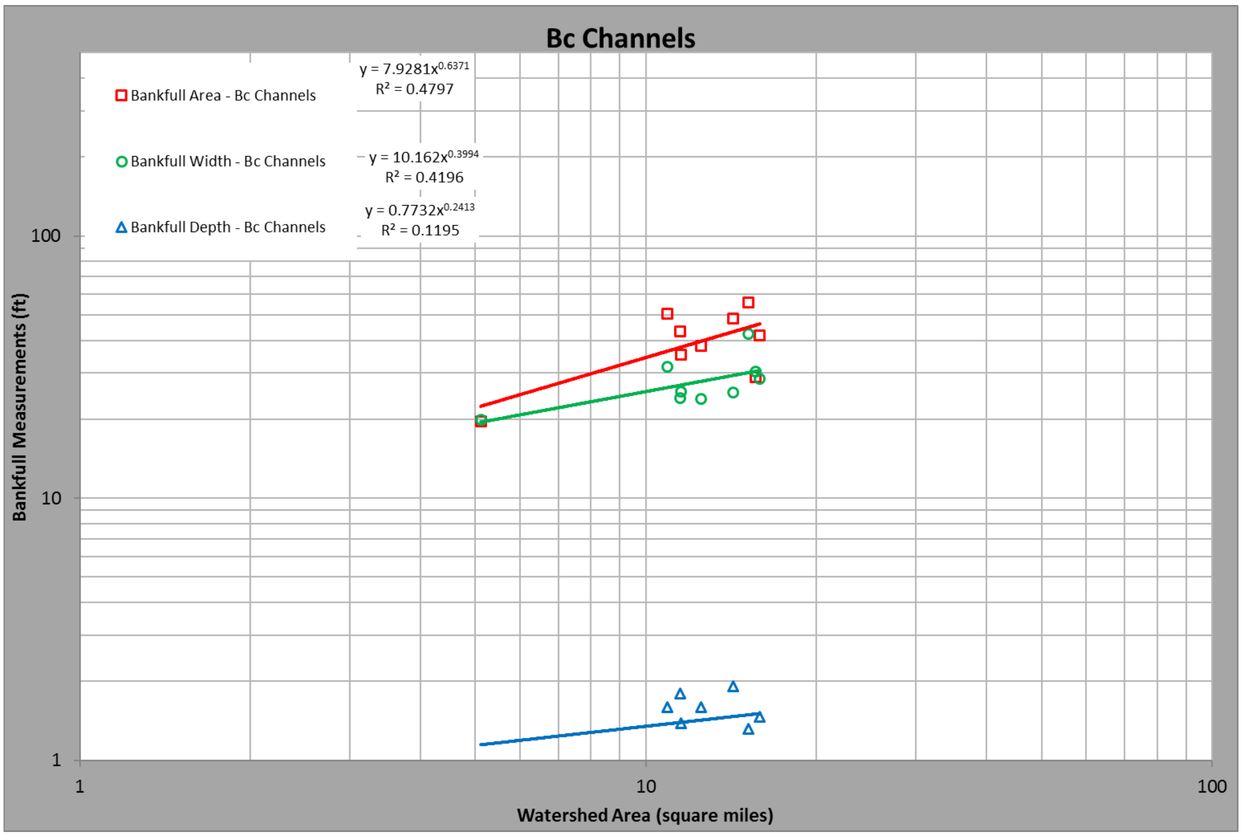
Watershed	Channel Type	Slope	Watershed Area	BKF Width	BKF Depth	W/D	BKF Area	Site Description
Merritt	B		0.25	6.8	0.82	8.3	5.6	East Branch Trib, upstream of Skyline
Merritt	B3	2.866%	1.13	15	0.9	16.7	13.5	East Branch, upstream of Skyline
Woods	B4	5.100%	2.05	14.4	0.86	16.7	12.4	13LS052
Talmadge	B		5.52	20.4	1.51	13.5	30.8	1/2 mile upstream of 61 Expressway
Kimball	B3	3.100%	13.6	25.7	1.26	20.4	32.44	13LS011
Cedar	B3	2.621%	14.5	30.96	1.83	16.9	56.53	Reference Reach
East Beaver	B		18.5	33.7	1.48	22.8	50	Upstream of EBV635
East Beaver	B		24.5	36	1.79	20.1	65	Downstream of Hwy 15
East Beaver	B		27	40.9	2.15	19.0	87.9	Upstream of MP7 maintenance road
Talmadge	B		3.16	18.4	1.23	15.0	22.5	upstream of Wahl Rd



