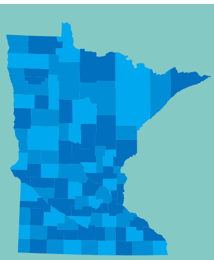
Stressor Identification

March 2018

# Lake Superior North Stressor Identification Report

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

MINNESOTA POLLUTION
CONTROL AGENCY



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# Key terms and abbreviations

| | |
|---|---|
| BANCS | Bank Assessment for Non-point source Consequences of Sediment |
| BEHI | Bank Erosion Hazard Index |
| BHR | Bank-Height Ratio |
| BTSA | Brook Trout Suitability Assessment |
| CADDIS | Causal Analysis/Diagnosis Decision Information System |
| DNR | Minnesota Department of Natural Resources |
| DO | Dissolved Oxygen |
| EPA | Environmental Protection Agency of the United States |
| IBI | Index of Biological Integrity |
| IWM | Intensive Watershed Monitoring |
| LMWL | Local Meteoric Waterline |
| MPCA | Minnesota Pollution Control Agency |
| NBS | Near-Bank Stress |
| PSI | Pfankuch Stability Index |
| RCA | Red Clay Area |
| SID | Stressor Identification |
| SOE | Strength of Evidence |
| TIV | Tolerance Indicator Values |
| TMDL | Total Maximum Daily Load |
| TSS | Total Suspended Solids |
| 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 was 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.
- Fish and aquatic macroinvertebrate assemblages in the Flute Reed River are negatively impacted by 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 that 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

As required by the Clean Water Legacy Act, the Minnesota Pollution Control Agency (MPCA) has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 81 Major Watersheds. This process is known as the Watershed Restoration and Protection Strategy (WRAPS).

A WRAPS is comprised of several types of assessments. The initial phase of WRAPS is called the Intensive Watershed Monitoring (IWM), through which the MPCA and partners characterize the overall health of streams and lakes, and identify impaired waters that do not meet establish standards. Results of monitoring completed by other state, federal, and local organizations are included in this process. This phase of WRAPS occurred between the years of 2013-2015 in the Lake Superior North Watershed, and resulted in the completion of the Monitoring and Assessment Report, which was completed for the Lake Superior North Watershed in 2017. An electronic copy of this report can be found by clicking the following link (Link: Lake Superior North Monitoring and Assessment Report).

The next phase of WRAPS development is known as the Stressor Identification (SID) Assessment. This process builds on the results of the IWM, but a greater emphasis is placed on the evaluating various physical and chemical factors that either harm or protect aquatic life in a given stream. Whereas IWM is geared to be a non-biased assessment of ecological health, the Stressor ID process often targets specific locations in a given watershed to highlight potential restoration or protection priorities. This document is the summary of Stressor Identification results for the Lake

Superior North Watershed. The material presented in this report will be used in planning of restoration and protection activities in conjunction with local, state, and federal agencies and various stakeholder groups.

# 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. 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 (MPCA, 2017). A few exceptions exist in localized areas that have been impacted by various land-uses related to resource extraction and development. Several reaches of the Flute Reed River are impaired for failing to meet water quality standards for total suspended solids (TSS) concentrations. Although some restoration work has been completed in the Flute Reed River, recent data continue to support a 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 TSS impairment listing for the Poplar River near Lutsen was recently removed, as restoration efforts to reduce sediment loading have been successful in meeting water quality targets.

No streams were found to be impaired based on biological indices (fish/aquatic macroinvertebrates). Yet, 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 Lake Superior North Watershed.

**Specific Objectives:**

1. Provide in-depth data collection to determine sediment sources and pathways within impaired watersheds and prioritize relevant restoration and 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 Index of Biological Integrity (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 and/or undersized road culverts)

Study watersheds were selected based on the current impaired waters list, input from MCPA and Minnesota Department of Natural Resources (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 1.

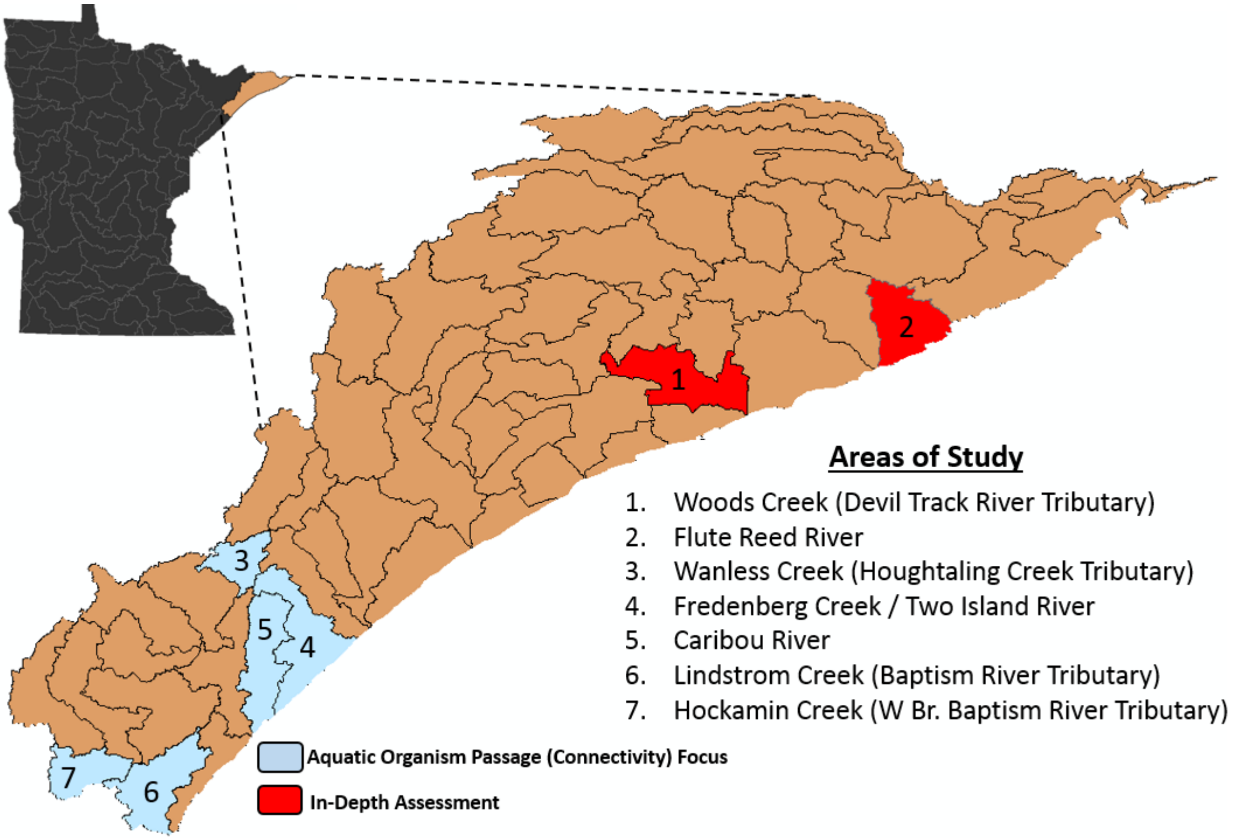


**Figure 1. Map of study areas within the Lake Superior North drainage basin**

**Table 1. Study area and specific objectives**

**In-Depth Watershed Assessments and Problem Investigations**

| Stream | Impairments | Objective *(see list of objectives in main text)* |
|---|---|---|
| Flute Reed River | Tot. Suspended Solids | 1,2,3,4 |
| Woods Creek (Devil Track R. Trib.) | 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 |
| Caribou River | Loss of connectivity | 4 |
| Lindstrom Creek (Baptism R. Trib.) | Loss of connectivity | 4 |
| Hockamin Creek (W. Br. Baptism R. Trib.) | Loss of connectivity | 4 |
| Numerous Streams along old LTV rail line | Loss of connectivity | 4 |

# 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 drainage are listed in Table 2. 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 | Relative Abundance |
|---|---|---|
| Brook Trout | Cold (Coldwater Obligate) | Abundant |
| Brown Trout | Cold (Coldwater Obligate) | |
| 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 |

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 Dingmann, 2016, personal comm.). The temperature criteria used in these models are based on the classifications of “growth,” “stress,” and “lethal” temperature ranges commonly used by MPCA, DNR, and other water resource professionals (Table 3). Two temperature metrics emerged from the analysis as strong predictors of salmonid presence and abundance; *% Growth* (percent of temperature readings in the growth range) and *Summer Average Temperature* (mean temperature recorded (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. salmonids almost always present and in good numbers; salmonids 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. Criteria used by DNR and MPCA for Brook Trout growth, stress, and lethal temperature ranges**

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

### 3.1.1 Thermal classification of Norh Shore coldwater streams

Unlike the spring-fed trout streams of the southeastern Minnesota's Driftless area, the hydrographs (stream flow patterns) of many northeastern Minnesota coldwater streams are heavily influenced by overland runoff, with many streams lacking a significant groundwater contribution (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 areas where colder water and ambient air temperatures persist throughout the year.

Given the unique qualities of northeastern Minnesota trout streams, a separate analysis of temperature and biological response metrics was completed. The approach used was similar to models developed by MPCA (Sandberg and Dingmann, 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 HUC 8 watersheds. The data used were collected during the monitoring seasons of 2011, 2013, and 2015. In all, 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 (% Brook Trout)* 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 2 and 3).

Four temperature regime categories (Area 1-4) were developed based on visual interpretations of the scatterplot results (Table 4). 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 stream temperature and biological metrics used to develop the four categorizes are described in Table 4.

**Table 4. Temperature regime categories developed based on visual interpretations of the scatterplot results of North Shore trout streams with temperature and fisheries data.**

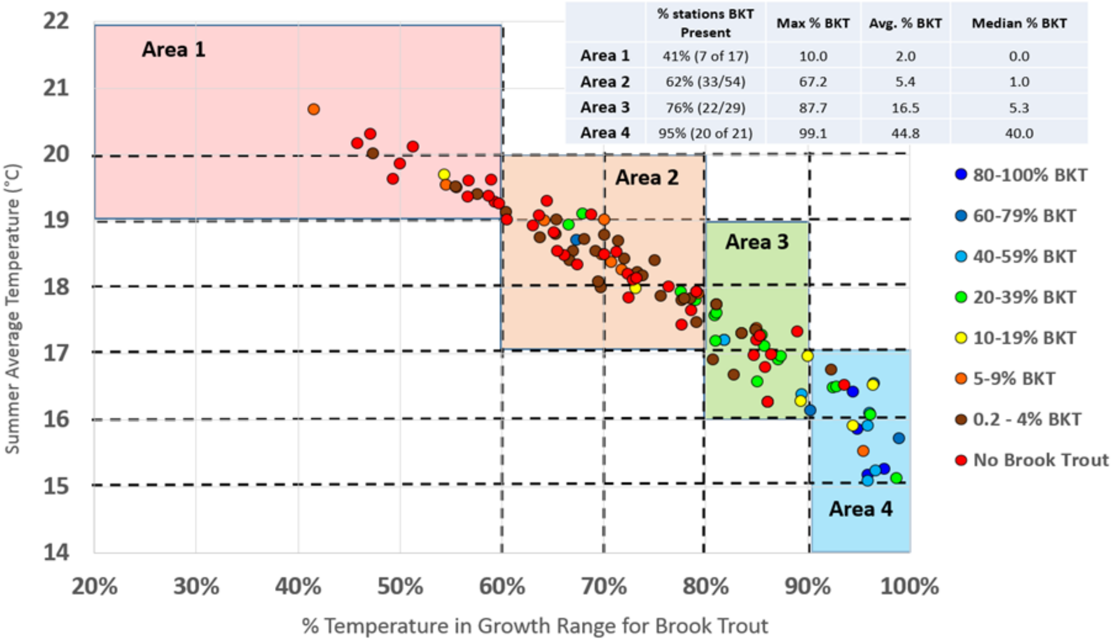
| Grouping | % Temperature Reading in Brook Trout Growth Range | Summer Average Temperature (C) |
|---|---|---|
| **Area 1** | <60% | >19 C |
| **Area 2** | 60-79% | 17 – 20 C |
| **Area 3** | 80-89% | 16 – 18 C |
| **Area 4** | 90 – 100% | <17 C |
| | | |

| Grouping | Description |
|---|---|
| **Area 1** | Brook Trout and coldwater species sometimes present, more often a mix of cool/warmwater taxa |
| **Area 2** | Can support Brook Trout/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/or other coldwater species, low taxa richness |

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 2, 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 Figures 2 and 3. 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.

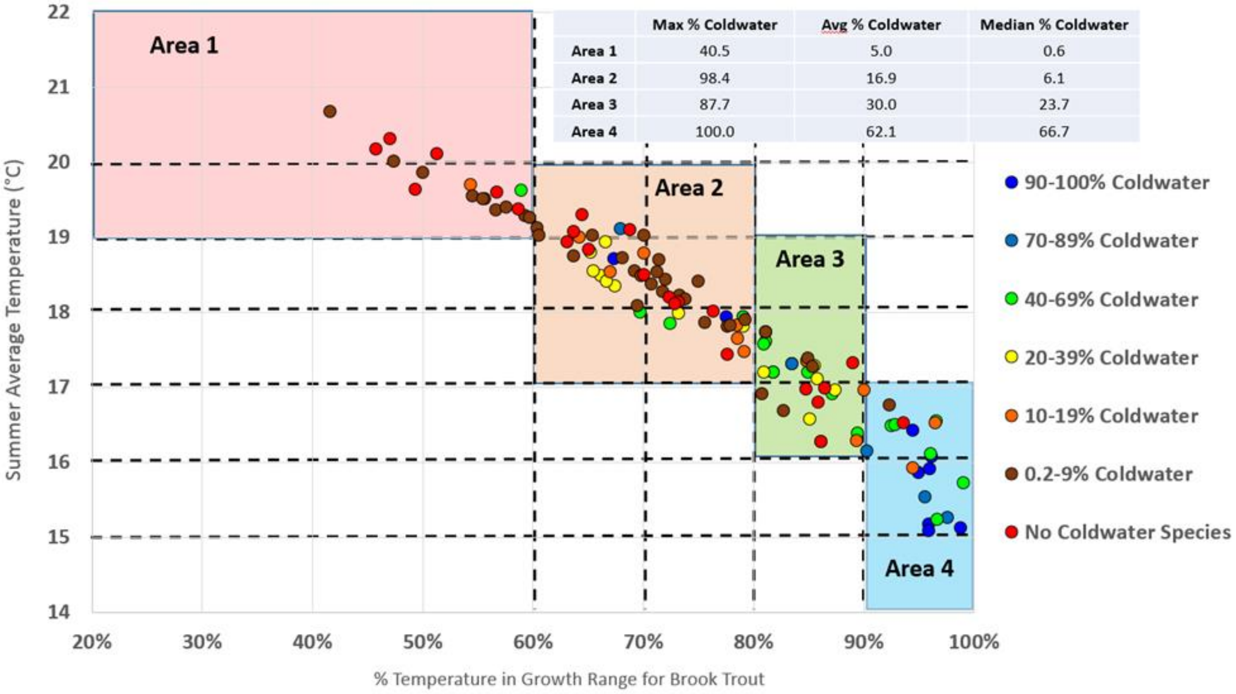
Despite some variable results, a clear trend is apparent, with stable, cold stream temperatures resulting in a greater probability of supporting Brook Trout and other coldwater species. Ninety-five percent (20 of 21) stations included in “Area 4” (>90% temperature in Brook Trout growth range and summer avg. temperature < 17 C) supported Brook Trout, usually in large 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 2). 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 2. Scatter-plot of summer average temperature vs percentage of time temperature was within Brook Trout growth range. Marker colors correspond to percent of Brook Trout in the sample. Data include all LS South/LS North 8-HUC 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 3. Scatter-plot of summer average temperature vs percentage 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 8-HUC stations with biological and temperature data from same season.**

## 3.2 Tolerance Indicator Values

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

This report uses TIV values exclusively to evaluate total suspended solids (TSS) as a stressor to aquatic life. TIV results from a series of reference sites are compiled and displayed in box-plot format to compare against individual results from the study stream, as shown in Figure 4. The acronyms for each class of reference sites is described in Table 5. A general indicator of tolerance (arrow along left side of y-axis) is included to show the direction of TIV response (positive or negative) to the particular stressor being evaluated.

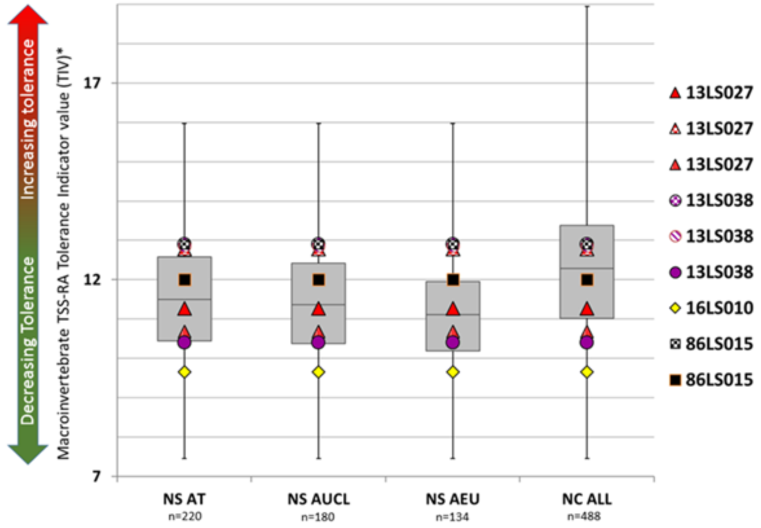


**Figure 4. Example of TIV results as used in later sections of this report. Acronyms are described in Table 5.**

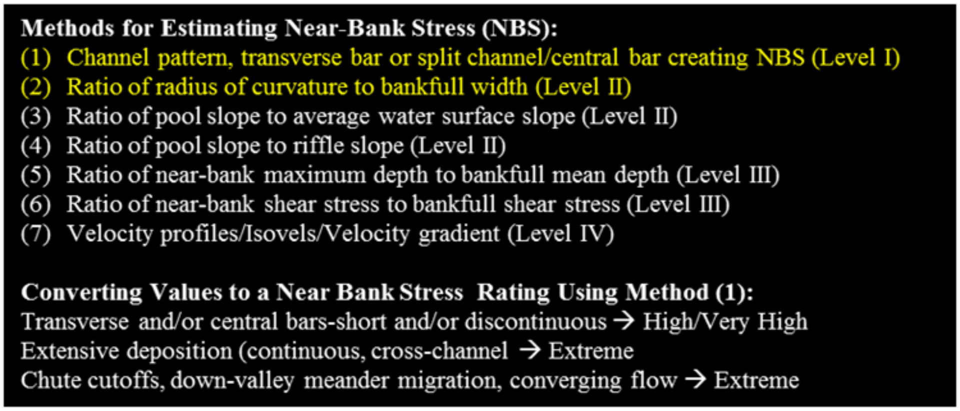
**Table 5. Description of various classes used to compare TIV values from reference stations against those of the study streams in this report.**

| Class Abbreviation | Name (long) | Description |
|---|---|---|
| NS AT | North Shore - Above Impairment Threshold of General Use Criteria | Collection of results from biological monitoring stations in Lake Superior South and North HUC 8 watersheds with IBI scores (fish or macroinvertebrates) greater than the General Use standard, but below the upper confidence limit. Northern Coldwater IBI class only. |
| NS AUCL | North Shore – Above Upper Confidence Limit of General Use Criteria | Collection of results from biological monitoring stations in Lake Superior South and North HUC 8 watersheds with IBI scores (fish or macroinvertebrates) greater than the upper confidence limit of the general use standard, but below the exceptional use standard. Northern Coldwater IBI class only. |
| NS AEU | North Shore – Above Exceptional Use Criteria | Collection of results from biological monitoring stations in Lake Superior South and North HUC 8 watersheds with IBI scores (fish or macroinvertebrates) greater than the exceptional use standard. Northern Coldwater IBI class only. |
| NC ALL | All Northern Coldwater Class | Collection of results from all of the Northern Coldwater IBI class stations |

## 3.3 Streambank erosion (BANCS Model) and Bank-Height Ratio

Bank Assessment for Non-point source Consequences of Sediment (BANCS) 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 6) and the distribution of energy and shear stress in the water (Figure 5) 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 NBS used in the BANCS model. Field-based data for methods #1 and #2 were used in Lake Superior North assessments.**

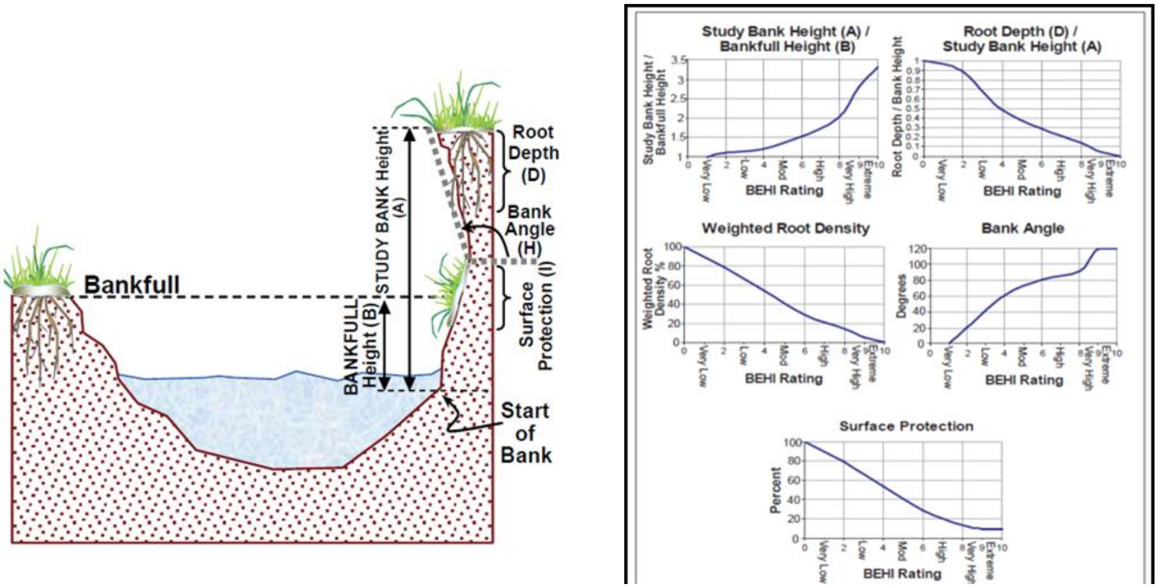


**Figure 6. Bank parameters collected in the field (left) and scoring system to develop BEHI rating (right).**

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 taken from Rosgen (2006):

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

## 3.4 Stream channel stability and habitat assessments

### 3.4.1 Brook Trout Suitability Assessment

The Brook Trout Suitability Assessment (BTSA) is a modification of an assessment developed by Bidelspach (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 are factored into the BTSA score and overall rating. A summary of the BTSA parameters, scoring system, and results in included in Appendix A.

### 3.4.2 Pfankuch Stability Index

The Pfankuch Stability Index (PSI) (Pfankuch, 1975) 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.

## 3.5 Stream connectivity, crossings, and aquatic organism passage

Stream connectivity refers to the maintenance of lateral, longitudinal, and vertical pathways for biological, hydrological, and physical processes. 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). Connectivity is also important for maintaining gene flow and resistance to disturbances, as metapopulations isolated by poorly designed culverts and natural barriers show decreased genetic diversity and may be more vulnerable to extirpation (Torterotot et al., 2014; Whiteley et al., 2013)

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 species) (Tabor et al, 2017). Similar impacts to the native sculpin species of Minnesota can likely be observed in streams fragmented by migration barriers.

A significant portion of the remaining native Brook Trout habitat in Minnesota lies 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.

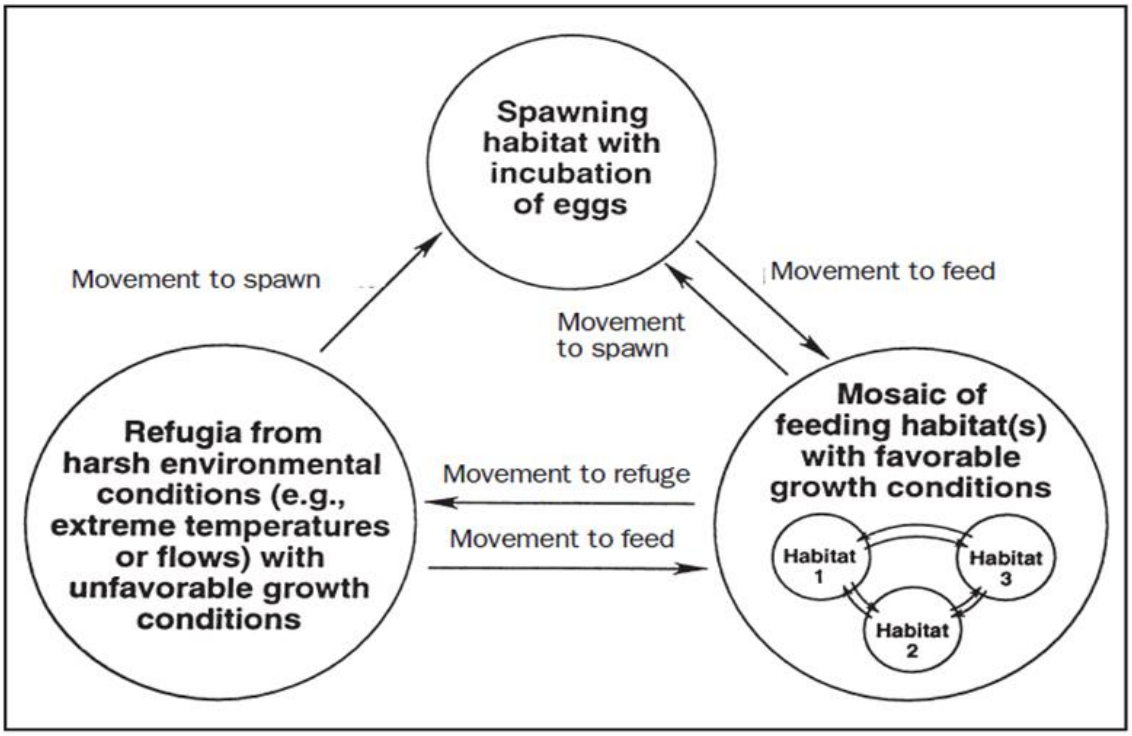


**Figure 7. The basic life cycle of stream fish with emphasis on patterns of habitat use and migration (from Schlosser, 1991).**

## 3.6 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), [δ = (Rsample/RVSMOW – 1) X 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 (δ2H = 8.17* δ18O + 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, a local meteoric waterline (LMWL) 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 & 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 plot below and to the right of 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. Zero or less evaporative loss is expected in streamflow dominated by saturated wetlands and groundwater springs because the water has less exposure to the atmosphere.

In a precipitation-driven watershed, the intersection of the LMWL and LEL represents the weighted mean annual precipitation of an area; it is also known as the inflow value. 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 (see map in figure 1). 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 percentage 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.

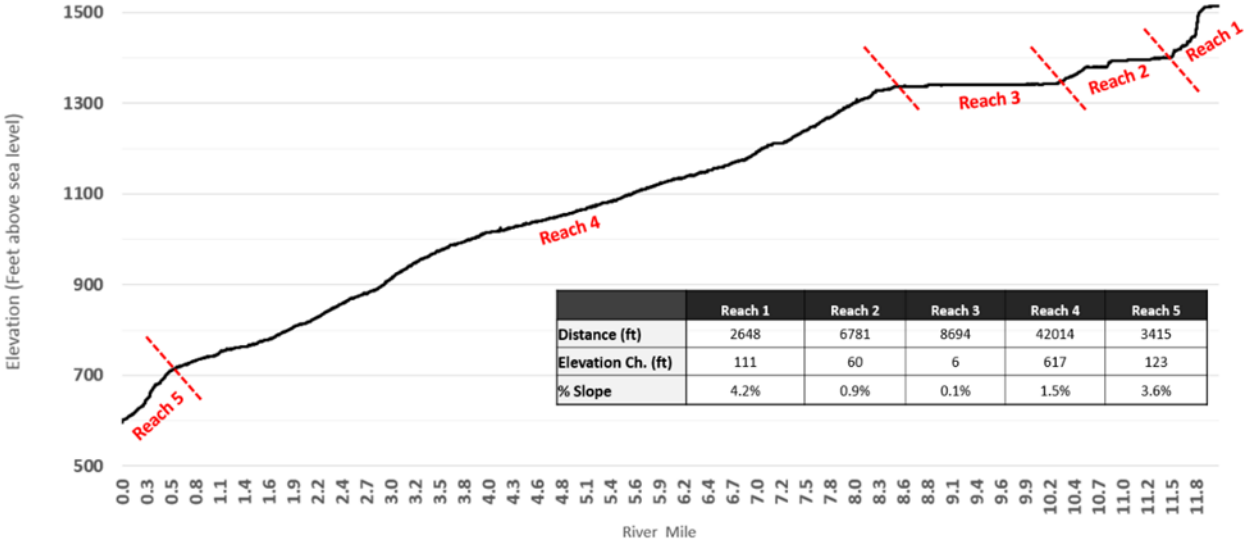
Land ownership in the watershed is 63% private, 27% state land, 9% federal land, and 1% county land. Among the 119 minor watersheds in the Lake Superior North basin, the Flute Reed Watershed has the 5th highest percentage of private land ownership. Myhr Creek, which is adjacent to the Flute Reed, has 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 disturbance (e.g. farming, timber harvest, urban development) (EPA, 1980).

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, and 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 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 and 10). 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 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. Examples of stream thalweg/valley wall intersection in red clay soils area of the Flute Reed River. Bank and bluff erosion is frequently observed in these areas.**

**Figure 9. Examples of stream thalweg/valley wall intersection in red clay soils area of the Flute Reed River. Bank and bluff erosion is frequently observed in these areas.**

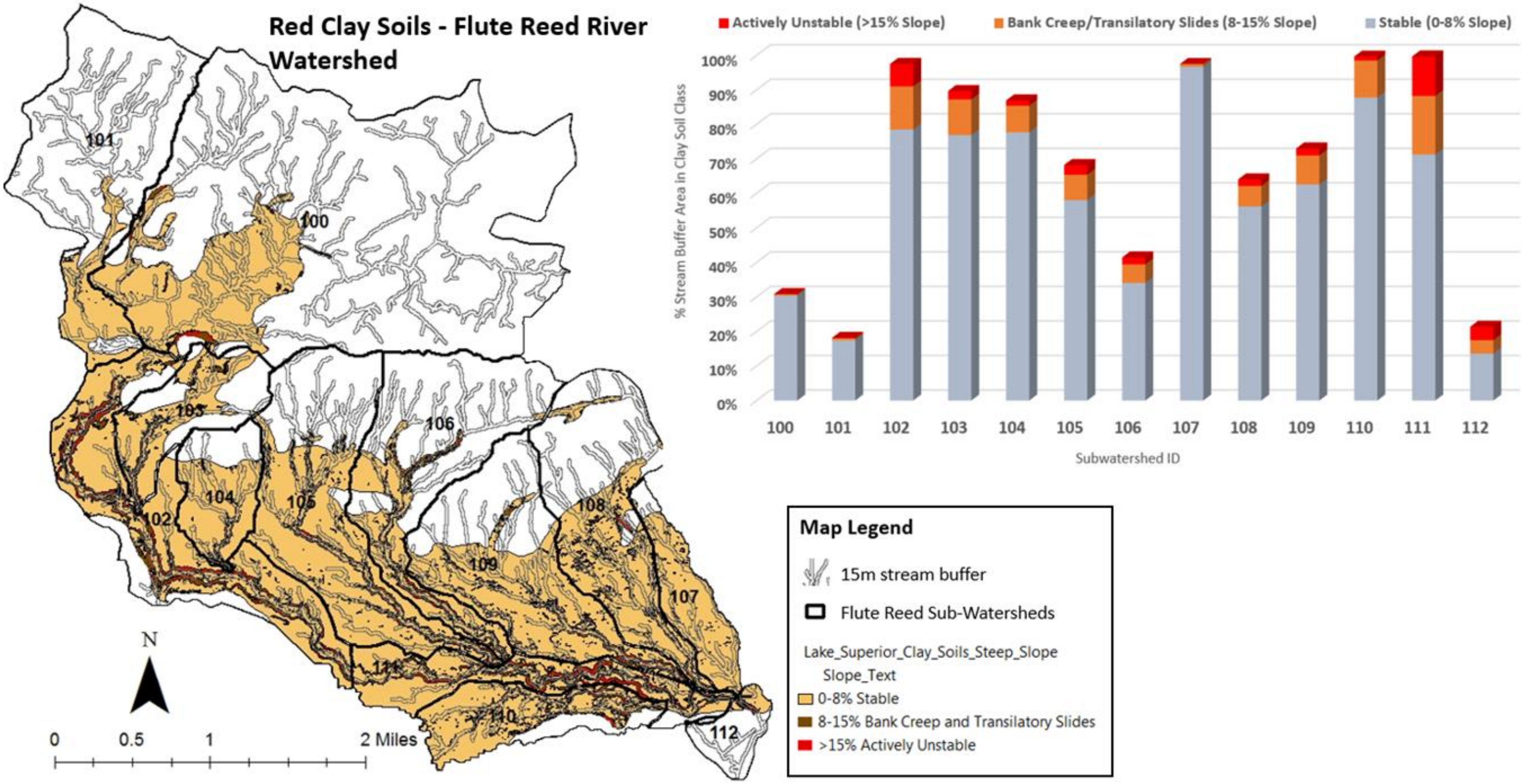
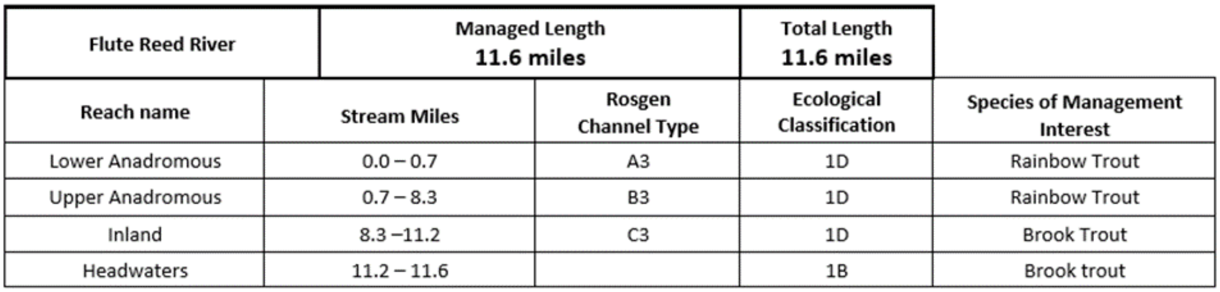


**Figure 10. Extent of red clay soil in the Flute Reed River Watershed, including percentage of land area in red clay soils area within 15-m buffer segments by sub-watershed.**

## 4.2 Overview of biological data

The Flute Reed River is a designated coldwater trout stream from its headwaters (Moosehorn Lake) to its confluence with Lake Superior. The most recent management plan, updated by DNR in the winter of 2016, has defined management goals for Rainbow Trout and Brook Trout (DNR, 2016). Table 6 and the following paragraphs following paragraphs provide a brief summary of DNR' sampling efforts and current management strategies for these species.

**Table 6. DNR management goals for reaches for the Flute Reed River.**



| Flute Reed River | Managed Length<br>11.6 miles | | Total Length<br>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 Flute Reed River fisheries management and sampling history

#### Brook Trout

Historic and contemporary sampling results indicate the Flute Reed River offers very marginal conditions for wild Brook Trout. Smith and Moyle (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 misidentified 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, 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 rivers 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 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 sac). 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 Rainbow Trout Management Summary for the Minnesota Waters of Lake Superior (DNR, 2015). 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 (DNR, 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.

## 4.2.2 MPCA Biological monitoring results

MPCA has sampled fish and aquatic macroinvertebrate communities at several locations in the Flute Reed River Watershed intermittently 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 Table 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 7). 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 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, and 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 (a positive indicator in coldwater streams) and supported relatively high populations of wild Rainbow Trout, which improved overall fish IBI scores.

### 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 7. Summary of Flute Reed River biological sampling stations, results, and applicable assessment criteria. Map of stations can be found in Figure 11. 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 |

| 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 |

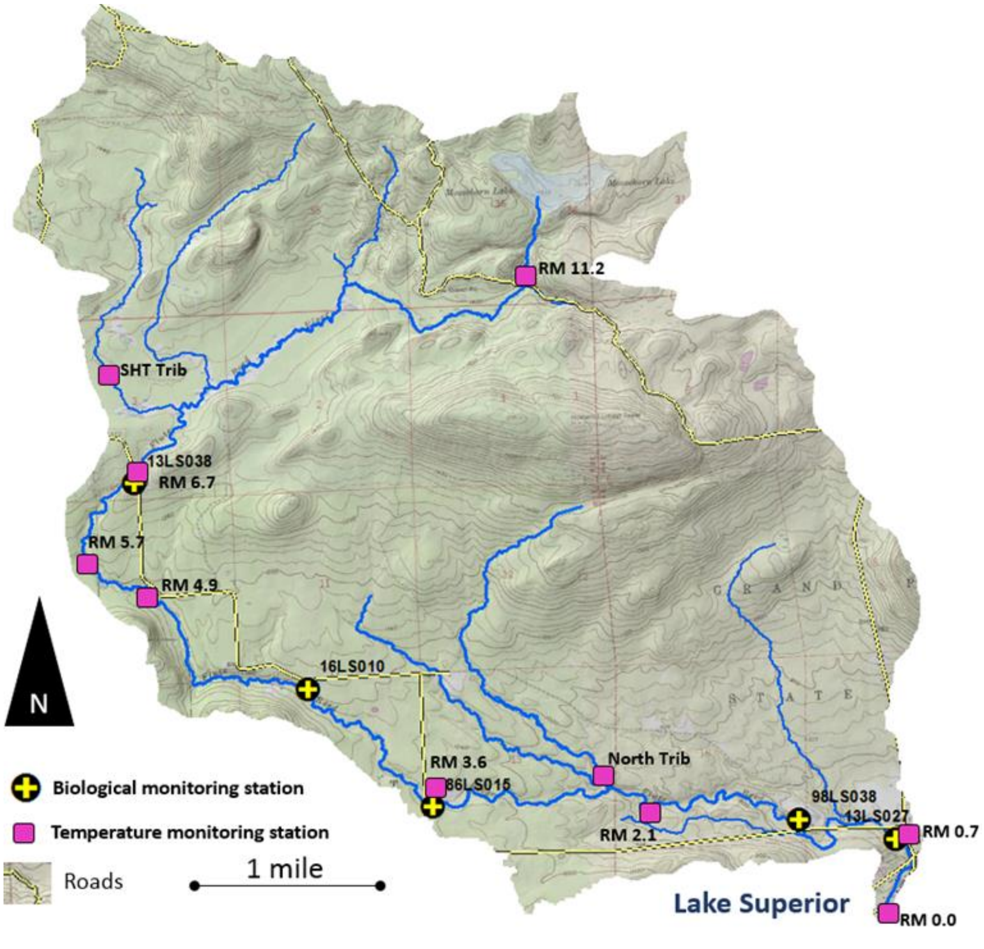


**Figure 11. Flute Reed River Watershed and biological monitoring stations.**

## 4.3 Total Suspended Solids impairment

The Flute Reed River was first listed as an impaired water in 2009 for failing to meet the aquatic life based water quality standard for total suspended solids (TSS). 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 2014 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 12.

### 4.3.1 Synoptic sampling results

Longitudinal synoptic sampling of 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. 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 in a headwaters tributary at station FT 9 (TSS=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 (see map in Figure 12). 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. Beaver dams as a sediment sources are discussed further in section 4.4.8.

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 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 or 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. Specific examples include establishment of forested buffers of long-lived conifer and hardwood species and installation of properly sized culverts or bridges at stream crossings. These tributaries will likely become more significant sediment sources as climate change is expected to produce more and more intense precipitation events.

### 4.3.2 Trends at “long-term” stations

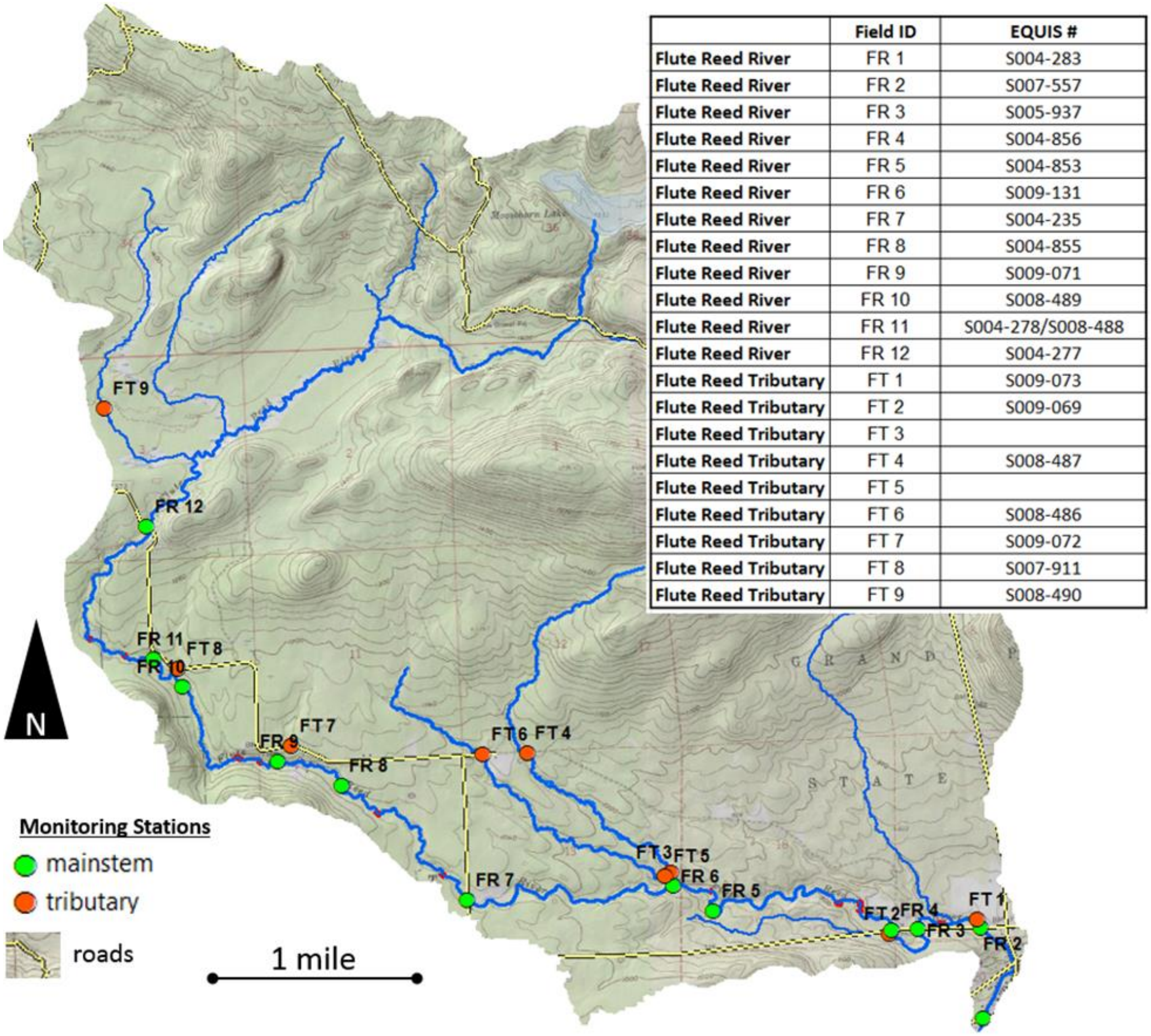
Larger TSS data sets are available for four monitoring stations, which have been sampled frequently over an eight-year period (2008-2016). These four stations are located in distinct areas of the watershed and can be used to evaluate TSS trends both spatially and over time. For the purpose of evaluating 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 15 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.

### 4.3.3 Load duration curve

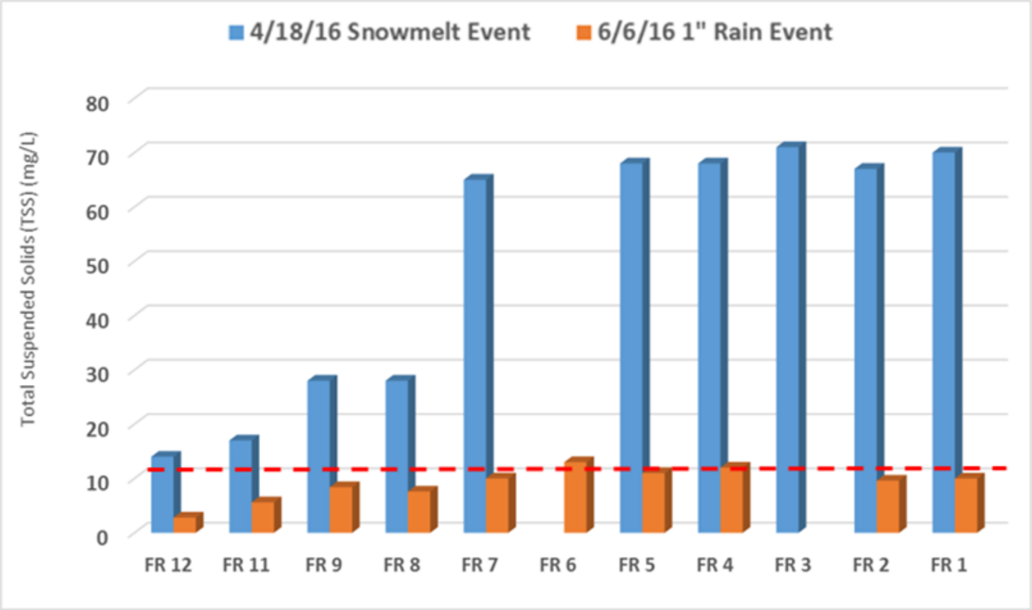
Over the past decade, Load Duration Curves (LDC) have been widely used in the development of TMDLs in Minnesota and other states. The load duration curve approach relies on setting a desired pollutant concentration, which is typically an established water quality standard, in this case 10 mg/L TSS (standard 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 17). The load duration curve shows TSS loadings exceeding the TMDL allocation most frequently during periods of very 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 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 12. Total suspended solids (TSS) monitoring stations within the Flute Reed River Watershed.**



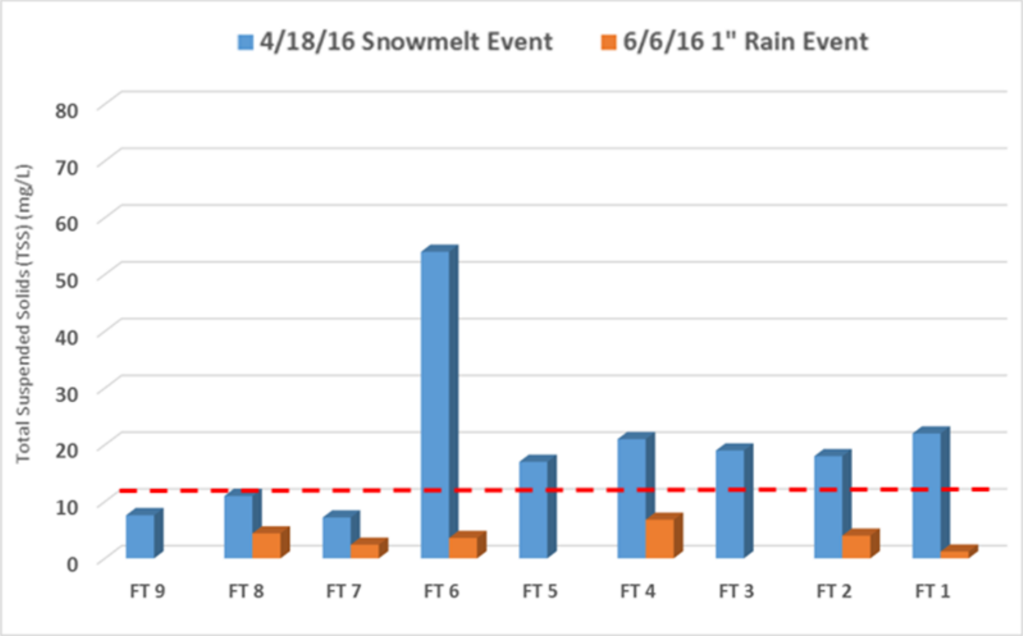


**Figure 13. Results of synoptic TSS sampling in the Flute Reed River Watershed for main stem stations (top) and tributary stations (bottom). The red dashed line indicates the 10mg/L water quality standard.**

**Figure 14. Visual demonstration of TSS increases from upstream (left) to downstream (right) from a May 11, 2015 sampling event. Bottles in the forefront are main stem stations, and bottles set back are tributary samples.**

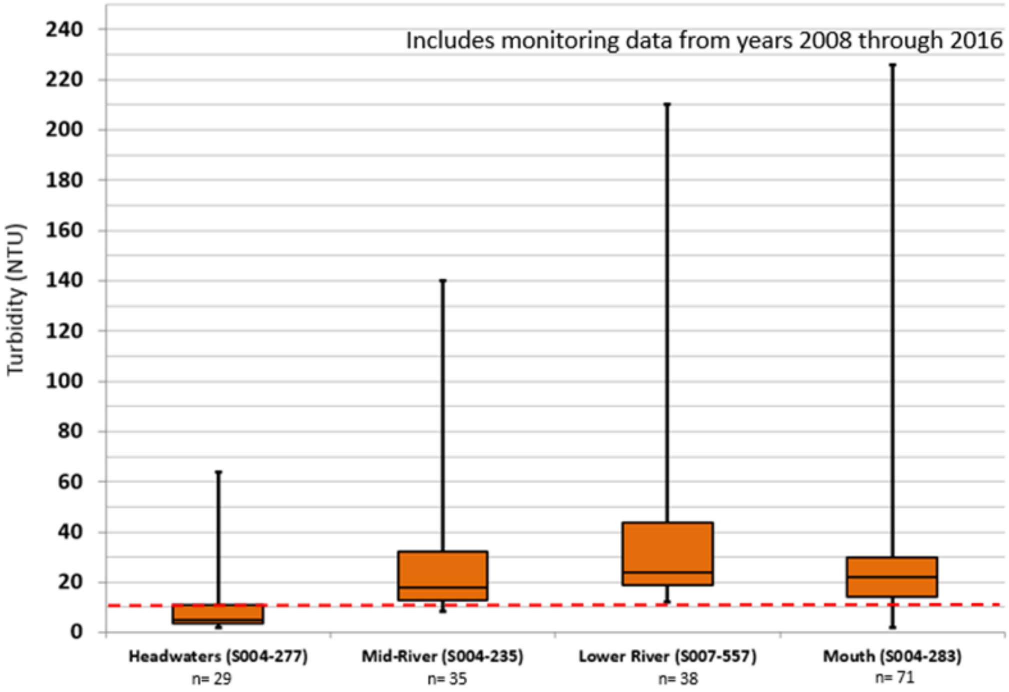


Figure 15. Distribution plots of turbidity data from representative monitoring stations in Flute Reed River.

