Lake Superior North Stressor Identification Report

A study of local stressors limiting the biotic communities in the Lake Superior North Watershed.

CLEAN WATER LAND & LEGACY AMENDMENT

Minnesota Pollution Control Agency

Month Year

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Guide to Template Structure

[Prior to beginning this report, please check with local partners, project managers and Stressor ID staff (if a consultant is contracted for the SID Report) to verify the most useful organization structure (i.e., organized by AUID or candidate causes). Section 4 outlines some criteria for cases where the report should be organized by AUID or candidate causes.]

[This SID Report Template is designed to simplify the SID Report writing process by providing guidance on content and structure as well as adding some consistency to reports written by various affiliates. The text bracketed in red directs the author(s) to example information or type of content that is applicable for a given section of the report. **Any text appearing in red in this template should be deleted when the report is completed.**]

[The checklist below contains items that are easily overlooked, but should be completed prior to submitting the final report. We suggest reviewing this checklist ***prior*** to beginning the SID Report to provide additional guidance on key items. **Delete this page when the report is finalized**.]

General:

- ☐ Have two Stressor ID Staff reviewed this report?
- ☐ Are the IBI thresholds and confidence intervals for fish/macroinvertebrates used in the analyses included in the report? Alternatively, it's okay to reference that information if it's provided elsewhere (e.g., in the Monitoring and Assessment Report?). (**Note:** ***It is important to clearly state the specific thresholds and confidence intervals used in the current SID analyses in the event that these numbers change in the future***.)

Formatting:

- ☐ Have the Table of Contents, List of Tables and List of Figures been updated?
- ☐ Has the month and year been inserted into the footer?
- ☐ Has the legislative page been completed? (only required if developed by MPCA staff, otherwise delete that section)
- ☐ Is the resolution on all figures appropriate?
- ☐ All elements of the tables/figures are legible?
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- ☐ Are x and y axes of figures clearly labeled with units?
- ☐ Captions – placed on top of all tables and beneath all figures.
- ☐ Are all the references cited in the report listed in the References page?
- ☐ Has the spelling and grammar been checked?
- ☐ Is the Clean Water Legacy Logo on the cover? (If funded locally this is not required)

Contents

Key terms and abbreviations

[Insert applicable key terms as needed with brief definitions here]

CADDIS	Causal Analysis/Diagnosis Decision Information System
EPA	Environmental Protection Agency of the United States
MPCA	Minnesota Pollution Control Agency
SID	Stressor Identification
SOE	Strength of Evidence
TMDL	Total Maximum Daily Load
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

The Lake Superior North Watershed is located in extreme northeastern Minnesota and contains many of the state's most pristine lakes and rivers. Many of the streams and rivers support robust populations of wild Brook Trout and other sensitive and relatively rare aquatic organisms.

Despite the abundance of healthy watersheds in this region, several streams are on the impaired waters list for water quality parameters, and localized impacts are present in many non-impaired waterbodies. This report builds upon intensive water quality and biological data that were collected in this watershed in 2013 and 2014. Additional monitoring efforts were completed in 2015 and 2016 in several watersheds that were identified as priorities for restoration and protection work. This report summarizes the follow-up "stressor identification" (Link: Stressor Identification Defined) monitoring completed in these priority watersheds with the goal of informing the Watershed Restoration and Protection Strategy (WRAPS) effort for the Lake Superior North basin.

Major focus areas and findings in this report are listed below:

- The Total Suspended Solids (TSS) impairment in the Flute Reed River is characterized by high magnitude, relatively short duration spikes in TSS concentrations during snowmelt and/or precipitation events. Major sources of sediment include streambank and bluff erosion resulting from stream channel incision, ravine/gully erosion, road ditches, overland runoff, and beaver activity.
- Biological integrity of the Flute Reed River is also negatively impacted fish passage barriers (improperly sized and installed road culverts), localized habitat degradation, and water temperatures that frequently exceed stress and lethal thresholds for Brook Trout and other sensitive coldwater obligate species.
- Woods Creek is a small coldwater tributary to the Devil Track River supporting a small population of wild Brook Trout, as well as several sensitive coldwater aquatic macroinvertebrate taxa. Restoration activities in this watershed should focus on replacing a road culvert at CR 58 impedes fish passage. Another priority project is the re-meandering of channelized headwaters stream reaches and re-vegetating the riparian corridor in those areas. Key protection areas include a headwaters tributary, which supplies baseflow and coldwater inputs to the creek, and several stream reaches that were found to support higher populations of wild Brook Trout.
- Barriers to fish migration were a major restoration/protection focus area across the Lake Superior North basin. In addition to the migration barriers discussed in detail within the Flute Reed River and Woods Creek, several other streams were evaluated for aquatic connectivity concerns. Reconnecting these river systems is one of the lowest cost, highest return investments in the field of watershed restoration and protection. Considering the exceptional ecological health of aquatic resources in the Lake Superior North, significant attention and funding should be dedicated to restoring or protecting ecological function through projects related to connectivity.

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.

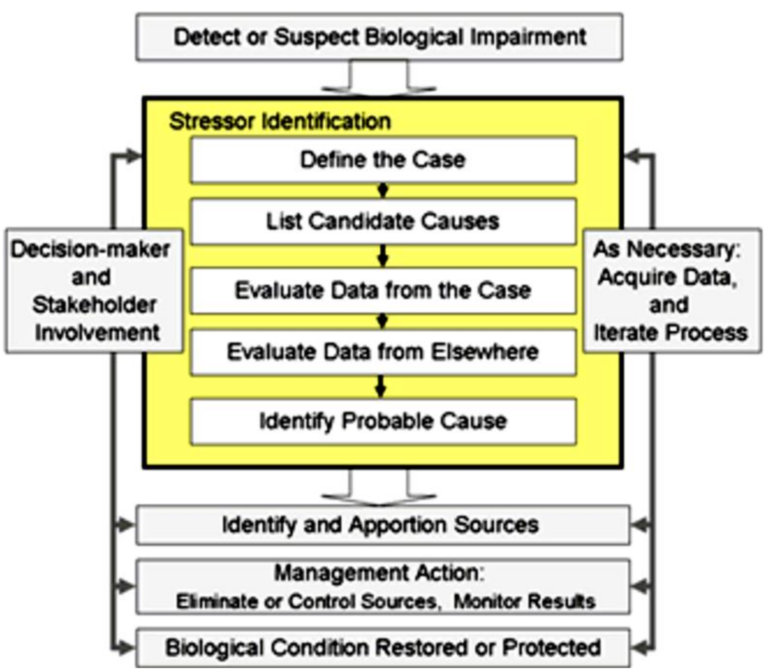


Figure 1. Conceptual diagram of the SID process for identifying the cause(s) of biological Impairment (Cormier et al 2003)

2.0 Introduction and study area

The Lake Superior North Watershed is located in extreme northeastern Minnesota and contains many of the state's most pristine lakes and rivers. Many of the streams and rivers support robust populations of wild Brook Trout and other sensitive and relatively rare aquatic organisms. This report builds upon intensive water quality and biological data that were collected in this watershed in 2013 and 2014. Despite the abundance of healthy watersheds in this region, several streams are on the impaired waters list for water quality parameters, and localized impacts are present in many others. Additional monitoring efforts were completed in 2016 to investigate several watersheds that were identified as priorities for restoration and protection work. This report summarizes the follow-up "stressor identification" (Link: Stressor Identification Defined) monitoring completed in these priority watersheds with the goal of informing the Watershed Restoration and Protection Strategy (WRAPS) effort for this watershed.

Review of Lake Superior North Watershed Assessment Process

The Lake Superior North Watershed Assessment report was published by MPCA in January of 2017 (Link: LS North Watershed Assessment Report). Nearly all of the streams assessed during that process met designated uses for aquatic life and aquatic recreation, and many of the streams (approximately 40% of those assessed) are considered to have "exceptional" biological communities and water quality (Sandberg, 2017). A few exceptions exist in localized areas of the watershed that have been impacted by various land-uses related to resource extraction and development.

For example, water quality impairments for turbidity/total suspended solids (TSS) remain for several streams (Poplar River, Flute Reed River). Restoration activities aimed at reducing sediment loads in the Poplar River watershed have led to reduced TSS concentrations and loadings in recent years, and as a result, the impairment designation may be removed shortly if monitoring results continue to show that water quality standards are being met. Although some restoration work has been completed in the Flute Reed River, recent data continue to support the TSS impairment listing. One additional reach of the Flute Reed was added to the impaired waters list during the most recent assessment process for failing to meet water quality standards for TSS.

The assessment report cited several current and potential threats to the biological integrity of the Lake Superior North watershed. Increased development of privately held land, degradation or removal of riparian and shore land vegetation, and infrastructure crossing or in the vicinity or streams (e.g. gravel roads, railroads) were all listed as threats and impacts from all of these sources were observed during follow-up monitoring work.

Rationale for Selection of Focus Sub-Watersheds

Typically, the primary focus of MCPA's "stressor identification" monitoring efforts is to identify the cause(s) of impaired aquatic assemblages (fish/macroinvertebrates). In the Lake Superior North watershed, as well as many of the less impacted areas of Northeastern Minnesota, the emphasis of this effort has shifted to restoration and protection goals due to the lack of conventional water quality and biological impairments. Listed below are four primary goals that provided the framework for stressor identification work in the LS North watershed.

Specific Objectives:

1. Provide in-depth data collection to determine sediment sources/pathways in TSS/turbidity impaired watersheds and prioritize restoration/protection targets

2. Evaluate biological response data to determine if there are any symptoms of stress related to increased TSS concentration in impaired waters
3. Evaluate stressors and prioritize restoration and protection projects for streams that are vulnerable to change or narrowly meeting fish and macroinvertebrate IBI criteria
4. Identify localized impacts that can be corrected with restoration strategies that are feasible and have high success rates (e.g. fixing perched/undersized road culverts)

Study watersheds were selected based on the current impaired waters list, input from MCPA/DNR staff, and suggestions from local units of government and citizen stakeholders. Table 1 lists the streams and watersheds evaluated during this study and the primary objective for each specific effort. The location of the study areas are shown in figure 2.

Table 1: Study areas and specific objectives

In-Depth Watershed Assessments and Problem Investigations		
Stream (Sub-Watershed)	**Impairments**	**Objective *(see list of objectives in main text)***
Flute Reed River (Flute Reed River)	Total Suspended Solids	1,2,3,4
Woods Creek (Devil Track River)	None	3,4

Localized Restoration and Protection Studies		
Stream (Sub-Watershed)	**Stressor**	**Objective *(see list of objectives in main text)***
Fredenberg Creek (Two Island River)	Loss of connectivity	4
Wanless Creek (Cross River)	Loss of connectivity	4
Numerous Streams along old LTV rail line	Loss of connectivity	4

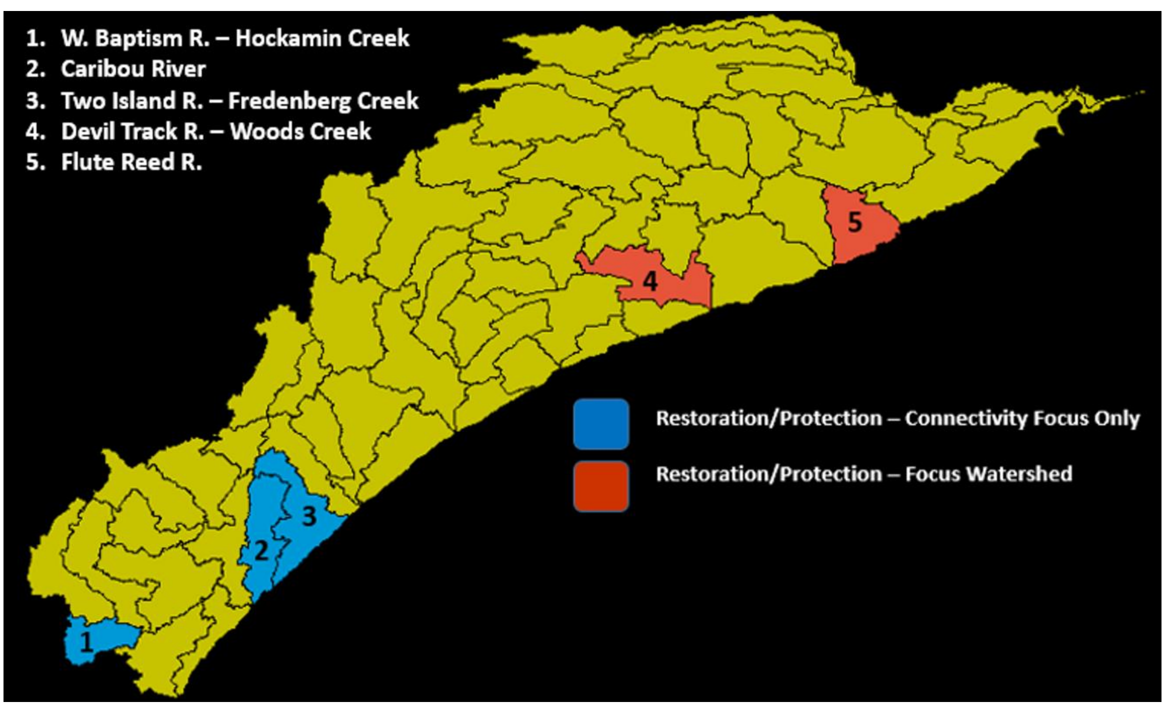


Figure 2: Map of study areas within the Lake Superior North drainage basin

3.0 Methods

3.1 Stream Temperature Monitoring and Analysis

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 2: Fish species included in various coldwater IBI metrics used by MPCA

Common Name	Thermal Class Metric	Status in LS 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 determine 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, MN 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) (Table 4). 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 3: Thermal criteria used by MN 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 SE MN Driftless area, the hydrographs (stream flow patterns) of many Northeastern MN coldwater streams are heavily influenced by overland runoff, with many streams lacking a significant groundwater contribution (more in section 4.8). Although there are many miles of designated trout streams in this region, a good portion of them offer marginal temperatures for supporting coldwater obligate species (e.g. Brook Trout). 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 where colder water and ambient air temperatures persist throughout the year.

Given the unique qualities of NE MN 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 included in the data set were exclusively found within the 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 Flute Reed River, Woods Creek, and other study watersheds are limiting for coldwater biota. The four categorizes are described based on stream temperature measures and biological condition in table 5.

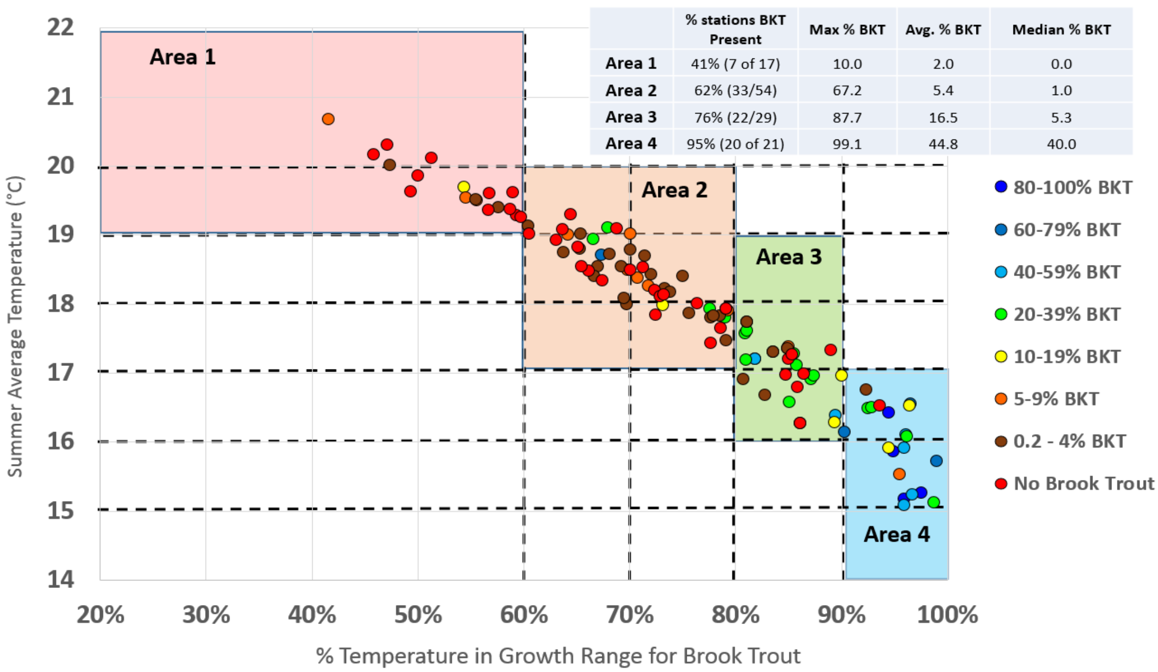
Table 4: Four temperature regime categories developed based on visual interpretations of the scatterplot results of North Shore trout streams with temperature/fisheries data

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

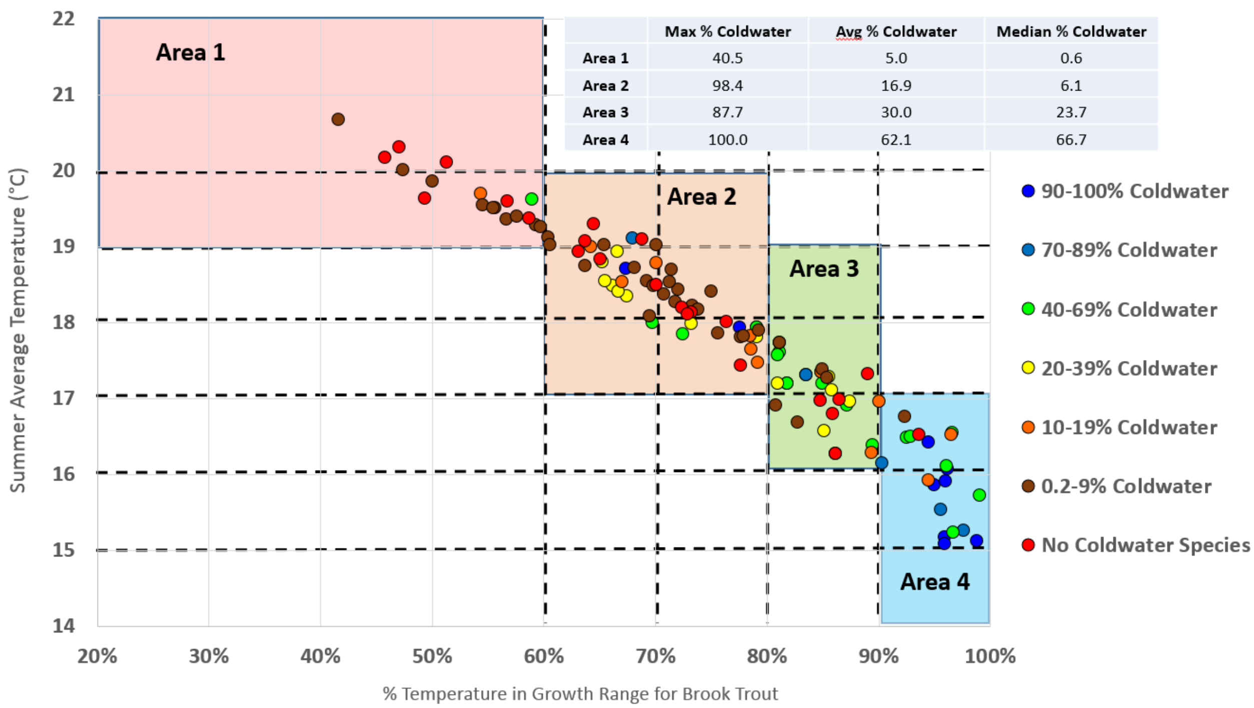
Brook Trout and other coldwater species were present at some stations in all four thermal categories, which highlights the difficulty in definitively predicting fish communities based on data from a single temperature monitoring point per stream reach. For example, two Brook Trout were sampled at Caribou 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 ability to migrate seasonally 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 avg. temperature < 17 C) supported BKT and most stations had relatively high populations. The majority (76% or 22/29) of stations within “Area 3” also supported Brook Trout, with slightly lower relative populations 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 4.7 (Flute Reed River) and 5.3 (Woods Creek) for a detailed evaluation of water temperature as a stressor to aquatic life in the impaired streams of the Lake Superior North watershed.



	% stations BKT Present	Max % BKT	Avg. % BKT	Median % BKT
Area 1	41% (7 of 17)	10.0	2.0	0.0
Area 2	62% (33/54)	67.2	5.4	1.0
Area 3	76% (22/29)	87.7	16.5	5.3
Area 4	95% (20 of 21)	99.1	44.8	40.0

Figure 3: 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 LS South/LS North 8HUC stations with biological and temperature data from same season.



	Max % Coldwater	Avg % Coldwater	Median % Coldwater
Area 1	40.5	5.0	0.6
Area 2	98.4	16.9	6.1
Area 3	87.7	30.0	23.7
Area 4	100.0	62.1	66.7

Figure 4: 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 LS South/LS North 8HUC stations with biological and temperature data from same season

3.2 Streambank Erosion Assessments (BANCS Model) and Bank-Height Ratio

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 which has not been published. 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 5: Methods for field determination of Near Bank Stress (NBS) used in the BANCS model. Field-based data for methods #1 and #2 were used in Lake Superior North assessments

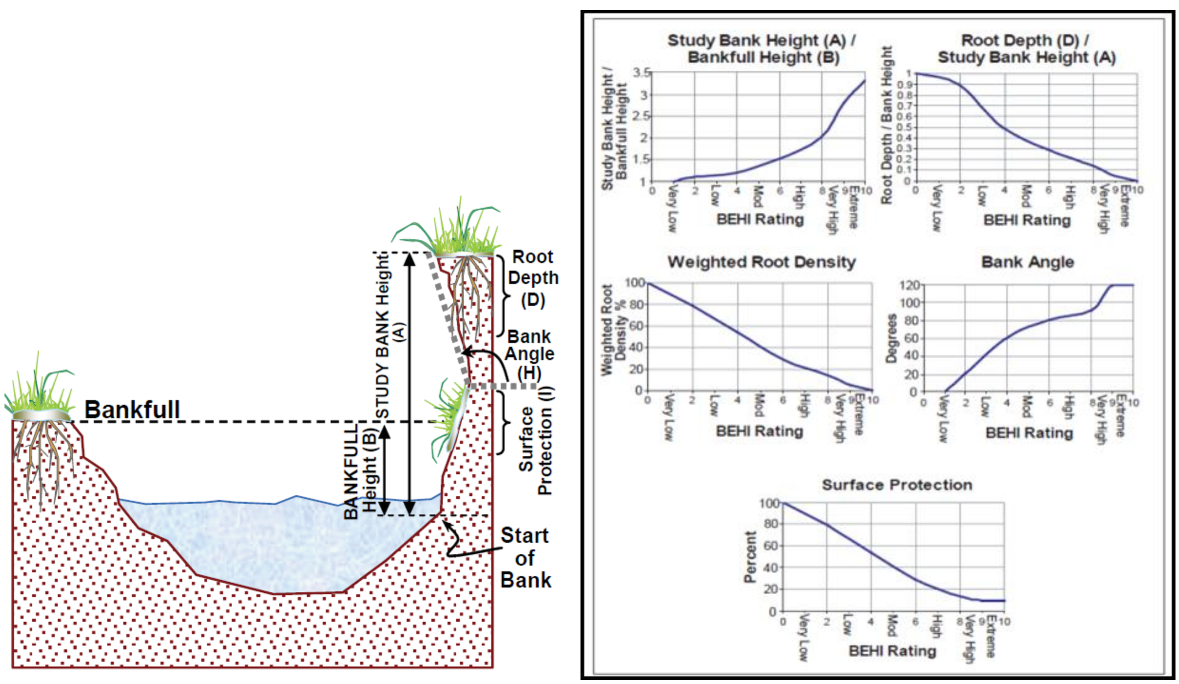


Figure 6: Bank parameters collected in the field (left) and scoring system to develop BEHI rating (right)

Bank-Height Ratio (BHR) measurements were used to measure the degree of channel incision along several of the streams covered in this report. If the BHR value is greater than 1.0, then flows greater than the bankfull discharge will be not access a floodplain and will be more prone to causing bank erosion. A BHR value of 1.0 (Low Bank height = Bankfull height) indicates connectivity to a floodplain, which results in less shear stress on streambanks and lower erosion potential.

The formula for calculating BHR is shown below:

$BHR = LBH/d_{bmx}$; --- BHR = Bank-Height Ratio LBH = Lowest Bank Height d_{bmx} = bankfull maxiumum depth

3.3 Stream Channel Stability and Habitat Assessments

Brook Trout Suitability Assessment (BTSA)

The Brook Trout Suitability Assessment (BTSA) is a modification of an assessment developed by Bidelspach and Geenen (2011) 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. Results from Pfankuch Stability Index forms, continuous temperature loggers, 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 degraded 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 (PSI)

The Pfankuch Stability Index (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. An example PSI data sheet and complete list of PSI results by station are included in Appendix A.

3.4 Stream Connectivity, Crossings, and Aquatic Organism Passage

Why is Stream Connectivity Important?

Stream connectivity refers to the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes (Annear, 2004). Stream ecosystems are highly complex, as fish movement, habitat heterogeneity, and life-stage dependent habitat requirements interact to influence fish distributions at the watershed scale (Fausch et al., 2002). 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 (figure 7).

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 demonstrated 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 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 main stem areas and tributaries for the purposes of spawning, feeding, and refuge from elevated water temperatures (Petty et al., 2012).

Culverts, dams, and other barriers to migration negatively affect many non-game native species as well. Log or metal weirs installed in streams along Puget Sound in Washington restricted dispersal, condition, and abundance of native sculpins (Cottus spp.) (Lantz et al, unpublished). Similar impacts to the native sculpin spp. of Minnesota can be expected in streams fragmented by migration barriers.

A significant portion of Minnesota's remaining native Brook Trout habitat is contained within the Lake Superior North watershed. Although much of the region is sparsely populated and land ownership is predominantly public (e.g. National Forest, State Parks or undeveloped State Land), a substantial network of infrastructure exists to promote tourism, recreation, and economic growth. Maintaining stream connectivity and aquatic organism passage is critical for the short and long-term health of these coldwater streams.

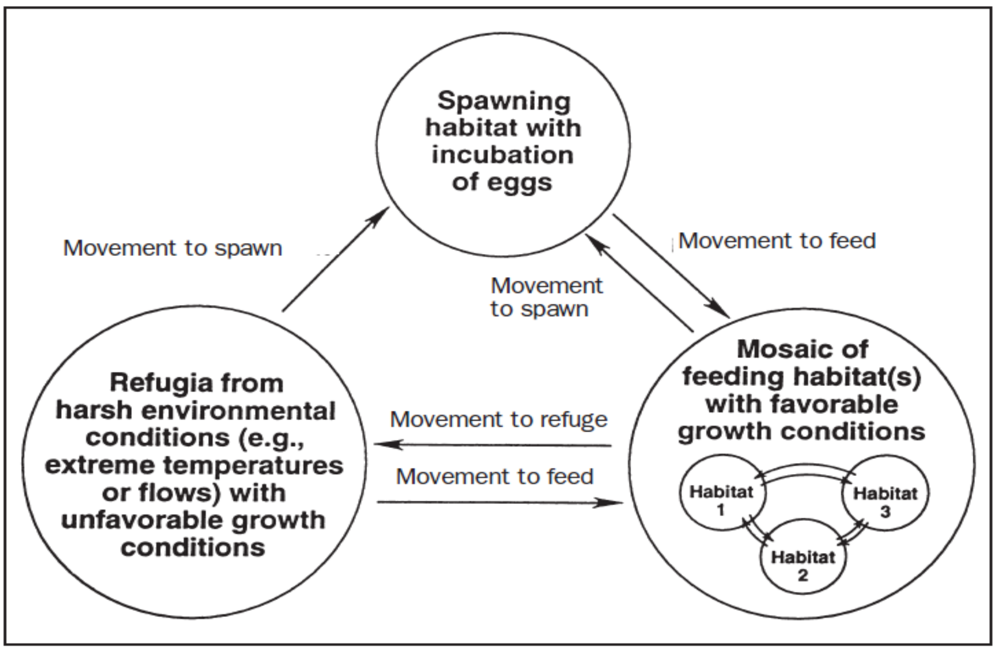


Figure 7: The basic life cycle of stream fish with emphasis on patterns of habitat use and migration (from Schlosser, 1991)

3.5 Stable Isotope: 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. Isotopes can 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 Rsample is the isotope ratio (18O/16O, 2H/1H) of the sample and RVSMOW 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 (18O or 2H) than the standard and a negative δ-‰ value signifies that the sample has less of the heavy isotope (18O or 2H) 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 ($\delta 2H = 8.17* \delta 18O + 11.27$), developed by Craig (1961) defines a linear relationship between δ18O and δ2H in waters derived from precipitation worldwide however this relationship can vary geographically. For this reason, local meteoric waterlines can be developed regionally. 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 δ18O and δ2H (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 precipiration-driven watershed, the intersection of the LMWL and LEL (inflow value) represents the weighted mean annual precipitation, also known as the 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.

4.0 Flute Reed River

4.1 Watershed Characteristics

The Flute Reed River drains an area of just over 17 square miles in Cook County, located in extreme Northeastern Minnesota. Its watershed is predominantly forested (87%, 2011 NLCD) with low percentages of developed land (2%, 2011 NLCD) and agricultural land (0%, 2011 NLCD). Total area of hydrological storage in the watershed (combined % of area in wetlands and water bodies) is 19.7%, most of which is provided by Moosehorn Lake, riparian wetlands, and beaver ponds. These hydrologic storage areas are critical features, as soils in this watershed have a moderately high potential to generate runoff during precipitation events. Nearly 46% of the total watershed area falls into the "red clay" area of the Western Lake Superior basin, which is composed of soils that are highly erodible (see section 4.1.1 for more on red clay soils).

The majority of the Flute Reed River has a moderate stream slope between 0.9% and 1.0% (Reach 4, Figure 8). Short stream reaches exhibit a much higher gradient (3.5% - 4.2%) in the headwaters and near the confluence with Lake Superior (Reach 1 and 5, Figure 8). A 2.9-mile section (Reach 2 and 3) with low stream gradient and extensive beaver ponding accounts for a significant portion of the river's headwaters.

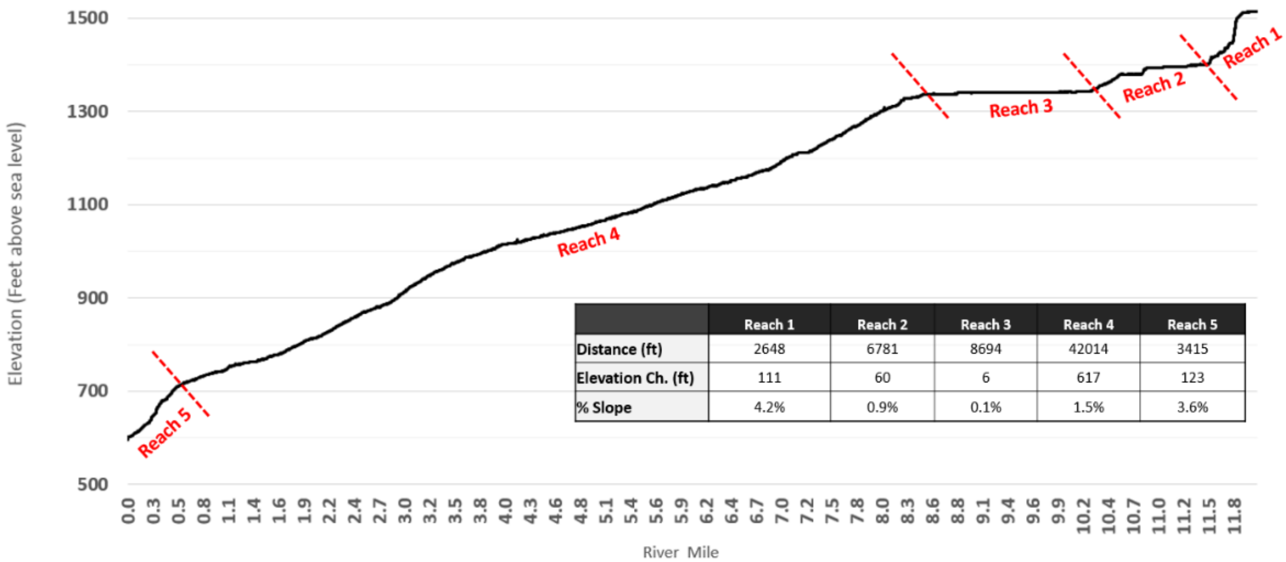
Land ownership in the watershed is 63% private, 27% state land, 9% federal land, and 1% county land. Among the 119 minor watersheds in the Lake Superior North basin, the Flute Reed watershed has the 5th highest percentage of private land ownership. Myhr Creek, which is adjacent to the Flute Reed, has the highest percent of private land at 82%. Although a significant portion of the private land in these watersheds remain forested, there is a high potential for further development in this region of the North Shore. Road construction/maintenance and timber harvest on private lands are two activities that are frequently observed in the Flute Reed watershed, and are likely negatively impacting hydrology and sedimentation due to the erosion prone clay soil geology.

4.1.1 Red Clay Soils

Red clay geology is a prominent feature of the Flute Reed watershed and profoundly impacts hydrology, sediment transport, and aquatic life. The red clay area (RCA) of Western Lake Superior extends in a narrow band from northeastern Minnesota to the western portion of Michigan's Upper Peninsula. The soils of the RCA were deposited as lake sediment during glacial periods, and as lake levels receded, formed much of the land mass along portions of Lake Superior's shoreline. Soil types of the RCA are predominantly red clays, interspersed with sands and silts. The soils are young in terms of geological time and are prone to high rates of erosion, particularly in areas with steep slopes and/or high rates of disturbance (e.g. farming, timber harvest, urban development) (EPA, 1979).

Slightly over half of the minor watersheds within the Lake Superior South and North basins contain RCA soils. RCA soils are most prevalent in the near-shore areas of Lake Superior and are less and less common moving up gradient and away from the lake. Large RCA deposits are located along the shoreline between the cities of Duluth and Beaver Bay, covering major watersheds like the Lester River, Knife River, Beaver River, Gooseberry River. Many of the streams located in this region are listed as impaired for total suspended solids (TSS) because of their sensitivity to erosion and various watershed disturbances. Another long band of RCA soils is located on the upper North Shore, extending from the town of Schroeder to Hovland. Fewer streams are impaired for TSS in this region with the exception of the Poplar River and Flute Reed River.

Nearly 51% of the Flute Reed River watershed falls within the RCA, a value that places it within the 90th percentile for this metric among all Lake Superior South and North minor watersheds. Many of the streams with >50% watershed area in RCA soils are impaired for TSS or contribute sediment loads to streams impaired for that parameter (e.g. Sucker River, Knife River, Skunk Creek, Beaver River, Flute Reed River). Bank erosion estimates prepared for the Flute Reed River show high erosion rates and sediment loading from numerous steeply sloped, large clay bluffs within the RCA (Figure 9). Recent restoration efforts have effectively stabilized several of these eroding bluffs, but many more are dispersed throughout the RCA portion of the Flute Reed watershed. The relationships between RCA soils, channel stability, and TSS are discussed in greater detail in section 4.3. Management recommendations for the red clay areas of the Flute Reed watershed are proposed in Appendix C.



	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Distance (ft)	2648	6781	8694	42014	3415
Elevation Ch. (ft)	111	60	6	617	123
% Slope	4.2%	0.9%	0.1%	1.5%	3.6%

Figure 8: Longitudinal slope profile of the Flute Reed River broken into five segments

Figure 9: Example of stream thalweg/valley wall intersection in red clay soils area of the Flute Reed River

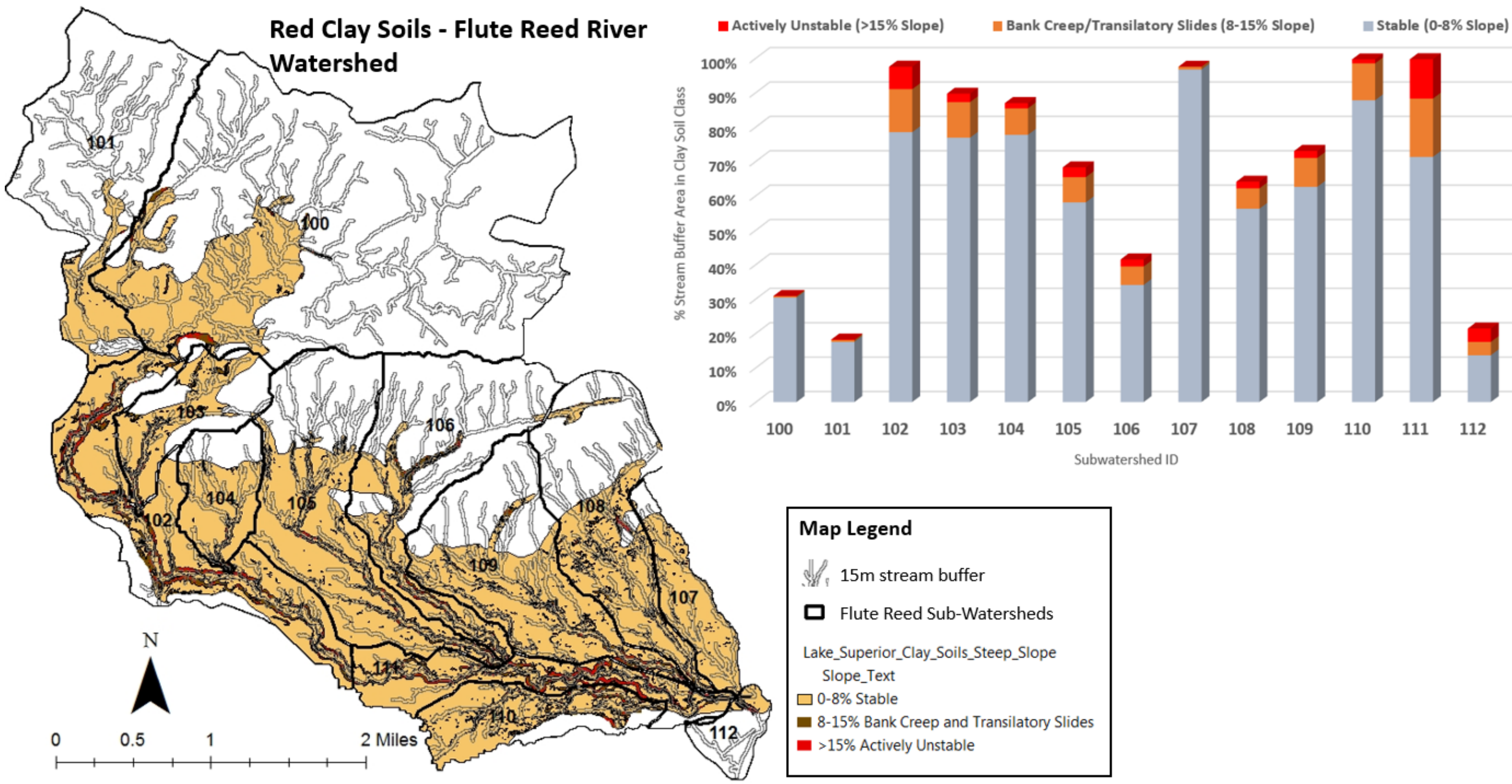


Figure 10: Extent of red clay soil in the Flute Reed River watershed, including percentage of land area in red clay soils area within 15-m buffer segments by sub-watershed

4.2 Overview of Biological Data

The Flute Reed River is a designated coldwater trout stream from its headwaters (Tom Lake) to its confluence with Lake Superior. The most recent management plan, updated by MN DNR in the winter of 2016, has defined management goals for Rainbow Trout and Brook Trout (Persons and Weberg, 2016). The following paragraphs provide a brief summary of MN DNR's sampling efforts and current management strategies for these species.

Table 5: MN DNR management goals for reaches of the Flute Reed River

Flute Reed River	Managed Length 11.6 miles		Total Length 11.6 miles	
Reach name	**Stream Miles**	**Rosgen Channel Type**	**Ecological Classification**	**Species of Management Interest**
Lower Anadromous	0.0 – 0.7	A3	1D	Rainbow Trout
Upper Anadromous	0.7 – 8.3	B3	1D	Rainbow Trout
Inland	8.3 –11.2	C3	1D	Brook Trout
Headwaters	11.2 – 11.6		1B	Brook trout

4.2.1 MN DNR Management and Sampling History

Brook Trout

Historic and contemporary sampling results indicate the Flute Reed River offers very marginal conditions wild Brook Trout. Moyle and Smith (1944) characterized the river as too warm for brook trout and recommended stocking brown trout in a 4.6 mile reach. In the 1970's Brook Trout were sampled from several locations in the upper reaches of the Flute Reed and a small headwaters tributary stream. However, no Brook Trout were sampled at these locations in subsequent visits to these monitoring stations in 1981. The area was sampled again in 2007 by angling, and one Brook Trout was taken although there is some suspicion that the sample may have been a mis-identified Splake, which are stocked annually in Moosehorn Lake just upstream of the sampling station. Based on this sampling history, some marginal habitat exists for wild Brook Trout populations in the upper-most reaches of the watershed, but sampling results are limited and natural background conditions (low streamflow, relatively warm water temperatures) are not optimal for this species.

Brook Trout have been stocked in the Flute Reed River watershed intermittently from 1901 through 1972, but all accounts indicate a failure to establish a viable self-sustaining population through natural (in-stream) reproduction. In the 2011 management plan, MN DNR stated a long term-goal of restoring the ability of the Flute Reed River to support Brook Trout using targeted protection and restoration activities within the watershed. The 2016 edition of the management plan dropped this goal, citing the current marginal conditions and potential for climate change to intensify stressful conditions in the future.

The current management plan still identifies the need to determine whether suitable conditions for Brook Trout exist in the headwaters. Additional temperature data were collected in the Flute Reed River headwaters in 2016, but fish and habitat conditions were not sampled upstream of river mile 7.9.

Rainbow Trout (Steelhead)

The Flute Reed River provides more miles of spawning and nursery habitat to anadromous Rainbow Trout (Steelhead) than any other stream along Lake Superior's United States shoreline north of the Knife

River. Adult Steelhead migrate into river from Lake Superior seasonally during periods of moderate to high streamflow, typically in the spring and less often during the fall season. After spawning in the early spring, the adult steelhead return to Lake Superior. Steelhead eggs hatch in four to seven weeks, depending on water temperature and the young-of-year (YOY) fish typically spend the first two years of their lives in their natal streams before becoming “smolt” and migrating out to Lake Superior. In most cases, adults return annually to their natal streams to reproduce. A typical life span for Steelhead Rainbow Trout is four to six years.

The MN DNR considers the Flute Reed River a “medium priority” stream in the area due to the lack of public access for angling. Over the past 30 years, the river has been heavily stocked with various strains of Steelhead fry (i.e. recently hatched but lacking yolk-sack). Stocking efforts were discontinued after 1991 due to funding shortages, and a change in management philosophy towards catch and release angling and wild Steelhead. More on this management approach can be found in the North Shore Steelhead Management Plan. Reproductive success of wild Steelhead has been adequate for sustaining good populations of YOY and age-1+ fish within three river miles of Lake Superior (Persons and Weberg, 2016). Additional miles of spawning and rearing habitat exists for several miles upstream, but access is limited due a number of factors, including road crossings, low streamflow conditions, and possibly due to an relatively high density of beaver dams along the stream corridor.

Figure 11: Wild adult Steelhead Rainbow Trout caught by an angler in the Flute Reed River

4.2.2 MPCA Biological Monitoring Results

MPCA has sampled fish and aquatic macroinvertebrate communities at numerous stations in the Flute Reed River watershed over the last several decades. Full fish and macroinvertebrate community samples were collected and used to calculate Index of Biological Integrity (IBI) scores to evaluate overall stream condition. A summary of the stations sampled, IBI results, and relevant biological criteria used to determine impairment status are included in Tables 6 and 7.

Fish Results

Overall, fish IBI results are well above the applicable IBI standard, indicating a relatively healthy coldwater fish assemblage at most monitoring stations (table 6). Fish IBI results at station 13LS038 (river mile 7.0) varied considerably between 2013 and 2014 sampling events, with the 2014 results falling just below the fish IBI standard. Physical habitat conditions and water chemistry at this location are excellent, but water temperatures in this reach routinely exceed the “stress” and “lethal” thresholds for Brook Trout. Warmer water temperatures at this station are clearly a limiting factor for stenothermic coldwater taxa. Creek Chub was the dominant species at this monitoring station, and small populations of headwaters/coolwater/wetland minnow species were also present (e.g. Northern Redbelly Dace, Pearl Dace, Finescale Dace).