Appendix E (continued)

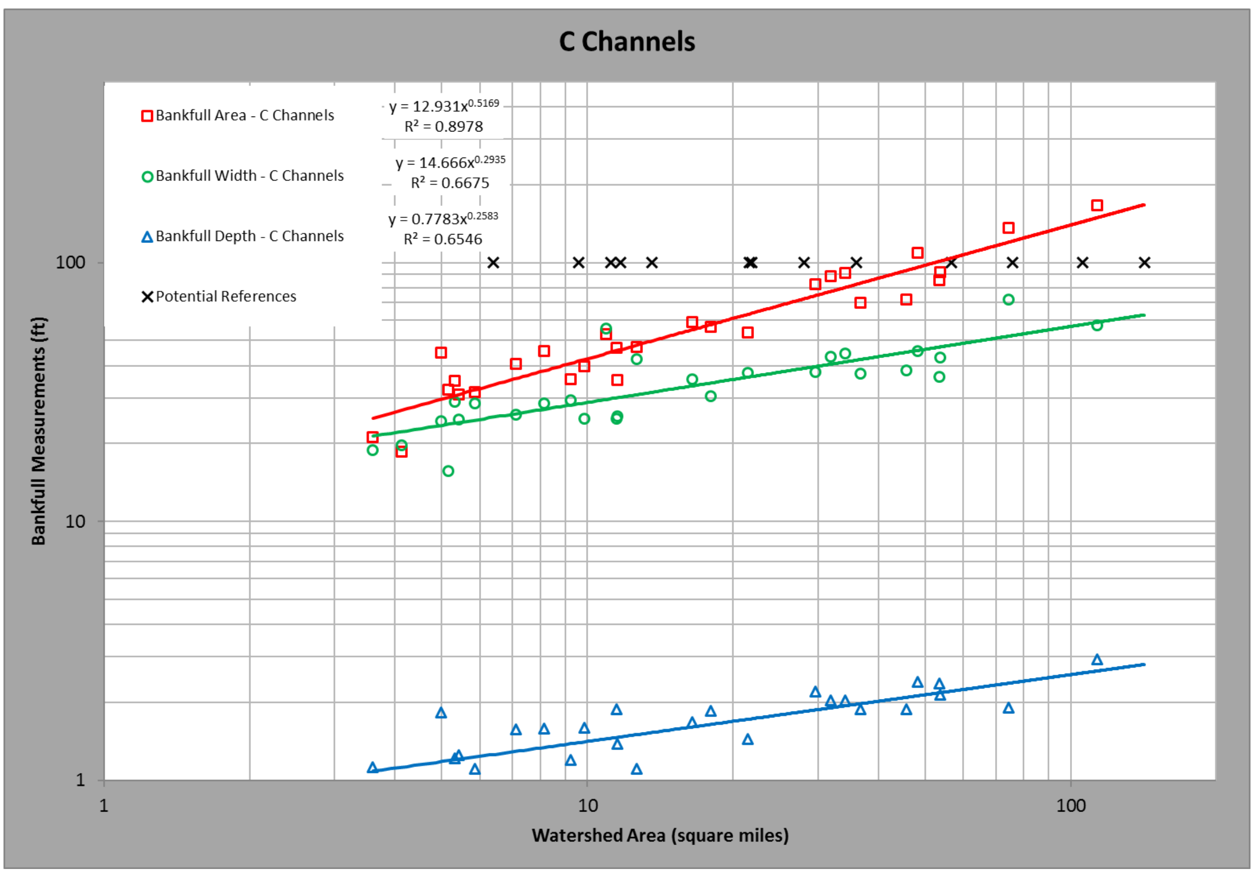
"Bc" channels

Watershed	Channel Type	Slope	Watershed Area	BKF Width	BKF Depth	W/D	BKF Area	Site Description
Mission	B4c	0.941%	10.93	31.63	1.6	19.8	50.49	US Hwy 23, XS32, 'B-reach' portion
Two Island River	B3c	1.681%	11.5	24.08	1.8	13.4	43.23	98LS028
Split Rock	B3c	1.907%	11.55	25.56	1.38	18.5	35.24	Reference Reach downstream of Alger Grade
Split Rock	B3c	0.917%	12.5	23.98	1.59	15.1	38.1	County Rd 3
Heartbreak	B3c	1.878%	14.27	25.3	1.91	13.2	48.4	97LS075
Flute Reed	B3c	1.823%	15.2	42.4	1.32	32.1	55.8	Downstream of Hwy 69 bridge
Hockamin Creek	B3c	1.149%	15.65	30.41	0.95	32.0	28.99	13LS034
Captain Jacobson	B4c	1.620%	5.11	19.9	0.98	20.3	19.6	11LS017
Encampment River	B1c	1.037%	15.89	28.5	1.46	19.5	41.6	11LS002