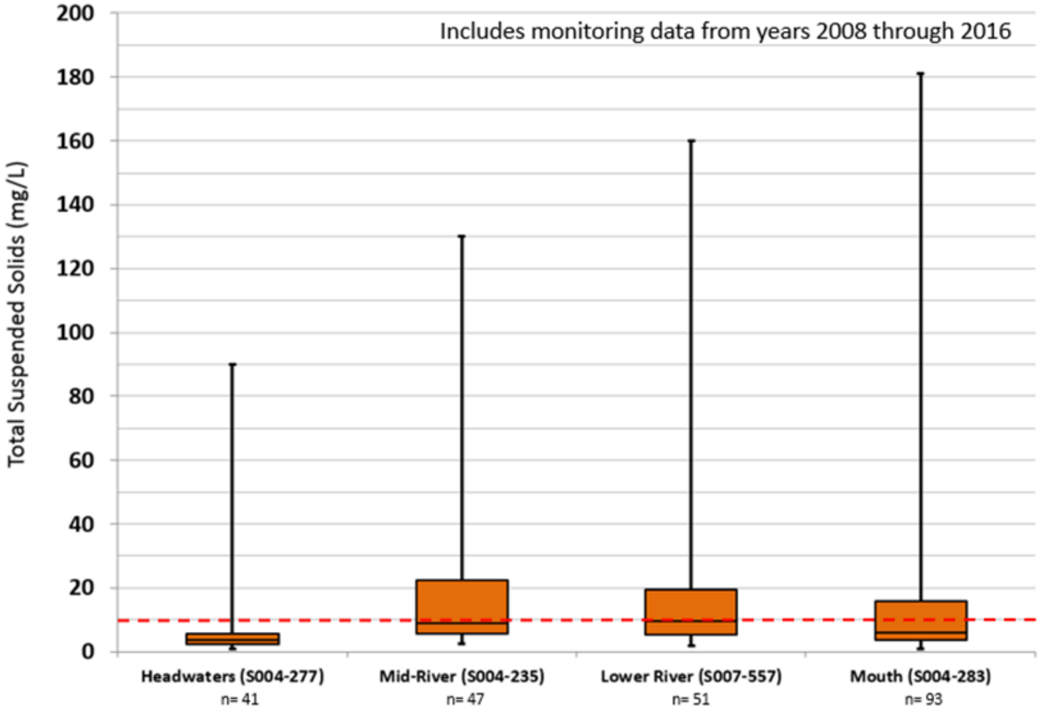
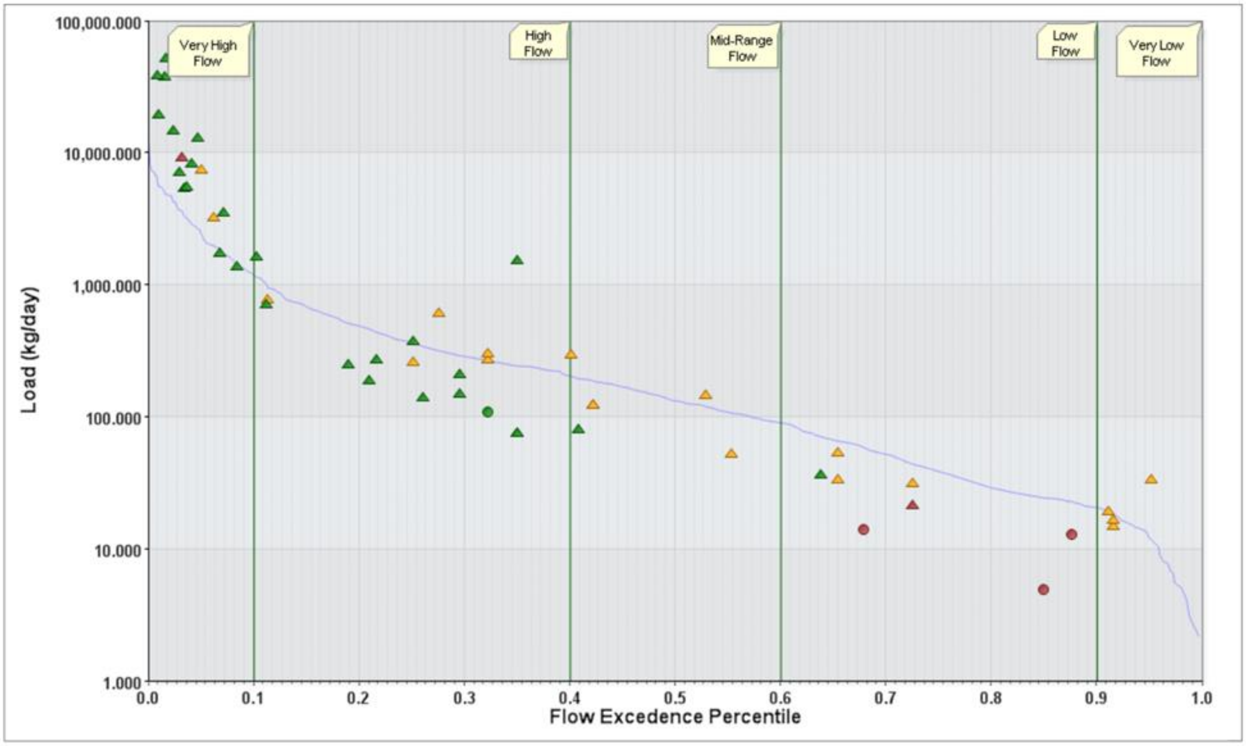
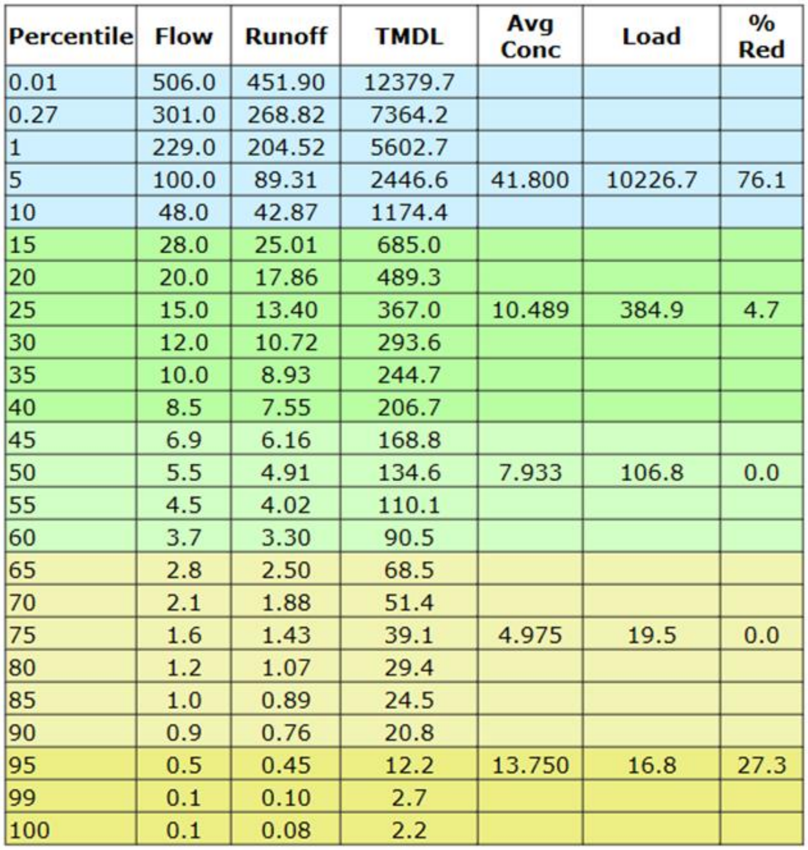


Figure 16. Distribution plots of TSS data from representative monitoring stations in Flute River.





| 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 17. TSS Load Duration Curve for the Flute Reed River.**

## 4.4 Flute Reed Watershed Sediment Sources and 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, 1996) 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, 1996) 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 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 18). 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 18).

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, labeled East Tributary (ET) and West Tributary (WT) 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** | C4/6 | 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** |

- **Reach 11**
- PSI = 103 (Mod. Unstable)
- Current → Potential Stream Type:
  - C4/6 → C4
- High width/depth ratio
- Shift towards finer substrate material
- Moderate to heavy bank cutting (2-5 ft)

- **Reach 13**
- PSI = 111 (Unstable)
- Current → Potential Stream Type:
  - C4b→C3b
- Frequent Mass Wasting (5-15 ft)
- Shift towards finer substrate material
- Less bank protection from boulders, stable vegetation

- **Reach 16 / 15**
- PSI = 68 / 55 (Stable)
- Current→Potential Stream Types:
  - E4 / B3 → E4/B3
- Stable E channels within old beaver impoundments (left photo, Reach 16)
- Stable B channels with in-tact riparian corridors of "vigor and variety → bank protection (right photo, reach 15)

**Figure 18. Examples of Flute Reed River stream reaches with Pfankuch Stability Index scores of "unstable", "moderately unstable", and "stable". The map in Figure 21 shows the locations of the stream reaches.**

### 4.4.2 BANCS model results

Several sources cite stream bank erosion and resulting sediment loads as threats to biological integrity in the Flute Reed River (MPCA, 2017; DNR, 2016b). 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). 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.

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 of 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 19-21). 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 sloped reaches (0.75 – 1.5%) of the C3-C4 channel type. Where these stream types dominate, lateral channel migration within the slightly entrenched valleys is resulting in high to extreme potential for erosion of stream banks and bluffs, many of which are composed of highly erodible and easily suspended clay soils. The banks of stream types C3 and C4 are, by definition, susceptible to accelerated bank erosion, dependent upon riparian vegetation condition. Additionally, the stability of these channel types is very susceptible to changes in the flow and sediment regime of the contributing watershed (Rosgen, 1996).

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 in these locations due to channel avulsion and re-suspension of settled clay particles with the impounded areas. In addition, large beaver impoundment can contribute significant sediment loads during dam failures, which rapidly release stored sediments downstream.

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 this assessment was to evaluate relative bank erosion risk by stream reach and prioritize areas for restoration and protection activities.

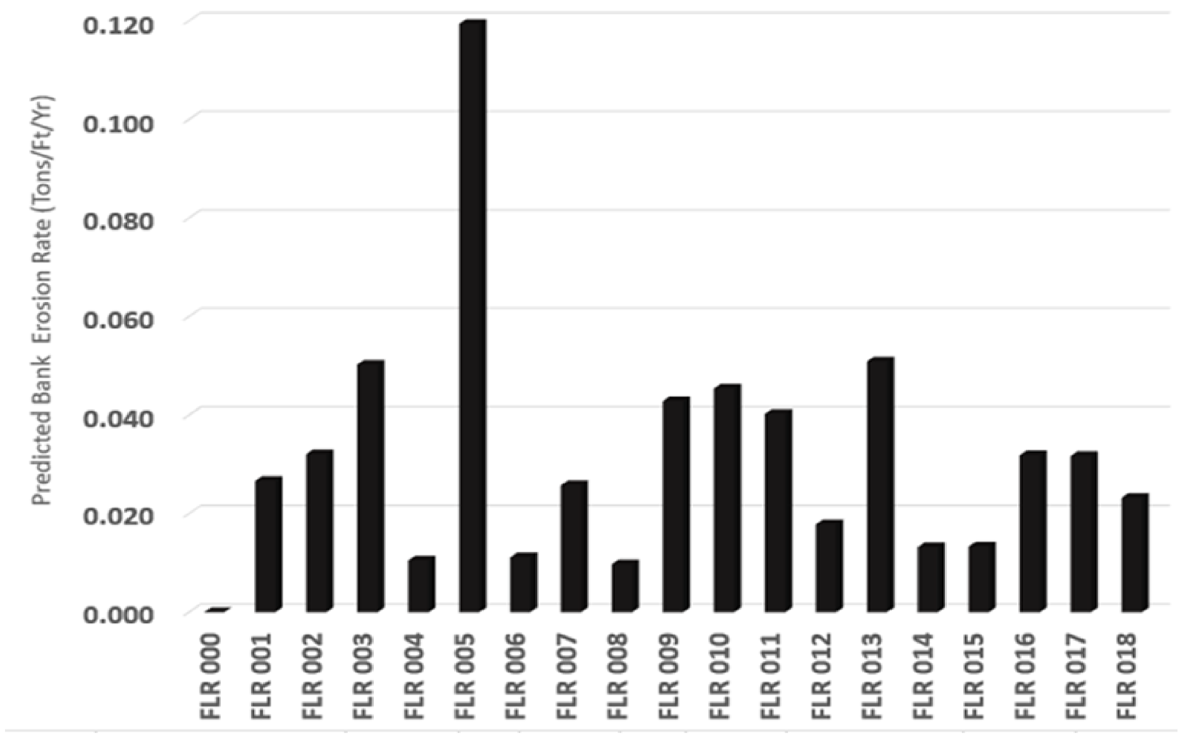


**Figure 19. Predicated bank erosion rates for the delineated stream reaches of two main tributary streams to the Flute Reed River. The map in Figure 22 shows the locations of the stream reaches.**

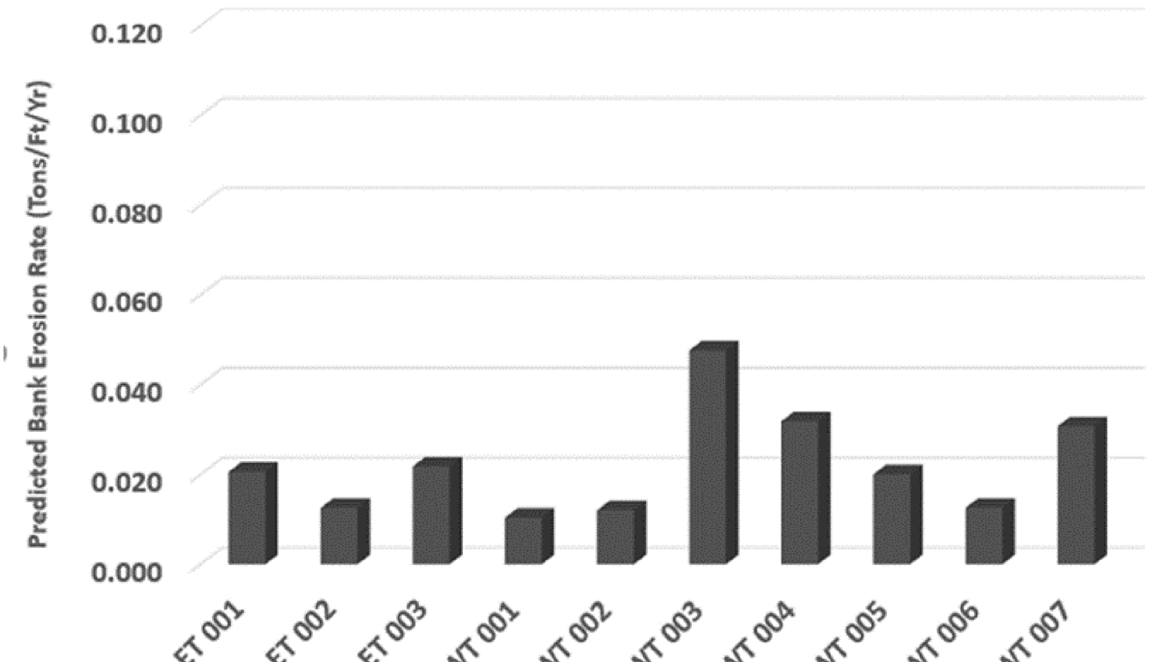
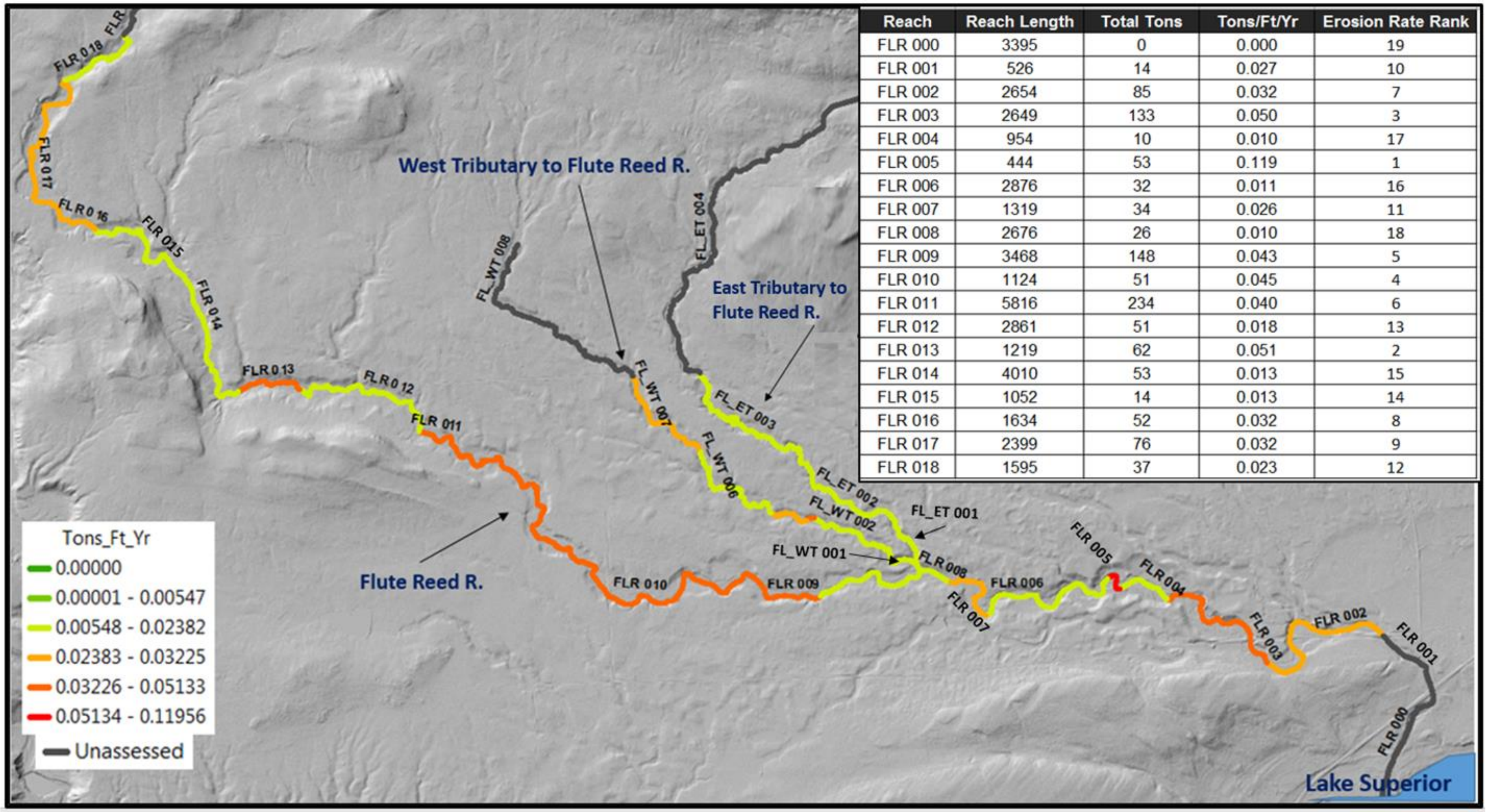


**Figure 20. Predicted bank erosion rates for the delineated stream reaches of the main stem of the Flute Reed River. The map in Figure 22 shows the locations of the stream reaches.**



| 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 21. Predicted bank erosion rates for the delineated stream reaches of the Flute Reed River and two major tributaries.**

### 4.4.3 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, a measure of floodplain connectedness. BHR is measured as Lowest Bank Height/ Max Bankfull Depth (Rosgen, 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 or 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. Symptoms 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.

### 4.4.4 Channel blockages and cut-offs

A certain amount of large, woody debris is desirable in streams to serve both physical and biological functions. However, when the frequency and magnitude of woody debris leads to channel blockages, sediment transport capacity can be altered, causing channel-offs and lateral channel migration. 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).

### 4.4.5 Mass wasting / Bluff and 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 26; “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 of a slightly entrenched 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 NBS 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.

## 4.4.6 Headcuts on tributaries/Gullies

Headcuts are erosional features found where an abrupt vertical drop (i.e. "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 22. Headcuts were also noted in many side channels near active or abandoned beaver dams.

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.

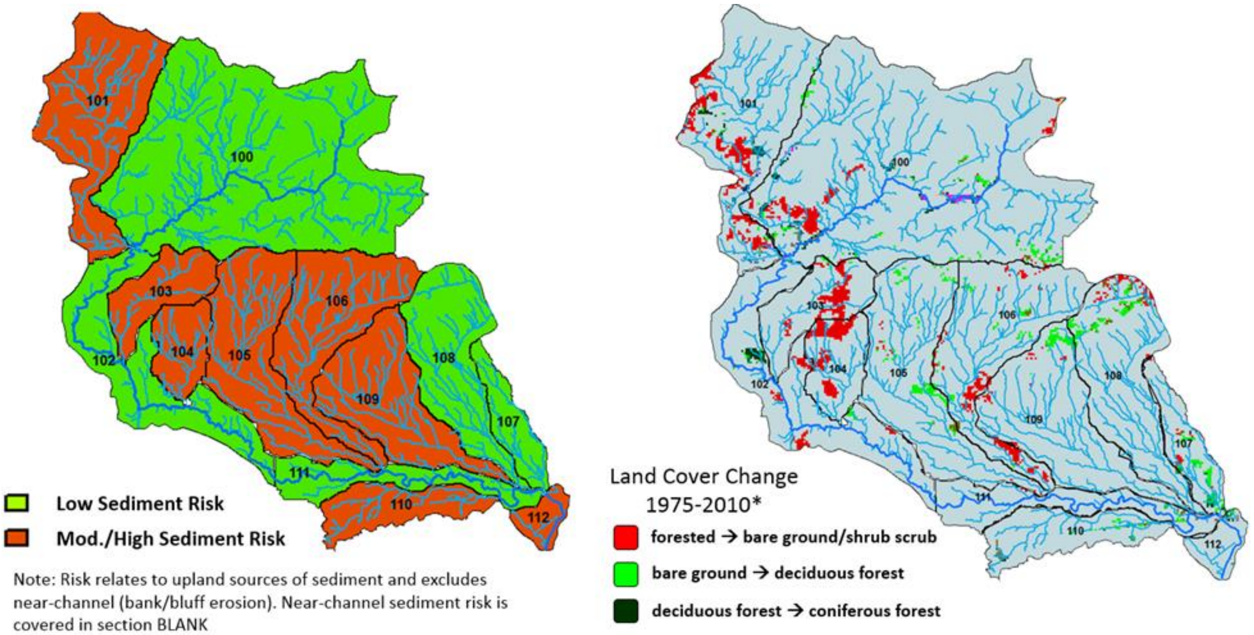
**Figure 22. Active headcut on Flute Reed River tributary during high flow.**

## 4.4.7 Upland Sources – roads, timber harvest, and open lands

A modified version of the Reconnaissance Level Assessment (RLA) portion of the Watershed Assessment of River Stability and Sediment Supply (WARSSS) (Rosgen, 2006) was used to identify potential sub-catchments that may be contributing a disproportionately high or low volume of sediment to the Flute Reed River. Of the numerous land-uses are linked to increased sediment delivery, land-uses related to silviculture (forest management) and transportation networks (roads, driveways, trails) were identified for further analysis within the WARSSS RLA framework.

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. An extensive network of mostly gravel roads connects major roads 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 (Figure 23). Variables such as road material, slope, proximity to waterbodies, and ditching practices were also considered in assessing overall risk of sediment delivery. Road density statistics and overall risk of sediment delivery from roads by sub-catchment is summarized by sub-catchment in Figure 23. Proper management of road ditches is critical for minimizing sediment loads in moderate to highly developed watersheds (Figure 24).

Forest cover has been reduced in the Flute Reed Watershed due to timber harvest and residential development. Timber harvest is a dynamic land use variable and proves difficult to track as new areas are logged and others regenerate from old cuts. Geospatial data from the Coastal Change Analysis Program (C-CAP) from 1975 and 2010 were used to evaluate timber harvest and other development by Flute Reed River Sub-watersheds based on forest type and percent "bare ground". Changes in C-CAP land cover linked to timber harvest or other causes of forest cover loss are listed in appendix H. Forest cover loss over the 35-year span ranged from a minimum of 2% to a maximum of 22% (average = 6%) among the thirteen sub-catchments evaluated. The table in Figure 23 provides a summary and discussion of land cover attributes by sub-watershed and risk of sediment delivery stemming from timber harvest or other forms of forest cover loss (e.g. disease, storms, and fire).



Note: Risk relates to upland sources of sediment and excludes near-channel (bank/bluff erosion). Near-channel sediment risk is covered in section BLANK

** Based on Coastal Change Analysis Program (C-CAP) Land Cover Atlas*

| Stream Name | Sub-Watershed | Drainage Area ($mi^2$) | WARSSS Summary | WARSSS Result |
|---|---|---|---|---|
| Tributary to Flute Reed R. | 100 | 4.1 | • Low road density (0.97%) and percent bare ground (3%)<br>• High percentage of wetlands, low gradient, abundant beaver dams<br>• **Dominant Stream Types:** E, C **Dominant Valley Types:** X, II | **RLA OK** |
| Tributary to Flute Reed R. | 101 | 1.4 | • Low road density (0.87%), but high % bare ground (10%) due to logging<br>• High percentage of wetlands, low gradient, heavily logged in lower ½<br>• **Dominant Stream Types:** E, C **Dominant Valley Types:** X, V | **Advance to RRISSC** |
| Flute Reed River | 102 | 1.3 | • Low road density (0.63%) and percent bare ground (3%)<br>• High % evergreen forest (36%), heavily forested (90%); some headcuts on tributaries evident<br>• **Dominant Stream Types:** C3, B3, E4, B3c **Dominant Valley Types:** X, V, VIII | **RLA OK** |
| Tributary to Flute Reed R. | 103 | 0.5 | • Moderate road density (1.66%); high bare ground (15%) – logging/ development<br>• Roads/logging activity in close proximity to stream corridor; headcuts observed<br>• **Dominant Stream Types:** C3, B3 **Dominant Valley Types:** V, X, II | **Advance to RRISSC** |
| Tributary to Flute Reed R. | 104 | 0.4 | • Moderate road density (1.16%); very high bare ground (22%) – logging/development<br>• Roads and forest clearing along steeply sloped streams; highest % logged in basin<br>• **Dominant Stream Types:** B, C, A, G? **Dominant Valley Types:** V, VIII, VII | **Advance to RRISSC** |
| Tributary to Flute Reed R. | 105 | 1.3 | • Moderate overall road density (1.82%) in sub-watershed, but high density in lower 1/2<br>• Relatively high % of land in "developed, moderate intensity" land-cover class<br>• **Dominant Stream Types:** C3, B3, E3/6, A/G? **Dominant Valley Types:** V, VII | **Advance to RRISSC** |
| Tributary to Flute Reed R. | 106 | 1.2 | • Low road density (0.53%); relatively high % bare ground (6%) due to logging/development<br>• Lower 1/3 of sub-watershed is highly altered from beaver activity and localized logging<br>• **Dominant Stream Types:** C5, E4, B3, A/G **Dominant Valley Types:** V, VII | **Advance to RRISSC** |
| Tributary to Flute Reed R. | 107 | 0.4 | • Low road density (0.86%) and percent bare ground (3%)<br>• Significant logging in the lower 1/3 of the sub-watershed in late 1980's<br>• **Dominant Stream Types:** B, C **Dominant Valley Types:** V, | **RLA OK** |
| Tributary to Flute Reed R. | 108 | 1.1 | • Lowest road density in Flute Reed basin (0.37%); low % bare ground (2.97%)<br>• Little to no evidence of logging in last 25 years<br>• **Dominant Stream Types:** C, B, A, E, G? **Dominant Valley Types:** V, VII, X | **RLA OK** |
| Tributary to Flute Reed R. | 109 | 1.1 | • Moderate road density (1.48%); relatively high % bare ground (6%) due to logging/ development<br>• Large clear cut (approx.. 38 acres)/roads appear in upper 1/2 of watershed in early 2000's<br>• **Dominant Stream Types:** B, C, G? **Dominant Valley Types:** V, VII | **Advance to RRISSC** |
| Tributary to Flute Reed R. | 110 | 0.5 | • Relatively high road density (2.72%); land cleared for logging is minimal<br>• Ditches along gravel road are source of sediment; multiple constructed impoundments on tributaries<br>• **Dominant Stream Types:** C, B, E **Dominant Valley Types:** V, VIII, X | **Advance to RRISSC** |
| Flute Reed River | 111 | 0.6 | • Low to moderate road density (1.19%); low % bare ground (1.57%);<br>• Highest % evergreen forest in drainage (40%) → fairly undisturbed riparian corridor<br>• **Dominant Stream Types:** C4, B3 **Dominant Valley Types:** V, VIII | **RLA OK** |
| Flute Reed River | 112 | 0.2 | • High road density (4.91%) and highest rate of land development in the Flute Reed drainage<br>• Channel mostly bedrock →resilient to disturbance; potential sediment input from ditches/runoff<br>• **Dominant Stream Types:** B2, A1 **Dominant Valley Types:** V, I, II | **Advance to RRISSC** |

**Figure 23. Maps of WARSSS RLA results for the Flute Reed River Watershed (upper left) and land-cover change based on C-CAP Land Cover Atlas data from 1975 and 2010 (upper right). The table provides summaries and final WARSSS result for each of the sub-catchments evaluated.**

### 4.4.8 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 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 zone, a high rate compared to the other two watersheds evaluated (Durfee Ck. = 3%; Reservation R. = 17%) (Table 9). 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. Impoundments created by beaver dams allow suspended sediment to settle to stream bottom, but disturbance from high flow events or catastrophic dam failure quickly re-suspends fine sediments like those that dominate much of the Flute Reed Watershed. Visual observations completed during field assessments revealed that turbidity levels often increased within and downstream of beaver dams (Figure 25). Although beaver impoundments are effective at trapping sediment, the clay and fine silt particles trapped behind many of the dams in the Flute Reed Watershed are easily re-suspended when disturbed, and create a nearly year-round potential of reducing water clarity.

**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. GLD = Glacial Lake Duluth boundary**

| WATERSHED | BEAVER DAM COUNT | BEAVER DAM DENSITY (DAMS/STREAM MILE) |
|---|---|---|
| **FLUTE REED UPSTREAM OF GLD** | 79 | 4.7 |
| **FLUTE REED WITHIN GLD** | 48 | 1.9 |
| **DURFEE CREEK UPSTREAM OF GLD** | 28 | 2.7 |
| **DURFEE CREEK WITHIN GLD** | 1 | 0.2 |
| **RESERVATION RIVER UPSTREAM OF GLD** | 76 | 1.7 |
| **RESERVATION RIVER WITHIN GLD** | 16 | 0.9 |

**Figure 24. (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 25. 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.**

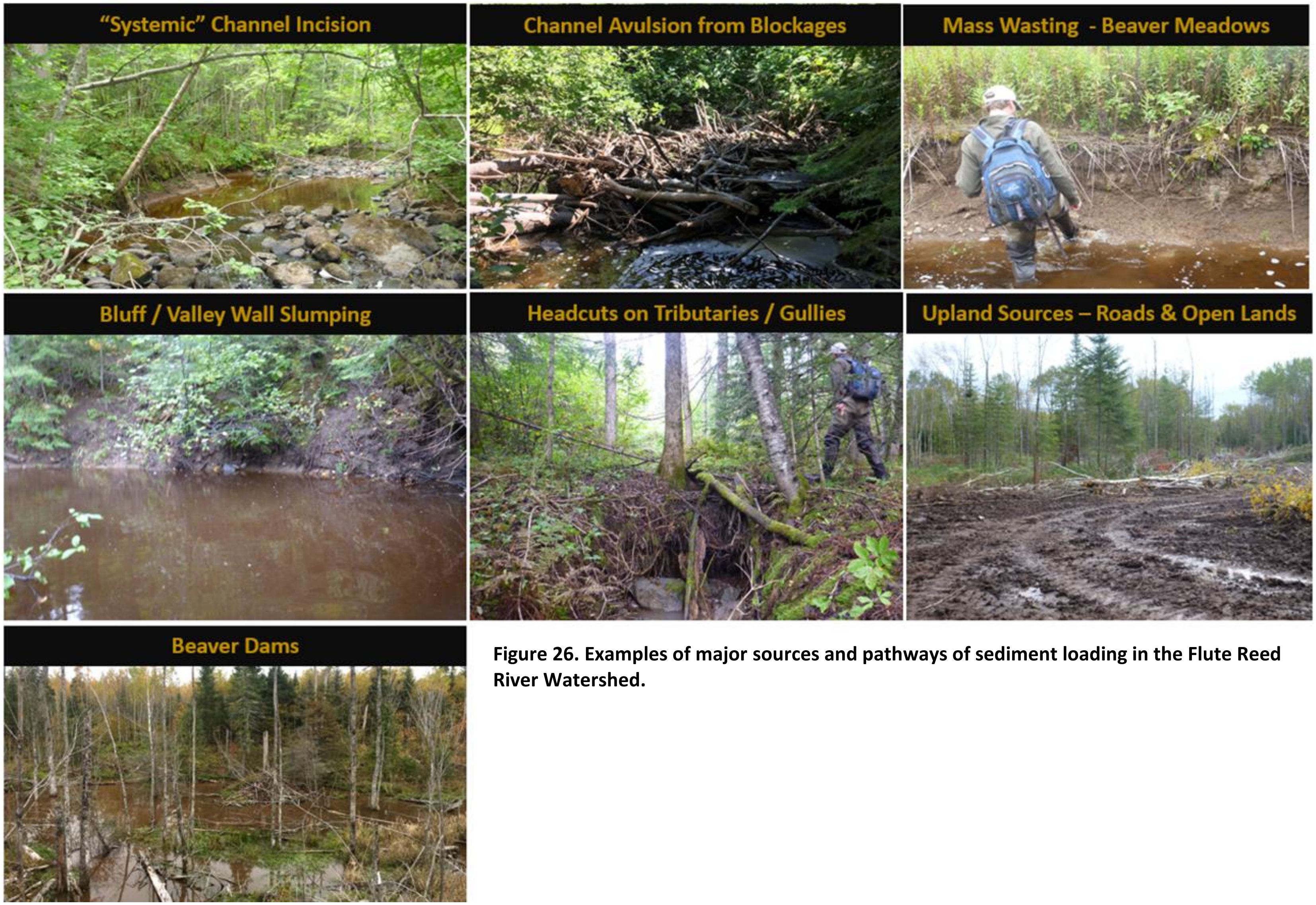


**Figure 26. Examples of major sources and pathways of sediment loading in the Flute Reed River Watershed.**

## 4.5 Biological response to elevated TSS concentrations

### 4.5.1 Fish community response to TSS

Fish community tolerance indicator values (TIV) are not strongly correlated with TSS results in the Flute Reed River Watershed. 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. Similarly, TSS concentrations do not show a strong correlation to coldwater fish IBI scores. The highest fish IBI scores 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. The lack of a stressor gradient linking high TSS concentrations with a more tolerant fish assemblage is likely an indicator that other stressors are more influential in limiting biological integrity in this watershed. Confounding stressors, likely water temperature, lower DO concentrations, and/or low streamflow, are contributing to the dominance of moderately tolerant species such as Creek Chub at station 13LS038 and falsely indicate a TSS-stressor response.

Fish TSS TIV were lower (more TSS intolerant species) at station 13LS027 due to a population naturally reproducing Rainbow Trout sampled at this monitoring station. Only two species were sampled at this station in 2014 (Rainbow Trout and Creek Chub) with numbers were evenly distributed between the two. Fish community TIV results for this station remain higher (more TSS tolerant) than the majority of the high quality reference stations within the Lake Superior North and South Watersheds (Figure 27). TSS concentrations frequently exceed the 10 mg/L water quality standard by a large margin during moderate to high streamflow conditions, but are often at or below the standard during low to moderate flows. Successful reproduction of Rainbow Trout in this reach is an indicator that the short duration spikes in TSS concentrations are not severe enough to eliminate all sensitive coldwater fish taxa.

### 4.5.2 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 28). 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 site. 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 29). 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 closely related to increasing TSS concentrations in this watershed. 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 favorable results, the Flute Reed River was not listed as impaired for MIBI despite frequent exceedances of the TSS water quality standard.

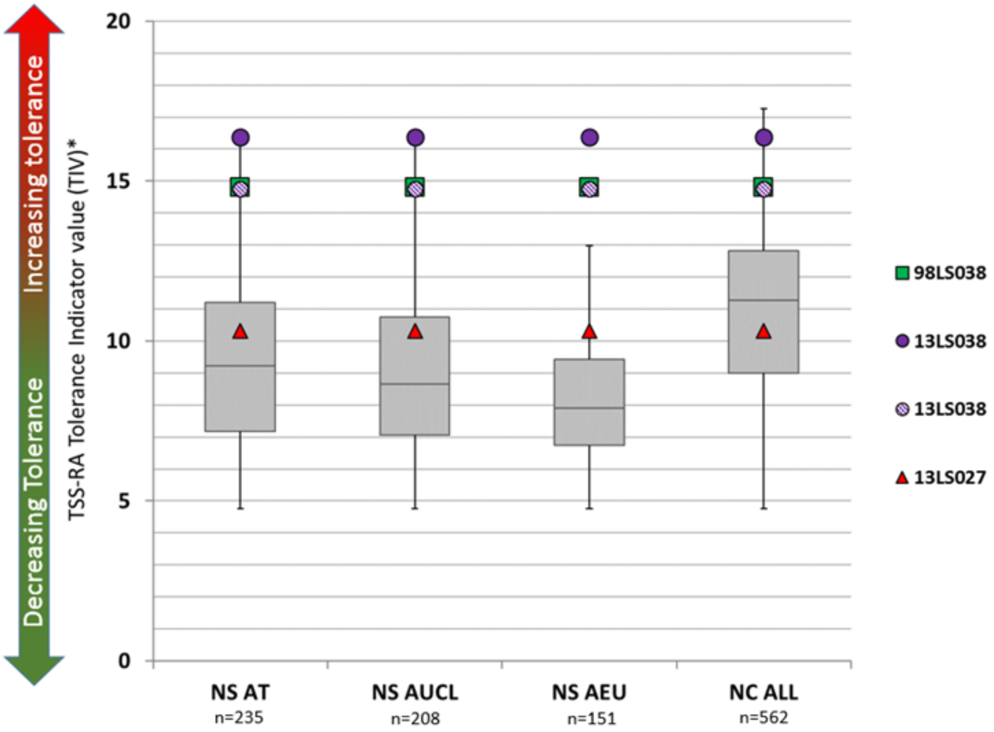


**Figure 27. Fish Tolerance Indicator Values (TIV) at Flute Reed River biological monitoring stations compared to distribution of results from comparable high quality reference stations.**

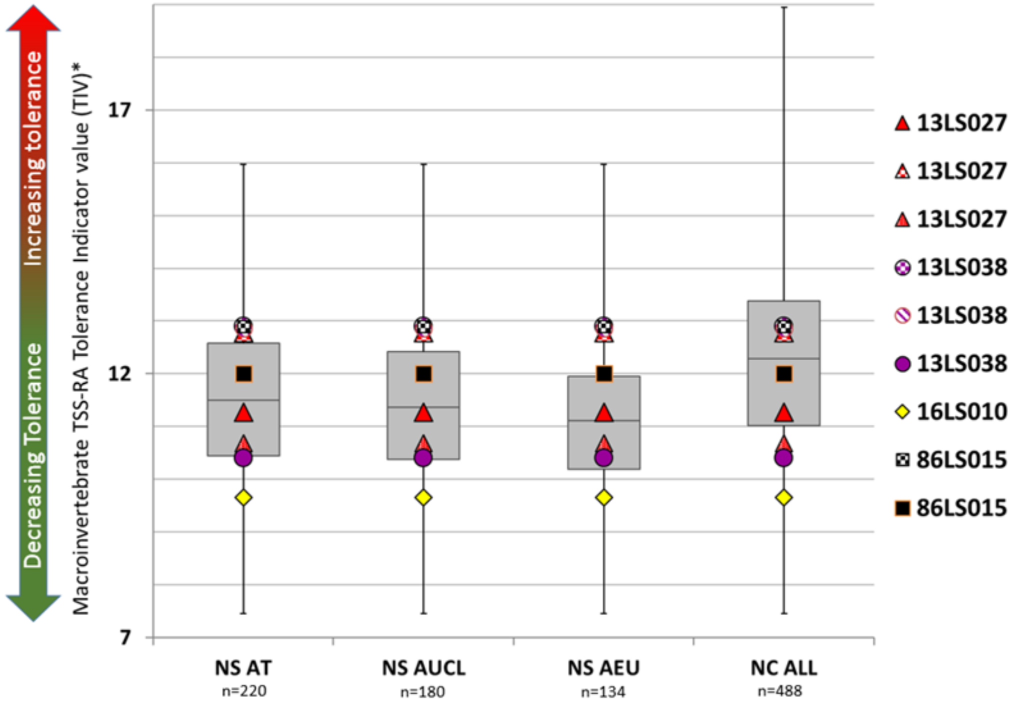


**Figure 28. Macroinvertebrate Tolerance indicator Values (TIV) for TSS at Flute Reed River biological monitoring stations compared to results from comparable high quality reference stations. Several stations have multiple sampling visits -- symbols in graph were changed slightly to indicate separate visits.**

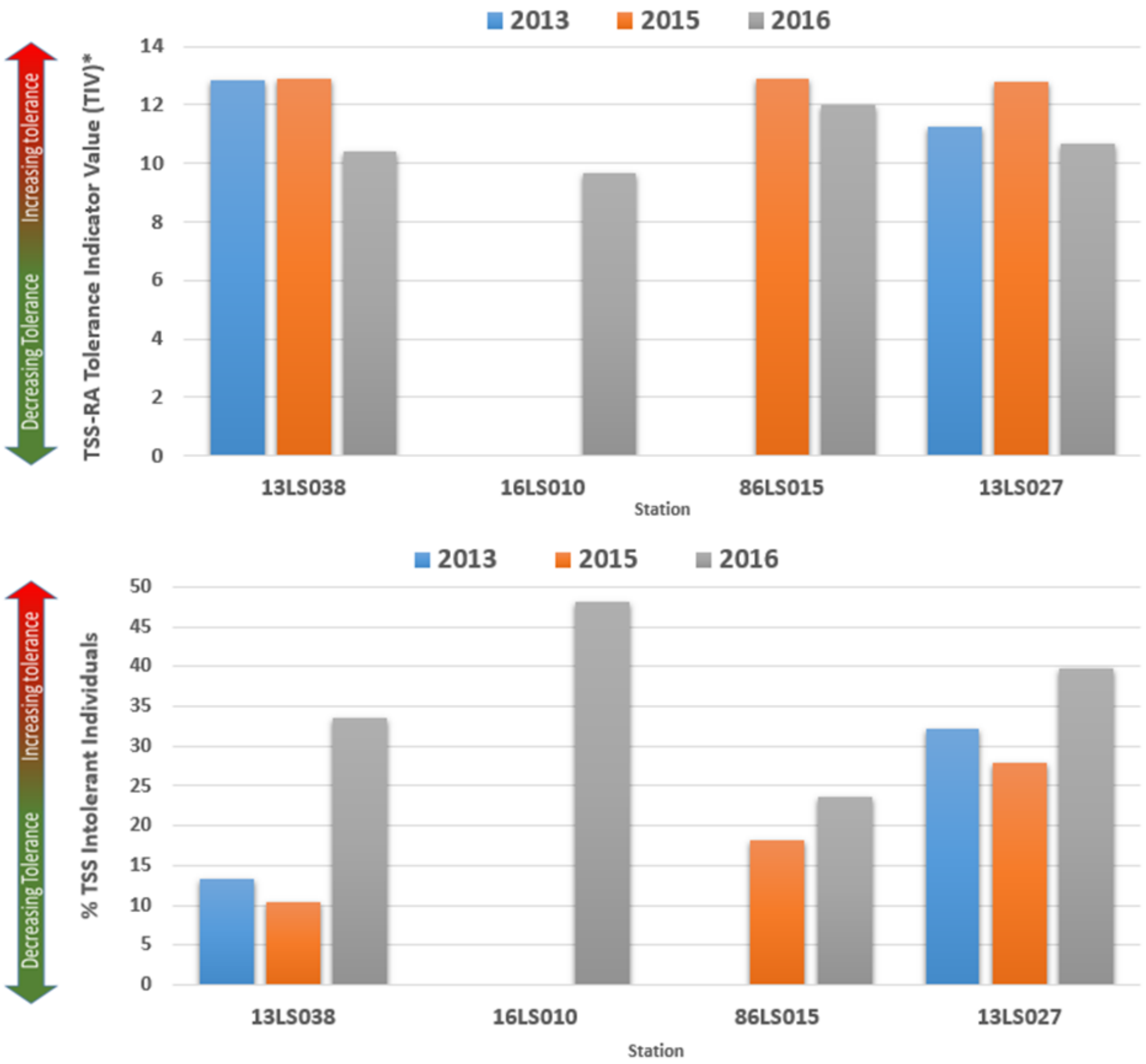


**Figure 29. Macroinvertebrate Tolerance Indicator Value (TIV) and percentage Tolerant Individuals related to TSS for Flute Reed River monitoring stations.**

## 4.6 Habitat quality

The Brook Trout Suitability Assessment (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 31). 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 30, 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 30, 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 (Figure 30, right photo). 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 30. 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.**

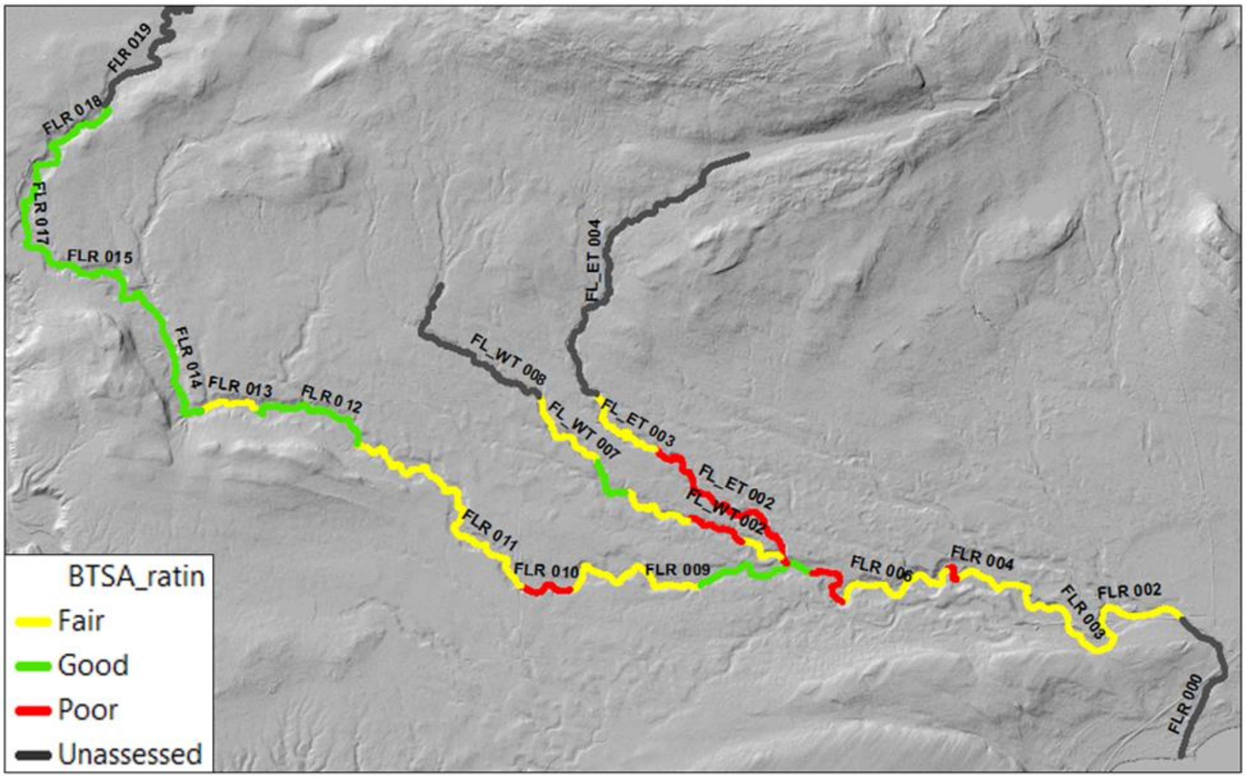


Figure 31. Map of BTSA ratings for Flute Reed River and major tributary streams.