Fish IBI scores were good to excellent at the other two monitoring stations, which are located in the lower reaches of the Flute Reed River. Both of these stations exhibited low taxa richness (2-3 species), but supported relatively high populations of wild Rainbow Trout which improved overall fish IBI scores. Creek Chub and Brook Stickleback (98LS038 only) were the other species sampled at these locations.

Macroinvertebrate Results

Macroinvertebrate IBI scores from the Flute Reed River were all above the general use standard (32), and most results surpassed the exceptional use standard (60) (click here for explanation of general/exceptional use) (Table 7). In contrast to the fish IBI results, the macroinvertebrate IBI scores show a general downward trend in an upstream to downstream direction. This trend may be due in part to elevated TSS concentrations and/or degraded habitat conditions in the lower half of the Flute Reed River main stem. The potential stressor-response relationship between elevated TSS and macroinvertebrate biological integrity in this watershed is evaluated in further detail in section 4.3.

Table 6: Summary of Flute Reed River biological sampling stations, results, and applicable assessment criteria (fish only). Map of stations can be found in figure 21. Bold Black text indicates IBI scores meeting aquatic life standards. Red text indicates IBI score failing to meet aquatic life standards. Blue highlights indicate scores that exceed exceptional use standards.

Station	Drainage Area (mi2)	Fish IBI Class	Fish IBI Result *(visit year)*	Fish IBI Result *(visit year)*	IBI Standard	IBI Lower Confidence Limit	IBI Upper Confidence Limit	Exceptional Use Threshold
13LS038	5.88	8	**53** (2013)	**33** (2014)	35	25	45	60
98LS038	12.17	8	**58** (1998)	-	35	25	45	60
13LS027	15.44	8	**60** (2014)	-	35	25	45	60

Table 7: Summary of Flute Reed River biological sampling stations, results, and applicable assessment criteria (macroinvertebrate results only). Map of stations can be found in figure 21. Bold Black text indicates IBI scores meeting aquatic life standards. Blue highlights indicate scores that exceed exceptional use standards.

Station	Drainage Area (mi2)	Invert IBI Class	Invert IBI Result *(visit year)*	Invert IBI Result *(visit year)*	Invert IBI Result *(visit year)*	IBI Standard	IBI Lower Confidence Limit	IBI Upper Confidence Limit	Exceptional Use Threshold
13LS038	5.88	11	**72** (2013)	**68** (2015)	**58** (2016)	32	20	44	52
16LS010	7.59	11	**59** (2016)	-	-	32	20	44	52
86LS015	7.89	11	**54** (2015)	**68** (2016)	-	32	20	44	52
13LS027	15.44	11	**39** (2013)	**44** (2015)	**53** (2016)	32	20	44	52

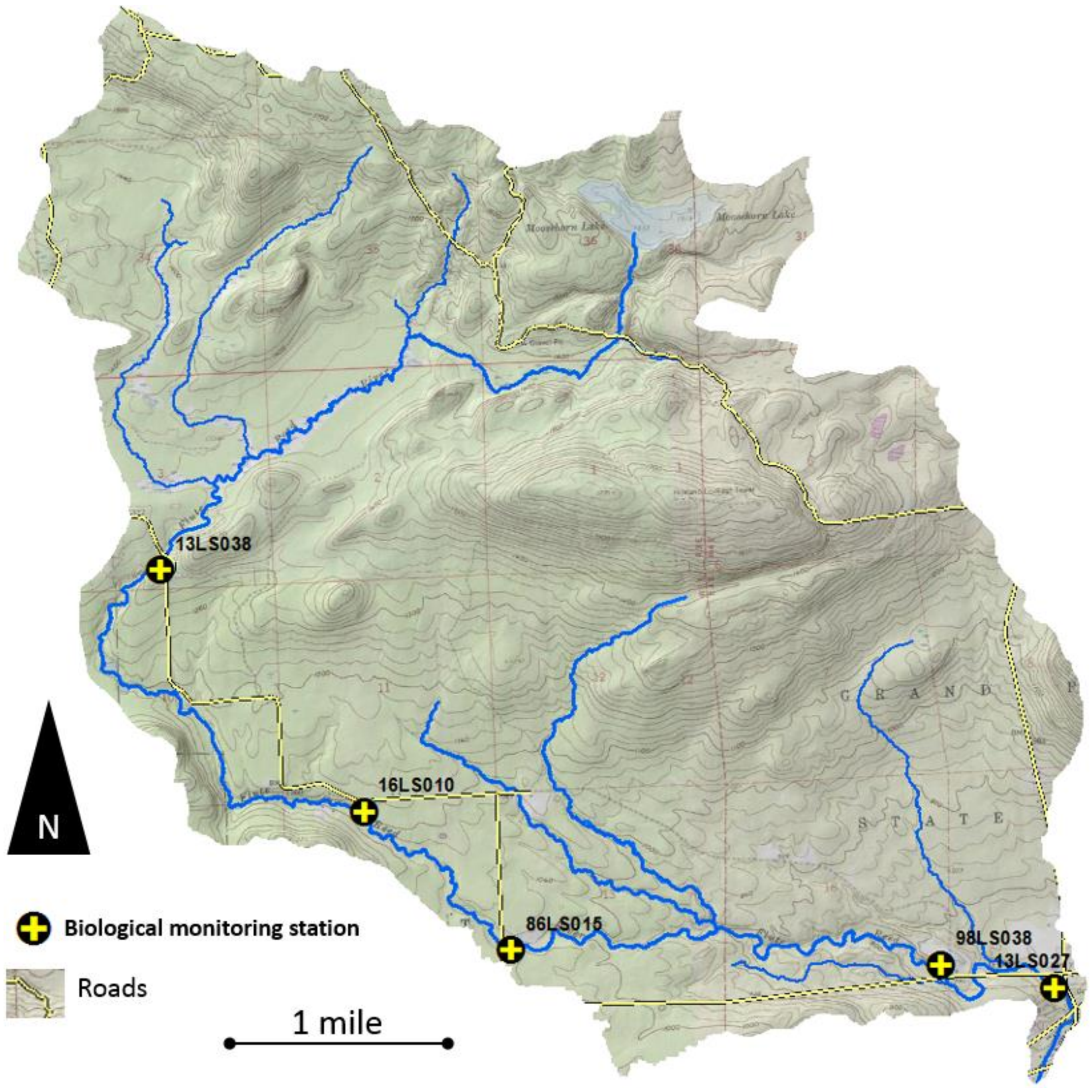


Figure 12: Flute Reed River watershed and biological monitoring stations

4.3 Turbidity/TSS Impairment

The Flute Reed River was first listed as an impaired water in 200_ for failing to meet aquatic life based water quality standard for total suspended solids. The initial impairment listing covered the lower 0.8 miles of the river due to a lack of data upstream of this point. The additional 10.3 river miles upstream were added to the impairment following the 2016 assessment process. Currently, the entire length of the Flute Reed River (Moosehorn Lake to Lake Superior) is listed as impaired for failing to meet the TSS standard for coldwater streams (10 mg/L).

Additional TSS data were collected throughout the Flute Reed River watershed in 2015 and 2016. The goals of this effort were to identify longitudinal trends in TSS concentrations over various flow regimes and identify areas contributing disproportionately high and low sediment loads. A map and table of TSS monitoring locations are included in figure 13.

4.3.1 Trends at "Long-Term" Stations

Larger TSS data sets are available for four monitoring stations, which have been sampled frequently over an eight-year period (2008-2016). These four stations are located in distinct areas of the watershed and can be used to evaluate TSS trends both spatially and over time. For the purpose of evaluation major shifts in TSS concentrations along the main stem of the Flute Reed, these four stations were categorized into "Headwaters" (FR 12; S004-277), "Mid-River" (FR 7; S004-235), "Lower River" (FR 2; S007-557), and "Mouth" (FR 1; S004-283).

Box-plot distribution charts of TSS and turbidity results from these four stations are shown in figure 16 and 17. The maximum values for both TSS and turbidity increase at a consistent rate from upstream to downstream, but median and interquartile range results show a slightly different pattern, with higher values at "Mid-River" and "Lower River" stations than observed downstream. Median TSS concentration is well below the 10 mg/L standard at the "headwaters" and "mouth" stations; but hovers near the impairment threshold at the "Mid-River" and "Lower River" stations. These results suggest that there are significant sources of TSS immediately downstream of the "Headwaters" sampling area within the "Mid-River" reach. The data also indicate that TSS concentrations are similar throughout much of the Flute Reed River during low to moderate flow conditions.

4.3.2 Synoptic Sampling Results

Longitudinal synoptic sampling of total suspended solids (TSS) was completed during four moderate to high flow events in 2015 and 2016. A total of 8-10 stations were sampled during these events, with several of these located on major tributaries to the Flute Reed River. Monitoring locations are displayed in figure 13.

The TSS standard of 10 mg/L was exceeded by at least three monitoring stations in each of the four synoptic sampling events. The highest TSS concentrations (range 17 mg/L - 181 mg/L) were observed during a May 2015 sampling event following a 2.2" rain over a 5-day period. All monitoring stations exceeded the 10 mg/L TSS standard during this sampling event with the exception of a station located the headwaters tributary FT 9 (4.4 mg/L). Results from the two snowmelt events sampled in March and April of 2016 illustrated the difference in TSS concentrations during a pre-snowmelt event (water running over anchor ice) and a snowmelt event during a complete thaw, as TSS concentrations were 2-3 times higher during the complete snowmelt event (figure 14).

TSS concentrations only narrowly exceeded the 10 mg/L standard at several stations following a 1" rainfall in June of 2016 (figure 14). All six of the tributary stations sampled had TSS concentrations below 10 mg/L. Six of ten stations sampled on the main stem of the Flute Reed River met the water quality standard, and those exceeding the standard did so by a narrow margin. Stations exceeding the standard were located between stations FR 6 and FR 4 (figure BL). Large beaver dams are present on the main stem and tributary streams in this area of the watershed, which may be linked to the higher TSS values.

Significant increases in TSS were routinely observed between stations FR 7 and FR 10 during the synoptic sampling events. This encompasses areas of the main stem between river mile 7.0 and 4.3. TSS concentrations rose sharply at station FR 7 (CR 70 - Camp 20 Rd) during every synoptic sampling event, particularly the May ’15 rain and April ’16 snowmelt. TSS concentrations also increased significantly within the approximately 3-mile reach downstream of FR 7 during the May 2015 rain event. Several prominent tributaries with high sediment loading potential and significant beaver activity empty into the Flute Reed River between these monitoring points. Relatively high bank erosion rates were predicted for many reaches of the Flute Reed River between river mile 4.3 and 7.0. Additional information on channel stability assessments and predicted bank erosion rates is included in section 4.4.2.

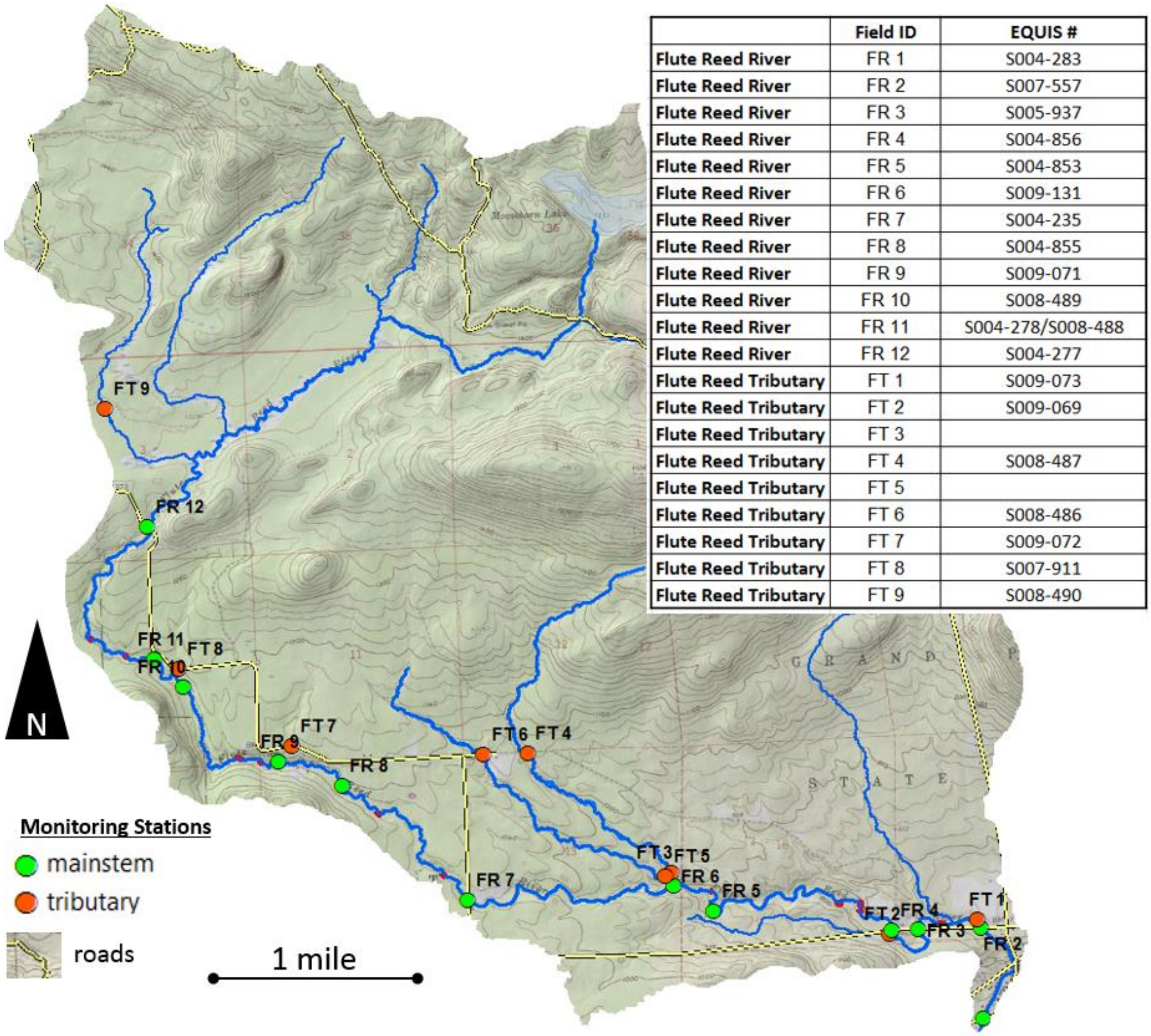
TSS concentrations varied considerably in tributary streams during the synoptic monitoring events. Stations FT 6 and FT 4 routinely recorded the highest TSS concentrations of all the tributary streams (range 3.6 mg/L – 54 mg/L). These two tributaries join to form a single channel several hundred feet upstream of its confluence with the Flute Reed River. Together, they have a drainage area of around 2.5 square miles and flow through relatively steep, clay soil dominated terrain that has seen considerable logging activity and road development over the past 30 years. A series of several large beaver dams were observed along both of these tributaries during a 2016 field assessment. Many of the beaver ponds were extremely turbid due to suspended clay particles.

Other tributary streams are contributing sediment to the Flute Reed River at high concentrations, but loadings from individual streams are relatively low due to lack of drainage area and sustained flow. The Flute Reed watershed contains a significant number of first and second order tributaries due to its highly dissected drainage pattern through moderately steep, poorly drained soils. Many of these smaller drainages support ephemeral streams that flow only during snowmelt of large rain events. Numerous headcuts were observed on tributary streams during field assessments. Cumulatively, these small tributary streams cannot be ignored as a significant source of sediment to the main stem of the Flute Reed River. Proper land-management near these small headwaters tributaries is a critical and attainable objective for reducing sediment loads.

4.3.3 Load Duration Curve

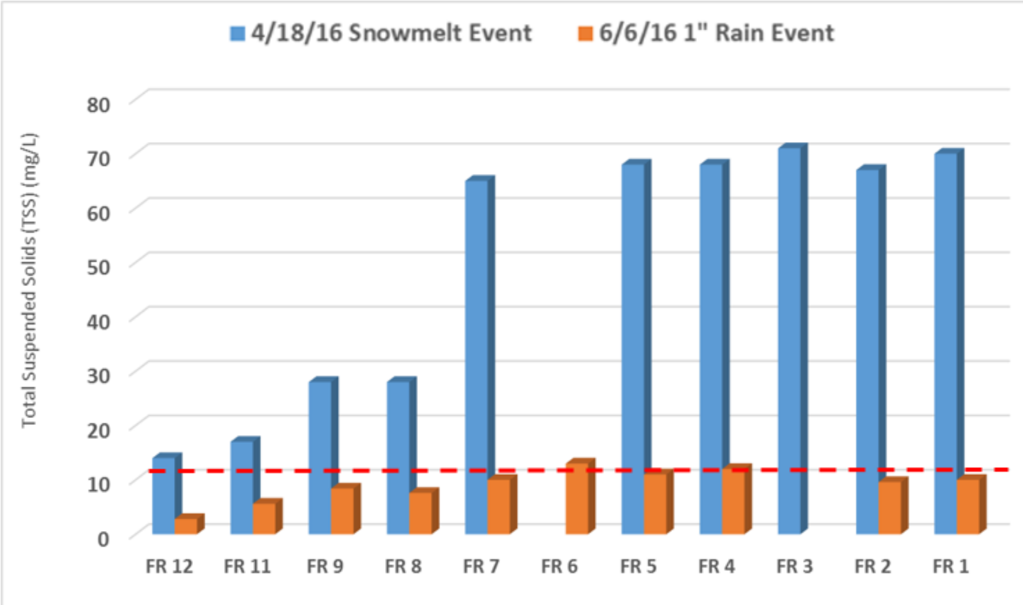
Over the past decade, Load Duration Curves (LDC) have been widely used in the development of TMDLs in Minnesota and other US States. The load duration curve approach relies on setting a desired pollutant concentration, which is typically an established water quality standard, in this case 10 mg/L TSS (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 Flute Reed River using streamflow and water chemistry data from the gauging station at RM 0.7 (figure 18). The load duration curve shows TSS loadings exceeding the TMDL allocation most frequently during periods of high streamflow (90th percentile and greater Mean Daily Flow). The average TSS concentration during this flow regime is 41.8 mg/L and a 76% reduction in sediment loading is needed to meet the aquatic life based standard of 10 mg/L. TSS load reductions are also needed to a lesser extent within the “high flow” and “very low flow” regime categories. The TSS results greater than 10 mg/L within the “very low flow” regime were likely influenced by construction activity related to bank stabilization projects upstream of the sampling point. Load reductions for TSS reductions are not expected to be required for the low flow - very low flow periods as most of the non-construction period sampling results meet the water quality standard.



	Field ID	EQUIS #
Flute Reed River	FR 1	S004-283
Flute Reed River	FR 2	S007-557
Flute Reed River	FR 3	S005-937
Flute Reed River	FR 4	S004-856
Flute Reed River	FR 5	S004-853
Flute Reed River	FR 6	S009-131
Flute Reed River	FR 7	S004-235
Flute Reed River	FR 8	S004-855
Flute Reed River	FR 9	S009-071
Flute Reed River	FR 10	S008-489
Flute Reed River	FR 11	S004-278/S008-488
Flute Reed River	FR 12	S004-277
Flute Reed Tributary	FT 1	S009-073
Flute Reed Tributary	FT 2	S009-069
Flute Reed Tributary	FT 3	
Flute Reed Tributary	FT 4	S008-487
Flute Reed Tributary	FT 5	
Flute Reed Tributary	FT 6	S008-486
Flute Reed Tributary	FT 7	S009-072
Flute Reed Tributary	FT 8	S007-911
Flute Reed Tributary	FT 9	S008-490

Figure 13: Total suspended solids (TSS) monitoring stations within the Flute Reed River watershed



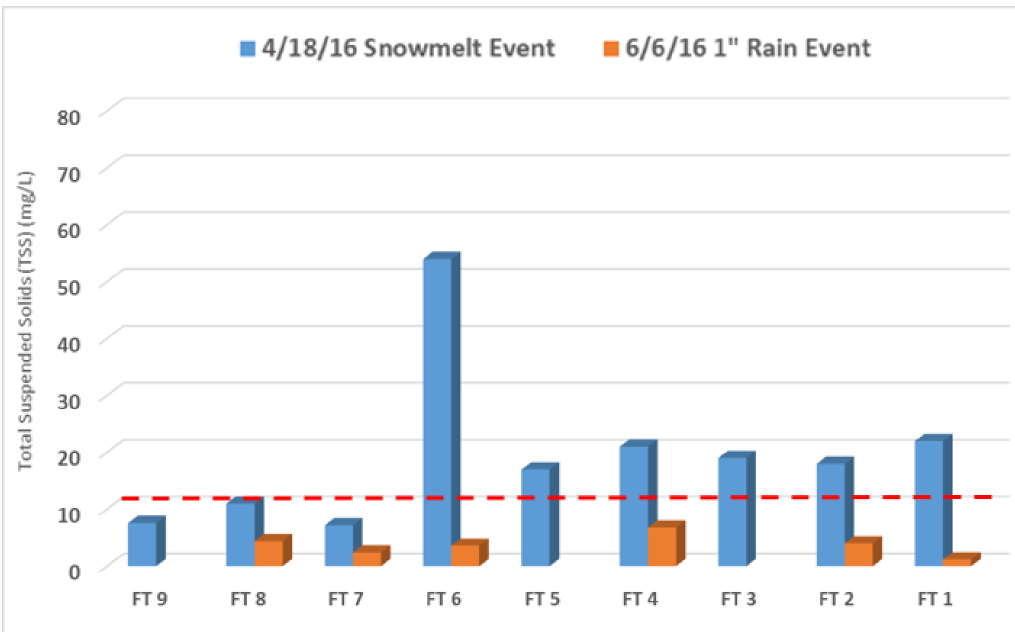


Figure 14: Results of synoptic TSS sampling in the Flute Reed River watershed for main stem stations (top) and tributary stations (bottom)

Figure 15: Visual demonstration of TSS increases from upstream (left) to downstream (right) from a 5/11/15 sampling event. Bottles in the forefront are main stem stations, and bottles set back are tributary samples

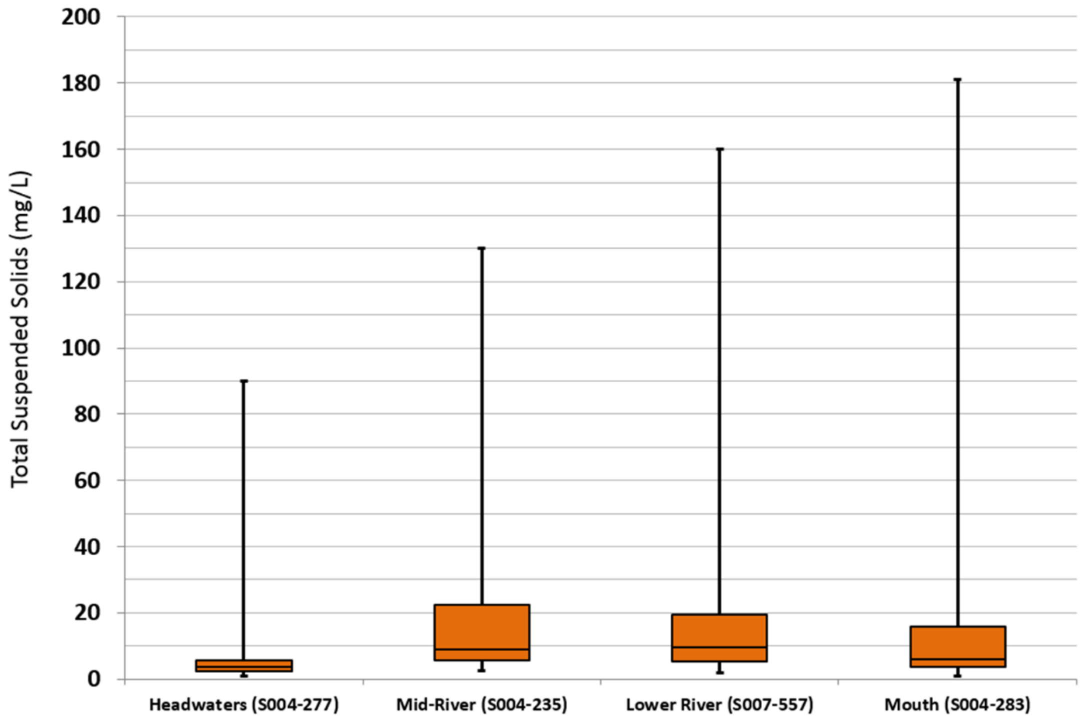


Figure 16: Results of synoptic TSS sampling in the Flute Reed River watershed.

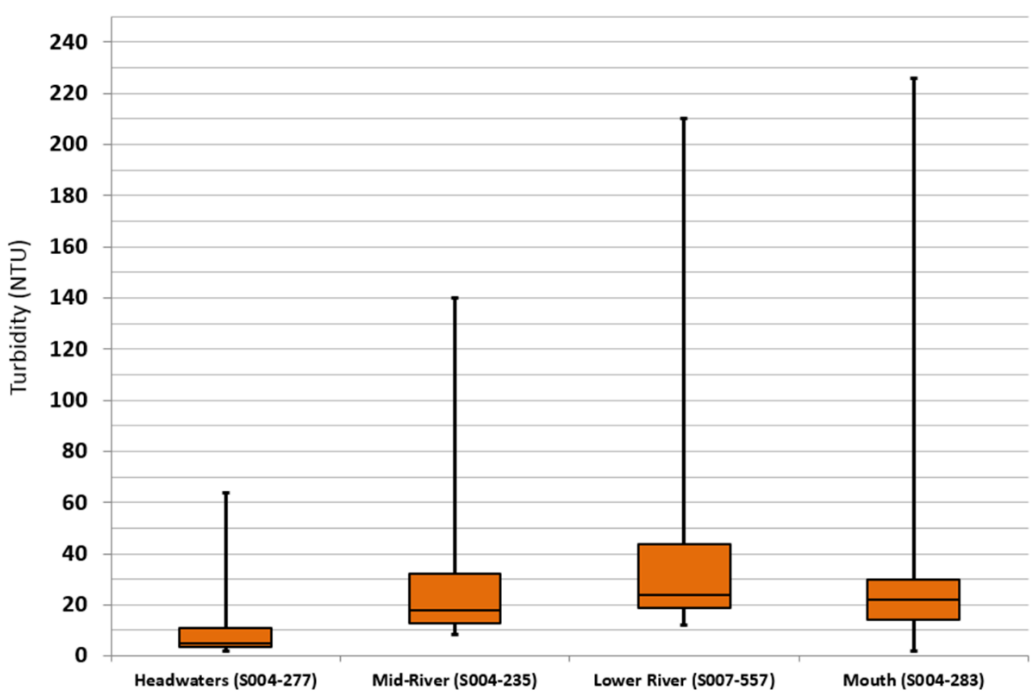
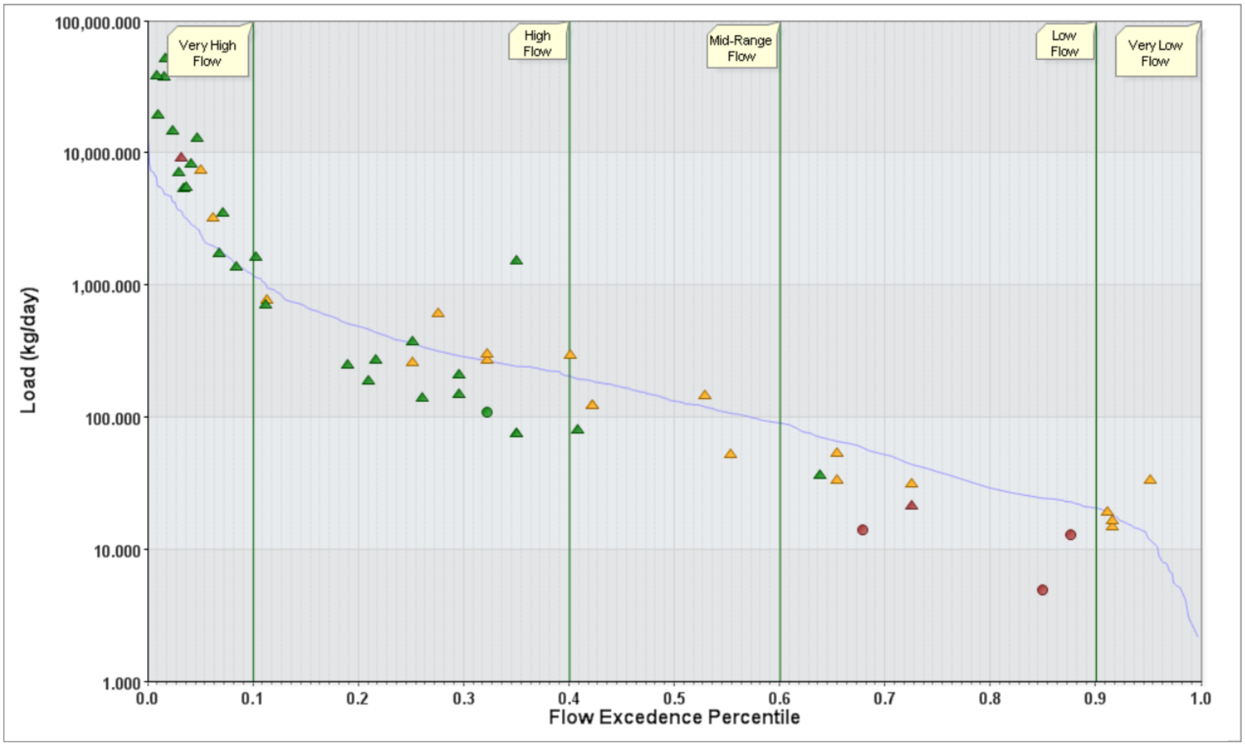


Figure 17: Results of synoptic TSS sampling in the Flute Reed River watershed



Percentile	Flow	Runoff	TMDL	Avg Conc	Load	% Red
0.01	506.0	451.90	12379.7			
0.27	301.0	268.82	7364.2			
1	229.0	204.52	5602.7			
5	100.0	89.31	2446.6	41.800	10226.7	76.1
10	48.0	42.87	1174.4			
15	28.0	25.01	685.0			
20	20.0	17.86	489.3			
25	15.0	13.40	367.0	10.489	384.9	4.7
30	12.0	10.72	293.6			
35	10.0	8.93	244.7			
40	8.5	7.55	206.7			
45	6.9	6.16	168.8			
50	5.5	4.91	134.6	7.933	106.8	0.0
55	4.5	4.02	110.1			
60	3.7	3.30	90.5			
65	2.8	2.50	68.5			
70	2.1	1.88	51.4			
75	1.6	1.43	39.1	4.975	19.5	0.0
80	1.2	1.07	29.4			
85	1.0	0.89	24.5			
90	0.9	0.76	20.8			
95	0.5	0.45	12.2	13.750	16.8	27.3
99	0.1	0.10	2.7			
100	0.1	0.08	2.2			

Figure 18: TSS Load Duration Curve for the Flute Reed River.

4.4 Flute Reed Watershed Sediment Sources & Pathways

4.4.1 Channel Stability

Channel stability and physical habitat conditions were evaluated in Flute Reed River watershed using two methodologies; the Pfankuch Stability Index (PSI) (Pfankuch, 1975) and a Brook Trout Suitability Assessment (BTSA). Background information on these two assessment methodologies are included in section 3.3. Both assessments were completed using visual observations collected during field investigations from Flute Reed RM 0.0 to RM 6.7 and two major tributaries. Data are summarized by stream reaches that were delineated based on Rosgen stream and valley types (Rosgen, 1995) and breakpoints determined by a change in habitat type, condition, or channel stability rating (Table 8). A total of 19 stream reaches were delineated using these criteria.

PSI ratings are adjusted by stream type (Rosgen, 1994) as sensitivity to disturbance is influenced by stream channel and valley characteristics. Common stream types in the watershed included B2/B3/B3c, C3-C4, and E4. The "B" channel types were associated with confined glacial trough valleys, moderately steep slopes, and larger substrate sizes (cobble/boulder). "C" channels were predominantly found in confined alluvial or fluvial valleys and were dominated by cobble substrates with smaller percentages of gravel, boulder, and silt/clay. "E" channels were found in unconfined lacustrine valleys, most of which were influenced by active or historic beaver impoundments.

PSI ratings for the main stem Flute Reed River were predominantly "stable" (9 of 19; 47%) or "moderately unstable" (8 of 19; 42%). Only two reaches were rated "unstable" (FLR 007 and FLR 013). Many of the "stable" PSI ratings were clustered near RM 6.7 and several stream miles downstream where riparian forest is mostly undisturbed, stream gradient is moderately steep, and substrates are larger in size (cobble/boulder) (e.g. reach 15 shown in figure 19). PSI ratings of "stable" were also observed in E type channels within lacustrine valley types where a combination of low bank heights (floodplain connectivity) and grass/forb vegetation have reduced bank erosion risk and maintained sediment transport capacity due to low width/depth ratios (e.g. reach 16, shown in figure 19).

A contiguous group of stream reaches stretching nearly two river miles was rated "moderately unstable" upstream of the camp 20 Rd (CR 70) crossing at river mile 3.6. Although PSI scores were not severe enough to be classified as "unstable", this reach is predicted to produce high sediment loads based on bank erosion potential (see section 4.4.2) and lack of "stable" PSI scores. Significant increases in TSS concentrations were observed immediately downstream of this reach during snowmelt conditions or following rain events.

Only 3 out of 19 reaches assessed (16%) received a rating of "unstable". PSI ratings in the "unstable" range were isolated to select reaches in the upper and middle sections of the Flute Reed River. Excess sediment deposition, high width to depth ratio, and debris jams were several symptoms of channel instability that were regularly observed in these areas. Localized bluff erosion was also observed within several of the stream segments with an "unstable" PSI rating.

In summary, the PSI results are more indicative of "systemic" channel instability concerns as opposed to localized hotspots of bank and bluff erosion. Several large eroding bluffs were noted during the channel stability assessment, but the abundance and wide dispersion of "moderately unstable" PSI scores within the lower ¾ of the watershed are likely a significant driver of TSS concentrations in the Flute Reed River. Slight to moderate rates of channel incision were observed along much of the Flute Reed River and its major tributary streams. Due to the lack of floodplain connectivity in these areas, low to moderate rates of streambank erosion is occurring throughout much of the watershed during moderate to high streamflow events.

Table 8: Pfankuch Stability Index results for the delineated stream reaches of the Flute Reed River and two major tributary streams. The location of each reach is shown in the map in Figure 22.

Reach #	Current Stream Type	Potential Stream Type	Pfankuch Score	Pfankuch Rating
FLR 000	B2	B2	56	Moderately Unstable
FLR 001	C4	C4	66	Stable
FLR 002	B3	B3	75	Moderately Unstable
FLR 003	C4	C4	95	Moderately Unstable
FLR 004	B3	B3	46	Stable
FLR 005	C4	C4	96	Moderately Unstable
FLR 006	B3	B3	45	Stable
FLR 007	B3	B3	97	Unstable
FLR 008	B3	B3	57	Stable
FLR 009	C4	C3	91	Moderately Unstable
FLR 010	C3	C3	88	Moderately Unstable
FLR 011	D6	C4	103	Moderately Unstable
FLR 012	B3c	B3c	56	Stable
FLR 013	C4b	C3b	111	Unstable
FLR 014	E4	E4	76	Moderately Unstable
FLR 015	B3	B3	55	Stable
FLR 016	E4	E4	68	Stable
FLR 017	C3	C3	56	Stable
FLR 018	B3	B3	49	Stable

Reach #	Current Stream Type	Potential Stream Type	Pfankuch Score	Pfankuch Rating
FL_ET 001	B3	B3	45	Stable
FL_ET 002	E4	E4	92	Moderately Unstable
FL_ET 003	C5	C4	108	Moderately Unstable
FL_WT 001	B3	B3	71	Moderately Unstable
FL_WT 002	Beaver Impoundment	C3	132	Unstable
FL_WT 003	C3	C3	76	Stable
FL_WT 004	B3	B3	56	Stable
FL_WT 005	C3	C3	90	Moderately Unstable
FL_WT 006	E3	E3	49	Stable
FL_WT 007	C3	C3	97	Moderately Unstable

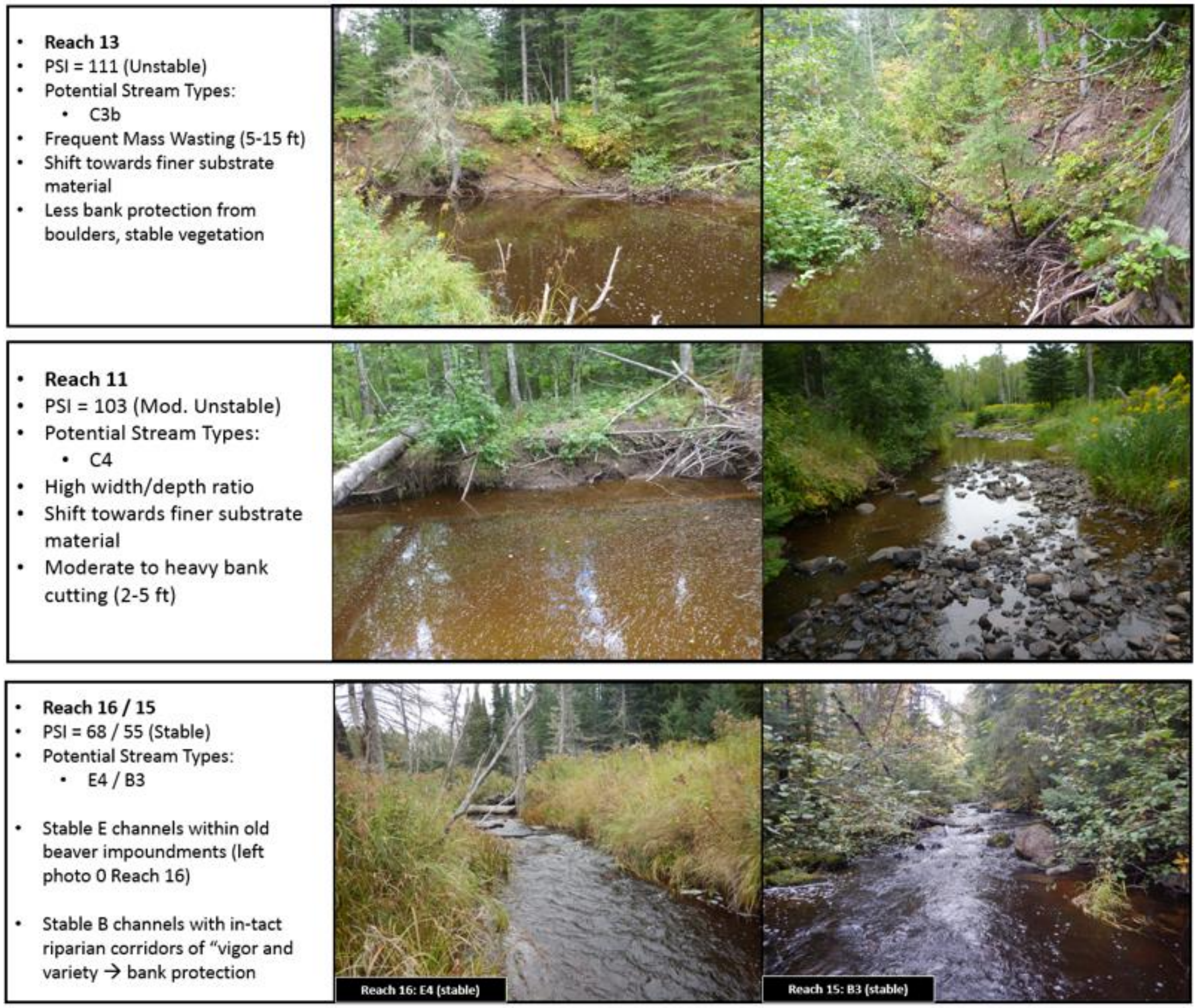


Figure 19: Examples of Flute Reed River stream reaches with Pfankuch Stability Index scores of "unstable", "moderately unstable", and "stable". The map in figure 22 shows the locations of the stream reaches.

4.4.2 BANCS Model Results

Several sources cite stream bank erosion and resulting sediment loads as threat to biological integrity in the Flute Reed River (Sandberg, 2016; Weberg, 2015). In the summer and fall of 2016, MPCA staff completed an assessment of streambank erosion potential in the Flute Reed River using the BANCS model developed by Rosgen (2006). Additional information on the BANCS methodology is included in section 3.2. The overall goals of this assessment were to quantify bank erosion potential in the Flute Reed River and two major tributaries by individual streambanks, as well as the river-reach scale to inform restoration and protection strategies.

BANCS model data were collected from 11 river miles within the Flute Reed watershed (8 miles of main stem, 3 miles of tributaries). Streambank lengths were delineated in the field based on changes in bank height and/or erosion risk. Predicted erosion rates were calculated using the curve developed by Rosgen (1996) using data from streams in Colorado. MPCA and South St. Louis County SWCD offices are currently developing a similar curve for streams along the North Shore of Lake Superior, but this regional curve was not ready for use in this report.

Predicted Erosion Estimates

The BANCS model provides predicted bank erosion estimates for the 1.0-1.5 year flood event (bankfull flow). The model predicted 1,165 tons sediment inputs from bank erosion for the 8-mile reach of the Flute Reed River assessed by the authors in 2016. This equates to 862 cubic yards of sediment, the equivalent of 62 dump truck loads. Results were summarized by stream reach to determine relative streambank erosion risk in the Flute Reed River (figures 20-22). Due to the variable length of the delineated stream reaches, the sum totals of predicted erosion were divided by the length of the reach to obtain estimated tons/ft/year. Predicted erosion rates were highest in reach FLR 005 (0.119 tons/ft/year), followed by reach FLR 013 (0.051 tons/ft/year) and FLR 003 (0.050 tons/ft/yr). The lowest predicted erosion rates were observed in three primary areas; (1) bedrock-controlled lower reaches; (FLR 000-001); (2) Steeper, cobble/boulder dominated reaches (FLR 006 – 008; approx. 2% slope, B2-B3 channel types); (3) lower gradient, meadow areas formerly impounded by beaver dams (FLR E3-E4 channel types).

The highest predicted erosion rates were observed in the central portion of the watershed (FLR 009 – FLR 011), and localized reaches in the lower 1/3 of the watershed (FLR 003 and FLR 005). The high erosion rates were associated with low to moderately slope reaches (0.75 – 1.5%) of the C3-C4 channel type. The slightly entrenched valleys associated with these channel types have led to lateral channel migration and high sheer stress on steep valley walls, many of which are composed of highly erodible clay soils.

An additional 263 tons of sediment derived from bank erosion were predicted from the two major Flute Reed River tributaries assessed. On average, predicted erosion rates within the tributaries were slightly lower than predicted values for the main stem of the Flute Reed River. A significant portion of these tributaries were impounded by beaver dams at the time of the BANCS assessment, which resulted in lower predicted bank erosion rates as many streambanks were submerged. Sediment inputs were observed due to channel avulsion and re-suspension of settled clay particles with the impounded areas.

Caution should be used in using these predicted values given that no validation of bank erosion rates has been completed in this watershed. The primary goal of the Flute Reed watershed BANCS assessment was to evaluate relative bank erosion risk by stream reach and prioritize areas for restoration and protection activities.