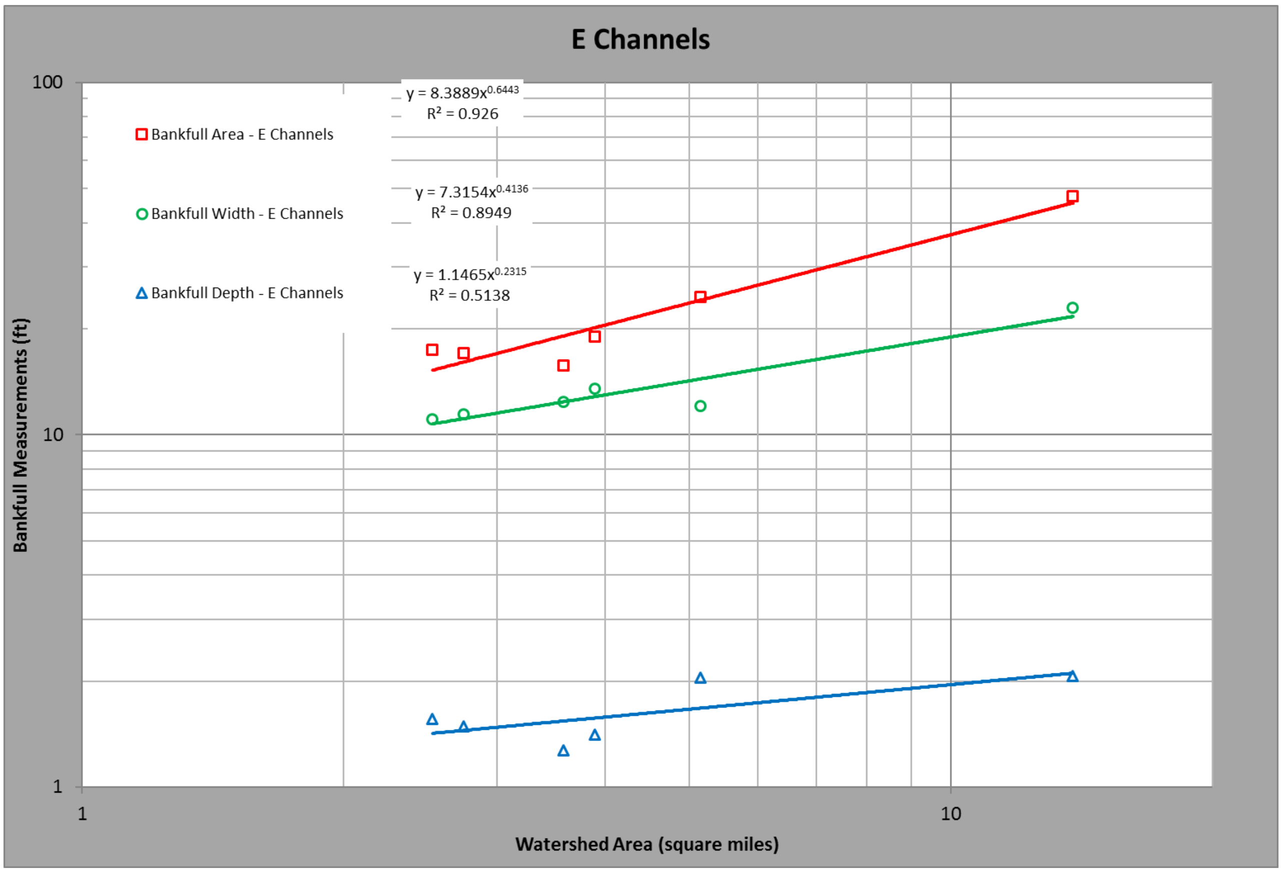
“C” Channels

Watershed	Channel Type	Slope	Watershed Area	BKF Width	BKF Depth	W/D	BKF Area	Site Description
Talmadge	C4	0.921%	4.13	19.7	0.94	21.0	18.6	Downstream of Lakewood Rd
McCarthy Creek	C4	0.799%	3.6	18.9	1.12	16.9	21.2	11LS007
Little Stewart	C4b	2.175%	4.99	24.45	1.83	13.4	44.8	XS100, DS of Junemann Bridge
Talmadge	C3	0.784%	5.15	15.7	0.93	16.9	32.2	McDonnell Rd Biosite
Tischer	C4	0.856%	5.32	28.9	1.21	23.9	35	Upstream of Arrowhead Rd
Talmadge	C3	1.378%	5.42	24.7	1.25	19.8	30.9	Upstream of Cant Rd
Talmadge	C4	1.835%	5.86	28.6	1.11	25.8	31.7	Level III site upstream of 61 Expressway
East Amity	C3	0.484%	7.11	25.8	1.57	16.4	40.7	Upstream of Ozan Restoration
East Amity	C4	0.599%	8.15	28.6	1.58	18.1	45.6	Gage site on East Branch
Silver Creek	C4	0.483%	9.23	29.5	1.2	24.6	35.4	02LS004
Little Gooseberry	C5	0.018%	9.87	24.9	1.59	15.7	39.6	11LS004
Mission	C4	1.196%	10.93	55.66	0.95	58.6	52.99	US Hwy 23, 'C portion', XS14, very high W:d
Two Island	C4	0.376%	11.5	24.9	1.88	13.2	46.8	98LS028 Upstream Reach