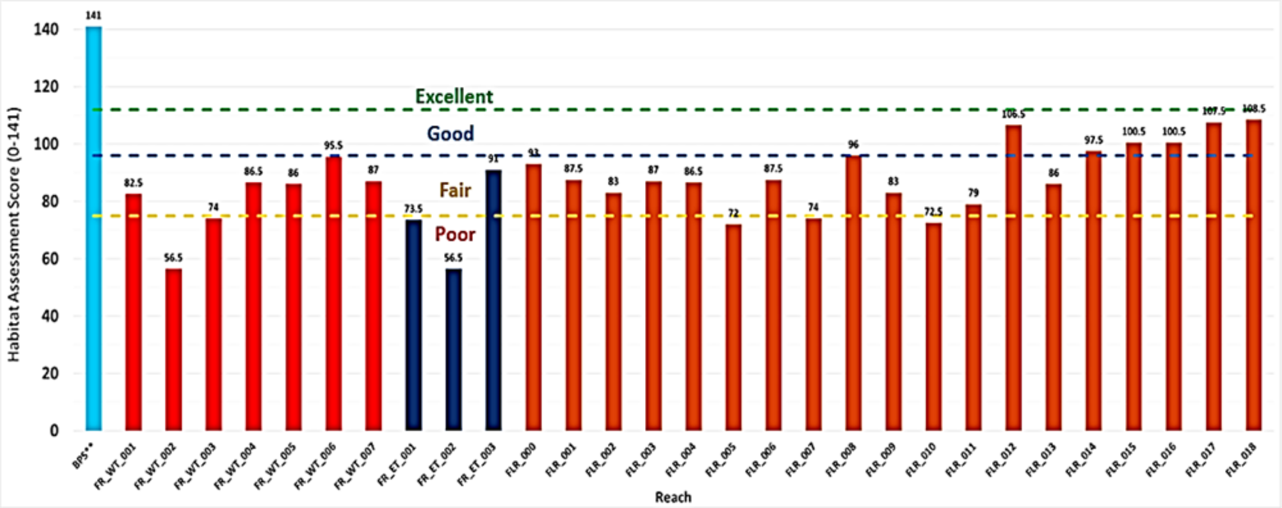


Figure 32. Overall BTSA scores for Flute Reed River (FLR_--- orange columns), West Tributary to Flute Reed (FR_WT--- red columns), and East Tributary to Flute Reed (FR_ET_--- blue columns). ** "BPS" = Best possible BTSA score (141).

## 4.7 Barriers to fish migration

### 4.7.1 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 a river's course. Three main criteria were used to identify culverts as partial or full barriers to fish passage - current velocity, absence of natural substrate within the crossing, and outlet perch height. The DNR crossing assessment form used for data collection is included in Appendix A. All culvert/bridge assessment points in the Flute Reed River Watershed are mapped in Figure 34, and the complete assessment results are included in Appendix B.

Of the thirteen crossings evaluated, six were span bridges, with all but one in 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. The bridges are properly aligned with the pattern, profile of the river, and do not have any negative effects on stream stability or aquatic organism passage.

The remaining seven crossings assessed are culverts. Two are located on the main stem of the Flute Reed River and five are on unnamed tributaries. The two main stem crossings are along County Road 70 (Camp 20 Rd) at RM 4.1 and RM 8.0. The culverts at both of these locations are 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 absent from culverts at both Camp 20 Rd crossings. An outlet drop of 0.25' to water surface was observed at the RM 4.1 crossing (Figure 33), 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 4.1 and 8.0 are priorities for replacement. The crossing at 4.1 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 4.1 and beyond.

**Figure 33. 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 of the Flute Reed River does not appear to be reduced due to roads and culverts based on our assessment. Some of these culverts may be providing grade control and thus protection against headcuts advancing up tributary streams. It is critical that each crossing be evaluated in this context before replacement occurs, and if culverts are replaced, proper grade control is installed.

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.

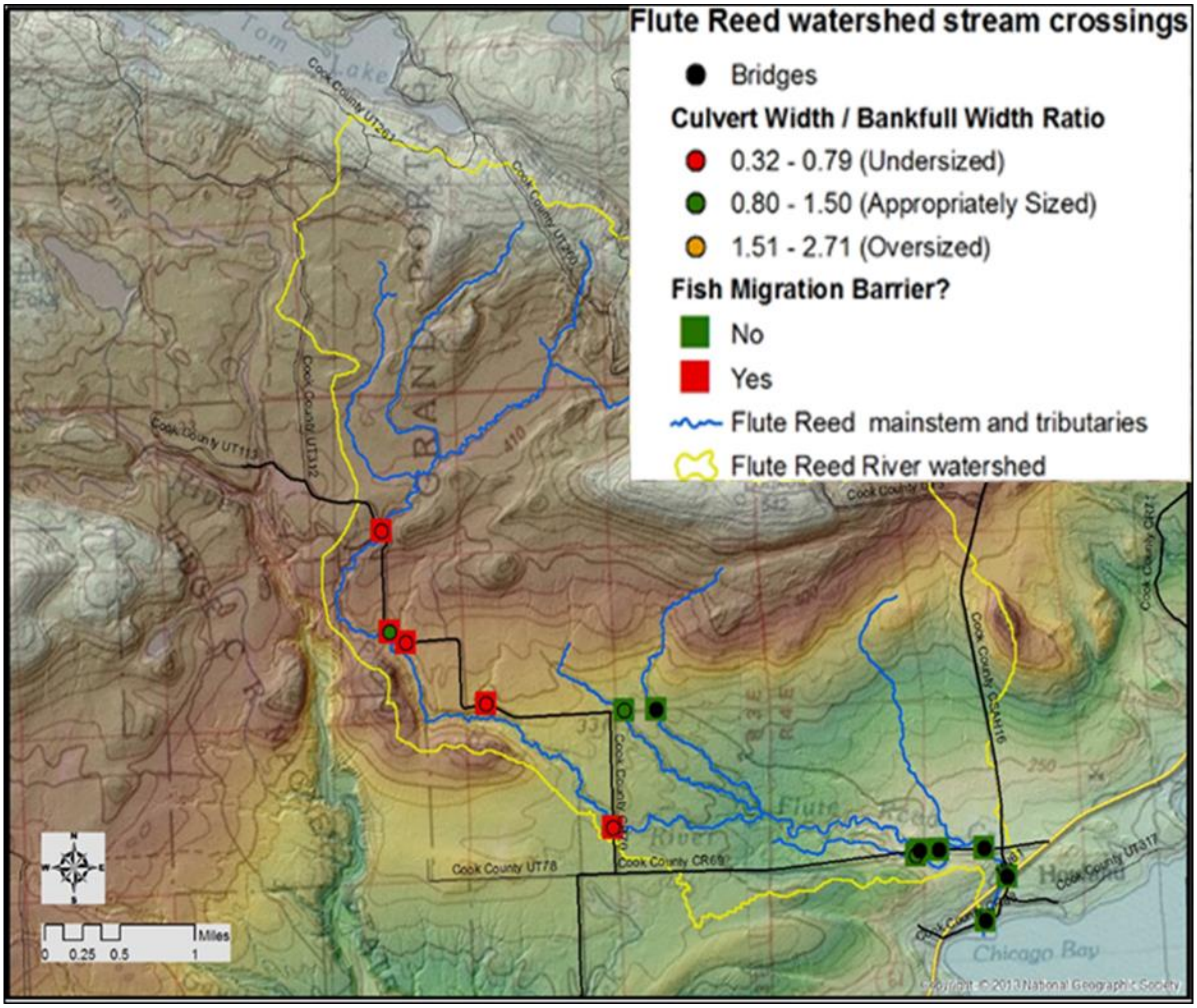


**Figure 34. Culvert sizing and fish migration barrier assessments for crossings in the Flute Reed River Watershed**

## 4.7.2 Beaver dams

The ability to migrate both upstream and downstream is essential. Species spawning in the spring season (e.g. Steelhead Rainbow Trout) often can often navigate beaver dams (Rasmussen, 1941; Grasse, 1951), but autumn spawners (e.g. Brook Trout) can be blocked during low-flow conditions when the dams are intact (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).

Non-game species, such as dace and darters, also need to migrate between deeper water habitats for winter refugia and back again to smaller, shallower habitats to spawn and feed during the spring and summer months. Beaver dams can block these migrations and thus exclude or contain these species in isolated reaches, making them more susceptible to drought, winterkill, and/or predation from larger species.

Beaver dams were abundant in the Flute Reed River compared to other streams along the North Shore (see Table 9). No specific biological 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 decisions regarding beaver impoundments, as their impacts on fish communities, physical habitat, and water quality can vary widely.

## 4.8 Water temperature

### 4.8.1 Review of water temperature data

Continuous water temperature data are available for several Flute Reed River monitoring stations dating back to 2011. 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 aquatic species requiring cold water. All temperature monitoring locations are shown in Figure 11 and summary statistics from all monitoring years are included in Appendix I.

Most reaches of the Flute Reed River possess 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°C and 19.5°C, with 25-35% of summer temperature readings exceeding the “stress” threshold for Brook Trout (>20°C). The warmest temperatures in the watershed are typically observed at RM 6.7, which is located downstream from numerous beaver impoundments. Most Flute Reed stations fall into “Area 2” on the scatter-plot (Figure 35), 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 35).

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% (Figure 35). Summer average temperature near Tom Lake Rd were approximately 2°C colder than all other stations monitored in 2016 (Figure 36). 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). 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 36). 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; Hudy et al., 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 two anthropogenic sources likely contributing to warmer water temperatures.

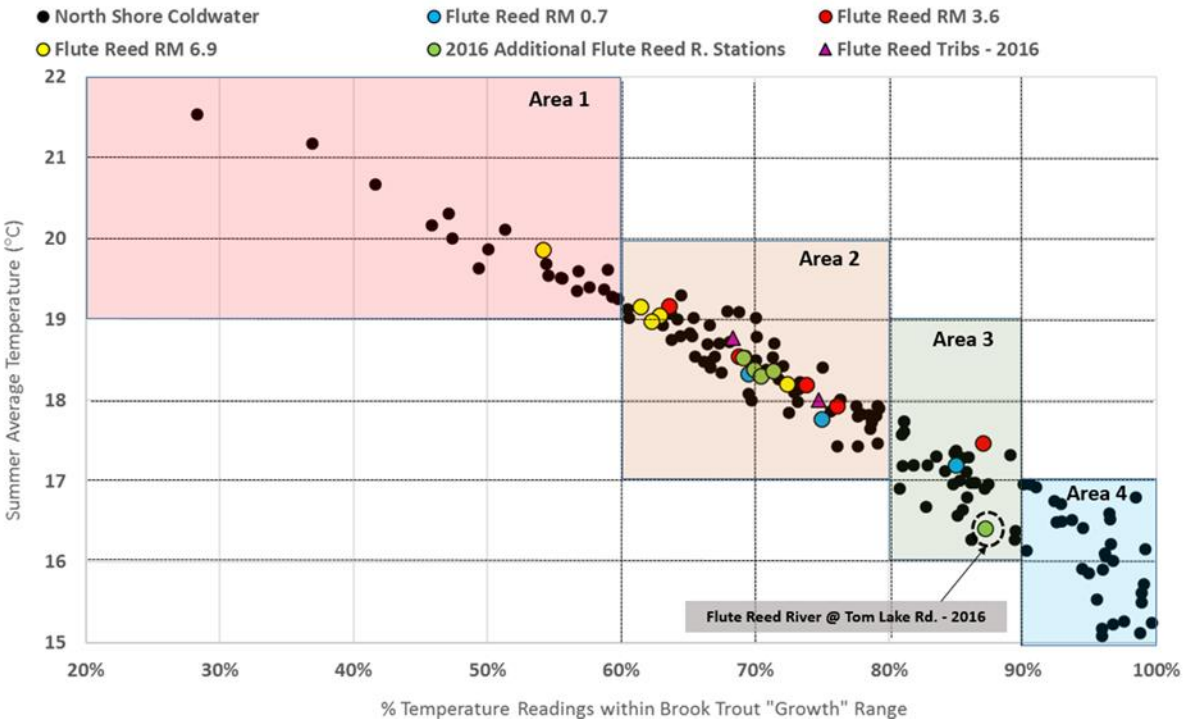


**Figure 36. Plot of Summer Average Temperature vs. percentage Time in Brook Trout temperature growth range. Flute Reed monitoring stations are shown in colored markers, while all other North Shore coldwater stations are shown as black markers. Temperature "areas" are discussed further in section 3.1.**

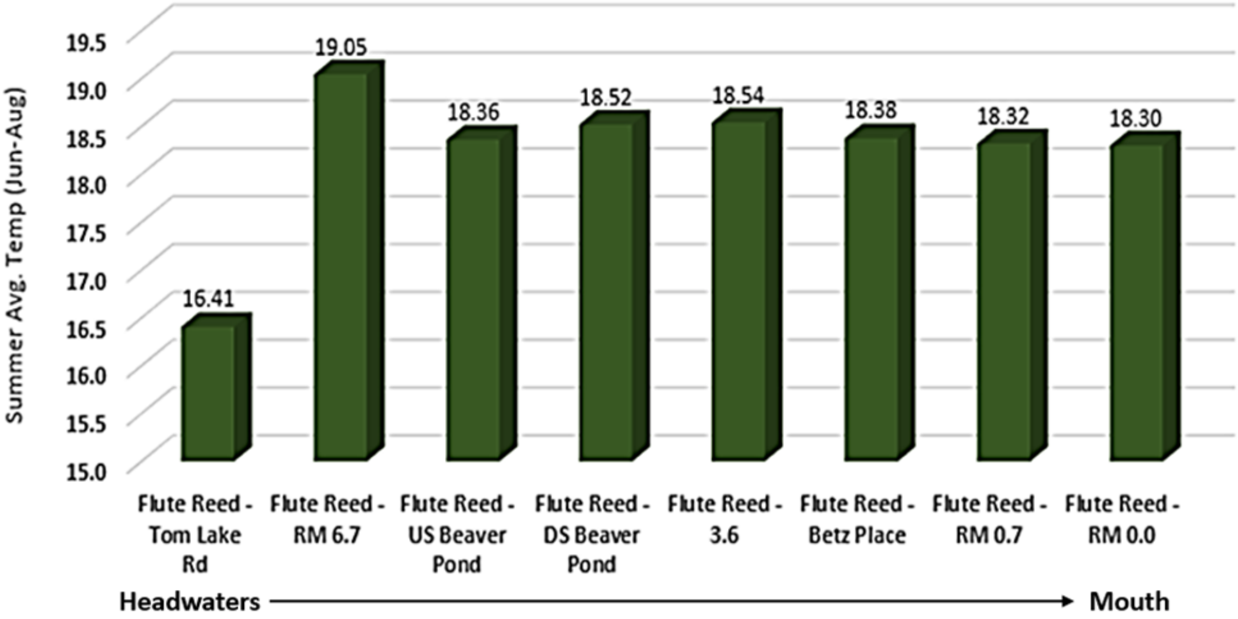


**Figure 35. A summary of average water temperatures in the Flute Reed River Watershed over the 2016 monitoring season.**

## 4.8.2 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, coldwater species Slimy Sculpin and Longnose Dace have also been sampled on rare occasions at RM 0.0 (mouth) of the Flute Reed. These two species have not been observed at any other station, so their presence at RM 0.0 is likely due to the proximity of this station to Lake Superior as opposed to conditions in the Flute Reed River itself.

The proportion of coldwater to warmwater 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 only 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 where water temperatures are much colder.

Fish migration barriers in the lower Flute Reed River (e.g. perched and undersized road culvert at Camp 20 Rd and numerous beaver dams) may 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 do not differ significantly from the lower river, which supports a wild Rainbow Trout population. 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 Rainbow Trout, and other coldwater species such as sculpin and longnose dace if present.

### Macroinvertebrate community and water temperature

Macroinvertebrate data are available for four stations in the Flute Reed River Watershed; 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 37). A lower proportion of coldwater individuals was observed at all stations in 2015 compared to the 2016 results, particularly 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 37).

At best, a weak relationship is present between water temperatures and the relative abundance of coldwater macroinvertebrate individuals and taxa within the Flute Reed Watershed. The thermal regime at nearly all Flute Reed stations can be classified as marginal coldwater and the macroinvertebrate community does not show a consistent pattern or split between 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 that offer more favorable thermal regimes for coldwater biota (Figure 38). This may be because coldwater macroinvertebrate taxa, in general, can tolerate slightly warmer water temperatures than sensitive coldwater fish, such as Brook Trout.

MIBI scores within the Flute Reed River Watershed all indicated full-support of aquatic life standards, and 7 out of 9 MIBI results meet the exceptional use criteria. Elevated water temperature does not appear to be a limiting factor for coldwater MIBI results in the Flute Reed River 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 |

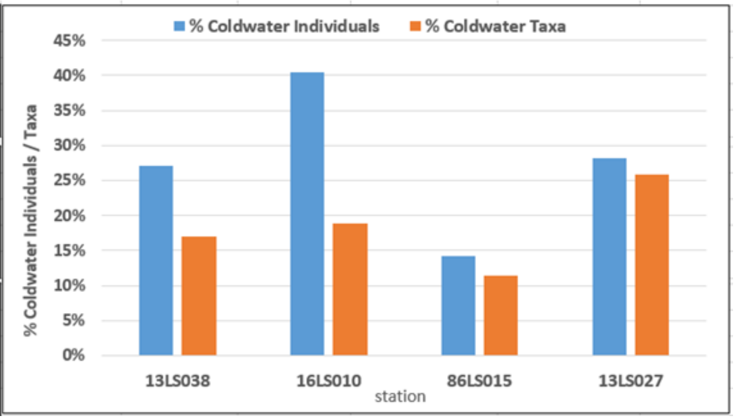


**Figure 37. Percent coldwater macroinvertebrate individuals (pct_CW), percent coldwater macroinvertebrate taxa (pct_CW_TAXA), and drainage area for Flute Reed River biological monitoring stations sampled in 2013, 2015, and 2016.**

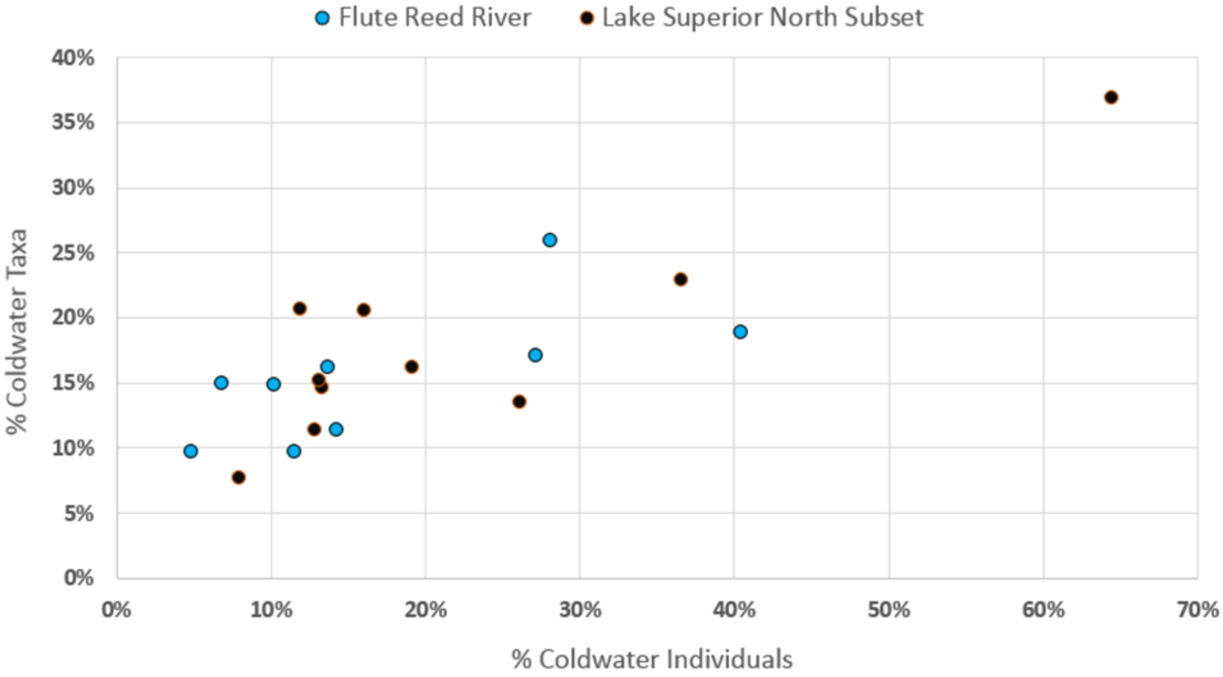


**Figure 38. Scatter-plot of percentage coldwater taxa and percentage coldwater macroinvertebrate individuals for Flute Reed River and a subset of non-impaired, high quality Lake Superior North streams (Woods Creek, Kimball Creek, Devil Track River, Poplar River, Heartbreak Creek, Two Island River, Fiddle Creek, Irish Creek, Little Devil Track River, and Caribou River). Results are comparable between the two groups aside from the outlier (Kimball Creek) in the Lake Superior North subset.**

## 4.9 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 (sample station FR 12 in Figure 39). 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 39.

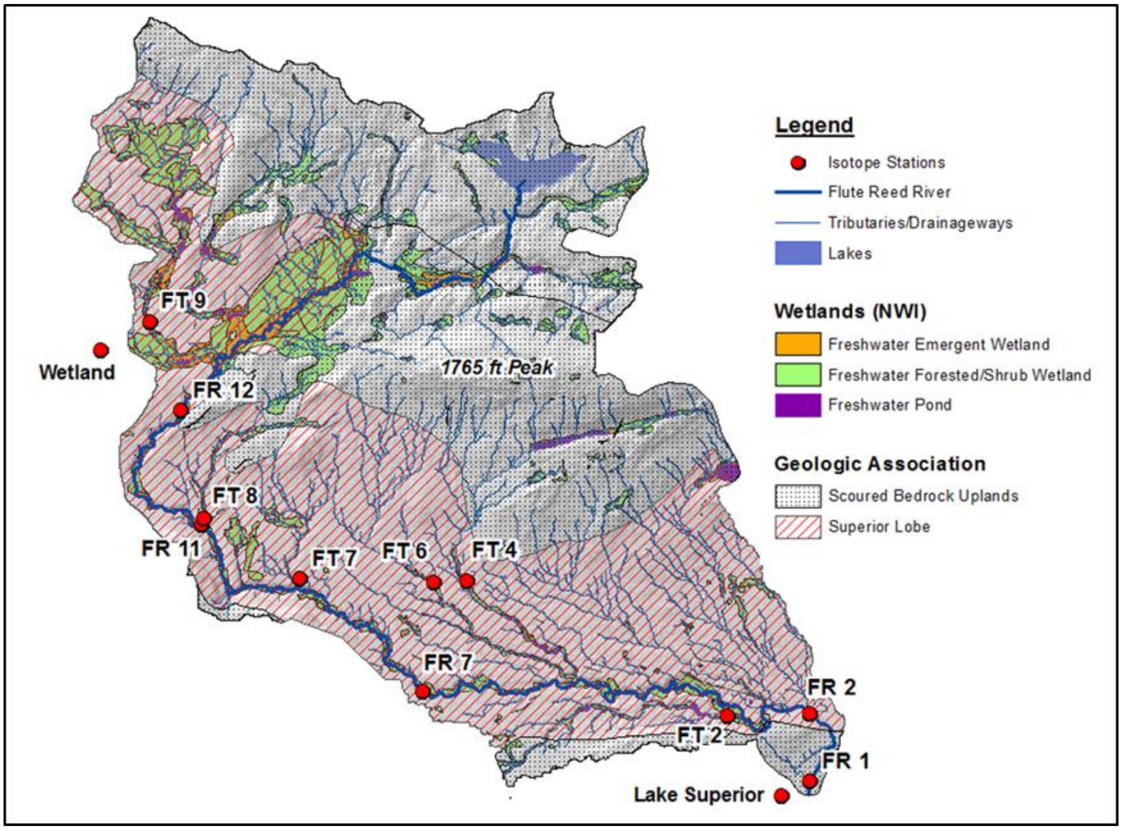


**Figure 39. Flute Reed River Watershed, hydrologic and geologic features, and isotope sampling stations.**

### 4.9.1 Geology

The Flute Reed Watershed landscape is dominated by rolling till plains of the Superior lobe and scoured bedrock terrain (Figure 39). 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 (FT 4) to the Flute Reed River. Another bedrock ridge extends laterally along the northern boundary of the watershed and smaller knobs at slightly lesser elevations are found in the upper drainage; these too drain to headwater wetlands and tributaries to the Flute Reed River. Tributaries are scattered throughout the watershed, but lower watershed tributaries lack the wetland connectivity present in the headwaters.

## 4.9.2 Flow duration curves and stream flashiness

A stream gage (Gage: 01015001 on CR69 - North Road, Hovland Minnesota) was operated from July 2013 to present, reporting water level and discharge. Daily flows range from less than 0.5 cfs to approximately 700 cfs during the gaged period. Flows greater than 300 cfs were estimated; they occurred during 2014, 2015, and 2016, and were isolated to snowmelt and large rain events. Flow records for this gage 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 60% and 40% of the time respectively, as shown in the flow duration curve (Figure 40). 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 (Figure 40). 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 curve groups with flashier streams including Amity Creek and Talmadge River. Similar drainage attributes such as watershed area, narrow elongated shape, and lake and wetland surface area may explain stark similarities in flow magnitude and flashiness between Flute Reed River and Amity Creek. The flat extension of the Flute Reed River duration curve in the 90th to 100th exceedence interval compared to Amity Creek and Talmadge River suggests more capacity to sustain flow during extreme low flow periods. More details on Flute Reed River flow sources during low flow dry conditions is found in the isotope section which follows.

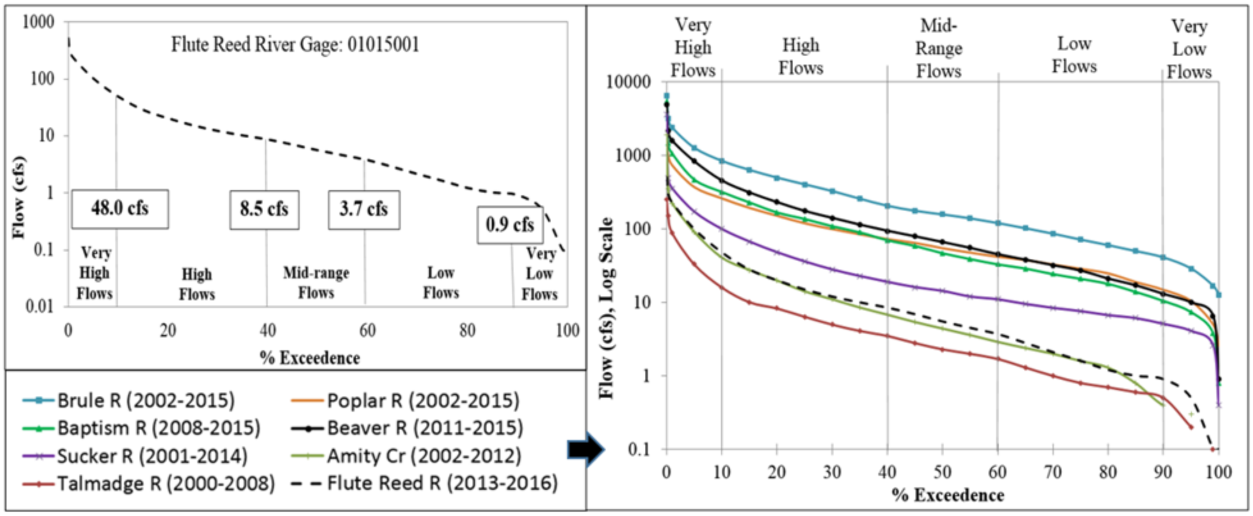


**Figure 40. (Left) Flow Duration Curve for the Flute Reed River, identifying five flow regimes based on data from 2013-2016. (Right) Comparison of the Flute Reed River flow duration curve to other North Shore of Lake Superior Streams based on flow gage records for the site-specific periods specified in the bottom left. The Flute Reed curve plots with flashy and lower flow-magnitude streams along the North Shore including Talmadge River and Amity Creek.**

## 4.9.3 Watershed isotope characterization

Detailed discussion on the application and methods of isotopic analysis of oxygen-18 ($\delta^{18}O$) and deuterium ($\delta^2H$) in hydrologic applications are located in Section 3.6 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; and has been interpreted as a signal of groundwater that has been seasonally well mixed.

### 4.9.4 Local Meteoric waterline for the Grand Marais/Hovland Area

Precipitation monitoring volunteers and MPCA staff collected rain and snow samples in the Lutsen and Hovland, Minnesota, area in years 2015 and 2016. Only samples that filled to the neck of the collection bottles were used to develop a LMWL ($\delta^2H = 7.6\ \delta^{18}O + 6.8$; $r^2 = 0.99$); eight rain and seven snow samples were used. 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 LEL ($\delta^2H = 5.19\ \delta^{18}O – 21.2$; $r^2 = 0.97$) was developed using samples from six Flute Reed River Watershed stream stations, a regional wetland, and Lake Superior; samples were collected in late summer (August 2016). Late summer samples were used because this is typically when evaporative loss signals in surface water sources (lakes, wetlands, and depressions) are observed regionally; as was confirmed in this dataset.

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 for precipitation. If the lake or aquifer is a primary flow source to receiving streams, the stream water will reflect this signal. Precipitation driven shallow lakes, 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).

### 4.9.5 Stream isotope sample collection

Stream isotope samples were collected from the Flute Reed River gage station (FR 2) and a headwater station (FR 12) 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 2017. Additionally, in August of 2016, samples of stream baseflow were collected at eleven stream stations, the bank seep, Lake Superior, and a wetland located just outside the boundary of the upper Flute Reed River Watershed; sample collection locations are identified in Figure 39. 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 $^2H$.

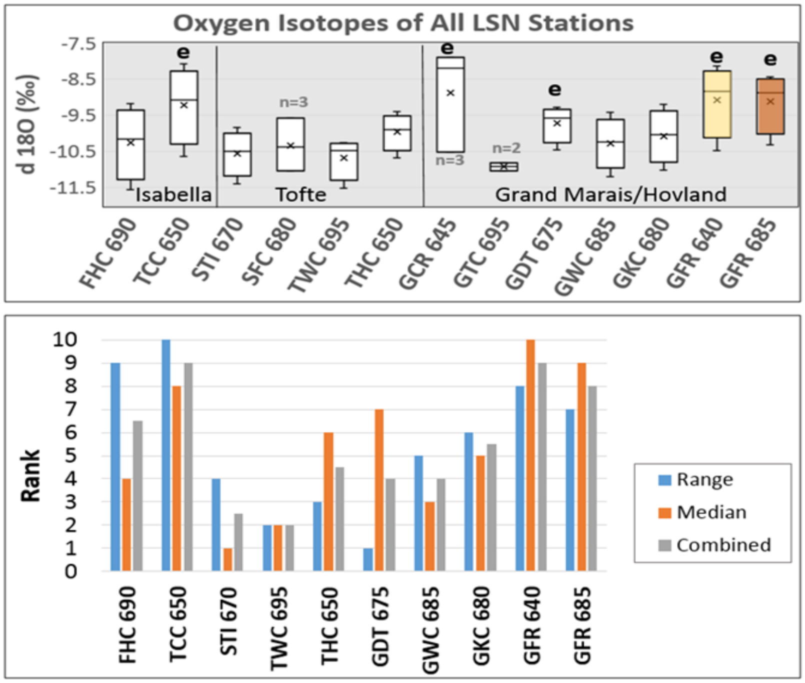
During the 2015 sampling season, samples were collected from 13 stream reaches across the Lake Superior North Watershed including Flute Reed stations FR 2 and FR 12. Elevation and geology of stream reaches varied as sample sites were located both near Lake Superior and at higher-elevation, inland locations. Samples were collected four times during the 2015 season; near-baseflow conditions were targeted. Sample dates were compared to the Flute Reed hydrograph. 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 0.9-2.0 cfs, with no very high flow events occurring within a few weeks prior to each sampling. Flow volume was 3.9 cfs for the June sample date which is a mid-range value; streamflows at the time were receding from a very high flow event that occurred one week prior to sampling. A range of flow levels were selected for isotope sampling in the 2016 and 2017.

### 4.9.6 Isotope signal variability along the North Shore

Understanding isotope signals and the related hydrologic processes in other regional streams is important in data interpretation of the Flute Reed Watershed, our primary study focus. Defining source waters that sustain flow in North Shore streams is important for managing coldwater species, especially during critical dry summer periods when flow and temperature may be limiting dispersal and survival. 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 (Figure 41). We sampled the majority of the stations four times during 2015; however, three stations had less than four samples: Fredenberg Creek, Cascade River and Thompson Creek. The number of samples collected for the three sites is specified in Figure 41. The letter ***e*** was placed above the box plot in Figure 41 for stations where evaporative losses in stream isotope samples were identified in two or more samples. Ten stream stations were sampled at least four times; they were ranked against each other based on the range (maximum minus minimum) and median oxygen isotope values. Then, for each site, a combined rank value was calculated by averaging the two rank values of range and median (Figure 41).

The ranking results of median and range for isotope signals show variability in stream source waters across the Lake Superior North watershed; and identify several streams with relatively strong groundwater contributions. A low-ranked (small) range in stream isotope signals indicates the presence of dominant source waters that have the capacity to hold water for over a season. Source water type (e.g. lake or aquifer) can be interpreted through analysis of median distribution (low rank = values closer to the inflow value) and signs of evaporative loss in the isotope. These data show that Devil Track River, Wanless Creek, Heartbreak Creek, Two Island River, and Woods Creek have the tightest oxygen isotope ranges (lowest range rank) in our dataset. This indicates a dominant flow source or greater water storage capacity in these watersheds.

In addition to a low range rank, Two Island River, Wanless Creek, and Woods Creek had the lowest median values; all within the range of groundwater signals observed in the study and had no signs of evaporative loss. This indicates that groundwater is a dominant flow source to these streams. Fredenberg 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. Based on the data collected and regional location, we suspect groundwater is also a dominant source in Fredenberg Creek, but more data is needed.



| **Stream** | **Station ID** |
|---|---|
| Hockamin Creek | FHC 690 |
| Cabin Creek | TCC 650 |
| Two Island River | STI 670 |
| Fredenberg Creek | SFC 680 |
| Wanless Creek | TWC 695 |
| Heartbreak Creek | THC 650 |
| Cascade River | GCR 645 |
| Thompson Creek | GTC 695 |
| Devil Track River | GDT 675 |
| Woods Creek | GWC 685 |
| Kimball Creek | GKC 680 |
| Flute Reed River<br>upper | GFR 640 (FR 12) |
| Flute Reed River<br>lower | GFR 685 (FR 2) |

**Figure 41. (Top) Oxygen Isotopes for LSN Streams collected in summer and fall of 2015. (Bottom) Ranking of range and median oxygen isotope values of LSN stream stations that had at least four samples collected in year 2015.**

### 4.9.7 Lake-fed streams

Our data infers that the Devil Track River stream station is highly influenced by Devil Track Lake; and groundwater inputs directly to the lake or connected stream reaches may be the source for the unique signal found at the stream station. We did not sample the lake itself, but the tight range (consistent signal across the season) at the downstream sample site indicates a dominant source of flow; and the evaporative signal indicates the source is surficial. An upstream source, Devil Track Lake, is a large lake (greater than 1800 acres in surface area) and deeper (max depth = 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 tributary confluence. The Devil Track River isotope signal range is tight and noticeably less evaporative than other lake-fed study rivers inferring that groundwater may play a role in providing this specific, moderately evaporative isotopic signature. At the sample location, major Coldwater tributaries that may have more groundwater influence such as Woods Creek and Little Devil Track River, located farther downstream, are not yet contributing flow. Woods Creek was identified in the preceding paragraph as a groundwater-dominant stream based on stream isotopes.

In contrast to the Devil Track River results, isotope data for other lake-fed streams including Cascade River, Cabin Creek, and Flute Reed River 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. A greater range in values, higher median values, and increased evaporative signals support this. In addition to lake inputs, groundwater springs are present in the Cascade River; as was field verified during the sample period. Thompson Creek, a tributary stream to Cascade River, had strong groundwater signals as was observed in the isotope data. Although Thompson Creek was only sampled twice, both samples had signals near the inflow value. One of those samples was collected in September, the month with the greatest evaporative losses (greatest deviation from the inflow value) seen in the greater LSN isotope sample dataset. Although lake and groundwater inputs are present near the Cascade River sample station, the isotope signals indicate that neither is a dominant source water year-round and that seasonal mixing dynamics are variable.

### 4.9.8 Source waters of the Flute Reed River

To better understand seasonal interaction between groundwater and stream water in the Flute Reed River Watershed, bank seep (soil water/groundwater) isotopes were compared to stream isotopes near the stream gage (FR 2) from 2016-2017 (Figure 42 and 43). The greatest correlation between stream and bank seep signals in 2016 were found in samples taken after high flow rain events of June and November 2016; and during the January to March winter season when stream channel is mostly covered in ice. Winter correlation reflects the dominant role groundwater plays in sustaining winter streamflow when freezing air temperatures limit infiltration and runoff processes. In contrast, rainstorm flow during the ice-free season was the hydrologic process driving stream and bank seep isotope values together. During the June event, both the stream and groundwater isotope signals changed by more than 1‰ indicating that both stream water and the soil/groundwater composition were altered by rainwater. During the late November event, streamflow showed a much larger change (-1.9‰) in isotope composition than the bank seep (-0.2‰). Prior to this late-fall rain event, air temperatures were below freezing for a week, which may have slowed infiltration processes.

The greatest discrepancy between stream water at FR 2 and bank seep isotope signals occurred during summer to early fall of the 2016 season, indicating a lack of surface water-groundwater connectivity during low flow periods. This is also suggested in the rank analysis (discussed in the previous two pages), as 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 variably-sourced throughout the summer season. Flute Reed River was one of five streams (out of thirteen) in the study that showed evaporative losses in stream isotopes. The evaporative signal indicates the presence of surface water sources of flow; and based on our knowledge of the watershed characteristics, sources could include Moosehorn Lake, wetlands, or beaver ponds. The range and median values, and the evaporative signal indicate 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.

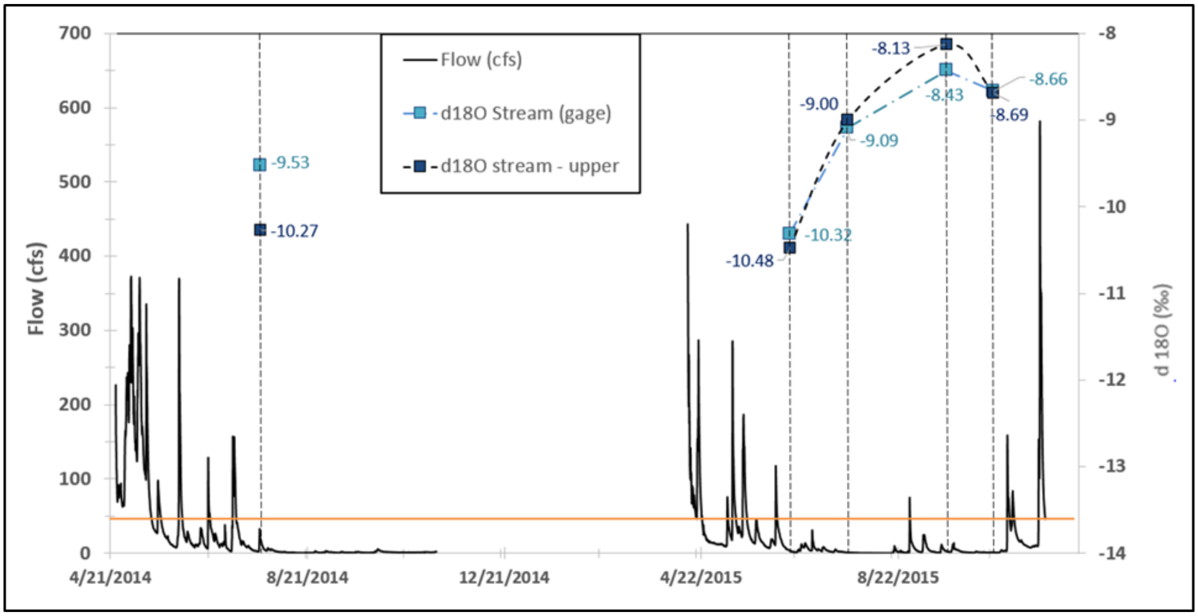


**Figure 42. Oxygen Isotopes for the Flute Reed River at two stream locations and a bank seep located at the gage in years 2016 plotted alongside the flow hydrograph. The orange line represents the lower limit for very high flow conditions.**

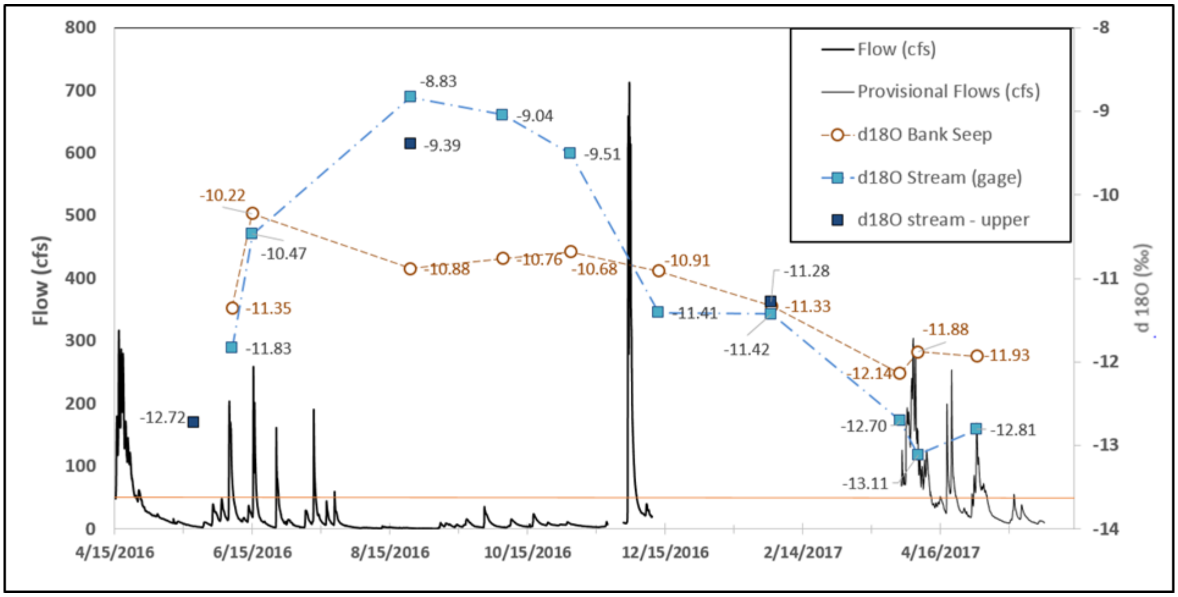


**Figure 43. Oxygen Isotopes for the Flute Reed River at two stream locations in years 2014-2015 plotted alongside the flow hydrograph. The orange line represents the lower limit for very high flow conditions.**

Stream isotopes collected at the gage station during the dry summer and fall seasons at first appear 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. To understand hydrologic source waters and pathways during low flow periods, source water analysis of samples collected in August 2016 at locations spanning across the watershed was completed. Samples were collected from the bank seep, a wetland, six tributary streams, and five locations on main stem Flute Reed within a three-hour period (Figure 44). Moosehorn Lake was not sampled due to limited access. Water was collected from the bank seep by applying pressure to the seep face, as it was not free flowing during the August visit. 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.