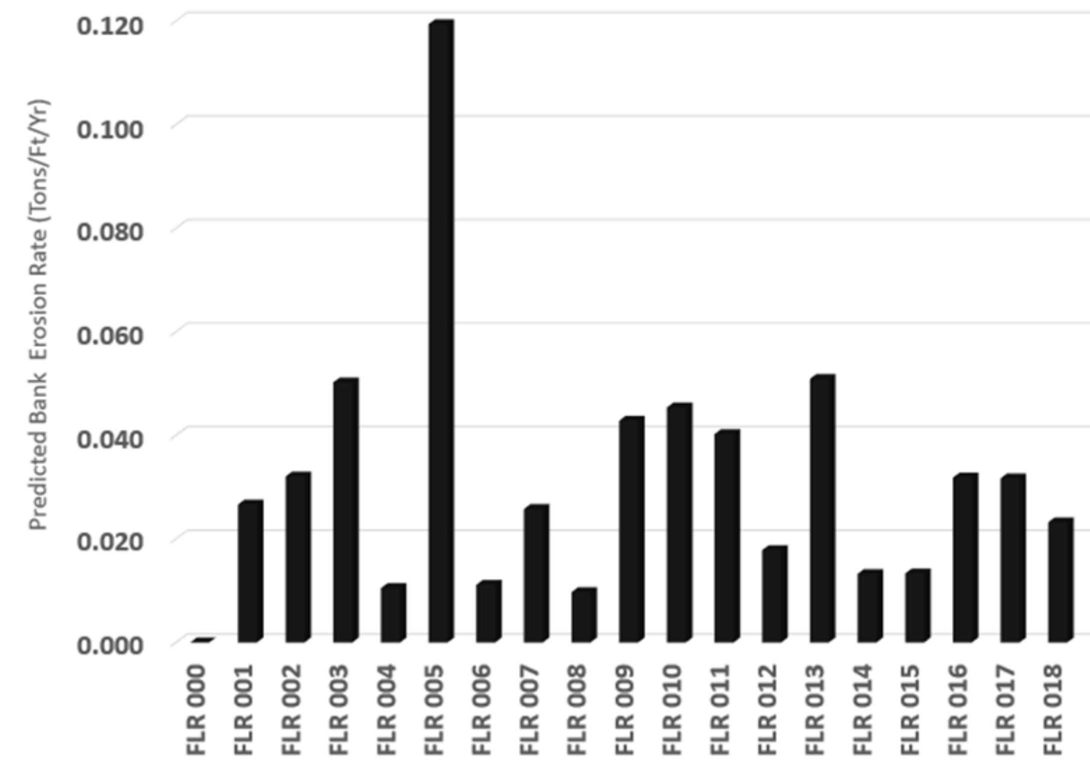


Figure 20: Predicted bank erosion rates for the delineated stream reaches of the main stem of the Flute Reed River. The map in figure 22 shows the locations of the stream reaches.

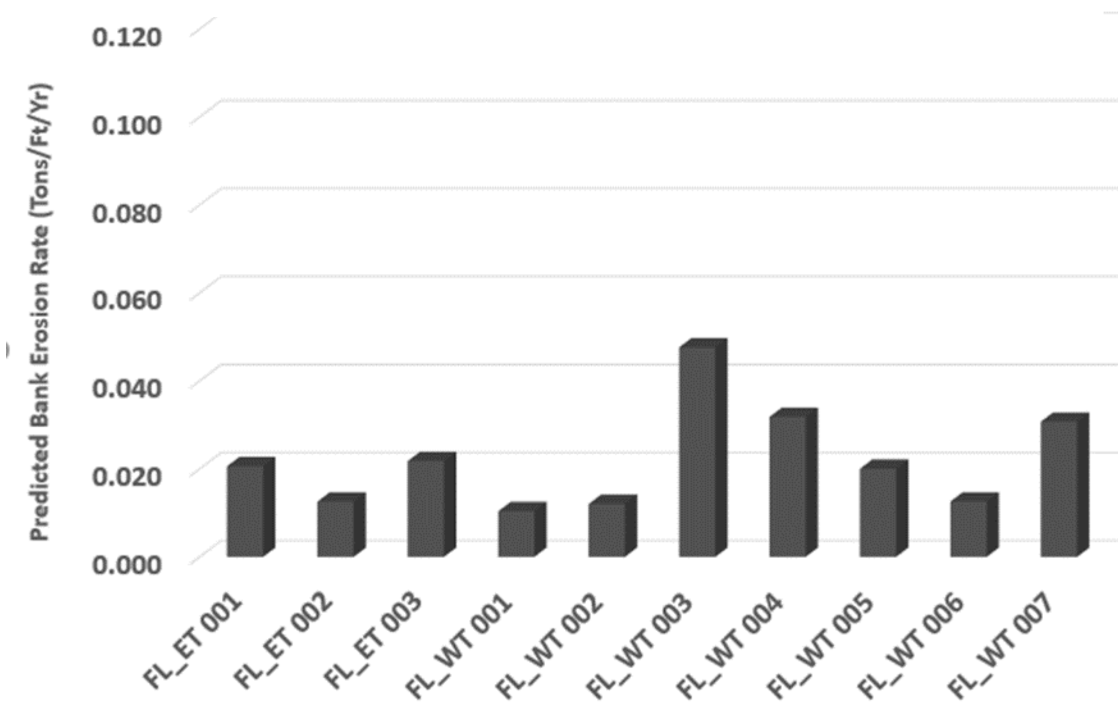
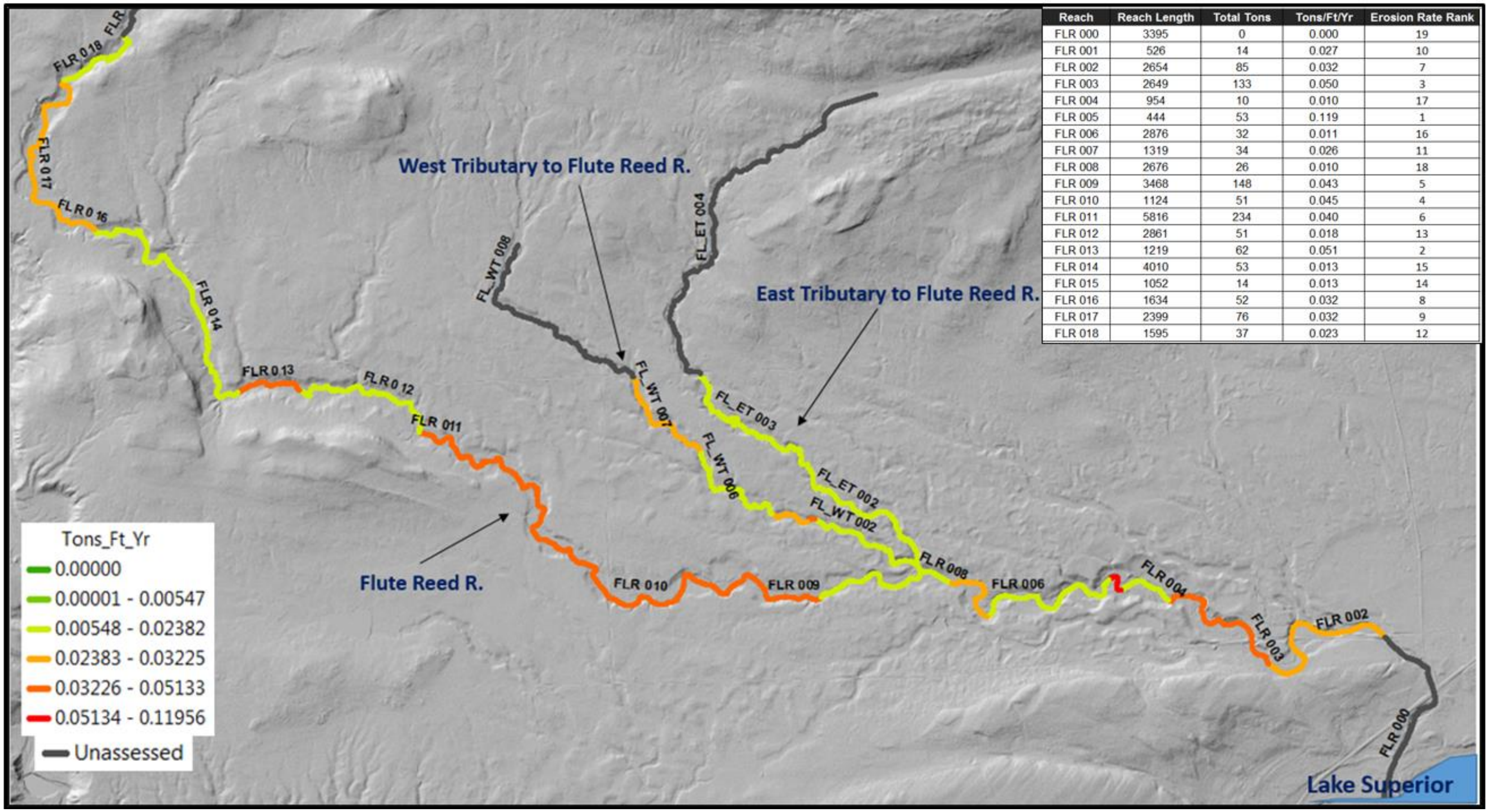


Figure 21: Predicted bank erosion rates for the delineated stream reaches of two main tributary streams to the Flute Reed River. The map in figure 22 shows the locations of the stream reaches.



Reach	Reach Length	Total Tons	Tons/Ft/Yr	Erosion Rate Rank
FLR 000	3395	0	0.000	19
FLR 001	526	14	0.027	10
FLR 002	2654	85	0.032	7
FLR 003	2649	133	0.050	3
FLR 004	954	10	0.010	17
FLR 005	444	53	0.119	1
FLR 006	2876	32	0.011	16
FLR 007	1319	34	0.026	11
FLR 008	2676	26	0.010	18
FLR 009	3468	148	0.043	5
FLR 010	1124	51	0.045	4
FLR 011	5816	234	0.040	6
FLR 012	2861	51	0.018	13
FLR 013	1219	62	0.051	2
FLR 014	4010	53	0.013	15
FLR 015	1052	14	0.013	14
FLR 016	1634	52	0.032	8
FLR 017	2399	76	0.032	9
FLR 018	1595	37	0.023	12

Figure 22: Predicted bank erosion rates for the delineated stream reaches of the Flute Reed River and two major tributaries.

Systemic Channel Incision

Bank-Height Ratio (BHR) measurements were collected along the Flute Reed River and two major tributaries to assess degree of channel incision. BHR is measured as Lowest Bank Height/ Max Bankfull Depth (Figure 23). A stream channel with a BHR of 1.0 is completely connected to an active floodplain at the bankfull discharge (approximately 1-1.5 year flood event), which reduces shear stress as floodwaters are dispersed across a flat depositional area. On the contrary, moderate to deeply incised stream channels (e.g. BHR = > 1.3) contain high flow events within the stream channel and contribute disproportionate amounts of sediment due to bank erosion resulting from high shear stress.

BHR values in the Flute Reed River varied widely (1.0 – 1.75), but the dominant BHR values indicate a stream channel that is slightly to moderately incised (BHR = 1.2-1.5) for very long distances. Stream channel incision in this watershed appears to be a "systemic" (watershed-wide) source of sediment as opposed to a localized concern affecting only a few specific reaches. Symptom associated with channel incision in the Flute Reed watershed include toe slope erosion and bank scouring, loss of streambank vegetation, increase in channel width-depth ratio, and physical habitat loss.

Channel Avulsion / Blockages

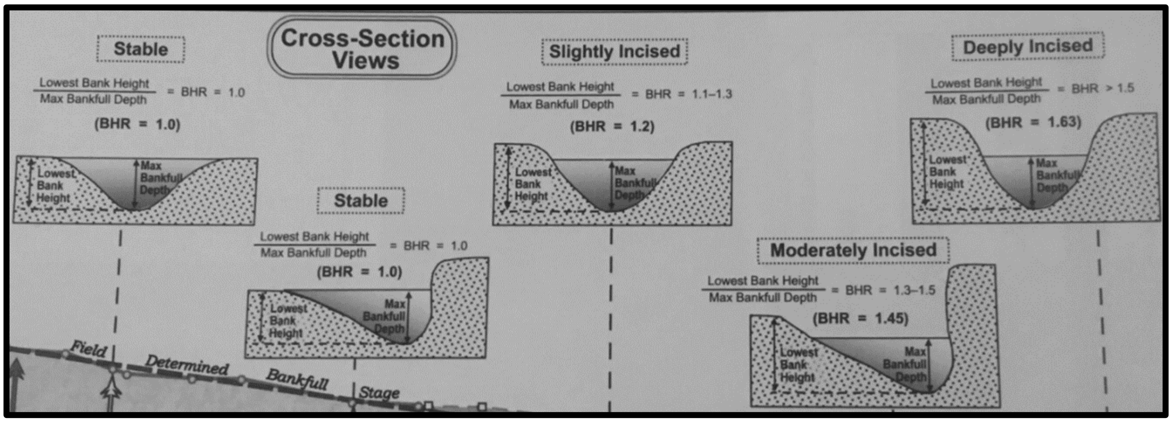


Figure 23: Description and diagram of variables and methodology for determining BHR (from Rosgen, 2006)

A certain amount of large, woody debris is desirable for both physical and biological and channel functions. However, when the frequency and magnitude of woody debris leads to channel blockages, sediment transport capacity can be reduced and channel avulsions and lateral channel migration become common. These processes are actively occurring in many reaches of the Flute Reed River and serve as a sediment source (and sink in some areas) throughout the watershed. Woody debris levels in many areas were rated as "extensive" or "dominating" based on methodologies defined in Rosgen (2008). An example of channel blockage due to extensive woody debris is shown in Figure 27.

Mass Wasting / Bluff & Valley Wall Erosion

Mass wasting is the geomorphic process by which soil, sand, and rock move downslope (and into rivers and streams). Localized areas of mass wasting were observed in the Flute Reed River watershed, contributing sediment yearlong but particularly during and after high water events. Several areas of mass wasting were observed within areas that were formerly flooded due to beaver impoundments (figure 27; "mass wasting- beaver meadows" photo). Erosion due to mass wasting processes were also evident in areas where the course of the river intersected the steep walls an unconfined valley. This scenario is common in many North Shore streams and presents a high risk for bank, terrace, and bluff erosion (Fitzpatrick et al., 2006).

BANCS assessment data were used to identify areas of active mass wasting or areas that may be prone to mass wasting in the future based on the following criteria: maximum bank heights greater than 5 feet; BEHI ratings of high, very high, or extreme; and near-bank stress ratings of moderate or higher. Twelve stream segments were identified that met these criteria. These mass erosion areas were found throughout the watershed, but were predominantly located in the middle to lower portion of the watershed. All mass wasting areas were found in areas where the active stream channel is eroding the valley wall. See Appendix BLANK for a map of mass wasting areas in the Flute Reed River watershed.

Headcuts on Tributaries/Gullies

Headcuts are erosional features found where an abrupt vertical drop ("knickpoint") occurs in a stream. As erosion of the knickpoint and streambed continues, the head cut will migrate upstream. Erosion of this type often results in stream channel incision and severe erosion of streambank and bed material. An example of a headcut erosional feature on an ephemeral tributary to the Flute Reed River is included in figure 24. Headcuts were also noted in many side channels near active or abandoned beaver dams.

Figure 24: Active headcut on Flute Reed River tributary during high flow

Field data collection for this stressor identification study focused primarily in the main stem of the Flute Reed River and the largest two tributary streams in the watershed. A large number of tributary streams (mostly ephemeral or intermittent) in the watershed were not evaluated in detail. Event based sampling results for TSS indicate that these tributaries are moderate sediment sources during wet conditions.

Upland Sources – Roads & Open Lands

The Flute Reed River watershed contains a relatively high proportion of privately owned and developed land compared to most watersheds in the Lake Superior North basin. A rather extensive network of mostly gravel roads leads to permanent and seasonal residences, as well as logging and recreational areas. Road densities were quantified by drainage catchments as part of an effort to investigate upland (non-stream channel) sources of sediment delivery. Road densities were calculated as percentage of watershed area covered by roads of any surface. Values ranged from 0.37% to 4.91% in the 13 sub-catchments evaluated. Variables such as road material, slope, proximity to waterbodies, and ditching practices are critical for assessing overall risk of sediment delivery. Proper management of road ditches is critical for minimizing sediment loads in moderate to highly developed watersheds. The photos in figure 25 show the importance of vegetation and stable ditch channel geometry in reducing sediment loss.

Forest cover has been reduced in the Flute Reed watershed due to timber harvest and residential development. Geospatial data from the Coastal Change Analysis Program (C-CAP) were used to evaluate timber harvest and other development by sub-watershed based on forest type and % "bare ground". Percent bare ground values ranged from a minimum of 2% to a maximum of 22% (average = 6%). Timber harvest is a dynamic land use variable and can be difficult to track as new areas are logged and others regenerate from old cuts. The sub-catchment C-CAP data summary and discussion presented in Appendix BLANK provides an initial assessment of land-use variables related to upland sediment sources.

Beaver Dams as a source of increased turbidity and total suspended solids

Beavers are often referred to as "ecosystem engineers" and are among the few species besides humans that can significantly change the geomorphology, hydrologic conditions, and associated biotic conditions of the landscape (Rosell et al., 2005). The ultimate effects of beaver on water quality, physical habitat, and water temperature are highly variable, and closely linked to background variables (stream order, geology, topography, etc.). Half of the Flute Reed River watershed (7.7 square miles) and 60% of its total length (including tributaries) is located within the boundary of Glacial Lake Duluth (GLD). Within this zone of former lake-bottom and shoreland sediments, the streambanks and bed are dominated by clay soils, which are easily suspended by disturbance (e.g. beaver activity). In contrast, several nearby watersheds were found only to have 30% (Reservation River) and 38% (Durfee Creek) of stream miles below within the glacial lake zone.

High resolution 2013 aerial photos were used to assess the abundance of beaver dams in the Flute Reed River watershed. Two other nearby watersheds, Reservation River and Durfee Creek, were also assessed for comparison. The total number of beaver dams were quantified for each watershed, as well as the number per stream mile. The location of each dam relative to the GLD boundary was also noted, as we hypothesized that dams within the GLD may be more vulnerable to generating elevated turbidity at low streamflow.

Nearly 38% (48 of 127) of the beaver dams counted in the Flute Reed watershed were located within the GLD, a high rate compared to the other two watersheds evaluated (Durfee Ck. = 3%; Reservation R. = 17%). The relatively high rate of beaver activity in the clay-dominated GLD may contribute to increased turbidity levels in the middle to lower reaches of the Flute Reed River. Dam construction, vegetation removal, and stirring of bottom and bank sediments in areas with clay-dominated soils results in sediments being suspended for long durations at low streamflow. Visual observations completed during field assessments revealed that turbidity levels often increased within and downstream of beaver dams (Figure 26).

Table 9: Beaver dam counts and densities observed in the Flute Reed River compared to a selection of streams within the Lake Superior North basin

Watershed	Beaver Dam Number	Beaver Dam Density (dams/stream mile)
Flute Reed above glacial lake	79	4.7
Flute Reed within glacial lake	48	1.9
Durfee Creek above glacial lake	28	2.7
Durfee Creek within glacial lake	1	0.2
Reservation River above glacial lake	76	1.7
Reservation River within glacial lake	16	0.9

Figure 25: (Left Photo) Stable, vegetated ditch in the Flute Reed River watershed during a snowmelt/rain event. (Middle Photos) Examples of ditch "maintenance" leading to instability and sediment loading in other watersheds along the North Shore of Lake Superior.

Figure 26: This series of photos was taken near a large beaver dam complex on the Flute Reed River. Photos #1 and #3 shows turbid water conditions within and below an impoundment created by a 6' beaver dam; photos #2 and #4 show improved water clarity upstream of the beaver dam complex. These photos suggest that beaver dams can be a localized source of increased TSS/turbidity in areas with large quantities of silt/clay substrate.

Figure 27: Examples of major sources and pathways of sediment loading in the Flute Reed River watershed.

4.4.3 Biological Response to Elevated TSS Concentrations

Fish Community Response to TSS

Fish community TSS TIV values for Flute Reed River were generally higher than results from regional streams of high biological integrity (figure 29). These results indicate a higher level of tolerance to elevated TSS concentrations within the fish community at many Flute Reed River stations. TIV values were particularly elevated (i.e. highly tolerant fish community) at stations 13LS038 and 98LS038. The fish community at these two stations was highly dominated by Creek Chub, which are moderately tolerant of elevated TSS concentrations. Small populations of several TSS-intolerant species were present at 98LS038 (Rainbow Trout) and 13LS038 (Finescale Dace, Pearl Dace).

Fish TIV results for TSS were significantly lower at station 13LS027 due to the relative abundance of wild Rainbow Trout sampled at this monitoring station. Only two species were sampled at this station in 2014 (Rainbow Trout and Creek Chub) and their numbers were evenly distributed. TIV results for this station fell between the median and 75th percentile values observed at high quality reference stations within the Lake Superior North and South watershed (figure 29). TSS concentrations frequently exceed the 10 mg/L water quality standard by a large margin during moderate to high streamflow conditions. The high magnitude, relatively short duration spikes in TSS concentration observed at this station likely prevent this station from achieving lower TIV values comparable to the highest quality streams along the North Shore of Lake Superior.

The fish community TIV values observed in this watershed are not strongly correlated with TSS results. TIV results were highest (most tolerant fish community) at station 13LS038, which is located in the upper 1/3 of the watershed where TSS concentrations rarely exceed the 10 mg/L TSS standard. During a spring 2016 rain/snowmelt event, TSS concentrations were six-times higher in the lower reaches of the river at station 13LS027 compared to station 13LS038. Confounding stressors, perhaps water temperature and/or low streamflow, are factors that can cause tolerant species such as Creek Chub to dominate marginal coldwater streams.

TSS concentrations also do not show a strong correlation to coldwater fish IBI scores. The highest fish IBI score in the watershed were observed at stations located in the lower reaches of the Flute Reed River (98LS038 and 13LS027) where TSS concentrations are highest. While elevated TSS concentrations are likely limiting the diversity and abundance of coldwater fish and macroinvertebrate biota in the Flute Reed River, stressor-response data show inconsistencies based on the results from within the Flute Reed River watershed. There appears to be a lack of a stressor gradient showing higher tolerance and lower IBI scores with increasing TSS concentrations.

Macroinvertebrate Community Response to TSS

Relative to the fish results, macroinvertebrate TSS TIV values for the Flute Reed River are more comparable to high quality reference streams in the Lake Superior South and North basins (figure 30). Stations 13LS027 and 13LS038 were each sampled three times, and a high degree of variability in the results is evident. Nearly all of the Flute Reed TIV results fell within the 25th – 75th percentile values of the reference streams. There is no discernable longitudinal trend in TIV results and the macroinvertebrate community in the Flute Reed can be categorized as relatively neutral in terms of tolerance to elevated TSS.

TIV results and community tolerance measures at station 16LS010 show a relatively sensitive macroinvertebrate community compared to other Flute Reed Stations and North Shore reference sites (figure 30). Station 16LS010 was only sampled a single time in 2016 and is located within a reach that was part of a recent stream restoration project. Slightly over 48% of the macroinvertebrate sample from this station was composed of individuals that are intolerant of elevated TSS concentrations (figure 28). Among the other three stations sampled in 2016, values for this metric ranged from 24%-40%. Similar to the other macroinvertebrate metrics evaluated, there does not appear to be a gradient of impact related to increasing TSS concentrations. Maximum TSS concentrations are typically observed near station 13LS027, which had the second highest percentage of TSS intolerant macroinvertebrates (40%).

Each of the nine sampling visits resulted in MIBI scores that met the coldwater MIBI standard, and 78% of the visits surpassed the exceptional use (EU) standard. Based on these results, the Flute Reed River was not listed as impaired for MIBI or any other biological indices despite frequent exceedances of the TSS water quality standard.

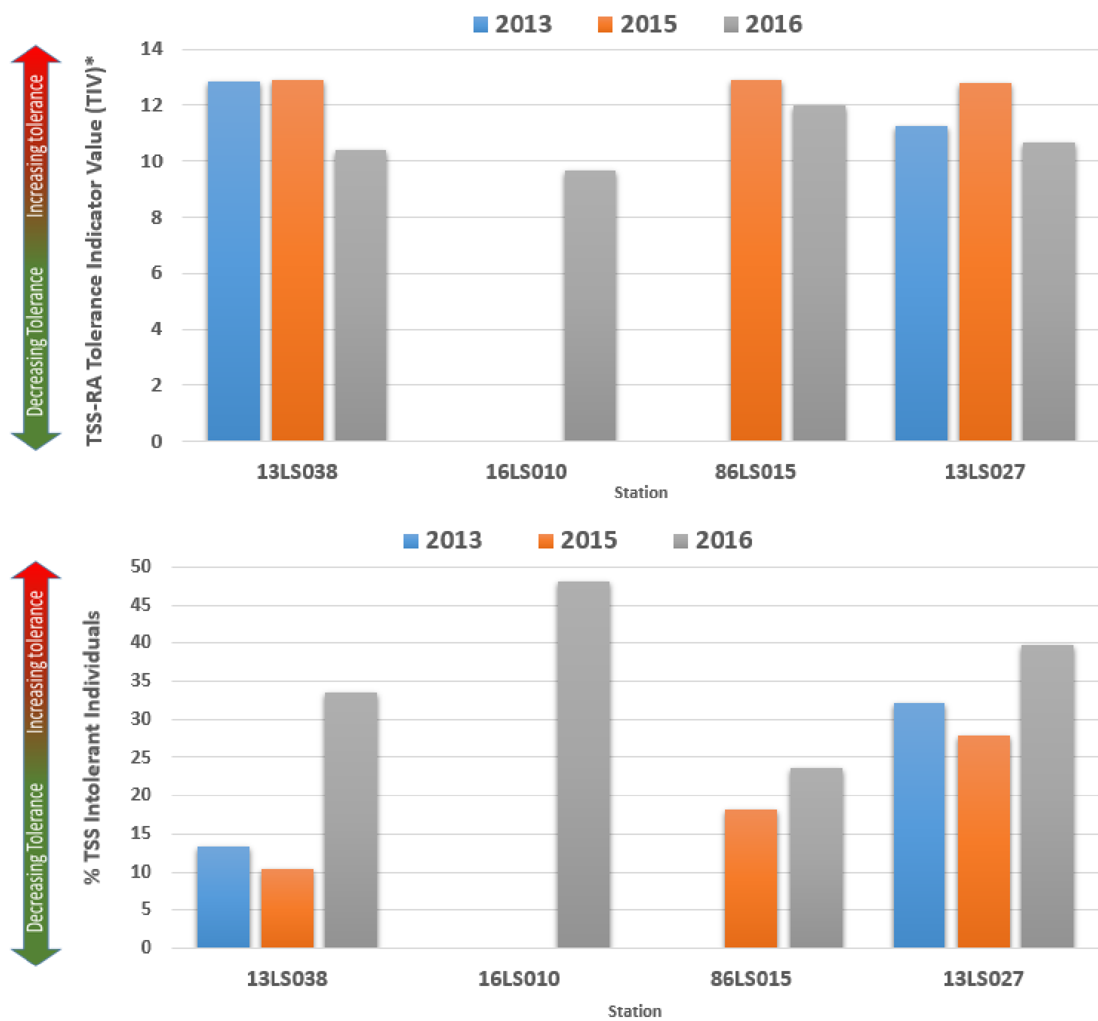


Figure 28: Macroinvertebrate Tolerance Indicator Value (TIV) and % Tolerant Individuals related to TSS for Flute Reed River monitoring stations

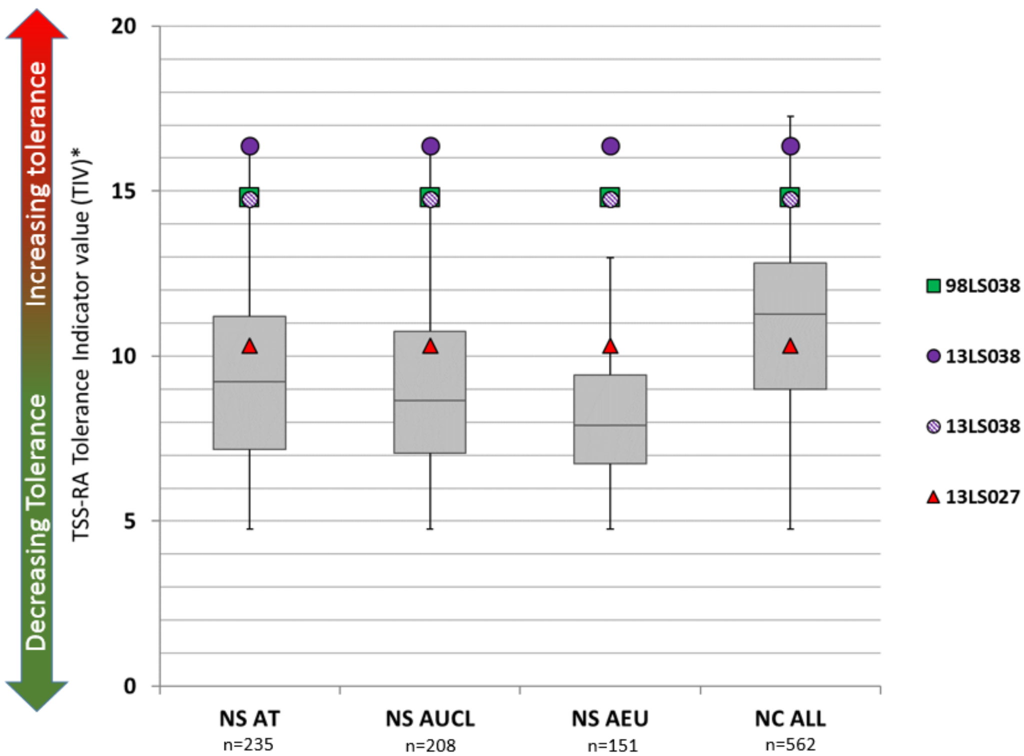


Figure 29: Fish Tolerance indicator Values (TIV) for TSS at Flute Reed River biological monitoring stations compared to results from comparable high quality reference stations.

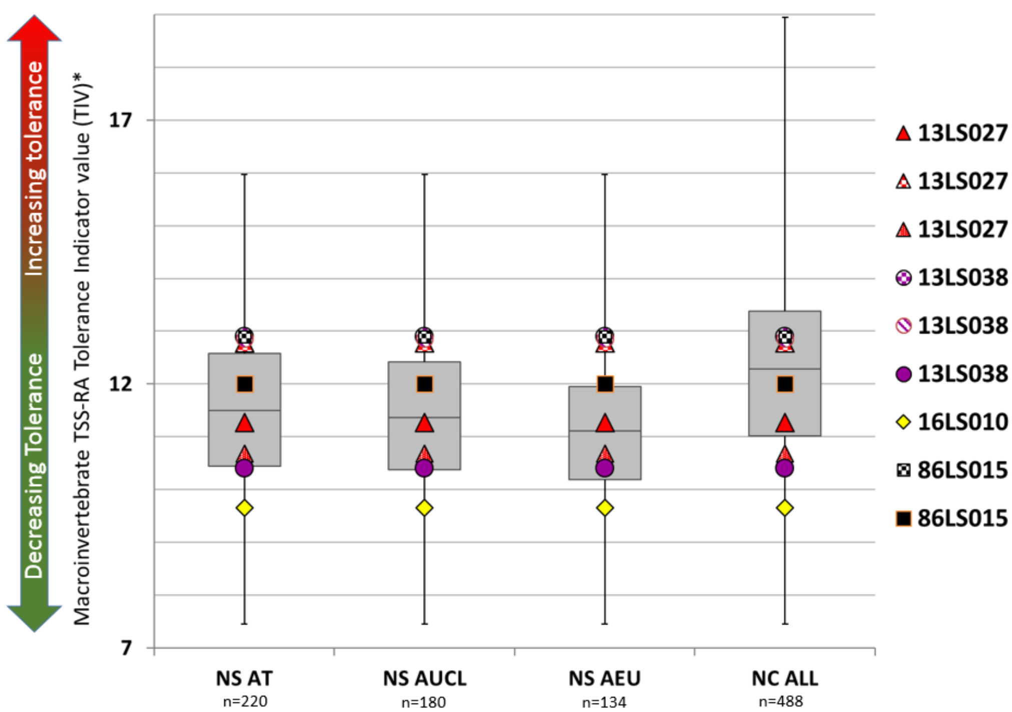


Figure 30: Macroinvertebrate Tolerance indicator Values (TIV) for TSS at Flute Reed River biological monitoring stations compared to results from comparable high quality reference stations.

5.0 Habitat Quality

The BTSA measures habitat conditions using 26 individual metrics related to water temperature, geomorphology and channel stability, and in-stream habitat conditions. Several critical metrics, such as water temperature, pool depths, and streamflow conditions, are weighted more heavily in the scoring system. Additional information on the BTSA can be found in section 3.

BTSA scores were calculated for each of the 19 Flute Reed River stream reaches delineated during field reconnaissance, as well as 10 additional reaches on two main tributary streams. Ratings of “fair” were given to 14 of the 29 total reaches assessed (48%). BTSA ratings of “fair” are common within the middle and lower reaches of the Flute Reed River main stem (figure 32). BTSA ratings of “poor” were given to seven (24%) of the reaches assessed, four of which were located on tributary streams. Poor BTSA scores are concentrated in the central portion of the watershed. The remainder of the assessed reaches (n=8; 28%) rated “good” (none were rated excellent). The majority if the “good” BTSA ratings are located in the headwaters region of the watershed.

Elevated water temperature, lack of gravel substrate, substrate embeddedness, and lack of deep pools are several significant habitat limitations based on BTSA metric scores. The dominant substrate in many of the moderately steep reaches (B channel type) (Figure 31, left photo) classified as cobble/boulder particles, which are too large to provide favorable spawning habitat for salmonids. Gravel substrates were abundant in select areas, particularly lower gradient stream reaches meandering through meadows created by old beaver impoundments (Figure 31, center photo). Substrate embeddedness scores varied widely in the watershed, but most reaches evaluated were impacted to some degree by fine particles partially burying coarser material. Based on the BTSA scores, the greatest risk of aquatic life stress related to substrate embeddedness occurs in reach FLR 007, with moderate-high risk between FLR 001-FLR 004 and FLR 008-FLR 012. Substrate embeddedness scores improved considerably near the upper extent of the assessment (FLR 014 – FLR 018) where gradient steepens and valley width and bank erosion potential decreases. Deep pools were present in areas of the Flute Reed River, but were widely spaced apart and many were the result of beaver impoundments.

Elevated water temperature was the most significant factor limiting Brook Trout presence/abundance in the BTSA analysis. Water temperature is the most heavily weighted BTSA metric, and continuous water temperature data suggest very marginal temperature regime for Brook Trout. The exception is the extreme headwaters reach, which remains within the thermal range for Brook Trout growth for most or all of the summer season (see section 4.7).

Figure 31: Scenes of physical habitat conditions on the Flute Reed River. (Left) Steep, cobble/boulder dominated reach; (Center) Low-gradient, gravel dominated reach within former beaver impoundment; (Right) Coarse substrate extremely embedded by sand and silt

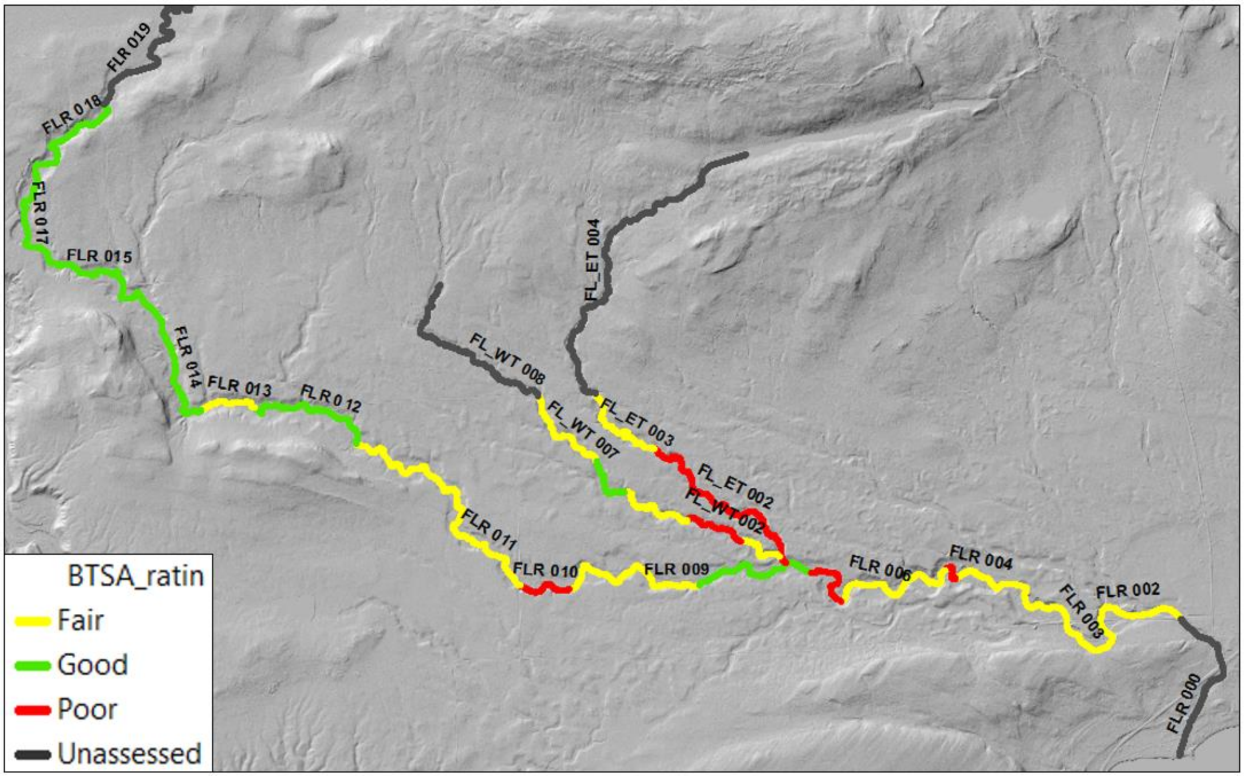


Figure 32: Map of BTSA ratings for Flute Reed River and major tributary streams.

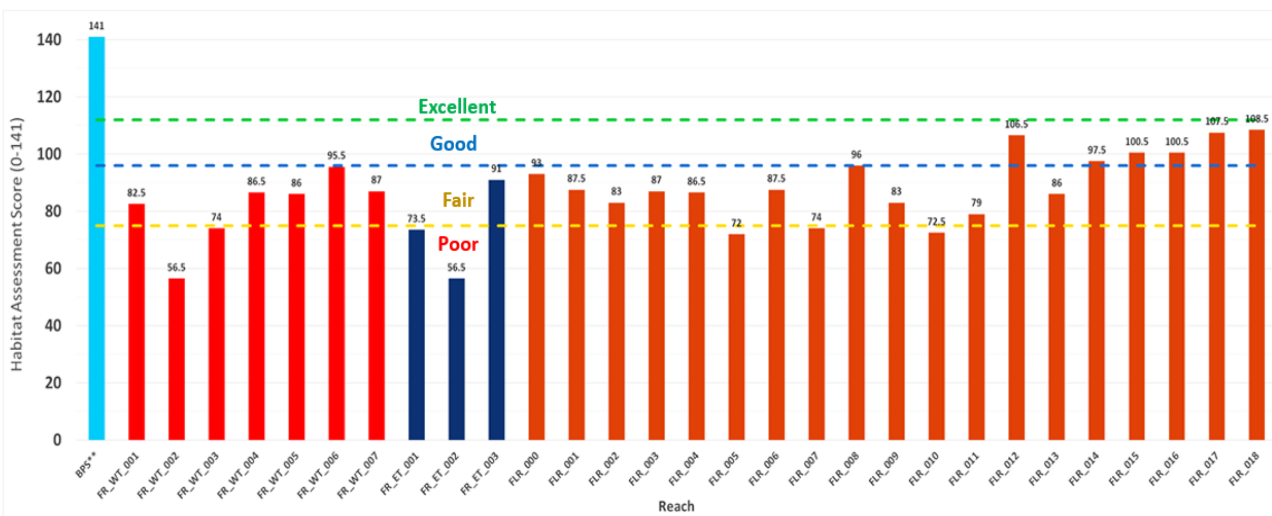


Figure 33: BTSA scores for Flute Reed River (FLR_--- orange columns), West Tributary to Flute Reed (FR_WT--- red columns), and East Tributary to Flute Reed (FR_ET_--- blue columns). ** "BPS" = Best possible BTSA score (141)

4.6 Barriers to fish migration

4.6.1 Road Crossings and Culverts

Thirteen road crossings in the Flute Reed River watershed were evaluated for proper alignment, culvert/bridge sizing, fish passage, and channel stability impacts. Properly sized culverts are those that closely match bankfull width (determined at riffles) and the alignment of crossings should not alter the natural pattern of rivers course. Three main criteria were used to identify culverts as partial or full barriers to fish passage; current velocity, absence of substrate, and outlet perch. The DNR crossing assessment form used for data collection is included in Appendix BLANK. All culvert/bridge assessment points in the Flute Reed River watershed are mapped in Figure 35.

Of the thirteen crossings evaluated, six were span bridges, with all but one crossing the lower reaches of the Flute Reed River. All of the bridges were sized correctly (crossing/bankfull width ratio close to or greater than 1.0) and had natural substrate through the crossing. They bridges are properly aligned with river pattern and were not negatively affecting stream stability or aquatic organism passage.

The remaining seven crossings assessed were culverts. Two were located on the main stem of the Flute Reed River and six were on unnamed tributaries. The two main stem crossings were located at County Road 70 (Camp 20 Rd), the southern crossing at river mile (RM) 4.2 and the northern crossing at RM 8.0. The culverts installed at both of these locations were significantly undersized, with culvert width / bankfull width ratios of 0.57 – 0.58 (i.e. culvert width was just over ½ bankfull width). In addition, natural substrate material was completely absent in the culverts at both Camp 20 Rd crossings. A minimum outlet drop of 0.25' was noted at the RM 4.2 crossing, and debris jams on the upstream side of the RM 8.0 culvert may impede fish passage at some flows. Based on the data collected, the crossings at RM 4.2 and 8.0 are priorities for replacement. The crossing at 4.2 is likely a higher priority given that it could be a partial barrier to Steelhead trout, as their seasonal spawning migrations have occasionally extended inland to RM 4.2 and beyond.

Figure 34: Undersized and perched culverts at Camp 20 Rd (CR 70)

Three of the five culverts assessed on tributary streams were flagged as too narrow and barriers to aquatic organism passage, although intermittent stream flow limits fish abundance/diversity in many of the tributaries assessed. Crossings of the three primary perennial tributary streams to the Flute Reed River were more favorable to fish passage and channel stability. Fish passage within and to the perennial tributary streams to the Flute Reed River does not appear to be reduced due to roads and culverts based on our assessment.

MPCA did not evaluate the Flute Reed River crossing at Tom Lake Rd (RM 7.87), but it is identified as a priority for replacement in the most recent DNR watershed management plan. This culvert is categorized as a partial or total barrier to fish passage depending on flow conditions. The management plan states DNR fisheries' goal of working with their forestry unit to remove or replace the culvert at this crossing.

In summary, culvert sizing and fish passage concerns are limited to the upper half of the Flute Reed River watershed. Top priorities for replacement or removal include the Tom Lake Rd crossing and the southern CR 70 crossing. Both of these are cited in the most recent DNR management plan as priority objectives. In addition to restoring full aquatic organism passage, properly installed crossing will reduce localized bank erosion and improve habitat conditions near the crossings.

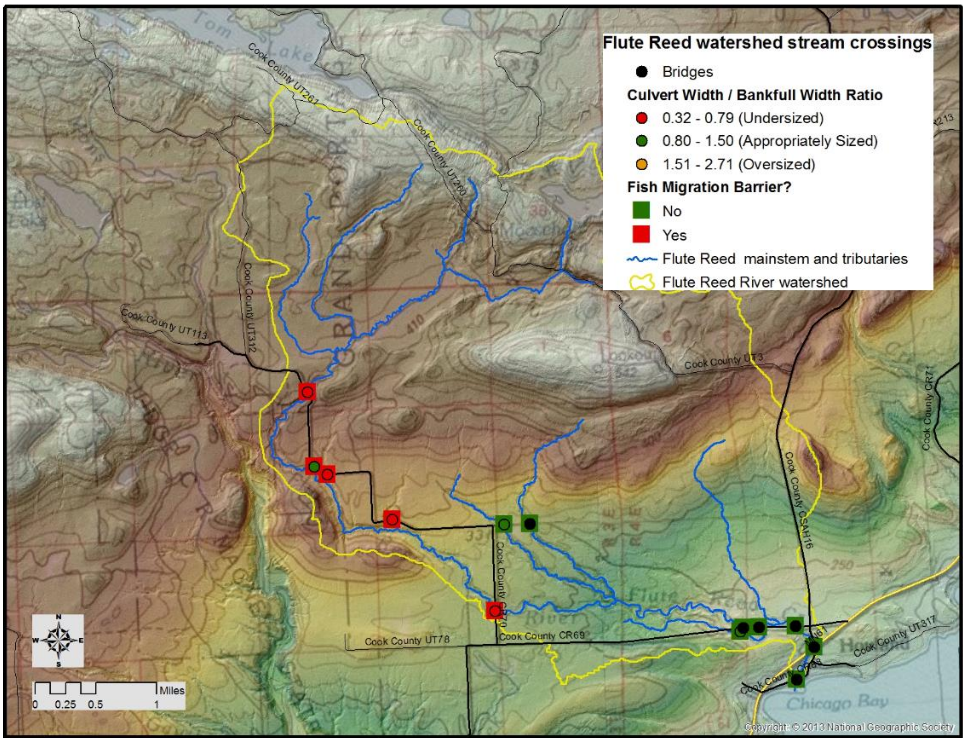


Figure 35: Culvert assessment results for the Flute Reed River watershed

4.6.2 Beaver Dams

For many species of fish (esp. salmonids), the ability to migrate both upstream and downstream is essential. Species spawning in the spring season (e.g. Steelhead Rainbow Trout) often can negotiate beaver dams (Rasmussen, 1941; Grasse, 1951), but autumn spawners (e.g. Brook Trout) can be blocked during low-flow conditions when the dams are in-tact (Cook 1940, Rupp 1955). While beaver dams can disrupt the movement and dispersal of fish and other aquatic life within a watershed, their presence has been linked to many positive ecological services. These include drought/winter refugia (Rosell et al., 2005); attenuation of flooding and low streamflow events (Parker 1986, Rutherford, 1955); and enhancing groundwater recharge by elevating the water table (Bergstrom, 1985; Johnston and Naiman, 1987).