Split Rock	C3	1.932%	11.55	25.56	1.38	18.5	35.24	"C" portion of Alder Grade Trail reach
Cabin Creek	C3	0.565%	12.65	42.5	1.11	38.3	47.25	88LS016
Amity	C3	1.267%	16.5	35.4	1.67	21.2	58.9	Gage site on Seven Bridges Road
French	C4	0.800%	18	30.4	1.85	16.4	56.3	Rosgen training site
Stewart River	C4	0.829%	21.51	37.4	1.44	26.0	53.79	2012 Post-flood, XS6
Lester	C4	0.498%	29.6	37.7	2.2	17.1	82.8	Upstream of Strand Rd
Gooseberry	C3	0.622%	31.87	43.37	2.04	21.3	88.4	Reference Reach upstream Hwy 3
Sucker	C4	0.749%	34.13	44.66	2.04	21.9	91.33	Interfluve reach 2013 (Ryan rd) after construction
Sucker	C3	1.400%	36.8	37.22	1.88	19.8	69.8	Gage site (before 2012 flood)
Poplar	C4	0.440%	45.7	38.3	1.88	20.4	72.2	Reference Reach at Barker Lake Road
Main Beaver	C3	1.047%	48.3	45.4	2.4	18.9	109	Cabin Level III Assessment site
Main Beaver	C4		53.4	36.2	2.37	15.3	85.6	Stable riffle upstream of Hwy 3
Cascade	C3	0.454%	53.63	42.9	2.14	20.0	92	13LS013
Gooseberry	C3	1.856%	74.5	71.9	1.9	37.8	136.3	Gage site
Poplar	C3	1.928%	113.26	57.13	2.92	19.6	166.73	Gage, XS1