Six tributaries located in various locations and draining a variety of landscapes were samples including three upper-watershed tributaries and three lower-watershed tributaries. The three upper-watershed tributaries (FT 7, FT 8, and FT 9) enter the Flute Reed River in the upper two-thirds of the flowage. The largest of the upper tributaries (FT 9) was flowing during sample collection, while the other two were not. It is located in the headwaters; it drains a wetland complex and both bedrock and till landscape. Similarly, only one of the three lower watershed tributaries (FT 4) was flowing during collection; it is connected to a wetland that captures the majority of the drainage from the south-facing slope of the 1765-ft high bedrock ridge. The remaining tributaries were not flowing during sample collection. Similarly, they lack wetland connectivity; and all but one (FT 6) drain till. Tributary FT 6 drains a small portion of the 1765-ft bedrock ridge, but primarily drains till.

Data results identify similarities and differences in hydrologic isotope signals throughout the watershed. The main stem 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 (FR 1, FR 2, and FR 7) show increased evaporation from the two upper main stem stations (FR 11 and FR 12). Our 2014-2016 record shows that overall, upper reach station FR 12 and lower reach station FR 2 correlate well (Figure 44). In fact, low flow events sampled in 2015 show little to no evaporative differences between upper and lower main stem stations. 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 effect has been observed in other isotope data collected along the North Shore of Lake Superior in recent years.

Main stem Flute Reed River signals do not clearly plot next to one specific source, but rather are grouped in the center of multiple other sources including four tributaries and Lake Superior. Although Lake Superior is not 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. More evaporation is observed in the main stem than all tributary streams, which indicates another source of flow to the system and/or excessive beaver ponding. Assuming Moosehorn Lake plots slightly to the right of Lake Superior on the LEL, it is a likely evaporative source to the Flute Reed River influencing the isotopic signal of downstream sample stations.

Tributary signal variability and groupings appear to be related to location and surficial geology (till versus scoured bedrock). The main stem signals plot closer to the till-draining tributaries than bedrock-draining tributaries (FT 4 and FT 6) that directly drain the scoured bedrock ridge. The three upper watershed tributaries that drain mostly till plot in a group just above the main stem signals and slightly below the LMWL. Those 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 also plotted near the main stem stations, but did not group with the upper watershed till-draining tributaries.

Unlike the others, the two tributaries that drain the high bedrock ridge plot above the LMWL and farther away from the main stem signals. This difference in placement in respect to the LMWL could be attributed to variables such as altitude, evaporation rates, or aquifer type (bedrock vs alluvial). One theory is that aquifers along steep bedrock ridges are dominated by winter precipitation, whereas aquifers set in till and alluvium or at lower elevations are dominated by summer rainfall. In addition to plotting above the LMWL, the bedrock tributary FT 4 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 one of two tributaries flowing 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. With only one sample collected at this stream station, the unique signal and seasonal dynamics of stream flow in this tributary could not be examined further.

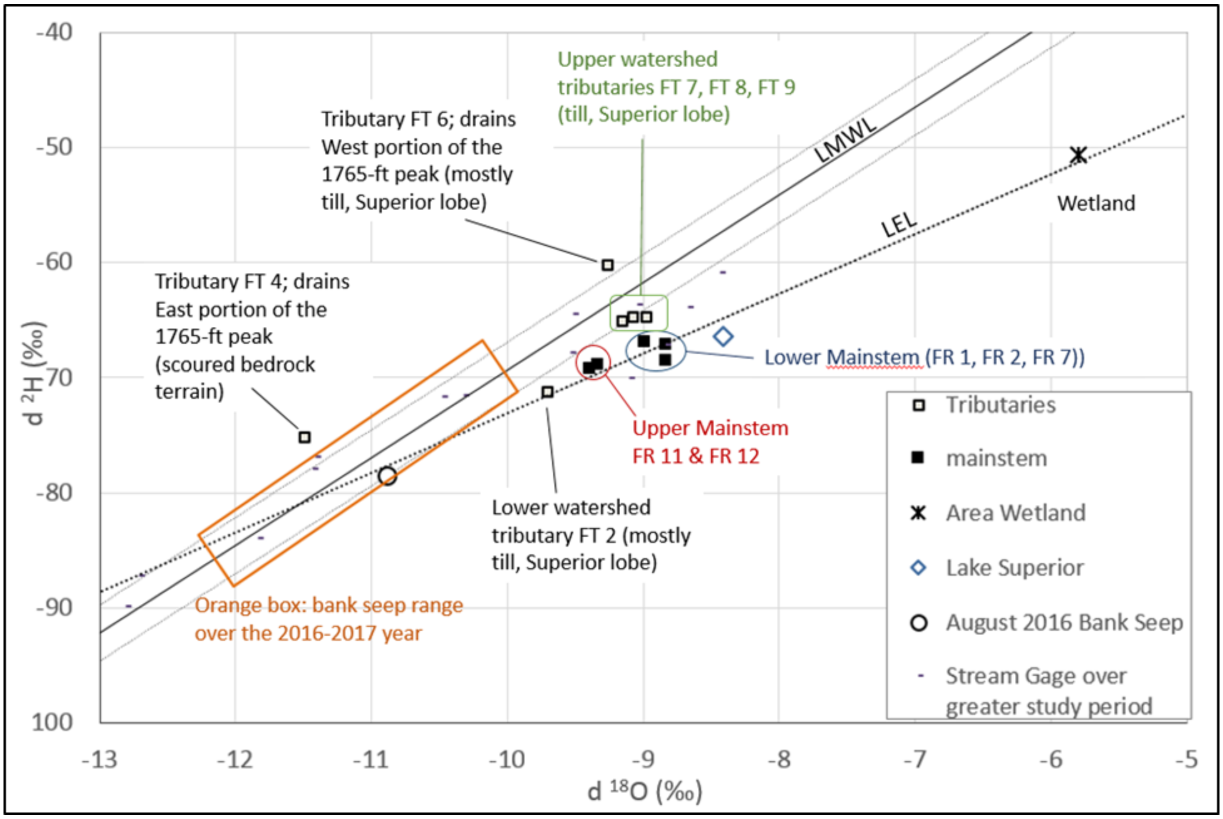


**Figure 44. Oxygen (d18O) and Hydrogen (d2H) isotopes of stream and potential source-waters collected during a low flow event in August of 2016. Main stem Flute Reed River stations plot in a group that is immediately surrounded by tributary and lake signals. Tributaries draining large bedrock ridges and seeps along the stream bank do not plot near main stem signals.**

The bank seep and the groundwater-dominant tributary FT 4 do not appear to be dominant contributors of flow in the Flute Reed River main stem; however till-draining tributaries in both the upper and lower watershed plot closely 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 recharged by direct infiltration of rainfall and mixing with partially evaporated soil moisture result in isotopic signals that plot below and parallel to the LMWL (Clark and Fritz, 1997; Allison et al., 1984). Several other samples collected at the stream gage station over the study period fell into this orientation (Figure 44). This suggests that soil interflow or shallow groundwater frequently recharged by rainfall are distinguishable sources of flow to the system.

The wetland signal is highly evaporative, plotting to the far right on 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 main stem 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. As mentioned, only study tributaries (FT 9 and FT 4) with obvious wetland connection were flowing during the August sample collection. While FT 9 isotopically plotted near main stem samples, FT 4 did not.

## 4.9.9 Conclusions

Our data suggests that Flute Reed River is an example of a lake-fed stream that is highly dependent on precipitation to supply flow. Isotopes show that the stream reacts quickly to high flow events, induced by both large rain events and snowmelt. While surface runoff was identified as the primary hydrologic process during high flow events, groundwater discharge likely plays a role in recharging stream flow following large rain events; additional isotope data could help define the timing of the two processes. Although defining source contributions during low flows is more complex, baseflow data from August 2016 indicates that shallow aquifer or soil interflow that is frequently recharged by rainfall is an important source of flow to the Flute Reed River in late summer. This was inferred by isotopic placement of both stagnant and flowing tributary streams in respect to the LMWL and LEL; and within close proximity to main stem isotope signals.

Although Moosehorn Lake was not sampled, we suspect it is another important source of flow to the Flute Reed River during the dry, late summer season. The Flute Reed River samples clearly plot along the LEL in August 2016; this indicates the presence of surficial source waters that have undergone evaporative processes. Mixing of surficial source waters with previously identified source waters (flowing tributaries and soil interflow) would explain the placement of Flute Reed River samples in Figure 44. Flute Reed River stations isotopically group between till/alluvium draining tributaries and Lake Superior. Although Lake Superior is not a source of flow to the Flute Reed River, it provides some insight to where Moosehorn Lake might plot isotopically. We suspect it would isotopically plot slightly to the right of Lake Superior due to higher evaporation rates off a smaller and warmer waterbody, but to the left of the wetland station on the LEL.

Wetland contributions to Flute Reed River streamflow are not clearly understood from the data collected in this study. The wetland sampled had a highly evaporative signal compared to stream water, which indicates that surficial wetland storage may not be a primary source of stream discharge during low summer flows. In contrast, flow from tributary FT 9, which initiates in a headwater wetland complex, was flowing during the August 2016 sample collection and isotopically plotted near the Flute Reed River samples. Wetland characteristics that might influence the storage and flow contributions include wetland type, vicinity to hillslopes, and geologic association. Both of these wetlands are primarily forested shrub type; however, FT 9 flows through multiple smaller emergent-type wetlands as well. The FT9 wetland complex is located below high-elevation bedrock features, whereas the sampled wetland is surrounded by a flatter till-dominant landscape. Future sampling of both Moosehorn Lake and multiple wetlands would help identify specific surficial storage sources important to sustaining Flute Reed River flows during dry periods. The primary obstacle to successfully sampling these watershed features during our study was accessibility.

Our data suggests that aquifer contributions to stream flow are relatively minor. A depleted isotope signal representative of seasonally well-mixed groundwater was collected from a bedrock-draining tributary (FT 4) that was flowing during the August 2016 sample collection effort. The depleted signal indicates increased winter-precipitation influence compared to the till/alluvial aquifer-draining tributaries when sampled in mid-summer. This may indicate that overall storage is greater in the bedrock aquifers, holding winter precipitation longer into the season; or that the snowpack: rainfall infiltration ratio in aquifers varies based on aquifer type and location. However, the tributary's isotope signal does not correlate with the other water samples collected in the system, which indicates that tributary is not a primary flow source to the Flute Reed River. In addition, bank seep and stream samples were compared and did not isotopically correlate during the dry summer months. Because the bank seep was not actively flowing during this period, we did not suspect that the single seep was feeding flow to the stream, rather we were considering similar seeps with greater flow and/or a cumulative flow source of aggregated seeps.

In our study on Lake Superior North streams, isotope data suggests that the Flute Reed River is more vulnerable to seasonal influences, particularly affecting low flow conditions, than most of the study streams in the LSN watershed. Examples of streams where groundwater appeared to be a strong source of summer baseflow include Wanless Creek, Woods Creek, Two Island River, and Thompson Creek. Devil Track River is an example stream where lake and groundwater sources combine to play a primary role in maintaining flow to the downstream system. The Flute Reed River data suggests that unlike these examples, it depends on multiple sources to sustain low summer baseflows, including a shallow lake, frequent precipitation to recharge shallow aquifers, and headwater wetland-fed tributaries. Similar isotope signals in the upper watershed and lower watershed sites support our theory that flow in the lower system is primarily derived in the upper watershed. The primary difference in isotopic composition between upper and lower main stem stations during the low flow conditions of August 2016 is a slight increased fraction of water loss due to evaporation in the lower watershed; and it is likely due to beaver dam ponding of stream water upstream of CR 70-Camp 20 Rd.

# 4.10 Summary and recommendations for Flute Reed River

## 4.10.1 Key stressors and threats

The fish and macroinvertebrate communities of Flute Reed River are relatively healthy and fully support coldwater IBI criteria. Several components of the physical and chemical habitats may be somewhat limiting compared to the highest quality streams along the North Shore. These include elevated water temperatures, physical habitat degradation, barriers to fish movement, and TSS concentrations that frequently exceed the 10 mg/L water quality standard. Table 10 summarizes key findings from the stressor analysis and the contributing sources and pathways. Restoration and protection activities should focus on these potential limiting factors as a means of improving ecological health in the Flute Reed Watershed.

**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.<br>• Temperatures remain suitable for supporting wild Steelhead Rainbow Trout population between RM 0.0 and RM 5.0 based on recent temperature data<br>• Sources of water temperature warming include beaver dams, turbid water, reduced riparian tree shading, low flow conditions. |
| **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.<br>• 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.<br>• 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.<br>• 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.<br>• Sources of elevated TSS include streambank and valley wall erosion, overland runoff from open lands and gravel/dirt roads, and beaver activity. |

## 4.10.2 Implementation suggestions – protection and restoration

Efforts to protect and preserve high quality habitats and ecological function is equally important as restoration goals are 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**

*** See location of this reach in Figure 21**

| Protection Area | Significance | Strategies |
|---|---|---|
| **Flute Reed R. Headwaters near Tom Lake Rd.** | • Coldest water temperatures in watershed.<br>• Wild Brook Trout observed in previous sampling events | • Conduct biological monitoring (fish/macroinvertebrates) in Flute Reed and tributaries near Tom Lake Rd to verify presence/absence of Brook Trout and other coldwater aquatic life<br>• Replace or remove road culvert at Tom Lake Rd to restore fish passage and reduce upstream ponding<br>• Forest management to deter any increases in beaver activity |
| **Flute Reed R. Reaches FLR 000 through FLR 004*** | • Critical spawning and rearing habitat for Steelhead Rainbow Trout | • Remove beaver dams within this reach to enhance fish passage and availability of spawning habitat<br>• Manage riparian areas for long-lived, native conifer and northern hardwood species<br>• Replace culvert at the lower Camp 20 Rd crossing with a bridge or structural plate arch culvert to restore fish passage to upstream habitats |
| **Flute Reed R. Reaches FLR 015 through FLR 018*** | • High degree of channel stability and excellent physical habitat conditions | • Preserve the relatively in-tact forested riparian corridor in this portion of the Flute Reed watershed |
| **Stable channels within former beaver impoundments**<br>**(e.g. Reach FLR 016)** | • Stable channels offering high quality habitat<br>• Monitoring/protection necessary to encourage forest succession that promotes further “recovery” and longevity of lotic environment | • Monitor the succession of these channels over time. Manage for free-flowing channel with highly vegetated banks and floodplain connectivity<br>• Manage riparian areas for long-lived, native conifer and northern hardwood species |

**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 |
| **Elevated Water Temperature** | Entire Watershed except extreme headwaters | • Manage riparian areas for long-lived, native conifer and northern hardwood species<br>• Additional targeted temperature monitoring around active beaver dams and historic dam sites. Monitor temperature changes upon several dam removals.<br>• Replace undersized culverts to reduce thermal loading due to upstream ponding |
| **TSS/Physical Habitat** | Throughout watershed, but particularly in reaches with moderate to high rates of channel incision and high width to depth ratios. These areas include reaches FLR 004* upstream through FLR 011* and the entirety of the two major tributaries (FL_WT and FL_ET)* | • 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)<br>• Install localized grade control structures near advancing head-cuts to prevent further channel incision and improve physical habitat |
| **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<br>• 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) |

*** See location of this reach in Figure 21**

# 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 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 a small resident population of naturally reproducing Brook Trout. Steelhead Rainbow Trout, which migrate into Woods Creek via the Devil Track River from Lake Superior, also use the creek for spawning and rearing. The majority of the watershed is within the Superior National Forest, although the upper 1/3 of the watershed is largely in private ownership.

DNR has intermittently monitored trout populations, water temperatures, and habitat conditions in Woods Creek over the past decade (DNR, 2016; DNR, 2016b). Summary reports from DNR have cited several unfavorable land uses and stream conditions that may limit trout populations and overall biological integrity in the Woods Creek watershed (Table 13). The MPCA's monitoring and assessment report (MPCA, 2017) corroborated many of the same findings. Further evaluation of these limiting factors, or "stressors", was completed by MPCA staff 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. These components of the Woods Creek watershed were evaluated 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<br>• Bedrock geology/waterfalls | **Cold Water Temperature** | • Groundwater inputs<br>• Undeveloped riparian corridor/ heavy shading |
| **Constructed Barriers** | • CR 58 culvert is barrier to fish passage<br>• Constructed impoundments in headwaters | **Pool Habitat** | • Step pool habitat due to high stream gradient/boulders |
| **Low Streamflow** | • Small drainage area<br>• Ditching<br>• Constructed impoundments in headwaters<br>• High width/depth ratio at low flow | **Abundant Gravel Substrate** | • Outwash Geology<br>• High gradient stream → stream-power to prevent deposition of fine substrates |
| **Habitat Degradation** | • Impacts from 2008 flood<br>• Bank erosion/channel incision/widening, loss of pool habitat | **Abundant Fish Cover** | • Large woody cover<br>• Boulders & plunge pools |

## 5.2 Overview of biological data

### 5.2.1 MPCA biological monitoring results

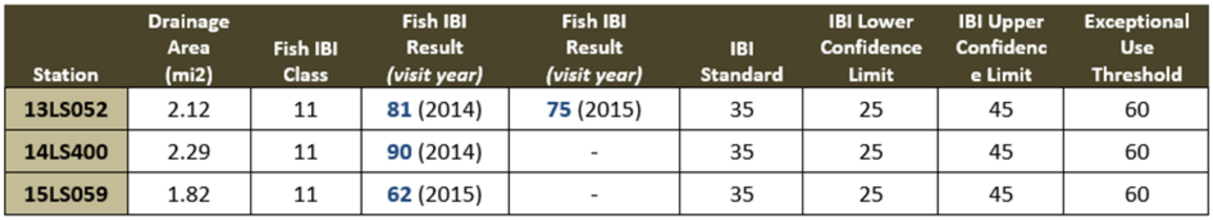
MPCA sampled fish and aquatic macroinvertebrates at three locations on Woods Creek as part of the greater Lake Superior North Watershed Monitoring and Assessment effort (Figure 45). Initially, only one monitoring station (13LS052) was placed on the creek at the CR 58 (Lindskog Rd), approximately 0.5 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.

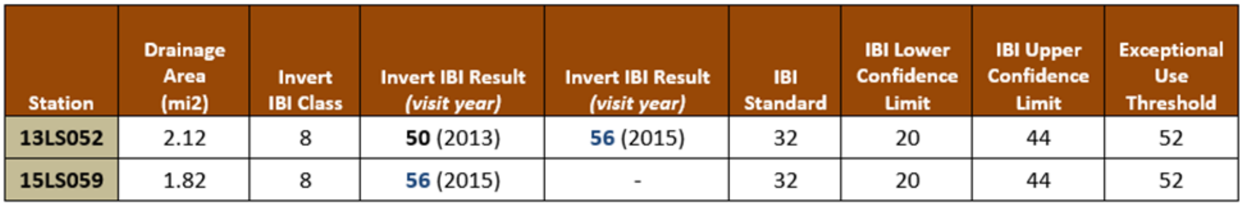
Although fish IBI scores were relatively high, Brook Trout and Rainbow Trout numbers were relatively low in most of the samples. Other coldwater species frequently observed in higher quality North Shore streams, such as Mottled and Slimy Sculpin, were notably absent from all Woods Creek stations. Both of these species are found in the Devil Track River downstream, but migration into Woods Creek is blocked by several barrier waterfalls. 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 are likely due the small drainage area and lack of connectivity to larger rivers due to natural and constructed barriers. Localized habitat degradation and extremely low stream flows are also prominent stressors in this watershed. Woods Creek should be a high priority for protection and restoration efforts, as many potential stressors render its Brook Trout population vulnerable to extirpation.

Aquatic macroinvertebrates were sampled at two locations, 13LS052 and 15LS059 (Figure 45, Table 14). 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, healthy DO concentrations, 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. Woods Creek biological sampling stations, results, and applicable assessment criteria. 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 | 11 | **81** (2014) | **75** (2015) | 35 | 25 | 45 | 60 |
| **14LS400** | 2.29 | 11 | **90** (2014) | - | 35 | 25 | 45 | 60 |
| **15LS059** | 1.82 | 11 | **62** (2015) | - | 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 | 8 | **50** (2013) | **56** (2015) | 32 | 20 | 44 | 52 |
| **15LS059** | 1.82 | 8 | **56** (2015) | - | 32 | 20 | 44 | 52 |

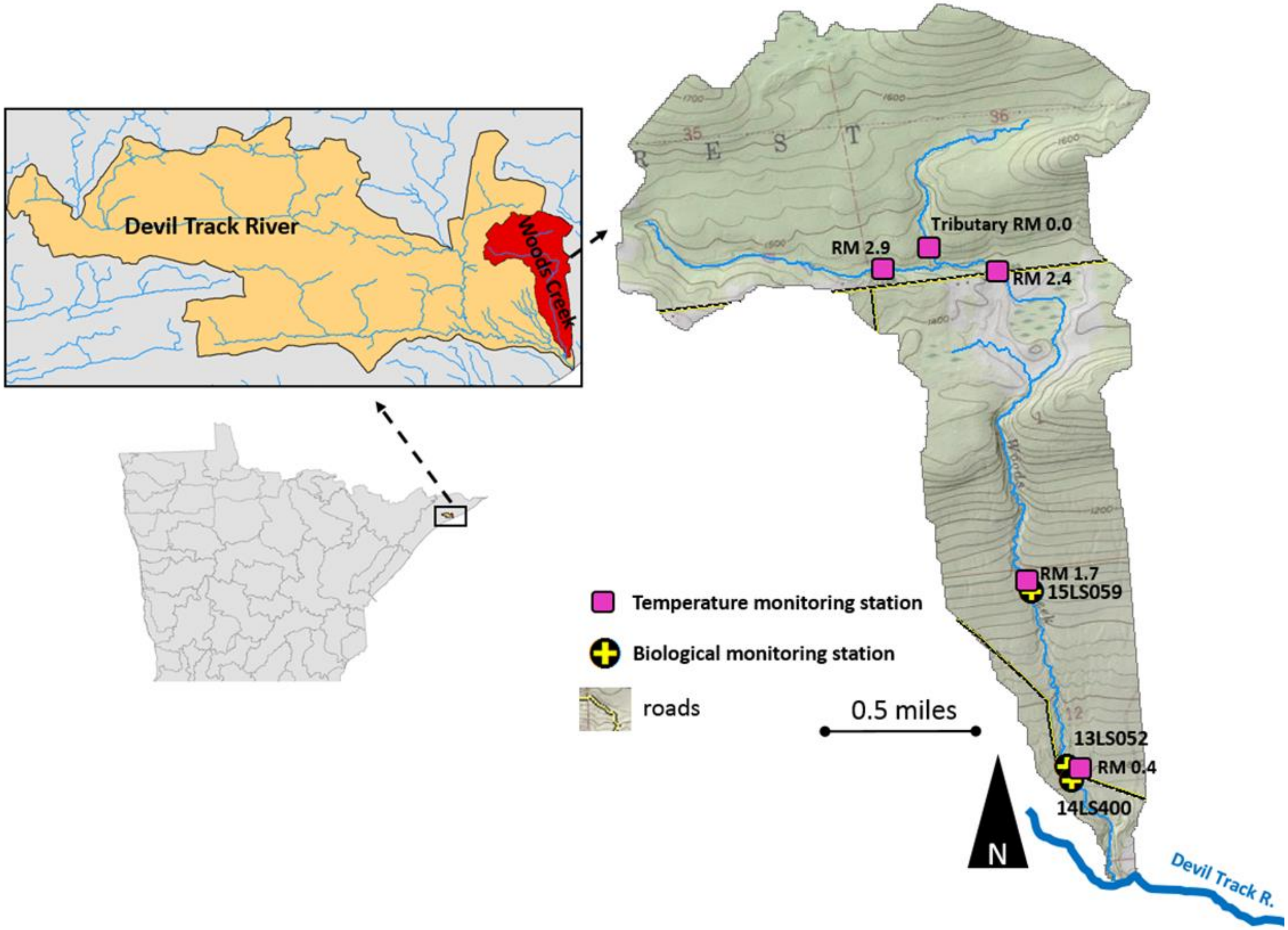


**Figure 45. Woods Creek biological (fish and macroinverterates) and stream temperature monitoring stations.**

Historically, Woods Creek supported a wild Brook Trout population throughout its entire length (DNR, 2015). Recent sampling completed by MPCA and DNR suggests that the range of their distribution in this watershed has decreased. In the summer of 2010, DNR did not observe any Brook Trout during a sampling effort that covered four stations. 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 more 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 46, bottom photos), 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, particularly in reaches with higher quality physical habitat.

In October of 2016, MPCA staff hiked approximately 1.6 stream-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 (nests) 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 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 and Rainbow Trout, but spawning migrations of adult Steelhead beyond the lower falls in Woods Creek remained undocumented.

In 2014 and 2015, MPCA sampled juvenile Rainbow Trout in Woods Creek at stations 14LS004 and 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 and rearing habitat upstream. Rainbow trout were sampled above the CR 58 crossing at 13LS052. There is evidence that adult steelhead have limited ability to pass through the CR 58 culvert at high flows. Replacing this crossing with a properly designed culvert or bridge to allow fish passage at all flows would enhance access to prime spawning and rearing habitat upstream, and would make this crossing navigable for non-game species with swimming abilities inferior to that of salmonid species (e.g. Rainbow Trout, Brook Trout).

Summer water temperatures in Woods Creek are among the coldest observed in Lake Superior’s North Shore tributaries (Figure 47). Several sensitive aquatic macroinvertebrates were sampled in Woods Creek in relatively large numbers during MPCA’s assessment monitoring. Woods Creek is one of nine streams in Minnesota in which *Isogenoides* (a stonefly) has been collected, based on records included in MPCA’s statewide biological monitoring database. Another rare coldwater macroinvertebrate taxa observed in Woods Creek was the caddisfly *Goera*, found at only 32 other sampling locations statewide, most of which are also located along Lake Superior’s North Shore. Other rare and/or sensitive coldwater taxa that were relatively abundant in Woods Creek include *Diplectrona* (a caddisfly), *Rhyacophila* (a caddisfly), *Agnetina* (a stonefly), *Rhithrogena* (a mayfly), *Leuctra* (a stonefly), and Capniidae (a stonefly family).

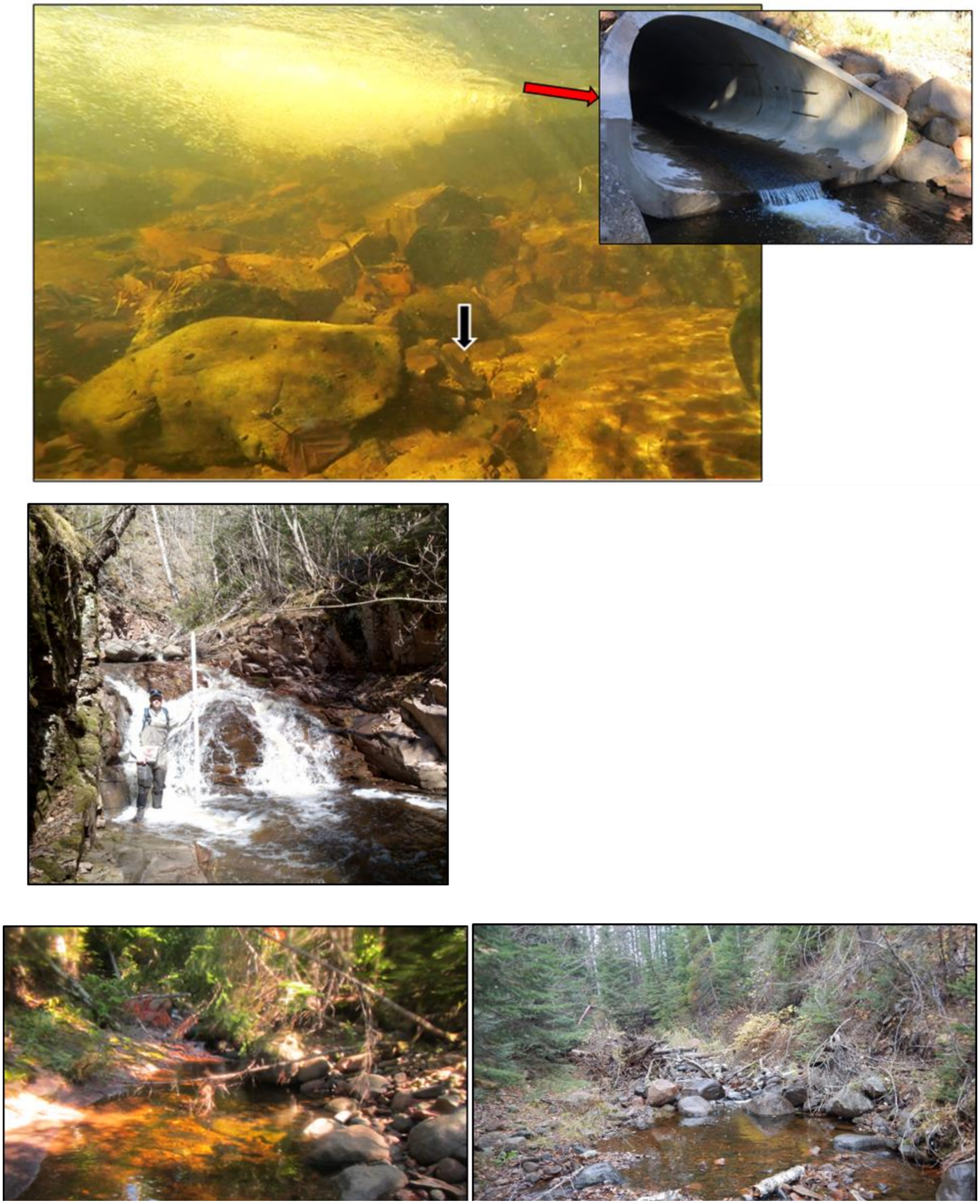


**Figure 46. (Top) Age-1 Steelhead Rainbow Trout in Woods Creek below CR 58 culvert. CR 58 crossing is a barrier to fish passage; (middle) some adult Steelhead Rainbow Trout are able to ascend these bedrock falls in the lower 0.4 river miles of Woods Creek to reach quality spawning and rearing habitat upstream; (bottom) 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 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 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). Woods Creek was listed among several streams with isotope results suggesting a strong groundwater component as the dominant flow source (see section 4.8).

Stream temperatures were more variable at stations located in the headwaters of Woods Creek (RM 2.4). Five years of continuous temperature data are available at RM 2.4, and the percent of temperature readings within the growth range for Brook Trout ranges from 76% in 2010 to 99% 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. Restoring the pattern of the stream channel and re-vegetating the riparian corridor with native plants and trees in this reach would protect against temperature increases and improve physical habitat.

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 (Table 15, Figure 47). Prior investigations on Woods Creek have noted that the tributary at RM 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) (DNR, 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 volumes, 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 lowering water temperatures in that reach.

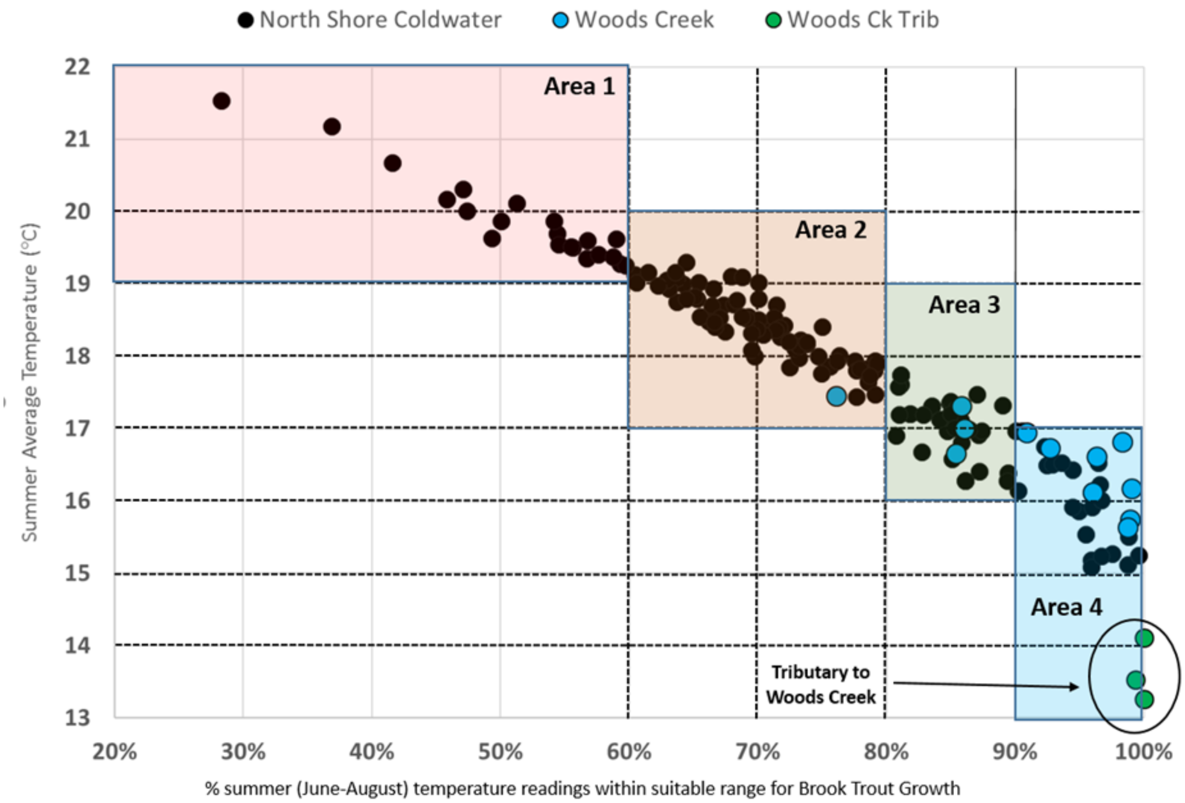


**Figure 47. Summer Average Temperature vs. percentage summer (June-August) temperature readings within suitable range for Brook Trout Growth. Woods Creek Watershed monitoring stations are shown in colored markers, while all other North Shore coldwater stations are shown as black markers. Temperature "areas" are discussed 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 (7.8° to 20°C) | Stress (>20°C to 25°C) | Lethal (>25°C) | No Growth (<7.8°C) | Summer Avg. (°C) | Summer Max (°C) |
|---|---|---|---|---|---|---|---|
| **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 | 96.5% | 3.4% | 0.0% | 0.0% | 16.55 | 22.18 |
| **RM 1.7** | 2010 | 99.1% | 0.9% | 0.0% | 0.0% | 16.16 | 20.89 |
| **RM 1.7** | 2016 | 85.9% | 14.1% | 0.0% | 0.0% | 17.28 | 24.53 |
| **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 2.4** | 2016 | 98.4% | 1.6% | 0.0% | 0.0% | 16.83 | 21.89 |
| **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 predicted bank erosion rates

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, 1996) 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.)

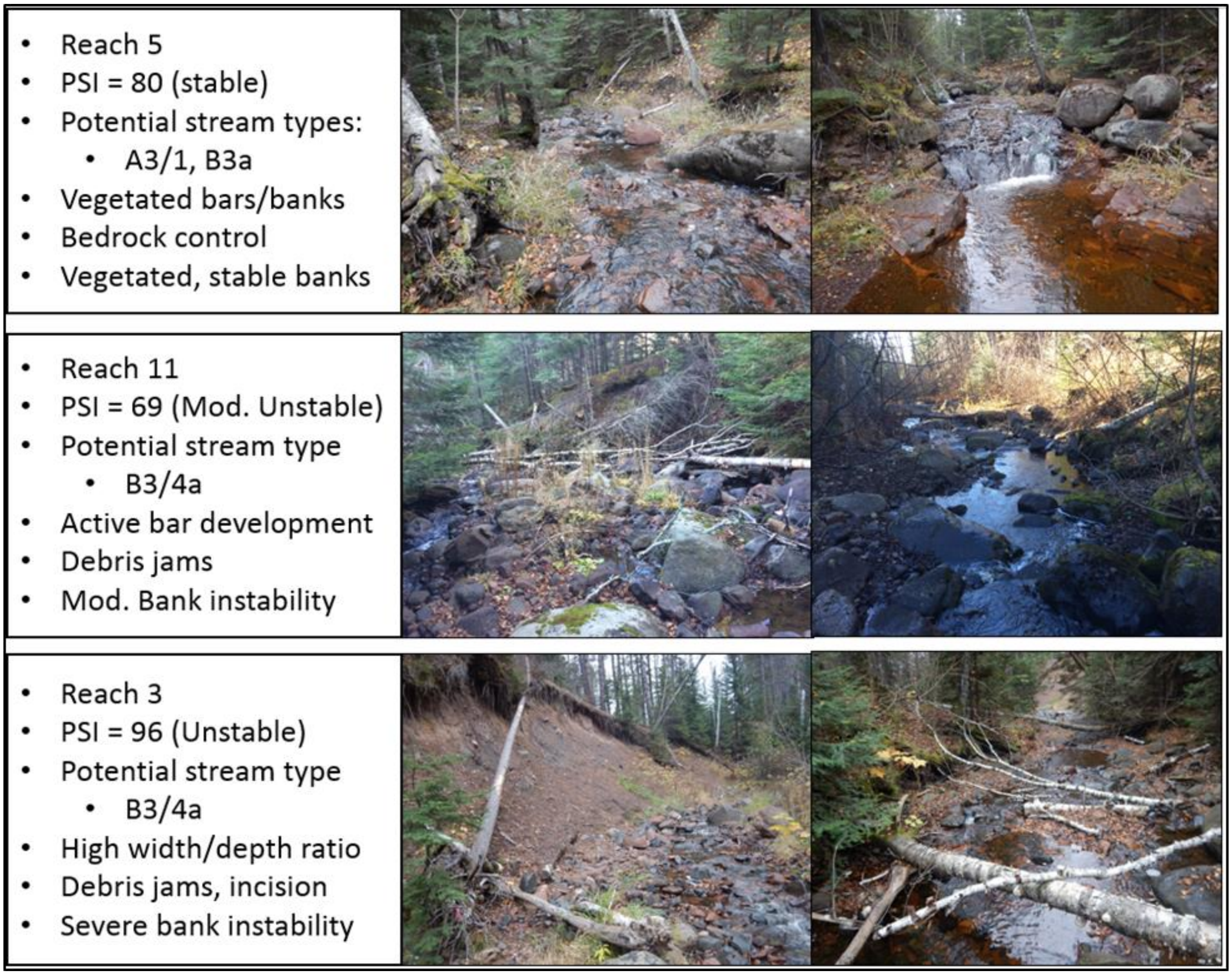
### 5.4.1 Channel stability assessments

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, and 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. The culvert at CR 58 is too narrow and the inlet elevation is set too high, which is causing sediment deposition upstream, as well as scouring and bank erosion downstream. 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 J.



- 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 48. 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

Two recent reports cited excess stream bank erosion as threat to biological integrity in Woods Creek (MPCA, 2017; DNR 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 goal of this assessment was to quantify bank erosion potential in Woods Creek by individual streambanks, as well as the river-reach scale to inform restoration and protection strategies.

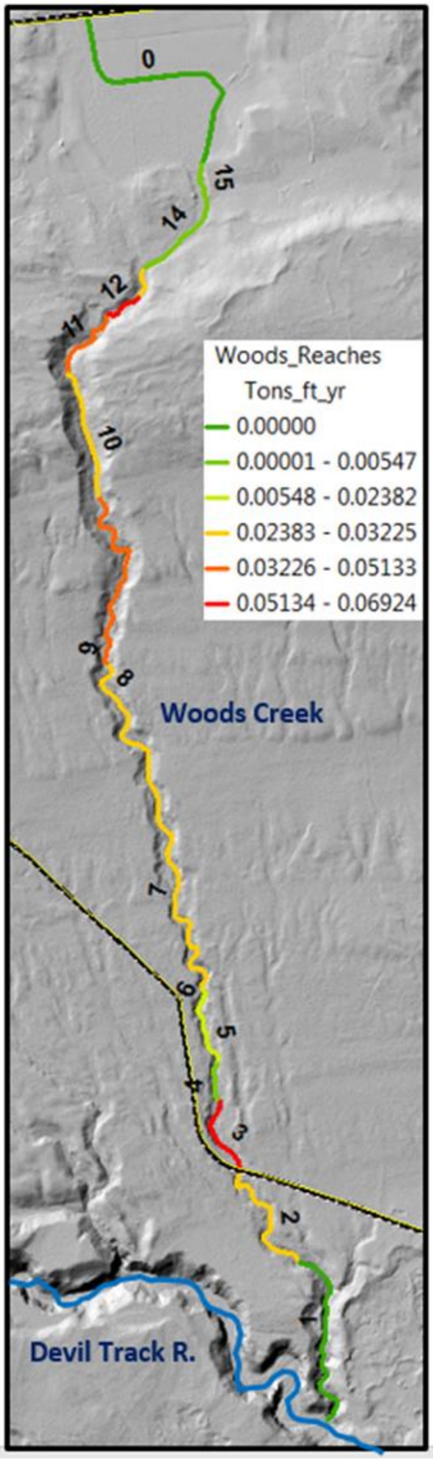
BANCS model data were collected over a two-day assessment of 2.4 river miles of Woods Creek, extending from the confluence at Devil Track River upstream to the lower extent of the channelized reach. A total of 109 measurements of bank height (estimated), length, and erosion potential were recorded using 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.

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 (Figure 49). 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 (Figure 49). 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-protected banks), 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.

Approximately 33% of the total predicted annual bank erosion is generated by 10 individual streambanks or unstable bluffs (Figure 50). 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. In addition to erosion caused by stream processes, several large bluffs are eroding due to freeze-thaw cycles and groundwater bank seeps.



| 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%*** |

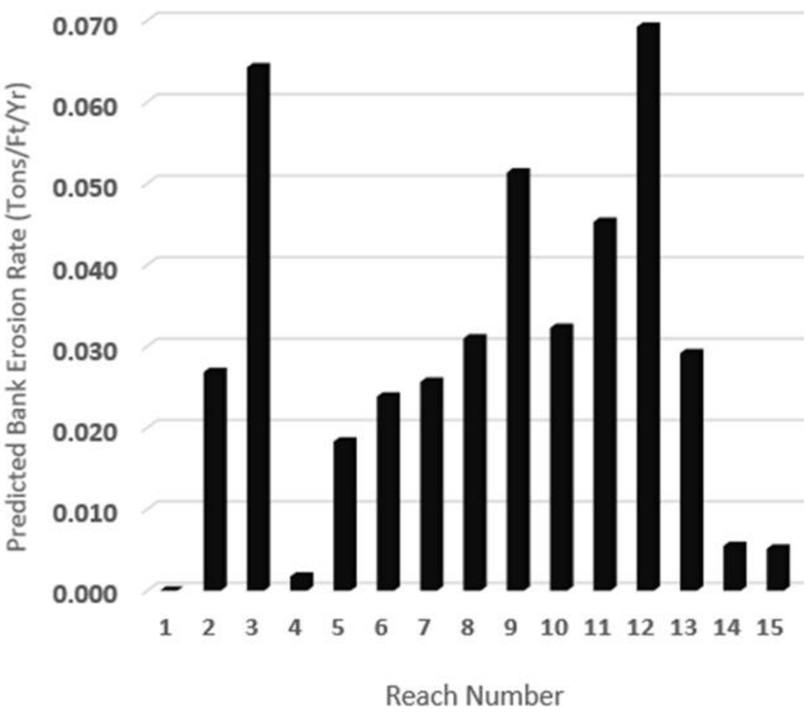
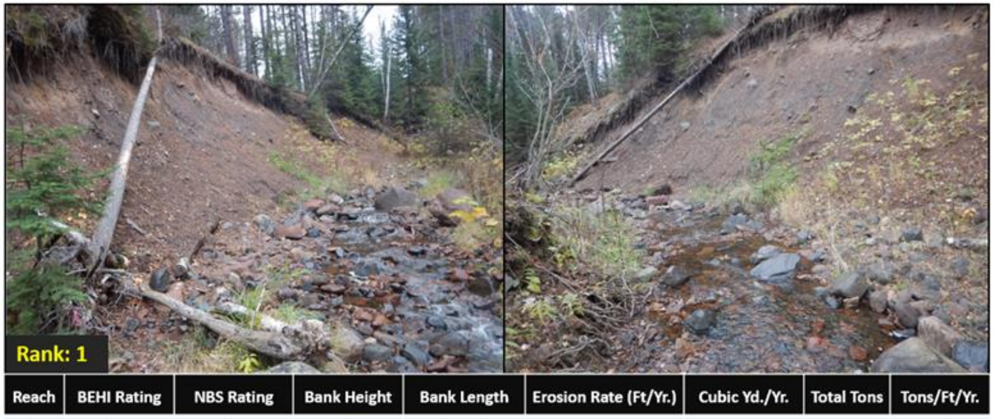
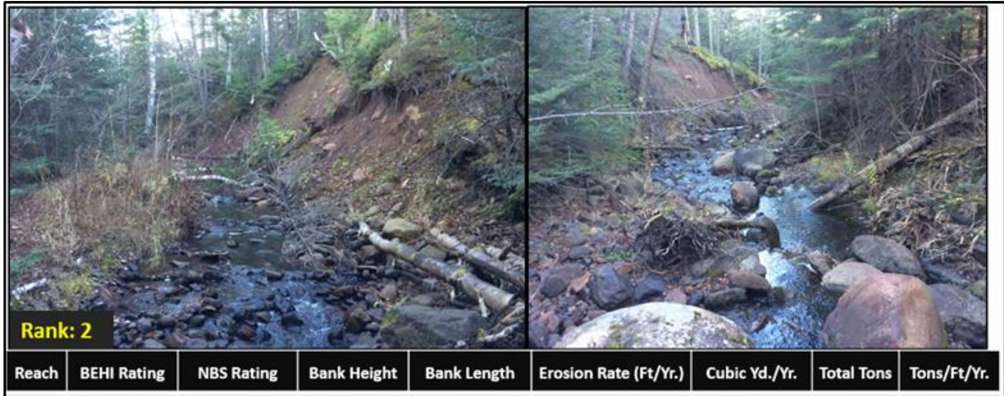


**Figure 49. Predicted bank erosion rates for the delineated stream reaches of Woods Creek.**



| 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 50. Photos and several attributes for the top three sediment sources based on BANCS model results. A table of the top ten sediment sources related to bank/bluff erosion are listed in the table at the bottom.**

| Rank | Reach | River Right or Left | BEHI | NBS | Height | Length | Total Tons | Tons/Ft/Yr | % of Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | Right | High | Moderate | 12 | 86.4 | 18.95 | 0.219 | 5.3% |
| 2 | 11 | Left | High | Moderate | 10 | 83.5 | 15.26 | 0.183 | 4.3% |
| 3 | 9 | Right | High | Moderate | 10 | 75.7 | 13.85 | 0.183 | 3.9% |
| 4 | 3 | Right | Moderate | Moderate | 7.5 | 123 | 11.34 | 0.092 | 3.2% |
| 5 | 2 | Right | Moderate | Low | 3.5 | 436.5 | 11.24 | 0.026 | 3.1% |
| 6 | 7 | Right | High | Moderate | 8 | 73.7 | 10.8 | 0.146 | 3.0% |
| 7 | 9 | Right | High | Moderate | 7 | 80.9 | 10.3 | 0.128 | 2.9% |
| 8t | 2 | Left | High | Moderate | 5 | 103.3 | 9.4 | 0.091 | 2.6% |
| 8t | 9 | Left | Moderate | High | 12 | 38.9 | 9.4 | 0.243 | 2.6% |
| 10 | 9 | Left | Moderate | Low | 5 | 196.8 | 7.2 | 0.037 | 2.0% |

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 increases. 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 51). 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 52 right photo) to a high of 2.0 (deeply incised, Figure 52 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.