Beaver dams were abundant in the Flute Reed River compared to other streams along the North Shore (see table 9). No data are available to assess whether or not they act as barriers to fish migration in this watershed. A specific investigation of the effects of beaver dams on migration, water quality, and water temperature would be useful to inform management.

4.7 Water Temperature

4.7.1 Review of Water Temperature Data

Continuous water temperature data are available for several Flute Reed River monitoring stations dating back to 2011. MN DNR routinely monitored temperature at three Steelhead Index Stations (STI) at RM 0.0, 0.7, 3.6, and 6.7 between the years of 2011 and 2016. MPCA added an additional six monitoring locations in 2016 to further evaluate water temperature as a potential limiting factor for Brook Trout and other stenothermic aquatic life. All temperature monitoring locations are shown in figure BLANK and summary statistics from all monitoring years are included in Appendix BLANK.

Most reaches of the Flute Reed River offer marginal to poor water temperatures for supporting Brook Trout and other coldwater obligate species. Based on all monitoring years, most stations had an average summer water temperature (June-August) between 17.5 and 19.5 degrees, with 25-35% of summer temperature readings exceeding the "stress" threshold for Brook Trout. The warmest temperatures in the watershed are typically observed at RM 6.7, which is located downstream from numerous beaver impoundments. Figure 36 shows a comparison Flute Reed temperature data to other streams along the North Shore of Lake Superior. Most Flute Reed stations fall into "Area 2" on the scatter-plot, which tends to include sites with marginal Brook Trout populations or an absence of Brook Trout. Stations within Area 3 and Area 4 are typically productive Brook Trout streams if other components (e.g. flow, physical habitat) are not limiting (Figure 36).

The coldest water temperatures in the Flute Reed River watershed are routinely observed in the extreme headwaters (near Tom Lake Rd) and in the lower reaches near its confluence with Lake Superior. In 2016, the Flute Reed River upstream of Tom Lake Rd remained in the temperature range for Brook Trout "growth" over 87% of the time between June 1st and August 31st, compared to a watershed average that season of 69%. DNR has historically observed Brook Trout near the Tom Lake Rd station, but no recent data were available for this report. Colder water temperatures are also commonly observed at RM 0.7 and RM 0.0, and to a lesser degree RM 3.6. Maintaining colder water temperatures at these stations is critical for rearing young Steelhead Rainbow Trout, which are typically observed in large numbers in this reach of the Flute Reed. Rainbow Trout have a slightly higher tolerance to warmer water temperatures than Brook Trout, and the thermal regime in the lower Flute Reed appears to be adequate for producing wild (naturally reproducing) Steelhead.

Warmer water temperatures in the Flute Reed River can be attributed, in part, due to natural background conditions. The clay-dominated soils of the watershed limit infiltration of snowmelt and rainfall, and much of the precipitation runs off the landscape into gullies as surface runoff. An assessment of source water areas, groundwater inputs, and evaporative loss suggest that the hydrological regime of the Flute Reed River is largely driven by surface runoff and groundwater inputs are minimal compared to high quality Brook Trout streams of the region (see section 4.8).

Beaver dams have been shown to cause detrimental increases in water temperature in coldwater streams (Avery, 1983; Patterson, 1951; Avery, 1992; Margolis et al., 2001). Numerous active and abandoned/breached beaver dams were observed in the Flute Reed River and major tributary streams. In 2016, continuous temperature data were collected above and below one major beaver dam complex (i.e. a series of active dams) to observe any changes in water temperature. An increase in water temperature was observed downstream of the beaver dams, but the difference in temperature was minimal and unlikely to cause any ecological changes (figure 37). A significant increase in water temperature was observed between Tom Lake Rd (RM 11.2) and the upper CR 70 crossing (RM 6.7). Beaver impoundments (both active and abandoned) are a dominant feature of the riparian corridor between these two stations and could not be ruled out as a major factor in the water temperature increase.

Percent forest cover, developed land, and road density are critical variables related to Brook Trout presence and abundance (Stranko et al, 2014; Herb and Stefan, 2009; Gillespie, 2008). The Flute Reed River watershed has a relatively high percentage of private/developed land compared to other North Shore watersheds. Small-scale logging operations are visible throughout the watershed, and many roads have been constructed to provide access to private land and logging areas. The majority of the watershed remains forested, but development and timber harvest are several anthropogenic sources of thermal loading.

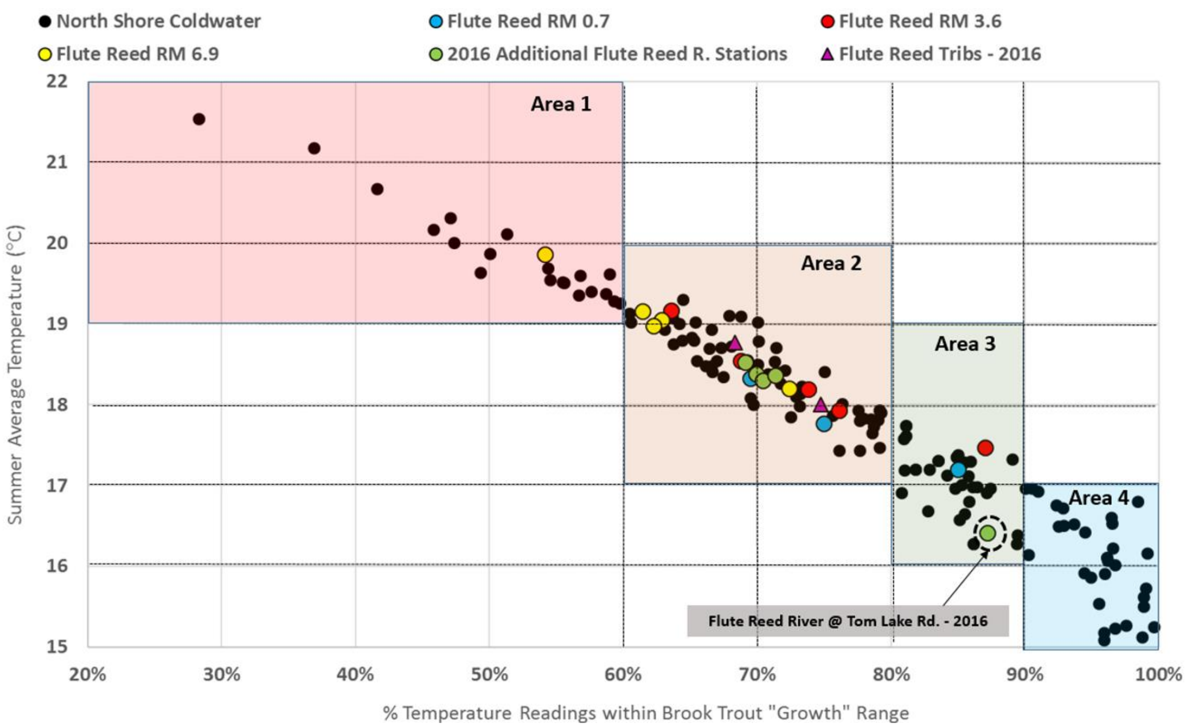


Figure 36: Plot of Summer Avg. temperature vs. % Time in Brook Trout temperature growth range. Flute Reed monitoring stations are shown in colored markers, while all other North Shore coldwater stations are shown as black markers. Temperature "areas" are discussed further in section 3.1

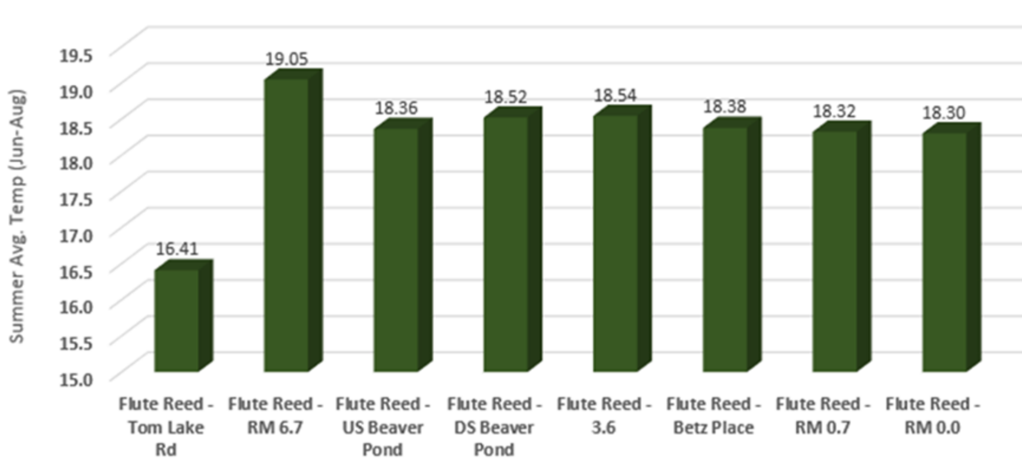


Figure 37: A summary of average water temperatures in the Flute Reed River watershed over the 2016 monitoring season

4.7.2 Biological Response to Water Temperature Gradient

Fish Community and Water Temperature

A clear spatial trend of coldwater fish distribution is present within the Flute Reed watershed. Based on fish community data from eleven stations, the relative proportions of coldwater individuals are consistently higher in the lower half of the watershed, yet range widely from 4% - 96% (average 56%). Wild Rainbow Trout account for the vast majority of the coldwater fish sampled in the lower watershed. The non-game species Slimy Sculpin and Longnose Dace are also present in small populations. The relative proportion of coldwater fish decreased substantially at stations 86LS016 and 13LS038, which are located in the reach upstream of the lower Camp 20 Rd (CR 70) crossing. Coldwater individuals accounted for 0%-11% of the total fish community at these locations. No reportable data are available for the headwaters area of the Flute Reed River near Tom Lake Road, but small Brook Trout populations have been observed sporadically in this portion of the watershed.

Fish migration barriers in the lower Flute Reed River (e.g. perched and undersized road culvert at Camp 20 Rd and numerous beaver dams) likely contribute to reduced coldwater fish abundance in the upper Flute Reed River. Water temperatures at station 13LS038 are marginal for supporting coldwater fish and macroinvertebrate populations, but the thermal regime for several river miles upstream of the perched/undersized culverts at Camp 20 Rd are not significantly different from the lower river, which supports a run of wild Steelhead Rainbow Trout. The migration barriers that prevent or deter movement into these colder reaches of the Flute Reed River should be removed to increased available spawning and rearing habitat for Steelhead trout.

Macroinvertebrate Community and Water Temperature

Macroinvertebrate data are available for four stations in the Flute Reed River watershed and these stations were sampled in 2015 and/or 2016. The percent of the macroinvertebrate community comprised of “coldwater” individuals ranged from 5 – 40%, with no clear spatial trend from upstream to downstream (figure 38). A lower proportion of coldwater individuals was observed at all stations in 2015 compared to the 2016 results, with significantly lower values at stations 13LS038 and 13LS027. The relative percent of coldwater macroinvertebrate taxa ranged from a low of 10% (stations 13LS027/13LS038 in 2013) to a high of 26% (station 13LS027 in 2016) (figure 38).

At best, a weak relationship is present between water temperatures and the relative abundance of coldwater macroinvertebrate individuals within the Flute Reed watershed. The thermal regime at nearly all Flute Reed stations can be classified as marginal coldwater and the macroinvertebrate population does not show a consistent pattern or split amongst stations dominated by coldwater or warmwater taxa. Relative percentages of coldwater taxa/individuals at Flute Reed River monitoring stations were comparable to a number of high-quality coldwater streams in the Lake Superior North basin with more favorable thermal regimes for coldwater biota (figure 39).

MIBI scores within the Flute Reed River watershed all indicated full-support of aquatic life standards, and most of the results (7 of 9; 78%) met the exceptional use criteria. Elevated water temperature does not appear to be a limiting factor for coldwater MIBI based on the following factors: high MIBI scores throughout the watershed, similarity of metric results to other high quality coldwater streams in the Lake Superior North basin, and the lack of a clear biological response to slight temperature differences between Flute Reed River monitoring stations.

2016 Data	pct_CW	pct_CW_TAXA	Drainage Area
13LS038	**27.1%**	**17.1%**	5.9
16LS010	**40.4%**	**18.9%**	7.6
86LS015	**14.2%**	**11.4%**	7.9
13LS027	**28.1%**	**25.9%**	15.4
2015 Data	**pct_CW**	**pct_CW_TAXA**	**Drainage Area**
13LS038	**4.9%**	**9.7%**	5.9
16LS010	**NO DATA**		7.6
86LS015	**10.2%**	**14.9%**	7.9
13LS027	**11.5%**	**9.7%**	15.4
2013 Data	**pct_CW**	**pct_CW_TAXA**	**Drainage Area**
13LS038	**6.8%**	**15.0%**	5.9
16LS010	**NO DATA**		7.6
86LS015			7.9
13LS027	**13.7%**	**16.2%**	15.4

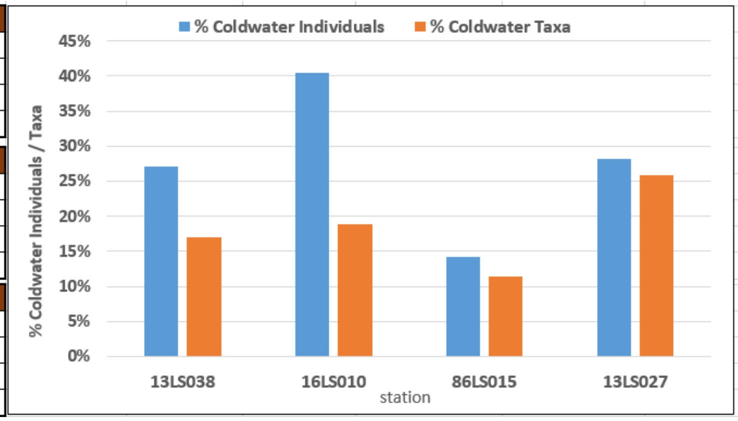


Figure 38: Percent coldwater macroinvertebrate individuals (pct_CW), percent coldwater macroinvertebrate taxa (pct_CW_TAXA), and drainage area for Flute Reed River biological monitoring stations sampled in 2013, 2015, and 2016.

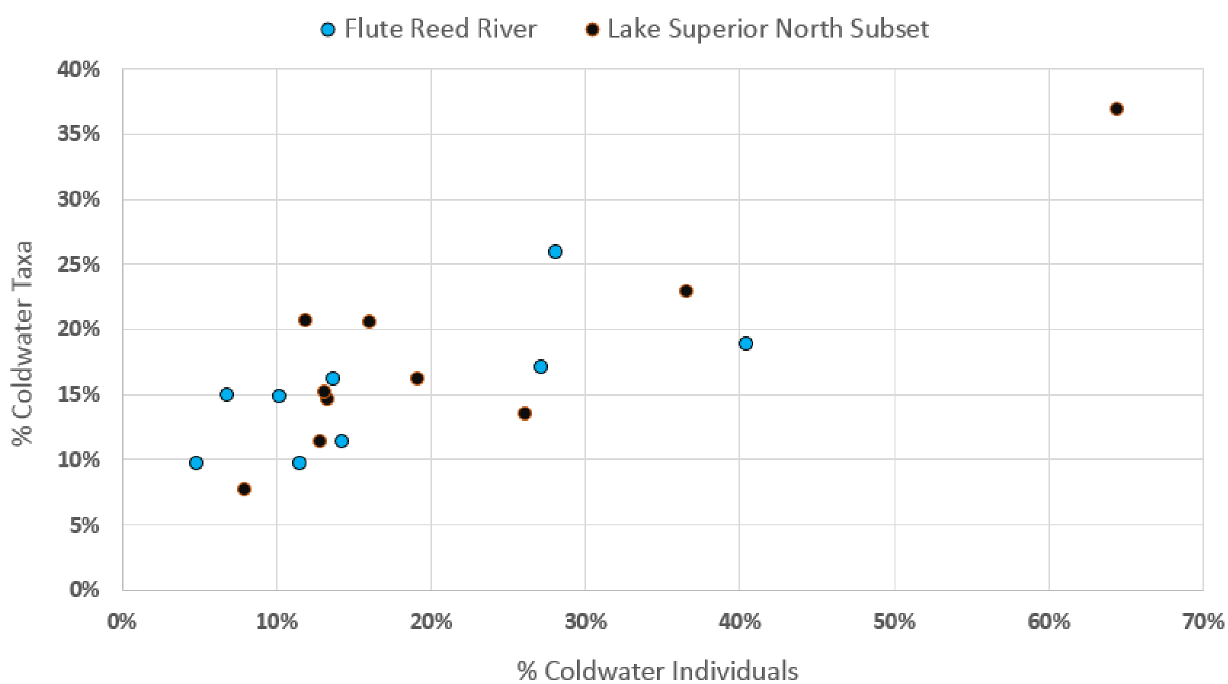


Figure 39: Scatter-plot of % coldwater taxa and % coldwater individuals for Flute River River and a subset of non-impaired, high quality Lake Superior North streams (Woods Creek, Kimball Creek, Devil Track River, Poplar River, Heartbreak Creek, Two Island River, Fiddle Creek, Irish Creek, Little Devil Track River, Caribou River). Results are comparable between the two groups aside from the outlier (Kimball Creek) in the Lake Superior North subset.

4.8 Hydrogeology of the Flute Reed River watershed

The Flute Reed River is 13 miles long and drains 17 mi^2 of watershed area to Lake Superior. Streamflow in the Flute Reed River begins in the headwaters at the outlet of Moosehorn Lake (area = 66 acres, max depth = 9 feet), the single lake in the watershed. Wetlands cover less than 2 mi^2 of the total drainage area and are primarily located in the upper watershed between Moosehorn Lake and river mile 9 (EQuis Station S004-277). Forested/shrub wetlands are the dominant wetland type (94%) with lesser abundance and area of emergent wetlands and freshwater ponds. Emergent wetlands are isolated to the stream riparian. Stream segments, water features, and the drainage boundaries of primary tributaries to the Flute ReedRiver are identified in Figure 40.

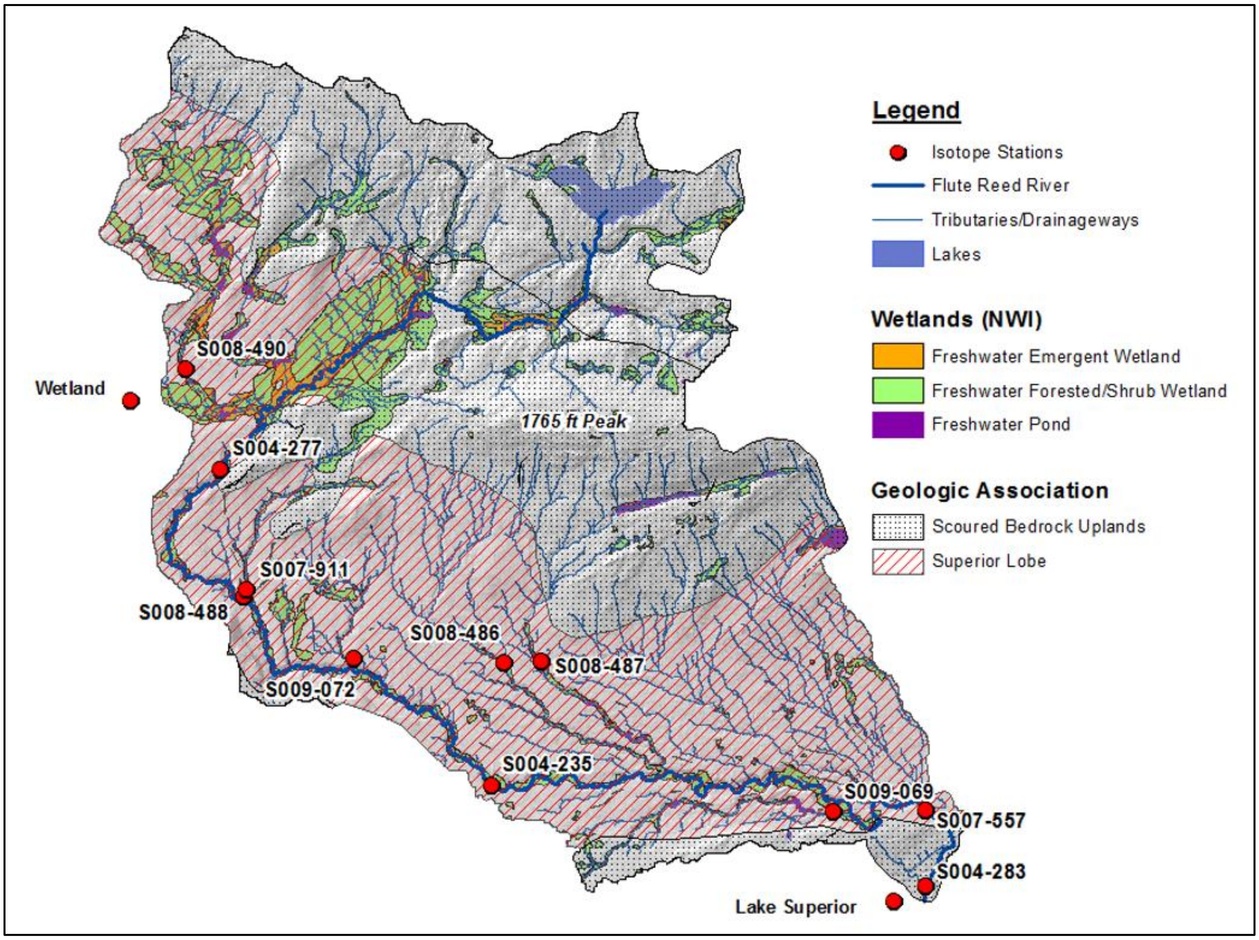


Figure 40: Flute Reed River watershed, hydrologic and geologic features, and isotope sampling stations.

Geology and Soils

The Flute Reed Watershed landscape is dominated by rolling till plains and scoured bedrock terrain. The steepest topography is found within the scoured bedrock features of the northeast section of the watershed. The highest land feature is located at the end of Tower Road in the eastern drainage and has a peak elevation of 1765 feet. The south-facing slope of the 1 mi^2 bedrock knob drains to a confined, narrow wetland pond and then to a tributary to the Flute Reed River. Another bedrock ridge extends laterally along the northern boundary of the watershed divide and several smaller knobs at slightly lesser elevations are found in upper drainage. These too drain to headwater wetlands and tributaries to the Flute Reed River. Additional tributaries are scattered throughout the watershed, but lower watershed tributaries lack the wetland connectivity present in the headwaters.

LandUse/LandCover/Disturbance

The Flute Reed River watershed is primarily forested with deciduous cover and smaller patches of mixed forest and evergreens. Other than forest canopy, landuse is primarily rural development and forest harvest. Map units derived from the MNDNR Forest Resources Assessment work shows forest disturbance has occurred on less than 5% percent of the watershed area during years 2000-2014. Disturbance is isolated to privately owned lands and is scattered throughout the watershed with the relatively larger disturbances located near Moosehorn Lake and along the Camp 20 Road corridor. Altered watercourse data created by the MPCA through aerial imagery shows that little to no stream channel alterations have occurred. No man-made dams exist in the watershed, although beaver dams are scattered throughout.

Flow Duration Curves and Stream Flashiness

An MPCA stream gage was operated from July 2013 to present. Daily flows range from less than 0.5 cfs to approximately 700 cfs during the gaged period. Flows greater than 300 cfs are estimated, occur during years 2014, 2015, and 2016 in the dataset, and areisolated to snowmelt and rain events. MPCA flow records show that water levels rise quickly following an event, peak within hours, and return to mid-range flows within a few days. Mid-range flows range from 3.7 cfs to 8.5 cfs and are exceeded 40% and 60% of the time respectively. Comparatively, mid-range flows for the nearby Brule River of Minnesota range from 120 cfs to 206 cfs. The Brule River watershed has a significantly larger drainage area (265 mi^2) and has 26% land cover in lakes and wetlands. The flow duration curve, showing the percent of time that a given discharge was exceeded, is displayed logarithmically and is compared to other North Shore streams in Figure 41.. 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. When compared to seven other North Shore stream gages, the Flute Reed River plot is similar to that observed in the Amity Creek watershed (watershed area = 16 mi^2, % wetlands =9, % lakes = 0.3) near Duluth, MN. Only the Talmadge River, a smaller watershed, showed a flashier hydrology. Similar drainage attributes such as watershed area and lake and wetland storage explain similarities in flow magnitude and flashiness between Flute Reed River and Amity Creek. Flute Reed River has a slightly higher wetland coverage and lesser urban/rural development than the Amity watershed which may help explain minor differences in shape in the very low flow regime. Flute Reed River trace shows more capacity to sustain flow during extreme low conditions which would indicate more surficial or subsurface storage of water to discharge flow to the stream during dry periods. More details on Flute Reed River flow sources during low flow dry conditions is found in the isotope section of this report.

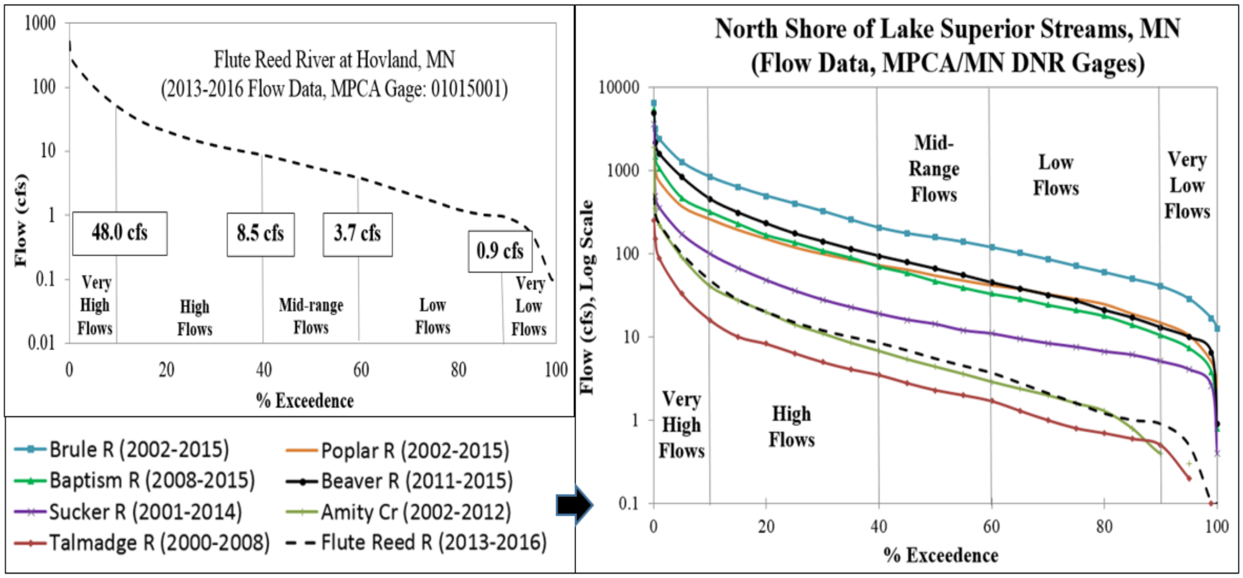


Figure 41: (Left) Flow Duration Curve for the Flute Reed River, identifying five flow regimes based on data from 2013-2016. (Right) Comparison of the Flute Reed River flow duration curve to other North Shore of Lake Superior Streams.

Watershed Isotope Characterization

Detailed discussion on the application and methods of isotopic analysis of oxygen-18 ($\delta^{18}O$) and deuterium (δ^2H) in hydrologic applications are located in Section 3.5 of this report. This includes the use of the local meteoric waterline (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 Isotope Sample Collection

Stream water samples were collected for oxygen and hydrogen isotopes from the Flute Reed River gage station (S007-557) and a headwater station (S004-277) multiple times during the 2014 to 2015 period of flow records. Monthly sample collection was continued at the gage station and a nearby channel bank seep during 2016 and into the 2017 year. In August of 2016, samples of stream baseflow within the Flute Reed River drainage were collected at eleven stream stations (including S007-557 and S004-277), the bank seep, Lake Superior, and a wetland located just outside the boundary of the upper watershed. Sample collection locations are identified in Figure 40. 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 ^2H.

During the 2015 sampling season, samples were collected from 13 stream reaches across the Lake Superior North watershed including the two Flute Reed stations. Elevation and geology of stream reaches varied as sample sites were located both near the lake and up the escarpment in headwater tributaries. Samples were collected four times during the 2015 season; and near-baseflow conditions were targeted. Sample dates were compared to the Flute Reed hydrograph. We found that July, September, and October 2015 samples were representative of the low flow regime. Reported flows at the Flute Reed River gage for these dates range from 0.9 and 2.0 cfs with no very high flow events occurring within a few weeks prior to each sampling. Flows were reported at 3.9 cfs for the June sample date which is a mid-range flow value as streamflows at the time were receding from a very high flow event that occurred one week prior to sampling. A range of flow events were also sampled in the 2016 and 2017 seasons including low flow events in August and October of 2016.

Local Meteoric Waterline for the Grand Marais/Hovland Area

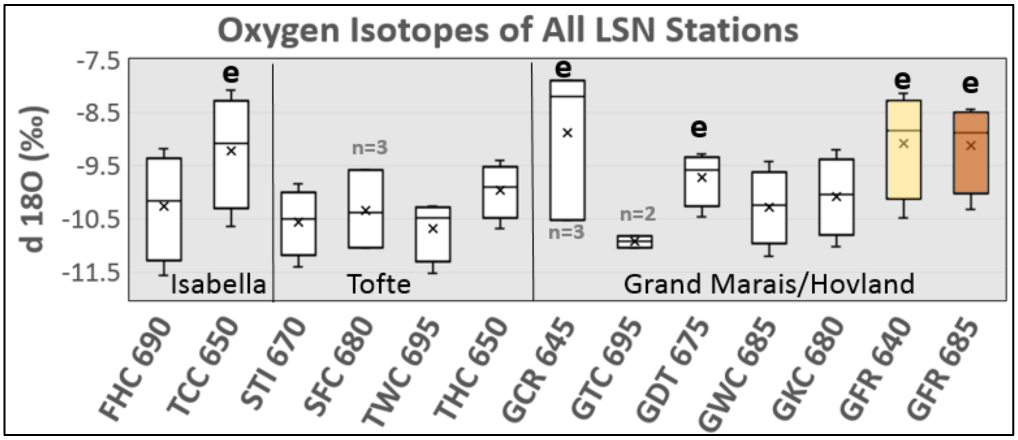
Precipitation monitoring volunteers and MPCA staff collected rain and snow samples in the Grand Marais and Hovland area in years 2015 and 2016. Only samples that filled to the neck of the collection bottles were used to develop a local meteoric water line (LMWL). Eight rain and seven snow samples collected between Lutsen and Hovland, MN, were used to develop a local meteoric waterline ($\delta^2H = 7.6\ \delta^{18}O + 6.8$; $r^2 = 0.99$) for the region. The wide range ($\delta^{18}O = 18$) in precipitation oxygen isotopic data for the area is indicative of the extreme seasonal variation in temperatures of the region. The local evaporative line (LEL: $\delta^2H = 5.19\ \delta^{18}O – 21.2$; $r^2 = 0.97$) was developed using low flow samples collected in August, 2016, from six Flute Reed River watershed stream stations, a regional wetland, and Lake Superior.

The weighted isotopic mean for regional precipitation or inflow value was estimated at -11.5 ‰ at the intersection of the LMWL and the LEL. Estimating the weighted mean for regional precipitation is important in explaining stream hydrology including source-water contributions and residence time. An aquifer or large lake that integrates annual precipitation over several years will have a small range of values near the mean average for precipitation. If the lake or aquifer is a primary flow source to receiving streams, the stream water will reflect this signal. Precipitation driven ponds, wetlands, and streams will likely have a larger range indicating less inter-annual consistency due to the mixing of groundwater with precipitation inputs (Brooks, et al., 2013). Bank seep water collected along the Flute Reed River during the 2016 to 2017 season indicates that area groundwater signals vary; with the bank seep signals ranging from -12.1 to -10.2 ‰.

Variability of Isotope Signals along the North Shore

Understanding isotope signals and the related hydrological response to weather events is important in data interpretation. The box plots below show distribution, median value, and average value of oxygen isotopes collected at thirteen stream stations within the Lake Superior North watershed in year 2015. We sampled the majority of the stations four times during the 2015 year; however, three stations had less than four samples. The streams are Fredenberg Creek, Cascade River and Thompson Creek. The number of samples collected for the three sites is identified in Figure 42. The letter ***e*** was placed above the box plot in Figure 42 for stations where evaporative losses in stream water were identified for two or more events. For stations that were sampled for all four events, we ranked the range and median values of oxygen isotopes. A combined ranking value was determined for each site by averaging the range and median ranks. The results are displayed in Figure 42.

This study aimed to better define source-waters that sustain flow in North Shore streams during critical dry summer periods when flow as well as temperature may be limiting coldwater species migration and survival. Figures 43 and 44 were used to help define source-waters in streamflow at our sample sites. Based on the ranking results of median value and range for isotope signals, we were able to conclude that greater lake and subsurface inputs were observed in stream water at several stations across the Lake Superior North watershed. Theoretically, a tight range in stream isotope signals indicates flow sourced from lakes and aquifers that have the capacity to hold water for over a season or more. These data show that Devil Track River, Wanless Creek, Heartbreak Creek, Two Island River, and Woods Creek, respectively in order from the lowest, have the tightest oxygen isotope ranges in our dataset.



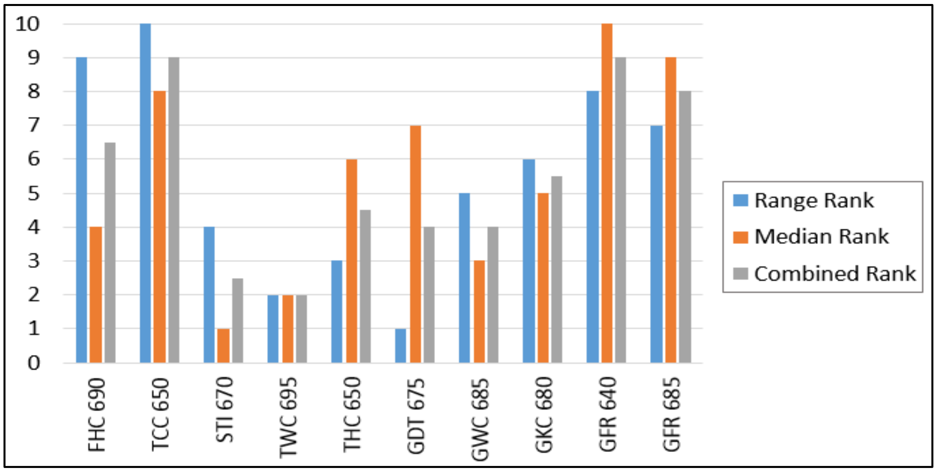


Figure 42: (Top) Oxygen Isotopes for LSN Streams, collected in summer and fall of 2015. (Bottom) Ranking of Range and Median Values of oxygen isotopes of LSN stream stations that had a complete set of four samples collected in year 2015.

These five streams also received the lowest combined ranking in which both range and median value distribution were considered. Median distribution along with evaporative losses in the isotope samples can help decipher between lake and aquifer-stored water. Two Island River, Wanless Creek, and Woods Creek received the lowest median value rankings, all within the range of groundwater signals observed in the study. In addition, evaporative losses were not observed in these three streams. Friedenberg Creek had a similar distribution to the Wanless Creek and Two Island River distributions, but one data point was lacking which excluded it from the ranking analysis. Signals within the groundwater range and the absence of evaporative loss indicates that subsurface storage is a dominant flow source to these streams. Because the signals at these same sites do not fluctuate much over the season relative to the greater dataset, groundwater discharge to these streams appears to be more constant throughout the seasons compared to other Lake Superior North streams.

Our data infers that the Devil Track River stream station is highly influenced by Devil Track Lake. We did not sample the lake itself, but the highly tight range (consistent signal across the season) at the downstream sample site indicates a dominant source of flow other than storm flow; and the evaporative signal indicates the source is surficial. Devil Track Lake is a large lake, greater than 1800 acres in surface area and deeper (50 feet) than many area lakes. The stream station was located approximately three miles downstream of the lake and just downstream of the Elbow Creek confluence. At this location, other major coldwater tributaries that may have more groundwater influence such as Woods Creek and

Little Devil Track River, located further downstream, are not yet contributing flow. The range is tight and less evaporative than several other lake-fed rivers. Groundwater discharge to this particular lake may play a role in providing the specific isotopic signature.

In contrast to the Devil Track River results, isotope data for other lake-fed streams including Cascade River and Cabin Creek indicate that they do not have a dominant single-source of flow and may be more vulnerable to seasonal changes than the Devil Track River site. The Cascade River station was located 2.5 miles downstream of headwater lakes. In addition to lake inputs, groundwater springs in both Devil Track and Cascade Rivers were field verified during the sample period; and our data shows that some tributary streams to these larger rivers have strong groundwater signals. Woods Creek in the Devil Track River watershed and Thompson Creek in the Cascade River watershed are examples. Thompson Creek was sampled twice during the season and both samples had signals near the mean annual precipitation value. One of those samples was collected in September, the month with the greatest evaporative losses seen in the entire LSN isotope sample dataset. Although lake and groundwater inputs are present near the Cascade River sample station, the isotope signals indicate that it has some vulnerability to seasonal variations in temperature and precipitation.

The upper and lower Flute Reed River ranked high for both range and median value, indicating that streamflow in the headwaters and near the gage station is more vulnerable to seasonal influences than many of the streams studied. The Flute Reed River is one of five streams in the study (out of thirteen) that showed evaporative losses in the stream signal. The range, median value, and evaporative signal indicates that groundwater discharge is not the dominant source of flow in this system during the dry critical months of summer; and a combination of sources may be needed to sustain summer baseflow.

To better understand this, bank seep (groundwater) isotopes were compared to stream isotopes near the stream gage station S007-557 over the course of a year (2016-2017). The greatest correlation in stream-groundwater signals in 2016 were found in samples taken after high flow rain events of June and December 2016, and during the January to March winter season. Winter correlation reflects the dominant role groundwater plays in sustaining winter flow when freezing air temperatures limit direct precipitation to the landscape in the snowpack and freezing of the upper soil profile slows interflow and infiltration processes. The correlation of groundwater and stream water data during post-high flow rain events of the ice-free season suggests that in addition to supplying streamflow through surface runoff, large rain events appear to easily replenish shallow groundwater in the system. We suspect that this high rate of aquifer replenishment increases the hydraulic gradient needed to then move soil moisture and groundwater to the stream. This phenomenon is clearest in the June rainfall data as groundwater signals fluctuate between sample dates in response to individual events.

A greater spread between stream and groundwater isotope signals occurs during low flow periods of the summer-fall 2016 season and during snowmelt and early spring rain events of 2017. Stream water at the gage is more isotopically enriched than seep groundwater during the summer-fall dry season and more depleted than seep groundwater during snowmelt. Interpretation of the early 2017 data is that snowmelt runoff is a driving force on streamflow in the spring season, depleting the stream water signal. The groundwater signal during this period also depletes as snowmelt replenishes groundwater through infiltration or losing stream conditions. The groundwater signal does not deplete as much as the stream channel showing that stream water is more easily re-mixed by snowpack melt.

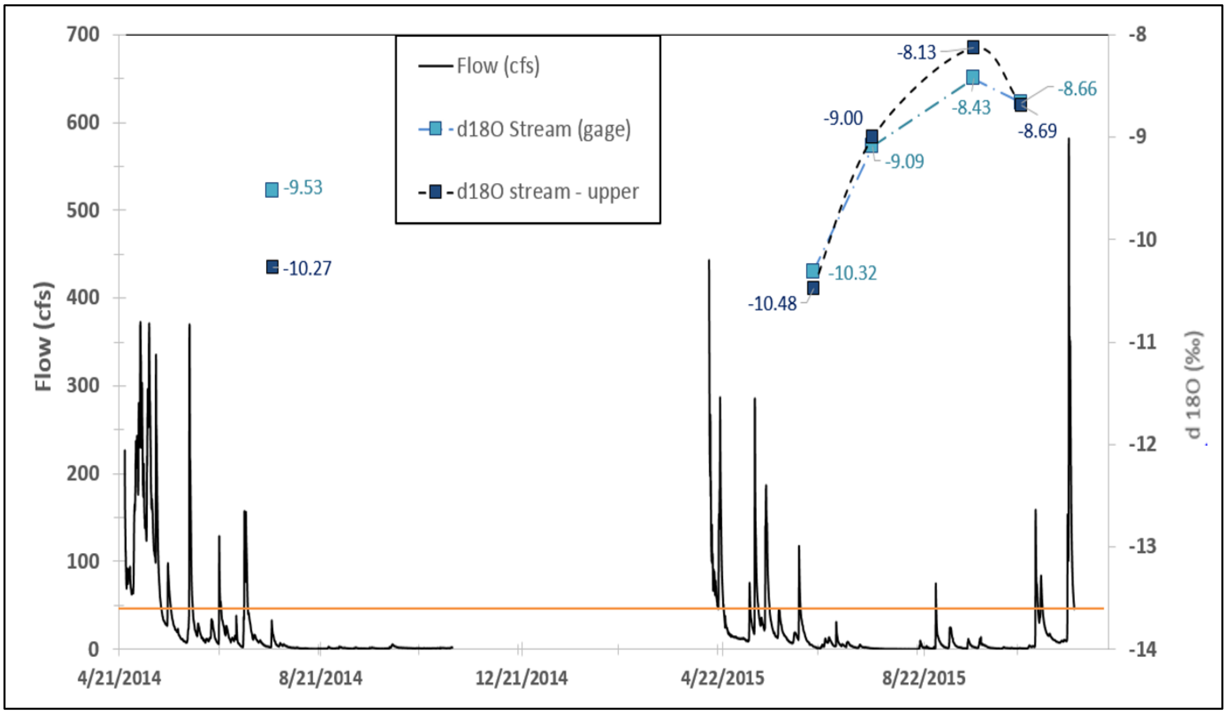


Figure 43: Oxygen Isotopes for the Flute Reed River at two stream locations in years 2014 - 2015 plotted alongside the flow hydrograph. The orange line represents the lower limit for very high flow conditions.