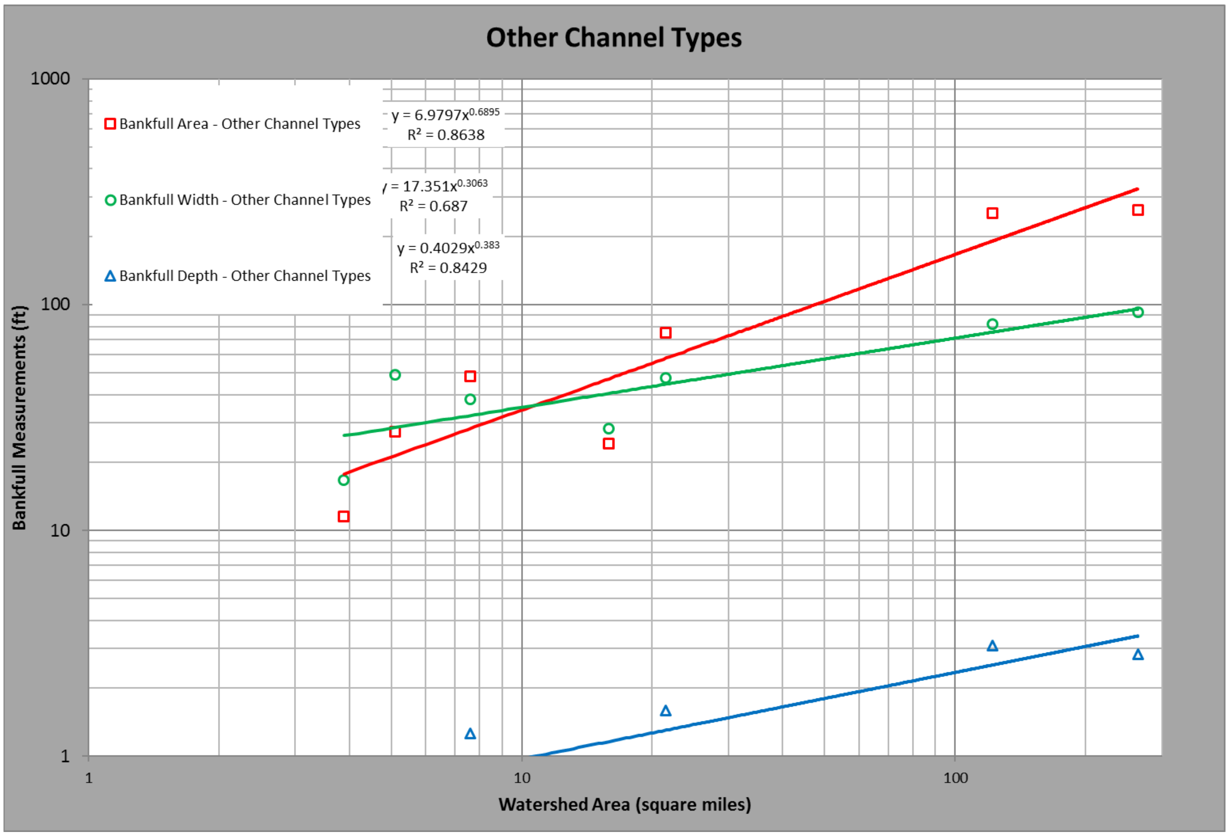
"E" Channels

Watershed	Channel Type	Slope	Watershed Area	BKF Width	BKF Depth	W/D	BKF Area	Site Description
Brophy Creek	E5	0.296%	2.53	11.1	1.56	7.1	17.4	10EM141
Talmadge	E4	0.878%	2.75	11.46	1.49	7.7	17.04	Upstream of Lester River Rd
Wanless Creek	E4	0.820%	3.58	12.42	1.27	9.8	15.72	13LS043
Crow Creek	E4	0.823%	3.89	13.5	1.41	9.6	19	98LS026
French	E4	0.600%		8.6	1.26	6.8	10.8	Miller Creek Reference Reach
West Beaver	E4	0.200%	5.15	12.1	2.04	5.9	24.6	Biosite 11LS028
Gooseberry	E5/3	0.237%	13.81	22.97	2.07	11.1	47.54	11LS030