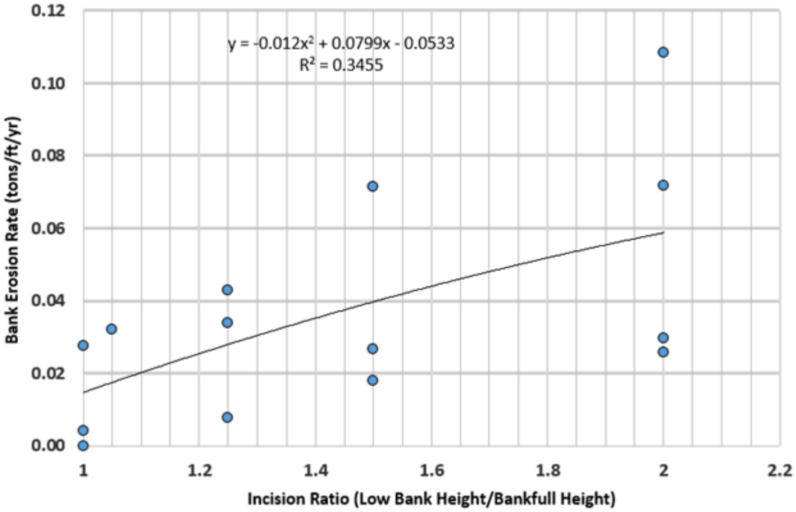


**Figure 51. Scatterplot of channel incision ratio versus predicted erosion rates for delineated stream reaches in Woods Creek.**

**Figure 52. Examples of BHR values of 2.0, deeply incised (left), and 1.0, stable and connected to floodplain (right), in Woods Creek. Yellow line approximates bankfull height. Predicted erosion rates were higher in reaches with high BHR values.**

## 5.5 Physical habitat assessments

The Brook Trout Suitability Assessment (BTSA) rates physical 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 (Figure 54). 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 (112) in the assessment. Reach 10 received the highest BTSA score (113).

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 (reaches 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 reaches 2-3, 9, and 13. Many of these areas also scored poorly in width-depth ratio 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 river miles of Woods Creek.

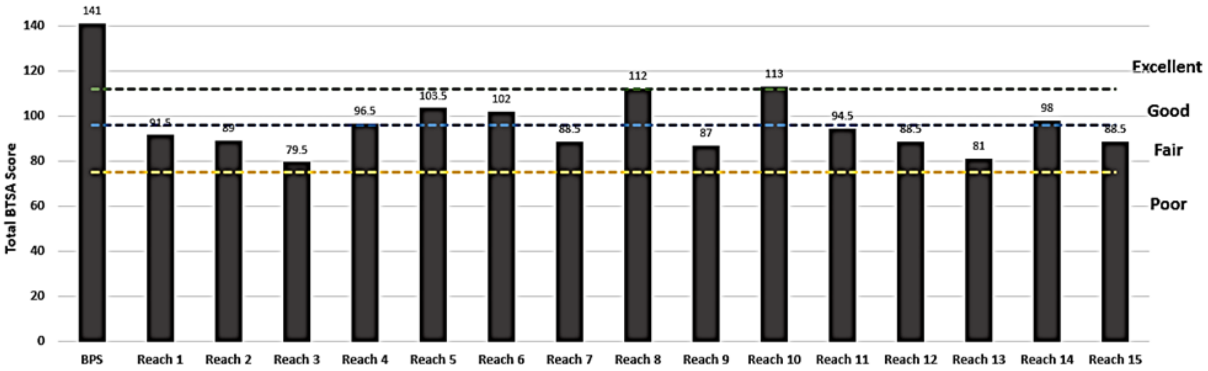


**Figure 53. BTSA scores and ratings for the assessed reaches of Woods Creek. BPS=Best Possible Score**

**Figure 54. 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 (middle), and step pool habitat/clean gravel substrate for spawning (right).**

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 56, 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 (photos 1 and 2, Figure 55). 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 55 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, or significant watershed disturbance, 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 shade when standing, and as deadfall, they provide in-stream cover and grade control. 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 avoided given its small drainage area, steep slopes, and 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 just downstream of the ditched portion of Woods Creek appeared to be most impacted by substrate embeddedness, particularly reach 13 (Figure 56, left). Land-uses that directly or indirectly increase sediment loading to the creek (ditching, dredging, roads, timber harvest, vegetation removal, etc.) 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 in Woods Creek up to and above CR 58. The concrete culvert at CR 58 is too narrow, 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 still limit upstream 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 57). The ditching and straightening of natural rivers 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 and riparian vegetation downstream of CR 60 would increase the overall mileage of quality coldwater habitat available and keep the stream from warming.

**Figure 55. Evidence of channel evolution towards a stable condition. Several channel evolution phases are evident in Woods Creek (1) high width/depth ratio, no floodplain or stable vegetation (2) high width/depth ratio, floodplain with patchy, but stable vegetation, (3 and 4) low to moderate with depth ratio, defined thalweg, increased sinuosity, connection to a vegetated floodplain.**

**Figure 56. Fine sand substrates embedded coarse gravel and cobble material in Reach 13 (left); Boulder and cobble material deposits on floodplain in reach 8 (right) are indicators of the extremely high stream power generated by the steep slope and entrenched valley of Woods Creek.**

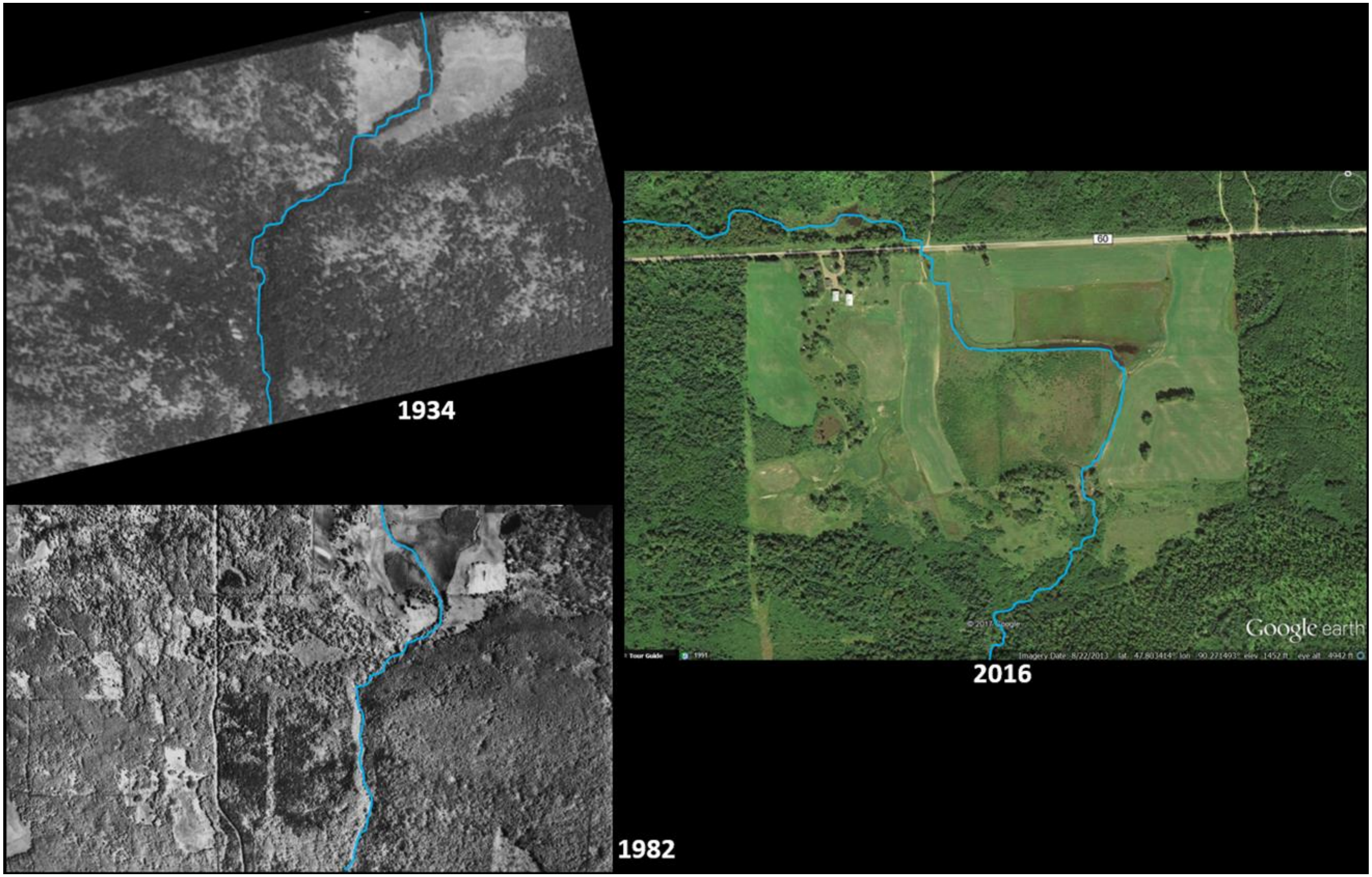


**Figure 57. Aerial photos (1934, 1982, and 2016) of Woods Creek near the CR 60 crossing. The stream channel within this reach was channelized sometime after the 1934 photo and remains a regularly excavated ditch.**

## 5.6 Brook trout distribution, habitat refuge, and migration barriers

A 2-mile assessment of Woods Creek was completed over two days (10/27 and 11/4) 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 level and water clarity 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.

### 5.6.1 Brook trout distribution

Sightings of Brook Trout were tallied 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, 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). Numerous age-1 and age-0 Brook Trout and Rainbow Trout were observed seeking thermal refuge and cover within this pool, which is located just upstream of the Devil Track-Woods Creek confluence. Visual observations of Brook Trout occurred almost exclusively in reaches with abundant pool habitat.

### 5.6.2 Habitat refuge areas

Access to refuge areas are critical in all streams and rivers, but are especially important in small, geographically isolated streams like Woods Creek. 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. Brook Trout sightings occurred almost exclusively in pool and glide habitats.

### 5.6.3 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 DNR (n=22) (DNR, 2015). Natural barriers were present in the form of bedrock drops, and boulder piles that developed during the flood of 2008. 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 headwaters reach in 2015 (DNR, 2015).

### 5.6.4 Non-natural barriers to fish migration

The two public road crossings of Woods Creek (CR 58 and CR 60) were assessed for fish passage, culvert sizing, and impacts to water quality and physical habitat. 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 B.

The culvert at County Road 58 (Lindskog Rd, RM 0.49) is the first crossing that migrating fish encounter upstream of the confluence with the Devil Track River (Figure 58). This crossing is a single 11.5' wide arched concrete pipe. The culvert bottom at its outlet sits 0.5 feet above the water surface at low flows. 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 is just over two river miles upstream of the CR 58 crossing. This crossing consists of three 3' wide corrugated metal culverts (Figure 58). 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 culvert at County Road 58 (RM 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 58. 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

Woods Creek supports a wild population of Brook Trout and Rainbow Trout, along with several rare coldwater macroinvertebrate taxa. This stream currently meets exceptional use aquatic life criteria for both fish and macroinvertebrate assemblages, yet several stressors render these species vulnerable to extirpation. 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). Table 17 summarizes key findings from the stressor analysis and the contributing sources and pathways. Restoration strategies are recommended in Table 18.

**Table 17. Summary of primary stressors to aquatic life in the Woods Creek Watershed.**

| Stressor/Threat | Summary |
|---|---|
| **Physical Habitat Degradation** | • Symptoms of stream channel instability (bank erosion, channel widening, and substrate embeddedness) 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. Reach 8)<br>• Much of the channel instability and habitat loss in Woods Creek can be attributed to a major flood event that occurred in the watershed in the summer of 2008.<br>• 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. DNR (Weberg, 2015) reported that silt has accumulated in the channel in the low-gradient reach below RM 2.4 (below Cook County Road 60). The main flow of Woods Creek has forced into 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 to fish migration, such as bedrock and boulder waterfalls and beaver dams, were observed throughout Woods Creek. These limit the ability of fish and other aquatic organisms to move freely under many flow conditions.<br>• 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). Biological data provide evidence that a very limited number of adult Steelhead Rainbow Trout have successfully passed through this culvert in recent years during high streamflow events in the spring. However, the improper design and installation of this culvert likely impedes passage of most trout and non-game species, especially at younger life stages. |
| **Flashiness, Stream Power, and Altered Hydrology** | • A2 and A3 stream types (Rosgen, 1996) are 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.<br>• Downstream of CR 60, the main channel of Woods Creek is ditched for approximately 0.5 miles. This ditched channel along with the deforested land in this area increases the hydrological “flashiness” (i.e. high frequency, short duration runoff events) and likely contributes to erosion of streambanks and streambed in reaches that are more prone to downcutting or widening (e.g. those lacking floodplain connectivity or bedrock-reinforced banks and bed)<br>• Aerial photos of the watershed show a series of private dams on Woods Creek near the intersection of CR 58 and CR 60. These impoundments may alter streamflow, increase water temperatures, and affect channel stability and habitat types. Numerous beaver dams are also present in this reach. |

**Table 18. 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.<br>• Establish a vegetated buffer along restored stream channel<br>• 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<br>• Conduct additional biological monitoring to determine if wild Brook Trout still inhabit Woods Creek and major tributary upstream of CR 60 |

## 5.6.2 Restoration and protection recommendations

Efforts to protect and preserve high quality habitats and ecological function are equally as important as restoration goals in this watershed. Several high quality and/or ecologically significant areas within the Woods Creek Watershed are listed in Table 19. Specific protection goals should be developed for these areas using input from stakeholders, resource managers, and watershed-planning processes (e.g. WRAPS). Additional priority protection areas should also be recommended as part of this process.

**Table 19. Recommended priority areas in the Woods Creek watershed**

| Protection Area | Significance |
|---|---|
| **Unnamed Tributary (Unnamed Creek S-67-1-1)**<br>**&**<br>**Woods Creek Headwaters**<br>**(TWP 62 RNG 1 SEC 35 & 36)** | • Major tributary entering Woods Creek at RM 2.71. DNR has reported that this tributary may contribute a greater amount of flow than the main stem of Woods Creek at this confluence point.<br>• 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. Private dams and ditching in the headwaters should be addressed to preserve as much baseflow as possible.<br>• 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. |
| **Lower Woods Creek to Confluence with Devil Track River** | • Woods Creek provides valuable spawning/rearing habitat as well as a thermal refuge area for fish in the lower Devil Track River. Many age-1 and age-0 Rainbow Trout and Brook Trout were observed in the lower reaches of Woods Creek during a mid-summer field investigation.<br>• Impacts from CR 58, including the impassable road culvert and bank erosion areas near and downstream of this crossing, threaten the quality habitat located within this reach |

# 6.0 Special Studies - Aquatic Organism Passage

## 6.1 Objectives

Climate models (Johnson et al. 2015) 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 remaining 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 and was a major priority for MPCA during the Lake Superior North WRAPS study.

## 6.2 Fredenberg Creek – Two Island River connectivity 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 were to:

- 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

### 6.2.1 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 square 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 59 and 60). 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 nearly pristine watershed conditions, aside from the fish passage barriers that 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 strems by providing access to critical spawning and rearing habitat and expanding thermal refugia.

**Figure 59. 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, other non-game fish species, and terrestrial and semi-aquatic species that use riparian corridor habitats (e.g. turtles, otters).**

**Figure 60. 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.**

## 6.2.2 Review of biological data

The fish community of Fredenberg Creek has been sparsely sampled by DNR over the past 30-40 years. MPCA has never sampled fish or macroinvertebrates in this stream. Several 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 DNR effort that included sampling at three stations; 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 61), meaning this stream provides important spawning and rearing habitat in the Two Island River drainage. This observation supports the early stream survey work of Moyle and Smith (1920), which cited Fredenberg Creek as valuable spawning area for Brook Trout. 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” (DNR, 2012).

Extremely 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.

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 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 Biological sampling

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 59. The results of this monitoring effort will be published in the fall/winter of 2017 and will be added to this report upon completion.

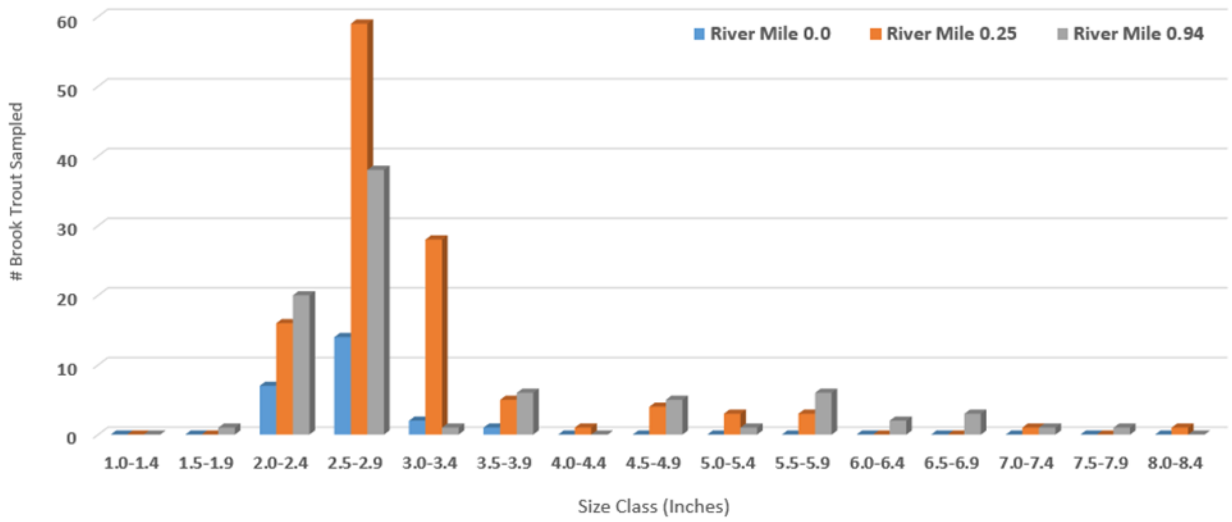


**Figure 61. Length frequency of Brook Trout sampled from Fredenberg Creek at three monitoring stations, September 2011.**

**Table 20: Fish species and population sizes observed in Fredenberg Creek during 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 |

### 6.2.3 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 in headwaters areas (Schlosser, 1995).

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

Fredenberg Creek is one of the coldest streams monitored to date on the North Shore (Figure 62). Temperature loggers were installed at three locations in Fredenberg Creek during the 2016 season; RM 0.05 (railroad crossing), RM 0.3 (CR 1), and RM 1.75 (Superior Hiking Trail crossing). Three loggers were also installed by DNR in 2012; RM (0.05 railroad crossing), RM 0.95 (near private residence on stream), and 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 the station. The coldest temperatures were observed near CR 1, and were only slightly warmer 1.5 river miles upstream near the headwaters. The entire length of Fredenberg Creek has water temperatures that are ideal for Brook Trout survival and growth

Temperature loggers were installed in Two Island River near its confluence with Fredenberg Creek in 2012 and 2016. Water temperatures in Two Island River were within the ideal range for Brook Trout growth 74 – 97% of the time, depending on the 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), which is evidence that inputs from Fredenberg Creek have a cooling effect on the Two Island River. Much colder temperatures (97% growth range) were observed in Two Island River near the railroad crossing just downstream of CR 1 , located approximately 2.9 stream-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.

Both Two Island River and Fredenberg Creek provide suitable water temperatures for supporting wild Brook Trout populations and other non-game species that require cold water. 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 than 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 during stressful mid-summer periods. Improving fish passage in Fredenberg Creek would provide an additional two miles of refuge for coldwater species in this river system.

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 |

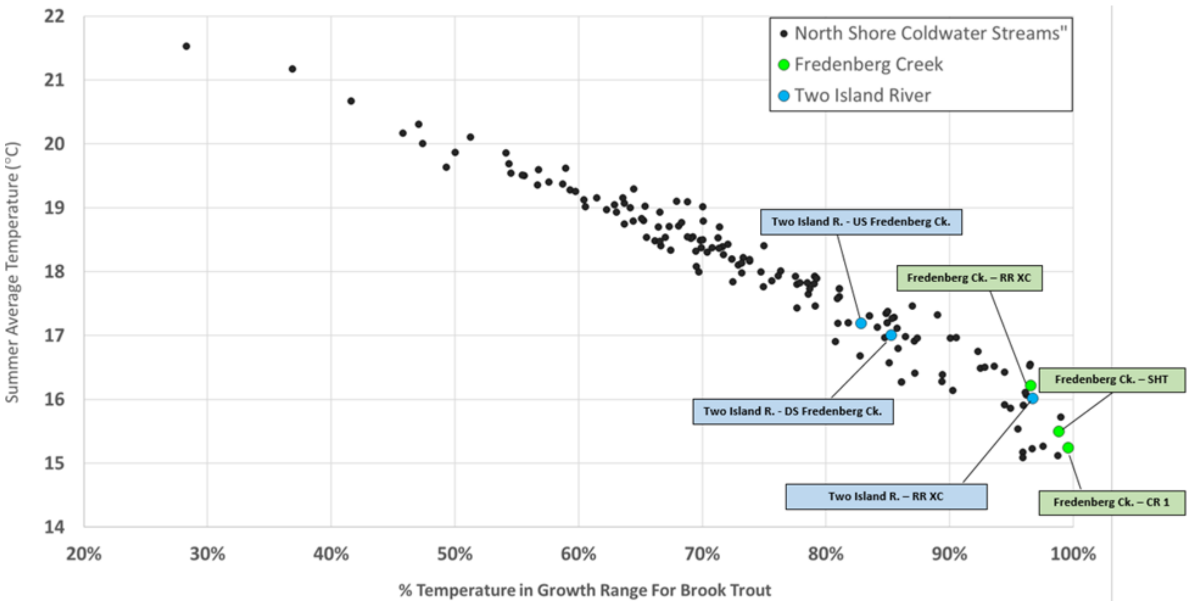


Figure 62. Scatter-plot of summer average water temperature and percentage temperature readings within the "growth" range for Brook Trout. Data are shown for Fredenberg Creek (green markers), Two Island River (blue markers), and other North Shore coldwater streams (black markers).

Figure 63. Photos of the Two Island River/ Fredenberg Creek confluence area. Confluence indicated by yellow arrow.

## 6.2.4 Physcial 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 of 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 1.5-mile reach of Fredenberg Creek upstream of CR 1 was assessed 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. The streambed was dominated by clean, coarse substrate that support healthy macroinvertebrate community and provide 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 64). 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 for at least 1.5 miles upstream of CR 1, and a restoration to re-establish connectivity of this reach to the Two Island River is strongly recommended. Restoring year-round connectivity to this high-quality coldwater reach of Fredenberg Creek would provide additional spawning and rearing habitat, as well as seasonal coldwater refuge for Brook Trout within the greater Two Island River system.

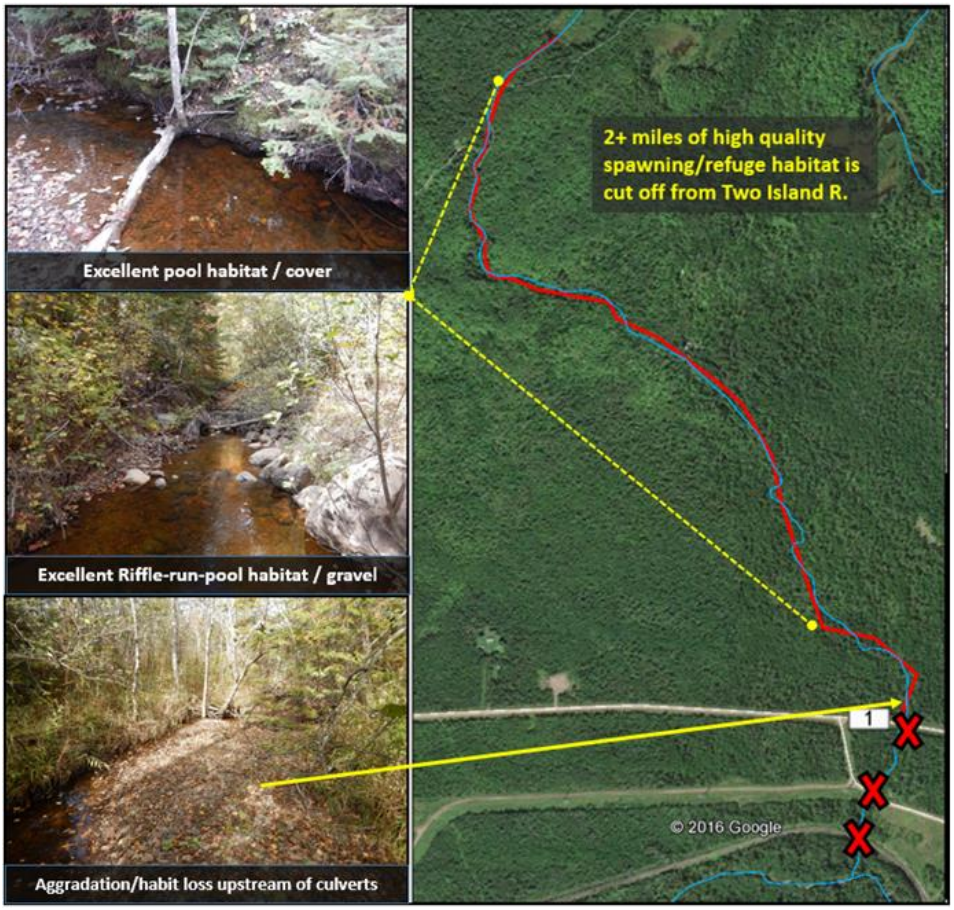


**Figure 64. Connectivity between a 2-mile reach of Fredenberg Creek and the Two Island River has been reduced by three road culverts, which are partial to complete barriers to fish migration.**

### 6.2.5 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, 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 (Figure 65 and 66). A stable reach located approximately 0.5 miles upstream of CR 1 was surveyed using the same methods. This reach is not influenced by the crossing at CR 1. This “reference reach” data is useful for determining the departure from a stable condition in Fredenberg Creek near the CR 1 culvert and downstream road crossings.

A plot of the Fredenberg Creek profile with the superimposed culvert outline and road prism 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 due to 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 67 and 68) shows that the channel has evolved into a braided D4 stream type, which is common in reaches where the rate of sediment supply far exceeds the rate of sediment transport. Fredenberg Creek at this location has a width/depth ratio of nearly 90 and shows signs of excessive deposition 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 indicate channel incision downstream of CR1 (Figure 69),most likely the result of the overly narrow culvert creating a “firehose 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 test the hypothesis that the culvert is out of equilibrium with the stream system and causing upstream aggradation and downstream incision, a reference reach located 0.5 miles upstream of CR 1 crossing was surveyed using the same methods. No symptoms of road crossing influence were observed in the reference reach. Approximately 275 feet of stream channel data was collected, including thalweg water surface, and bankfull stage elevations. 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.

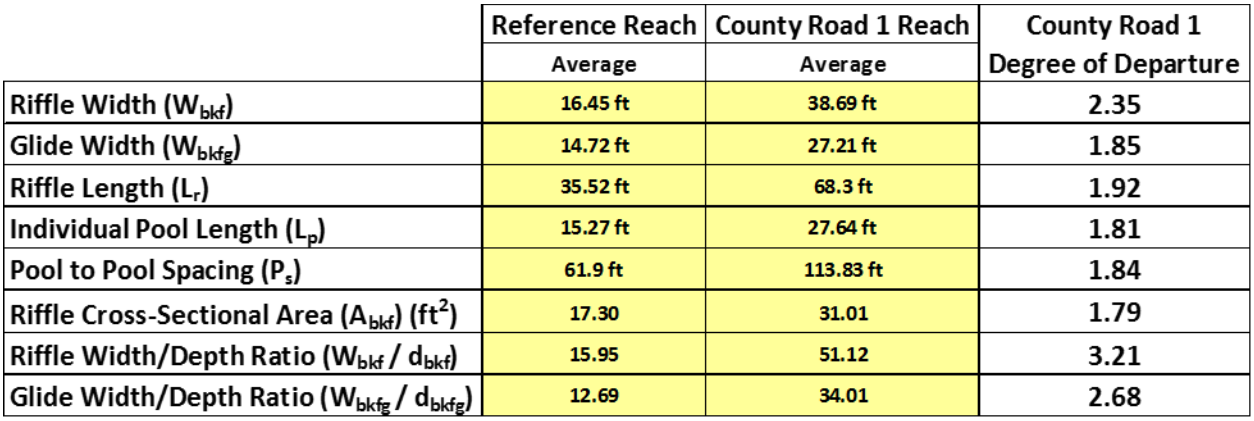
The resulting profile shows a much more consistent slope of 1.8% throughout the reach (Figure 66). Cross-section data from the reference reach (Figure 69) shows a stream channel with good floodplain connection and a width/depth ratio of 16.4, which is more favorable for maintaining sediment transport than the wider, shallower channel near CR 1. The increased 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 deposits on the floodplain and channel margins, rather than the channel bottom, which maintains clean spawning gravels, (3) keeping pools scoured deep, which creates overhead cover and habitat diversity.

Additional geomorphic characteristics of the reference reach showed just how much of an impact the culvert is having on the bankfull channel at CR 1 (Table 22). This impact is called the “degree of departure” and is expressed as a dimensionless ratio (Study Reach Parameter / Reference Reach Parameter). Riffle features near County Road 1 are, on average, 2.3 times wider (at bankfull flow) than 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 for Brook Trout spawning habitat, as brook trout are 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.

Pool-to-pool spacing, riffle lengths, and pool lengths immediately upstream of CR 1 are all several times longer than observed within the reference reach 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, and thus often lack depth and thus provide lower quality cover for fish.

The degradation of physical habitat upstream of CR 1 can be directly linked to the undersized culvert at this road crossing. Replacing the current culvert with a bridge or culvert that matches the bankfull width of 15.5 feet will restore natural transport of water and sediment through this crossing, and allow this reach to readjust and stabilize over time.

**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 |

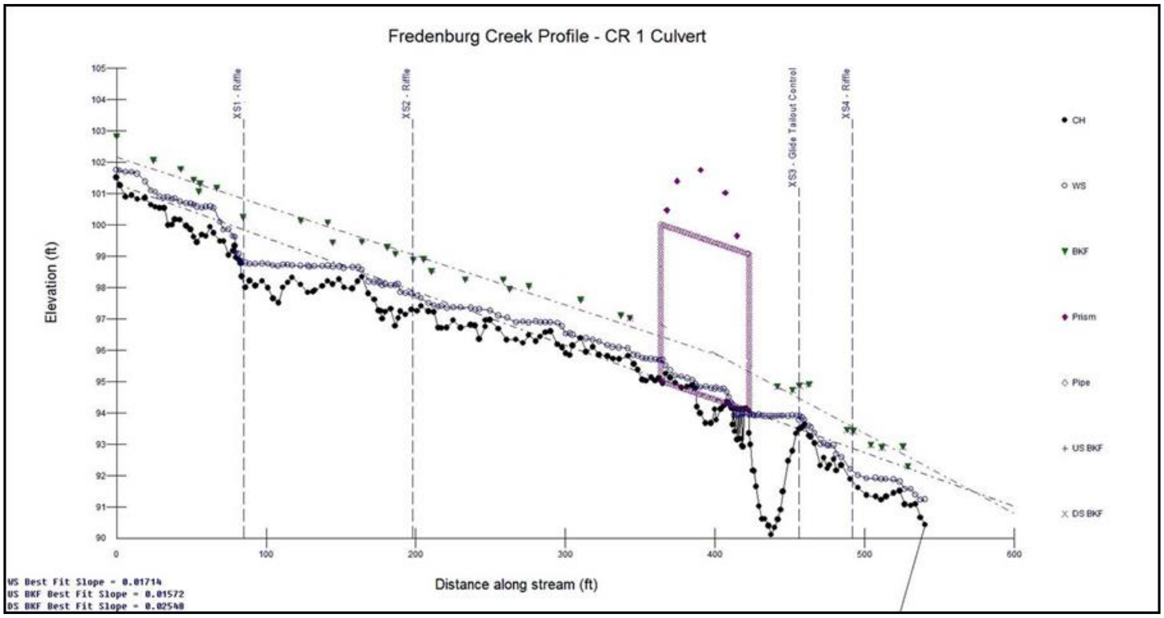


**Figure 65. Profile of Fredenberg Creek showing change in channel slope upstream and downstream of the CR1 crossing.**

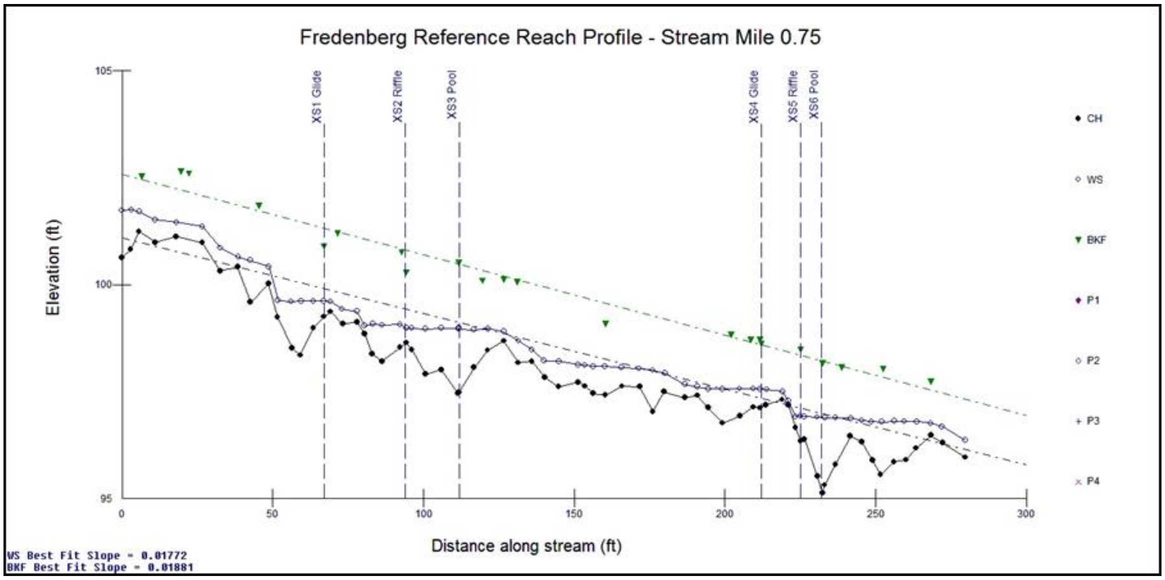


**Figure 66. Channel profile of Fredenberg Creek reference reach at stream mile 0.75.**

**Figure 67. Photo showing the effects of excessive deposition in Fredenberg Creek upstream of CR1.**

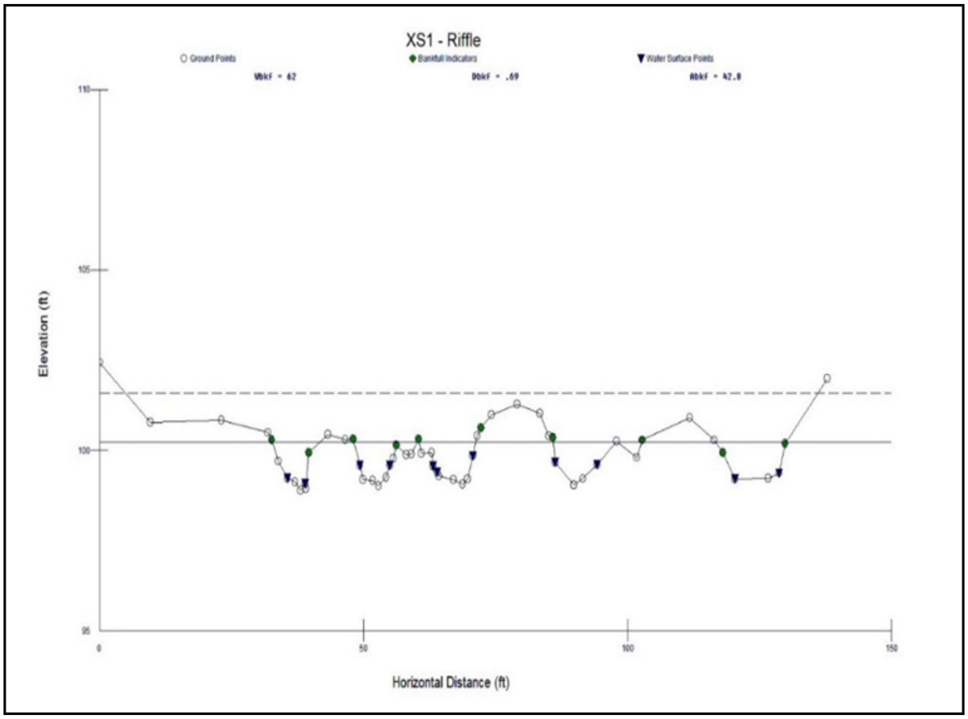


**Figure 68. Surveyed riffle cross-section upstream of CR 1. The undersized and improperly set road culvert at CR 1 is causing excessive deposition of sediment and increased width to depth ratio upstream of the crossing.**

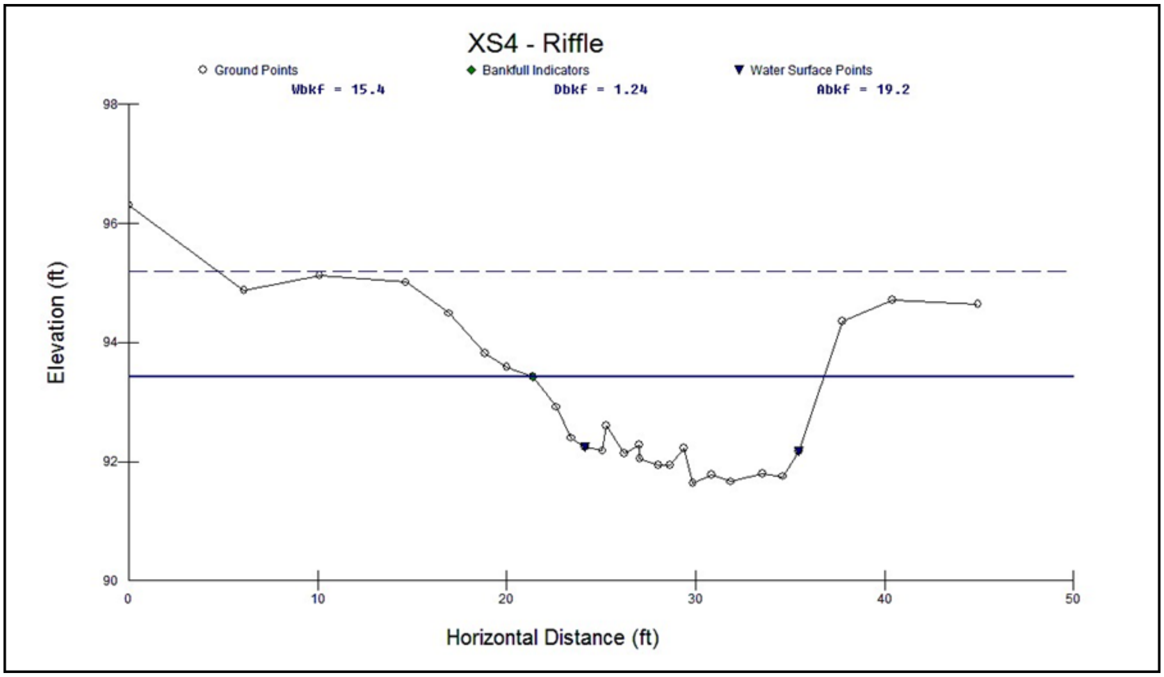


Figure 69. Channel cross-section of Fredenberg Creek approximately 70 feet downstream of CR1.

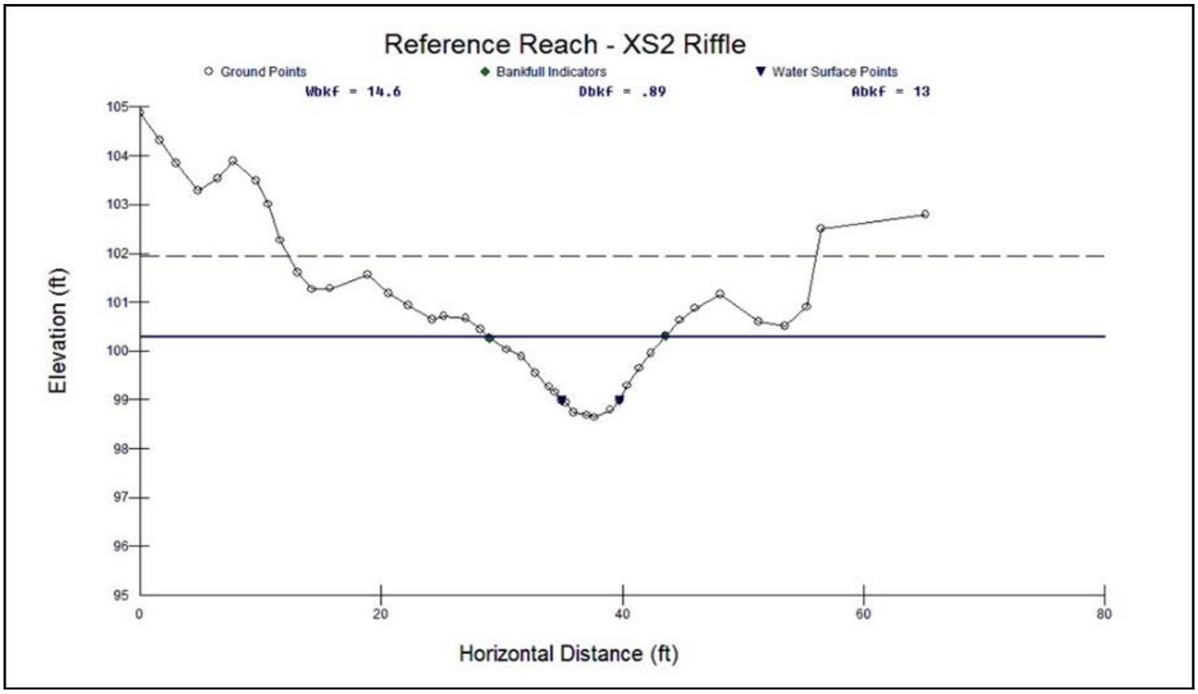


Figure 70. Riffle cross-section of the Fredenberg Creek reference reach at stream-mile 0.75.

### 6.2.6 Restoration recommendations for Fredenberg Creek

Watersheds along the North Shore of Lake Superior are a stronghold for native Brook Trout. However, a changing climate and habitat fragmentation resulting from roads and other landscape alterations threaten the longevity of these critical habitats. The focus of the proposed project is restoring connectivity between two high quality wild Brook Trout streams near Schroeder, Minnesota. Fredenberg Creek is a 2nd 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.

## 6.3 Hockamin Creek and West Branch Baptism River

### 6.3.1 Background

Hockamin Creek is a 3rd order (Strahler) coldwater stream, originating in a series of springs and swamps, before flowing approximately 12 miles to its confluence with the West Branch Baptism River in Finland, Minnesota. A relatively small population of native Brook Trout is sustained in several reaches of Hockamin Creek through natural reproduction. This stream was heavily fished in the 1920's through the 1950's with limits of 8-12 brook trout commonly taken, and unconfirmed reports of brook trout of up to 18 inches during this period were recorded (DNR, 2011). A 1981 DNR assessment reported the fish pressure as "light," no current fishing pressure estimate is available but pressure is presumed to be light.

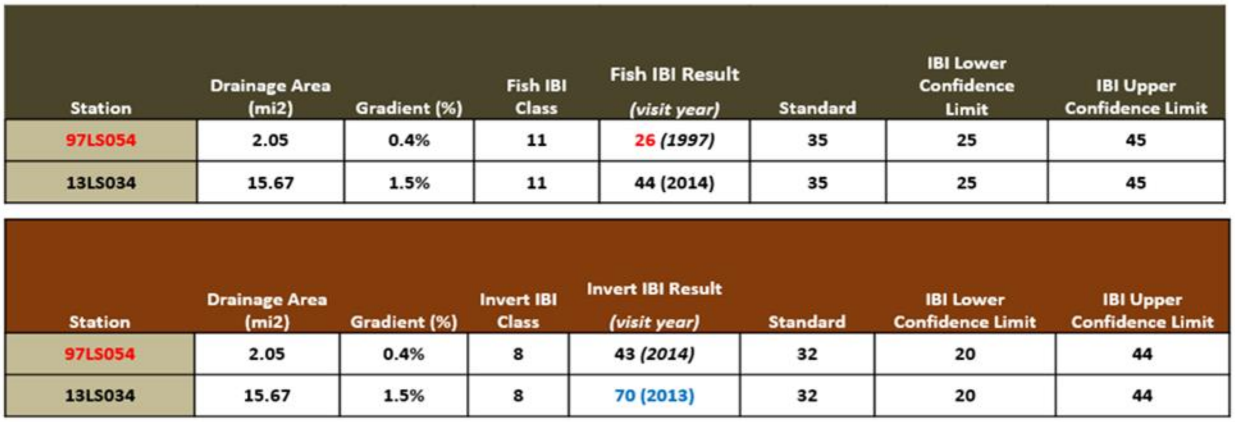
MPCA sampled two locations on Hockamin Creek for the purpose of index of biological integrity (IBI) assessments (Figure 73). Fish IBI results for these stations (13LS034 and 97LS054) are "fair" in comparison to many coldwater streams in the area. Station 97LS054 is located near the headwaters of the watershed and offers marginal coldwater habitat, likely due to natural background conditions (e.g. small drainage area, wetland influence). The dominant fish species at this location (Brook Stickleback/Central Mudminnow) suggest that DO and streamflow are limiting factors.

Brook Trout were present at or near station 13LS034 in 1981 and again in 2011 and 2014. No trout were sampled at this station in 2013. Despite the presence of Brook Trout at this station, FIBI scores are only narrowly above the impairment threshold due to the presence of several pioneer species (Creek Chub/Johnny Darter) and the omnivorous White Sucker. These species are commonly found in many marginal-fair coldwater streams in the region and are not necessarily and indicator of a degraded stream.

Macroinvertebrate IBI (MIBI) scores are available for two stations on Hockamin Creek (97LS054 and 13LS034). Results from both stations meet the general use standards for coldwater MIBI (Table 23). MIBI results from station 13LS034 meet exceptional use criteria and follow the same pattern as the fish results with a higher score than the station in the headwaters. The macroinvertebrate community at 97LS054 is likely limited by many of the same factors as the fish community at that location.

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. Hockamin Creek and other coldwater streams with “patchy” networks of suitable habitat may be the first to lose sensitive coldwater taxa if fish migration barriers such as culverts remain abundant in North Shore watersheds.

**Table 23. Hockamin Creek biological sampling stations, results, and applicable assessment criteria. 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) | Gradient (%) | Fish IBI Class | Fish IBI Result *(visit year)* | Standard | IBI Lower Confidence Limit | IBI Upper Confidence Limit |
|---|---|---|---|---|---|---|---|
| 97LS054 | 2.05 | 0.4% | 11 | 26 *(1997)* | 35 | 25 | 45 |
| 13LS034 | 15.67 | 1.5% | 11 | 44 (2014) | 35 | 25 | 45 |

| Station | Drainage Area (mi2) | Gradient (%) | Invert IBI Class | Invert IBI Result *(visit year)* | Standard | IBI Lower Confidence Limit | IBI Upper Confidence Limit |
|---|---|---|---|---|---|---|---|
| 97LS054 | 2.05 | 0.4% | 8 | 43 *(2014)* | 32 | 20 | 44 |
| 13LS034 | 15.67 | 1.5% | 8 | 70 (2013) | 32 | 20 | 44 |

## 6.3.2 Monitoring and restoration objectives

The Lake Superior North Monitoring and Assessment Report (MPCA, 2015) noted a perched road culvert just upstream of biological monitoring station 13LS034 on Heffelfinger Rd (Figure 71). Additional reconnaissance in the watershed revealed an additional perched culvert 0.7 river miles downstream at Breezy Lane Rd (Figure 71). These perched culverts are barriers to upstream fish migration at all or most flows, and effectively eliminate fish access to 10-11 miles of Hockamin Creek located upstream from the crossings. Fish and other aquatic organisms are unable to migrate upstream from the lower reaches of Hockamin Creek and the W. Branch Baptism River.