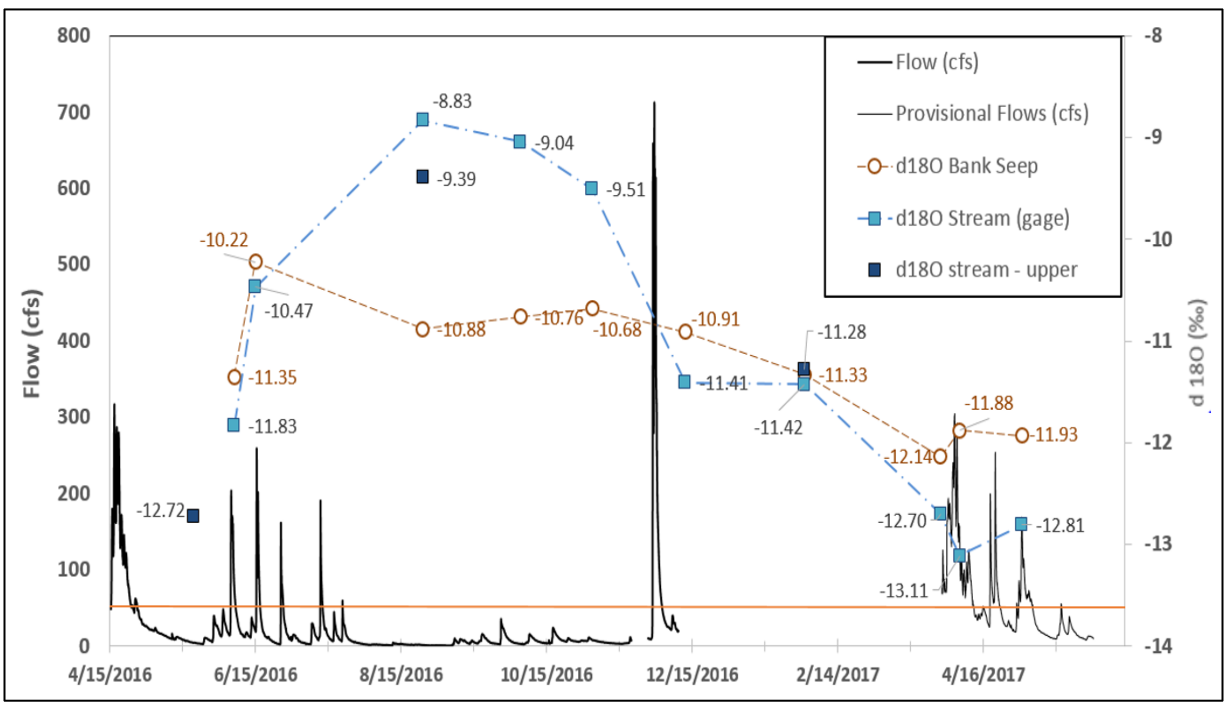


Figure 44: Oxygen Isotopes for the Flute Reed River at two stream locations and a bank seep located at the gage in years 2016 plotted alongside the flow hydrograph. The orange line represents the lower limit for very high flow conditions.

Enrichment of stream water at the gage station during the dry summer and fall seasons of years 2014 to 2016 at first appears more complex to analyze as some of the signals show evaporation losses (placement on the LEL), others show enrichment through rainfall (placement on the LMWL), and several fall between these lines. Interpretation of isotope data for the August 2016 low flow event when multiple flow sources and waterways were analyzed is used to better understand low flow isotope signals and related hydrologic processes within the watershed. Samples were collected from tributaries, a wetland, the bank seep, and multiple locations on mainstem Flute Reed within a three-hour period.

We sampled six tributaries located in various locations and draining various geologic features. The sample set included three upper watershed tributaries S008-490, S007-911, and S009-072 that originate in Superior lobe till and enter the Flute Reed River in the upper two-thirds of the flowage. The largest of the three tributaries, station S008-490, is located in the headwaters and drains a wetland complex. It was the most accessible to sample out of several tributaries that drain headwater wetlands in the watershed. It was flowing during the low flow event. The two smaller upper watershed tributaries sampled were located in the middle third of the flowage, draining the landscape and lacking major wetland connectivity. They were dry with pooled water collected at culverts.

Three tributaries that enter the Flute Reed River in the lower third of the flowage were also sampled. Two tributaries (west: S008-486 and east: S008-487) drain the 1765-ft bedrock peak and enter the Flute Reed from the north. The east tributary is connected to a wetland that captures the majority of the drainage from the south-facing slope of the bedrock ridge. This tributary was flowing during collection. The west tributary drains portions of the ridge, but mostly lies in Superior lobe till. The channel was mostly dry and water was collected from a stagnant pool at the downstream side of a culvert. Finally, tributary S009-069 enters the Flute Reed River just upstream of the gage station and drains the till landscape in the lower watershed with little to no wetland connections. It too was dry with water collected from a culvert-side pool.

Water was collected from the bank seep by applying pressure to the seep face, as it was not free flowing. Major wetlands within the watershed were not easily accessible so a nearby wetland that is located just outside of the Flute Reed drainage was sampled as representative of a regional wetland signal. Moosehorn Lake was not sampled due to limited access.

Data results identify similarities and differences in hydrologic isotope signals throughout the watershed. The mainstem sites plot in a cluster along the LEL, although some separation of upper and lower watershed stations is apparent. Watershed stations located in the lower watershed on the west-to-east oriented reach along the North Road (S004-235 to the mouth) show increased evaporation from the two upper mainstem stations located further north on Camp 20 Road. Our 2014-2016 record shows that overall, the upper reach station S004-277 and the lower reach gage station correlate well (Figures XX and XX). In fact, low flow events sampled in 2015 show little to no evaporative differences between upper and lower mainstem stations. A series of beaver dams were impounding stream water between the two reaches in 2016. We suspect evaporative processes on water pooled behind the beaver dams may be responsible for the differences in isotopic signals. This beaver dam effect has been observed in other isotope data collected along the North Shore of Lake Superior in recent years.

Mainstem signals do not clearly plot next to one specific source rather are grouped in the center of multiple other sources including tributaries and Lake Superior. Although we do not believe that Lake Superior is a source of flow to the stream system, it may be representative of Moosehorn Lake, which was not sampled. Based on the difference in lake size, the fraction of water loss to evaporation from Moosehorn Lake is expectedly higher than Lake Superior, theoretically pushing the signal slightly to the right along the LEL.

Tributary signal variability and groupings appear to be related to location and surficial geology (till versus scoured bedrock). The mainstem signals plot closer to the till draining tributaries than the tributaries that directly drain the scoured bedrock ridge. The three upper watershed tributaries that drain mostly till plot in a group just above the mainstem signals and slightly below the LMWL. The three tributaries grouped isotopically regardless of whether they were flowing or stagnant and regardless of whether they were connected to wetlands. The small till-draining tributary in the lower watershed plotted to the left of the mainstem signals. More evaporation is observed in the mainstem than the tributaries, which indicates another source of flow to the system. Assuming Moosehorn Lake plots slightly to the right of Lake Superior on the LEL, it likely is the evaporative source influencing the Flute Reed River in the upper and lower reaches.

Unlike the others, the two tributaries that drains the high bedrock ridge plot above the LMWL and further away from the mainstem signals. This difference in placement in respect to the LMWL could be attributed to variables such as altitude, evaporation rates, or bedrock verses alluvial aquifers. One theory is that aquifers along steep bedrock ridges are dominated by winter precipitation recharge, whereas aquifers set in till and alluvium are dominated by summer rainfall. In addition to plotting above the LMWL, the bedrock tributary S008-487 most closely reflects a groundwater signal, plotting near the inflow value and showing no evaporative influences. This tributary drains a wetland at the base of the high bedrock ridge. It was also one of the few tributaries identified with flowing water on the day of sampling. The signal not only is depleted compared to all other surface water sources collected, but it is also more depleted than the bank seep at the gage and plots above the range of signals observed from the seep throughout the season. With only one sample collected at this stream station, the excess deuterium could not be examined further.

The bank seep and the groundwater dominant tributary S008-487 do not appear to be dominant contributors of flow in the mainstem; however till-draining tributaries in both the upper and lower watershed plot close enough to assume a relationship. As mentioned, the upper watershed tributaries plot just below the local meteoric waterline, but clearly above the LEL. Other studies have found that groundwater that is recharged by direct infiltration of rainfall and mixing with partially evaporated soil moisture can result in isotopic signals that plot below and parallel to the LMWL (Clark and Fritz, date; Allison et al., 1984). Several other samples collected at the stream gage station over the study period fell into this orientation (Figure 45). This suggests that soil interflow or shallow groundwater frequently recharged by rainfall are distinguishable sources of flow to the system. What we do not understand is why the bank seep signal correlates more with what we would consider an annually mixed signal, plotting near the inflow value.

The wetland signal is highly evaporative, plotting to the far right of the LEL. This particular wetland was not within the boundaries of the Flute Reed River drainage, but was located just outside of the boundary. Comparison to the mainstem stations indicates that outflow from similar wetland complexes is not the primary source of streamflow in the watershed during low flow conditions. That does not mean that wetland storage and discharge do not play an important role in the hydrology of the system.

Based on comparison of all signals, several conclusions are inferred. First, stream signals at the gage correlate well with upper mainstem signals for most of the record and under various streamflow regimes. Evaporate losses between the upper and lower mainstem stations during dry low flow conditions of August 2016 are likely due to beaver dam ponding of stream water. A depleted signal representative of seasonally well mixed groundwater was collected from a bedrock draining tributary, although the specific tributary does not appear to be a dominant flow source to the Flute Reed River. The bank seep also does not appear to be a dominant flow source. Till-draining tributaries have signals that plot just below the LMWL and just above mainstem stations. Signals of these tributary waters under low flow conditions may represent the signals of shallow alluvial aquifers that recharge frequently from precipitation and evaporated soil moisture that makes its way down through the soil profile. Mainstem stations plot near these tributaries, some of which are not flowing. Because the majority of the tributaries were not flowing to the mainstem, we suspect that subsurface flow from the shallow alluvial aquifers are a strong source of flow to the mainstem. However, at least one headwater tributary was flowing and did plot near mainstem stations as well. Because the upper and lower mainstem clearly has an evaporative signal, another source is also present. Because the evaporative signal is found in upstream stations as well as downstream stations, Moosehorn Lake and upstream wetlands are likely the "second" source of flow in the mainstem. One wetland was sampled and was highly evaporative and plotted far from mainstem stations. This may be a signal specific to that single wetland or it may indicate the Moosehorn Lake is the "second" source of flow.

In our study on Lake Superior North streams, isotope data suggests that the Flute Reed River is more vulnerable to seasonality, particularly affecting low flow conditions than most of the study streams. Groundwater appears to be a strong source of summer baseflow in several of the study streams including Wanless Creek, Woods Creek, Two Island River, and Thompson Creek. Devil Track River is an example where lakes play a primary role in maintaining flow to the downstream system. Flute Reed River is an example of a lake-fed stream that is highly dependent on precipitation to supply flow.

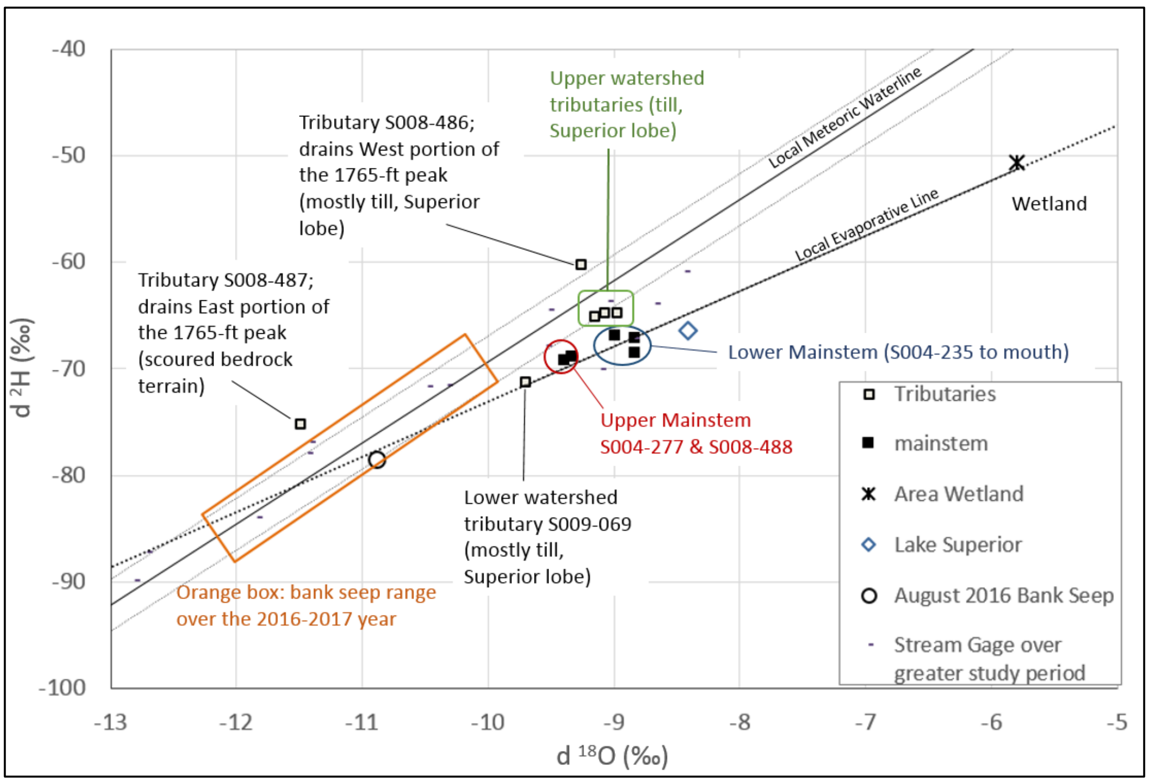


Figure 45: Oxygen (d18O) and Hydrogen (d2H) isotopes of stream and potential source-waters collected during a low flow event in August of 2016. Mainstem Flute Reed River stations plot in a group that is immediately surrounded by tributary and lake signals. Tributaries draining large bedrock ridges and seeps along the stream bank do not plot near mainstem signals.

We conclude that Moosehorn Lake, alluvial/till aquifer discharge, and perennial headwater tributaries (example: S008-490) are the likely primary sources of flow to the mainstem Flute Reed River during the critical low flow months of summer. Only a fraction of the tributaries flow during the dry summer season limiting their overall contribution outside of runoff events. Bedrock-draining tributaries have a signal showing more winter precipitation mix than till/alluvial aquifer-draining tributaries when sampled in mid-summer. This may indicate that overall storage is greater in the scoured bedrock aquifers holding winter precipitation there longer into the season; or that the snowpack: rainfall infiltration ratio to aquifers varies based on aquifer type and location. Because the bedrock tributary signals plot so far from mainstem signals, we conclude that the overall contribution to mainstem flow is low. The same is true for the bank seep, which also plots far from the mainstem signal in mid-summer. Alluvial/till aquifer tributaries have isotope signals that more closely resemble the mainstem; however, the similarities may be more closely tied to similar aquifer storage than direct tributary discharge to the Flute Reed River, as many of them are dry. Moosehorn Lake, although not sampled, is suspected to be a consistent headwater source of flow to the river based on an unidentified evaporative signal in the Flute Reed River. The wetland sampled had a highly evaporative signal, which indicates that surficial wetland storage may not be a primary source of stream discharge during low summer flows.

4.8 Summary and Recommendations for Flute Reed River

4.8.1 Key Stressors and Threats

Stressors to aquatic life in the Flute Reed River watershed include elevated water temperatures, physical habitat degradation, barriers to fish movement, and elevated TSS concentrations. Table 10 summarizes key findings from the stressor analysis and the contributing sources and pathways.

Table 10: Summary of primary stressors to aquatic life in the Flute Reed River watershed.

Stressor/Threat	Summary
Elevated Water Temperature	• Temperatures in most reaches of the Flute Reed River are marginal to poor for supporting Brook Trout and other sensitive coldwater obligates species. The extreme headwaters of the river provide cold enough water temperatures to support wild Brook Trout. • Temperatures remain suitable for supporting wild Steelhead Rainbow Trout population between RM 0.0 and RM 5.0 based on recent temperature data • Sources of water temperature warming include beaver dams, turbid water, reduced riparian tree shading, low flow conditions. Climate change is another threat to the longevity of coldwater species in this watershed.
Physical Habitat Degradation	• Physical habitat loss due to channel incision, widening, and sediment deposition is evident in many reaches, particularly between RM 6.0 and Lake Superior. • Deposition of fine sediment (silt/clay) on the surface of coarser substrates (gravel/cobble/boulder) is evident in many areas, reducing spawning areas for fish and critical habitat for aquatic macroinvertebrates. • Sources of habitat degradation include bank erosion (caused by channel incision/widening), beaver dams, road and ditch runoff, sediment transport issues related to road culverts
Aquatic Organism Passage Barriers	• Several road culverts in the Flute Reed River watershed are undersized, perched, and/or improperly set. The result is a loss or elimination of fish passage, as well as migratory barrier or other aquatic and terrestrial life. Two crossings on CR 70 and one on Tom Lake Road are priorities for replacement with properly sized and installed culverts or bridges.
Elevated TSS Concentrations	• The Flute Reed River is currently listed as impaired for elevated TSS concentrations. Water quality standards are most frequently violated downstream of the lower CR 70 crossing, but also occur upstream of this point. • Elevated TSS concentrations occur primarily during high magnitude, low frequency snowmelt and precipitation events. TSS concentrations during low to moderate streamflow conditions generally meet WQ standards for aquatic life. • Sources of elevated TSS include streambank and valley wall erosion, overland runoff from open lands and gravel/dirt roads, and beaver activity.

4.8.2 Implementation Suggestions – Protection and Restoration

Efforts to protect and preserve high quality habitats and ecological function is equally important to restoration goals for the watershed. Several high quality and/or ecologically significant areas in the watershed are highlighted below. Specific protection goals should be developed for these areas through input from stakeholders, resource managers, and watershed-planning processes (e.g. WRAPS). Input regarding additional priority protection areas should also be part of this process.

Table 11: Suggestions for priority protection areas in the Flute Reed River watershed

Protection Area	Significance
Flute Reed R. near Tom Lake Rd.	• Coldest water temperatures in watershed. • Wild Brook Trout observed in previous sampling events
Flute Reed R. Reaches FLR 000 through FLR 004*	• Critical spawning and rearing habitat for Steelhead Rainbow Trout
Flute Reed R. Reaches FLR 015 through FLR 018*	• High degree of channel stability and excellent physical habitat conditions
Stable channels within former beaver impoundments (e.g. Reach FLR 016)	• Stable channels offering high quality habitat • Monitoring/protection necessary to encourage forest succession that promotes further "recovery" and longevity of lotic environment

Table 12: Stressors/threats to aquatic life in the Flute Reed River watershed and recommended implementation actions

Stressor or Threat	Location	Restoration Action
Fish Passage	Camp 20 Rd/Tom Lake Rd	• Replace existing undersized/perched culverts with properly sized and installed culverts or bridges
TSS/Physical Habitat	Throughout watershed, but particularly in riparian corridor and steeply sloped areas dominated by clay soils	• Follow sustainable forestry practices as outlined in the following documents; "Managing Woodlands on Lake Superior's Red Clay Plain (http://dnr.wi.gov/files/pdf/pubs/fr/fr0385.pdf)
TSS/Physical Habitat	Throughout watershed, especially in areas currently impacted by beaver impoundments	• Propagation of conifer and other species that are undesirable to beaver harvest. Implement a long-term monitoring effort within the reach to observe changes in stream temperature, suspended and bedded sediment, and physical habitat conditions.
TSS/Physical Habitat	Gravel Roads and Road Ditches	• Further assess stability of road ditches in the Flute Reed River watershed an their contribution to sediment loads • Discourage routine ditch dredging with heavy equipment. Follow guidelines included in "Field Guide for Maintaining Rural Roadside Ditches (U of MN, 2014) (click here - web link)

5.0 Woods Creek

5.1 Stream and watershed characteristics

Woods Creek is a steep, second order tributary of the Devil Track River with a drainage area of slightly over 2 square miles. It is a designated coldwater trout stream from its headwaters to its confluence with the Devil Track River, a length of approximately 3.7 river miles. Recent fisheries survey results confirm this stream supports a population of naturally reproducing Brook Trout, as well as Steelhead Rainbow Trout, which enter the Woods Creek via the Devil Track River. The majority of the watershed is within the Superior National Forest, although the upper 1/3 of the watershed is largely in private ownership.

The Minnesota DNR has routinely monitored trout populations, water temperatures, and habitat conditions in Woods Creek over the past decade (Weberg, 2016). MN DNR has regularly cited several unfavorable land uses and stream conditions that may limit trout populations and overall biological integrity in the Woods Creek watershed. The MPCA's monitoring and assessment report (Sandberg, 2015) corroborated many of the same findings. Further evaluation of these limiting factors, or "stressors", was the primary focus of MPCA's efforts in 2015 and 2016. An additional emphasis was placed on documenting the critical habitat features in this watershed that allow this small stream to support sensitive coldwater fish and macroinvertebrate taxa. Table 13 summarizes the various components of the Woods Creek watershed that were evaluated in detail with the overall goal of developing a restoration/protection plan.

Table 13: Stressors and key habitat features affecting aquatic life in the Woods Creek watershed.

Limitations/"Stressors"	Causes/Pathways	Critical Habitat	Causes/Pathways
Natural Barriers	• High stream gradient • Bedrock geology/waterfalls	**Cold Water Temperature**	• Groundwater inputs • Undeveloped Riparian Corridor/Shading
Constructed Barriers	• CR 58 culvert is barrier to fish passage • Constructed impoundments in headwaters = barriers?	**Pool Habitat**	• Step pool habitat due to high stream gradient/boulders
Low Streamflow	• Small drainage area • Ditching, constructed impoundments in headwater • high width/depth ratio at low flow	**Abundant Gravel Substrate**	• Outwash Geology • High gradient stream → stream-power to prevent deposition of fine substrates
Habitat Degradation	• Impacts from 2008 flood • Bank erosion/channel incision/widening, loss of pool habitat	**Abundant Fish Cover**	• Large Woody Debris • Boulders/Plunge pools

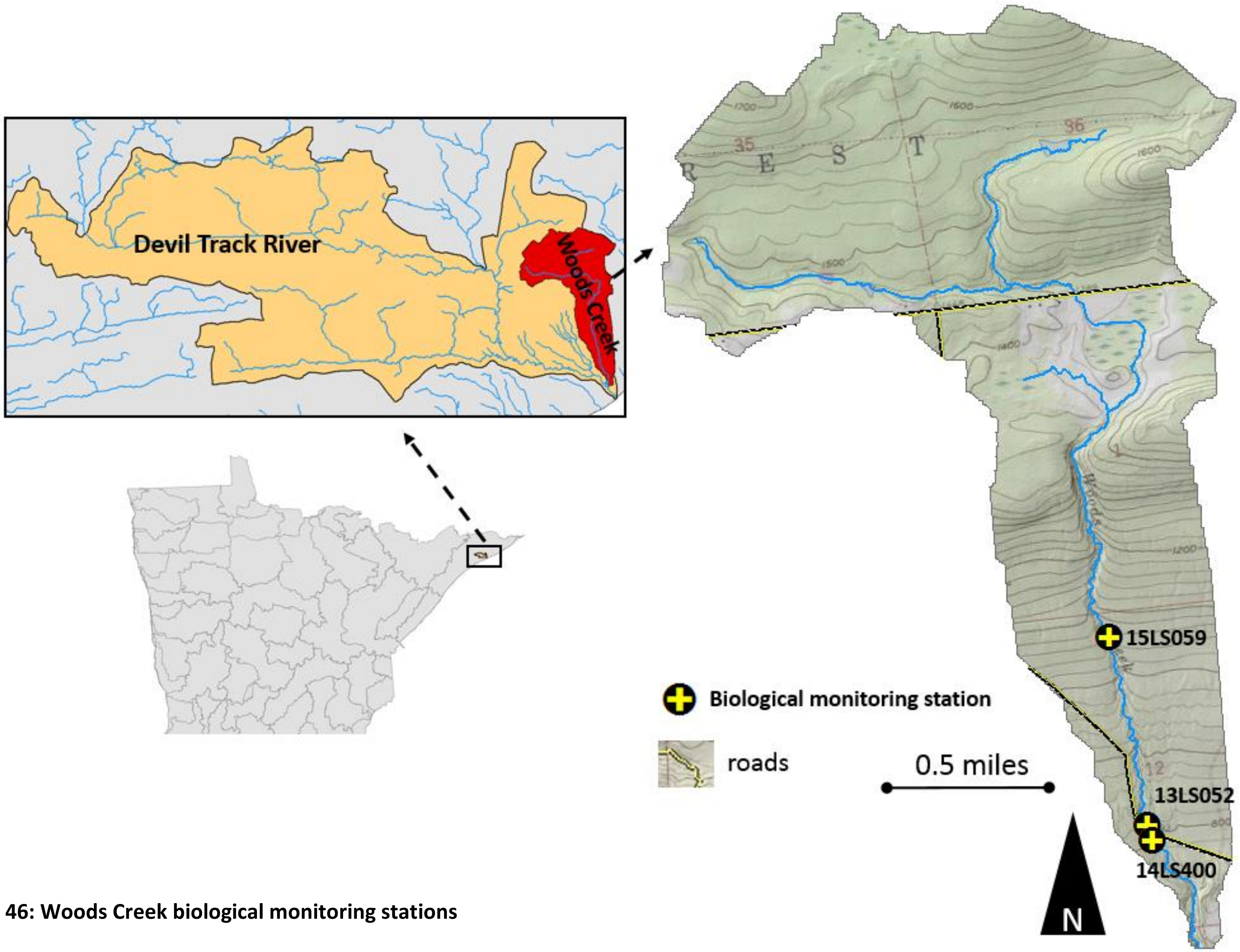


Figure 46: Woods Creek biological monitoring stations

5.2 Overview of biological data

5.2.1 MPCA biological monitoring results

MN PCA sampled fish and aquatic macroinvertebrates at three locations on Woods Creek as part of the greater Lake Superior North Watershed Monitoring and Assessment effort (figure 46). Initially, only one monitoring station (13LS052) was placed on the creek at the CR 58 (Lindskog Rd), approximately 0.5 river miles upstream of its confluence with the Devil Track River. Although this station is representative of overall stream conditions, additional stations were added in following years to evaluate biological integrity within high quality habitat areas and above and below the perched culvert crossing at CR 58.

Fish IBI results indicate a healthy coldwater fish community in Woods Creek, particularly higher up in the watershed where habitat conditions are better suited for Brook Trout survival and reproduction. All three stations surpassed the “exceptional-use” fish IBI threshold (60), which entails a higher level of protection for the high-quality coldwater fish community observed in this stream.

Although fish IBI scores were relatively high, Brook Trout and Rainbow Trout numbers were relatively low in most of the samples. Other coldwater species frequently observed in higher quality North Shore streams, such as mottled and Slimy Sculpin, were notably absent from all Woods Creek stations. Creek Chub and Central Mudminnow were sampled in moderate abundance, often outnumbering Brook Trout and other coldwater taxa. Low overall fish counts and lack of coldwater taxa in this stream may be linked to the small drainage area and highly fragmented nature of this stream. Degraded habitat conditions and extremely low stream flows are also a likely factor. Woods Creek should be a high priority for protection and restoration efforts given that a minor change in fish community structure could cause drastic swings in fish IBI results.

Aquatic macroinvertebrates were sampled at two locations, 13LS052 and 15LS059 (figure 45, Table 14). Macroinvertebrate Index of Biological Integrity (MIBI) scores at both stations were indicative of health coldwater invertebrate communities. The maximum MIBI scores at both stations surpassed the exceptional use standard. Stonefly and caddisfly taxa richness values were relatively high in Woods Creek, which is a positive reflection of the cold water temperatures and abundant coarse substrates. Relative to the fish IBI scores, MIBI results were somewhat lower due to a lack of Odonate (dragonfly) taxa and “long-lived” taxa (those that require more than one year to complete their life cycle).

Table 14: Summary of Flute Reed River biological sampling stations, results, and applicable assessment criteria (fish only). Map of stations can be found in figure 21. Bold Black text indicates IBI scores meeting aquatic life standards. Red text indicates IBI score failing to meet aquatic life standards. Blue highlights indicate scores that exceed exceptional use standards.

Station	Drainage Area (mi2)	Fish IBI Class	Fish IBI Result *(visit year)*	Fish IBI Result *(visit year)*	IBI Standard	IBI Lower Confidence Limit	IBI Upper Confidence Limit	Exceptional Use Threshold
13LS052	2.12	8	**81** (2014)	**75** (2015)	35	25	45	60
14LS400	2.29	8	**90** (2014)	-	35	25	45	60
15LS059	1.82	8	**62** (2014)	-	35	25	45	60

Station	Drainage Area (mi2)	Invert IBI Class	Invert IBI Result *(visit year)*	Invert IBI Result *(visit year)*	IBI Standard	IBI Lower Confidence Limit	IBI Upper Confidence Limit	Exceptional Use Threshold
13LS052	2.12	11	**50** (2013)	**56** (2015)	32	20	44	52
15LS059	1.82	11	**56** (2015)	-	32	20	44	52

Historically, Woods Creek supported a wild Brook Trout population throughout its entire length (Weberg, 2014). Recent sampling completed by MPCA and DNR suggests that the range of their distribution in this watershed has decreased. In 2010, MN DNR did not observe any Brook Trout during a sampling effort that covered four stations (Weberg, 2016). Very small populations of Brook Trout (range 0-4 individuals) were observed at station 13LS052 (RM 0.4) over a sampling period that covered 2013 – 2015. Over this period, electrofishing was also completed at RM 2.4, but no Brook Trout were observed at that location.

In 2015, MPCA sampled a remote reach of Woods Creek off the Superior Hiking Trail that provided more favorable Brook Trout habitat (Station 15LS059, figure 45). This reach offered several deep pools and significant fish cover (figure 49), both serving as refuge for summer and winter low flow periods. A total of 16 Brook Trout (size range 2.9 – 7.7 inches) were sampled at this station in August of 2015. These results are evidence that a viable Brook Trout population remains in Woods Creek in with more favorable habitat.

In October of 2016, MPCA staff hiked approximately 1.6 miles of Woods Creek, from CR 58 crossing up to the ditched portion of the stream that crosses private property. Brook Trout and several spawning redds were observed in eight locations, predominantly in the upper 1/3 of the assessed reach. Available data suggests Brook Trout are most abundant in the reach between RM 1.0 – 1.8 due to favorable habitat conditions.

Woods Creek enters the Devil Track River approximately 0.3 river miles upstream of the shores of Lake Superior. Steelhead Rainbow Trout entering the Devil Track River during seasonal spawning migrations have access to Woods Creek, however, the lower portion of Woods Creek is extremely high gradient (>10% slope in areas) and is contains numerous 7-8' bedrock drops within a steep canyon. Until recently, these bedrock falls were believed to be barriers to upstream migration of adult Steelhead. Several pools downstream of the falls were known to provide thermal relief and refuge for juvenile Brook Trout/Rainbow Trout, but spawning migrations of adult Steelhead beyond the lower falls in Woods Creek were undocumented.

In 2014 and 2015, MPCA sampled juvenile Rainbow Trout in Woods Creek at stations 14LS004/13LS052, approximately 0.4 miles upstream of the Devil Track River confluence. This sample provides evidence that adult Steelhead are able to ascend the lower canyon of Woods Creek to access spawning/rearing habitat upstream. Rainbow trout were sampled above the CR 58 crossing at 13LS052. It appears that adult steelhead are able to pass through the CR 58 culvert at high flows, but installing a properly designed culvert to allow fish passage at all flows would enhance access to prime spawning/rearing habitat upstream.

Summer water temperatures in Woods Creek are among the coldest observed in Lake Superior's North Shore tributaries (figure 50). Several sensitive aquatic macroinvertebrates were sampled in Woods Creek during MPCA's assessment monitoring. Amphinemura, Epeorus, Rhithrogena (add more a few more sentences on inverts)

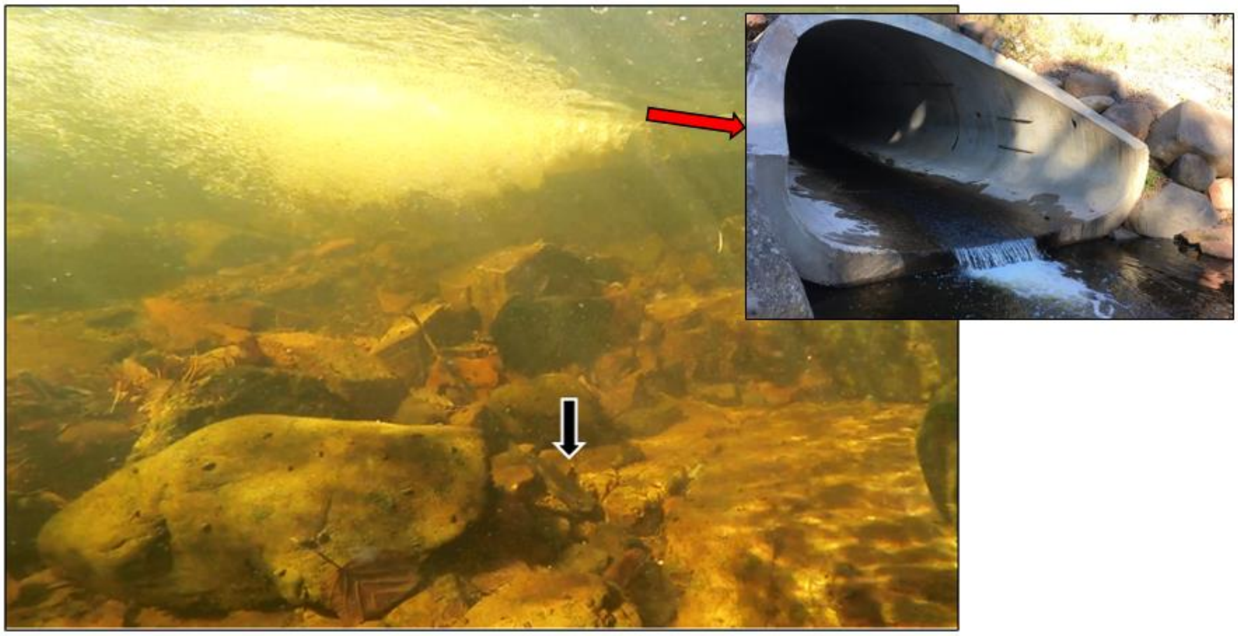


Figure 48: Age-1 Steelhead Rainbow Trout in Woods Creek below CR 58 culvert. CR 58 crossing is a barrier to fish passage.

Figure 47: Adult Steelhead Rainbow Trout are able to ascend these bedrock falls in the lower 0.4 river miles of Woods Creek to reach quality spawning and rearing habitat upstream.

Figure 49: Examples of quality pool habitat and cover at station 15LS059. Brook Trout numbers were significantly higher here compared to other monitoring stations.

5.3 Water Temperature

5.3.1 Review of water temperature data

Water temperature data were collected by MPCA and MN DNR staff during summers of 2010, 2011, 2014, 2015, and 2016. Overall, the thermal regime of Woods Creek is excellent for supporting stenothermic (i.e. capable of living or surviving within a narrow temperature range) coldwater fish and macroinvertebrate taxa. Water temperatures during the summer months (June-August) were typically within the "growth range" for Brook Trout between 90-99% of the time in between river mile (RM) 0.0 and RM 1.7, which is where Brook Trout have been predominantly sampled in Woods Creek. This reach of Woods Creek consistently offers some of the coldest water temperatures among the North Shore Lake Superior coldwater streams for which continuous temperature data are available (figure 50).

More variable stream temperatures were observed at stations located closer to the headwaters of Woods Creek (RM 2.4). Five years of continuous temperature data are available at river mile 2.4, and percent of temperature readings within the growth range for Brook Trout ranges from a low of 76.1% in 2010, to a high of 98.8% in 2014. This wide range in summer stream temperatures is not observed at other monitoring stations. In 2010, a significant difference in stream temperature was evident between RM 2.9 (91% growth range / 9% stress range) and RM 2.4 (76% growth range / 23% stress range / 1% lethal range). The 0.5-mile reach between these two stations is frequently impounded by beaver dams, which may be responsible for the observed increase in temperature.

In addition to beaver dams, other potential sources that may increase water temperatures include the loss of riparian vegetation and stream channelization (ditching) downstream of CR 60. Riparian vegetation has been removed along nearly 0.5 river miles of the creek, and active dredging of the stream channel removes shading and cover provided by undercut banks and large woody debris.

Coldwater inputs to Woods Creek include springs and seeps along the steep ravine in the lower 1.7 river miles, and a cold tributary stream that joins Woods Creek just upstream of the CR 60 crossing. Based on three years of continuous monitoring data, this tributary runs colder than Woods Creek, and nearly always supports a temperature regime that is suitable for Brook Trout growth (figure 50). Prior investigations on Woods Creek have noted that the tributary at mi 2.71 appeared to contribute a greater amount of water than the main stem of Woods Creek at their confluence. Flow measurements during August electrofishing assessments confirmed that the flow rate in the unnamed tributary was substantially higher than in Woods Creek (0.17 CFS vs. 0.01 CFS) (Weberg, 2015).

Overall, water temperatures in Woods Creek are suitable for supporting a wild Brook Trout population, as well as other stenothermic fish and macroinvertebrate species. Given the low flow rates, lack of tributary streams, and physical habitat limitations of this waterbody, it is clear that cold water temperatures are particularly critical for sustaining Brook Trout in this watershed. Protection measures should be implemented to preserve the integrity of coldwater inputs to the creek (unnamed tributary, seeps and springs). Restoration efforts such as revegetating the riparian corridor downstream of CR 60 would decrease the susceptibility of the creek to warming. Targeted temperature monitoring near beaver impoundments and private dams in the headwaters would help inform restoration and management decisions for reducing thermal loading in that reach.

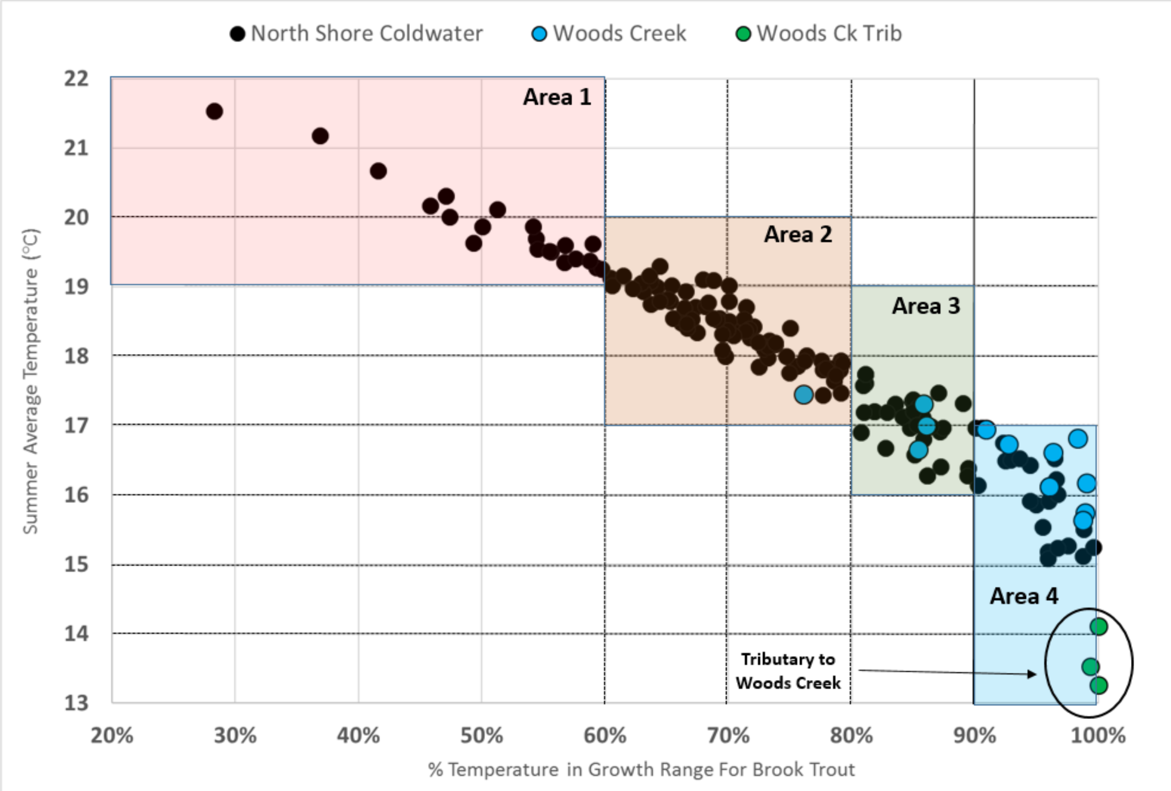


Figure 50: Plot of Summer Avg. temperature vs. % Time in Brook Trout temperature growth range. Flute Reed monitoring stations are shown in colored markers, while all other North Shore coldwater stations are shown as black markers. Temperature "areas" are discussed further in section 3.1

Table 15: Woods Creek water temperature data related to Brook Trout growth, stress, and lethal thresholds

Station (RM = River Mile)	Year	Growth	Stress	Lethal	No Growth	Summer Avg.	Summer Max
13LS052 (RM 0.4)	2010	96.4%	3.6%	0.0%	0.0%	16.57	21.13
13LS052 (RM 0.4)	2011	92.8%	7.2%	0.0%	0.0%	16.72	22.71
13LS052 (RM 0.4)	2014	99.0%	1.0%	0.0%	0.0%	15.70	
13LS052 (RM 0.4)	2015	96.1%	3.6%	0.0%	0.0%	16.11	22.97
13LS052 (RM 0.4)	2015	96.5%	3.4%	0.0%	0.0%	16.55	22.18
RM 1.7	2016	85.9%	14.1%	0.0%	0.0%	17.28	24.53
RM 1.7	2010	99.1%	0.9%	0.0%	0.0%	16.16	20.89
RM 2.4	2016	98.4%	1.6%	0.0%	0.0%	16.83	21.89
RM 2.4	2010	76.1%	22.7%	1.2%	0.0%	17.43	26.06
RM 2.4	2011	85.5%	14.1%	0.4%	0.0%	16.65	26.65
RM 2.4	2014	98.8%	1.2%	0.0%	0.0%	15.62	22.71
RM_2.4	2015	86.1%	13.9%	0	0	16.98	24.82
RM 2.9	2010	90.9%	9.1%	0.0%	0.0%	16.93	21.75
Tributary RM 0.0	2010	100.0%	0.0%	0.0%	0.0%	14.10	19.06
Tributary RM 0.0	2014	100.0%	0.0%	0.0%	0.0%	13.26	17.80
Tributary RM 0.0	2015	99.4%	0.0%	0.0%	0.6%	13.53	19.01

5.4 Channel stability and physical habitat conditions

Channel stability and physical habitat conditions were evaluated in Woods Creek using two methodologies; the Pfankuch Stability Index (PSI) (Pfankuch, 1975) and a Brook Trout Suitability Assessment (BTSA). Background information on these two assessment methodologies are included in section 3.2. Both assessments were completed using visual observations collected during field investigations along Woods Creek from RM 0.0 to RM 2.0. Data are summarized by stream reaches that were delineated based on Rosgen stream and valley types (Rosgen, 1995) and breakpoints determined by a change in habitat type, condition, or channel stability rating (Table 16). A total of 14 stream reaches were delineated using these criteria.

Additional habitat features, stream characteristics, and biological observations were noted and mapped during the 2.0-mile field assessment of Woods Creek. These include deep pools (>1 ft at low flow), barriers to fish migration (natural – e.g. waterfalls, and unnatural – e.g. road culverts), and visual observations of Brook Trout and active spawning areas (discussed in more detail in section 5.5.

5.4.1 Results of Channel Stability Assessments

PSI stability ratings are adjusted by the potential "stable" stream type for a given reach. Stream types with steeper slopes and entrenched valleys (e.g. A and B types) were highly dominant within the portion of Woods Creek assessed using the PSI. "A" type channels are typically found where slopes range from 4%-10%, with cascading step pool morphology, irregularly spaced drops, and deep scour pools (Rosgen, 1995). "B" type channels are moderately entrenched with moderately steep slopes, and are considered inherently stable systems that contribute low sediment loads.

B stream types have lower thresholds for being declared "unstable" or "moderately unstable" in the PSI methodology (see table 16). They are considered low sediment-supply stream types, and should be relatively stable if the dominant substrate types are larger in size (bedrock, boulder, cobble). If indicators of channel instability (pool filling, bar development, bank erosion) are observed within a B type stream reach, it is likely that it will be classified as moderately unstable or unstable by the PSI. As a result, disturbances within the watershed (e.g. clear cutting, ditching, roads) and catastrophic weather events (e.g. high magnitude/low frequency floods) have a greater likelihood of leading to channel instability ratings in Woods Creek compared to many other streams of more resilient stream types.

Of the 15 stream reaches assessed, Pfankuch Stability Index (PSI) results classified 4 (27%) as "stable", 4 (27%) as "moderately unstable", and 7 (46%) as "unstable." PSI ratings of "unstable" were most frequently linked to channels currently in the B and F stream type, while stable reaches were most commonly observed in conjunction with the A and C channel types (Table 16). There does not appear to be a strong longitudinal pattern in channel stability along the length of Woods Creek, other than the last 0.4 river miles, which were all categorized as "unstable".