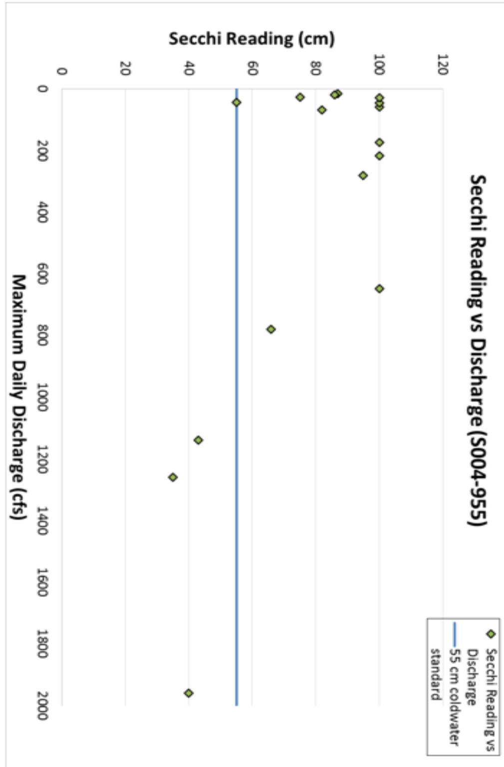
“Other” Channel Types

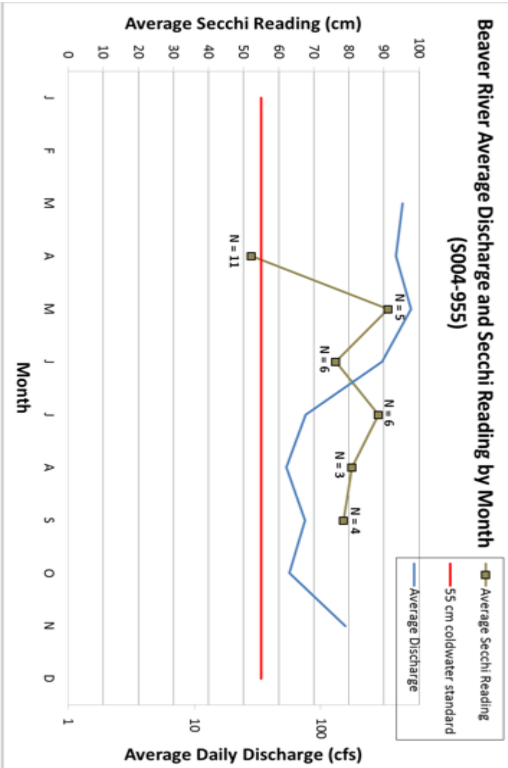
Watershed	Channel Type	Slope	Watershed Area	BKF Width	BKF Depth	W/D	BKF Area	Site Description
Crow Creek	F4	0.823%	3.89	16.7	0.69	24.2	11.5	98LS026
Captain Jacobson	D4	1.620%	5.11	48.84	0.56	87.2	27.32	11LS017
East Amity	F4	1.060%	7.62	38.2	1.26	30.3	48.11	97LS038
Encampment R	F1b	3.304%	15.89	28.3	0.86	32.9	24.3	11LS002
Stewart River	F4	0.829%	21.51	47.27	1.59	29.7	75.13	XS2 (2012 post-flood survey)
Main Beaver	C4c	0.075%	122	82	3.1	26.5	253.7	Gage site
Brule	F3/2	0.875%	264	92.6	2.84	32.6	263	Upstream of Hwy 61

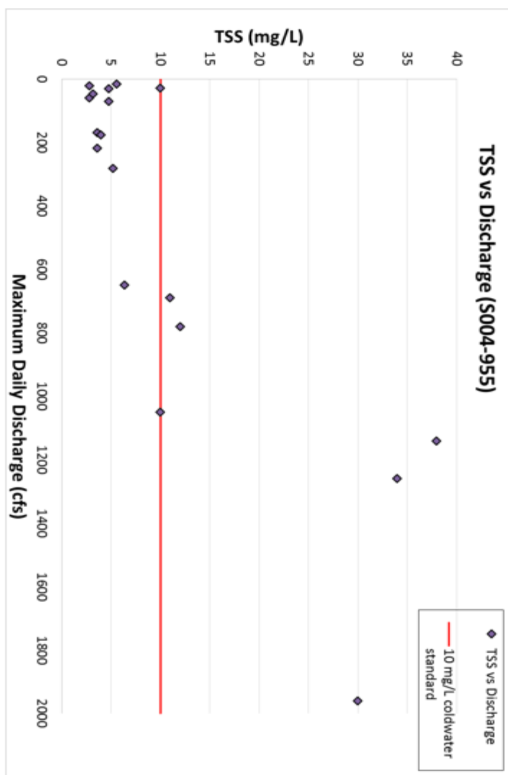


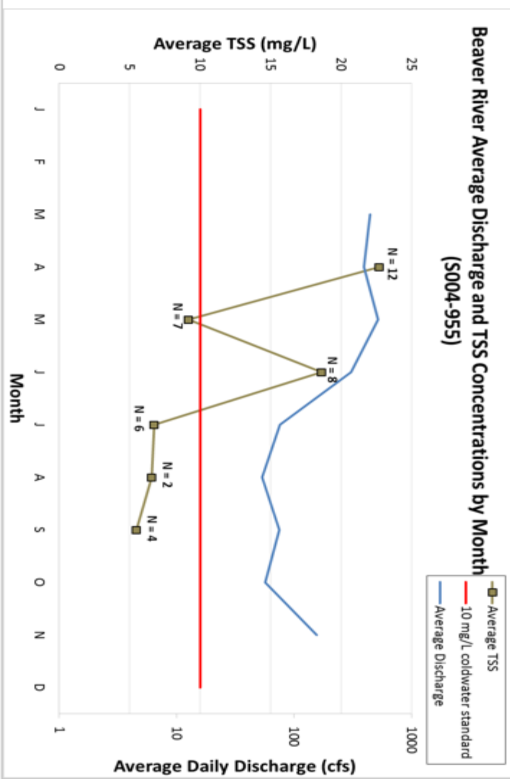
Appendix F

Seasonal analysis of TSS and transparency data for the Beaver River.