Additional data were collected to evaluate stream crossings for proper sizing, alignment, and aquatic organism passage. In addition, stream temperature data were collected at several locations in Hockamin Creek and the West Branch Baptism River to investigate thermal refuge areas and suitability for Brook Trout and other coldwater taxa. These data sets were used to prioritize recommendations for removal of fish passage barriers in the watershed and protection measures for quality habitat areas.

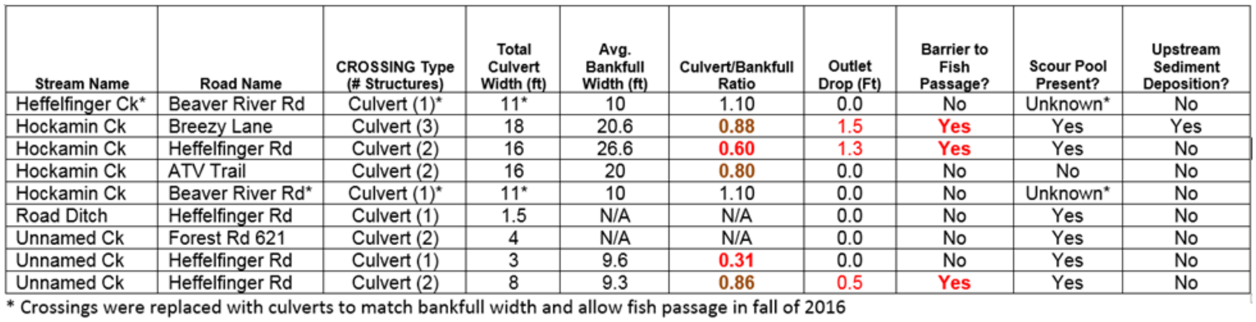
## 6.3.3 Road crossing assessment and barriers to fish passage

Eleven stream crossings by roads or trails were identified in the Hockamin Creek watershed using aerial photography. Five of the crossings are located on the main stem of Hockamin Creek and the rest on tributary streams of varying sizes. A rapid assessment of eight crossings was completed using DNR protocols (see appendix A) to evaluate for proper sizing, installation, and potential to reduce or eliminate fish passage or cause physical habitat degradation. The remaining three crossing are located in the headwaters of first order tributaries and were not assessed during this study.

Three of the five crossings on the main stem of Hockamin Creek are undersized based on bankfull channel widths collected at each site. The crossing at Heffelfinger road is significantly undersized (0.60 culvert to bankfull width ratio), while the other two undersized crossings are much closer to proper bankfull design criteria (0.80-0.88 ratio) (Table 24). Several crossings of tributary streams are also undersized, particularly the crossing of unnamed coldwater tributary at Heffelfinger Road with a culvert to bankfull width ration of 0.31. Culvert replacements at two locations (Heffelfinger Creek at Beaver River Road; Hockamin Creek at Beaver River Road) were completed by DNR Forestry in the fall of 2016. Prior to replacement, both of these crossings were undersized and impeded aquatic organism passage. The newly installed crossings match bankfull width and have restored passage for aquatic life.

Outlet drops (perched culverts) ranging in height from 0.5 – 1.5 feet were observed during baseflow (low flow) at three crossings in the Hockamin Creek Watershed. Several crossings in the lower reaches of Hockamin Creek present significant to severe barriers to fish passage (Table 24). The crossing at Breezy Lane is considered a “significant barrier” with limited to no fish passage at low to moderate flow conditions. The Heffelfinger Road crossing of Hockamin Creek is a “severe barrier” with an outlet drop present during all flow conditions, which eliminates passage for all or most species.

**Table 24. Summary of crossing assessments completed in the Hockamin Creek Watershed.**



| Stream Name | Road Name | CROSSING Type (# Structures) | Total Culvert Width (ft) | Avg. Bankfull Width (ft) | Culvert/Bankfull Ratio | Outlet Drop (Ft) | Barrier to Fish Passage? | Scour Pool Present? | Upstream Sediment Deposition? |
|---|---|---|---|---|---|---|---|---|---|
| Heffelfinger Ck* | Beaver River Rd | Culvert (1)* | 11* | 10 | 1.10 | 0.0 | No | Unknown* | No |
| Hockamin Ck | Breezy Lane | Culvert (3) | 18 | 20.6 | **0.88** | 1.5 | **Yes** | Yes | Yes |
| Hockamin Ck | Heffelfinger Rd | Culvert (2) | 16 | 26.6 | **0.60** | 1.3 | **Yes** | Yes | No |
| Hockamin Ck | ATV Trail | Culvert (2) | 16 | 20 | **0.80** | 0.0 | No | No | No |
| Hockamin Ck | Beaver River Rd* | Culvert (1)* | 11* | 10 | 1.10 | 0.0 | No | Unknown* | No |
| Road Ditch | Heffelfinger Rd | Culvert (1) | 1.5 | N/A | N/A | 0.0 | No | Yes | No |
| Unnamed Ck | Forest Rd 621 | Culvert (2) | 4 | N/A | N/A | 0.0 | No | Yes | No |
| Unnamed Ck | Heffelfinger Rd | Culvert (1) | 3 | 9.6 | **0.31** | 0.0 | No | Yes | No |
| Unnamed Ck | Heffelfinger Rd | Culvert (2) | 8 | 9.3 | **0.86** | 0.5 | **Yes** | Yes | No |

* Crossings were replaced with culverts to match bankfull width and allow fish passage in fall of 2016

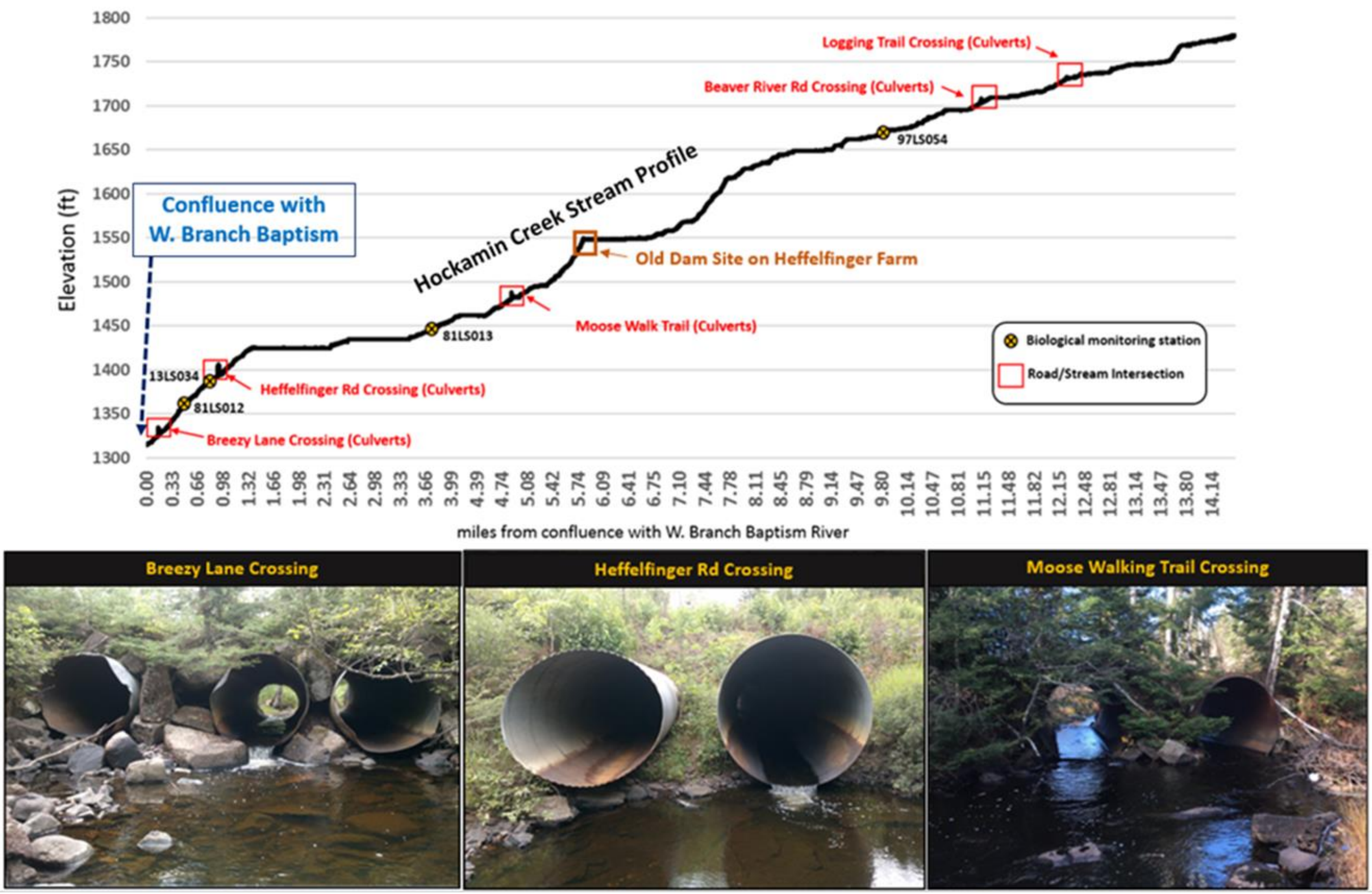


**Figure 71. Profile of Hockain Creek generated with 1-m LIDAR elevation and watercourse data (top). Crossings of Hockamin Creek at three locations; Breezy Lane, Heffelfinger Rd, and Moose Walk Trail. The crossings at Breezy Lane and Heffelfinger Rd are barriers to aquatic organism passage and should be replaced.**

### 6.3.4 Water temperature and coldwater suitability

Water temperatures in Hockamin Creek are highly variable by stream reach due to beaver dams, stream morphology, riparian vegetation, and hydrogeology. Continuous stream temperature data were collected at several stations during the 2011, 2014, 2015, and 2016 monitoring seasons. Loggers were generally deployed within biological monitoring reaches as a means of developing linkages between thermal regime and changes in fish and macroinvertebrate assemblages. Additional consideration during site selection was given to the location of fish migration barriers, as thermal refuge areas are a critical factor in prioritizing barrier removal.

As a general trend, water temperatures warm considerably as Hockamin Creek courses from its headwaters to its confluence with the West Branch Baptism River. Temperatures remained within the "growth range" for Brook Trout 83% - 95% of the summer (June-August) at stations 81LS013 (RM 4.84) and the DNR monitoring station at RM 10.70 (Beaver River Rd) (Figure 72). Temperatures remain cold and suitable for Brook Trout due a heavily forested riparian corridor, and a stream channel and valley that is predominantly narrow and moderately entrenched aside from several areas affected by beaver activity and/or a broadening of the river valley. The channel also courses between several prominent topographic features in this reach, which likely increase groundwater inputs and results in colder water temperatures than other areas of the watershed.

Water temperatures recorded at stations 13LS034 (Heffelfinger Rd) and near the mouth of Hockamin Creek were considerably warmer, with only 62% - 70% of the summer temperature readings within the growth range. Stressful temperatures for Brook Trout regularly occur 30-40% of the summer season within this portion of Hockamin Creek. A beaver dam located approximately 0.5 river miles upstream of Heffelinger Road impounds the creek for a length of nearly 2 miles (Figure 71). The resulting stagnant water and increased exposure to solar radiation likely contribute significantly to the warming water temperatures.

Low numbers of wild Brook Trout (min = 3; max = 9) have been sampled near Heffelfinger Road despite the marginal water temperatures, possibly due to the high quality physical habitat conditions in this reach and/or localized thermal refugia not detected by temperature logger deployments (e.g seeps or upwelling of groundwater). No reportable biological monitoring data is available for the extreme lower reaches of Hockamin Creek (Breezy Lane and downstream to W. Branch Baptism) but visual observations of Brook Trout have been common during site visits to this area.

Slightly larger populations of Brook Trout (min = 7; max = 14) have been observed upstream at station 86LS013, where summer water temperatures are more suitable for coldwater taxa. Slimy Sculpin, another stenothermic coldwater species, has also been sampled at this location. In addition to these desirable coldwater species, taxa richness was lower (n=3) and the pioneer and tolerant species observed elsewhere in Hockamin Creek were not observed at this location.

Based on water temperature results, biological data, and aerial photo evaluations, the optimal coldwater habitat in Hockamin Creek is located between its confluence with Heffelfinger Creek (RM 5.8) and station 86LS013 (RM 3.7) and perhaps localized areas upstream of the Heffelfinger Creek confluence that offer adequate DO and physical habitat (higher gradient, non-impounded areas). Due to the aquatic organism, passage barriers at Heffelfinger Rd and Breezy Lane, trout and non-game species downstream of RM 1.0 are unable to access this quality coldwater habitat. The barriers also effectivity eliminate aquatic connectivity between the West Branch Baptism River and 13 miles of Hockamin Creek.

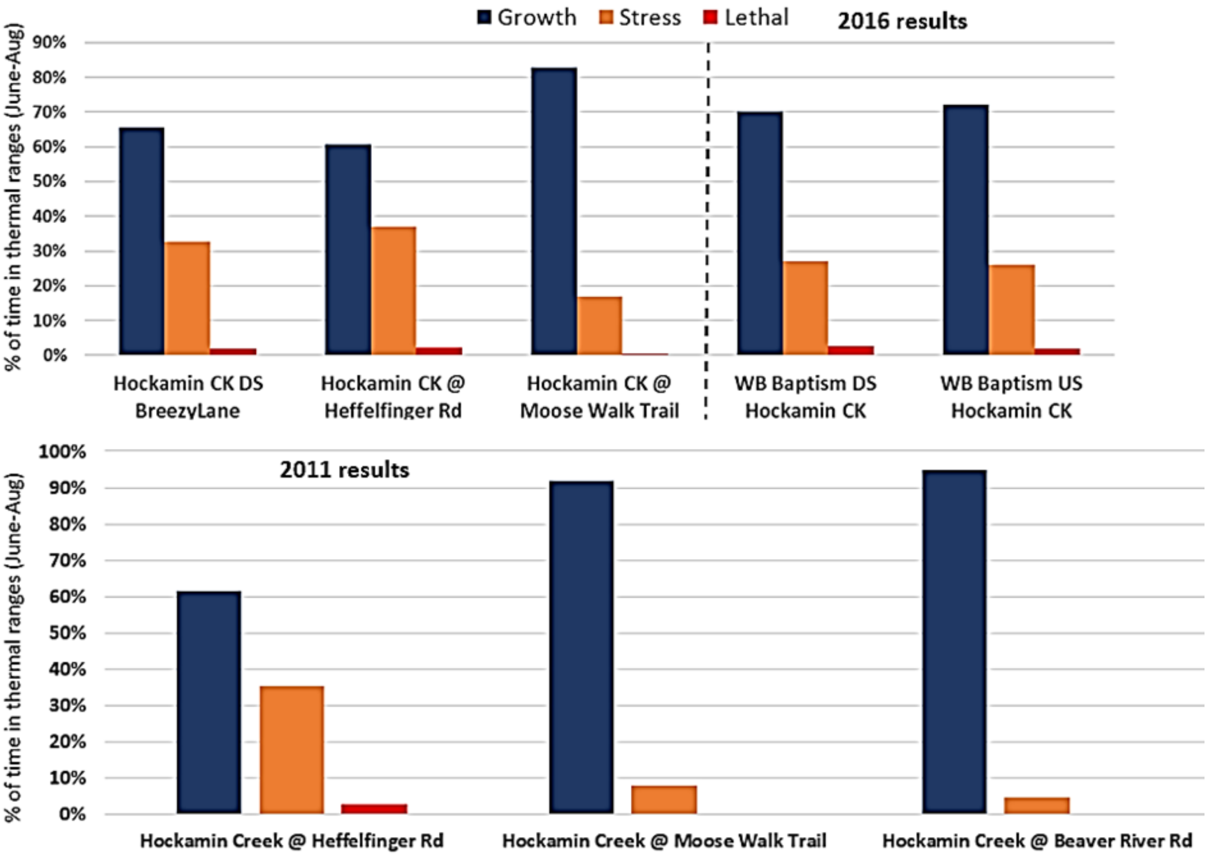


**Figure 72. Water temperture summaries for several monitoring stations on Hockamin Creek and West Branch Baptism River.**

### 6.3.4 Recommendations for restoration and protection

Perched and undersized road culverts in lower Hockamin Creek are barriers to upstream fish migration at all or most flows, and greatly reduce or eliminate access to 10-11 miles of habitat upstream of the crossings (not including additional mileage from tributary streams). Fish and other aquatic organisms are unable to migrate upstream from the lower reaches of Hockamin Creek and the W. Branch Baptism River. Restoring connectivity would allow access to the highest quality coldwater habitat in the Hockamin Creek Watershed, and provide a long-term or permanent connection to larger waterbodies downstream.

The highest priority crossings to restore are Heffelfinger Road and Breezy Lane crossings of Hockamin Creek, both of which are located within one river mile of the confluence with the West Branch Baptism River (Figure 73). 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.

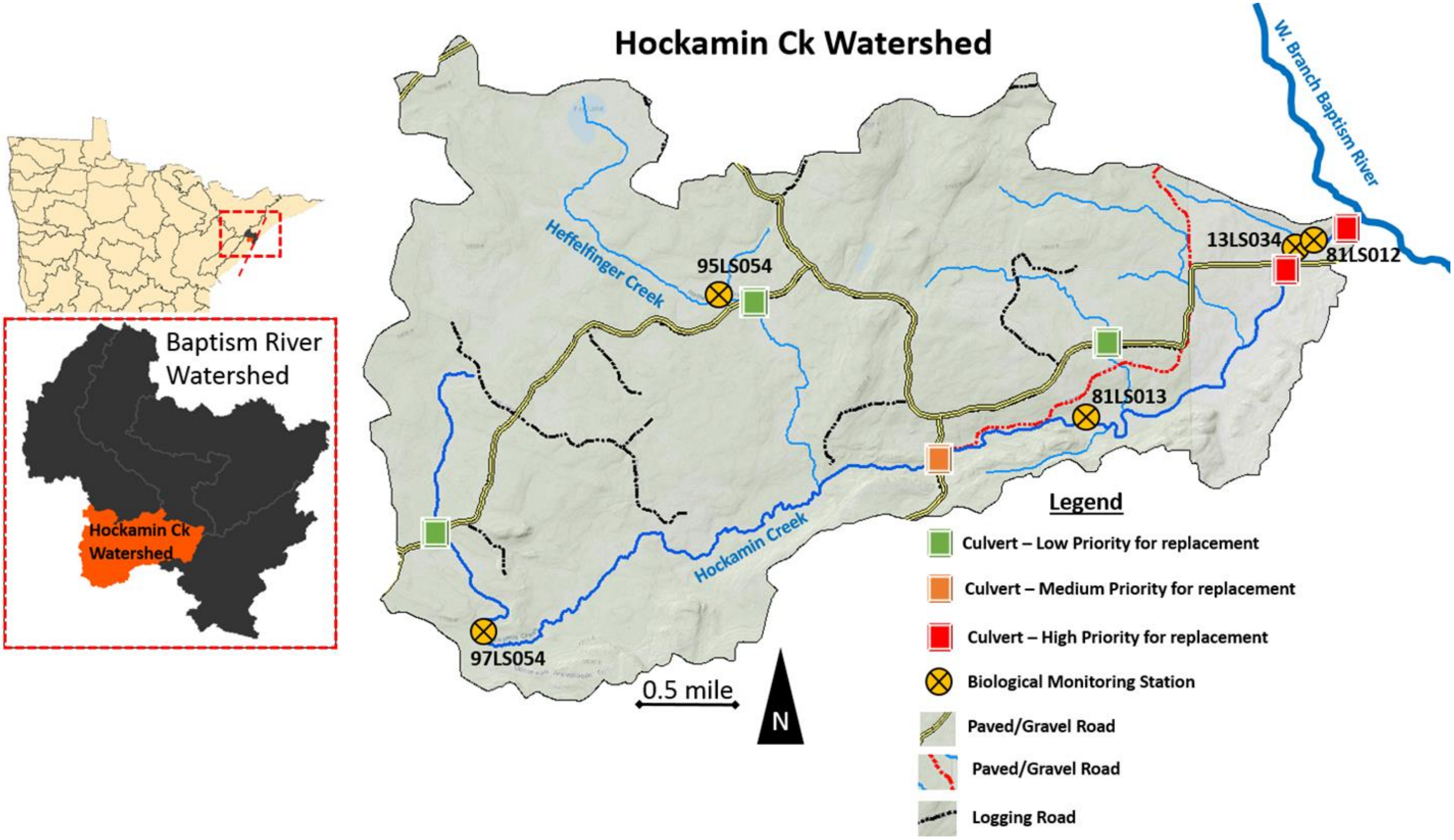


**Figure 73. Hockamin Creek road crossings, monitoring locations, and prioritization ratings for culvert replacements to restore fish passage.**

## 6.4 Lindstrom Creek

Lindstrom Creek is a 5.3 mile-long coldwater tributary to the Baptism River originating from several hillslope springs north of Lax Lake. Approximately 32% of its watershed is located within Tettegouche State Park, where development and land alterations have been minimal. Outside of the park boundaries, portions of the watershed have been developed for a variety of land uses – residential, industrial (gravel mining), and recreational (ATV/snowmobile trails). Several major roads, minor roads, and private drives cross Lindstrom Creek and its major tributaries. Concerns over fish passage and loss of aquatic connectivity due to this road and trail network prompted an investigation of stream crossings in this watershed.

### 6.4.1 Biological data

DNR has sampled fish populations in Lindstrom Creek sporadically over the past 60 years (1954, 1955, 1971, 1981, 2000, and 2010). Although individual populations have varied spatially and temporally, Brook Trout have been observed in all DNR assessments, which covers five stations on the main stem of the creek (Figure 74). In the most recent assessment (2010), Brook Trout were observed at all three monitoring stations sampled (RM 0.0, 2.26, and 2.84). Brook Trout have not been stocked in Lindstrom Creek since 1967 and populations are maintained solely by natural reproduction. Rainbow Trout continue to be stocked in the Baptism River, and several were sampled at the RM 0.0 station of Lindstrom Creek in 2010. This observation proves there is some level of connectivity between these two streams for a variety of age-classes despite several bedrock drops near their confluence.

### 6.4.2 Stream temperature and physical habitat conditions

DNR monitored water temperatures in Lindstrom Creek at several locations in 2000 and 2010. Temperatures were predominantly in the optimal range for the survival and growth of Brook Trout, particularly at the RM 2.29 and RM 2.86 stations. Water temperatures remained in the optimal range between 94-100% of the monitoring period (mid-summer to early fall) at these stations. Temperatures at RM 0.0 were less favorable, yet still adequate for Brook Trout survival and growth (80-89% readings in growth range, 11-19% readings exceeded “stress” threshold). Available data suggest that the coldest water temperatures in Lindstrom Creek are found near the RM 2.26 monitoring station (Lax Lake Rd crossing), but the spatial extent of the current data is somewhat limited.

Adequate baseflow and thermal regime for supporting trout and other sensitive aquatic life is sustained due to prominent groundwater inputs in this watershed. Lindstrom Creek has been regularly classified as a highly quality trout stream in DNR reports. Physical habitat ratings are excellent at the existing monitoring sites, and the abundance of clean gravel and cobble support healthy aquatic macroinvertebrate communities and a wild, self-sustaining Brook Trout population.

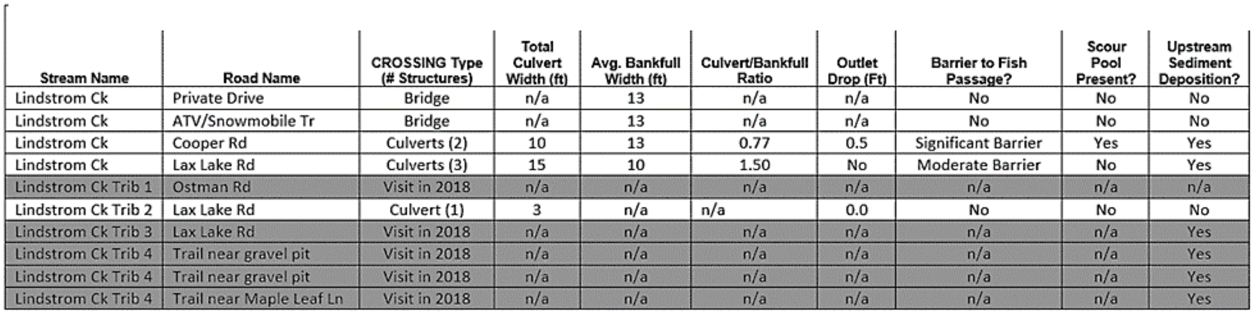
### 6.4.3 Road crossing assessment and barriers to fish passage

Ten stream crossings were identified in the Lindstrom Creek Watershed using aerial photos and LIDAR derived stream profiles (Figure 74 and Table 25). Four crossings are located on the main stem of Lindstrom Creek, two of which are span bridges located within 0.4 river miles of the confluence with the Baptism River. The remaining crossings are all culverts, located on four primary tributaries to Lindstrom Creek. An ATV trail crosses the main stem of the creek near the biological monitoring station at RM 2.84. No bridge or culvert is in place at this crossing, and ATV traffic is causing streambank/streambed erosion and channel widening. Increased embeddedness of coarse gravel and cobble substrate was noted at crossing (DNR, 2010).

Field inspections were completed at five crossings in 2017. The remainder of the crossings will be evaluated in 2018. Two barriers to fish migration were observed noted on the main stem of Lindstrom Creek. The first barrier is located approximately 0.5 river miles upstream of the Lindstrom Creek-Baptism River confluence at Cooper Rd. This crossing is considered a significant barrier due to an outlet drop of 0.5 ft, a partially blocked inlet, a lack of natural substrate, and a culvert span that is less than bankfull width (0.77 culvert/bankfull width ratio) (Table 27). The next barrier in the upstream direction is located at Lax Lake Rd, approximately RM 2.26 of Lindstrom Creek. This crossing was rated a minor barrier due to partially plugged culverts, low water depth within culverts, and lack of natural substrate within the culvert.

Additional barriers to aquatic organism passage are predicted on several main tributaries upon completion of field inspections in 2018. Several signs of improperly sized and/or installed culverts, such as downstream scour pools and “ponding (i.e. stagnant water) upstream of crossings, are evident in the most recent aerial photos. In addition, there appears to be several main tributary streams that are impeded by undersized culverts and the road grade along Lax Lake Rd.

**Table 25. Results of cuvlert asssessments within the Lindstrom Creek Watershed**



| Stream Name | Road Name | CROSSING Type (# Structures) | Total Culvert Width (ft) | Avg. Bankfull Width (ft) | Culvert/Bankfull Ratio | Outlet Drop (Ft) | Barrier to Fish Passage? | Scour Pool Present? | Upstream Sediment Deposition? |
|---|---|---|---|---|---|---|---|---|---|
| Lindstrom Ck | Private Drive | Bridge | n/a | 13 | n/a | n/a | No | No | No |
| Lindstrom Ck | ATV/Snowmobile Tr | Bridge | n/a | 13 | n/a | n/a | No | No | No |
| Lindstrom Ck | Cooper Rd | Culverts (2) | 10 | 13 | 0.77 | 0.5 | Significant Barrier | Yes | Yes |
| Lindstrom Ck | Lax Lake Rd | Culverts (3) | 15 | 10 | 1.50 | No | Moderate Barrier | No | Yes |
| Lindstrom Ck Trib 1 | Ostman Rd | Visit in 2018 | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Lindstrom Ck Trib 2 | Lax Lake Rd | Culvert (1) | 3 | n/a | n/a | 0.0 | No | No | No |
| Lindstrom Ck Trib 3 | Lax Lake Rd | Visit in 2018 | n/a | n/a | n/a | n/a | n/a | n/a | Yes |
| Lindstrom Ck Trib 4 | Trail near gravel pit | Visit in 2018 | n/a | n/a | n/a | n/a | n/a | n/a | Yes |
| Lindstrom Ck Trib 4 | Trail near gravel pit | Visit in 2018 | n/a | n/a | n/a | n/a | n/a | n/a | Yes |
| Lindstrom Ck Trib 4 | Trail near Maple Leaf Ln | Visit in 2018 | n/a | n/a | n/a | n/a | n/a | n/a | Yes |

## 6.4.4 Recommendations for restoration

Lindstrom Creek is a high quality coldwater stream that supports a wild Brook Trout population throughout most of its length, and provides rearing habitat for Rainbow Trout stocked into the Baptism River. This relatively pristine watershed is partially protected by Tettegouche State Park, but several road and trail networks disrupt longitudinal connectivity and negatively influence aquatic organism passage. Replacing the poor crossings at Cooper Road and Lax Lake Road with open bottom pipe-arch design crossings or bridges would create a contiguous 5+ miles of high quality coldwater habitat along the main stem of Lindstrom Creek.

Additional culvert replacements may be recommended after the remaining crossings are assessed in 2018. Several spring-fed tributaries appear to be impounded and fragmented by private access roads, trails, or major public roads.

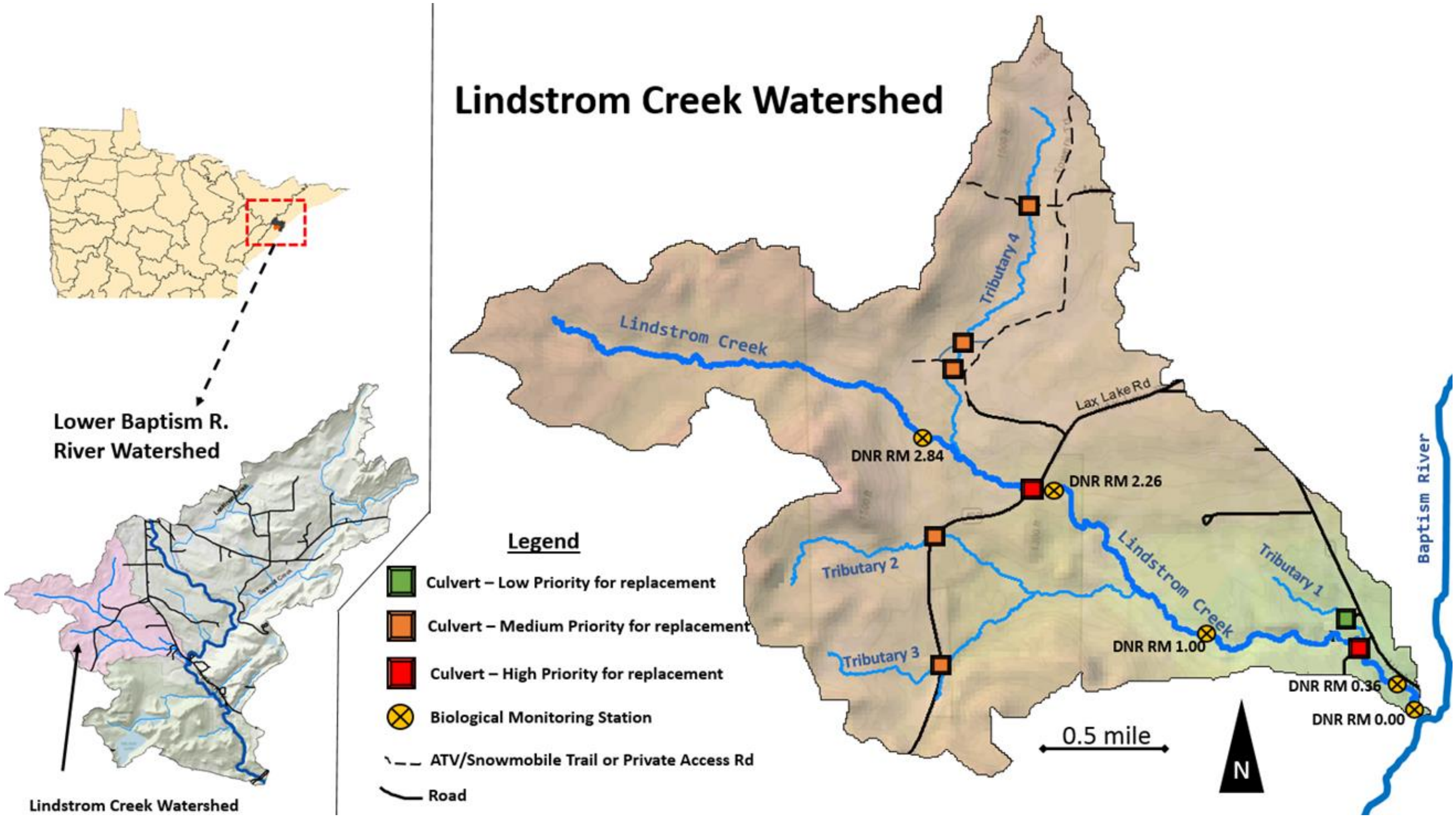


**Figure 74. Biological monitoring stations and road and trail crossings within the Lindstrom Creek Watershed. Culverts are prioritized for replacement based on their ability to allow for fish passage, sizing, and overall condition.**

**Figure 75**. **Perched and improperty set culverts at the Cooper Rd crossing create a partial barrier to fish passage (left), while a span bridge located just downstream allows full fish passage and helps maintain channel stability.**

**Figure 76. Looking downstream at Cooper Rd crossing of Lindstrom Creek. Blockages of the river-right culvert distrupt sediment transport and alter current velocities and water depth and velocity within the structures.**

**Figure 77. Perched and improperty set culverts at the Cooper Rd crossing create a partial barrier to fish passage (left), while a span bridge located just downstream allows full fish passage and helps maintain channel stability.**

## 6.5 Wanless Creek

Wanless Creek is a small tributary of Houghtaling Creek within the greater Cross River Watershed. Wild Brook Trout were present (n=7) in a 2013 sampling of station 13LS043 (area highlighted in red in Figure 78) 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. Overall, physical habitat conditions are excellent for supporting Brook Trout and other sensitive coldwater obligate fish and invertebrate taxa. However, a pair of undersized road culverts on Forest Road 1855 is disrupting sediment transport and causing pooling and sediment aggradation for several hundred feet upstream of the crossing (Figure 78). Additionally, these culverts are likely impeding fish passage 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.

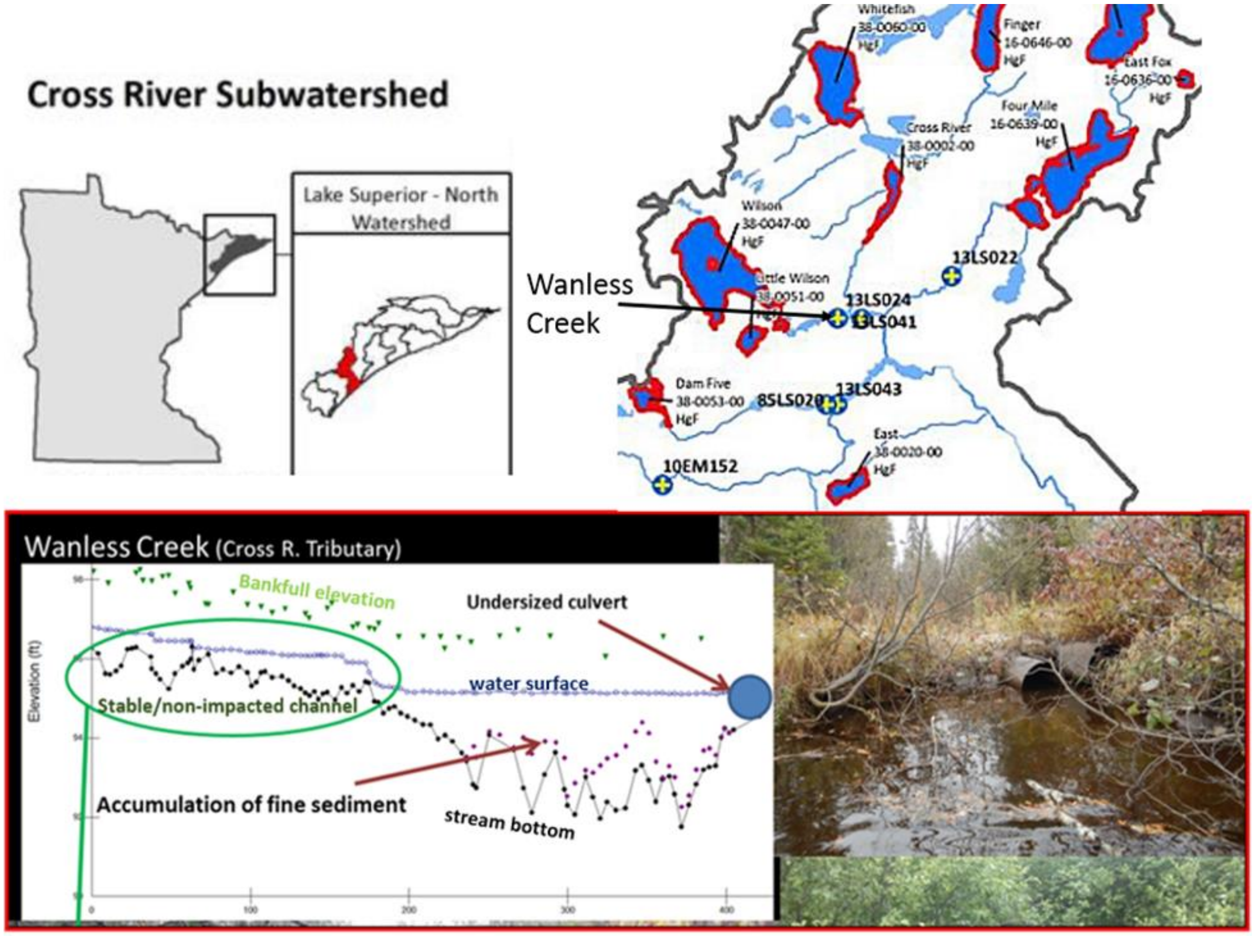


**Figure 78. Location of Wanless Creek (left) and impacts of an undersized and improperly set culvert at Superior National Forest Road 1855.**

## 6.6 Aquatic connectivity issues along old LTV railroad grade

The Cliffs-Erie/LTV railroad line opened in 1956 to transport taconite from Hoyt Lakes, Minnesota to Schroeder, Minnesota. The railroad line closed in early 2001 when the LTV Mining Company ended operations at Taconite Harbor in Schroeder. The entire railroad line was recently acquired by Cleveland-Cliffs following the bankruptcy of LTV in 2001. 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 railroad's major stream crossings within the Lake Superior North 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. The crossing at Moose Creek is included in Figure 79 as an example of the LIDAR and aerial photo based assessment. The remaining crossings are included in appendix G.

The crossing of Moose Creek near Cramer, Minnesota provides and exampe of the impacts caused by the LTV railroad grade. The culvert under the railroad grade is likely severely undersized and improperly set. The result is significant ponding and sediment deposition upstream of the crossing, and a 4-ft drop from the culvert bottom to the water surface on the downstream end (Figure 80). This crossing is a complete fish migration barrier and degrades physical habitat conditions near the crossing. The LTV railroad grade has a similar impact on the several dozen quality trout sterams aling its course.

Nearly every crossing assessed using this methodology revealed substantial upstream habitat loss and fish migration barriers. Field visits were made to several of these crossings (Two Island River and Caribou River) to validate these conclusions. Removing the numerous fish migration barriers would reconnect hundreds of miles of high quality stream habitat, and return these areas to their original state as free-flowing rivers. MPCA and partners are discussing plans for a field-based assessment of the entire railroad line in 2018 or 2019.

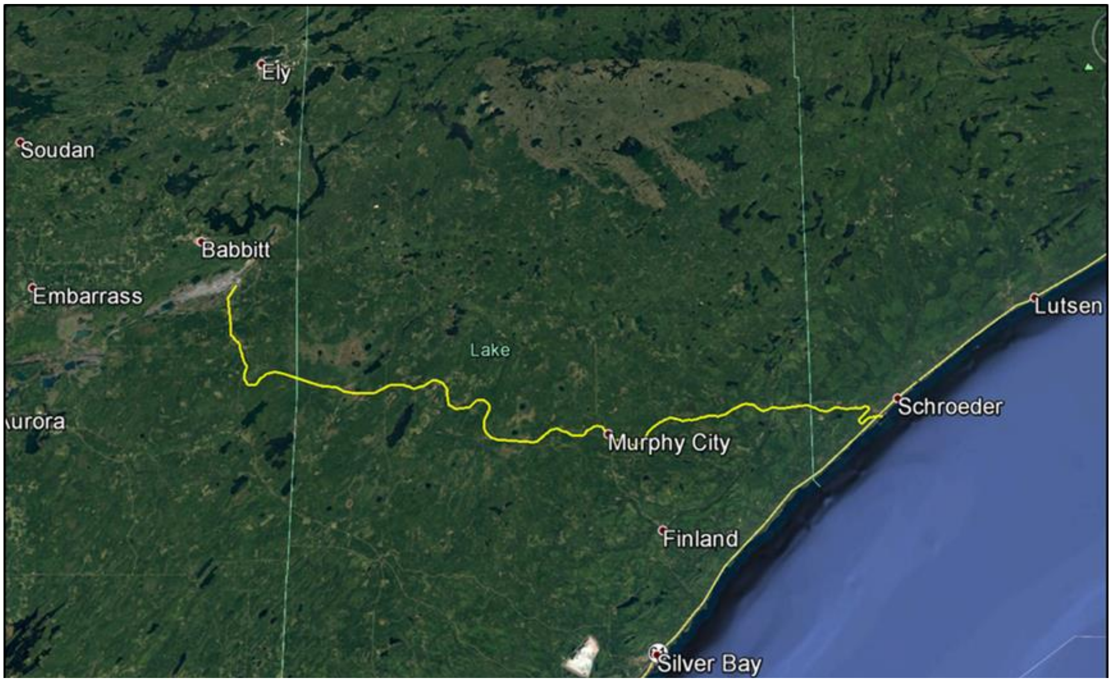


**Figure 79. Route of inactive LTV railroad grade from Schroder, Minnesota to Babbitt, Minnesota.**

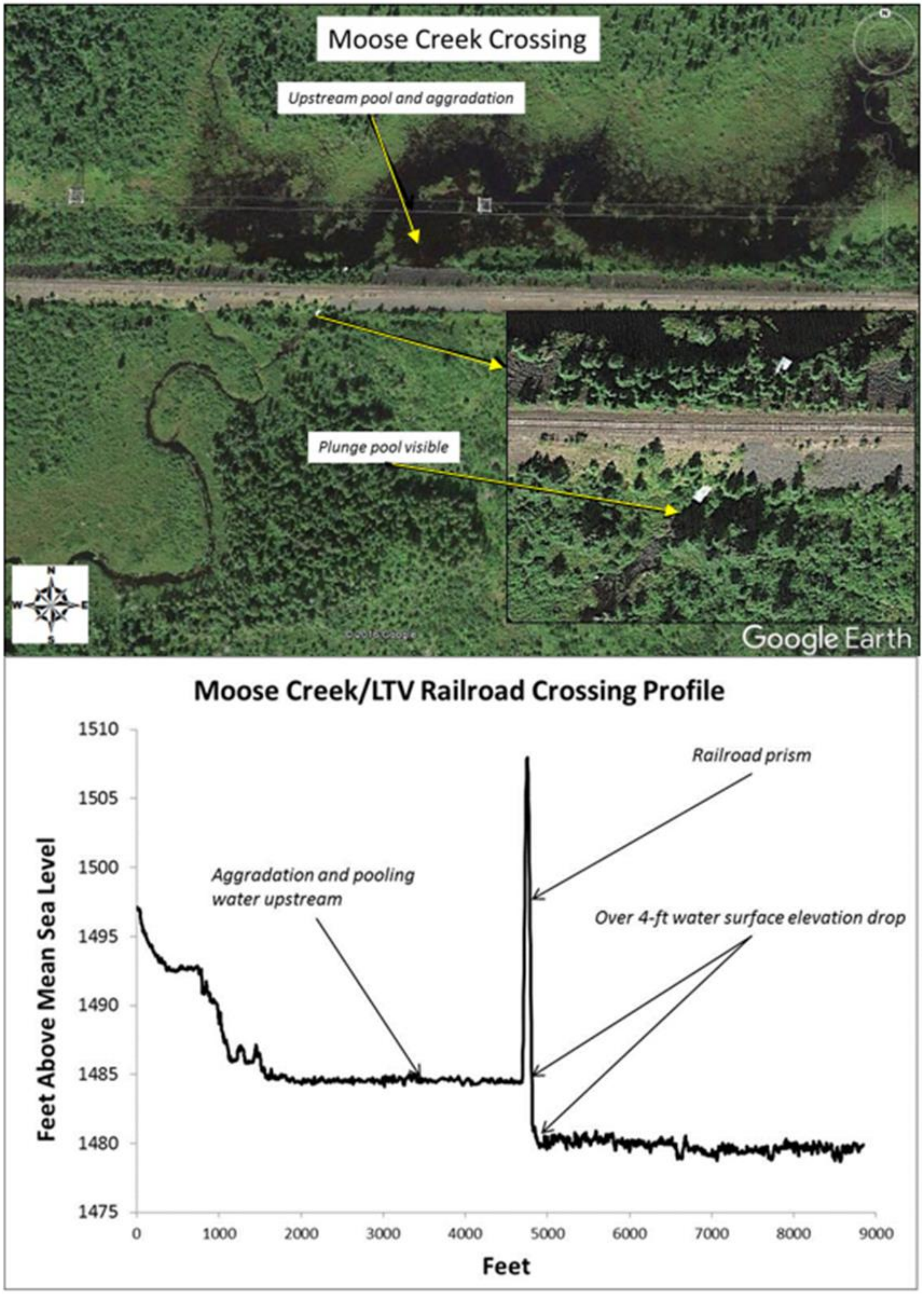


**Figure 80. The decomissioned LTV railroad cuts across Moose Creek near Cramer, Minnesota. The culvert under the railroad grade is likely severely undersized and improperly set. The result is significant ponding and sediment deposition upstream of the crossing and a complete barrier to aquatic organism migration due to a 4-ft drop from the culvert bottom to the water surface on the downstream end.**

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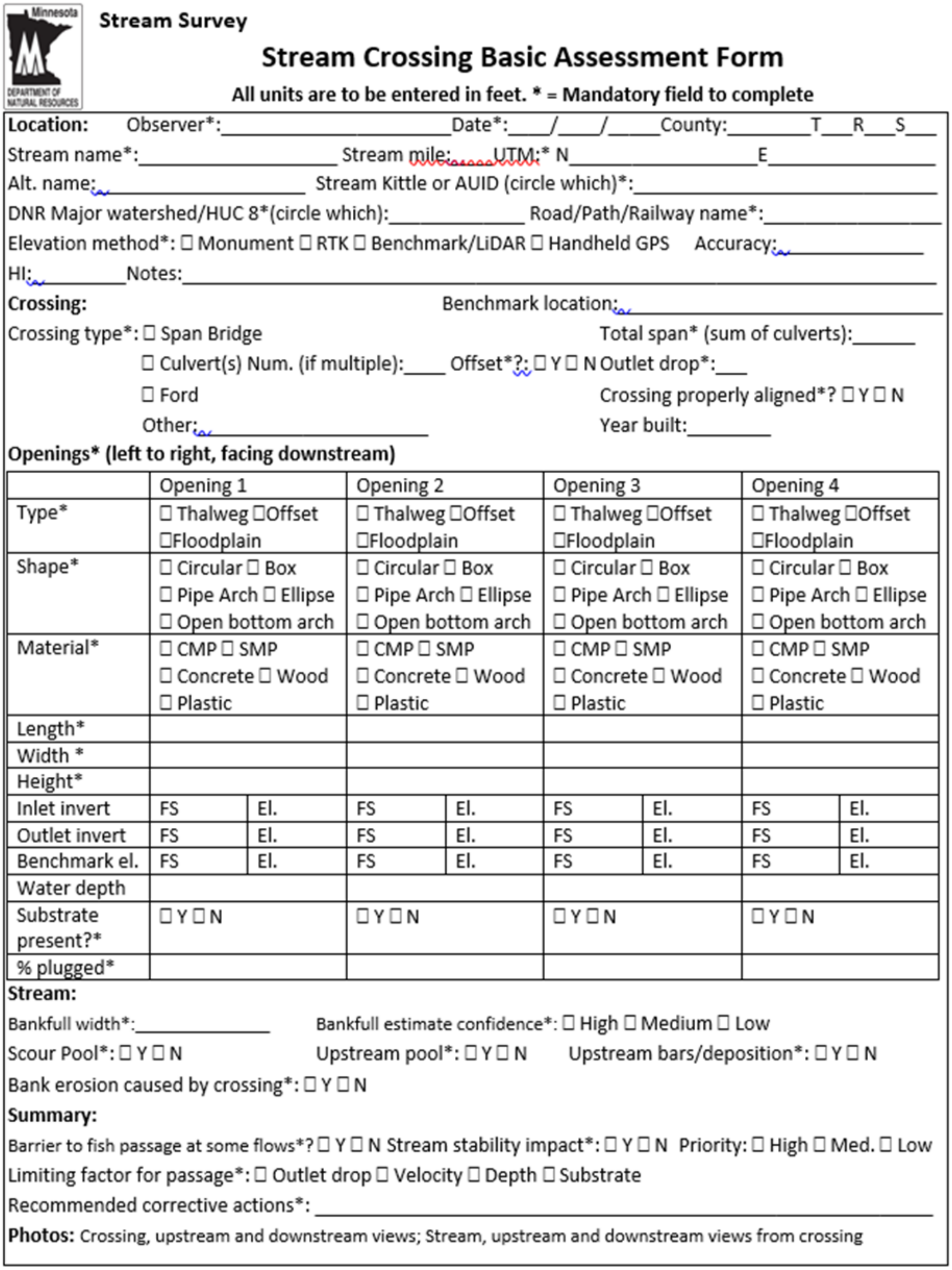
# Appendix A –DNR culvert assessment form and instructions