Many reaches with poor/unstable PSI ratings displayed the same indicators of channel instability. Mass erosion (mass wasting) of the stream valley wall was observed in numerous reaches, most significantly in reaches 2 and 3 near the CR 58 crossing. Other poor PSI metric scores in Woods Creek were related to channel capacity (high width/depth ratio), cutting (erosion of lower banks), changes in substrate composition (e.g. increased deposition of fines), and obstructions to flow (e.g. log jams causing channel migration and widening). A complete table of PSI metric results is included in Appendix BLANK.

- Reach 5
- PSI = 80 (stable)
- Potential stream types:
  - A3/1, B3a
- Vegetated bars/banks
- Bedrock control
- Vegetated, stable banks

- Reach 11
- PSI = 69 (Mod. Unstable)
- Potential stream type
  - B3/4a
- Active bar development
- Debris jams
- Mod. Bank instability

- Reach 3
- PSI = 96 (Unstable)
- Potential stream type
  - B3/4a
- High width/depth ratio
- Debris jams, incision
- Severe bank instability

Figure 51: Examples of reaches with stable, moderately unstable, and unstable PSI ratings in Woods Creek

Table 16: Stream types and Pfankuch stability scores/ratings for delineated reaches of Woods Creek

Reach #	Current Stream Type	Potential Stream Type	Pfankuch Score	Pfankuch Rating
1	A1a+	A1	81	Unstable
2	A3/1	A2/1	96	Unstable
3	F4a	B3a	96	Unstable
4	B3a / A1	B2/1a	65	Unstable
5	A3/1	A3/1	80	Stable
6	B3a / A1	B3a	73	Mod. Unstable
7	F3a / B3a	B3a	99	Unstable
8	A4 - A3/1	A3/1	93	Mod. Unstable
9	B3a / F2b	B3a	101	Unstable
10	A2/1a+ / B3	A3/1	59	Stable
11	B3/4a	B3a	69	Mod. Unstable
12	B3	B4a	84	Mod. Unstable
13	B4a	B4a	101	Unstable
14	C3b	C3b	45	Stable
15	E4	E4	74	Stable

5.4.2 BANCS model results and predicted erosion rates

Several sources cited excess stream bank erosion as threat to biological integrity in Woods Creek (Sandberg, 2016; Weberg, 2015). In the fall of 2016, MPCA staff completed an assessment of streambank erosion potential in Woods Creek using the BANCS model developed by Rosgen (2006). Additional information on the BANCS methodology is included in section 3.2. The overall goals of this assessment were to quantify bank erosion potential in Woods Creek by individual streambanks, as well as the river-reach scale to inform restoration and protection strategies.

BANCS model data were collected over a two-day assessment of 2.4 river miles of Woods Creek, extending from the confluence at Devil Track River upstream to the lower extent of the channelized reach. A total of 109 measurements of bank height (estimated), length, and erosion potential were recorded using a digital mapping application. Streambank lengths were delineated based on changes in bank height and/or erosion risk. Predicted erosion rates were calculated using the curve developed by Rosgen (1996) using data from streams in Colorado. MPCA and South St. Louis County SWCD offices are currently developing a curve for streams along the North Shore of Lake Superior, but this regional curve was not ready for use in this report.

Predicted Erosion Estimates

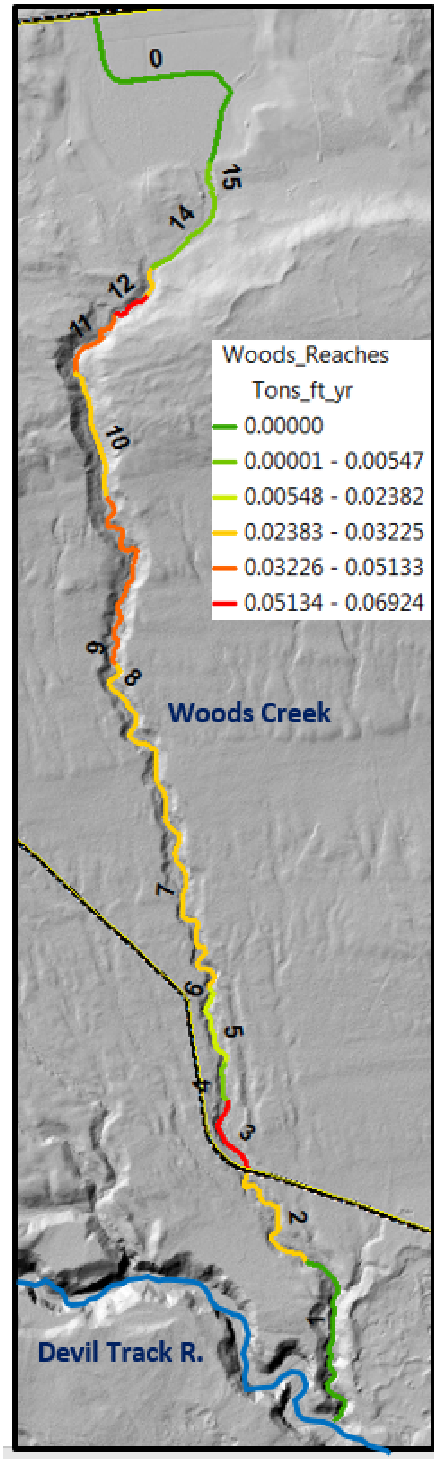
The BANCS model provides predicted bank erosion estimates for the 1.0-1.5 year flood event (bankfull flow). The model predicted nearly 359 tons of annual sediment loss due to bank erosion in the 2.4-mile reach assessed in fall of 2016. This equates to 239 cubic yards of sediment, the equivalent of 19 dump truck loads. Results were summarized by stream reach to determine relative streambank erosion risk in Woods Creek (table 52). Due to the variable length of the delineated stream reaches, the sum totals of predicted erosion were divided by the length of the reach to obtain estimated tons/ft/year. Predicted erosion rates were highest in reach 12 (0.069 tons/ft/year), followed closely by reach 3 (0.064 tons/ft/year). Other areas with relatively high predicted erosion rates include reach 9 (0.051 tons/ft/yr) and reach 11 (0.045 tons/ft/yr.) The average predicted erosion rate for the 14 reaches evaluated came out to 0.031 tons/ft/yr.

A low risk for streambank erosion potential was observed in reach 1 (uncalculated, but very low due to bedrock), reach 4 (0.002 tons/ft/yr), reach 15 (0.005 tons/ft/yr), reach 14 (0.005 tons/ft/yr), and reach 5 (0.018 tons/ft/yr). Common attributes of reaches with low erosion potential included lower stream gradient (reaches 14 and 15 only), floodplain connectivity at higher flows, and bedrock outcrops along the stream bottom and banks.

Some caution should be used in using these predicted values given that no validation of bank erosion rates in Woods Creek has been completed. The 2008 flood event caused significant bank erosion and channel incision throughout Woods Creek and many of the indicators of erosion risk (e.g. steep non-vegetated banks, bluff failure) may actually be lag effects from this event that are in the process of recovery. Annual or semi-annual floods (bankfull flows) may not be significant enough to de-stabilize these areas as some of the predicted values may indicate. BANCS model estimates do provide valuable results for comparing relative bank erosion risk by reach in this watershed.

Areas of Significant Bank Erosion

Approximately 33% of the total predicted annual bank erosion is generated by 10 areas of significant channel instability. Table BLANK provides a data summary and geographic location of these 10 locations. The top three sources of sediment are shown in figure 53.. The majority of these features are valley wall slumps with high erosion potential, bank heights of over 7 feet, and lengths of 40 feet or longer. Many of these areas are eroding due to freeze/thaw and bank seeps in addition to stream processes.



Reach	Total Tons	Reach Length	Tons/Ft/Yr.	% of Total
1	0*	1613'	0.000*	0.0%*
2	30	1126'	0.027	8.4%
3	43	664'	0.064	11.9%
4	0	251'	0.002	0.1%
5	10	561'	0.018	2.9%
6	3	109'	0.024	0.7%
7	51	1974'	0.026	14.1%
8	38	1240'	0.031	10.7%
9	91	1782'	0.051	25.5%
10	31	972'	0.032	8.7%
11	31	678'	0.045	8.6%
12	15	210'	0.069	4.1%
13	10	338'	0.029	2.7%
14	4	747'	0.005	1.1%
15	2	308'	0.005	0.4%
TOTAL	***359***	***12572***	***0.029***	***100.0%***

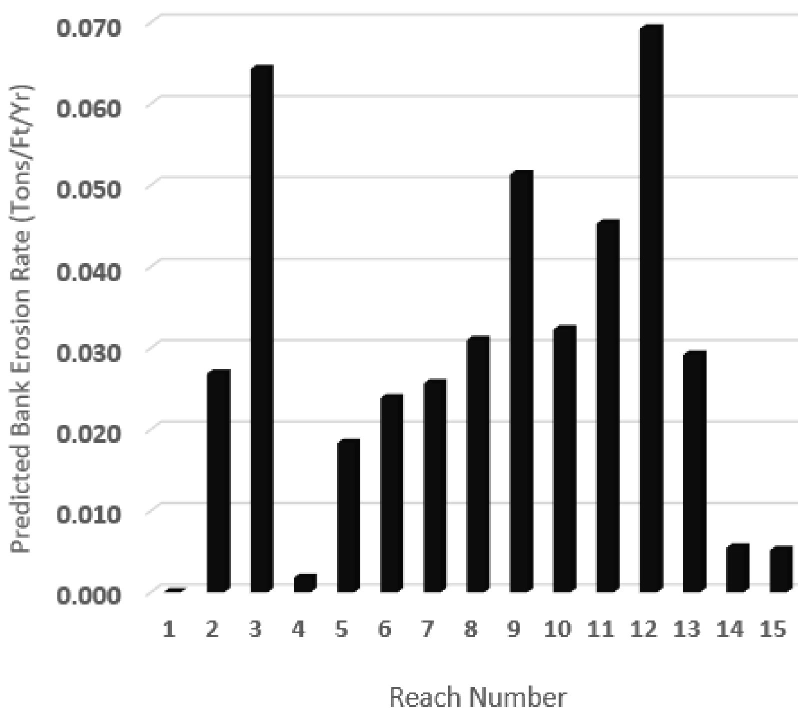


Figure 52: Predicted bank erosion rates for the delineated stream reaches of Woods Creek.

Reach	BEHI Rating	NBS Rating	Bank Height	Bank Length	Erosion Rate (Ft/Yr.)	Cubic Yd./Yr.	Total Tons	Tons/Ft/Yr.
3	High	Moderate	12’	86.4’	0.38	14.57	18.95	0.219

Reach	BEHI Rating	NBS Rating	Bank Height	Bank Length	Erosion Rate (Ft/Yr.)	Cubic Yd./Yr.	Total Tons	Tons/Ft/Yr.
11	High	Moderate	10’	83.5’	0.38	11.74	15.26	0.183

Reach	BEHI Rating	NBS Rating	Bank Height	Bank Length	Erosion Rate (Ft/Yr.)	Cubic Yd./Yr.	Total Tons	Tons/Ft/Yr.
9	High	Moderate	10’	75.7’	0.38	10.26	13.85	0.183

Figure 53: Photos and several attributes for the top three sediment sources based on BANCS model results.

Channel Incision and Predicted Erosion Rates

Bank-height ratio (BHR) is a measure of the degree of stream channel incision, where a BHR of 1.0 indicates no incision, and values >1.0 indicate channel incision of increasing degree as the BHR value increase. See section 3.2 for more information on the BHR.

As expected, the predicted bank erosion rates in Woods Creek show a positive relationship with bank-height ratio (figure 54). An increase in BHR generally results in increased shear stress and stream power, and has the potential to lower the streambed and enlarge the channel (Rosgen, 2006). BHR values in Woods Creek ranged from 1.0 (connected to floodplain, figure 55 right photo) to a high of 2.0 (deeply incised, figure 55 left photo). BHR values were highly variable in Woods Creek, often changing many times in several hundred feet of stream channel. The dominant BHR value was used in the cases where variability was high. The relationship of BHR to predicted erosion rates in Woods Creek clearly demonstrate the importance of floodplain connectivity in steep gradient, high stream power systems. Stream restoration activities in the Woods Creek watershed should aim to increase floodplain connectivity in sections that remain severely incised.

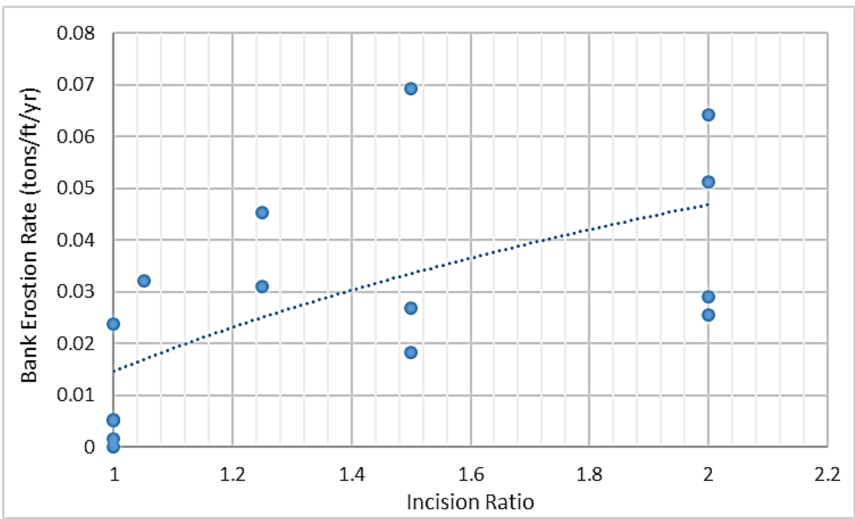


Figure 54: Scatterplot of channel incision ratio versus predicted erosion rates for delineated stream reaches in Woods Creek

Figure 55: Examples of BHR values of 2.0 (deeply incised) and 1.0 (stable, connected to floodplain) in Woods Creek. Yellow line approximates bankfull height. Predicted erosion rates were higher in reaches with high BHR values.

5.4.3 Physical habitat assessments

The Brook Trout Suitability Assessment (BTSA) rates habitat conditions using 26 individual metrics related to water temperature, geomorphology and channel stability, and in-stream habitat conditions. BTSA scores were calculated for each of the 15 stream reaches delineated during field reconnaissance. Ratings of “fair” were given to 9 (60%) of reaches assessed, while 4 (27%) reaches received a “good” rating and 2 (13%) were rated “excellent”. The stream reaches rated “good” or “excellent” were moderately clustered together between reach 4 and reach 11. The largest number of Brook Trout sampled to date in Woods Creek (n=16) occurred at station 15LS059, which is located in reach 8. This reach had an excellent BTSA rating and the second highest overall score in the assessment.

Pool habitat, substrate embeddedness, bank erosion rate, and width/depth ratio were the BTSA metrics that varied most significantly and had the strongest influence on overall ratings. Excellent pool habitat was observed in Reaches 1, 6, and 10, while deep pools were relatively non-existent near the upstream extent of the survey (Reach 12-15). Lower width-depth ratios were present in entrenched valleys (often bedrock controlled) and in areas that have since re-stabilized/re-vegetated since the flood event in 2008. Bank erosion rates were highest in Reach 2-3, 9, and 13. Many of these areas also scored poorly in width-depth ration metrics, as high rates of bank erosion tend to be associated with channel incision and widening.

Water temperature, which is the most heavily weighted metric in the BTSA, received the maximum score for all reaches given available data indicate excellent water temperatures throughout the lower 2.0 RM of Woods Creek.

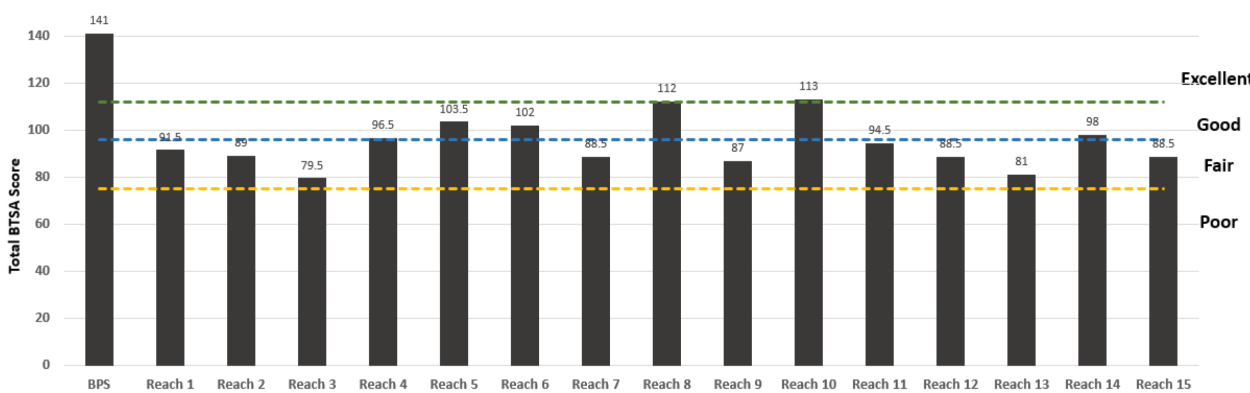


Figure 56: BTSA scores and ratings for the assessed reaches of Woods Creek. BPS=Best Possible Score

Figure 57: Examples of quality habitat observed in Woods Creek between Reach 5 and Reach 10. Narrow channel maintains adequate water depth at low flow (left), boulder pile step pool habitat and large woody cover (left), and steep pool habitat/clean gravel substrate for spawning (right).

5.4.4 Discussion of physical habitat and channel stability conditions

The steep slope (avg. around 7%) and confined valley of Woods Creek generates extremely high stream power during floods and high flows. A significant flood event in 2008 mobilized a large amount of boulder, cobble, and gravel substrate as bedload (figure 59, right). Sections of the creek with less entrenched valleys, essentially those that lacked bedrock controls, experienced significant channel incision and widening and much of the bedload was deposited in these areas (photo 2, figure 58). In the nine years since this flood event, the stream channel in many areas appears to be in the process of evolving towards a stable "B" or "A" stream type. Figure 58 highlights several reaches of Woods Creek that are in various stages of the channel evolution process. In the absence of another high magnitude/low frequency flood event, most reaches of Woods Creek will continue to develop stable floodplains and trend towards a more stable form.

In-stream cover, pool depth, and clean coarse substrates (gravel, cobble) are critical habitat components that contribute to sustaining wild Brook Trout populations in Woods Creek. Currently, the majority of the creek's watershed is covered by mature forest stands with relatively little development evident outside of the headwaters region. Mature trees within the riparian corridor of the creek provide significant shad when standing, and in-stream cover and grade control as deadfall. Like most North Shore watersheds, timber harvest has occurred in the watershed on both public and private lands, but recent activity appears to be minimal. Timber harvest in this watershed should be heavily scrutinized given its small drainage area, steep slopes, and relatively isolated wild Brook Trout population.

A shift in substrate composition towards finer particles like sand and silt (embeddedness) was observed in localized areas of Woods Creek. Higher rates of embeddedness were observed in lower gradient reaches with extensive bank/bluff erosion or sediment sources upstream. Areas of just downstream of the ditched portion of Woods Creek appeared to be most impacted by substrate embeddedness, particularly reach 13 (figure 59, left). Land-uses that directly (ditching/dredging/roads) or indirectly increase sediment loading to the creek (timber harvest, vegetation removal) could result in the loss of additional suitable spawning habitat and reduce benthic productivity.

Recent sampling results provided evidence of Steelhead Rainbow Trout spawning and rearing activity in Woods Creek up to and above CR 58. The concrete culvert at CR 58 is undersized, perched, and lacks natural substrate materials along the bottom of the culvert. Adult steelhead are likely the only fish capable of passing through this structure. This crossing was determined to be a barrier to most species at most flows. Replacing this crossing to restore full aquatic organism passage would increase access to quality habitat observed in Reaches 4-11, although some natural barriers would limit movement for non-game fish, Brook Trout, and sub-adult steelhead.

Stream stability and habitat conditions were not assessed within the channelized portion of Woods Creek (RM 2.0 – 2.5) or above the CR 60 crossing. This reach was channelized at some point between 1934 and 1982 based on available aerial photos (figure 60). The ditching and straightening of natural rivers frequently results in habitat degradation, a decline or complete loss of sensitive species, altered hydrology, and increased sediment loads (Allen, 1995; Schlosser, 1982; Lau, 2006; Landwehr and Roads, 2003). A restoration project to re-establish a natural channel downstream of CR 60 would increase the overall mileage of quality coldwater habitat available, and along with a full riparian corridor restoration would reduce thermal loading.

Figure 58: Channel evolution….

Figure 59: Fine sand substrates embedded coarse gravel and cobble material in Reach 13 (left); boulder and cobble material deposits on floodplain in reach 8 are indicators of the extremely high stream power generated by the steep slope and entrenched valley of Woods Creek.

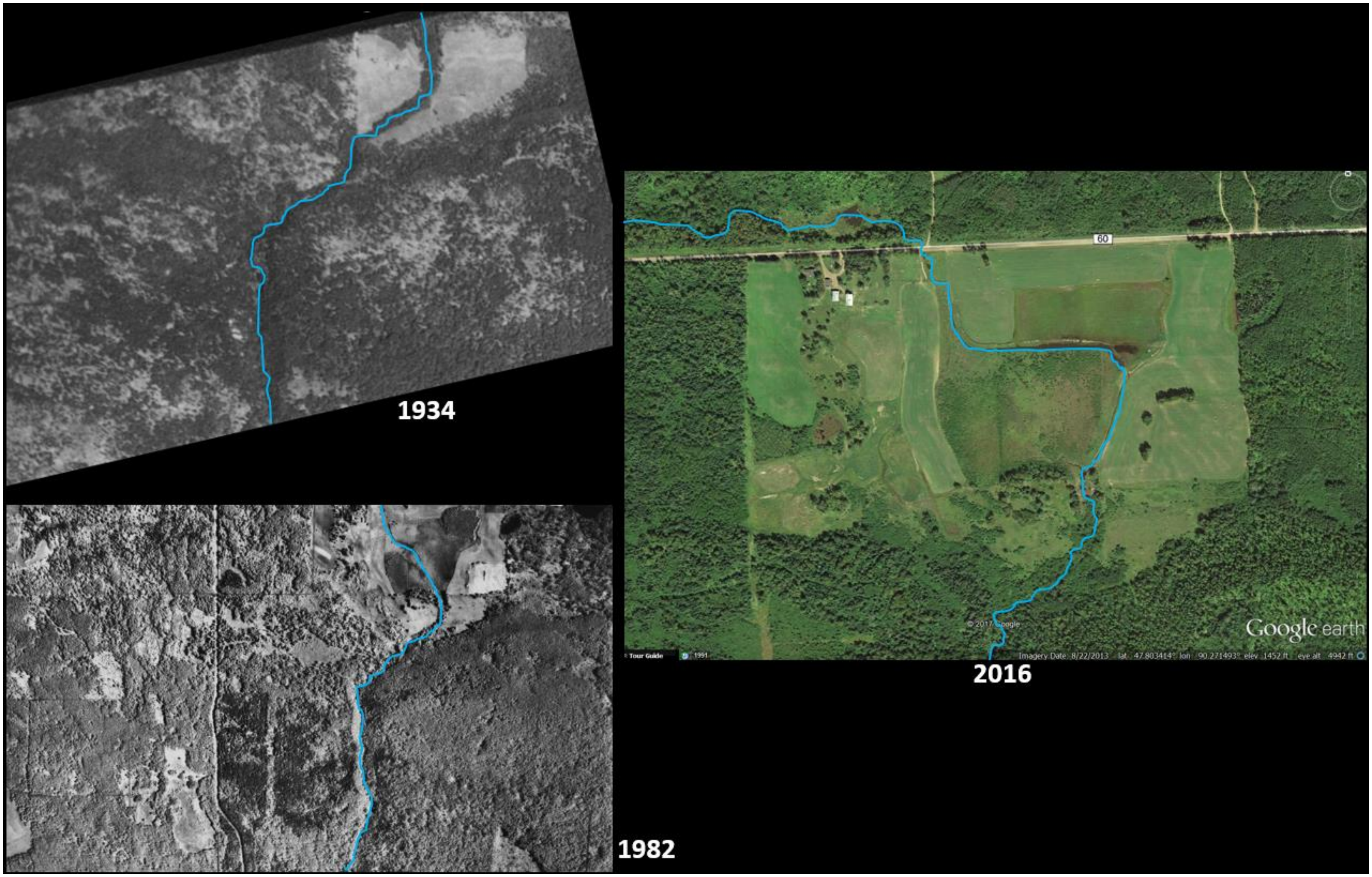


Figure 60: Aerial photos (1934, 1982, and 2016) of Woods Creek near the CR 60 crossing. The stream channel within this reach was channelized sometime after the 1934 photo and remains a regularly excavated ditch.

5.5 Brook Trout distribution, habitat refuge, and migration barriers

A 2-mile assessment of Woods Creek was completed over two days (10/27/16 and 11/4/16) in the fall of 2016 from the Devil Track River confluence upstream to the pastured area south of CR 58. Data collection objectives included visual assessments of Brook Trout distribution and spawning intensity, physical habitat conditions, channel stability and bank erosion assessments, and identification of barriers to fish migration (both natural and constructed). Flow and water clarity conditions were exceptional for carrying out visual assessments. The results of the channel stability and bank erosion estimates are discussed in detail in sections 5.4.2 and 5.4.3. Results for the other parameters of interest are presented in this section.

5.5.1 Brook Trout distribution

Visual confirmations of Brook Trout were tallied in eight times during the two-day, 2-mile assessment on foot. Multiple fish were observed in some instances, but most observations were of only one individual. Most observations of Brook Trout (6 of the total 8) occurred within reaches 8-11 (see map in figure 52), which are characterized by steep stream slope, deep pools, boulder/cobble substrate, and abundant fish cover in the form of woody debris. The other observations of Brook Trout occurred in the pool below the CR 58 culvert (upper end of reach 2) and below a bedrock waterfall in the extreme lower reaches of Woods Creek (lower end of reach 1). Based on visual assessments, Brook Trout populations appear to be the most robust in stable, high gradient reaches with abundant pool habitat.

5.5.2 Habitat refuge areas

Access to areas of refugia are critical in all streams and rivers, but are. Deep and shallow pool habitats are critical for adult Brook Trout during low summer and winter streamflow (Sotiropoulos et al., 2006, Mollenhauer et al., 2013). Pool habitats deep enough to provide refuge were mapped throughout the 2-mile reach of Woods Creek. Many of these pools were relatively shallow (<1 ft. depth) but still represent critical habitat due to the small size of the creek. A total of 32 pool refuge areas were mapped along the 2-mile segment. Pool habitat areas were most abundant in reaches 1, 2, 9, and 10. Partial and full barriers (bedrock step falls) to fish movement were observed within these reaches which may limit accessibility to some pools during low flows. Visual observations of Brook Trout were during the survey occurred almost exclusively in pool habitat areas.

5.5.3 Natural barriers to fish migration

Potential barriers to fish movement were mapped during the BANCS model data collection effort. Twenty-nine potential barriers to fish movement were identified between RM 0.0 and 2.0, which is a comparable result to previous assessment completed by MN DNR (n=22) (Weberg, 2015). Natural barriers were present in the form of bedrock drops, and boulder piles that developed during the flood of 2008. MN DNR also noted numerous dams in the lower gradient headwaters reach of Woods Creek. Four impoundments have been constructed by private landowners along Woods Creek upstream of RM 2.5. Five active beaver dams were also observed within this reach in 2015 (Weberg, 2015).

5.5.4 Non-natural barriers to fish migration

Only two road crossings were assessed in the Woods Creek watershed. Both crossings were located on county roads (CR 58 and CR 60). There are at least three additional crossings in the headwaters area upstream of County Road 60, but these are all on private land and permission to assess them was not obtained. A full table of assessment data can be found in Appendix BLANK.

The culvert at County Road 58 (Lindskog Rd) and stream-mile 0.49 (Figure BLANK) is the first crossing that migrating fish encounter upstream of the confluence with the Devil Track River. This crossing is a single 11.5’ wide arched concrete pipe. The outlet drops over half a foot at low flow. At a minimum, this crossing is a seasonal barrier to certain species and age-classes of fish due to limited water depth, water velocity, and lack of natural substrate within the crossing. The width ratio of 0.79 is also just below the "undersized" threshold. A plunge pool and large eroding bank just downstream of the culvert are also indicators of an undersized and improperly installed crossing.

The crossing at County Road 60 (Figure 61) is just over two river miles upstream of the CR 58 crossing. The CR 60 crossing consists of three 3' wide circular pipes. The bankfull width in this reach is only about 6', meaning the crossing is adequately sized to pass bankfull flows. No water surface drop at the outlet was observed, and natural substrate was present within all three pipes. There were no indications that these culverts presented migration barriers to fish, or were otherwise negatively affecting Woods Creek. A freshly dug ditch was observed on the upstream side of the crossing along a private drive in November of 2016. The slope and positioning of this ditch may be prone to erosion and may contribute excess sediment to Woods Creek if vegetation fails to stabilize.

In summary, only one crossing in the Woods Creek watershed was determined to be negatively affecting connectivity and stream stability. The box culvert at County Road 58 (stream-mile 0.49) is a high priority for replacement. A culvert with a bottom is not recommended due to the steep slope of the stream and the potential for substrate to be removed at high flows. Instead, the proposal for replacement at this location is a bottomless arch culvert or bridge that is at least as wide as the bankfull channel (14.5 feet) and that has natural channel substrate and a step/pool morphology through the crossing to provide energy dissipation, sediment transport, and fish passage.

Figure 61: Woods Creek crossing under CR 58 crossing (left) and CR 60 (below). The CR 58 crossing is a barrier to fish migration and a priority for restoration.

5.6 Summary and Recommendations for Woods Creek

5.6.1 Key Stressors and Threats

Stressors to aquatic life in Woods Creek include physical habitat degradation and barriers to fish movement. Low flow conditions during dry periods are also a limiting factor in this watershed, a condition that occurs due to a combination of natural factors (small drainage area) and land-use impact (timber harvest, ditching, private dams). Table17 summarizes key findings from the stressor analysis and the contributing sources and pathways.

Table 17: Summary of primary stressors to aquatic life in the Flute Reed River watershed.

Stressor/Threat	Summary
Physical Habitat Degradation	• Symptoms of stream channel instability (bank erosion, channel widening) are reducing habitat quality in several reaches of Woods Creek (e.g Reach 3). These areas support fewer wild Brook Trout than more stable reaches (e.g. • Much of the channel instability and habitat loss in Woods Creek can be attributed to a major flood event that hit the Woods Creek watershed in 2008. • Approximately 0.5 miles of Woods Creek has been channelized downstream of CR 60 to drain riparian wetlands. Habitat conditions were not assessed within this reach, but were rated as poor based on channel instability and habitat loss associated with most channelized streams. MN DNR (Weberg, 2015) reported that silt has accumulated in the channel in the low-gradient reach below mile 2.4 (below Cook County Road 60) with the main flow of Woods Creek appearing to have migrated to a drainage ditch developed by the landowner. Cattle have been allowed to cross the stream just below mile 2.4 resulting in additional bank erosion and channel widening
Aquatic Organism Passage Barriers	• Natural barriers (bedrock/boulder waterfalls) to migration were observed throughout Woods Creek, limiting the ability of fish and other aquatic organisms to move freely under many flow conditions. • The concrete road culvert at the CR 58 crossing is undersized, lacks natural substrate on the bottom of the culvert, and has an outlet drop (perched). A few adult Steelhead Rainbow Trout have successfully passed through this culvert in recent years during high streamflow events in the spring. However, the improper design/installation of this culvert likely impedes passage of most trout and non-game species, especially younger life stages.
Flashiness, Stream Power, and Altered Hydrology	• "A2 and A3" stream types (Rosgen, 1996) are a common in the Woods Creek watershed. These stream types generate high stream power due to steep slopes and highly entrenched valleys. Large quantities of sediment have been transported and deposited along Woods Creek due to flood events in the past 10 years. • The main channel of Woods Creek is ditched for approximately 0.5 miles downstream of CR 60. This ditched channel along with the deforested land in this area increases the "flashiness" (i.e. high frequency, short duration runoff events) and likely contributes to local channel instability in downstream stream reaches. • Aerial photos of the watershed show a series of private dams on Woods Creek near the intersection of CR 58 and CR 60. This impoundment may alter streamflow and increase water temperatures. Numerous beaver dams are also present in this reach.

5.6.2 Restoration and protection recommendations

Efforts to protect and preserve high quality habitats and ecological function is equally important to restoration goals for the watershed. Several high quality and/or ecologically significant areas in the watershed are highlighted below. Specific protection goals should be developed for these areas through input from stakeholders, resource managers, and watershed-planning processes (e.g. WRAPS). Input regarding additional priority protection areas should also be part of this process.

Table 18: Recommended priority areas in the Woods Creek watershed

Protection Area	Significance
Unnamed Tributary (Unnamed Creek S-67-1-1) **&** **Woods Creek Headwaters (TWP 62 RNG 1 SEC 35 & 36)**	• Major tributary entering Woods Creek at RM 2.71. MN DNR has reported that this tributary may contribute a greater amount of flow than the main stem of Woods Creek at this confluence point. • Flow rates in the lower reaches Woods Creek can drop below 1.0 cfs during baseflow conditions. Protecting flow inputs from major tributary streams is a very high priority. • The headwaters of Woods Creek is a mix of undeveloped/forested land and developed agricultural, residential, and industrial property. A significant amount of land north of CR 60 remains heavily forested, providing a high quality buffer for Woods Creek and a major tributary.

Table 19: Stressors in the Woods Creek watershed and recommended restoration activities

Stressor	Location	Restoration Action
Fish Passage	Woods Creek crossing of CR 58 (Lindskog Rd)	• Replace existing culvert with bottomless arch culvert or bridge that is at least as wide as the bankfull channel (14.5 feet) and that has natural channel substrate and a step/pool morphology through the crossing to provide energy dissipation, sediment transport, and fish passage. A culvert with a bottom is not recommended due to the steep slope of the stream and the potential for substrate to be removed at high flows.
Physical Habitat Degradation	Downstream of CR 60	• Re-align and re-meander Woods Creek through original stream channel downstream of CR 60. • Establish a vegetated buffer along restored stream channel • Work with landowner to provide stable crossings for cattle, farm equipment, etc.
Altered Hydrology/ Physical Habitat	Upstream of CR 60 to Hedstrom's Lumber Yard	• Investigate effects of private impoundments on water temperature, streamflow, and physical habitat conditions • Conduct additional biological monitoring to determine if wild Brook Trout still inhabit Woods Creek and major tributary upstream of CR 60

6.0 Fredenberg Creek – Two Island River Connectivity Study

6.1 Project Objectives

Climate models (Johnson et al. 2013) predict major losses (34%) in Brook Trout habitat along the southern half of the North Shore (between cities of Duluth and Silver Bay) by the year 2060. Predicted losses for the northern portion of the shore are lower (11%), as habitat shifts northward in response to increasing regional air temperatures. Preparing for climate change requires action to protect and restore the highest quality remaining habitats to support this priority species. Restoring aquatic connectivity to fragmented watersheds is one of the most cost-effective strategies in conservation (Trout Unlimited, date).

Improving longitudinal connectivity in streams (e.g. aquatic organism passage) was a major priority for MPCA during the Lake Superior North WRAPS study. During initial stream crossing reconnaissance efforts, a series of undersized, damaged, and/or perched culverts were observed in the lower reaches of Fredenberg Creek, near its confluence with the Two Island River. Further evaluations of three crossings were completed during the summer and fall of 2016 to determine whether they functioned as barriers to aquatic organism passage (e.g. “fish passage”). The overall goals of this effort included:

- Compare current culvert sizing, condition, placement to recommended designs
- Determine whether current culverts are barriers to aquatic organism passage (non-barrier, partial, or complete)
- Monitor and assess conditions in Fredenberg Creek to determine its ecological significance (thermal refuge, spawning and rearing area) within the Two Island River watershed
- Determine quantity and quality of stream miles that can be reconnected if fish passage is restored or enhanced
- Prioritize culvert replacements, engage key landowners and stakeholders, and develop conceptual designs and cost estimates for potential projects to restore connectivity

6.2 Project Area Summary

Fredenberg Creek and Two Island River are designated trout streams on Minnesota’s North Shore of Lake Superior, located near the town of Schroeder. Both of these streams currently support wild populations of native Brook Trout and other non-game coldwater fish species. Fredenberg Creek is a small (2.4 sq mile drainage area) second order stream, entering the Two Island River approximately 1.5 miles upstream of Lake Superior. Impassable road culverts and bedrock waterfalls within the first 0.5 miles upstream of Lake Superior prevent the migration of Steelhead Rainbow Trout and other migratory species from moving up the Two Island River into Fredenberg Creek. Therefore, the stream connectivity study described in this report is focused on inland, resident populations of Brook Trout and non-game coldwater species found in these streams (e.g. Slimy Sculpin, Longnose Dace).

Three Fredenberg Creek road crossings (Railroad, Fly Ash Road, and County Road 1) were evaluated for fish passage and proper sizing in 2016. All three were determined to be undersized and are full to partial barriers to fish passage based on sizing, outlet drop, and lack of natural substrates within the crossing (figure 62). Sediment deposition and habitat degradation was observed immediately upstream of these crossings. A stream reconnaissance was also completed upstream of the final barrier at County Rd 1. This reconnaissance revealed that no further barriers exist upstream of the project area, and habitat quality and water temperatures are excellent for Brook Trout.

Fredenberg Creek is among the coldest streams in the region during summer, with pristine watershed conditions aside from the fish passage barriers, which reduce its ecological function. Two Island River is listed as an “exceptional use” stream based on a healthy coldwater fish assemblage, but water temperatures just above its confluence with Fredenberg Creek have exceeded “stress” and “lethal” temperature thresholds for the Brook Trout. Reconnecting this tributary will benefit Brook Trout in both streams by providing access to critical spawning and rearing habitat and expanding thermal refugia.

Figure 62: Longitudinal profile of Fredenberg Creek and location of the three undersized and poorly installed road culverts that act as partial to full barriers to the migration of wild Brook Trout populations.

Figure 63: Water level view of perched and undersized road culvert at Cook County HWY 1. The culvert is fractured in numerous locations along its length beneath the road allowing water to flow freely beneath the road grade.

6.3 Review of biological Data

The fish community of Fredenberg Creek has been sampled minimally by MN DNR over the past 30-40 years. MPCA has never sampled fish or macroinvertebrates in this stream. Several MN DNR fish surveys were completed in the 1980's near the Ash Cell Road and County Rd 1 crossings. The stream was not surveyed again for over twenty years, until a 2012 MN DNR effort which covered three stations at river mile (RM) 0.00 (at confluence with Two Island River), RM 0.25 (upstream of CR 1), RM 0.94 (near private residence on creek).

Wild Brook Trout were common to abundant at RM 0.25 in the 1980's, and at all stations during the 2012 sampling effort. Brook Trout numbers were slightly lower in 2012 at RM 0.25 (the only station sampled in both 1989 and 2012) but the size composition was similar. Overall, length-frequency data indicates a high percentage of the Brook Trout in Fredenberg creek are young-of-year (YOY, <age 1) (Figure 64), which is evidence that this stream provides important spawning and rearing habitat in the Two Island River watershed. This observation is corroborated by the early stream survey work of Moyle and Smith (1920), which cited Fredenberg Creek as valuable spawning area for Brook Trout. MN DNR commented that the number of Brook Trout sampled in Fredenberg Creek is "extraordinarily high compared to other tributary streams in the Two Island River drainage."

Extreme low flow conditions were observed during the late summer/early fall months of 2012. This drought period may have been linked to the lower Brook Trout numbers observed during that sampling year. More importantly, these low flow conditions represent a potential recurring threat to fish populations in Fredenberg Creek given its small drainage area. Enhancing or restoring the connectivity of this stream to the larger, Two Island River, will increase resiliency of Fredenberg Creek Brook Trout to stressful drought conditions. Connectivity of tributaries to larger rivers systems will be critical for maintaining ecological integrity in watersheds, especially given the potential of global climate change to alter flow patterns and water temperatures in North Shore coldwater streams.

Additional biological sampling is recommended in the Fredenberg Creek watershed to understand the movement of Brook Trout and other fish species between Two Island River and Fredenberg Creek under current conditions. The three stream crossings in the lower 0.25 river miles of Fredenberg Creek appear to be complete or seasonal barriers to fish passage. As of the 2012 sampling by MN DNR, both streams supported healthy populations of wild Brook Trout, but the extent to which these populations interact is relatively unknown. The only record of fish migration out of Two Island River into Fredenberg Creek was documented in 1989, when two age-1 Rainbow Trout were sampled at RM 0.2 (just downstream of CR 1). These fish were stocked into Two Island River in 1988. Based on this observation, the railroad and Ash Cell Rd culverts were passable in the late 1980's, but available data do not provide a means of assessing the ability of fish to pass through the CR 1 crossing.

Update: 2017 sampling effort

MN DNR completed biological monitoring (fish assessments only) at several locations in Fredenberg Creek and Two Island River during the summer and fall of 2017. Sampling objectives included recording populations of wild Brook Trout (and other non-game species) near the confluence of these river systems, and evaluating fish movement between the two streams and through three culverts shown in figure 62. The results of this monitoring effort will be published in the fall/winter of 2017 and will be added to this report upon completion.

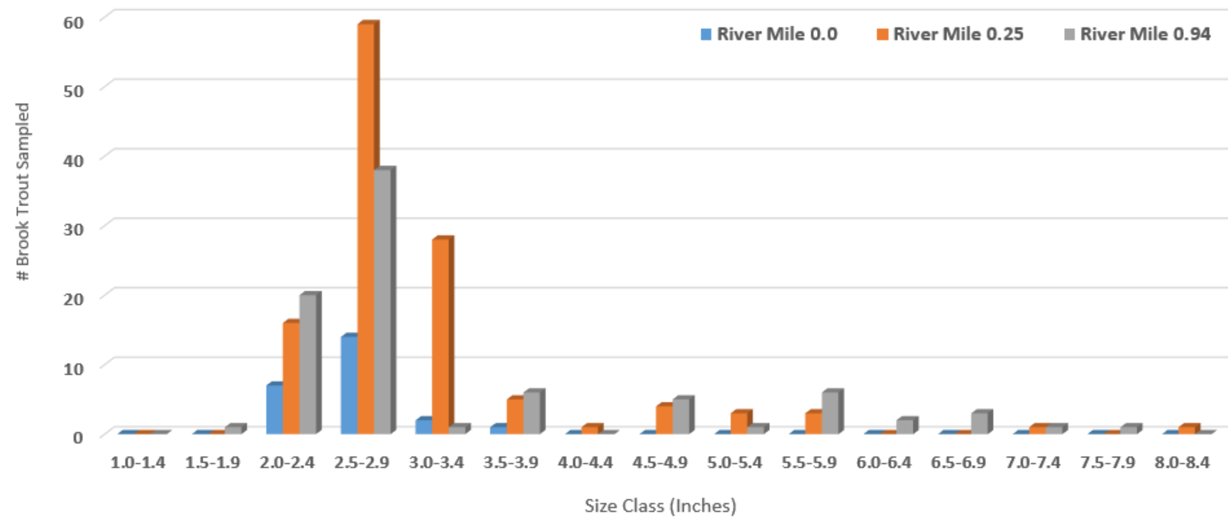


Figure 64: Length frequency of Brook Trout sampled from Fredenberg Creek at three monitoring stations, September 2011.

Table 20: Fish species and population sizes observed in Fredenberg Creek during MN DNR monitoring efforts in 1984, 1989, and 2012. The results of 2017 sampling efforts are still being processed.

Station	Year Sampled	Blacknose Dace	Brook Trout	Creek Chub	Mottled Sculpin	Pearl Dace	Rainbow Trout	Slimy Sculpin
RM 0.20	1984	0	63	0	1	0	0	0
RM 0.15	1989	1	355	10	0	6	2	5
RM 0.25	2012	0	121	0	0	0	0	6
RM 0.00	2012	0	24	1	0	0	0	4
RM 0.94	2012	0	84	0	0	0	0	17

6.4 Water Temperature Data

Maximum water temperatures and locations of coldwater inputs are two primary drivers of Brook Trout movement in streams (Petty et al., 2012). Researchers in Wisconsin documented long distance seasonal movements of trout (up to 20 miles) between small feeder creeks and larger rivers. The warmer, deeper, larger river provides exceptional winter habitat and greater forage allowing fish to grow larger when temperatures are suitable. The smaller, colder, tributary streams provide thermal refuge during the summer, as well as superior spawning and rearing habitat. Refugia from harsh environmental conditions and emigration/immigration of fish based on large-scale spatial habitat relationships significantly shape population dynamics in streams, particularly small headwaters drainages (Schlosser, 1995).