Appendix G

Flow

Talmadge River TSS and Secchi Summary								
		TSS				Secchi		
Site (*Co-located Biosite*)	Site Description	# of Samples	Average (mg/L)	% Exceeding Standard	Drainage Area (miles^2)	# of Samples	Average (cm)	% Exceeding Standard
S007-449	TALMADGE R AT LESTER R RD	4	7	0%	2.74	4	100	0%
S007-448 (*01LS005*)	TALMADGE R AT WAHL RD	4	7	25%	3.16	4	91	0%
S007-447 (*01LS004*)	TALMADGE R AT LAKEWOOD RD	4	17	50%	4.11	4	75	25%
S007-614 (*11LS038*)	TALMADGE R NW OF MCDONNELL RD	2	31	50%	5.13	2	61	50%
S001-755 (*13LS110*)	TALMADGE R AT CO RD 281	33	21	27%	5.42	111	85	17%
S008-003	TALMADGE R (TALMADGE CK), W OF FLYNN RD AND UPSTR OF TRIB MOUTH, N OF DULUTH, MN	1	10	100%	5.53	1	76	0%
S007-446 (*01LS002*)	TALMADGE R AT CSAH-61 EXPRESSWAY	4	158	75%	5.87	4	30	75%
S005-468	TALMADGE R, 100 YDS BELOW MN-61, 6 MI NE OF DULUTH				5.96	88	80	18%
S007-445 (*01LS001*)	TALMADGE R AT CSAH-61, 10.7 MI NE DULUTH, MN	4	159	100%	5.96	4	31	75%
Tributaries								
S007-450	UNN STR AT CANT RD	4	21	50%	0.10	4	59	50%
S007-984	UNN STR (TALMADGE R TRIB) TO TALMADGE R, UPSTR OF CONFLU WITH TALMADGE R, W OF FLYNN RD AND N OF DULUTH, MN. T51N R13W S24	1	25	100%	0.19	1	21	100%
S007-451	UNN STR AT LAKEWOOD RD	4	28	100%	0.83	4	76	25%