**Stream Survey**

## Stream Crossing Basic Assessment Form

**All units are to be entered in feet. * = Mandatory field to complete**

**Location:** Observer*:____________________Date*:___/___/____County:________T___R___S___

Stream name*:__________________ Stream mile:_____UTM:* N________________E________________

Alt. name:___________________ Stream Kittle or AUID (circle which)*:____________________________

DNR Major watershed/HUC 8*(circle which):____________ Road/Path/Railway name*:________________

Elevation method*: ☐ Monument ☐ RTK ☐ Benchmark/LiDAR ☐ Handheld GPS Accuracy:____________

HI:________Notes:______________________________________________________________

**Crossing:** Benchmark location:____________________________

Crossing type*: ☐ Span Bridge Total span* (sum of culverts):______

☐ Culvert(s) Num. (if multiple):____ Offset*?: ☐ Y ☐ N Outlet drop*:___

☐ Ford Crossing properly aligned*? ☐ Y ☐ N

Other:____________________ Year built:________

**Openings* (left to right, facing downstream)**

| | Opening 1 | | Opening 2 | | Opening 3 | | Opening 4 | |
|---|---|---|---|---|---|---|---|---|
| Type* | ☐ Thalweg ☐Offset<br>☐Floodplain | | ☐ Thalweg ☐Offset<br>☐Floodplain | | ☐ Thalweg ☐Offset<br>☐Floodplain | | ☐ Thalweg ☐Offset<br>☐Floodplain | |
| Shape* | ☐ Circular ☐ Box<br>☐ Pipe Arch ☐ Ellipse<br>☐ Open bottom arch | | ☐ Circular ☐ Box<br>☐ Pipe Arch ☐ Ellipse<br>☐ Open bottom arch | | ☐ Circular ☐ Box<br>☐ Pipe Arch ☐ Ellipse<br>☐ Open bottom arch | | ☐ Circular ☐ Box<br>☐ Pipe Arch ☐ Ellipse<br>☐ Open bottom arch | |
| Material* | ☐ CMP ☐ SMP<br>☐ Concrete ☐ Wood<br>☐ Plastic | | ☐ CMP ☐ SMP<br>☐ Concrete ☐ Wood<br>☐ Plastic | | ☐ CMP ☐ SMP<br>☐ Concrete ☐ Wood<br>☐ Plastic | | ☐ CMP ☐ SMP<br>☐ Concrete ☐ Wood<br>☐ Plastic | |
| Length* | | | | | | | | |
| Width * | | | | | | | | |
| Height* | | | | | | | | |
| Inlet invert | FS | El. | FS | El. | FS | El. | FS | El. |
| Outlet invert | FS | El. | FS | El. | FS | El. | FS | El. |
| Benchmark el. | FS | El. | FS | El. | FS | El. | FS | El. |
| Water depth | | | | | | | | |
| Substrate present?* | ☐ Y ☐ N | | ☐ Y ☐ N | | ☐ Y ☐ N | | ☐ Y ☐ N | |
| % plugged* | | | | | | | | |

**Stream:**

Bankfull width*:_____________ Bankfull estimate confidence*: ☐ High ☐ Medium ☐ Low

Scour Pool*: ☐ Y ☐ N Upstream pool*: ☐ Y ☐ N Upstream bars/deposition*: ☐ Y ☐ N

Bank erosion caused by crossing*: ☐ Y ☐ N

**Summary:**

Barrier to fish passage at some flows*? ☐ Y ☐ N Stream stability impact*: ☐ Y ☐ N Priority: ☐ High ☐ Med. ☐ Low

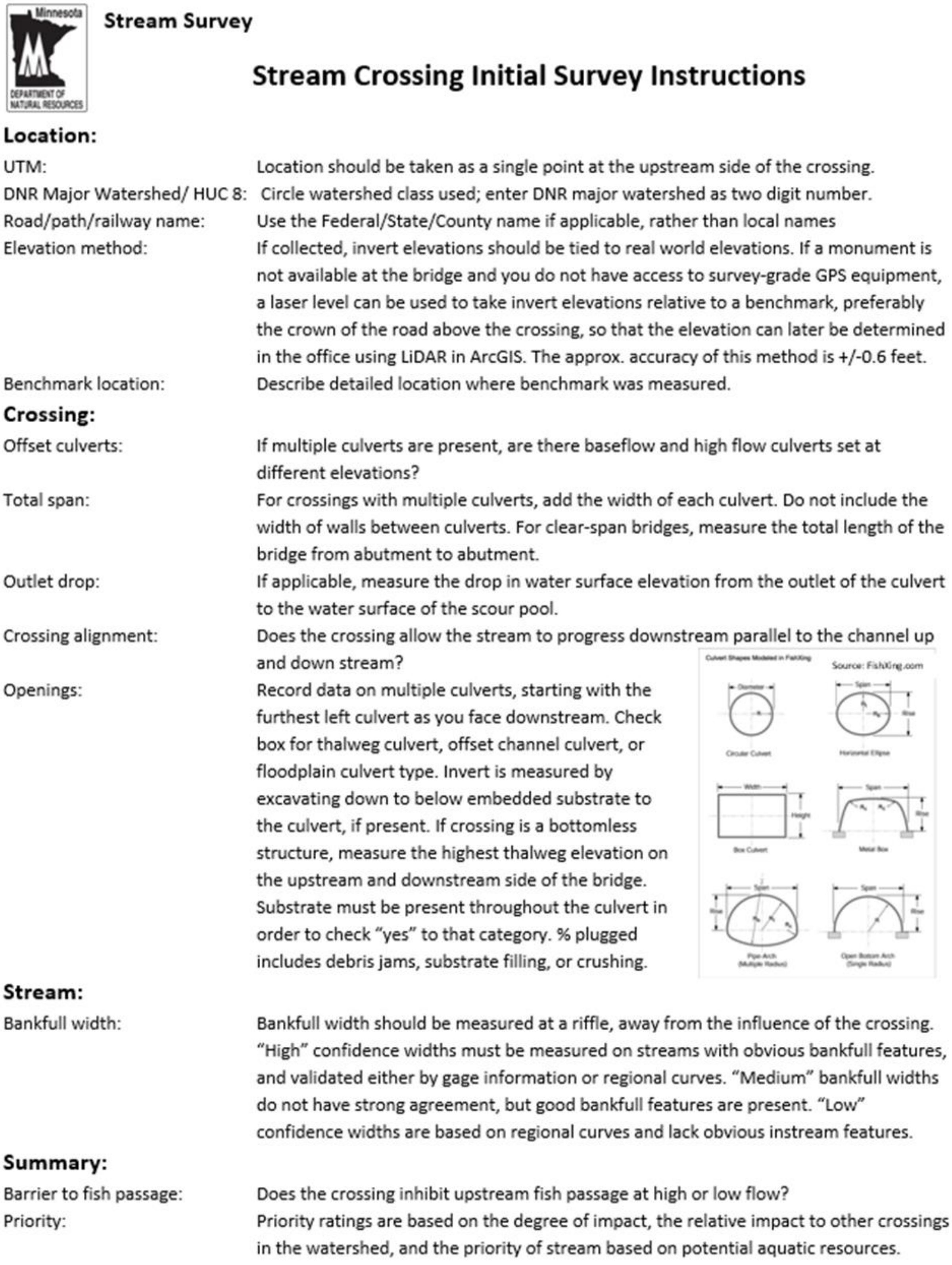
Limiting factor for passage*: ☐ Outlet drop ☐ Velocity ☐ Depth ☐ Substrate

Recommended corrective actions*: ________________________________________________

**Photos:** Crossing, upstream and downstream views; Stream, upstream and downstream views from crossing

**Figure 81. Data sheet for the DNR stream crossing assessment.**

# Appendix A (continued) DNR culvert assessment form and instructions



Minnesota DEPARTMENT OF NATURAL RESOURCES

**Stream Survey**

## Stream Crossing Initial Survey Instructions

### Location:

| | |
|---|---|
| UTM: | Location should be taken as a single point at the upstream side of the crossing. |
| DNR Major Watershed/ HUC 8: | Circle watershed class used; enter DNR major watershed as two digit number. |
| Road/path/railway name: | Use the Federal/State/County name if applicable, rather than local names |
| Elevation method: | If collected, invert elevations should be tied to real world elevations. If a monument is not available at the bridge and you do not have access to survey-grade GPS equipment, a laser level can be used to take invert elevations relative to a benchmark, preferably the crown of the road above the crossing, so that the elevation can later be determined in the office using LiDAR in ArcGIS. The approx. accuracy of this method is +/-0.6 feet. |
| Benchmark location: | Describe detailed location where benchmark was measured. |

### Crossing:

| | |
|---|---|
| Offset culverts: | If multiple culverts are present, are there baseflow and high flow culverts set at different elevations? |
| Total span: | For crossings with multiple culverts, add the width of each culvert. Do not include the width of walls between culverts. For clear-span bridges, measure the total length of the bridge from abutment to abutment. |
| Outlet drop: | If applicable, measure the drop in water surface elevation from the outlet of the culvert to the water surface of the scour pool. |
| Crossing alignment: | Does the crossing allow the stream to progress downstream parallel to the channel up and down stream? |
| Openings: | Record data on multiple culverts, starting with the furthest left culvert as you face downstream. Check box for thalweg culvert, offset channel culvert, or floodplain culvert type. Invert is measured by excavating down to below embedded substrate to the culvert, if present. If crossing is a bottomless structure, measure the highest thalweg elevation on the upstream and downstream side of the bridge. Substrate must be present throughout the culvert in order to check "yes" to that category. % plugged includes debris jams, substrate filling, or crushing. |

Culvert Shapes Modeled in FishXing

Source: FishXing.com

### Stream:

| | |
|---|---|
| Bankfull width: | Bankfull width should be measured at a riffle, away from the influence of the crossing. "High" confidence widths must be measured on streams with obvious bankfull features, and validated either by gage information or regional curves. "Medium" bankfull widths do not have strong agreement, but good bankfull features are present. "Low" confidence widths are based on regional curves and lack obvious instream features. |

### Summary:

| | |
|---|---|
| Barrier to fish passage: | Does the crossing inhibit upstream fish passage at high or low flow? |
| Priority: | Priority ratings are based on the degree of impact, the relative impact to other crossings in the watershed, and the priority of stream based on potential aquatic resources. |

# Appendix B - Culvert assessment results for Flute Reed R., Woods Ck, Fredenberg Ck, Little Manitou R.

| Stream Name | Street Name | OPENING | Crossing Type | # of culverts | Outlet Drop (ft) | Total Span (ft) | Properly Aligned | Opening Type | Opening Shape | Opening Material | Length (ft) | Width (ft) | Height (ft) | Water Depth (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flute Reed | Chicago Bay Rd | | Span Bridge | | 0 | 52 | Y | Thalweg | Bridge | Concrete | 31 | 52 | 9.5 | 1 |
| Flute Reed | MN HWY 61 | | Span Bridge | | 0 | 30 | Y | Thalweg | Bridge | Concrete | 55 | 30 | 22 | 1 |
| Flute Reed | CR 69 - East crossing | | Span Bridge | | 0 | 40 | Y | Thalweg | Bridge | Concrete | 35 | 40 | 19.5 | 1 |
| Flute Reed | CR 69 - Middle crossing | | Span Bridge | | 0 | 28 | Y | Thalweg | Bridge | Wood | 26.5 | 28 | 15 | 1 |
| Flute Reed | CR 69 - West crossing | | Span Bridge | | 0 | 76 | Y | Thalweg | Bridge | Wood | 27 | 76 | 15 | 1 |
| Flute Reed | CR 70 - South crossing | 1 | Culverts | 2 | 0.25 | 11.5 | N | Thalweg | Circular | CMP | 54 | 7 | 7 | 0.7 |
| Flute Reed | CR 70 - South crossing | 2 | Culverts | 2 | 0.75 | 11.5 | N | Offset | Circular | CMP | 50 | 4.5 | 4.5 | 1.25 |
| Flute Reed | CR 70 - North crossing | 1 | Culverts | 2 | 0.25 | 12 | N | Offset | Circular | CMP | 40 | 5 | 5 | |
| Flute Reed | CR 70 - North crossing | 2 | Culverts | 2 | 0.25 | 12 | N | Thalweg | Circular | CMP | 46 | 7 | 7 | |
| Flute Reed Tributary | CR 70 | | Culverts | 1 | 0 | 3 | Y | Thalweg | Circular | SMP | 40 | 3 | 3 | 0.3 |
| Flute Reed Tributary | CR 70 | | Culverts | 1 | 0.9 | 7.5 | Y | Thalweg | Ellipse | CMP | 56 | 7.5 | 6 | 0.7 |
| Flute Reed Tributary | CR 70 | | Culverts | 1 | 0 | 4 | N | Thalweg | Circular | CMP | 45 | 4 | 4 | 0.05 |
| Flute Reed Tributary | Private drive | | Culverts | 1 | 0 | 6 | N | Thalweg | Ellipse | CMP | 25 | 6 | 3 | 0.75 |
| Flute Reed Tributary | Flute Reed Rd | | Culverts | 1 | 0 | 8 | N | Thalweg | Ellipse | CMP | 45 | 8 | 6 | 0.25 |
| Flute Reed Tributary | Flute Reed Rd | | Span Bridge | | 0 | 12 | N | Thalweg | Bridge | Wood | 12 | 12 | 5 | 0.5 |

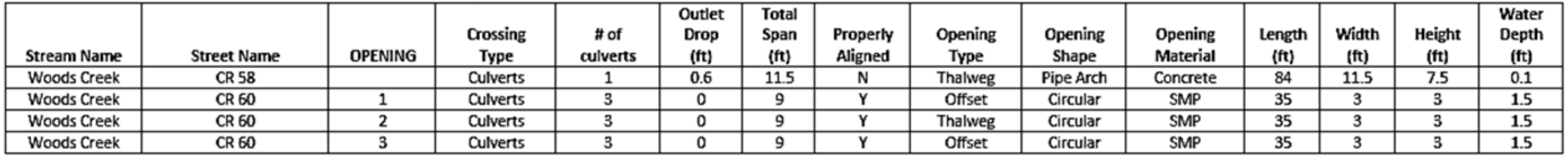
Continued from table above

| Stream Name | Street Name | Substrate in Culvert? | % plugged | Bankfull Width (ft) | Scour Pool? | Upstream Pool? | Upstream Deposition? | Bank Erosion? | Fish Barrier? | Stream Stability Impact | Recommended corrective actions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Flute Reed | Chicago Bay Rd | Y | 0% | 33.5 | N | N | N | N | N | N | None |
| Flute Reed | MN HWY 61 | Y | 0% | 35 | N | N | N | N | N | N | None |
| Flute Reed | CR 69 - East crossing | Y | 0% | 31 | N | N | N | N | N | N | None |
| Flute Reed | CR 69 - Middle crossing | Y | 0% | 29 | N | N | N | N | N | N | None |
| Flute Reed | CR 69 - West crossing | Y | 0% | 28 | N | N | N | N | N | N | None |
| Flute Reed | CR 70 - South crossing | N | 0% | 20 | Y | Y | Y | Y | Y | Y | Replace with a bridge or an open bottom arch culvert matching BKF W |
| Flute Reed | CR 70 - South crossing | N | 0% | 20 | Y | Y | Y | Y | Y | Y | Replace with a bridge or an open bottom arch culvert matching BKF W |
| Flute Reed | CR 70 - North crossing | N | 10% | 21 | Y | Y | N | Y | Y | Y | Replace with a bridge or an open bottom arch culvert matching BKF W |
| Flute Reed | CR 70 - North crossing | N | 10% | 21 | Y | Y | N | Y | Y | Y | Replace with a bridge or an open bottom arch culvert matching BKF W |
| Flute Reed Tributary | CR 70 | N | 0% | 5.5 | Y | N | N | Y | Y | N | Replace with culvert matching BKF W, install floodplain culverts |
| Flute Reed Tributary | CR 70 | N | 0% | 11 | Y | N | N | N | Y | N | Replace with culvert matching BKF W, install floodplain culverts |
| Flute Reed Tributary | CR 70 | N | 0% | 5 | N | N | N | Y | Y | Y | Stabilize headcuts upstream and downstream of crossing |
| Flute Reed Tributary | Private drive | Y | 0% | 7 | N | N | N | N | N | N | None |
| Flute Reed Tributary | Flute Reed Rd | Y | 0% | 10* | N | N | N | N | N | N | None |
| Flute Reed Tributary | Flute Reed Rd | Y | 0% | 12* | N | N | N | N | | | |

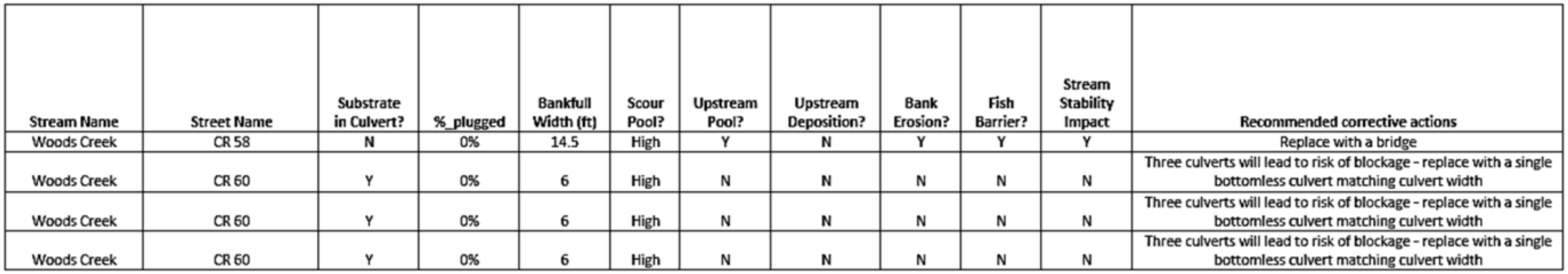
* Bankfull width predicted using regional curve

# Appendix B – Culvert assessment results for Flute Reed R., Woods Ck, Fredenberg Ck, Little Manitou R.

## Woods Creek Culvert Assessment Summary

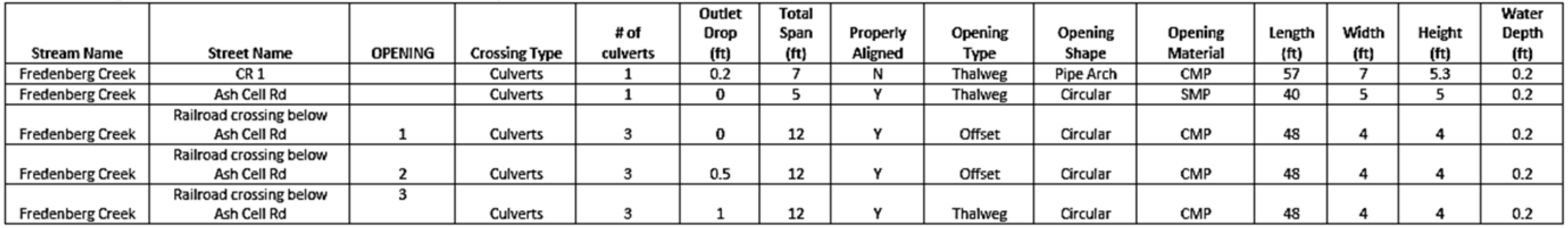


| Stream Name | Street Name | OPENING | Crossing Type | # of culverts | Outlet Drop (ft) | Total Span (ft) | Properly Aligned | Opening Type | Opening Shape | Opening Material | Length (ft) | Width (ft) | Height (ft) | Water Depth (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Woods Creek | CR 58 |  | Culverts | 1 | 0.6 | 11.5 | N | Thalweg | Pipe Arch | Concrete | 84 | 11.5 | 7.5 | 0.1 |
| Woods Creek | CR 60 | 1 | Culverts | 3 | 0 | 9 | Y | Offset | Circular | SMP | 35 | 3 | 3 | 1.5 |
| Woods Creek | CR 60 | 2 | Culverts | 3 | 0 | 9 | Y | Thalweg | Circular | SMP | 35 | 3 | 3 | 1.5 |
| Woods Creek | CR 60 | 3 | Culverts | 3 | 0 | 9 | Y | Offset | Circular | SMP | 35 | 3 | 3 | 1.5 |

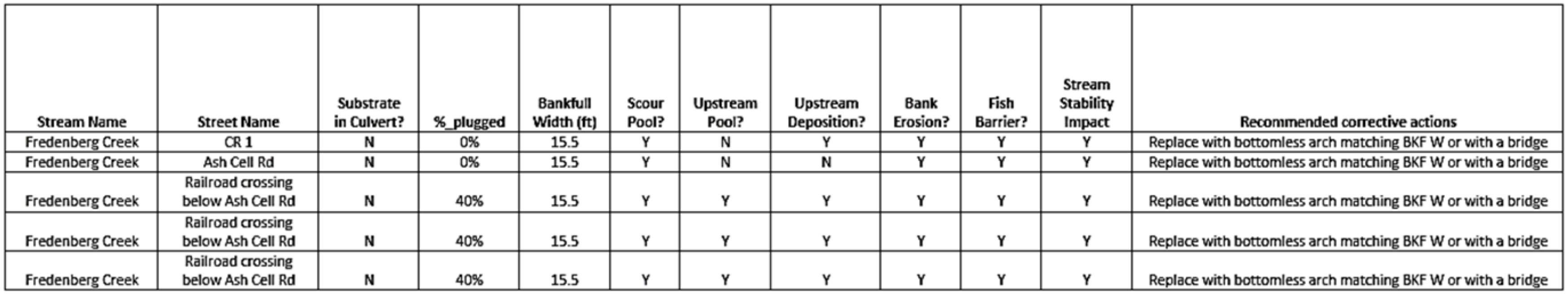


| Stream Name | Street Name | Substrate in Culvert? | %_plugged | Bankfull Width (ft) | Scour Pool? | Upstream Pool? | Upstream Deposition? | Bank Erosion? | Fish Barrier? | Stream Stability Impact | Recommended corrective actions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Woods Creek | CR 58 | N | 0% | 14.5 | High | Y | N | Y | Y | Y | Replace with a bridge |
| Woods Creek | CR 60 | Y | 0% | 6 | High | N | N | N | N | N | Three culverts will lead to risk of blockage - replace with a single bottomless culvert matching culvert width |
| Woods Creek | CR 60 | Y | 0% | 6 | High | N | N | N | N | N | Three culverts will lead to risk of blockage - replace with a single bottomless culvert matching culvert width |
| Woods Creek | CR 60 | Y | 0% | 6 | High | N | N | N | N | N | Three culverts will lead to risk of blockage - replace with a single bottomless culvert matching culvert width |

## Fredenberg Creek Culvert Assessment Summary

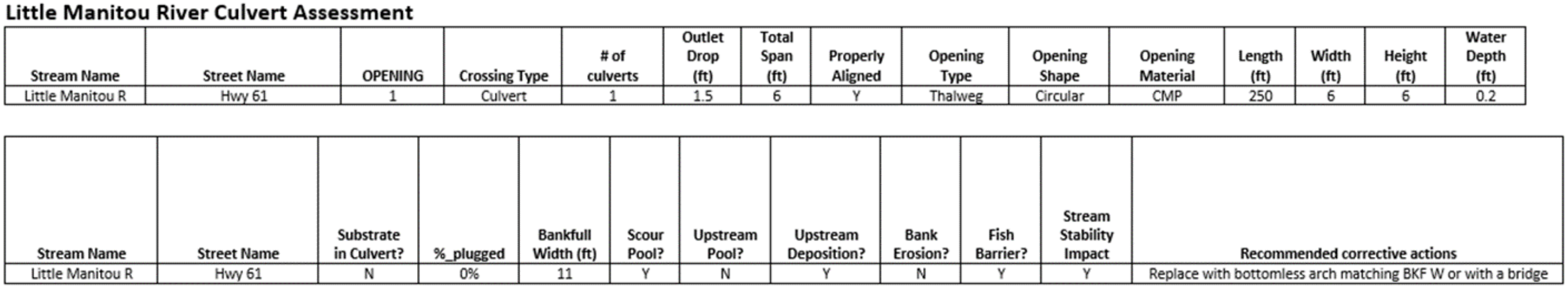


| Stream Name | Street Name | OPENING | Crossing Type | # of culverts | Outlet Drop (ft) | Total Span (ft) | Properly Aligned | Opening Type | Opening Shape | Opening Material | Length (ft) | Width (ft) | Height (ft) | Water Depth (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fredenberg Creek | CR 1 |  | Culverts | 1 | 0.2 | 7 | N | Thalweg | Pipe Arch | CMP | 57 | 7 | 5.3 | 0.2 |
| Fredenberg Creek | Ash Cell Rd |  | Culverts | 1 | 0 | 5 | Y | Thalweg | Circular | SMP | 40 | 5 | 5 | 0.2 |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | 1 | Culverts | 3 | 0 | 12 | Y | Offset | Circular | CMP | 48 | 4 | 4 | 0.2 |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | 2 | Culverts | 3 | 0.5 | 12 | Y | Offset | Circular | CMP | 48 | 4 | 4 | 0.2 |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | 3 | Culverts | 3 | 1 | 12 | Y | Thalweg | Circular | CMP | 48 | 4 | 4 | 0.2 |



| Stream Name | Street Name | Substrate in Culvert? | %_plugged | Bankfull Width (ft) | Scour Pool? | Upstream Pool? | Upstream Deposition? | Bank Erosion? | Fish Barrier? | Stream Stability Impact | Recommended corrective actions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fredenberg Creek | CR 1 | N | 0% | 15.5 | Y | N | Y | Y | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |
| Fredenberg Creek | Ash Cell Rd | N | 0% | 15.5 | Y | N | N | Y | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | N | 40% | 15.5 | Y | Y | Y | Y | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | N | 40% | 15.5 | Y | Y | Y | Y | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |
| Fredenberg Creek | Railroad crossing below Ash Cell Rd | N | 40% | 15.5 | Y | Y | Y | Y | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |

# Appendix B – Culvert assessment results for Flute Reed R., Woods Ck, Fredenberg Ck, Little Manitou R.



**Little Manitou River Culvert Assessment**

| Stream Name | Street Name | OPENING | Crossing Type | # of culverts | Outlet Drop (ft) | Total Span (ft) | Properly Aligned | Opening Type | Opening Shape | Opening Material | Length (ft) | Width (ft) | Height (ft) | Water Depth (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Little Manitou R | Hwy 61 | 1 | Culvert | 1 | 1.5 | 6 | Y | Thalweg | Circular | CMP | 250 | 6 | 6 | 0.2 |

| Stream Name | Street Name | Substrate in Culvert? | %_plugged | Bankfull Width (ft) | Scour Pool? | Upstream Pool? | Upstream Deposition? | Bank Erosion? | Fish Barrier? | Stream Stability Impact | Recommended corrective actions |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Little Manitou R | Hwy 61 | N | 0% | 11 | Y | N | Y | N | Y | Y | Replace with bottomless arch matching BKF W or with a bridge |

# Appendix C – Additional results and maps for Woods Creek Reconnaissance

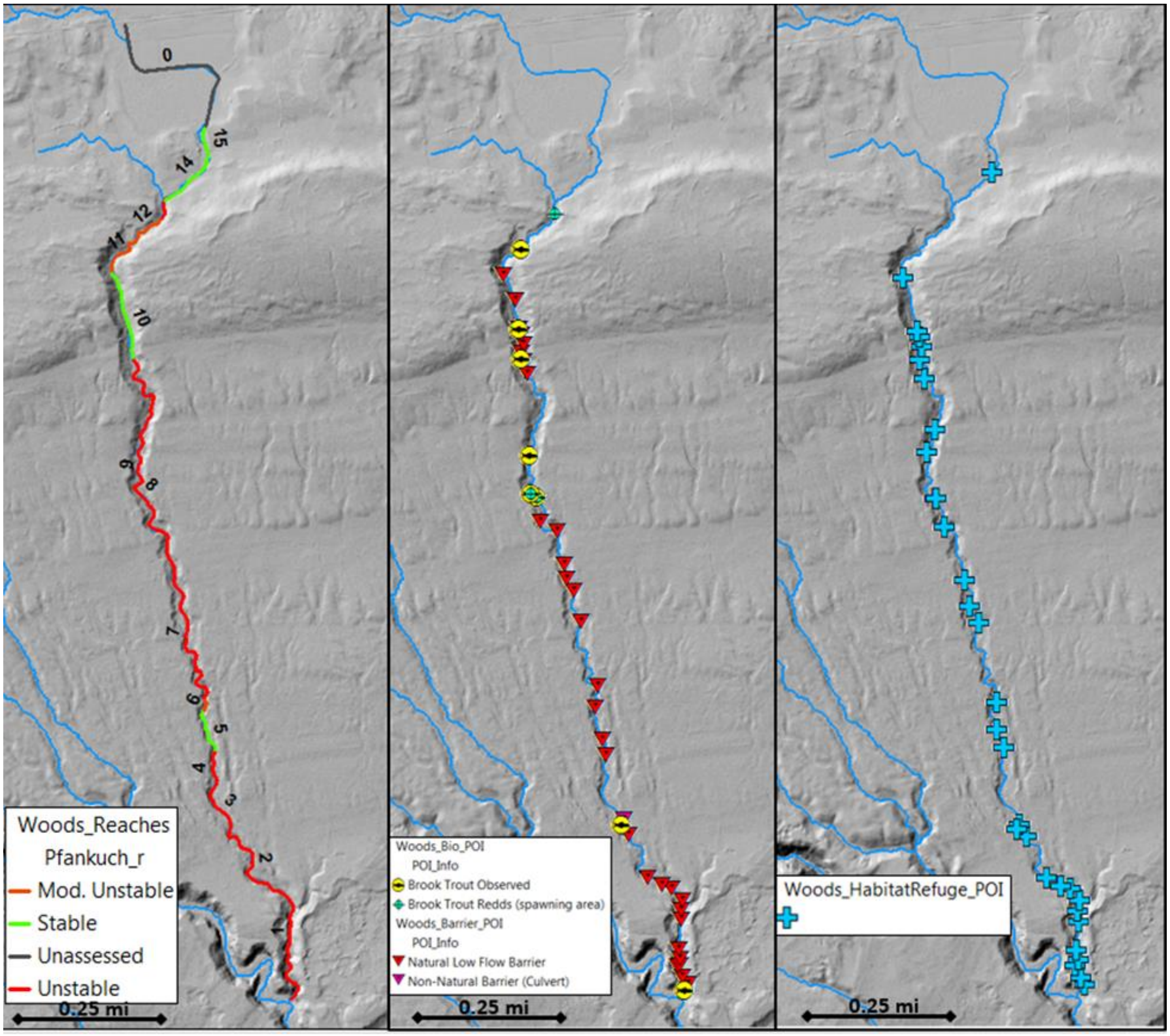


Figure 82. Additional results of Woods Creek stream reconnaissance. Pfankuch Stability Index results (left), locations of barriers to fish migration, observations of Brook Trout and spawning areas (center); and deep pool habitat (right).

# Appendix D – 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 connectivity to an active floodplain, resulting in increased bank erosion, sedimentation, and physical habitat degradation. 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 wheelbarrow. 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 #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.

**Figure 83. Eroding bank in the lower reaches of Woods Creek that could be stabilized using a low-impact restoration approach as described above.**

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.

**Figure 84. Examples of braided and over-widened section of Woods Creek that could be improved using low-impact restoration options as described above.**

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.

**Figure 85. Example of head-cut on Woods Creek that could be stabilized using a low-impact restoration approach as described above.**

# Appendix E – 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. Visual assessments reveal that turbidity levels are increased within and downstream of beaver dams (Figure 86).

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 sources are leaves, buds, and stems gathered 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 elevate turbidity and total suspended solid (TSS) levels in some North Shore streams, even at low flows.

Half of the Flute Reed River Watershed area, and 60% of its total stream length (including tributaries), is located within the historic Glacial Lake Duluth lakebed. Signs of the glacial lakeshore 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 is easily suspended by beaver activity. Other watersheds nearby have proportionately less area within the glacial zone, and therefore contain less clay soil. Only 30% of the stream length of Reservation River and 38% of Durfee Creek is located 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 87). The beaver dams are located on the main stem, main tributaries, and on minor tributaries.

A higher percentage of beaver dams within the Flute Reed Watershed are located within the glacial lake area compared to 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 26). The Durfee Creek Watershed had only one dam within the glacial lake area.

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 other watersheds evaluated. Densities in all watersheds are higher than the state average of 0.6 dams/stream mile, (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 because of harvest and flooding. Little shade is present and the backed up water can quickly warm making unfavorable conditions for trout.

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 86. Increased turbidity levels observed downstream of beaver dams during low flow periods.**

**Table 26. Beaver dam counts and densities observed in the Flute Reed River compared to a selection of streams within the Lake Superior North basin. GLD = Glacial Lake Duluth boundary.**

| WATERSHED | BEAVER DAM COUNT | 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 |

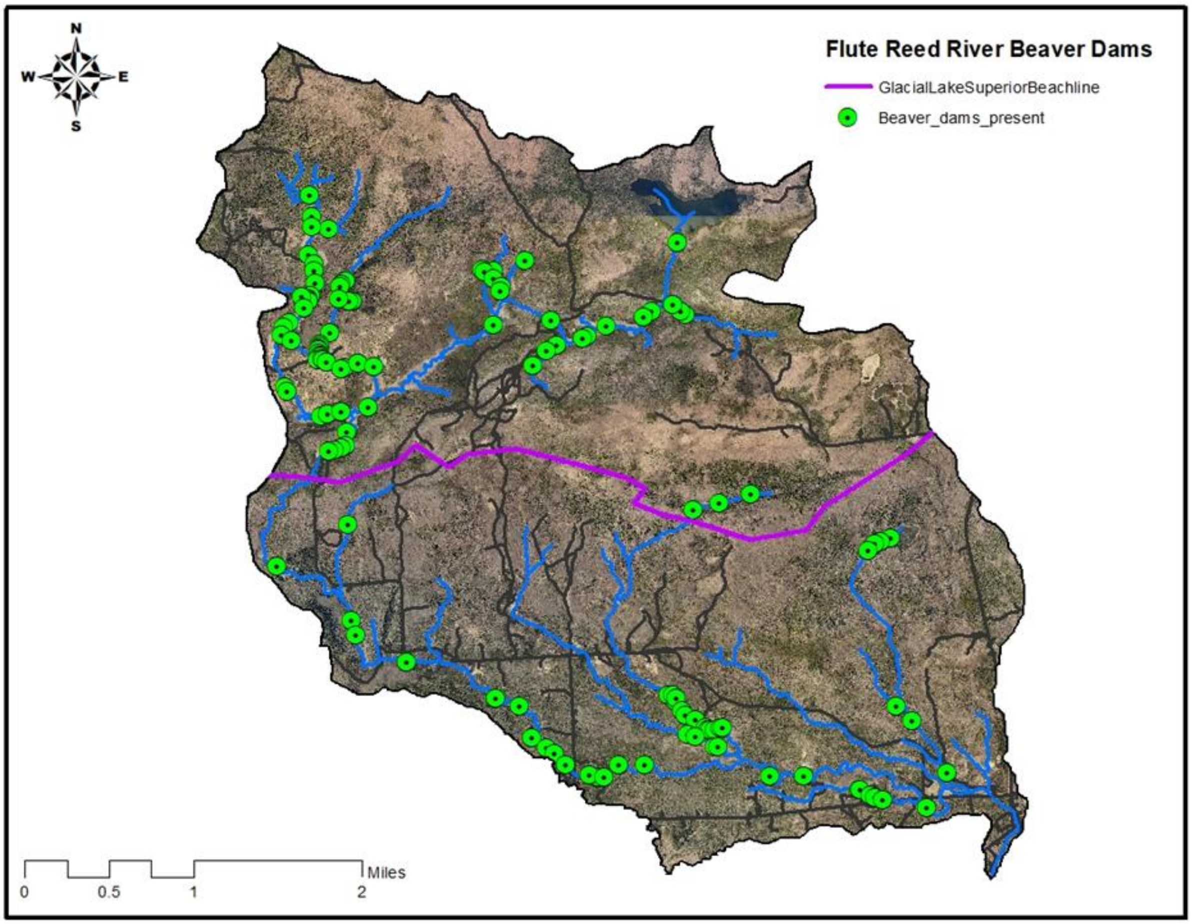


Figure 87. Current beaver dam locations throughout the Flute Reed River Watershed.

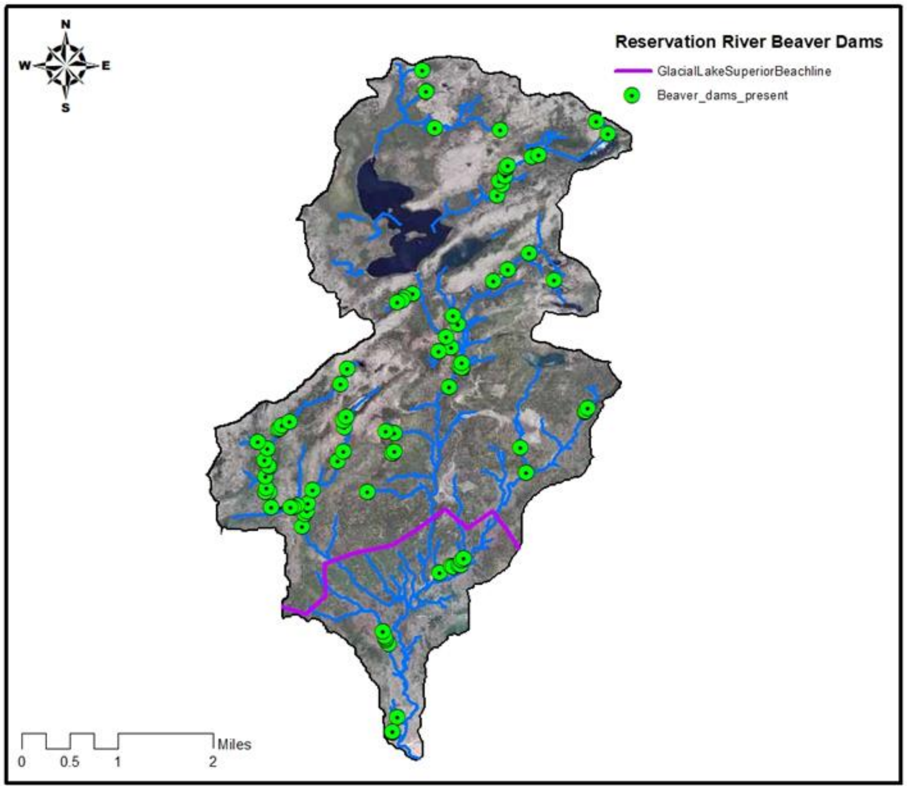


Figure 88. Current beaver dam locations throughout the Durfee Creek Watershed.

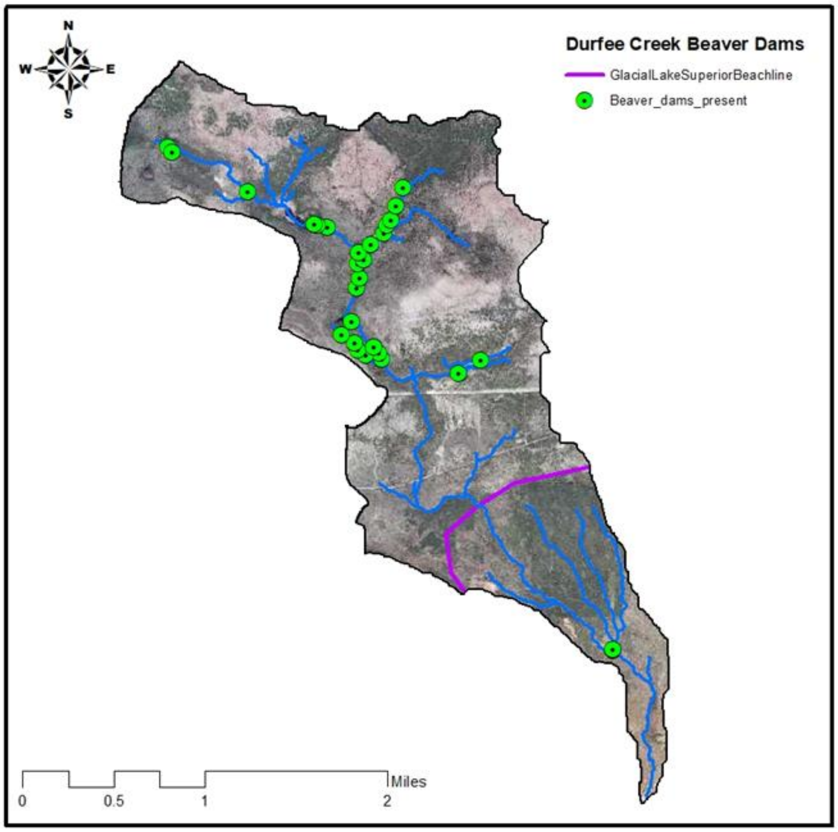


Figure 89. Current beaver dam locations throughout the Reservation River Watershed.

# Appendix F-Best management practices in red clay soil 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 G: Desktop assessments of LTV railroad steam crossings in LS North HUC 8 Watershed

## 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 90. Aerial photo of Two Island River RR crossing, showing large plunge pool and visible waterfall at outlet.**

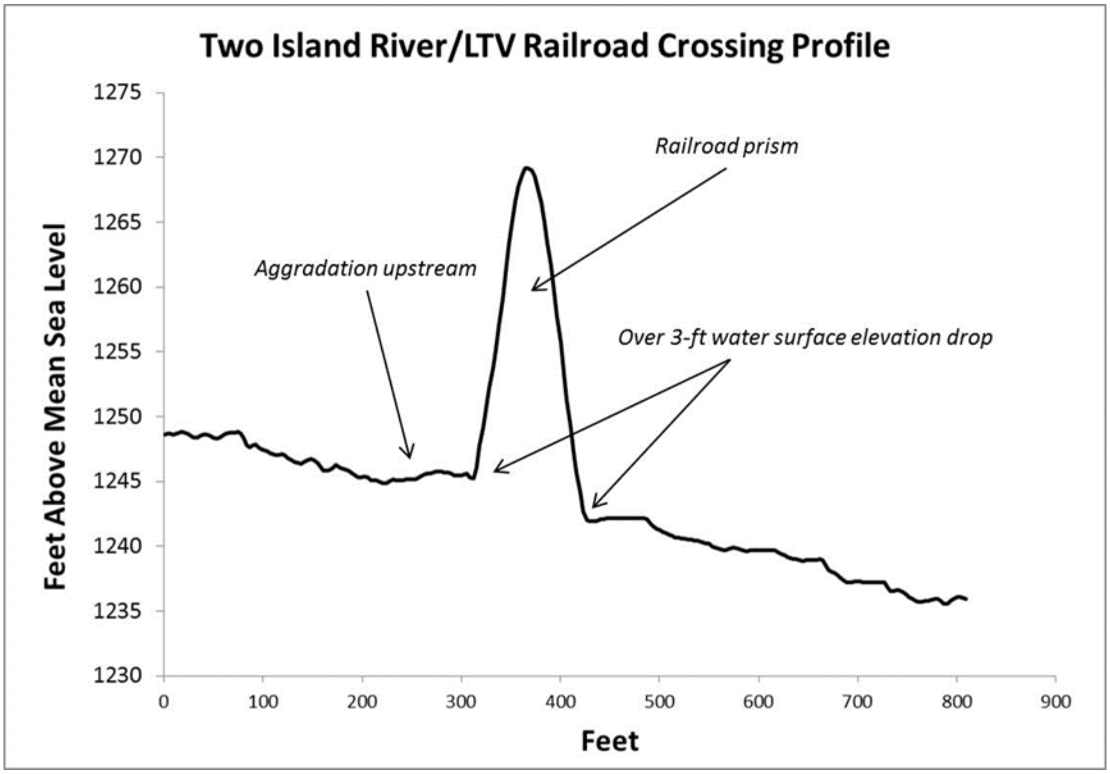


**Figure 91. LiDAR profile of Two Island River RR crossing showing potential upstream aggradation and 3 ft drop in water surface elevation.**

# 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 |

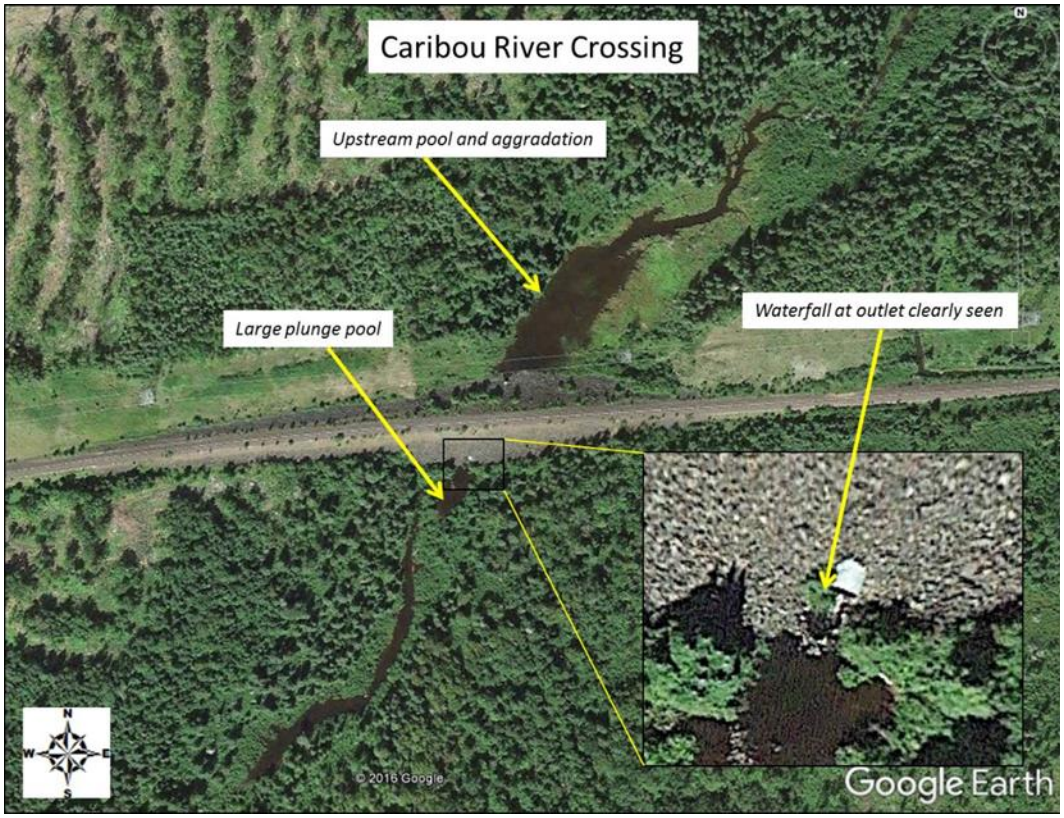


Figure 92. Aerial photo of Caribou River RR crossing, showing large plunge pool, visible waterfall at outlet, and large ponded area upstream.