Continuous temperature loggers were installed in several reaches of the Two Island River and Fredenberg Creek in 2012 (MN DNR) and 2016 (MN PCA) to compare the thermal regimes and suitability for coldwater biota.

6.4.1 Fredenberg Creek Water Temperature

Temperature loggers were installed at three locations in 2016; RM 0.05 (Railroad Crossing), RM 0.3 (CR 1), and RM 1.75 (Superior Hiking Trail crossing). Three loggers were also installed by MN DNR in 2012; RM (0.05 Railroad Crossing), RM 0.95 (near private residence on stream), RM 2.50 (headwaters). Water temperatures in Fredenberg Creek were within the ideal range for Brook Trout growth 95-100% of the time. Stressful temperatures for Brook Trout were rarely observed; 0% - 5.2% of the monitoring period depending on station. Coldest temperatures were down near CR 1, just slightly warmer 1.5 river miles upstream near the headwaters. The entire length of Fredenberg Creek supports temperatures that are ideal for Brook Trout survival and growth. Based on available data, Fredenberg Creek is one of the coldest streams monitored to date on the North Shore (figure 65).

6.4.2 Two Island River Water Temperature

Temperature loggers were installed in Two Island River near its confluence with Fredenberg Creek in 2012 and 2016. Additional stations were monitored by MN DNR in 2012, but were a considerable distance from Fredenberg Creek and not relevant to this study. Water temperatures in Two Island River were within the ideal range for Brook Trout growth 74 – 97% of the time, depending on station and monitoring year. The warmest temperatures were observed just upstream of the Fredenberg Creek confluence (83% of monitoring period within growth range temperatures, 17% stress, 0% lethal). Inputs from Fredenberg Creek have a cooling effect on the Two Island River. Much colder temperatures (97% growth range) were observed in Two Island Creek near Railroad XC, approximately 2.9 miles upstream of Fredenberg Creek. The outlet of Dyers Lake and loss of canopy cover (shading) are the likely drivers of warmer water temperatures in the lower portions of Two Island River.

6.4.3 Discussion of water temperature data

Both Two Island River and Fredenberg Creek provide suitable water temperatures for supporting wild Brook Trout populations and other non-game coldwater obligate species. Temperatures in Fredenberg Creek remained in the growth range for Brook Trout for nearly the entire period of record at most stations, rarely exceeding established thresholds for “stressful” water temperatures. Data from 2012 and 2016 show that the Two Island River is considerably warmer Fredenberg Creek near the confluence of the two streams (Table 21). This observation illustrates the importance of Fredenberg Creek as a coldwater input and thermal refuge area during stressful mid-summer periods. Improving fish passage in Fredenberg Creek would provide an additional two miles of refuge for coldwater species in this drainage.

Table 21: Water temperature summary statistics for Fredenberg Creek and Two Island River

2016 Season							
Stream / Station	**Growth**	**Stress**	**Lethal**	**No Growth**	**Summer Avg. Temp**	**July Avg. Temp**	**Summer Max Temp**
Fredenberg Ck. / RR XC (RM 0.05)	98.8%	1.2%	0.0%	0.0%	15.5	16.2	21.3
Fredenberg Ck. / CR 1 (RM 0.3)	99.6%	0.4%	0.0%	0.0%	15.2	15.8	20.7
Fredenberg Ck. / SHT (RM 1.75)	96.6%	3.4%	0.0%	0.0%	16.2	16.7	22.0
Two Island R. / RR XC	96.7%	3.3%	0.0%	0.0%	16.0	17.0	22.8
Two Island R / US Fredenberg	82.9%	16.8%	0.3%	0.0%	17.2	18.3	26.0
Two Island R / DS Fredenberg	85.3%	14.5%	0.2%	0.0%	17.0	18.1	25.6

2012 Season							
Stream / Station	**Growth**	**Stress**	**Lethal**	**No Growth**	**Summer Avg. Temp**	**July Avg. Temp**	**Summer Max Temp**
Fredenberg Ck. / RR XC (RM 0.05)	94.6%	5.2%	0.0%	0.0%	15.9	17.4	22.9
Fredenberg Ck. / RM 0.95	100.0%	0.0%	0.0%	0.0%	13.1	13.9	17.5
Fredenberg Ck. / RM 2.50	99.5%	0.5%	0.0%	0.0%	15.5	17.0	20.6
Two Island DS Fredenberg	74.0%	25.5%	0.5%	0.0%	18.2	20.2	25.7

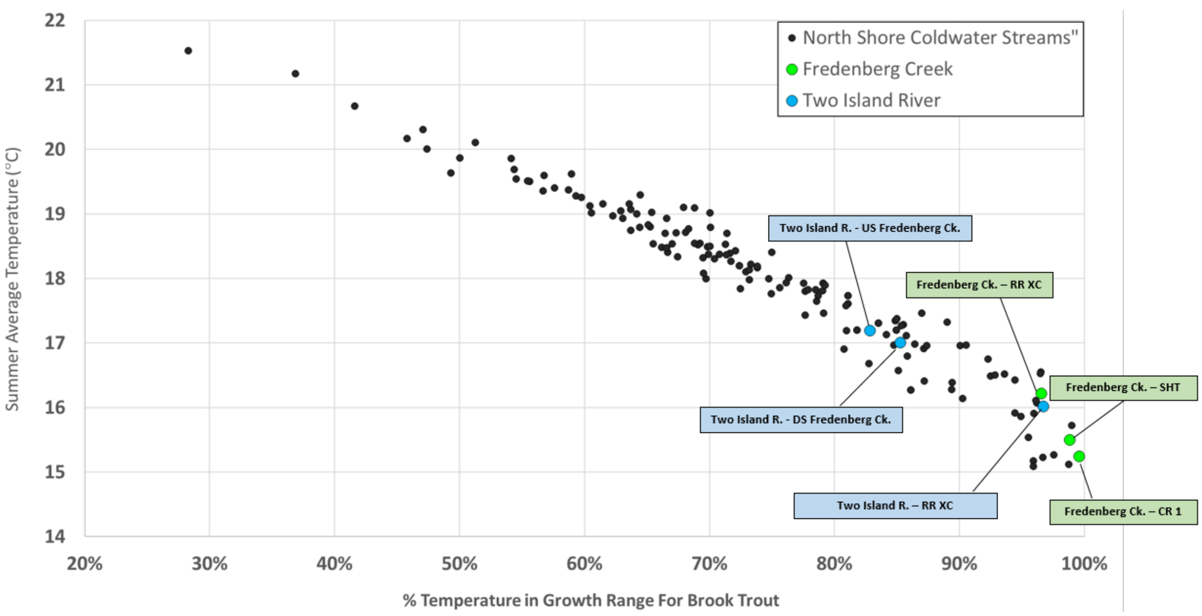


Figure 65: Scatter-plot of summer average water temperature and % temperature readings within the "growth" range for Brook Trout. Data are shown for Fredenberg Creek (green markers), Two Island River (blue markers), and other North Shore coldwater streams (black markers).

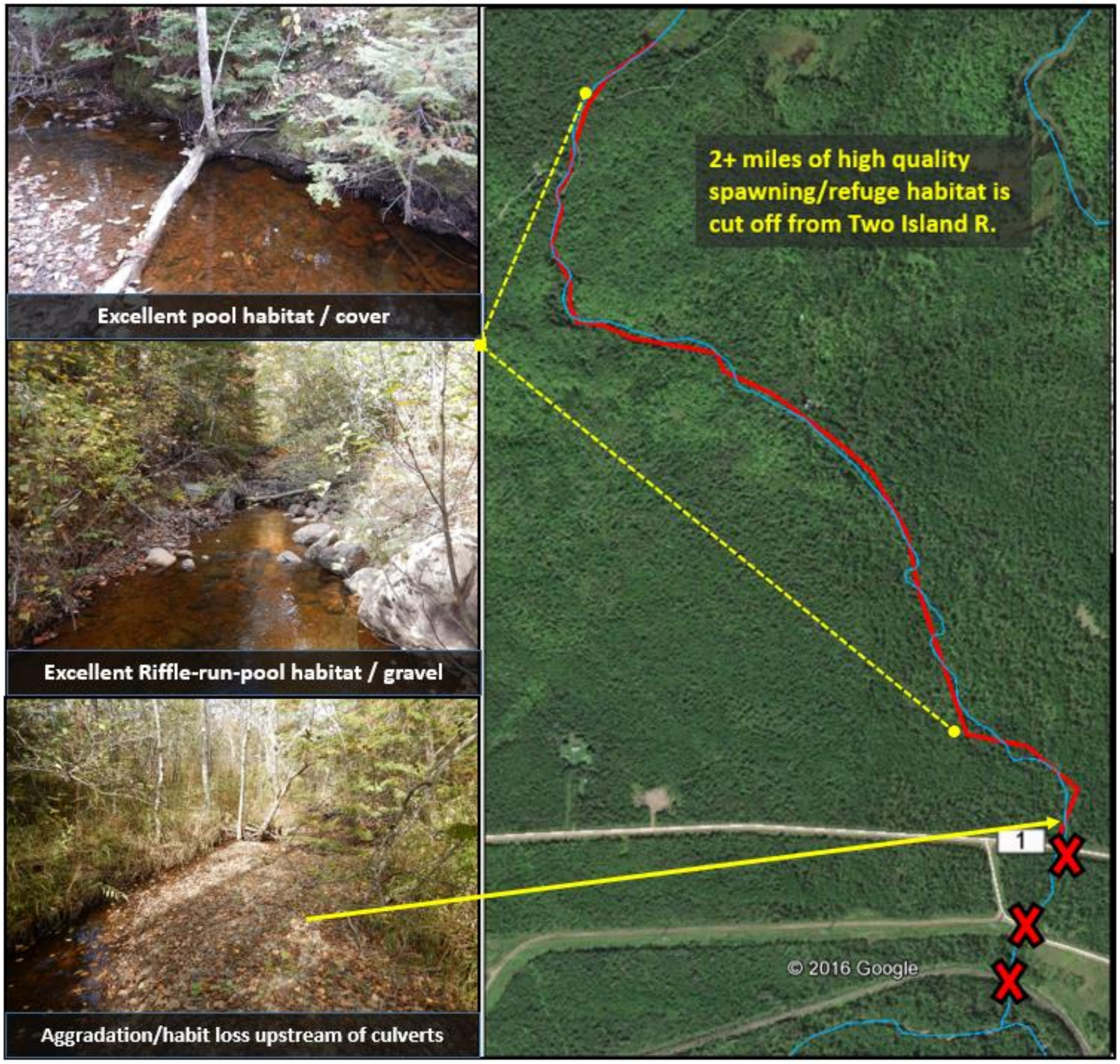
Figure 66: Photos of the Two Island River/ Fredenberg Creek confluence area. Confluence indicated by yellow arrow.

6.5 Physical habitat and stream channel stability

Understanding stream channel condition and habitat characteristics is critical for prioritizing restoration projects related to connectivity. Stream habitat features such as pool depth, fish cover, substrate size, and gradient all factor into the viability a stream reach to support natural reproduction, juvenile survivorship, and growth in native fish populations. A series of habitat and stream condition assessments, both rapid (qualitative) and detailed (quantitative), were completed in Fredenberg Creek to aid in establishing a priority ranking for stream connectivity projects in this watershed.

A reconnaissance-level assessment was completed on a 1.5 mile reach of Fredenberg Creek upstream of CR 1 to document general stream channel characteristics, habitat quality, and identify any natural/anthropogenic barriers to fish passage. Physical habitat conditions were excellent for Brook Trout. Substrates were dominated by clean, coarse materials that should support healthy benthos and ideal spawning habitat for Brook Trout. Relatively deep pools are maintained even during low flow conditions due to the riffle-run-pool/step pool nature of the stream and the stability of the stream channel (figure 67). Several reaches displayed some lag deposits of gravel, channel braiding, and bank erosion in response to a large rain event in 2008. No additional natural or constructed barriers to fish migration were observed within the 1.5 mile reach upstream of CR 1. Several small step-pool drops were observed, but these would be easily navigated by Brook Trout and non-game coldwater species at most life-stages.

Overall, physical habitat and stream channel conditions are excellent upstream of CR 1 and a restoration to re-establish connectivity of this reach to the Two Island River is strongly recommended. This reach of the creek, which is currently disconnected from the Two Island River by the series of impassable culverts downstream, could provide additional spawning and rearing habitat as well as coldwater refugia for Brook Trout within the greater Two Island River system.


Excellent pool habitat / cover
Excellent Riffle-run-pool habitat / gravel
Aggradation/habit loss upstream of culverts
2+ miles of high quality spawning/refuge habitat is cut off from Two Island R.
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© 2016 Google

Figure 67:

6.6 Survey Data from Potential Project Area

Additional geomorphic data was collected at the County Road 1 crossing in October 2016 to support the initial conclusion that this culvert represents a barrier to fish migration and is negatively affecting stream stability and fish habitat. Channel bottom (thalweg), water surface, and bankfull relative elevations were measured using a total station. Approximately 550 feet of the channel profile and four cross-sections were surveyed in order to assess conditions both up- and downstream of the culvert. A reach approximately 0.5 miles upstream that was in good condition was also surveyed using the same methods. This "reference reach" data is useful for determining the departure from a stable condition in Fredenberg Creek as a result of the CR 1 culvert. This data was compiled and analyzed using RiverMorph software.

A plot of the Fredenberg Creek profile with the superimposed culvert outline and road prism (Figure 68) shows the massive plunge pool that has formed immediately below the culvert. The culvert corrosion can also clearly be seen about halfway down where the channel bottom drops through the culvert. For approximately 350 feet upstream and 100 feet downstream of the crossing, the average slope of the channel is about 1.77%. This is very close to the slope of the culvert (1.62%) and indicates that the culvert was installed at the right slope.

Profile and cross-section data show that the overly-narrow CR 1 culvert is not only creating a fish migration barrier, but it is having a significant impact on sediment transport and the stability of the stream. As stated before the average slope of the entire reach is 1.77%, however when measured separately, the average slopes of the channel upstream and downstream of the crossing are drastically different. Upstream of the crossing the average slope of the channel is 1.57%, while downstream it is 2.55%. Defined pools and riffles are almost nonexistent upstream of the culvert.

Cross-section data upstream of the CR1 crossing indicate aggradation to the stream channel, most likely as a result of the narrow culvert. Culverts that are much narrower than the width of the channel impound water at higher flows. This lowers the effective slope and increases the width/depth ratio, decreasing the sediment transport capability of the stream and increasing deposition during these high flows events. Over time the channel will fill in and evolve into a new stream type. Cross section #1 (Figure BLANK) shows that the channel has evolved into a braided Rosgen D4 stream type, which is common in reaches where the rate of sediment supply far exceeds the sediment transport rate. Fredenberg Creek at this location has a width/depth ratio of nearly 90 and shows signs of excessive deposition (Figure BLANK) and annual shifts in streambed morphology. The pools have almost completely filled in with sediment; in fact, the profile shows that the only defined pool in the reach is the massive plunge pool immediately below the culvert.

Conversely, cross-section data also indicates channel incision downstream of CR1 (Figure BLANK). This is most likely the result of the overly narrow culvert that creates a "shotgun effect" during high flows. Impounded water upstream of the crossing increases head pressure and greatly increases water velocities within the culvert. In Fredenberg Creek this has caused channel bed scouring and floodplain abandonment in the downstream direction. Bankfull indicators are approximately 1.1 feet lower than the previous floodplain (incision ratio = 1.5). Flows higher than the bankfull stage at this location are completely contained within the channel, increasing near-bank stress and resulting in excessive bank erosion.

To further support the hypothesis that the culvert is out of equilibrium with the stream system and is causing aggradation upstream and incision downstream, a reference reach 0.5 mile upstream was surveyed using the same methods. This reach was upstream from any road crossing influence. The reference reach can be compared to the CR1 reach to determine the degree to which the CR1 culvert is creating a departure from a stable condition. Approximately 275 feet of stream channel data was collected, including thalweg water surface, and bankfull stage elevations. The resulting profile shows a much more consistent slope of 1.8% throughout the reach (Figure BLANK).

Cross-section data from the reference reach (Figure BLANK) shows a stream channel with good floodplain connection and a width/depth ratio (16.4) which is more favorable for maintaining sediment transport. The increase channel stability resulting from equilibrium in sediment supply/transport has many added benefits, including: 1) decreasing the low-flow channel width which reduces stream temperatures, 2) fine sediment deposition on the floodplain and channel margins which maintains clean spawning gravels, 3) keeping pools scoured deep which creates overhead cover and habitat diversity (Figure BLANK).

Additional geomorphic characteristics of the reference reach when compared to the reach at County Road 1 show just how much of an impact the culvert is having on the bankfull channel (Table BLANK). This impact is called the “degree of departure” and is expressed as a dimensionless ratio (Study Reach Parameter / Reference Reach Parameter). Riffles features near County Road 1 are, on average, 2.3 times wider (at bankfull flow) than what would be expected in a stable stream. The bankfull width/depth ratio of the riffle, which is a key driver of the stream’s sediment transport capability, is 3.2 times larger than that of the reference. Similarly, the average glide is almost 2 times wider than reference. This has negative consequences on brook trout spawning habitat, as brook trout would be less likely to spawn in wide, shallow glides that leave them more exposed to predation during spawning. Over-widened glides cause more deposition of silt and fine sediment as well, which smother trout eggs. Wider riffles and glides also increase the rate of solar and atmospheric warming during the summer and the possibility of harmful anchor ice in the winter.

Morphological energy dissipation in the County Road 1 reach is also far from what would be expected in a stable channel and is indicative of a stream channel that has unraveled. Pool-to-pool spacing, riffle lengths, and pool lengths are all 1.8-1.9 times longer than the reference condition for Fredenberg Creek. This results in severe impacts to channel stability and habitat diversity. Longer riffles have the capacity to build up more momentum in flood events and increase the likelihood of channel bed scour. Longer pools have a greater tendency to fill in with sediment. This was directly observed in the vicinity of County Road 1, as pools tended to be shallow (excluding the plunge pool immediately below CR1) and had less habitat diversity.

All of these consequences to the stream channel and the aquatic habitat it provides can be directly tied back to the undersized culvert located on County Road 1. This supports the conclusion that the crossing needs to be replaced with a bridge or a culvert that at least matches the bankfull width of 15.5 feet. Should that occur, it is possible that over time the stream channel will readjust to a restored sediment transport regime and stability will return to the reach.

Table 22: Select geomorphic parameters showing the departure from a reference condition for the County Road 1 reach.

	Reference Reach	County Road 1 Reach	County Road 1
	Average	Average	Degree of Departure
Riffle Width (W_{bkf})	16.45 ft	38.69 ft	**2.35**
Glide Width (W_{bkfg})	14.72 ft	27.21 ft	**1.85**
Riffle Length (L_r)	35.52 ft	68.3 ft	**1.92**
Individual Pool Length (L_p)	15.27 ft	27.64 ft	**1.81**
Pool to Pool Spacing (P_s)	61.9 ft	113.83 ft	**1.84**
Riffle Cross-Sectional Area (A_{bkf}) (ft^2)	17.30	31.01	**1.79**
Riffle Width/Depth Ratio (W_{bkf} / d_{bkf})	15.95	51.12	**3.21**
Glide Width/Depth Ratio (W_{bkfg} / d_{bkfg})	12.69	34.01	**2.68**

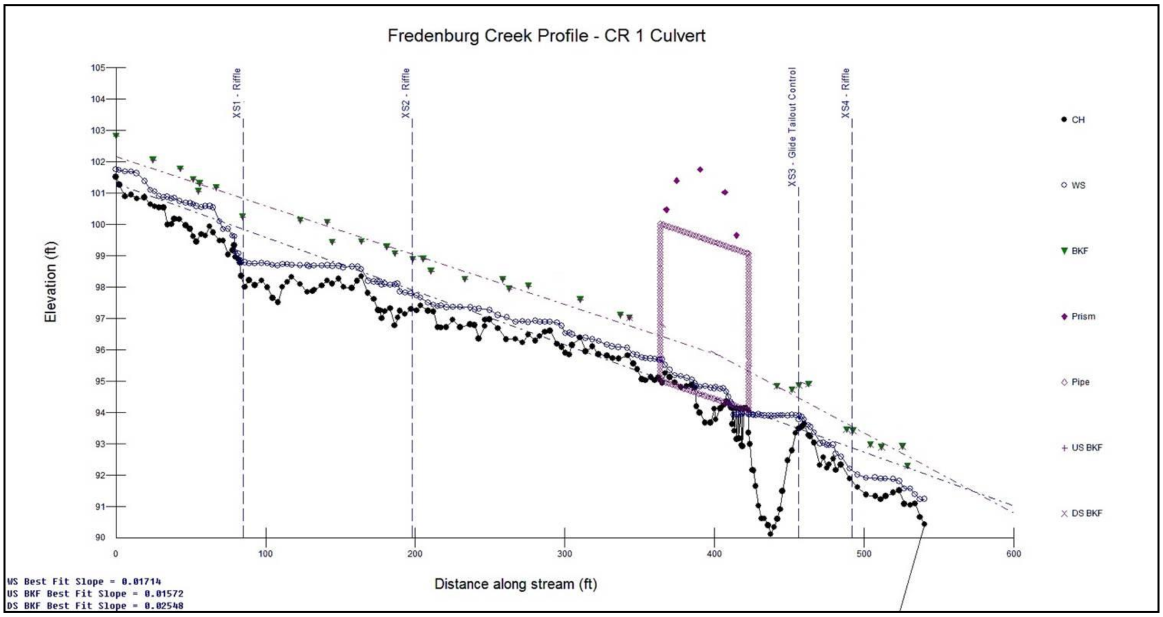

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Figure 68: Profile of Fredenberg Creek showing change in channel slope upstream and downstream of the CR1 crossing

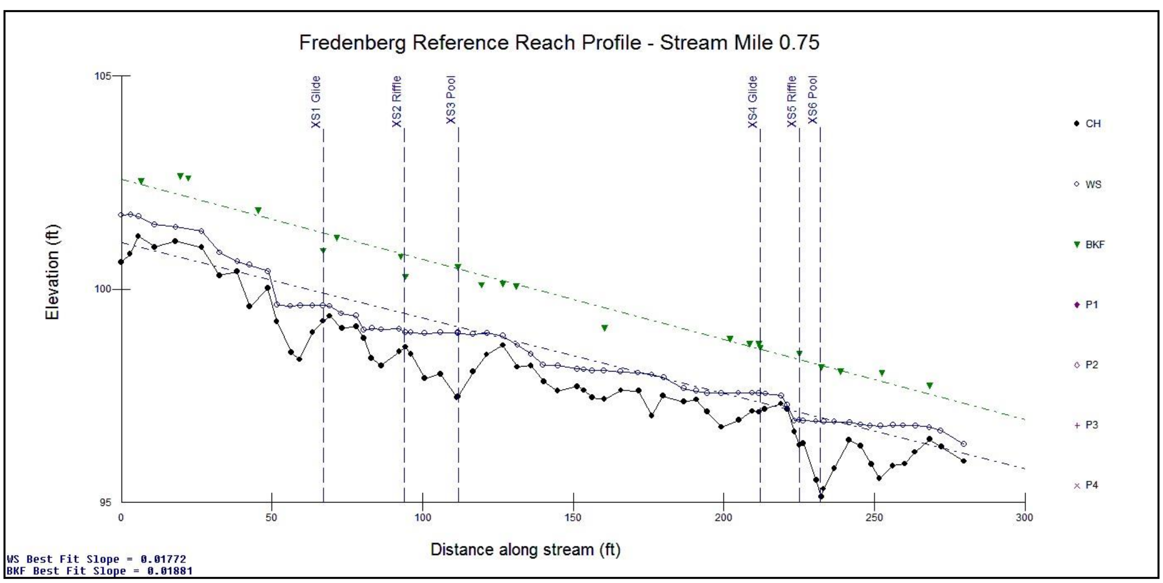


Figure 69: Channel profile of Fredenberg Creek reference reach at stream mile 0.75

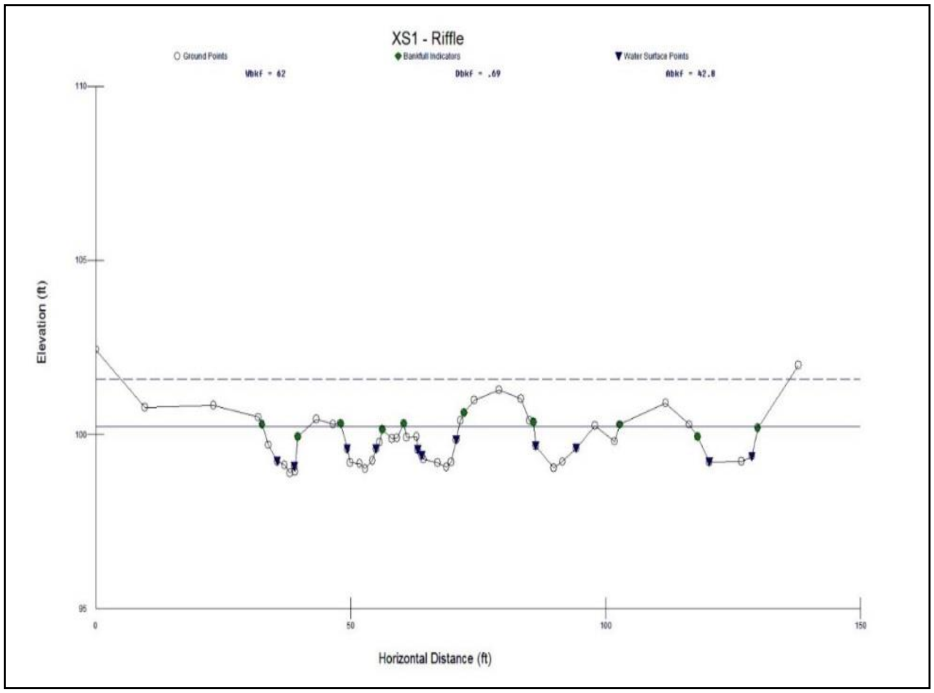


Figure 19: Photo showing the effects of excessive deposition in Fredenberg Creek upstream of CR1

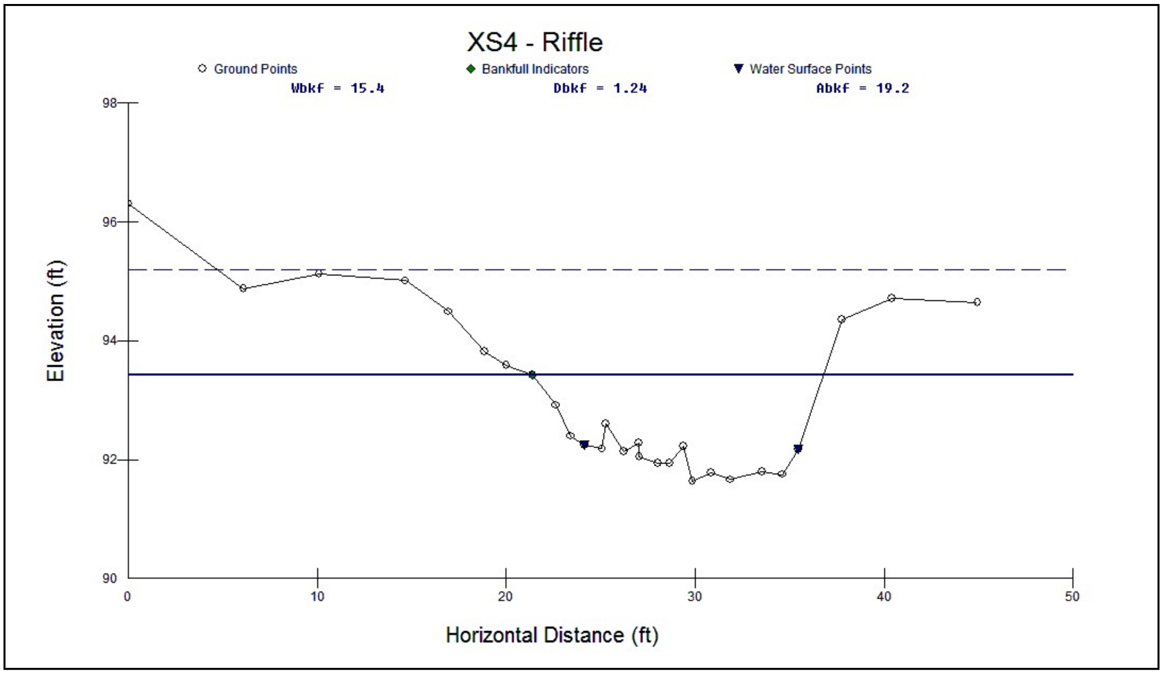


Figure 70: Channel cross-section of Fredenberg Creek approximately 70 feet downstream of CR1

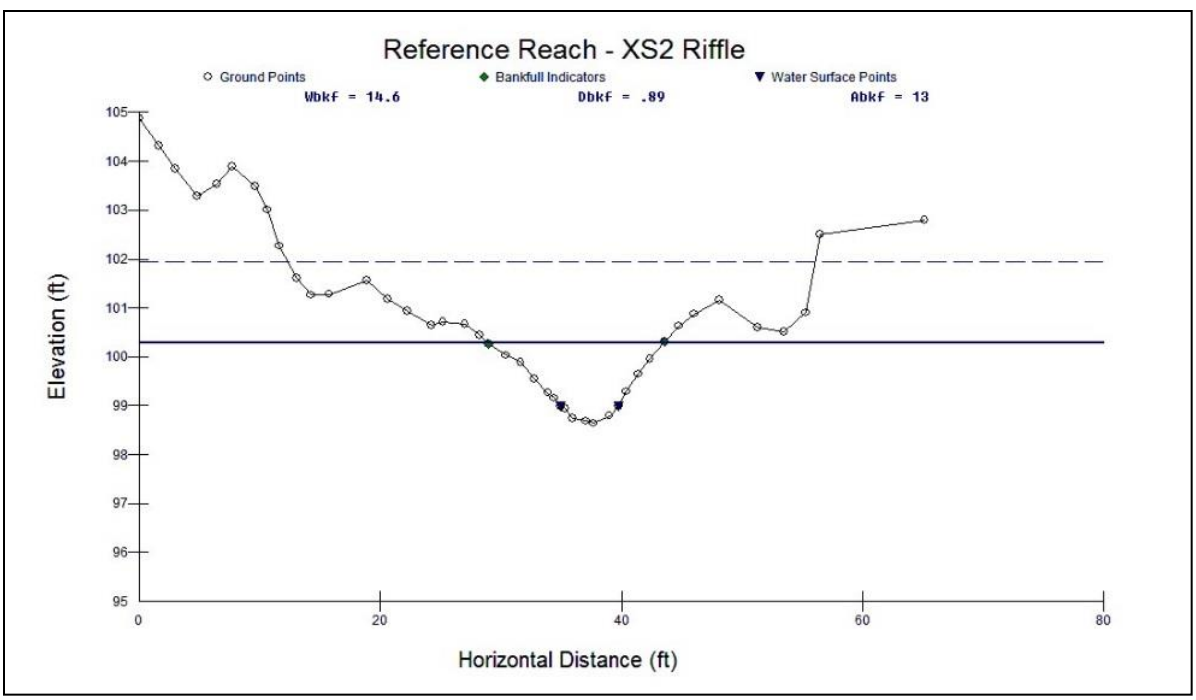


Figure 71: Riffle cross-section of the Fredenberg Creek reference reach at stream-mile 0.75

6.7 Recommendations and project needs

Watersheds along the North Shore of Lake Superior are a stronghold for native Brook Trout, but a changing climate and habitat fragmentation threaten the longevity of these critical habitats. The focus of this proposed project is restoring connectivity between two high quality wild Brook Trout streams near Schroeder, MN. Fredenberg Creek is a 2^{nd} order tributary of the Two Island River and provides exceptional spawning/rearing habitat and a thermal refuge. Currently, 97% of the habitat available in this tributary is inaccessible due to three impassable culverts immediately upstream of the confluence area.

Funding should be pursued to remove the three barriers to fish passage with properly designed and installed crossings as part of a larger effort to restore connectivity in the Fredenberg Creek watershed Reconnecting these streams will protect wild Brook Trout in this watershed by enhancing habitat complexity and expanding thermal refuge areas. Project outcomes include increased numbers and distribution of Brook Trout, increased resiliency to disturbance, localized habitat improvements, and decreased risk of road failure. This project provides an opportunity to work with federal, state, and local agencies as well as two private landholders.

Appendix A – Low-Impact Restoration Options for Woods Creek

Certain reaches of Woods Creek within United States Forest Service property are unstable in spite of the excellent condition of the riparian corridor. Many of these reaches have limited or no floodplain access and bank erosion, sedimentation, and habitat degradation are the result. The channel is currently undergoing an evolutionary sequence and is trying to return to a stable state of equilibrium.

In some places, it may be beneficial to actively restore the stream channel and assist in accelerating the channel evolution process. Large projects utilizing natural channel design methods often require heavy machinery and a moderate amount of riparian disturbance to return rivers to their stable state. In some areas of Woods Creek that may be the best course of action, especially areas that are more incised and where access is not as difficult. However, the density of riparian vegetation is quite high in many reaches of Woods Creek. That, coupled with the relative inaccessibility of much of this area, the small size of the stream channel, and the abundance of rock and logs to be utilized for in-stream structures, provides an opportunity to implement lower-impact projects. These projects could be completed in areas where there is floodplain access and all that is needed is some bank protection, increased sediment transport capability, and/or riparian restoration.

The following scenarios describe lower impact restoration options that could be accomplished by a combination of hand crews and smaller machinery such as a mini skid steer or mechanized wheel barrow. These restoration options would still require an in-depth assessment and design of each reach and consider factors such as upstream sediment inputs, availability of materials, local stream power, etc. Individual project designs would need to follow widely accepted natural channel design methods and be based on appropriate dimension, pattern, and profile data taken from the reference reach.

Low-Impact Restoration Option #1:
Remove log jams that are preventing fish passage and reducing sediment transport capability. Each log jam should be assessed to determine any negative consequences of removal (e.g. removal will cause a headcut to propagate upstream).

Low-Impact Restoration Option #2:

Reduce sediment supply by creating rock and log structures (j-hooks, stream barbs, vanes, etc.) that redirect high flows and decrease shear stress at the toe of the largest eroding banks.

Low-Impact Restoration Option #3:

Install rock-clusters or other structures to hold grade and stop advancing headcuts or to prevent future downcutting of the channel bed.

Low-Impact Restoration Option #4:

Reposition rocks and logs in areas where the stream is braided or over-widened and pools are filling due to a lack of sediment transport capability. The goal will be to center flows, reduce width/depth ratios, and scour deeper pools for fish habitat.

Appendix B – Beaver dam density comparisons in Lake Superior North

Increased turbidity levels at low flow periods in the Flute Reed watershed are thought to be the result of beaver activity in the clay-dominated glacial lakebed of the lower watershed.

Total suspended solid samples were taken after rain and snowmelt events on the Flute Reed River. These samples indicate that TSS levels are very high within some areas of the watershed. (turbidity levels at low flows have also been shown to be at increased levels---CHECK GAGE DATA)

Visual assessments reveal that turbidity levels are increased within and downstream of beaver dams (Figure 72).

Downstream end of beaver dam complex. Note Turbid water. **Upstream end of beaver dam complex. Note improved water clarity.**

Downstream of beaver dam. Note Turbid Water. **Upstream of beaver dam. Note improved water clarity.**

Figure 72. Increased turbidity levels observed downstream of beaver dams during low flow periods.

Beaver are an abundant species throughout Minnesota's Lake Superior watershed. This species spends its time cutting wood, hauling branches, and building dams. Beavers primary food source are leaves, buds, and stems which they gather from trees that they cut down in the riparian area. Beavers drag these materials to their pond where the food is stored for winter. These activities cause this large rodent to disturb the stream banks and bed. If significant amounts of clay are present in the area (i.e., if the beaver activity occurs within the clay deposits of the Glacial Lake Duluth lakebed), this activity can result in sediments being suspended. This suspended sediment can lead to high turbidity and total suspended solid (TSS) levels in some North Shore streams, even at low flows.

Half of the Flute Reed River watershed (7.7 square miles), and 60% of the stream length (including tributaries) is located within the historic Glacial Lake Duluth lakebed. Signs of the glacial lake shore can be observed using LiDAR and is located near Tom Lake Road in the Flute Reed watershed. The portion of the Flute Reed watershed located within the glacial lake area contains a significant amount of clay materials. The stream banks and bed are comprised of this clay, which are easily suspended by beaver activity. Other watersheds nearby have less of their area within the glacial zone and therefore contain less clay. Only 30% of the stream length of Reservation River and 38% of Durfee Creek is located below within the glacial lake zone.

The Flute Reed watershed contains a considerable number of beaver dams compared to other North Shore streams. These dams are located throughout the watershed, starting in the headwaters and extending downstream to County Road 69(Figure 73). The beaver dams are located on the mainstem, main tributaries, and on minor tributaries.

A high percentage of beaver dams within the Flute Reed watershed are located within the glacial lake area than in neighboring watersheds. In the Flute Reed watershed 48 of the 127 dams are within the glacial lake. Both the Durfee Creek and Reservation River watersheds had much fewer beaver dams in the lower watershed/glacial lake area than the upper watershed, and both watersheds had significantly less beaver dams in the glacial lake area than in the Flute Reed watershed (table). The Durfee Creek watershed had only one dam within the glacial lake area. Although each watershed had a much higher density of beaver dams in the upper watersheds, the Flute Reed watershed has a much higher density in this area, further indicating that beaver activity in the clay dominated glacial lakebed is a significant source of low flow turbidity.

Beaver dam density (dams per mile of stream) was calculated by visually locating dams using a combination of LiDAR and the most recent aerial imagery. The density of dams was calculated for the Flute Reed River watershed, as well as neighboring Durfee Creek and Reservation River watersheds. The density was notably higher in the Flute Reed River watershed than in the Reservation River or Durfee Creek watersheds (**Error! Reference source not found.**). Densities in all watersheds are higher than the s tate average of 0.6 dams/stream mile, (MN DNR 2017b) indicating that beaver populations are higher in this region of the Lake Superior North watershed than in other parts of the state.

An attempt to calculate the density of beaver dams for the Flute Reed River watershed in the 1940s was also made using the earliest available aerial images. Unfortunately, this method was inaccurate because the resolution of the images was not high enough to visually assess the presence of dams.

Beaver dam density was broken into sub-watersheds within the larger Flute Reed River watershed to determine if there is a relationship between stream and riparian features and the number of dams. Channel slope was analyzed using LiDAR and no relationship was observed between the channel slope and the density of dams. Additionally, there was no discernible relationship between riparian evergreen land cover (National Land Cover Database 2011) and beaver dam density. The amount of logging within the sub-watersheds was calculated from 1975 – 2010. This factor also did not result in a relationship with the number of beaver dams in the Flute Reed River watershed.

Beavers not only increase the amount of suspended solids but the dams also affect water temperature. In North Shore streams where ground water is scarce, beaver ponds can drastically increase water temperatures. Beaver ponds have little vegetation on the banks as a result of harvest and flooding. Little shade is present and the backed up water can quickly warm making unfavorable conditions for trout.

Watershed	Beaver Dam Number	Beaver Dam Density (dams/stream mile)
Flute Reed above glacial lake	79	4.7
Flute Reed within glacial lake	48	1.9
Durfee Creek above glacial lake	28	2.7
Durfee Creek within glacial lake	1	0.2
Reservation River above glacial lake	76	1.7
Reservation River within glacial lake	16	0.9

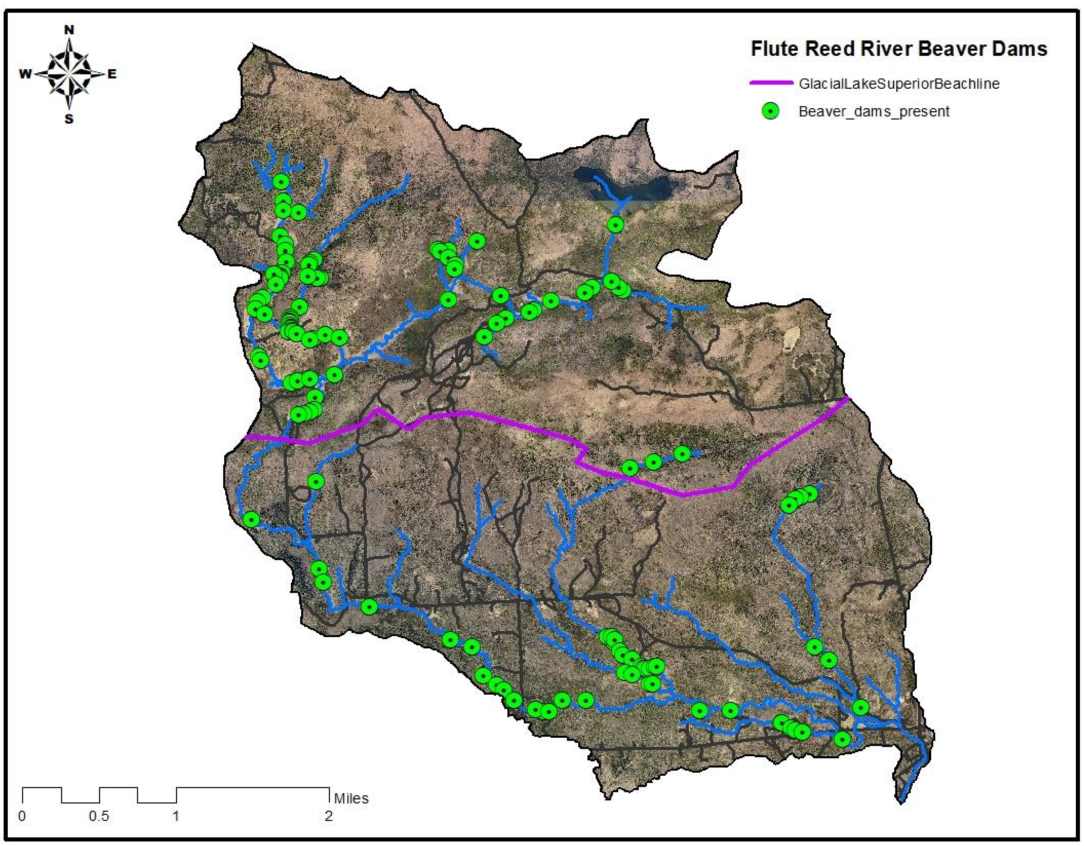


Figure 73. Current beaver dam locations throughout the Flute Reed River watershed.

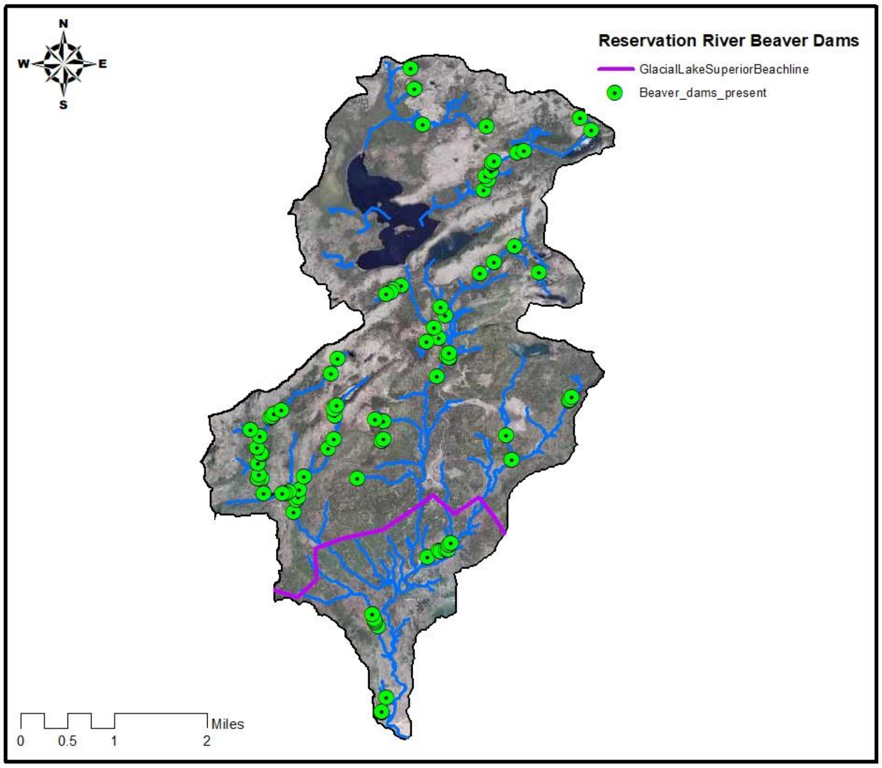


Figure 74. Current beaver dam locations throughout the Reservation River watershed.