Beaver River TSS and Secchi Summary

		TSS				Secchi		
Site	Site Description	# of Samples	TSS Average (mg/L)	TSS % Exceeding Standard	Drainage Area	# of Samples	Secchi Tube Average (cm)	Secchi Tube % Exceeding Standard
	Beaver River Mainstem							
S007-598	UNN STR (MILEPOST 7 OUTLT) TO BEAVER R AT CSAH-3 2.4 MI W OF BEAVER BAY, MN	1	3	0%	4.46	2	100	0%
S007-357	BEAVER R AT CSAH-15, 6.3 MI NE OF SILVER CK, MN.	3	5	33%	4.70	4	100	0%
S008-004	BEAVER R, UPSTR OF CONFL WITH BIG THIRTYNINE CK, 5.4 MI NW OF BEAVER BAY, MN	2	4	0%	16.33	1	100	0%
S007-356	BEAVER R 1.8 MI S OF CSAH-15, 5.4 MI NW OF BEAVER BAY, MN	3	7	33%	40.16	3	100	0%
S006-273	BEAVER RIVER AT COUNTY STATE AID HIGHWAY 3, 3.5 MILES WEST OF BEAVER BAY,	6	8	17%	53.92	6	86	17%
S007-967	BEAVER R AT CSAH-3, 2.4 MI W OF BEAVER BAY, MN	2	2	0%	64.11	1	100	0%
S007-968	BEAVER R AT CSAH-3, DNSTR OF S007-967, 2.4 MI W OF BEAVER BAY, MN	3	5	0%	68.75	2	95	0%
S000-252	BEAVER R SOUTH OF CSAH-3 1.5 MI NW OF BEAVER BAY	18	57	22%	69.22	26	31	8%
S007-355	BEAVER R AT CSAH-4, 2.3 MI NW OF BEAVER BAY, MN	5	13	80%	70.93	6	59	67%
S007-970	BEAVER R, N OF CSAH-4, 1 MI NW OF BEAVER BAY, MN	2	12	50%	121.72	2	66	50%
S007-971	BEAVER R, N OF CSAH-4, .6 MI N OF BEAVER BAY, MN	1	5	0%	122.43	1	91	0%
S007-354	BEAVER R AT MN-61, NE SIDE OF BEAVER BAY, MN	4	15	75%	122.99	5	63	60%
S004-955	BEAVER R JUST UPSTRM OF US-61 AT BEAVER BAY	39	14	44%	122.99	35	44	29%
S006-234	BEAVER RIVER JUST DOWNSTREAM OF MINNESOTA STATE HIGHWAY 61 IN BEAVER BAY. SITE IS LOCATED 24 MILES NORTHEAST OF TWO HARBORS, MINNESOTA.	11	6	9%	122.99	20	31	30%
	Big Thirtynine Creek							
S007-408	BIG THIRTYNINE CK AT NAT FOREST RD 397, 4.8 MI W OF BEAVER BAY, MN	1	1	0%	3.70	2	92	0%
S007-411	LITTLE THIRTYNINE CK AT CSAH-15, 4.5 MI SW OF BEAVER BAY, MN	3	2	0%	4.99	4	100	0%
S007-410	LITTLE THIRTYNINE CK, ABOVE CONFL WITH BIG THIRTYNINE CK AT T56 R8W S30, 6.5 MI NE OF SILVER CK, MN	4	32	0%	6.89	4	100	0%
S007-407	BIG THIRTYNINE CR AT CSAH-15, 4.9 MI SW OF BEAVER BAY, MN	3	5	33%	13.74	4	97	0%
S007-406	BIG THIRTYNINE CR, ABOVE CONFLUENCE OF LITTLE THIRTYNINE CK, AT T56 R8W S30, 5.7 MI NW OF BEAVER BAY, MN	5	5	20%	16.74	5	100	0%
S007-367	BIG THIRTYNINE CR, W OF TAILINGS BASIN AT T56 R8W S30, 5.7 MI NW OF BEAVER BAY, MN	2	4	0%	23.83	2	100	0%
	West Branch Beaver River							
S007-365	UNN STR AT CSAH-3, 4.5 MI W OF BEAVER BAY, MN. T55 R8W S18	4	10	50%	1.90	5	64	60%
S007-364	BEAVER RIVER, WEST BRANCH	3	11	67%	2.91	2	62	50%
S007-363	BEAVER RIVER, WEST BRANCH	4	7	25%	5.15	1	28	100%
S007-362	BEAVER R NEAR CSAH-3, 3.8 MI E OF BEAVER BAY, MN	4	9	50%	8.79	6	51	67%
	East Branch Beaver River							
S007-412	FORTYTHREE CK (MI POST FORTY-THREE CK) AT CSAH-31, 2.3 MI SE OF BEAVER BAY, MN	2	4	0%	5.44	3	95	0%
S007-414	UNN STR (LAX LK) .2 MI E OF CSAH-31 (AT WAX RD CROSSING), 2.3 MI SE OF BEAVER BAY, MN. T56 R8W S14	2	2	0%	6.08	3	100	0%
S007-413	CEDAR CK, .25 MI W OF CSAH-4, 2.7 MI NW OF SILVER BAY, MN. T56 R8W S23	4	9	25%	14.38	6	98	0%
S007-361	BEAVER R, E BR, AT HEFFELFINGER RD (FOREST RD 397), 3.1 MI WNW OF BEAVER BAY, MN	1	2	0%	18.45	2	100	0%
S007-603	BEAVER R, E BR, AT CSAH-15 (SUP NAT FOREST HWY 11), 3.4 MI S OF BEAVER BAY, MN	4	6	25%	24.53	5	99	0%
S007-360	BEAVER R, E BR, AT CSAH-4, 2.5 MI NW OF SILVER BAY, MN	4	14	50%	30.28	5	84	20%
S006-277	BEAVER RIVER, EAST BRANCH JUST EAST OF COUNTY STATE AID HIGHWAY 4, 2.5 MILES NORTHWEST OF SILVER BAY, MINNESOTA	4	12	25%	46.22	N/A	N/A	N/A
S007-359	BEAVER R, E BR, CSAH-5, 2 MI W OF SILVER BAY, MN	4	16	50%	46.86	5	77	40%
S007-358	BEAVER R, E BR, 800 FT W OF GOLF COURSE RD & .3 MI E OF CSAH-4 (AT GOLF COURSE TRL), 1.25 MI NW OF BEAVER BAY, MN	4	19	75%	50.25	4	57	40%