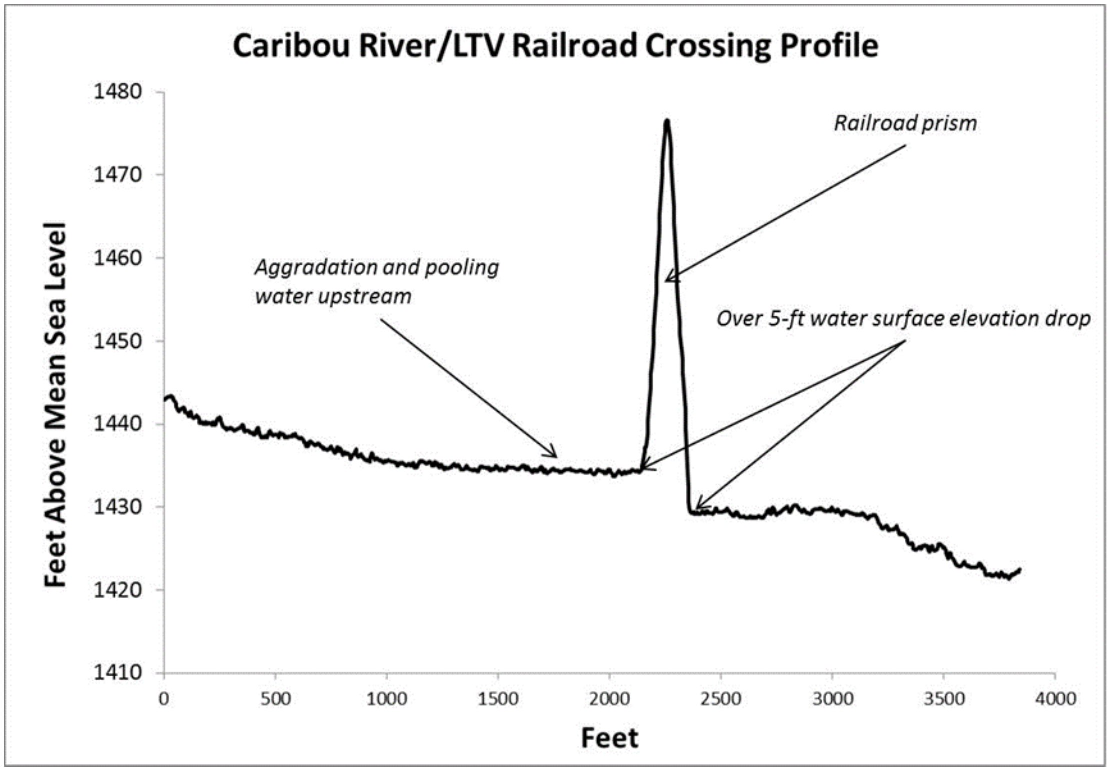


Figure 93. LiDAR profile of Caribou River RR crossing showing upstream pooling and aggradation and 5 ft drop in water surface elevation.

# 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 |

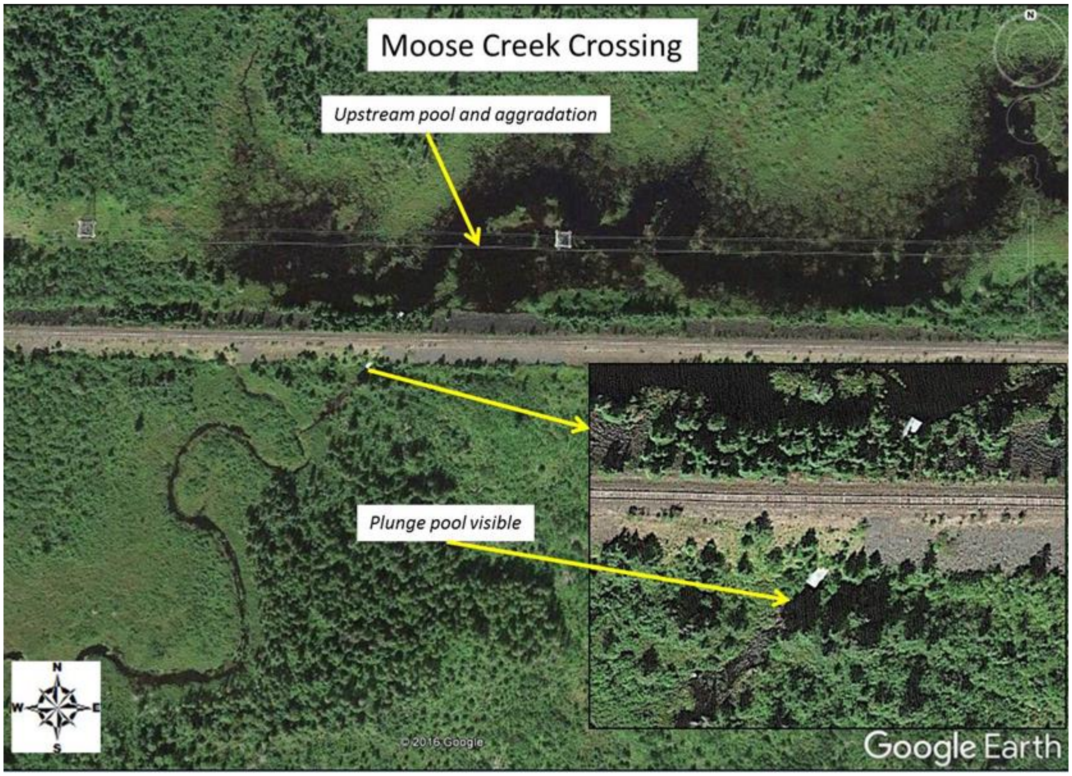


**Figure 94. Aerial photo of Moose Creek RR crossing, showing plunge pool and large ponded area upstream.**

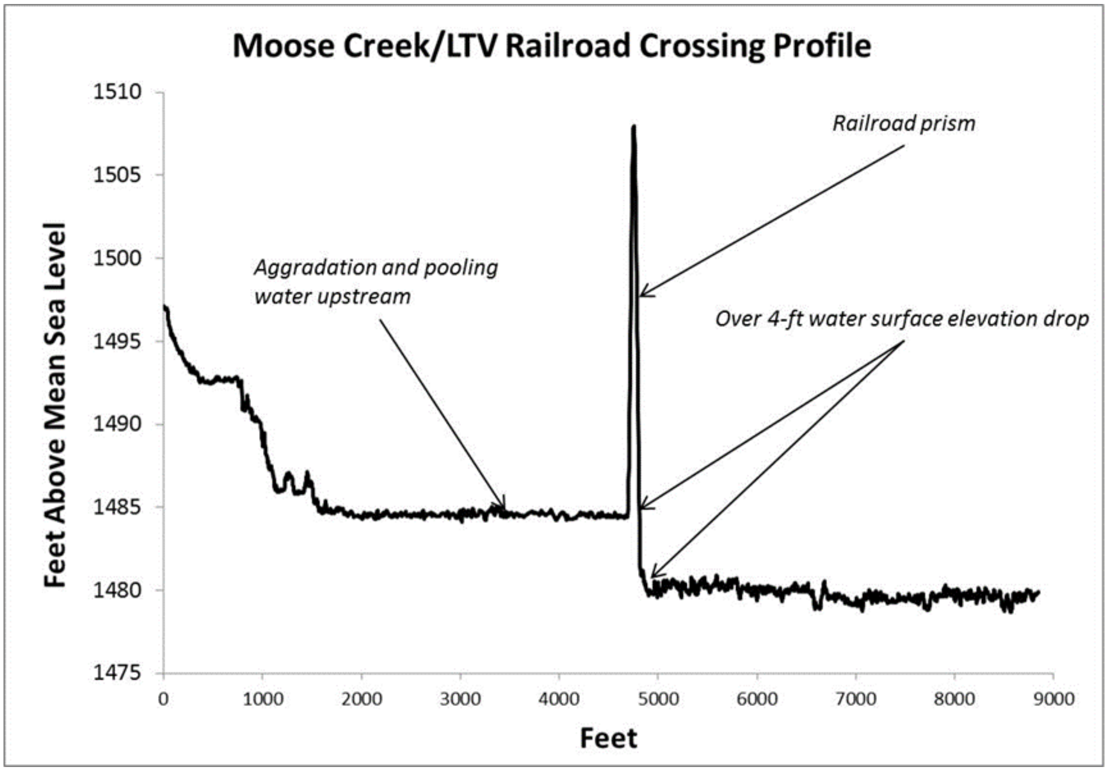


**Figure 95. LiDAR profile of Moose Creek RR crossing showing upstream pooling and aggradation and 4 ft drop in water surface elevation.**

# 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 96. Aerial photo of the South Branch Manitou River RR lower crossing, showing plunge pool downstream of culvert.**

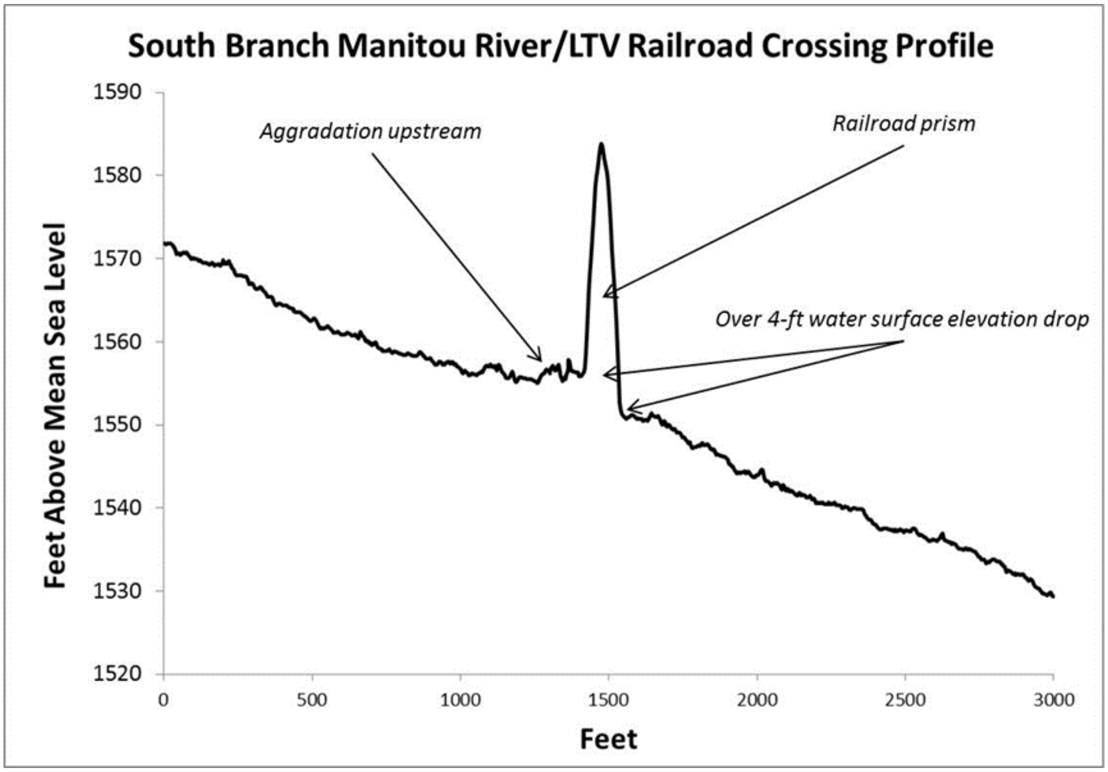


**Figure 97. LiDAR profile of the South Branch Manitou River RR lower crossing showing upstream aggradation and a 4 ft drop in water surface elevation.**

## 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 98. Aerial photo of the South Branch Manitou River RR upper crossing, showing large ponded area upstream**

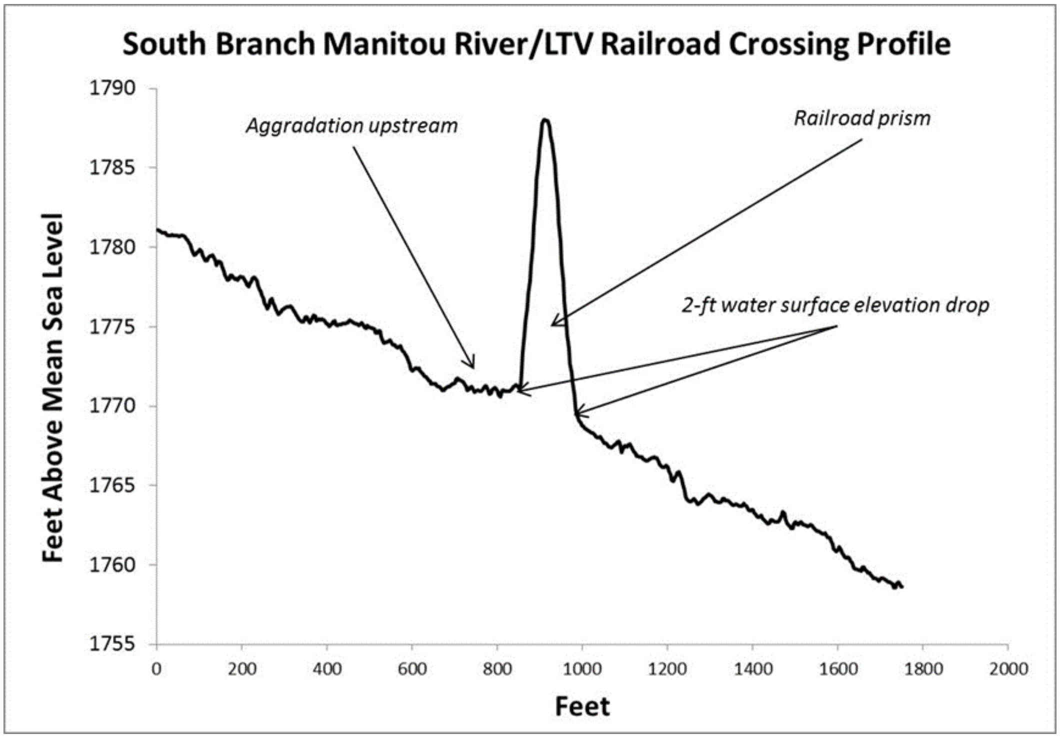


**Figure 99. LiDAR profile of the South Branch Manitou River RR upper crossing showing upstream aggradation and a 2 ft drop in water surface elevation.**

## 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 100. Aerial photo of the Baptism River RR crossing, showing large ponded area upstream of culvert.**

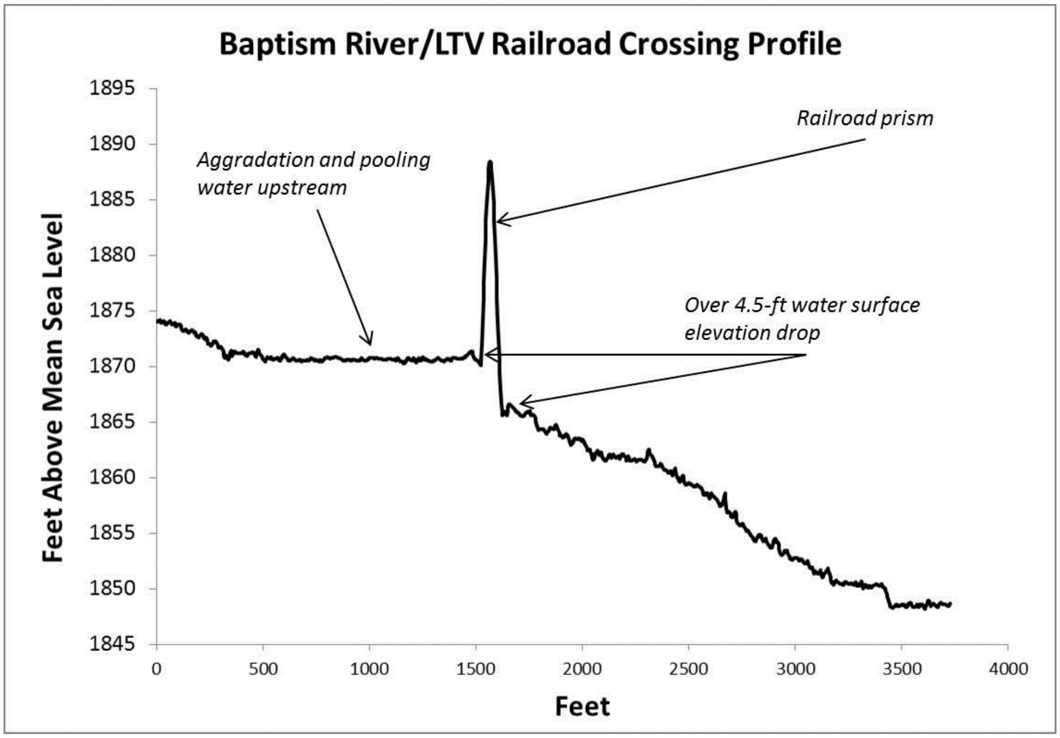


**Figure 101. LiDAR profile of the Baptism River RR crossing showing upstream aggradation and pooling and a 4.5 ft drop in water surface elevation.**

## 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 102. Aerial photo of the Unnamed Creek RR crossing, showing large ponded area upstream of culvert.**

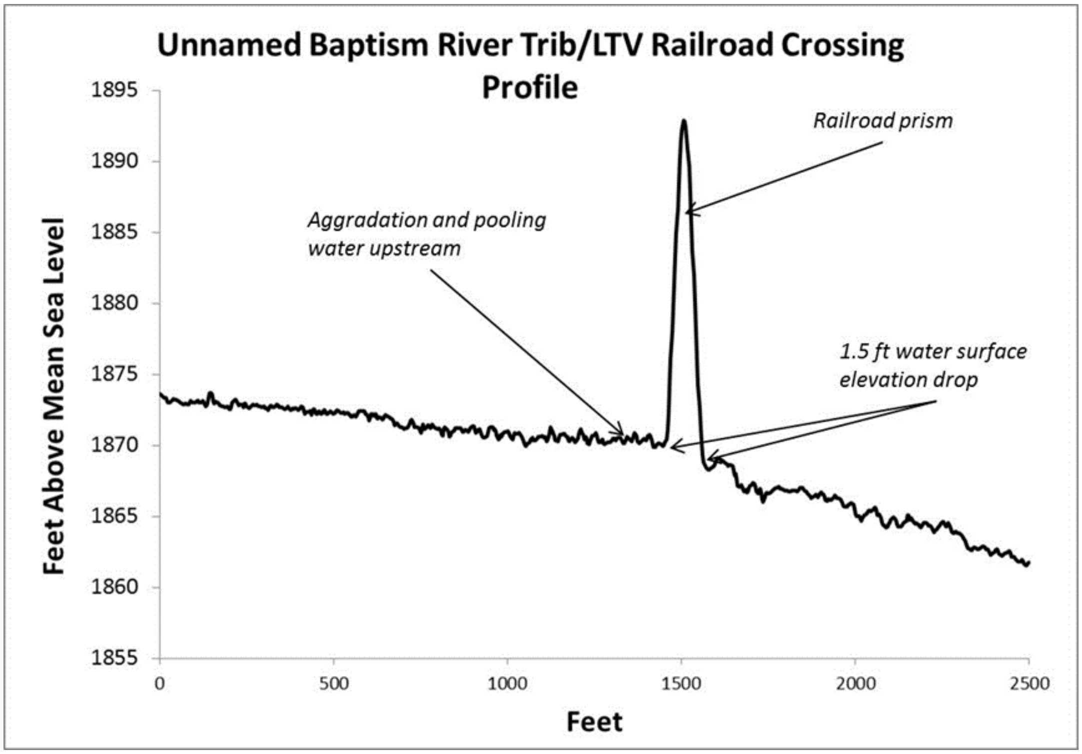


**Figure 103. LiDAR profile of the Unnamed Creek RR crossing showing upstream aggradation and pooling and a 1.5 ft drop in water surface elevation.**

## 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 104. Aerial photo of the Crown Creek RR crossing. Crown Creek is difficult to see near the crossing.**

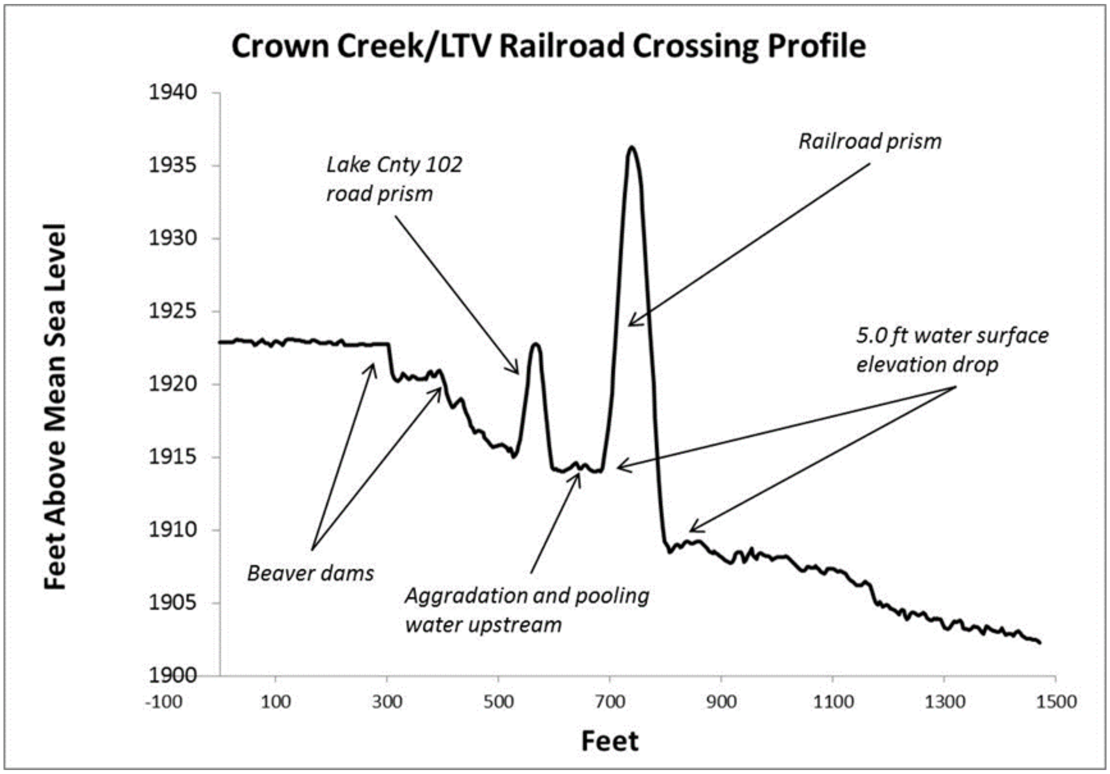


**Figure 105. LiDAR profile of the Crown Creek RR crossing showing upstream aggradation and pooling and a 5.0 ft drop in water surface elevation.**

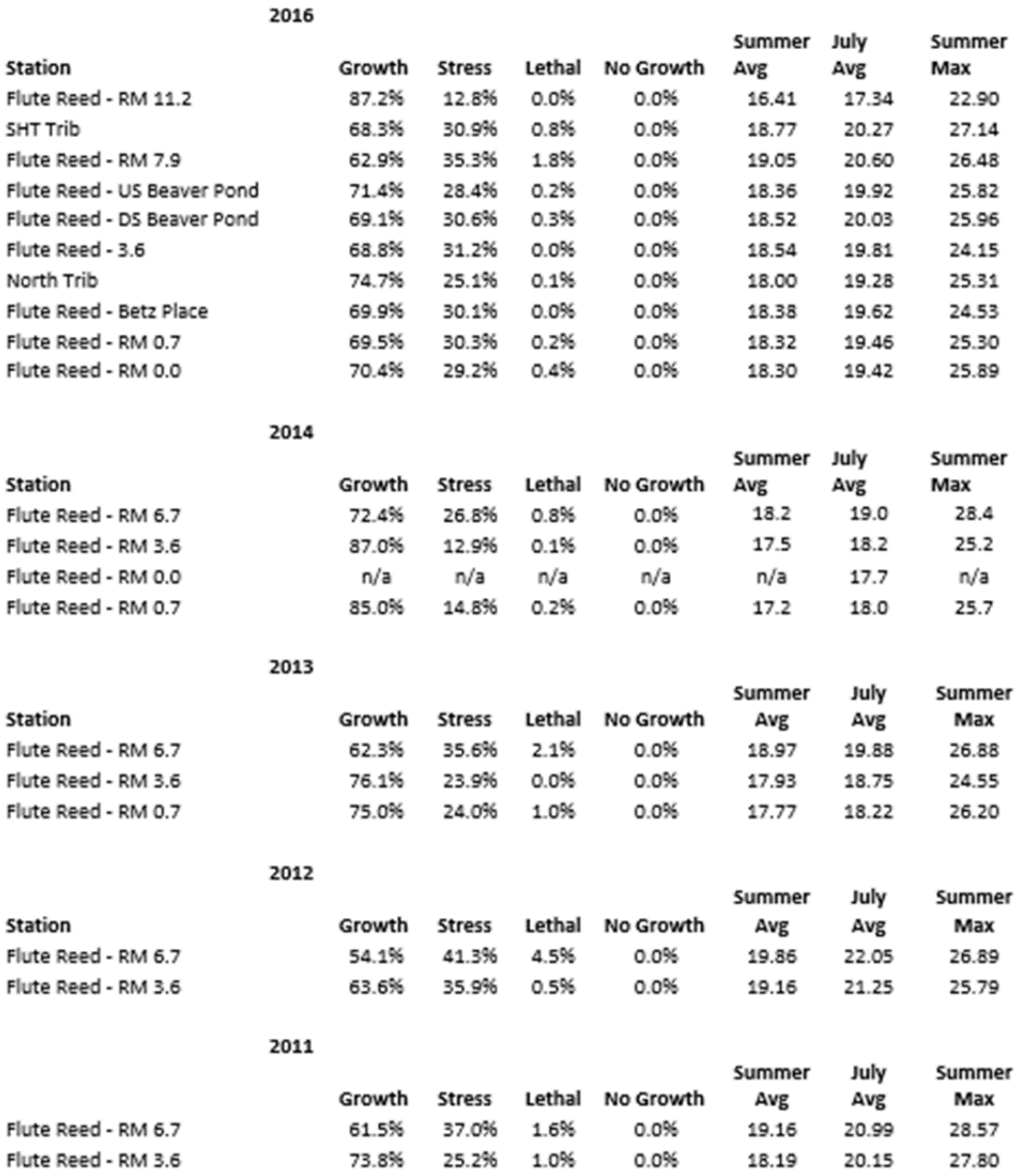
# Appendix H – Coastal change analysis program (C-CAP) data used in Flute Reed River Watershed analysis

| Class_Names |
|---|
| Deciduous Forest to High Intensity Developed |
| Deciduous Forest to Medium Intensity Developed |
| Deciduous Forest to Low Intensity Developed |
| Deciduous Forest to Developed Open Space |
| Deciduous Forest to Cultivated |
| Deciduous Forest to Pasture/Hay |
| Deciduous Forest to Grassland |
| Deciduous Forest to Scrub/Shrub |
| Deciduous Forest to Bare Land |
| Evergreen Forest to High Intensity Developed |
| Evergreen Forest to Medium Intensity Developed |
| Evergreen Forest to Low Intensity Developed |
| Evergreen Forest to Developed Open Space |
| Evergreen Forest to Cultivated |
| Evergreen Forest to Pasture/Hay |
| Evergreen Forest to Grassland |
| Evergreen Forest to Deciduous Forest |
| Evergreen Forest to Mixed Forest |
| Evergreen Forest to Scrub/Shrub |
| Evergreen Forest to Bare Land |
| Mixed Forest to High Intensity Developed |
| Mixed Forest to Medium Intensity Developed |
| Mixed Forest to Low Intensity Developed |
| Mixed Forest to Developed Open Space |
| Mixed Forest to Cultivated |
| Mixed Forest to Pasture/Hay |
| Mixed Forest to Grassland |
| Mixed Forest to Deciduous Forest |
| Mixed Forest to Scrub/Shrub |
| Mixed Forest to Bare Land |

**Figure 106. List of C-CAP land cover parameters used to estimate loss of forest cover in the Flute Reed River Watershed.**

# Appendix I – Flute Reed river water temperature summary

**Table 27. Summary of water temperature data collected within the Flute Reed River watershed in 2011, 2012, 2013, 2014, and 2016. Growth, Stress, Lethal, No Growth thresholds are based on Brook Trout (see section 3.1 of this report)**



2016

| Station | Growth | Stress | Lethal | No Growth | Summer Avg | July Avg | Summer Max |
|---|---|---|---|---|---|---|---|
| Flute Reed - RM 11.2 | 87.2% | 12.8% | 0.0% | 0.0% | 16.41 | 17.34 | 22.90 |
| SHT Trib | 68.3% | 30.9% | 0.8% | 0.0% | 18.77 | 20.27 | 27.14 |
| Flute Reed - RM 7.9 | 62.9% | 35.3% | 1.8% | 0.0% | 19.05 | 20.60 | 26.48 |
| Flute Reed - US Beaver Pond | 71.4% | 28.4% | 0.2% | 0.0% | 18.36 | 19.92 | 25.82 |
| Flute Reed - DS Beaver Pond | 69.1% | 30.6% | 0.3% | 0.0% | 18.52 | 20.03 | 25.96 |
| Flute Reed - 3.6 | 68.8% | 31.2% | 0.0% | 0.0% | 18.54 | 19.81 | 24.15 |
| North Trib | 74.7% | 25.1% | 0.1% | 0.0% | 18.00 | 19.28 | 25.31 |
| Flute Reed - Betz Place | 69.9% | 30.1% | 0.0% | 0.0% | 18.38 | 19.62 | 24.53 |
| Flute Reed - RM 0.7 | 69.5% | 30.3% | 0.2% | 0.0% | 18.32 | 19.46 | 25.30 |
| Flute Reed - RM 0.0 | 70.4% | 29.2% | 0.4% | 0.0% | 18.30 | 19.42 | 25.89 |

2014

| Station | Growth | Stress | Lethal | No Growth | Summer Avg | July Avg | Summer Max |
|---|---|---|---|---|---|---|---|
| Flute Reed - RM 6.7 | 72.4% | 26.8% | 0.8% | 0.0% | 18.2 | 19.0 | 28.4 |
| Flute Reed - RM 3.6 | 87.0% | 12.9% | 0.1% | 0.0% | 17.5 | 18.2 | 25.2 |
| Flute Reed - RM 0.0 | n/a | n/a | n/a | n/a | n/a | 17.7 | n/a |
| Flute Reed - RM 0.7 | 85.0% | 14.8% | 0.2% | 0.0% | 17.2 | 18.0 | 25.7 |

2013

| Station | Growth | Stress | Lethal | No Growth | Summer Avg | July Avg | Summer Max |
|---|---|---|---|---|---|---|---|
| Flute Reed - RM 6.7 | 62.3% | 35.6% | 2.1% | 0.0% | 18.97 | 19.88 | 26.88 |
| Flute Reed - RM 3.6 | 76.1% | 23.9% | 0.0% | 0.0% | 17.93 | 18.75 | 24.55 |
| Flute Reed - RM 0.7 | 75.0% | 24.0% | 1.0% | 0.0% | 17.77 | 18.22 | 26.20 |

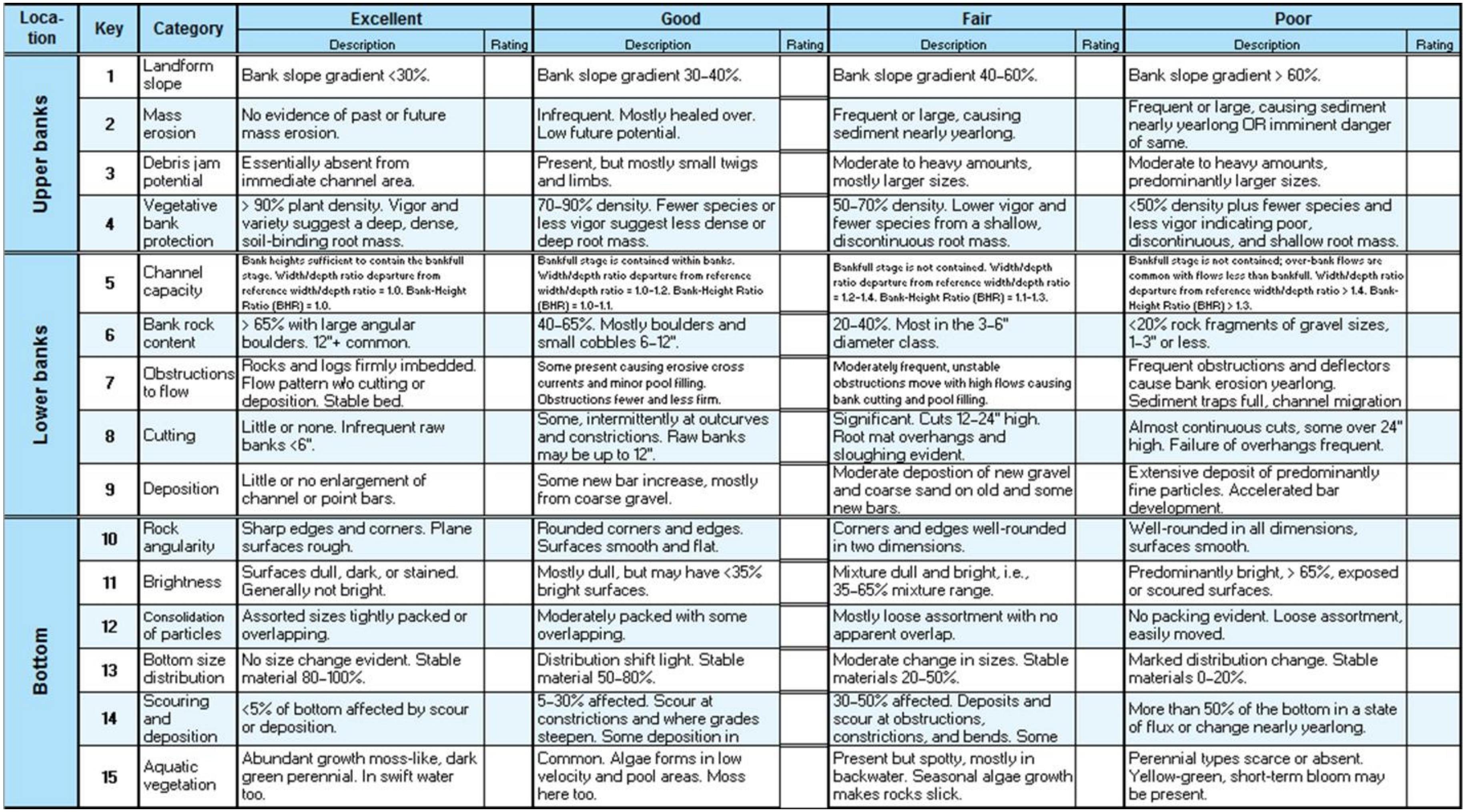
2012

| Station | Growth | Stress | Lethal | No Growth | Summer Avg | July Avg | Summer Max |
|---|---|---|---|---|---|---|---|
| Flute Reed - RM 6.7 | 54.1% | 41.3% | 4.5% | 0.0% | 19.86 | 22.05 | 26.89 |
| Flute Reed - RM 3.6 | 63.6% | 35.9% | 0.5% | 0.0% | 19.16 | 21.25 | 25.79 |

2011

|  | Growth | Stress | Lethal | No Growth | Summer Avg | July Avg | Summer Max |
|---|---|---|---|---|---|---|---|
| Flute Reed - RM 6.7 | 61.5% | 37.0% | 1.6% | 0.0% | 19.16 | 20.99 | 28.57 |
| Flute Reed - RM 3.6 | 73.8% | 25.2% | 1.0% | 0.0% | 18.19 | 20.15 | 27.80 |

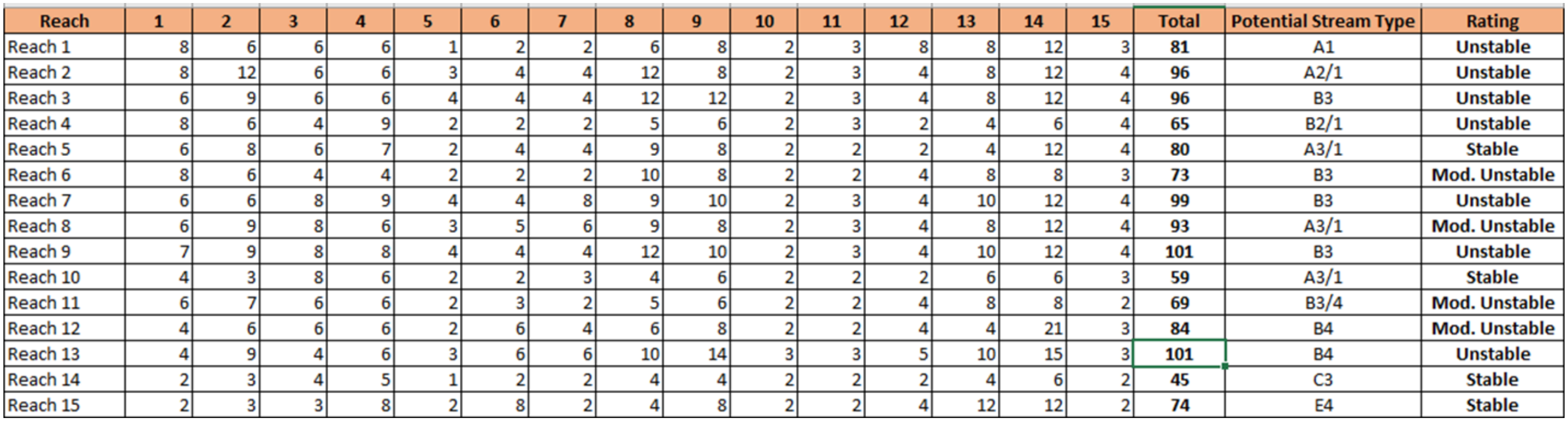
# Appendix J – Pfankuch stability assessments of Woods Creek and Flute Reed River



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

**Figure 107. Blank Pfankuch Stability Index form. Numbers in the key column correspond to the data tables on the following pages.**

**Table 28. Woods Creek Pfankuch Stability Index results.**



| Reach | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total | Potential Stream Type | Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reach 1 | 8 | 6 | 6 | 6 | 1 | 2 | 2 | 6 | 8 | 2 | 3 | 8 | 8 | 12 | 3 | **81** | A1 | **Unstable** |
| Reach 2 | 8 | 12 | 6 | 6 | 3 | 4 | 4 | 12 | 8 | 2 | 3 | 4 | 8 | 12 | 4 | **96** | A2/1 | **Unstable** |
| Reach 3 | 6 | 9 | 6 | 6 | 4 | 4 | 4 | 12 | 12 | 2 | 3 | 4 | 8 | 12 | 4 | **96** | B3 | **Unstable** |
| Reach 4 | 8 | 6 | 4 | 9 | 2 | 2 | 2 | 5 | 6 | 2 | 3 | 2 | 4 | 6 | 4 | **65** | B2/1 | **Unstable** |
| Reach 5 | 6 | 8 | 6 | 7 | 2 | 4 | 4 | 9 | 8 | 2 | 2 | 2 | 4 | 12 | 4 | **80** | A3/1 | **Stable** |
| Reach 6 | 8 | 6 | 4 | 4 | 2 | 2 | 2 | 10 | 8 | 2 | 2 | 4 | 8 | 8 | 3 | **73** | B3 | **Mod. Unstable** |
| Reach 7 | 6 | 6 | 8 | 9 | 4 | 4 | 8 | 9 | 10 | 2 | 3 | 4 | 10 | 12 | 4 | **99** | B3 | **Unstable** |
| Reach 8 | 6 | 9 | 8 | 6 | 3 | 5 | 6 | 9 | 8 | 2 | 3 | 4 | 8 | 12 | 4 | **93** | A3/1 | **Mod. Unstable** |
| Reach 9 | 7 | 9 | 8 | 8 | 4 | 4 | 4 | 12 | 10 | 2 | 3 | 4 | 10 | 12 | 4 | **101** | B3 | **Unstable** |
| Reach 10 | 4 | 3 | 8 | 6 | 2 | 2 | 3 | 4 | 6 | 2 | 2 | 2 | 6 | 6 | 3 | **59** | A3/1 | **Stable** |
| Reach 11 | 6 | 7 | 6 | 6 | 2 | 3 | 2 | 5 | 6 | 2 | 2 | 4 | 8 | 8 | 2 | **69** | B3/4 | **Mod. Unstable** |
| Reach 12 | 4 | 6 | 6 | 6 | 2 | 6 | 4 | 6 | 8 | 2 | 2 | 4 | 4 | 21 | 3 | **84** | B4 | **Mod. Unstable** |
| Reach 13 | 4 | 9 | 4 | 6 | 3 | 6 | 6 | 10 | 14 | 3 | 3 | 5 | 10 | 15 | 3 | **101** | B4 | **Unstable** |
| Reach 14 | 2 | 3 | 4 | 5 | 1 | 2 | 2 | 4 | 4 | 2 | 2 | 2 | 4 | 6 | 2 | **45** | C3 | **Stable** |
| Reach 15 | 2 | 3 | 3 | 8 | 2 | 8 | 2 | 4 | 8 | 2 | 2 | 4 | 12 | 12 | 2 | **74** | E4 | **Stable** |

**Table 29. Flute Reed River Pfankuch Stability Index results.**

| Reach | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total | Potential Stream Type | Rating |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLR_000 | 6 | 3 | 2 | 3 | 2 | 2 | 2 | 4 | 8 | 1 | 2 | 2 | 8 | 8 | 3 | 56 | B2 | Mod. Unstable |
| FLR_001 | 6 | 6 | 4 | 3 | 1 | 4 | 2 | 4 | 4 | 3 | 2 | 4 | 8 | 12 | 3 | 66 | C4 | Stable |
| FLR_002 | 4 | 6 | 4 | 3 | 2 | 2 | 4 | 10 | 8 | 3 | 2 | 4 | 8 | 12 | 3 | 75 | B3c | Mod. Unstable |
| FLR_003 | 6 | 7 | 4 | 3 | 3 | 6 | 4 | 10 | 12 | 3 | 3 | 4 | 8 | 18 | 4 | 95 | C4 | Mod. Unstable |
| FLR_004 | 4 | 3 | 2 | 3 | 1 | 2 | 4 | 4 | 4 | 2 | 2 | 2 | 4 | 6 | 3 | 46 | B3 | Stable |
| FLR_005 | 6 | 8 | 4 | 3 | 3 | 6 | 4 | 11 | 12 | 3 | 3 | 4 | 8 | 18 | 3 | 96 | C4 | Mod. Unstable |
| FLR_006 | 4 | 3 | 2 | 3 | 1 | 2 | 4 | 4 | 4 | 2 | 1 | 2 | 4 | 6 | 3 | 45 | B3 | Stable |
| FLR_007 | 5 | 7 | 4 | 6 | 2 | 4 | 5 | 8 | 12 | 2 | 3 | 4 | 14 | 18 | 3 | 97 | B3 | Unstable |
| FLR_008 | 4 | 6 | 4 | 3 | 2 | 4 | 3 | 5 | 4 | 2 | 2 | 2 | 8 | 6 | 2 | 57 | B3 | Stable |
| FLR_009 | 4 | 6 | 4 | 6 | 3 | 6 | 5 | 8 | 6 | 3 | 2 | 5 | 12 | 18 | 3 | 91 | C3/4 | Mod. Unstable |
| FLR_010 | 4 | 6 | 8 | 9 | 2 | 6 | 6 | 6 | 8 | 3 | 2 | 4 | 8 | 12 | 4 | 88 | C3 | Mod. Unstable |
| FLR_011 | 2 | 6 | 6 | 9 | 3 | 6 | 8 | 6 | 14 | 3 | 3 | 4 | 12 | 18 | 3 | 103 | C4/6 | Mod. Unstable |
| FLR_012 | 4 | 3 | 4 | 6 | 2 | 4 | 2 | 5 | 4 | 2 | 2 | 3 | 4 | 8 | 3 | 56 | B3c | Stable |
| FLR_013 | 6 | 9 | 6 | 9 | 3 | 6 | 6 | 10 | 12 | 3 | 3 | 5 | 12 | 18 | 3 | 111 | C3b | Unstable |
| FLR_014 | 4 | 7 | 6 | 9 | 2 | 4 | 4 | 6 | 4 | 2 | 2 | 4 | 8 | 12 | 2 | 76 | E4 | Mod. Unstable |
| FLR_015 | 5 | 6 | 5 | 4 | 1 | 3 | 4 | 5 | 4 | 2 | 1 | 2 | 6 | 6 | 1 | 55 | B3 | Stable |
| FLR_016 | 2 | 3 | 4 | 6 | 2 | 6 | 4 | 4 | 8 | 3 | 3 | 4 | 8 | 8 | 3 | 68 | E4 | Stable |
| FLR_017 | 4 | 6 | 6 | 3 | 1 | 4 | 5 | 5 | 4 | 2 | 1 | 2 | 4 | 8 | 1 | 56 | C3 | Stable |
| FLR_018 | 4 | 6 | 5 | 3 | 1 | 4 | 4 | 5 | 4 | 2 | 1 | 1 | 2 | 6 | 1 | 49 | B3 | Stable |
| FR_ET_001 | 4 | 3 | 4 | 3 | 1 | 2 | 4 | 4 | 4 | 2 | 1 | 2 | 4 | 6 | 1 | 45 | B3 | Stable |
| FR_ET_002 | 2 | 3 | 8 | 3 | 4 | 6 | 4 | 8 | 4 | 2 | 2 | 8 | 12 | 24 | 2 | 92 | E4 | Mod. Unstable |
| FR_ET_003 | 6 | 9 | 6 | 3 | 3 | 8 | 6 | 12 | 12 | 2 | 2 | 6 | 12 | 18 | 3 | 108 | C4 | Mod. Unstable |
| FR_WT_001 | 2 | 6 | 4 | 6 | 3 | 4 | 4 | 6 | 8 | 1 | 2 | 4 | 8 | 12 | 1 | 71 | B3 | Mod. Unstable |
| FR_WT_002 | 4 | 9 | 8 | 9 | 4 | 8 | 8 | 6 | 16 | 4 | 4 | 8 | 16 | 24 | 4 | 132 | C3 | Unstable |
| FR_WT_003 | 2 | 3 | 6 | 9 | 2 | 6 | 4 | 6 | 8 | 2 | 1 | 4 | 8 | 12 | 3 | 76 | C3 | Stable |
| FR_WT_004 | 2 | 3 | 4 | 3 | 1 | 4 | 4 | 6 | 4 | 1 | 1 | 2 | 8 | 12 | 1 | 56 | B3 | Stable |
| FR_WT_005 | 2 | 6 | 6 | 9 | 3 | 6 | 8 | 8 | 8 | 2 | 3 | 4 | 12 | 12 | 1 | 90 | C3 | Mod. Unstable |
| FR_WT_006 | 2 | 3 | 2 | 9 | 1 | 6 | 2 | 4 | 4 | 1 | 1 | 2 | 4 | 6 | 2 | 49 | E3 | Stable |
| FR_WT_007 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 8 | 3 | 2 | 5 | 10 | 18 | 3 | 97 | C3 | Mod. Unstable |