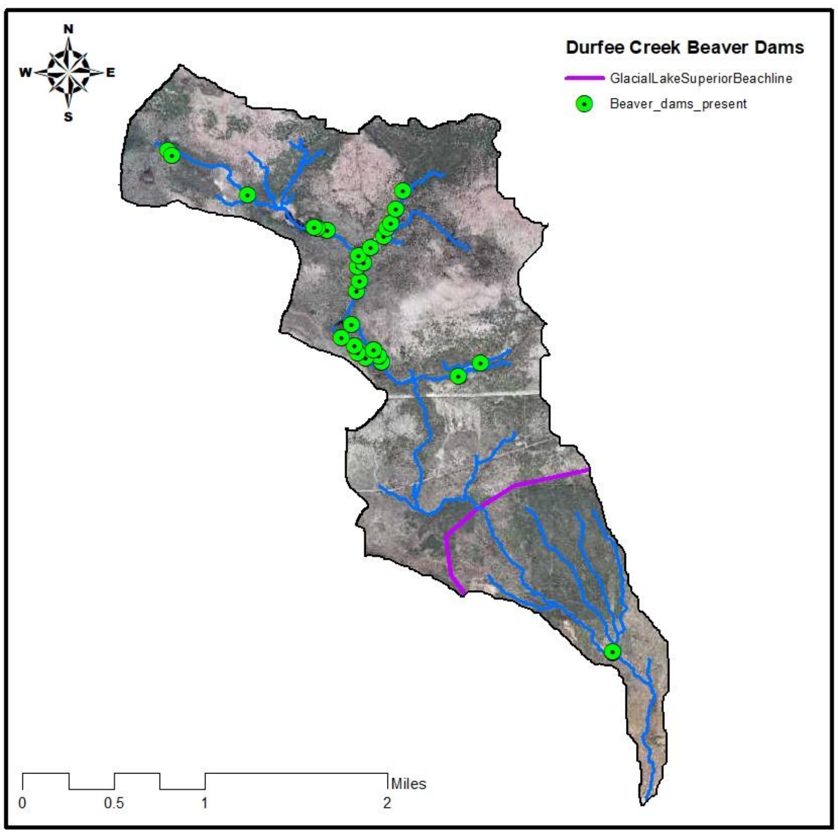


Figure 75. Current beaver dam locations throughout the Durfee Creek watershed.

<u>Citations</u>

Minnesota Department of Natural Resources (MN DNR). 2017a. Minnesota Forestry History Stories – Peak Logging Years. Website.

Friedman, S. K, and P. B. Reich. 2005. Regional Legacies of Logging: Departure from Presettlement forest Conditions in Northern Minnesota. Ecological Applications 15:726-744.

Minnesota Department of Natural Resources (MN DNR). 2017b. Beaver. Website.

Minnesota Trappers Association. History of Trapping and the Fur Trade in Minnesota. Website.

Appendix C – Best Management Practices in Red Clay Soils Areas

The high erosion potential linked to RCA soils must be factored into land and watershed management decisions. Wisconsin DNR published a useful guide covering many of the common conservation concerns and best management practices recommended for areas within the red clay plain along Lake Superior. (http://dnr.wi.gov/files/pdf/pubs/fr/fr0385.pdf). The following recommendations are taken from this guidance document and should be incorporated into the management plan for the Flute Reed River watershed and other areas with red clay soils.

(1) Manage Forests to Reduce Runoff and

a. Forested areas along streams and in upland areas of watersheds provide benefits such as: reducing precipitation disturbance of forest floors, slowing spring snowmelt, reducing overland runoff, and stabilization of soils due to deep rooting systems.

b. Forest composition is a critical component of effective management in red clay areas. Species such as white pine, eastern hemlock, northern white cedar, white spruce, balsam fir, ironwood, and American elm are species that effectively stabilized many steep valley walls prior to European settlement (WI DNR,)

c. Land in "young forest" can speed up snowmelt rates and increase the magnitude of surface water runoff. Avoid harvesting all the trees in stand and plan cuts so mature, uncut stands will intercept runoff generated from harvested areas.

d. Maintain a significant portion of the riparian corridor in larger, longer-lived tree species.

e. Protect headwaters streams.

   i. Mark headwaters streams by flagging or painting nearby trees and be aware of these markings during forest harvest or development.

   ii. Promote growth of native, large, older-aged trees in the riparian corridor of headwaters streams. Leave dead and downed trees in the riparian area.

(2) Maintain Sable Slopes

a. Avoid conducting forest management activities on steep slopes, avoid use of mechanized equipment on or above steep slopes, and avoid activities that will cause channelized flow to steeply sloped areas to prevent rill and gully formation.

(3) Managing Aspen and Beaver

a. Manage riparian areas for species other than aspen, which is the preferred food and dam building material for beaver. Plant and promote the growth of native, long-lived conifers or northern hardwood species.

b. Avoid clear-cutting aspen in riparian areas, as this will result in aspen regrowth and local overpopulations of beaver

c. Removal of beavers and dams may be required to protect coldwater trout streams.

(4) Designing and installing forest road systems

a. Rebuild and stabilize old roads, as opposed to building new ones.

b. Surface roads and trails with gravel, especially if used during non-frozen conditions

c. Keep road ditches vegetated and connected to a floodplain. Use geotextiles, rock-lining, or other ditch BMPs when vegetation alone is not sufficient.

(5) Stream Crossings

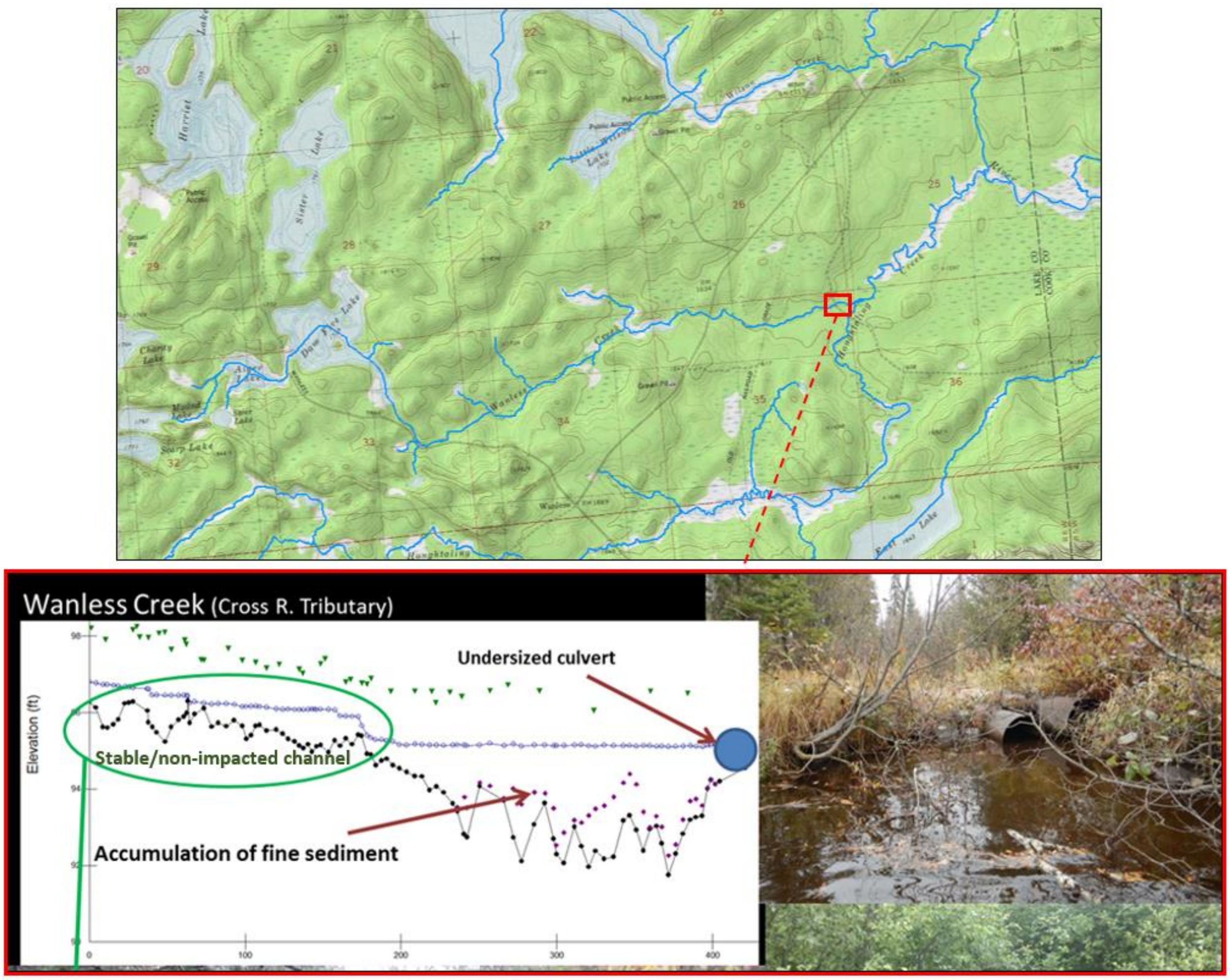
- **a.** Temporary stream crossing structures are advised if a permanent stream crossings is not needed.
- **b.** Constructed bridges instead of culverts when possible. Structural plate-arch culverts are preferred if one must be installed. These culverts ensure fish passage and maintain a natural stream profile and substrate. Standard corrugated-round culverts are least desirable and often cause detrimental impacts to streams.

http://dnr.wi.gov/files/PDF/pubs/ss/SS0025.pdf

Appendix D: Aquatic Connectivity Issues in Wanless Creek

Wanless Creek is a small tributary of Houghtaling Creek, which eventually flows into the Cross River. Wild Brook Trout were present (n=7) in a 2013 sampling of station 13LS043 (area highlighted in red in figure BLANK) and have been sampled in larger populations at other stations upstream of this station. Stream temperatures at 13LS043 remain suitable for supporting sensitive coldwater fish and macroinvertebrates, and overall, habitat conditions are excellent. An undersized and improperly installed road culvert on Forest Road 1855 is disrupting sediment transport and causing pooling and sediment aggradation for several hundred feet upstream of the crossing (figure BLANK). These culverts likely to be impeding fish passage as well due to being undersized and lacking natural stream substrate within the pipes.

Replacing the undersized culverts with a single, properly sized and installed structure would eliminate the habitat degradation caused by the crossing. Fish passage for all species under all flow conditions would be restored, allowing fish and other aquatic life improved mobility between Wanless Creek, Houghtaling Creek, and the Cross River. This site is located within the Superior National Forest, which has been active in the effort to restore fish passage where it has been impeded by road crossings.



Appendix E: Aquatic Connectivity Issues along old LTV Railroad Grade

The Cliffs-Erie/LTV railroad line opened in 1956 to transport taconite from Hoyt Lakes, MN to Schroeder, MN. The railroad line closed in early 2001 when the LTV Mining Company ended operations at Taconite Harbor in Schroeder. Over its 60+ mile course, the railroad grade crosses a large number of rivers, streams, and wetland areas. Many of the railroad/stream intersections feature culverts that are too small or improperly placed to allow for aquatic organism passage and adequate sediment transport. This section highlights some of the major stream crossings within the Lake Superior drainage basin.

Crossings were assessed using aerial photos and sub-meter LIDAR (Light Detection and Ranging) elevation data. Aerial photos were used to evaluate the presence/absence of indicators of channel instability and improper culvert sizing. LIDAR data were used to develop longitudinal profiles and gather elevation data around the crossings.

Figure 76

TWO ISLAND RIVER

Crossing Details	
Stream:	Two Island River
Longitude:	-90.977956°
Latitude:	47.536733°
Potential Problem(s):	Perched and/or undersized culvert
Evidence:	Large downstream plunge pool, waterfall at outlet can be seen on aerial photo, LiDAR profile shows upstream aggradation and large water surface elevation drop in the culvert
Length of upstream channel affected:	100 ft
Approximate culvert length:	100 ft
Approximate water surface slope within culvert:	3.7%
Approximate prism height:	25 ft

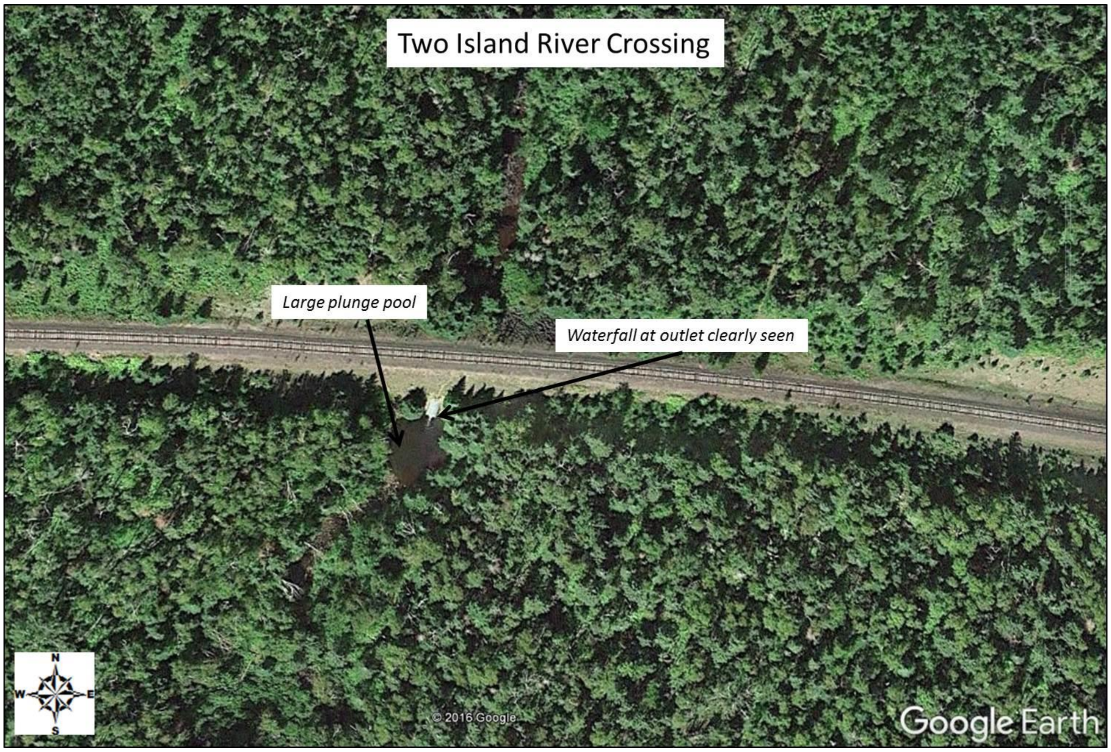


Figure 77: Aerial photo of Two Island River RR crossing, showing large plunge pool and visible waterfall at outlet

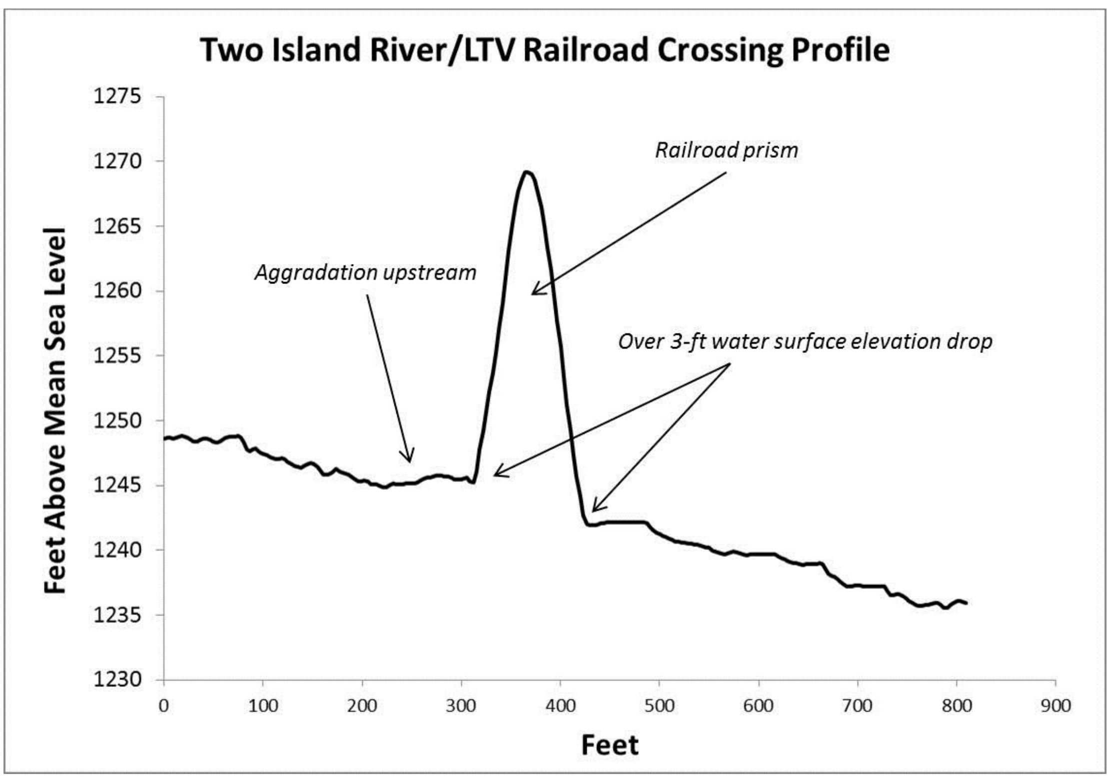


Figure 78: LiDAR profile of Two Island River RR crossing showing potential upstream aggradation and 3 ft drop in water surface elevation

CARIBOU RIVER

Crossing Details	
Stream:	Caribou River
Longitude:	-91.035555°
Latitude:	47.538427°
Potential Problem(s):	Perched and/or undersized culvert, upstream culvert invert set too high
Evidence of problem:	Large downstream plunge pool, waterfall at outlet and large ponded area upstream can be seen on aerial photo, LiDAR profile shows upstream pool and large water surface elevation drop in the culvert
Length of upstream channel affected:	1000 ft
Approximate culvert length:	180 ft
Approximate water surface slope within culvert:	2.8%
Approximate prism height:	45 ft

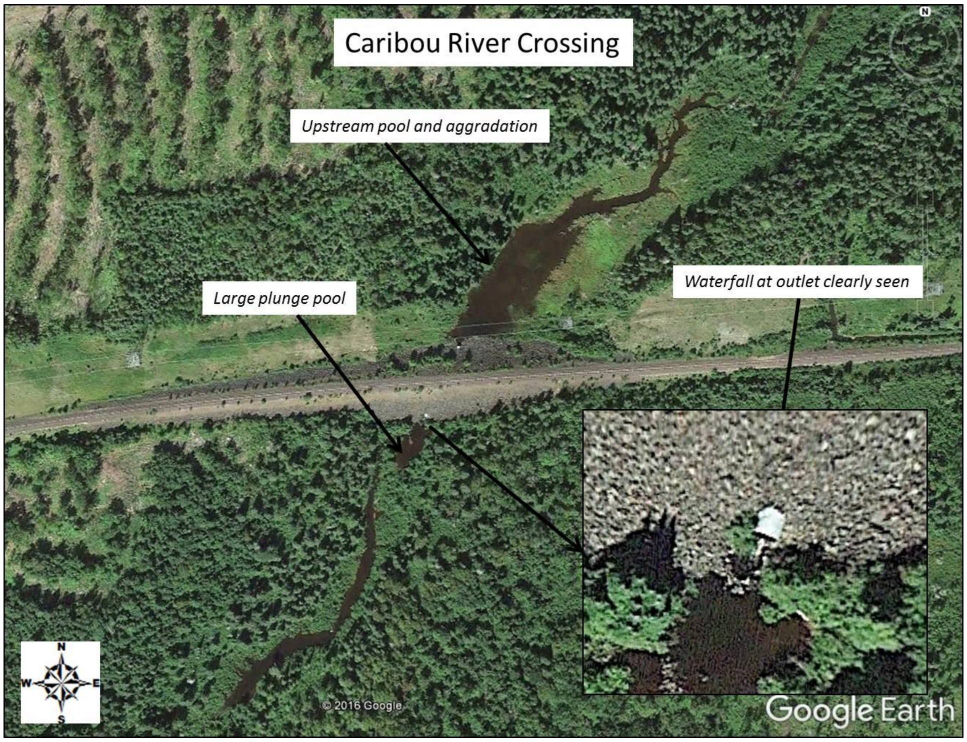


Figure 79: Aerial photo of Caribou River RR crossing, showing large plunge pool, visible waterfall at outlet, and large ponded area upstream

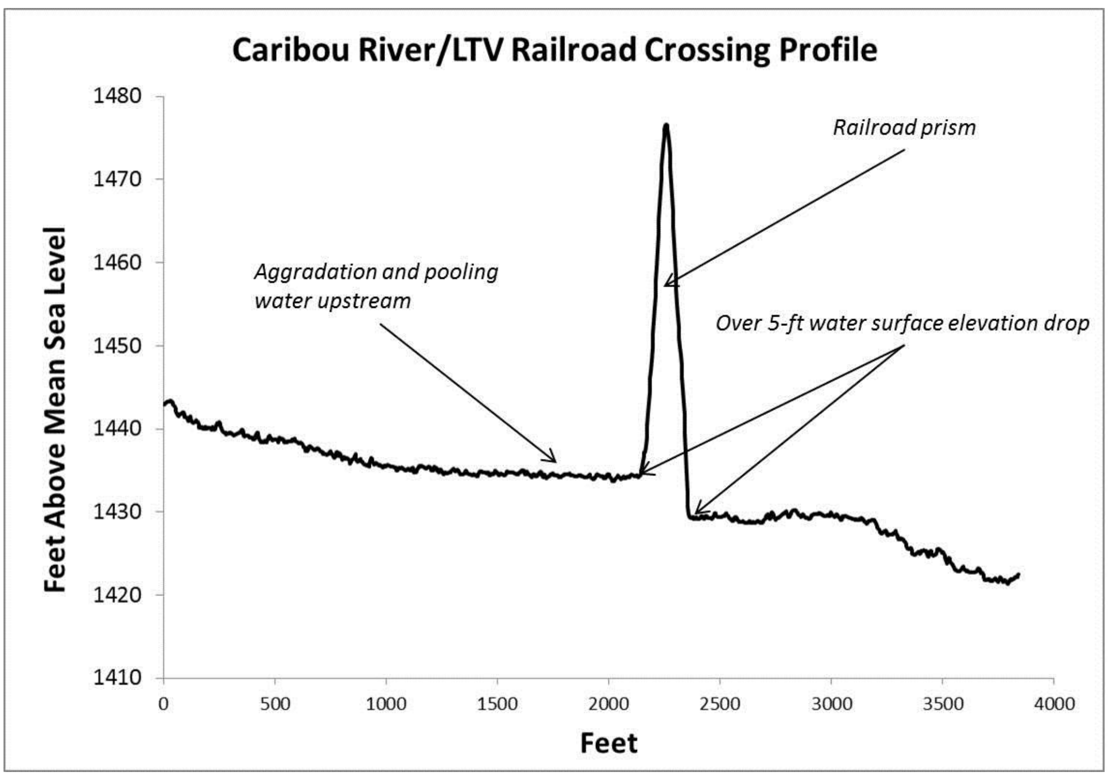


Figure 80: LiDAR profile of Caribou River RR crossing showing upstream pooling and aggradation and 5 ft drop in water surface elevation

MOOSE CREEK (tributary to the Manitou River)

Crossing Details	
Stream:	Moose Creek
Longitude:	-91.116692°
Latitude:	47.540444°
Potential Problem(s):	Perched and/or undersized culvert, upstream culvert invert set too high, or debris jam located at culvert invert
Evidence of problem:	Downstream plunge pool and large ponded area upstream can be seen on aerial photo, LiDAR profile shows upstream pool and large water surface elevation drop in the culvert
Length of upstream channel affected:	2500 ft
Approximate culvert length:	130 ft
Approximate water surface slope within culvert:	3.3%
Approximate prism height:	25 ft

Figure 81: Aerial photo of Moose Creek RR crossing, showing plunge pool and large ponded area upstream

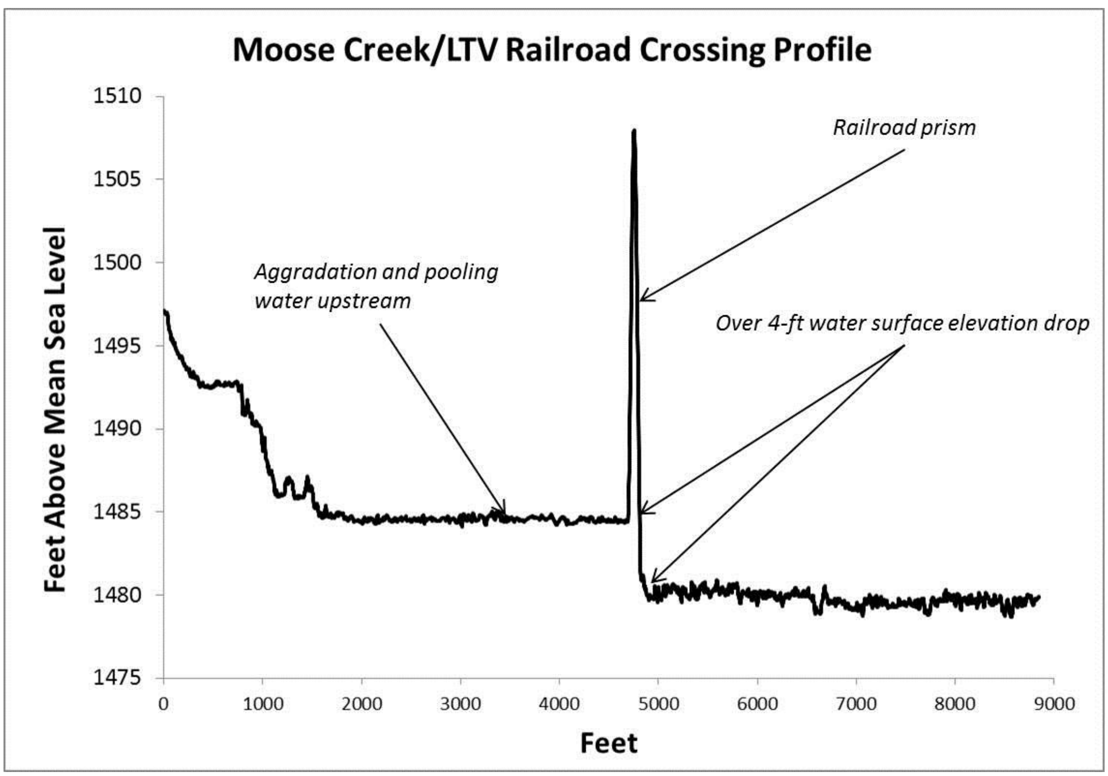


Figure 82: LiDAR profile of Moose Creek RR crossing showing upstream pooling and aggradation and 4 ft drop in water surface elevation

SOUTH BRANCH MANITOU RIVER, lower crossing

Crossing Details	
Stream:	South Branch Manitou River
Longitude:	-91.153440°
Latitude:	47.530007°
Potential Problem(s):	Perched and/or undersized culvert
Evidence of problem:	Large downstream plunge pool, waterfall at outlet can be seen on aerial photo, LiDAR profile shows upstream aggradation and large water surface elevation drop in the culvert
Length of upstream channel affected:	300 ft
Approximate culvert length:	120 ft
Approximate water surface slope within culvert:	3.8%
Approximate prism height:	30 ft

Figure 83: Aerial photo of the South Branch Manitou River RR lower crossing, showing plunge pool downstream of culvert

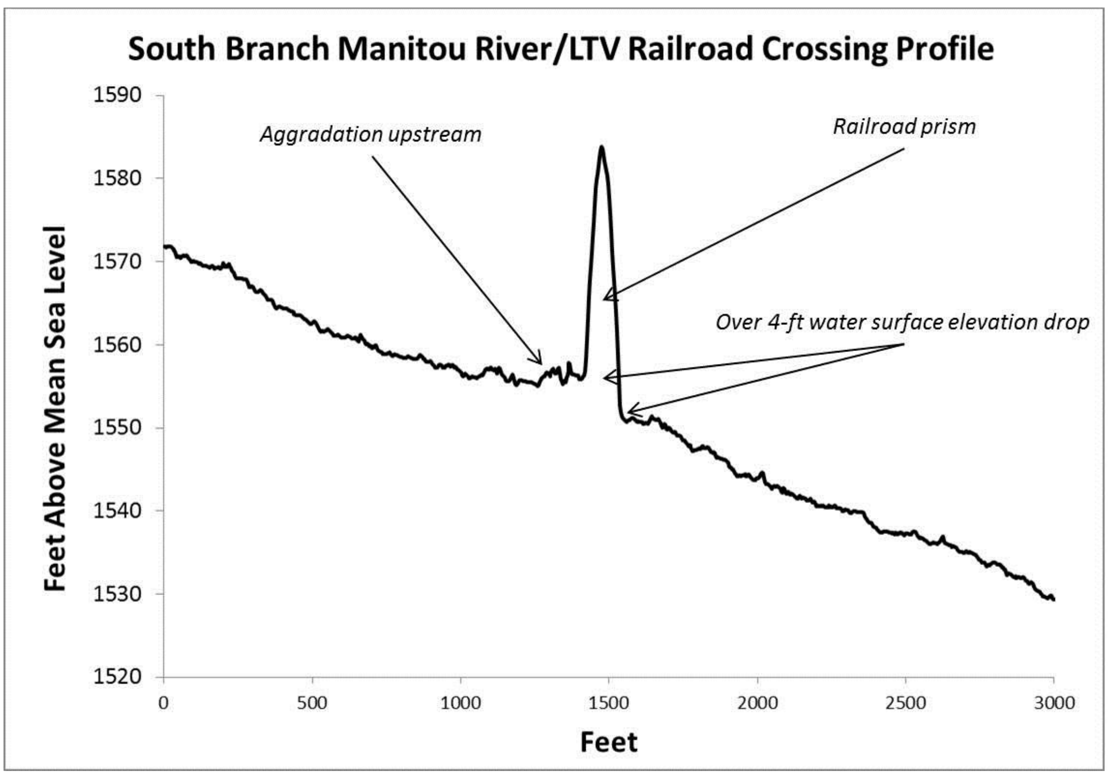


Figure 84: LiDAR profile of the South Branch Manitou River RR lower crossing showing upstream aggradation and a 4 ft drop in water surface elevation

SOUTH BRANCH MANITOU RIVER, upper crossing

Crossing Details	
Stream:	South Branch Manitou River
Longitude:	-91.257447°
Latitude:	47.518102°
Potential Problem(s):	Upstream culvert invert set too high, or debris jam located at culvert invert
Evidence of problem:	Aerial photo shows large upstream ponded area, LiDAR profile shows upstream aggradation and 2' water surface elevation drop in the culvert
Length of upstream channel affected:	500 ft
Approximate culvert length:	85 ft
Approximate water surface slope within culvert:	2.4%
Approximate prism height:	18 ft

Figure 85: Aerial photo of the South Branch Manitou River RR upper crossing, showing large ponded area upstream

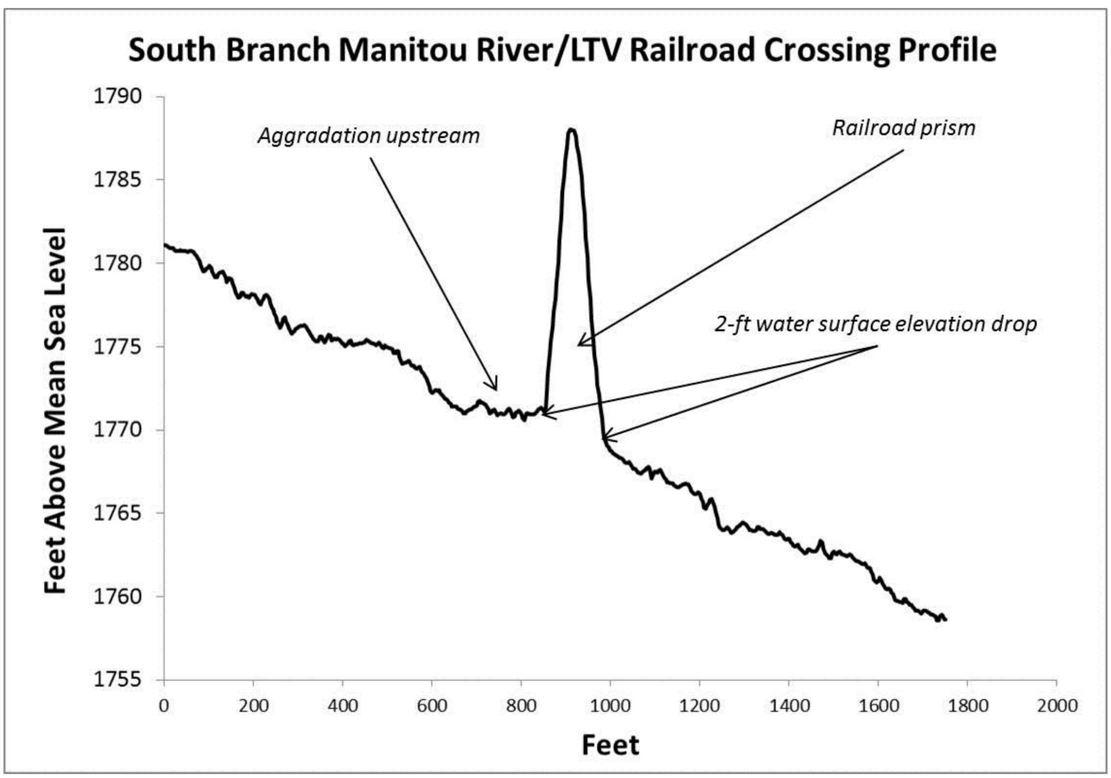


Figure 86: LiDAR profile of the South Branch Manitou River RR upper crossing showing upstream aggradation and a 2 ft drop in water surface elevation

BAPTISM RIVER

Crossing Details	
Stream:	Baptism River
Longitude:	-91.333318°
Latitude:	47.518038°
Potential Problem(s):	Upstream culvert invert set too high, or debris jam located at culvert invert
Evidence of problem:	Aerial photo shows large upstream ponded area, LiDAR profile shows upstream pooling and aggradation and 4.5' water surface elevation drop in the culvert
Length of upstream channel affected:	1000 ft
Approximate culvert length:	100 ft
Approximate water surface slope within culvert:	4.5%
Approximate prism height:	22 ft

Figure 87: Aerial photo of the Baptism River RR crossing, showing large ponded area upstream of culvert

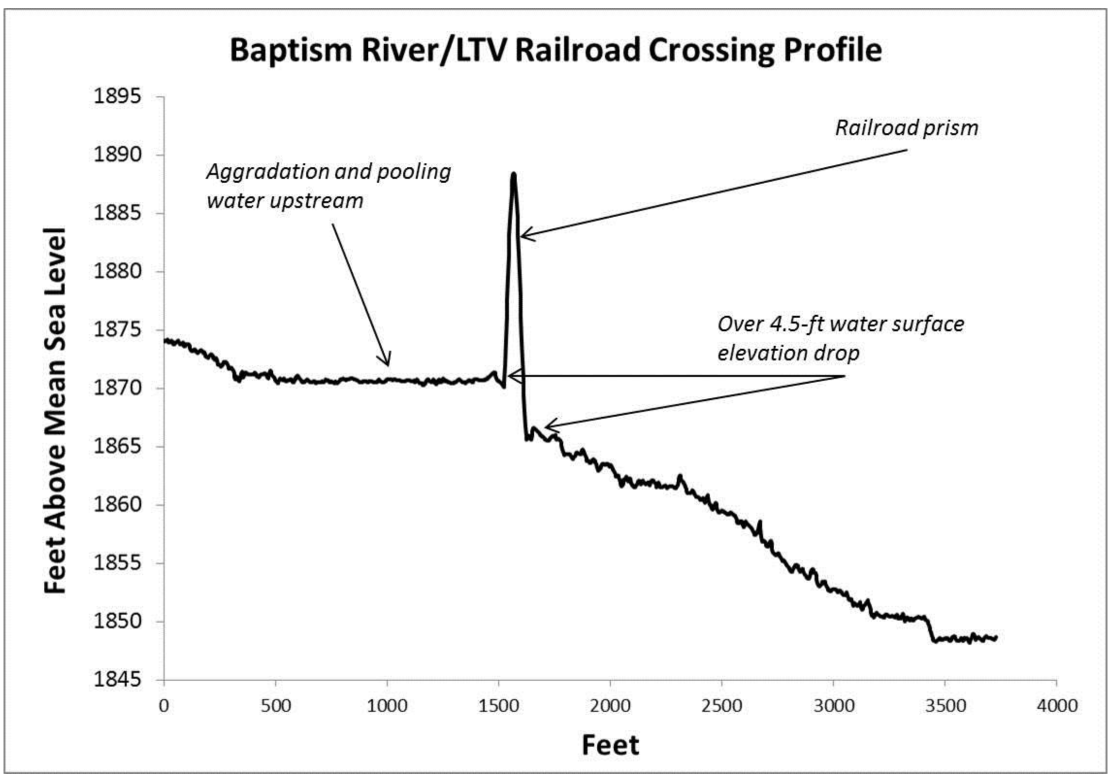


Figure 88: LiDAR profile of the Baptism River RR crossing showing upstream aggradation and pooling and a 4.5 ft drop in water surface elevation

UNNAMED CREEK (tributary to the Baptism River)

Crossing Details	
Stream:	Unnamed Creek
Longitude:	-91.337764°
Latitude:	47.519229°
Potential Problem(s):	Upstream culvert invert set too high, or debris jam located at culvert invert
Evidence of problem:	Aerial photo shows large upstream ponded area, LiDAR profile shows upstream pooling and aggradation and 1.5' water surface elevation drop in the culvert
Length of upstream channel affected:	500 ft
Approximate culvert length:	90 ft
Approximate water surface slope within culvert:	1.7%
Approximate prism height:	24 ft

Figure 89: Aerial photo of the Unnamed Creek RR crossing, showing large ponded area upstream of culvert

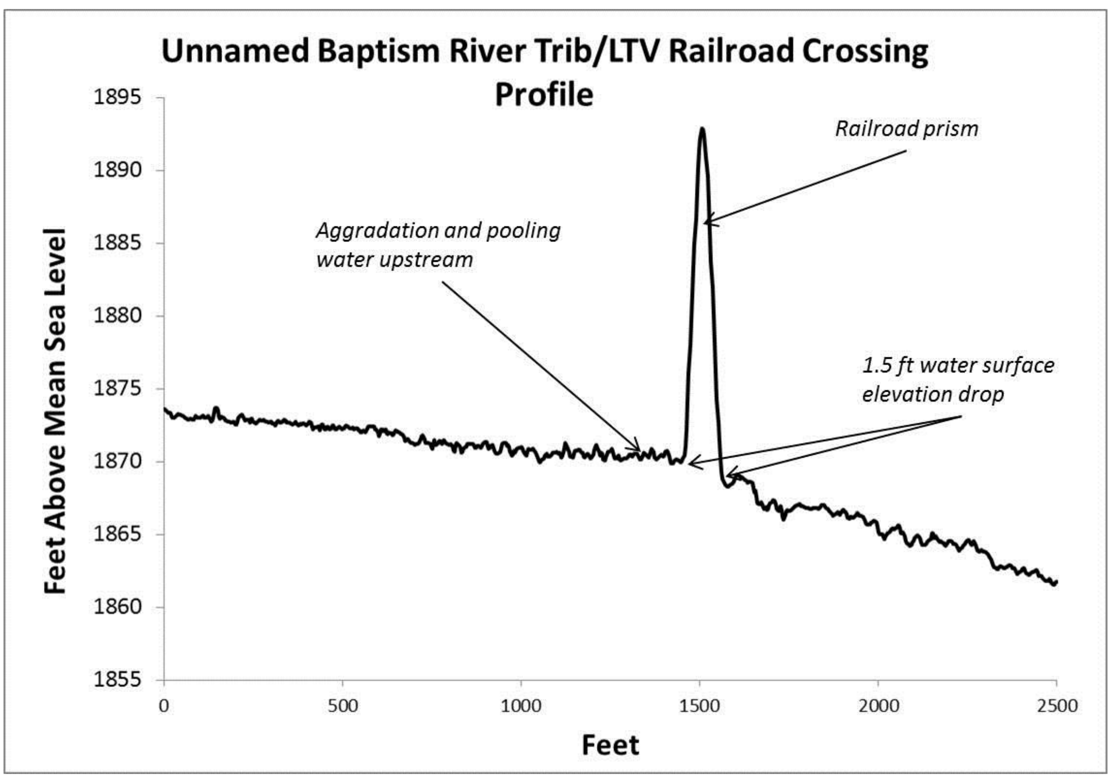


Figure 90: LiDAR profile of the Unnamed Creek RR crossing showing upstream aggradation and pooling and a 1.5 ft drop in water surface elevation

CROWN CREEK (tributary to the Baptism River)

Crossing Details	
Stream:	Crown Creek
Longitude:	-91.421882°
Latitude:	47.507649°
Potential Problem(s):	Upstream culvert invert set too high, or debris jam located at culvert invert
Evidence of problem:	Aerial photo is inconclusive, but LiDAR profile shows upstream aggradation and 5.0’ water surface elevation drop in the culvert
Length of upstream channel affected:	50 ft
Approximate culvert length:	95 ft
Approximate water surface slope within culvert:	5.3%
Approximate prism height:	27 ft

Figure 91: Aerial photo of the Crown Creek RR crossing. Crown Creek is difficult to see in the vicinity of the crossing.

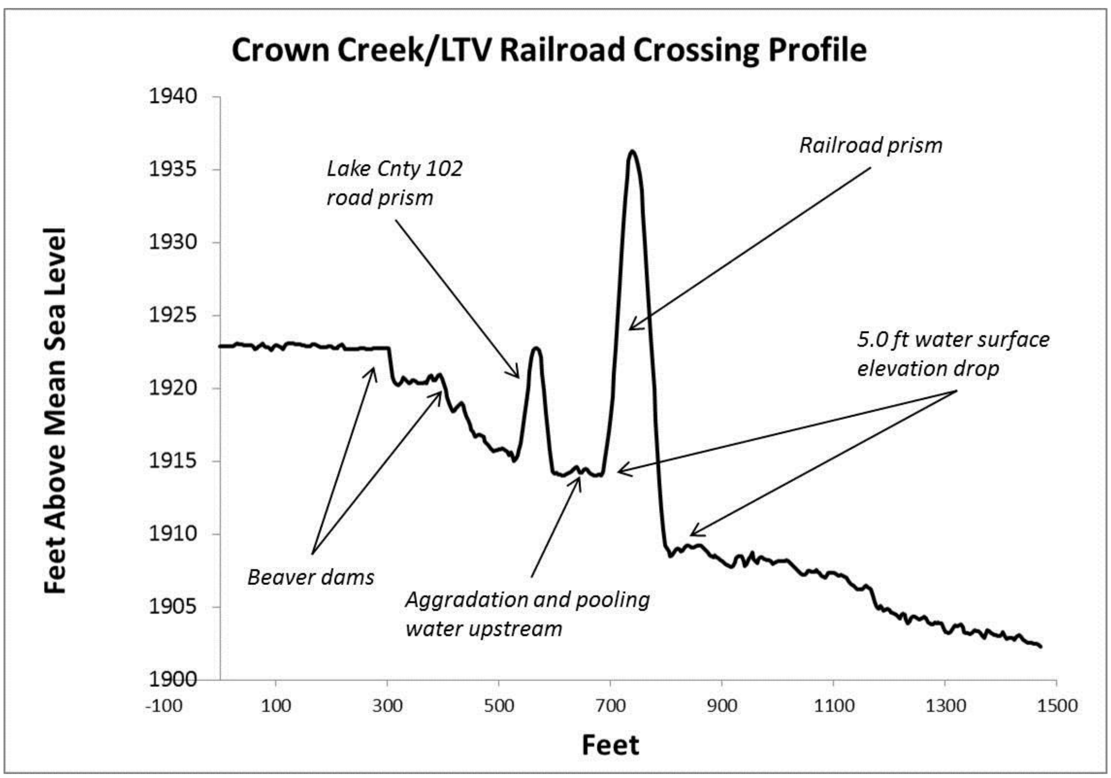


Figure 92: LiDAR profile of the Crown Creek RR crossing showing upstream aggradation and pooling and a 5.0 ft drop in water surface elevation